2024 Maribyrnong River Flood Model Report

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2024 Maribyrnong River Flood Model Report

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007	Draft Final Report 2	3/5/24	Melbourne Water	Draft Final Report re-issued including minor amendments
008	Draft Final Report 3	5/6/24	Melbourne Water	Draft Final Report re-issued with minor amendments
009	Final Report	13/6/24	Melbourne Water	Final Report

Limitations

The sole purpose of this report and the associated services performed by Jacobs is to undertake a flooding assessment for the Lower Maribyrnong, in accordance with the scope of services set out in the contract between Jacobs and Melbourne Water (the Client). As described in this report, the scope of services was developed with the Client.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the Client and/or from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate, or incomplete, then it is possible that our observations and conclusions, as expressed in this interim report, may change.

Jacobs derived the data in this report from information sourced from the Client, third parties, and/or available in the public domain at the time or times outlined in this interim report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations, and conclusions expressed in this report. Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures, and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

This report should be read in full, and no excerpts are to be taken as representative of the final findings. Jacobs accepts no responsibility for using any part of this report in any other context.

Topographic data used in this study included that sourced from a LiDAR and ground survey that was carried out by third parties. Undertaking independent checks on the accuracy of the topographic data was outside Jacobs's scope of work for this study, except where otherwise stated in the report.

The sole purpose of the flood modelling undertaken for this report is to define flood behaviour in the vicinity of the project sites. Flood extents and flood behaviour around the boundary of the TUFLOW hydraulic model domain should be interpreted with caution.

This report has been prepared on behalf of, and for the exclusive use of, Melbourne Water, and is subject to, and issued in accordance with, the provisions of the contract between Jacobs and Melbourne Water. Jacobs accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party.

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Abbreviations and definitions

1D Hydraulic Model	1-Dimensional hydraulic model where flood levels are determined by cross sections perpendicular to the flow path.
2D Hydraulic Model	2-Dimensional hydraulic model based on terrain/elevation data at a specified grid size. Capable of modelling floods across a floodplain where flow direction varies in space and time.
1D/2D Hydraulic Model	Coupled 1D/2D modelling, typically the floodplain would be represented in 2D and the main flow paths in 1D together with small scale hydraulic structures.
AEP	Annual Exceedance Probability. The probability that an event of a given size will be equalled or exceeded in a given year.
ARI	Average Recurrence Interval. The inverse of the AEP expressed as a return period. For instance, the 1% AEP is equivalent to the 100-year ARI event.
ARR 2019	2019 release of Australian Rainfall & Runoff Guidelines.
Afflux	Typically referred to as a change in a water level due to an obstruction.
Attenuation	The reduction in the peak flow and shape of a hydrograph due dissipation, friction and changes in the storage characteristics within a waterway.
Bathymetry	Survey representing the underwater terrain (elevation).
BoM	Bureau of Meteorology
Conveyance	The capacity of a waterway to carry flows and is a function of geometry and bed resistance typically expressed as Manning's values.
DEECA	Victorian Department of Energy, Environment and Climate Action
DELWP	Victorian Department of Environment, Land, Water and Planning (now DEECA)
DEM	Digital Elevation Model
DTM	Digital Terrain Model
Design event	A theoretical flood event representing a specific likelihood of occurrence (for example the 1% AEP flood).
FFA	Flood Frequency Analysis.
Flood depth	The height or elevation of floodwaters above ground level.
Flood level	The height or elevation of floodwaters relative to a datum (typically the Australian Height Datum).
Floodplain storage	The area in a floodplain which is capable of storing flood waters during a flood event.
FME	Feature Manipulation Engine
Freeboard	Freeboard is the difference between the floor level of a building and the 100-year ARI flood level
GIS	Geographic Information System
Hydraulics	The term given to the study of water flow in rivers, estuaries and coastal systems.
Hydrograph	A time series of flow which changes at each timestep and naturally captures the peak flood flow.
Hydrology	The term given to the study of the rainfall-runoff process in catchments.
LiDAR	Light Detection and Ranging is a remote sensing method that uses light in the form of a pulsed laser to distance to the Earth.
m AHD	Meters Australian Height Datum.
m/s	Metres per second (a measure of speed / velocity).
m^3/s	Cubic metres per second (a measure of flow).

Manning's "n" value	A coefficient which represents the roughness of terrain on which water flows over.
ML	Megalitres (equal to a million litres)
MLS	Mobile Laser Scanning
MMBW	Melbourne and Metropolitan Board of Works
MW	Melbourne Water Corporation.
Peak flood level, flow or velocity	The maximum flood level, flow or velocity occurring during a flood event at a particular location.
RORB	Runoff routing computer model for hydrologic analysis of catchment runoff.
SES	State Emergency Services
SGS	Sub-Grid Sampling
TUFLOW	Fully two-dimensional and one-dimensional unsteady flow hydraulic computer modelling software.
Velocity	The speed at which the floodwaters are moving. Typically, modelled velocities in a river or creek are quoted as the depth and width averaged velocity, i.e. the average velocity across the whole river or creek section if a one-dimensional solution is used; and depth average if a two-dimensional solution is used.
VRC	Victoria Racing Club
Water Surface Elevation	Water Surface Elevation, the surface of the water at a given point.
WMIS	Victorian Government's Water Measurement Information System

Terminology between ARI and AEP

When describing the magnitude of flood events, this report uses both Average Recurrence Interval (ARI) and Annual Exceedance Probability (AEP). The ARI terminology has generally been preferred to remain consistent with the work completed in the early 2000's and to avoid confusion when cross-referencing information.

Australian Rainfall and Runoff (ARR) 2019, recommends that rare events should be expressed as an Annual Exceedance Probability (AEP). AEP is the probability of an event being equalled or exceeded within a year and may be expressed as either a percentage (%) or 1 in X. For example, a 1% AEP event or 1 in 100 AEP has a 1% chance of being equalled or exceeded in any year.

Average Recurrence Interval (ARI) was a term commonly used in the past (ARR, 1987) and was defined as the average period between occurrences equalling or exceeding a given value. The use of terms such as "recurrence interval" and "return period" are no longer recommended as they imply that a given event magnitude is only exceeded at regular intervals, such as every 100 years.

1. Introduction

Jacobs was approached in March 2023 and commissioned by Melbourne Water in April 2023 to undertake flood modelling of the Lower Maribyrnong River for provision of updated flood information for the Lower Maribyrnong River Valley. This report documents the hydrologic and hydraulic calibration stages as well as the final modelling results and a summary of the flood mapping outputs.

1.1 Purpose of project

The purpose of the project is to provide updated flood information of the Lower Maribyrnong River to inform decision-making. This updated flood information is reflective of current catchment conditions, latest data available, climate change, revised guidance from the introduction of ARR19 and relevant industry practise in developments in modelling methodology. The technical outcome of this project is to produce robust and defensible water level, and other hydraulic properties, for a given probability of exceedance under current conditions and also taking into account climate change.

The provision of this updated flood information also assists in Melbourne Water addressing the Panel recommendations of the *Maribyrnong River Flood Event – Independent Review* (August 2023).

1.2 Sources of flooding

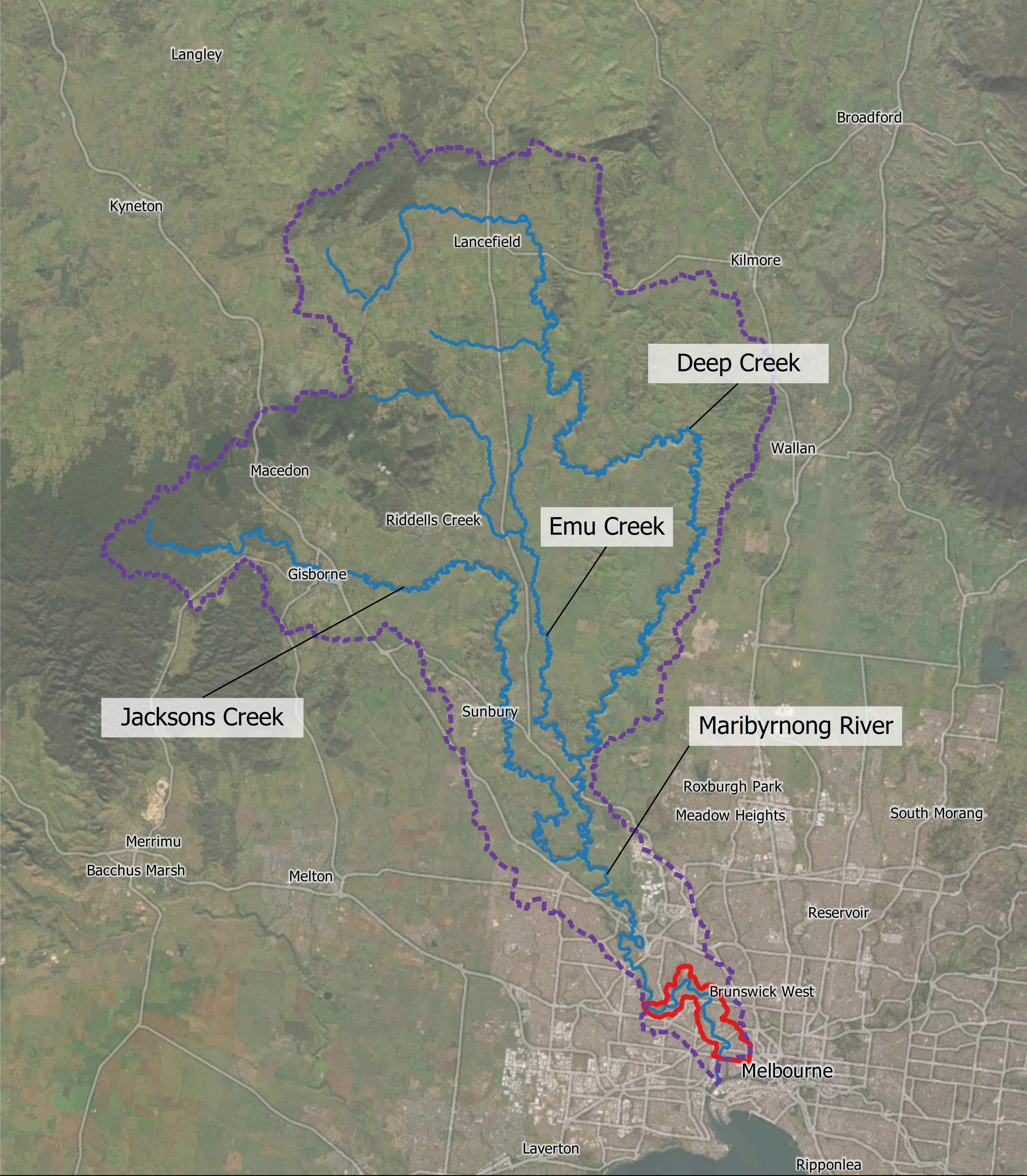
To assess the flooding to the Lower Maribyrnong River floodplain requires an understanding of the potential sources of flooding. Figure 1-1 shows the Maribyrnong River catchment and main watercourses. The Lower Maribyrnong River for the purposes of this report, is considered to be downstream of the streamflow gauging station at Keilor. This project delivers flood maps of the Maribyrnong River reach from Solomons Ford to Footscray Road with subsequent projects programmed to flood map from Keilor to Solomons Ford.

The major source of flood risk to the Lower Maribyrnong River floodplain emanates from the Maribyrnong River itself and its major upstream tributaries: Jacksons Creek, Emu/Bolinda Creek and Deep Creek (see Figure 2-1 for the catchments of these tributaries). In the most downstream reaches, there is also the potential for storm tide[1] flooding from Port Phillip via the lower reaches of the Yarra River.

In addition to the major tributaries, there are minor tributaries that discharge to the Lower Maribyrnong River namely Taylors Creek and Steele Creek as well as the local catchment that flows directly into Maribyrnong River between Solomons Ford and Footscray Road. Due to the time delay of flows coming from the wider Maribyrnong catchment compared to flows from these nearby catchments, they are not significant contributors to flooding along the Maribyrnong River in the events represented in the model. However, these have been included for completeness. This is not to say that there are areas in the Lower Maribyrnong floodplain where these sources of flooding are not significant; however, these are mapped and addressed via Municipality studies such as the Maribyrnong Flood Mapping Study or the Moonee Valley Flood Mapping Study.

There is also the possibility of local urban stormwater that drains directly to the Maribyrnong River causing flooding. However, as the purpose of this project is to assess flooding from the Maribyrnong River, this source has not been assessed. This source of flooding is typically addressed in Municipality studies.

[1] Refer to http://www.bom.gov.au/cyclone/tropical-cyclone-knowledge-centre/understanding/storm-surge/



Legend

- Maribyrnong catchment boundary
- Mapping extent
- Major watercourses

MGA Zone 55

0 5 10 15 20 km

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Figure 1-1: Maribyrnong catchment overview with mapping extent

Disclaimer: Produced by Jacobs for the Lower Maribyrnong Flood Mapping Study, a Melbourne Water project. Jacobs does not warrant that this document is definitive nor free of errors and does not accept liability for any loss caused or arising from reliance upon information provided herein. This map should be read in conjunction with 2024 Maribyrnong River Flood Model Report. Background imagery from ESRI

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1.3 Study approach

The purpose of the study was to produce flood mapping products to support a variety of Melbourne Water business functions and these flood mapping products were be produced from a flood model, that is, the flood model will underpin all the study outcomes.

The flood model of the Lower Maribyrnong River is a combination of an event-based flood model (RORB) and hydraulic model (TUFLOW). RORB is a runoff and streamflow routing program that is used to calculate flood hydrographs from rainfall and other catchment and channel inputs. The model subtracts losses from rainfall to determine rainfall excess and routes this through catchment storages to produce streamflow hydrographs at points of interest. RORB is a spatially distributed, non-linear model that is applicable to both urban and rural catchments. The model can account for both temporal and spatial distribution of rainfall and rainfall losses. It is based on catchment geometry and topographic data which are defined in the catchment file.

The purpose of the event-based flood model was to calculate the catchment's response to runoff for observed events and to calculate the runoff for a given probability of occurrence to allow the determination of flood risk. The runoff was then applied to the hydraulic model which calculates the extent, depth, velocity and other hydraulic properties. These modelling activities were augmented by empirical analysis of other flood forming variables such as tidal levels and baseflow and verification of key input datasets such as rainfall, topographic levels and rating curves.

A key part of the hydrologic investigation was Flood Frequency Analyses (FFA) at key gauges in the catchment. The results of the FFA were used to assist calibration of the RORB flood event model.

A 2D TUFLOW hydraulic model with embedded 1D elements was developed for the Lower Maribyrnong that extends from Solomon's Ford to downstream of Footscray Road near the confluence with the Yarra River. The mapping extent is illustrated in Figure 1-1. This mapping extent covers the Lower Maribyrnong River and its floodplain including Maribyrnong Township, Ascot Vale, Kensington, Footscray and the surrounding areas. The Maribyrnong River flow was applied to the upstream extent of the model with a downstream boundary set to a tidal level. Lateral flows from sub-catchments in the Lower Maribyrnong were applied where required.

1.3.1 Previous reports

Other previous reports that were completed as part of this Lower Maribyrnong River Flood Mapping project include:

Maribyrnong Flood Event October 2022- Post Event Analysis (Jacobs, 2023a)

- This report was commissioned to prepare a post-flood analysis in the Maribyrnong River catchment soon after the event. The initial version was made available in November 2022, with subsequent versions incorporating new and emerging data, updates and revision to live data and analysis to assist Melbourne Water to provide answers to enquiries. This report documented rainfall and river conditions prior to and during the October 2022 flood event using publicly available information.

  The analysis focused on Deep Creek at Darraweit Guim and the Lower Maribyrnong River, in and around Maribyrnong Township.

Lower Maribyrnong HEC-RAS Model Verification (Jacobs, 2023b)

- The purpose of this memorandum is to compare flood levels and extents calculated with a version of the GHD (2003) HEC-RAS Lower Maribyrnong River Flood model[2] to observations from the October 2022 flood event and the May 1974 flood event. This analysis found that the model was able to reproduce observed flood levels for the 1974 event, with the average difference between the observations and modelled levels being 30mm. For the 2022 event the model on average overpredicted flood level by

[2] Given the passage of time it is likely that the version of the HEC-RAS model run was different to that developed by GHD in 2003 and therefore results are likely to be different to those calculated with the HEC-RAS model delivered in 2003.

55mm, once spurious data was removed (refer to Appendix A). It was concluded that this model was still a useful tool for floodplain management in the Lower Maribyrnong pending the development of a new model using updated methods which are provided by the current project.

Mid Maribyrnong HEC-RAS Model Verification (Jacobs, 2023c)

- The purpose of this memorandum is to compare flood levels and extents calculated with the GHD (2003) HEC-RAS Mid Maribyrnong Flood model[2] to observations from the October 2022 flood event and the May 1974 flood event. This memorandum found that for both the 1974 and 2022 flood events the model underpredicted flood levels at Canning Street and over predicted flood levels at Maribyrnong Township. It was concluded that this model should not be used for floodplain management in the Lower Maribyrnong and should be calibrated to the available data. Refer to Section 3.4.2.

Bathymetric Comparison Memorandum (Jacobs, 2023d)

- This memorandum compared bathymetric dataset over time for the Lower Maribyrnong River to the bathymetric survey obtained in May 2023. This memorandum documented the findings that there were changes in bathymetry but overall, the differences between older datasets and the newly commissioned bathymetry were within expected ranges.

Schematisation Memorandum (Jacobs, 2023e)

- A Schematisation Memorandum (Jacobs 2023) was produced for this study that details the proposed approach and methodology for the hydrology (RORB) and hydraulic (TUFLOW) modelling. This was reviewed by Melbourne Water and external reviewers and discussed in a workshop. Some key changes have occurred to the initially proposed methodology:
  - The calibration of the RORB model to four gauges throughout the catchment was changed to calibration to the Maribyrnong River at the Keilor gauge. The primary reason for this change was data availability and data reliability and it became apparent that a re-rate of gauges in a hydraulic model would be required.
  - The approach in the schematisation report stated that event calibration would inform the choice of routing parameters for the RORB model. The approach for determining routing parameters is now based on fitting Monte Carlo results to the FFA quantiles (refer Section 4).
  - The hydraulic model was extended to upstream of the Maribyrnong River at the Keilor gauge for the sole purpose of routing the flood wave from Keilor to Solomons Ford. The detail in this part of the hydraulic model is not commensurate with the detail in the hydraulic model downstream of the Solomons Ford and results are not presented. This reach of the river will be flood mapped in future programmed work. This report only presents the results downstream of Solomons Ford and upstream of Footscray Road Bridge and this extent is referred to as the mapping extent.
  - Other minor changes: Where there are differences between the Schematisation Memorandum and this report, the details of this report are correct. This is the natural model development process of any project, when new information becomes available and further analysis is complete it is appropriate to adjust methods to the new information.

Best Fit Memorandum (Jacobs, 2023f)

- This memorandum compared the results of the Flood Frequency Analysis presented in this report using the software TUFLOW Flike to results using the software Best-Fit to ensure correct application of historic information. The results from this comparison confirmed that the TUFLOW Flike results were correct.

HEC-RAS Update - Model and Report (mid and lower) (Jacobs, 2023g)

- The purpose of this work was to update the Mid and Lower- Maribyrnong HEC-RAS models to provide interim flood information for the area. This involved calibration to the 2022 flood event, verification to the 1974 event and modelling of the 1% Annual Exceedance Probability (AEP) event. Flood mapping products were also developed as part of this work.

Survey Report - Maribyrnong River Flood Modelling (Jacobs, 2023h)

- This work delivered a high-quality homogenous dataset across the Lower Maribyrnong River hydraulic model extent to support flood modelling and mapping. It involved a variety of surveying tasks and following best survey practices, allowing the Jacobs survey team to independently validate all data incoming as suitable, complete and accurate. The report (Jacobs, 2023h) detailed the methodology and accuracy of the analysis.

1.4 Report layout

This report has been structured to summarise the relevant data collection, hydrologic and hydraulic modelling work undertaken to develop the model and final setup used for the 2024 Maribyrnong River Flood Model for Melbourne Water. The report is structured with the following sections to highlight the development of the model for its current purpose:

- Data (see Section 3)

An overview of the review and identification of relevant information for the hydrologic and hydraulic model setup.

- Hydrology (see Section 4)

An outline of the how the hydrologic model was developed, different approaches trialled, and the ultimate approach adopted for the purposes of this study.

- Tidal (see Section 5)

Details the analysis and adopted downstream boundary conditions of the hydraulic model.

- Hydraulics (see Section 6)

An overview of the hydraulic model development, calibration, validation and verification.

- Results (see Section 7)

A brief summary of results, highlighting the 1% AEP and 1% AEP with climate change flood behaviour within the mapping extents / study area. This section also provides details of GIS deliverables that have been provided as per Melbourne Water Technical Specifications.

- Sensitivity analysis (see Section 8)

A summary of the sensitivity activities undertaken.

- Recommendations (see Section 9)

An outline of some of the key possible limitations, assumptions and recommendations for future work.

2. Catchment Description

The Maribyrnong catchment lies to the north-west of Melbourne and covers approximately 1,400 km^2 (Figure 2-1). The Maribyrnong River is a major river system in the Port Phillip and Westernport Region. Beginning in the southern slopes of the Great Dividing Range at Mt Macedon, the river is 160 km long and travels south to join the Yarra River just upstream of Port Phillip. The lower part of the Maribyrnong River is tidally influenced due to this proximity to Port Phillip. The catchment includes the major tributaries of (in order of contributing catchment area) Deep Creek, Jacksons Creek together with the Emu Creek and Bolinda Creek system. Deep Creek and Jacksons Creek are the two main tributaries that join to form the Maribyrnong River at Keilor North. These two creeks have the greatest influence on downstream flows. Rosslynne Reservoir, the single major storage within the catchment whose function is water supply, is located in the upper catchment of Jacksons Creek.

The catchment boundary extends from Mt Macedon near Rosslynne Reservoir in the west, to the Cobaw Ranges and Mount William in the north and to Pretty Sally Hill and Konagaderra in the east. The shape of the catchment is wider in the northern, upstream, section, with the southern downstream area being narrower, where the lower section of the river flows southeast through the Melbourne metropolitan area.

The climate of the Maribyrnong catchment is temperate, with a marked non-uniform rainfall distribution throughout the year. The period between August to November typically experiences the most significant rainfall. The spatial variations in annual rainfall are largely due to the interaction of topography and prevailing rain-bearing westerly winds, with a rain shadow effect present from the Bulla/Sunbury area to Darraweit Guim. The average annual rainfall in the upper Maribyrnong catchment exceeds 1,000mm in the ranges, declining to less than 500mm on the mid and lower plains.

The topography of the Maribyrnong River Valley was formed over millions of years, with water eroding through the basalt plains northwest of Melbourne to create a complex landscape of gorges and river flats and with a hinterland that consists of relatively flat basalt plains. The majority of the stream systems in the catchment are characterised by incision of deep and often narrow valleys in the surrounding plains, with steep valley escarpment slopes predominating.

The catchment encompasses a mixture of land uses including agricultural lands, natural grasslands and woodlands present in the upper and mid catchment and densely populated urban areas in the lower catchment. A number of larger rural townships are scattered throughout the catchment. The predominant land use in rural areas is mixed farming and grazing. The lower reaches of the Maribyrnong River form part of Greater Melbourne and are urbanised areas that were substantially developed in the 20th Century. New urban areas, specifically around Taylors Lakes, Gisborne and Sunbury, have seen substantial suburban development in the 21st Century. Similarly, significant infill development and densification has occurred in the City of Melbourne, City of Maribyrnong and Moonee Valley City Council in the past 20 years. This lower part of the catchment is highly urbanised and whilst much of the low-lying riverine floodplain and river frontage areas are utilised for open space and recreational purposes, some residential and industrial development has occurred in the floodplain where the river broadens in its lower reaches, such as in Maribyrnong Township and around Kensington.

Streamflow gauges are present on major tributaries of the Maribyrnong River catchment, with selected gauges shown in Figure 2-2. Figure 2-2 shows that rainfall gauges are generally well distributed across the catchment, with the exception of the central part of the upper catchment. The key river flow gauges in the study area are those for the lower Maribyrnong located at Keilor (upstream) and Maribyrnong (downstream). The Keilor gauge (230150A) is located at a river crossing in Brimbank Park in an area known as Horseshoe Bend. At this location all major tributaries have combined so that no major additional inflows are expected beyond this point. Consequently, flow at this gauge is a good estimate of flow in the lower reaches of the Maribyrnong River. The Maribyrnong gauge (230106A) is located at Chifley Drive in Maribyrnong. This gauge only records water levels. At this location all smaller tributaries (Thompson and Steele Creeks) have joined the main river channel, the catchments of which are more urbanised than those of the upstream tributaries.

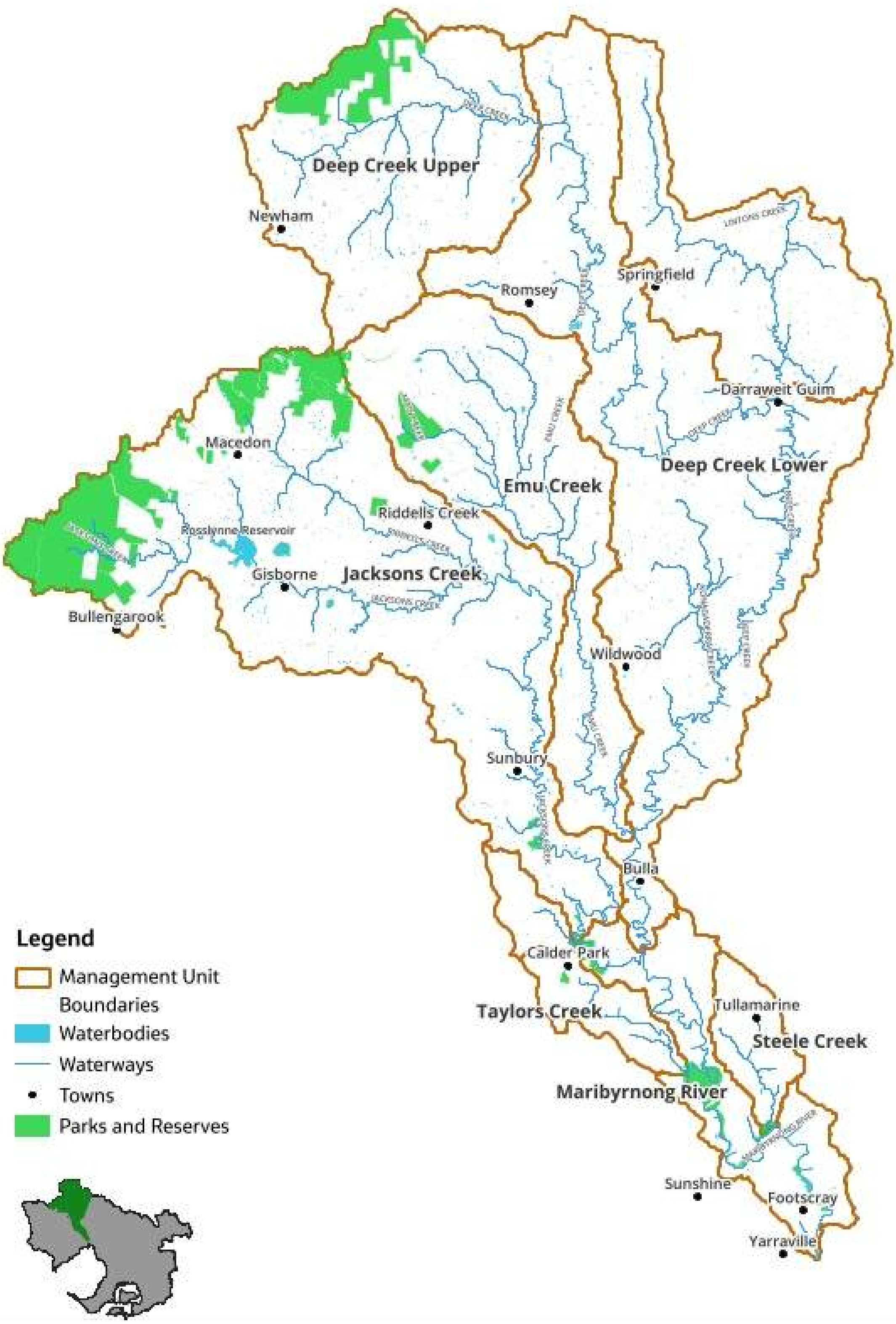
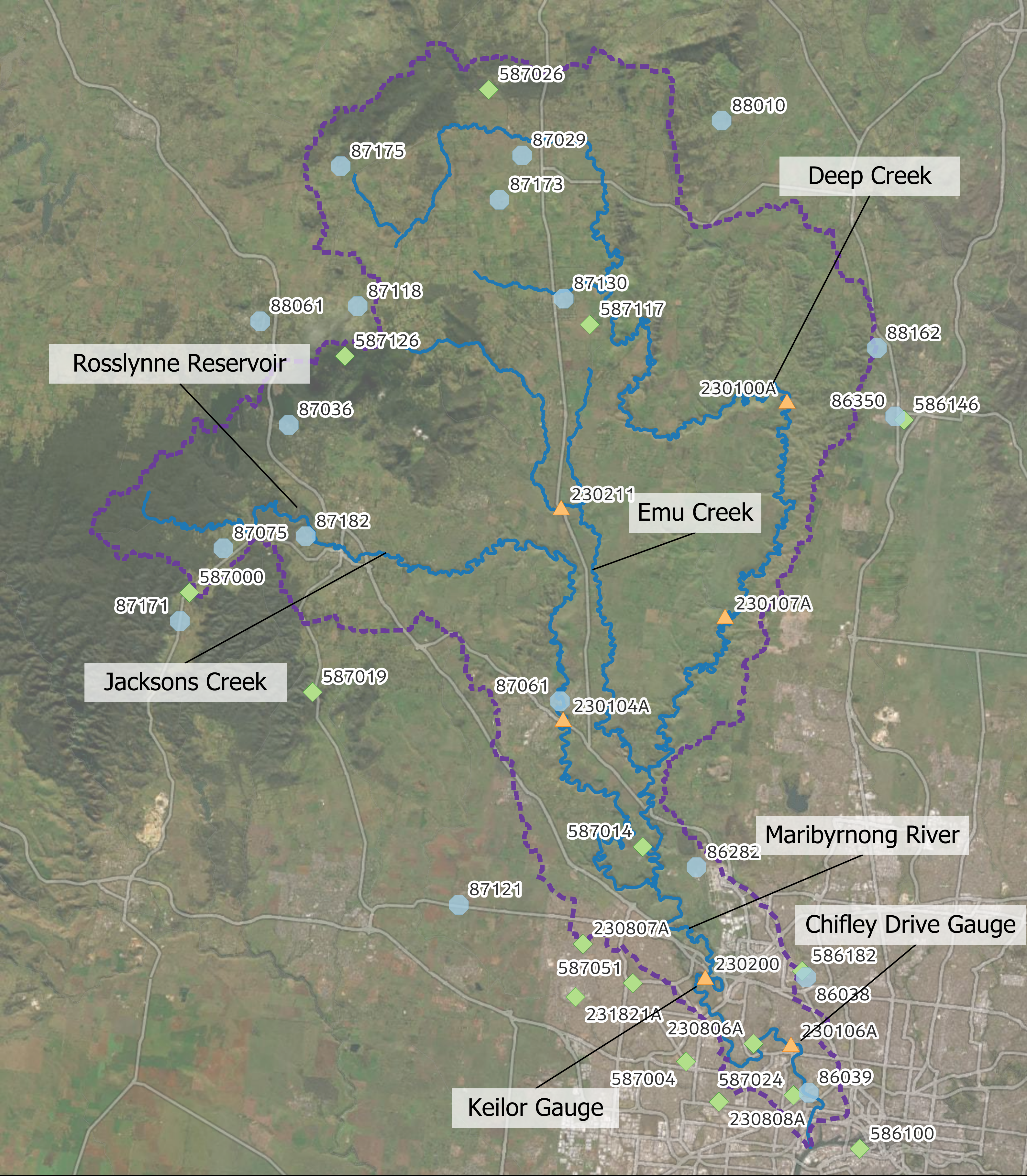


Figure 2-1: Location and catchment boundary of the Maribyrnong River catchment and its major tributaries (Modified from source: Victorian Healthy Waterways).



Legend

- Maribyrnong catchment boundary
- Major watercourses
- BoM rainfall gauges
- MW rainfall gauges
- Streamflow gauges

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MGA Zone 55

0 5 10 15 km

Figure 2-2: Maribyrnong catchment with key watercourses and hydrological data collection network

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2.1 Flood history

A review of historic information was completed to provide an understanding of the flood history of the Lower Maribyrnong catchment. This information was also used to validate the annual maxima series, with particular focus on the early period of record, as there was greater uncertainty in earlier records, prior to commencement of gauging.

The Maribyrnong River has a long history of flooding, as detailed in Table 2-1.

Prior to 2022, the previous major flood event on the Maribyrnong River was the 1974 event. This event had estimated damages of between $12 and $15 million (Melbourne and Metropolitan Board of Works (MMBW), 1986) (monetary value estimated in 1986). The peak flow rate of the 1974 event reached approximately 710m^3/s and had an estimated Annual Exceedance Probability (AEP) of 2% as reported in MMBW, 1986. The largest flood on record was in 1906 with an estimated flow of 880m^3/s and was reported to have a 1 in 140 AEP (as reported in MMBW, 1986).

Table 2-1: History of Maribyrnong River Flooding at Chifley Drive gauge (taken from SES (2018)[3]).

Height (metres)	Impact/level
4.50m	8 September 1906 Highest recorded flooding affecting the Maribyrnong Flood Plain.
4.26m	22 September 1916 Second highest recorded flooding
4.20m	14 May 1974 Although the third highest flood level in recorded history, it caused the greatest degree of damage to residential, industrial and public utilities.
3.83m	15 September 1993 Anglers Tavern lounge and bistro areas under nearly two metres of water, and a further 50 residences flooded over floor level.
2.9m	Major flood level Tram services along routes 57 & 82 and bus services 468 & 952 along Raleigh Road likely to be impacted.
2.83m	10 November 1954 Maribyrnong River breaks its banks causing 200 families to be temporarily homeless. More than 60 rescued by Army boats.
2.3m	Moderate flood level Maribyrnong River Trail flooded at various locations. Burton Crescent Reserve impacted.
2.21m	14 January 2011 Flooding of the lower floor at the Anglers Tavern commenced. Closure of Chifley Drive, Plantation Street and nearby adjoining roads. Infrastructure improvements then implemented and have reduced the risk of similar floods having the same impact.
1.7m	Minor flood level

[3] Victorian State Emergency Services – Maribyrnong Local Flood Guide https://www.ses.vic.gov.au/documents/8655930/9320127/Maribyrnong+Township+-+August+2022+-+FINAL.pdf/d2898043-0356-2dc2-3b5e-f767b0cf6912?t=1665524197120

Note that Height (metres) corresponds to Water Course Level (m) taken from BoM Water Data Online. In 2008 the datum of Chifley Drive gauge was altered. Pre-2008 Heights are in Chart datum and post-2008 Heights are m AHD (refer Section 6.10.4).

The review included data from newspaper archives and media reports obtained from Trove (trove.nla.gov.au, accessed on 02/11/2022) and information listed in the MMBW Maribyrnong River Flood Mitigation Study (March 1986). A number of historic flood events were reported in newspapers from as early as 1883. Table 2-2 summarises key reports relating to large flood events on the Maribyrnong River prior to 1960. Information on flood events subsequent to 1960 has been obtained from a local library search, online newspaper archives and reports such as MMBW (1975, 1976 and 1986) and the available gauge records.

This review resulted in the incorporation of the 1871, 1891, 1901 and 1906 flood events in the FFA as historic events. This review also confirmed the 1954 flood and indicated that there were no records of large floods in the data gap from 1956 to 1968.

Table 2-2: Summary of historic information and newspaper reports relating to large historic flood events on the Maribyrnong River.

Year	Maribyrnong River at Keilor Peak Flow (m^3/s) (rank)	Report	Report date	Source & hyperlink
1871	600 (5)	Reports in 1906 (rank 1) confirm that flooding reached a level 'higher than the flood of 1871'. This confirms the original ranking and occurrence of a major event during this year. Maribyrnong River also referred to as the Saltwater River.	10/9/1906	The Argus
1883	-	Reports in 1891 refer to observing the 'biggest flood for eight years' – however there are no records with sufficient information to validate this. This could be an error and the report meant in 20 years.	26/6/1891	The Age
1891	560 (6)	Heavy flooding reported in June 1891– threat to life and property. The impact of bridges on the river damming back waters was noted by newspapers.	26/6/1891 18/7/1891	The Age Independent
1901	320 (21)	Reports in 1932 noted the 'heaviest rainfall since 1901'. No further reports to provide additional details.	14/10/1932	The Age
1906	880 (1)	Numerous newspaper reports on the magnitude, impact and devastation of this event in September 1906 – largest flood on record. Notable remarks: ▪ River reached half a mile wide at Maribyrnong Road bridge. ▪ Water reached depth of 7ft at Maribyrnong Hotel (present day Burton Crescent) (measured against lamppost). ▪ Unprecedented damage to property and livestock. ▪ Loss of life. ▪ Weakness of city's drainage network noted.	15/9/1906 10/09/1906	Independent The Argus

Year	Maribyrnong River at Keilor Peak Flow (m^3/s) (rank)	Report	Report date	Source & hyperlink
1906 (cont.)	880 (1)	▪ Rain fell continuously for 12 hours with the total falls ranging from 70mm at Maribyrnong to 125mm at Deep Creek in the upper catchment (MMBW, 1986). ▪ The railway bridge was '*ascribed the bulk of the damage*', which held back tons of debris and '*dammed back the force of the water and drove it along the railway embankment*'. ▪ Photographs of devastation and damage published (see Plate 2-1). ▪ Several reports about calls for funding and flood mitigation increased since this event.	15/9/1906	Leader
1909	474 (9)	Reports of flooding where the river rose 9ft in a few hours - tea houses, pleasure gardens, boat quays and Anglers Rest Hotel was half submerged. Spongs Hotel isolated (see photos in 'Leader'). Trams impacted. The report mentions that September 1906 flood was 4ft higher than this flood.	20/9/1909	The Herald Leader
1910	81 (65)	New Maribyrnong Bridge almost completed – report notes that old bridge was acting as barrier to flow. The new bridge will positively impact flood levels up and downstream, benefiting the low-lying land on the west side of the bridge.	24/8/1910	The Herald
1916	632 (4)	Anxiety of residents reported upon in newspapers with relatively recent memory of the 1906 event. Reports note the change in flood conditions since the upgrade of the railway bridge at Footscray and the old Maribyrnong Road bridge – removal of obstructions, flow and channel now unimpeded. However, they also note that compared to the last large flood (1906) there had been more development/properties built on low-lying land/floodplain areas. Further calls for flood relief channels and levees to be built.	27/9/1916 28/9/1916	The Age The Essendon Gazette and Keilor, Bulla and Broad-meadows Reporter
1924	461 (10)	Reports of flood events in August and October 1924. Property and businesses flooded.	27/8/1924 7/11/1924	The Herald The Argus

Year	Maribyrnong River at Keilor Peak Flow (m^3/s) (rank)	Report	Report date	Source & hyperlink
1932	376 (15)	Reports of this event being the 'largest flood since 1916'. This is an inconsistency given that 1924's flood was larger, however reasons for this could include the speed at which waters rose and/or lack of prior warning of a flood, making the impact more pronounced. Footscray Road behind racecourse 'turned into a lake'. Anglers Arms Hotel ground floor rooms inundated with water up to 4ft. Boats were torn from moorings. Heavy rains combined with saturated ground and snow melt in upper catchment. Quick event – very little/no warning. The river went from normal levels to +over 8ft in 4 hours.	30/8/1932 31/8/1932	The Herald The Age
1942	-	Report confirming that a flood as large as 1906 had not occurred since. Houses were now built in areas that were flooded back in 1906 – residents were worried about potential flooding if a large event were to happen again.	24/4/1942	Sunshine Advocate
1954	520 (7)	Flooding reported with significant damage to property for several events over Nov-Dec period. Some properties flooded 4 times in 7 weeks. Evacuations, rescues, power outages and travel disruptions (airport closed) reported.	13/12/1954 14/12/1954	The Age The Argus
1974	726 (3)	Reported as the 'great flood of 1974 which left Flemington under water'. Reports of 'Maribyrnong residents endangered by rising flood waters with the Army responding with watercraft to rescue those in danger'. Noted other 'significant floods of 1916, 1934, halfway through the fifties and 1964'. Reported that a railway bridge under construction blocked the flow and caused property damage to a factory on Hobsons Road, that had not occurred in any preceding floods from 1936. A rescue was required from a property on Navigator Street and homes in Raleigh Road were flooded. Later report notes extensive flooding from the 1974 event, support and compensation avenues for those impacted as well as significant political discussion on development in flood-prone areas.	18/2/1983 22/05/1974 23/05/1974 30/05/1974	The Age Essendon Gazette Northern Regional Northern Regional
1983	400 (12)	Report confirming widespread flooding including '32 homes in Maribyrnong evacuated with roads throughout the area cut'. 'Maribyrnong River peaked at 3.6m'. Noted that most 'residents were spared property damage' but two barges became lodged under the Maribyrnong Road Bridge.	17/10/1983 19/10/1983	The Age Essendon Gazette

Year	Maribyrnong River at Keilor Peak Flow (m^3/s) (rank)	Report	Report date	Source & hyperlink
1993	510 (8)	Reports of "residents, some business and the council are facing thousands of dollars in damage bills following the Maribyrnong River floods which peaked at 3.8m above normal levels"	20/09/1993	Essendon Gazette
2011	379 (14)	Report of Anglers Tavern bar and beer garden flooding, river peaking at 2.21m at 7:30am and no other reports of flooding.	16/01/2011	Sydney Morning Herald
2022	768 (2)	Reports of the Maribyrnong River breaching its banks, flooding more than 240 homes.	20/10/2022	The Age

Plate 2-1: Flooding at Maribyrnong Road Bridge in 1906 (Saltwater River is the old name for the Maribyrnong River) from Maddigan and Frost (1995).

2.1.1 Recommendation

The data collection and analysis has found a minor discrepancy between the flow rates at Keilor and the resulting levels at Maribyrnong Township, that is, the ranks of the flows at Keilor are not the same as the ranks of the levels at Maribyrnong Township. The work detailed within this report has been undertaken to ensure that this discrepancy did not have a material effect on modelling results. The most notable discrepancy is the 1916 event which is the 5th highest flow rate at Keilor, but the 2nd highest water level at

Maribyrnong. It is recommended that this discrepancy is further investigated noting that there are numerous possibilities for consideration, such as:

- There have been significant changes to the Lower Maribyrnong River in the early part of the 19^{th} Century such as the creation of Coode Island and other channel works on the Lower Maribyrnong and Yarra Rivers.
- The presence of numerous low-lying bridges which were reported to have contributed to flooding.
- The location of Keilor gauging station has moved overtime which means gauged heights for this gauge cannot be directly compared without a datum correction.
- The method of calculating discharge for historic events is currently unknown.

3. Data

This section documents the data that was utilised to inform this flood mapping study and the investigations undertaken to confirm the data was fit for purpose.

3.1 Guidelines and Specifications

The following should be referred to in conjunction to this report:

- Melbourne Water (October 2023) AM STA 6200 Flood Mapping Projects – Specification August 2023 ("Technical Specifications").
- Australian Rainfall and Runoff: A Guide to Flood Estimation 2019 (ARR2019).

3.2 Previous studies

In addition to the reports discussed in Section 1.3.1, the following studies have been completed in the catchment in relation to flooding:

- MMBW (1975). Report on flood of May 1974 Maribyrnong River basin (prepared by Beardwood, B. et al)
- MMBW (1976). Report on flood mitigation in the Maribyrnong River Basin: a preliminary hydrological study.
- MMBW (1986). Maribyrnong River Flood Mitigation Study.
- State Rivers and Water Supply Commission of Victoria (1984), Victorian Surface Water Information to 1982 ("Red Book").
- Rural Water Commission of Victoria (1990), Victorian Surface Water Information to 1987 ("Blue Book").
- GHD (2003a). Maribyrnong River Hydraulic Model: Final Report.
- GHD (2003b). Flood Mapping of Maribyrnong River: Stages A and B Report – Volume 1.
- GHD (2003c). Flemington Racecourse Flood Protection: Investigation of Maribyrnong River Flood Protection: Final Report.
- CPG (2012). Urban Growth Area Flood Mapping Project: Emu Creek (Drain 6341).
- BMT WBM (2013). Ascot Vale Main Drain Flood Mapping: Final Report.
- Melbourne Water (2013). Jacksons Creek Flood Mapping.
- Melbourne Water (2015). Deep Creek.
- Aurecon Jacobs Joint Venture (2018). West Gate Tunnel Project, Design Package: WGT-401-300-DPK-AJV-300-000-0001, Maribyrnong River – Flood Mitigation, Preliminary Design Report, WGT-401-300-REP-AJV-300-000-0001.
- Cardno (2021). Flood Modelling Report: Romsey South Drain Catchment.
- Cardno (2022a). Flood Modelling Report: Jacksons Creek.
- Cardno (2022b). Flood Modelling Report: Riddells Creek Catchment.

In addition to these reports the following hydraulic models, in draft form, were made available for the project. These models have been developed as part of Melbourne Water's Flood Mapping programme.

- Engeny (2023a). Maribyrnong Council flood mapping.
- Engeny (2023b). Moonee Valley Council flood mapping.

Of these, the MMBW (1975, 1976 & 1986) and GHD (2003a, 2003b & 2003c) were the most relevant.

The data for peak flows at Keilor was sourced from:

- Bureau of Meteorology (BoM) Water Data Online[4] for data from 1908 to 2023.
- Victorian Water Measurement Information System[5] (WMIS) for data from 1908 to 2023.
- MMBW 1986 for historic peak flows from prior to the instrumental records at this site i.e. before 1908.

3.3 Rainfall

Rainfall data has been obtained from a variety of sources including:

- The Bureau of Meteorology – daily rainfall data as listed in Table 3-1.
- Melbourne Water – daily and pluviograph rainfall data as listed in Table 3-1.
- Gridded rainfall dataset as listed in Table 3-2.

Table 3-1: List of BoM and Melbourne Water rainfall gauges in and around the catchment together with key information.

Site Name	BOM Ref No.	MW Ref No.	Start of Record	End of Record
Bullengarook East	87075		1951	2023
Flemington Racecourse	86039		1904	..
Melbourne Airport	86282		1970	..
Macedon Forestry	87036		1873	..
Romsey	87130		1970	..
Lancefield (Winery)	87173		1993	..
Newham (Cobaw)	87175		1995	..
Gisborne (Rosslynne Reservoir)	87182		2008	..
Essendon Airport	86038		1929	..
Wallan	86350		1979	..
Hesket (Straws Lane)	87118		1968	..
Rockbank (Melton)	87121		1969	..
Bullengarook South	87171		1992	..
Willowmavin (Avalon Station)	88010		2001	..
Woodend	88061		1889	..
Wallan (Kilmore Gap)	88162		1993	..
Avondale Heights Rain Gauge		230806A	2014	..
Sydenham Rain Gauge		230807A	2014	..
Bulla Rain Gauge		587014	1980	..
Footscray Rain Gauge		587024	1998	..
Lancefield North Rain Gauge		587026	1999	..

[4] http://www.bom.gov.au/waterdata/

[5] https://data.water.vic.gov.au/

Site Name	BOM Ref No.	MW Ref No.	Start of Record	End of Record
Romsey Rain Gauge		587117	1976	..
Mount Macedon Rain Gauge		587126	1999	..
Wallan Rain Gauge		586146	1977	..
Essendon North Rain Gauge		586182	1990	..
Sunshine North Rain Gauge		587004	1981	..
Braybrook Rain Gauge		230808A	2014	..
Caroline Springs Rain Gauge		231821A	2014	..
Docklands Rain Gauge at Point Park		586100	1995	..
Mount Bullengarook Rain Gauge		587000	2006	..
Toolern Vale Rain Gauge		587019	2006	..
St Albans Rain Gauge		587051	1989	..

Table 3-2: List of gridded rainfall datasets available together with key information.

Dataset	Availability (years)	Temporal resolution	Spatial resolution
BARRA	1990 – 2019	6-hour	$12km^2$
IMERG	2000 – 2023	30min	$10km^2$
RADAR (Seed et al, 2022)	2019 - 2023	15min	$500m^2$
SILO	1889 – 2022	daily	$5km^2$
AWAP	1900 – 2023	daily	$5km^2$

3.3.1 Comparison of gridded rainfall datasets

The gridded rainfall datasets were compared to the BoM and Melbourne Water daily rainfall gauges as shown in Figure 3-1. This figure shows that AWAP and SILO data have good fits to the BoM gauges, but AWAP has a better fit to the Melbourne Water gauges. Considering that the Melbourne Water gauges were, in general, pluviographs which will be used for model calibration, the AWAP dataset was adopted as the gridded dataset for use in this study.

Figure 3-2 is a comparison of catchment average rainfall from the gridded datasets. This plot shows that AWAP and SILO data were similar, with RADAR and IMERG consistently being lower.

Figure 3-3 is a comparison of gridded datasets and individual daily rainfall gauges.

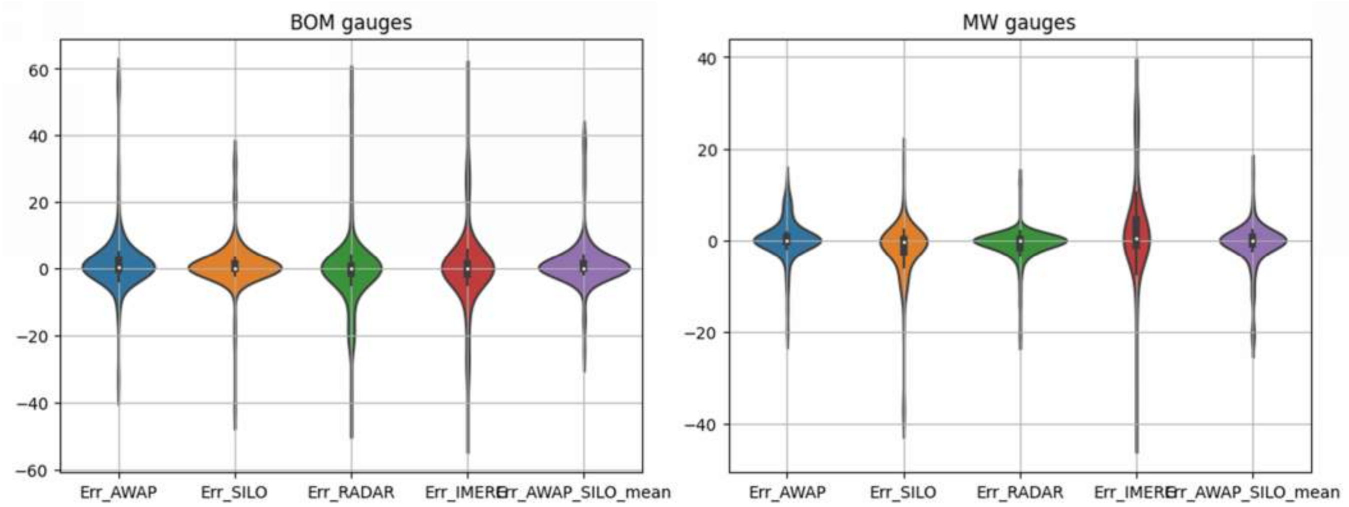

Figure 3-1: Comparison of difference (errors) between gridded datasets to BoM gauges (left hand side) and Melbourne Water gauge (right hand side).

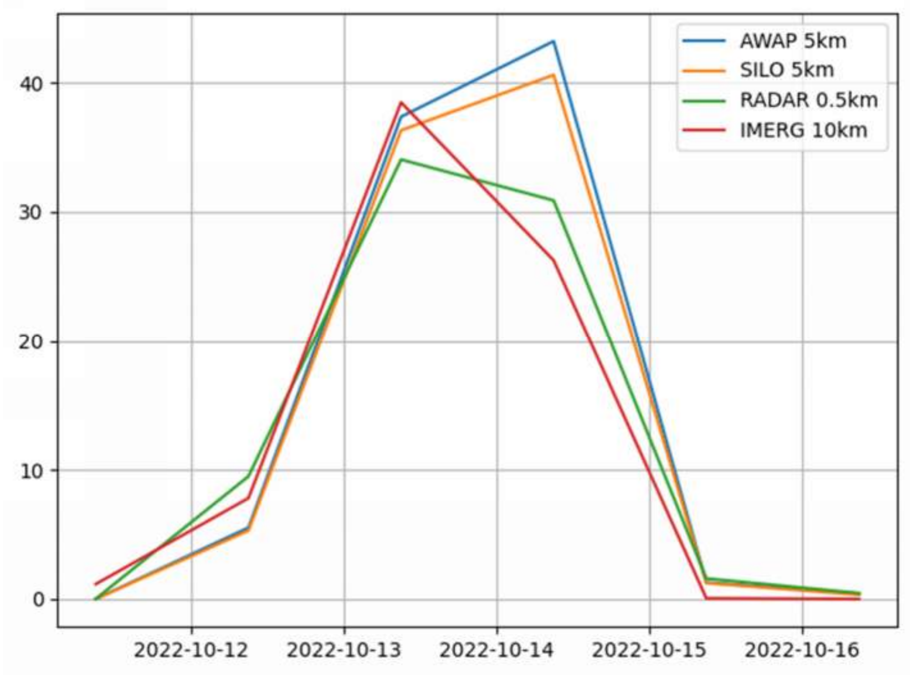

Figure 3-2: Comparison of catchment average rainfall from gridded datasets associated with the October 2022 event.

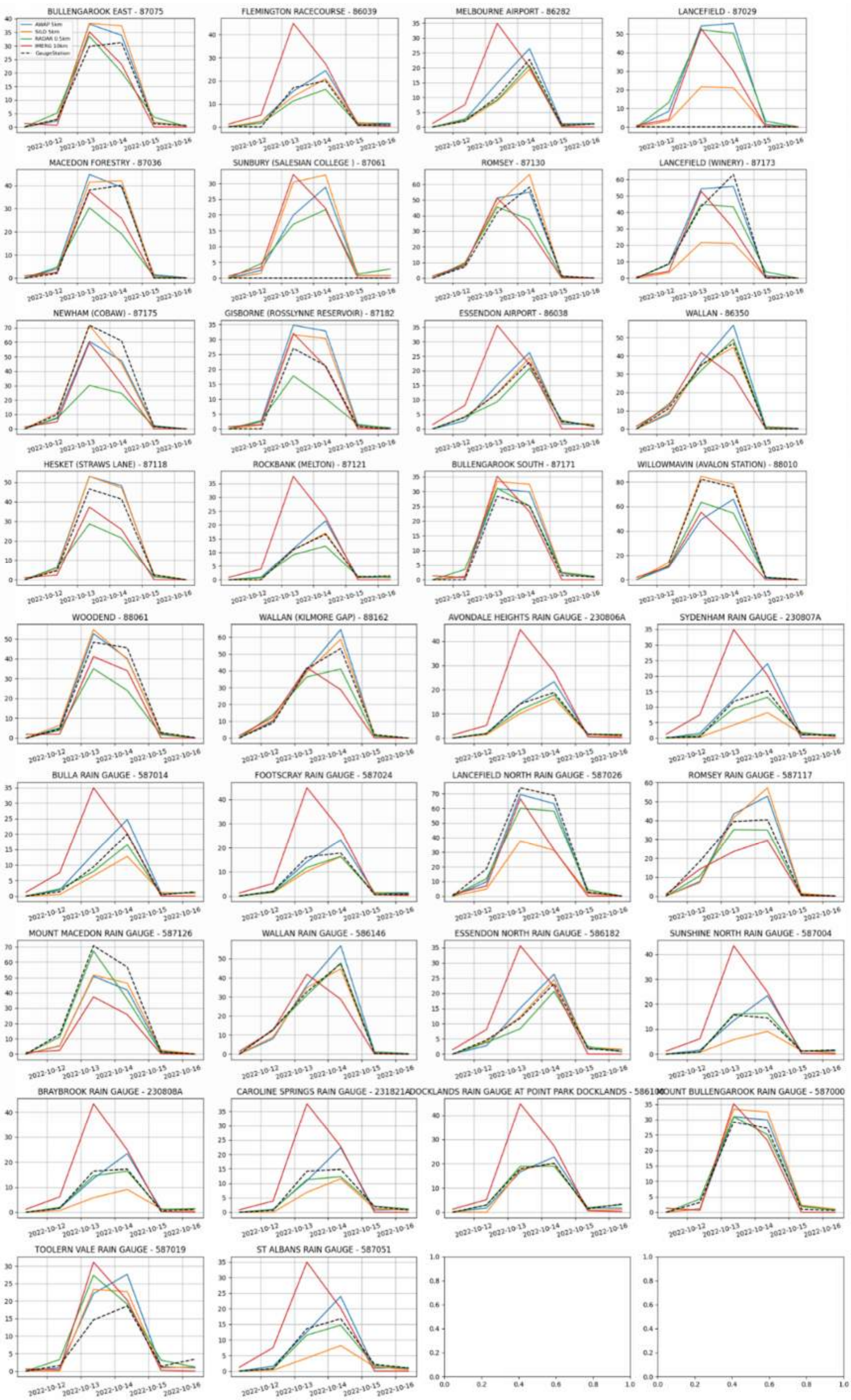

Figure 3-3: Comparison between gridded datasets and individual daily rainfall gauges.

3.4 Streamflow

Streamflow data for the catchment was obtained from the Australian Bureau of Meteorology (BoM) Water Data Online[6] and the Victorian Government's Water Measurement Information System[7] (WMIS). Streamflow data was not obtained for use in this study from Melbourne Water's Rainfall and river levels[8] as this is understood to be live data, prior to being verified, with the intent for an immediate observational use. BoM & WMIS datasets, on the other hand, are not live, are verified prior to publication and for this reason were the preferred data sources for this study. Initial comparisons identified differences between data from BoM and WMIS for common gauges. There are a number of streamflow gauge owners within the catchment and while it would have been possible to obtain quality controlled data from Melbourne Water, at the sites they owned, there were other data owners in the catchment. Given this, using common data sources (BoM and WMIS) was preferred. Historic information was also obtained from the Victorian Surface Water Information to 1982 "Red Book" (State Rivers and Water Supply Commission of Victoria, 1984) and the Victorian Surface Water Information to 1987 "Blue Book" (Rural Water Commission of Victoria, 1990).

3.4.1 Available streamflow gauges

The streamflow gauges located in the study area are listed in Table 3-3 along with identification if each gauge record contained data for the October 2022 event and the number of events, within each gauge record, that could be used for calibration and/or validation. The availability of WMIS data is shown in Figure 3-4.

Table 3-3: Streamflow gauge data for the study area.

Site Id	Site Name	2022 event data	Number of Events**
230104	Jackson Creek @ Sunbury	No	5
230200	Maribyrnong River @ Keilor	Yes	5
230201	Deep Creek @ Bulla (Above Emu Creek Junction)	No	0
230202	Jackson Creek @ Sunbury	Yes	5
230203	Emu Creek @ Sunbury	No	0
230204	Riddells Creek @ Riddells Creek	Yes	5
230205	Deep Creek @ Bulla (D/S Of Emu Creek Junct.)	Yes	5
230206	Jackson Creek @ Gisborne	Yes	5
230207	Maribyrnong River @ Arundel	No	0
230208	Deep Creek @ Darraweit Guim	No	2
230209	Barringo Creek @ Barringo (U/S Of Diversion)	Yes	5
230210	Saltwater Creek @ Bullengarook	Yes	5
230211	Emu Creek @ Clarkefield	No	3
230212	Barringo Creek @ Barringo (Ds Of Diversion Weir)	No	2
230213	Turritable Creek @ Mount Macedon	Yes	4
230214	Willimigongon Creek @ Mount Macedon	No	1
230216	Jackson Creek @ Rosslynne Reservoir (Head Gauge)	Yes	2
230217	Garden Hut Creek @ U/S Of Lancefield Reservior	Yes	2

[6] http://www.bom.gov.au/waterdata/

[7] https://data.water.vic.gov.au/

[8] https://www.melbournewater.com.au/water-and-environment/water-management/rainfall-and-river-levels#/

Site Id	Site Name	2022 event data	Number of Events**
230218	Bolinda Creek @ Mount Eliza	No	2
230219	Boyd Creek @ Darraweit Guim	No	1
230220	Jackson Creek @ Clarkfield	No	0
230221	Saltwater Creek @ Saltwater Road	No	1
230222	Gisborne Creek U/S Of Rosslynne Reservoir	No	1
230223	Slaty Creek @ Rosslynne Reservoir	No	1
230224	Barringo Creek @ Sanatorium Lake	No	1
230225	Gisborne Creek @ Burnt Mill East Road	No	1
230226	Slaty Creek @ Blackwood Road	No	1
230227	Main Creek @ Kerrie	Yes	3
230228	Long Gully Creek @ Lancefield	No	1
230229	Unnamed Creek @ Cobaw	No	1
230231	Willimigongon Ck @ Mt Macedon-Anzac Rd	Yes	3
230232	Deep Creek @ Bolinda	Yes	3
230233	Jackson Creek @ Gisborne Treatment Plant	Yes	2
230239	Stoney Creek U/S Ord Hill Reservoir	Yes	2
230240	Jackson Creek @ Salesian College Sunbury*	-	-
230242	Jacksons Creek @ U/S Riddles Creek Rwp Outfall	Yes	1
230243	Bolinda Creek Pdr Flow @ Bolinda Creek Offtake	Yes	1
230246	Deep Creek @ Romsey	Yes	1
230250	Deep Creek @ Romsey Treatment Plant	No	0
230704	Bolinda Creek Offtake @ Bolinda Creek	Yes	1
230706	Main Creek Offtake @ Forster Reservoir	Yes	1
230707	Pipeline Inflow @ Lancefield Basin	Yes	1

* Only stage data available, no flow data available.

** Number of events identified as potential calibration or validation events in Section 3.4.2.

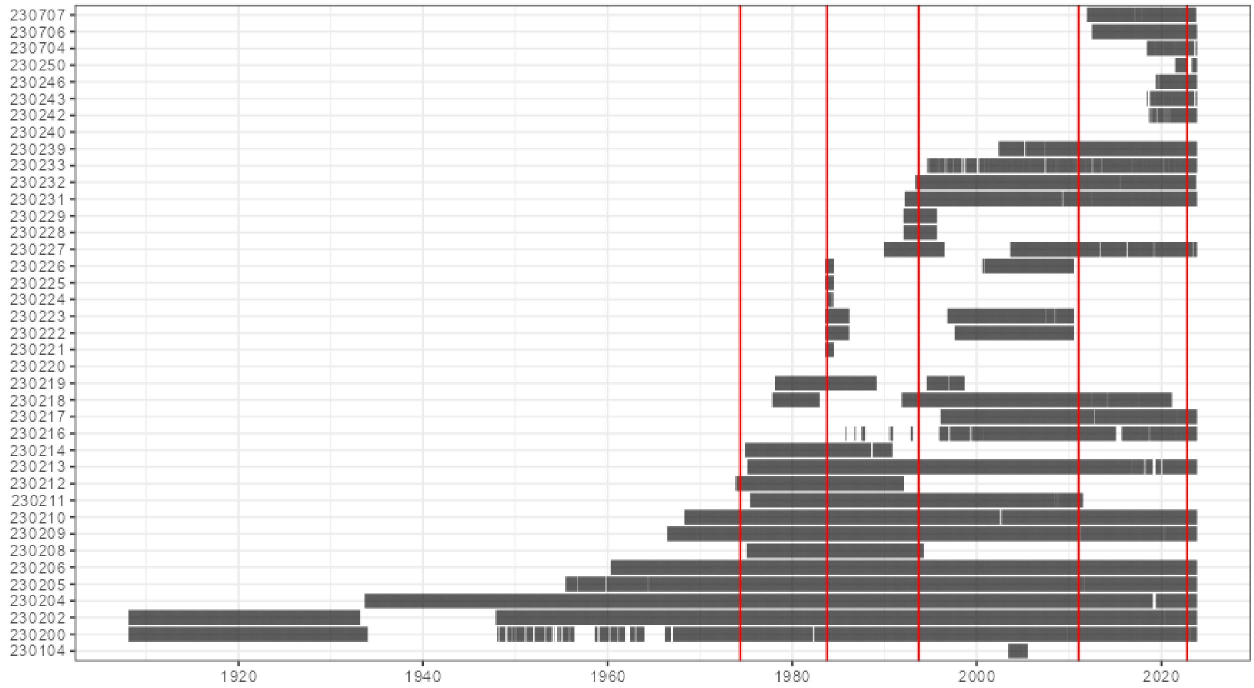

Figure 3-4: Available record of streamflow gauges from WMIS within the study catchment (vertical red lines are dates of calibration and validation events).

3.4.2 Streamflow gauges selected for hydrological analysis

Initially calibration of the hydrology model to a gauge on each of the main tributaries (Jackson Creek, Emu Creek and Deep Creek) as well as the Maribyrnong River at Keilor was tested. However, through the data preparation and review process, data issues at gauges were uncovered, such as potential gauge recording issues, re-rating issues and some unresolved questions around Jacksons Creek as discussed below. Given these issues, the hydrological analysis focused on using only the Maribyrnong River at Keilor streamflow gauge. This was considered appropriate for the following reasons:

- The Keilor gauge has a catchment area of approximately 1,300km^2 which compared to a total Maribyrnong catchment area of 1,400km^2. Hence, this gauge location is able to quantify the vast majority of the flow into the Lower Maribyrnong. Noting that runoff in the catchment downstream of this gauge is small in comparison to Maribyrnong River floods.
- The October 2022 flood event was similar, albeit slightly lower than, the key flood levels of interest such as the 1% AEP event and 1% AEP including climate change levels. This means that there is not a significant extrapolation of information.
- The information at the Keilor gauge is sufficient to support lumped parameterisation of the RORB model and provides a good validation of the 1% AEP flood estimates at the Keilor gauge (Section 4.3.3).

Further consideration of the Keilor gauge is provided in Section 4.2.7.

3.4.2.1 Keilor gauge history

The Keilor gauge has move over time having four different locations since 1908 as listed in Table 3-4. The information in Table 3-4 shows that gauge has moved a significant distance over time which means that recorded stages at different locations cannot be directly related to each other, and care needs to be taken when comparing discharges. Taking this into account this study has verified by secondary means the largest flood events; 1906 and 1974 as detailed in Section 4.2.7. The current location is shown in Plate 3-1.

In reviewing the available data for the various Keilor sites it was noted that:

- There are some inconsistencies regarding available dates between the various source of data.
- The calculation of discharge at earlier site is not clearly documented (which is typical for streamflow data of this age).
- On the WMIS all data is reported to Gauge no. 230200.

Table 3-4: Keilor gauge site history.

Location reference	Owner	Location
Site A	Jan 1908 – Dec 1933 Nov 1947 – May 1958	
Site B	May 1956 – Dec 1963	
Site C	Mar 1966 – Dec 1985	
Site D	Jun 1982 – Current	

Plate 3-1: Maribyrnong at Keilor streamflow gauge – note the distortion due to the panoramic photo.

3.4.2.2 Noted streamflow gauge issues

As part of the development of the hydrological models, review of streamflow information was undertaken as described above. This section documents some of these findings for completeness.

Bolinda Creek at Mount Eliza

In the Emu / Bolinda Creek catchment the only gauge available for the 2022 event was Bolinda Creek at Mount Eliza. Review of the volume runoff recorded at this gauge compared to the rainfall (from AWAP) suggested that the runoff ratio for the event was 80% whereas for other gauges the percentage runoff was in the 40-60% range, as expected. It was therefore deemed unrealistic and the gauge was excluded.

Deep Creek at Bulla

The Deep Creek at Bulla gauge was initially selected to replace the Emu Creek gauge as it is downstream of the Bolinda (Emu) Deep Creek confluence. Initially it was understood from Melbourne Water hydrographers that this gauged failed during the 2022 event. Examination of records found that there are four data records on the BoM Water Data Online site (see Table 3-5), but data is only available for three of these sites for the October 2022 event as shown in Figure 3-5. Where data is available the information is almost identical; however, 230102A only partially recorded the event. When there is complete recorded data for the event, the actual recorded peak appears to be unusual (Figure 3-5). This suggests that there is clearly some doubt about this information.

Table 3-5: Details of various Deep Creek at Bulla sites.

Name	Number	Owner	Latitude	Longitude	Captured data
Deep @ Bulla	230205A	VIC - Gippsland and Southern Rural Water Corporation (Southern Rural Water)	-37.6314	144.801	Recorded data
Deep @ Bulla	230205	VIC - Department of Environment, Land, Water and Planning	-37.6314	144.801	Recorded data
Deep @ Bulla - Thiess	230205A	VIC - Melbourne Water Corporation (Melbourne Water)	-37.6341	144.798	Did not record data
Deep Ck-Bulla	230102A	VIC - Melbourne Water Corporation (Melbourne Water)	-37.6314	144.801	Partially recorded data

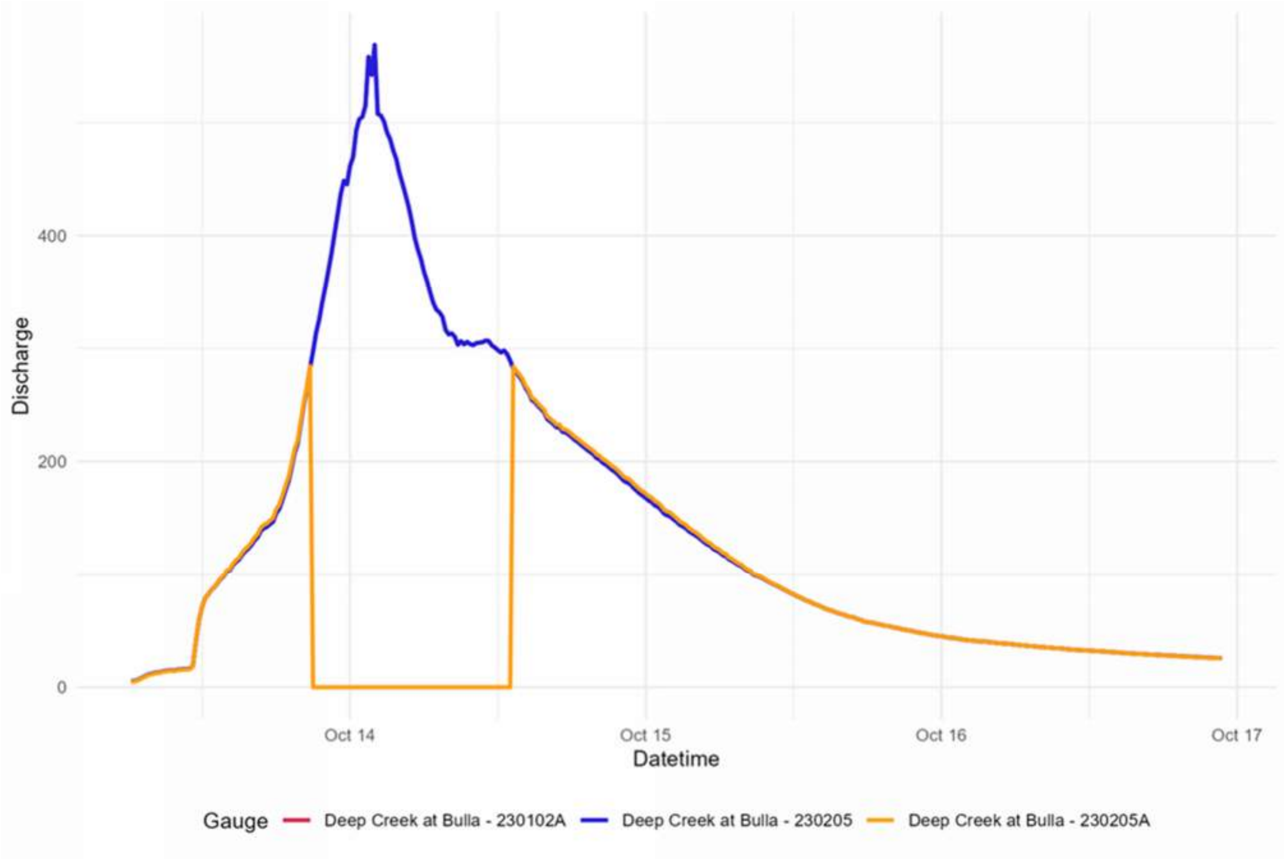

Figure 3-5: Various Deep Creek at Bulla gauges recorded data for the October 2022 flood event. This plot shows that 230102A and 230205 have the same recorded data whereas 230205A did not capture the peak.

Jackson Creek at Sunbury

The streamflow data for Jackson Creek at Sunbury gauge (230202) has been reviewed for use in this study and a number of concerns were raised, as follows:

- The published rating table does not appear to fit the gauge data well, see Figure 3-6.
- This rating curve did not represent the high flows well, for instance the 1993 gauging with a stage of 3.94m and a discharge of 403m^3/s plots well below the rating table. For this stage the rating table returns a flow of 285m^3/s. Given the importance of high flows, this was not considered acceptable for the study.

There were also some discrepancies between various data sources, particularly for events in the 1950's and 1960's as listed in Appendix F. Data relating to these events was extracted from the Melbourne Water archive; however, this information did not clarify the discrepancies.

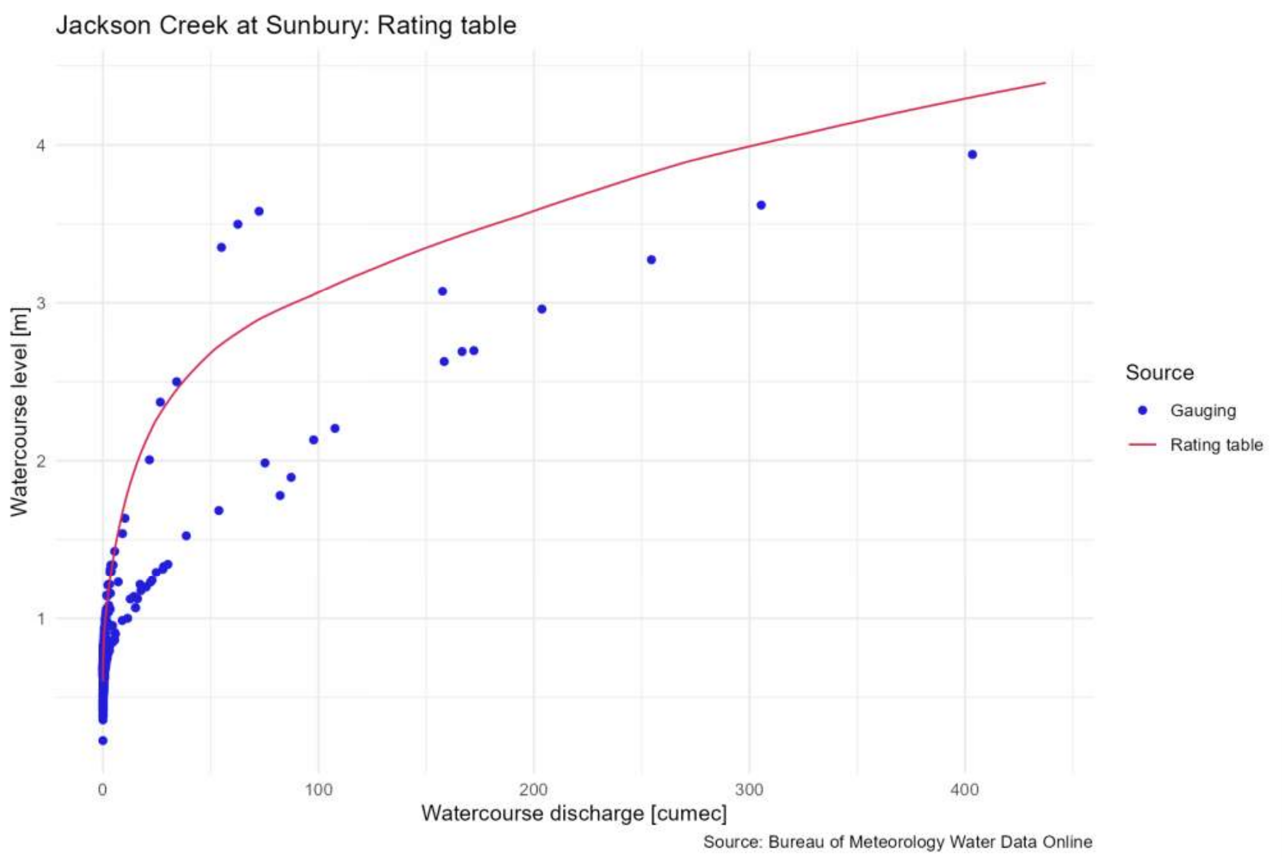

Figure 3-6: Published rating table versus gaugings.

3.4.3 Key gauges for hydraulics

The key streamflow gauges for the hydraulic modelling were:

- Maribyrnong River at Keilor (230200) – provides the recorded discharge data for application to the upstream boundary for the hydraulic model for calibration, validation and verification events. For design events this was also the location of calculations for the main Maribyrnong River inflow.
- Maribyrnong River at Chifley Drive Maribyrnong (230106A) – provides recorded water levels for hydraulic model calibration and validation. A photo of the piezometers and gauge boards are shown in Plate 3-2. The gauge is located 15km downstream of the Keilor gauge and 9km upstream of the Yarra River confluence. The datum at this gauge was converted from chart datum to Australian Height Datum (AHD) as discussed in Section 6.10.4.

An additional gauge used for the hydraulic modelling was:

- Yarra River at Crown Melbourne Spencer Street Southbank (229663A) – provides recorded water levels in the tidal estuary section of Yarra River near the confluence with Maribyrnong River. Tidal data is discussed in more detail in Section 5.

The location of these three gauges in relation to the hydraulic model extent is shown in Figure 3-7.

Plate 3-2: Piezometer and gauge boards at Chiefly Drive gauge.

Legend

- TUFLOW model extent
- Maribyrnong River
- Moonee Ponds Creek
- Outflow (Tidal) Boundary
- Inflow Boundary
- Chifley Drive Gauge
- Keilor Gauge
- Southbank gauge

MGA Zone 55

0 1 2 3 km

Jacobs

Figure 3-7: Locations of key gauges used in the hydraulic model with all 3 gauges

Disclaimer: Produced by Jacobs for the Lower Maribyrnong Flood Mapping Study, a Melbourne Water project. Jacobs does not warrant that this document is definitive nor free of errors and does not accept liability for any loss caused or arising from reliance upon information provided herein. This map should be read in conjunction with 2024 Maribyrnong River Flood Model Report. Background imagery from Metromap

Project Number: IA5000NN

FINAL

3.4.4 Dates of flood events for calibration, validation and verification

The dates of flood events for calibration, validation and verification were based on the flow record at Keilor as well as the impact of the event. The Keilor gauge was chosen as this gauge is considered to have the most relevant information for flood events in the Lower Maribyrnong River. The selection criteria for these flood events were:

- Size of the event at Keilor and Maribyrnong. The largest of these events are displayed on a "Candy" Pole on Chifley Drive at Maribyrnong near the Chifley Drive gauge as shown in Plate 3-3.
- How recent the event was? The more recent the event, the more relevant current catchment conditions.
- The availability of data including rainfall, streamflow and stage and other flood data such as surveyed flood marks and observed flood extents.

Using these criteria, the following events were selected for calibration, validation and verification:

- The **October 2022** event.
  - Selected as calibration event for hydrology and hydraulics.

  This event was selected as this was a recent event in the catchment, with significant public interest and a rich set of flood data.
- The **January 2011** event.
  - Selected as calibration event for hydrology and validation event for hydraulics.

  This event was selected as it was the largest recent event before the 2022 event.
- The **September 1993** event.
  - Selected as validation event for hydrology and hydraulics.

  This event was selected as it was the largest since the 1974 event and most of the significant catchment changes in the Lower Maribyrnong had occurred.
- The **October 1983** event.
  - Selected as calibration event for hydrology and validation event for hydraulics.

  This event was selected as it was the fourth largest event since the Maribyrnong River at Keilor gauge was installed at its current location and also had a number of surveyed flood marks to allow hydraulic model to be validated against.
- The **May 1974** event.
  - Selected as verification event for hydraulics.

  This event was selected as it was the largest event prior to 2022 in the modern period. This event pre-dates the installation of the Keilor gauge in its current location and there have been significant alterations to the catchment since this time; however, this event is widely considered to be of a similar magnitude to the 2022 event and has a rich set of data to calibrate and/or validate hydrologic and hydraulic models to.

Plate 3-3: Candy pole at Chifley Drive Maribyrnong showing the level of large flood event in the Maribyrnong River. Photograph taken 29/10/2023.

3.4.5 Re-rating of flows at Keilor

Streamflow gauging stations typically record water stage, and this water level is converted to streamflow or discharge through a relationship that is referred to as a rating table or rating curve. Essentially correlates a given water stage to a discharge. Mathematical relationships are developed from measured flow rates and water stages known as rating curves that infill data gaps and extend the relationship to higher flows. A consequence of this, for flows that are outside of the range of the measured data, is that there is a degree of uncertainty and the further outside of this range the greater the uncertainty. This issue is particularly relevant to flood flows, which by their nature are infrequent and collecting data in these situations can be difficult and hazardous. When new measurements become available the rating table should be updated or re-rated.

Gaugings were undertaken at a number of Melbourne Water's streamflow sites during the October 2022 flood event. This included the gauge at Keilor. Following the October 2022 event, the Keilor rating table was updated (17/10/2022) as shown in Figure 3-8 and this was applied to the October 2022 event but not retrospectively to datasets held by various agencies, that is, historic flood events were not updated which is consistent with standard practice (see Section 4). However, for the purpose of this study historic flood events were re-rated using the October 2022 rating table update. This is an unusually high gauging which results in a high degree of confidence in the rating table which is further discussed in Section 4.2.7.

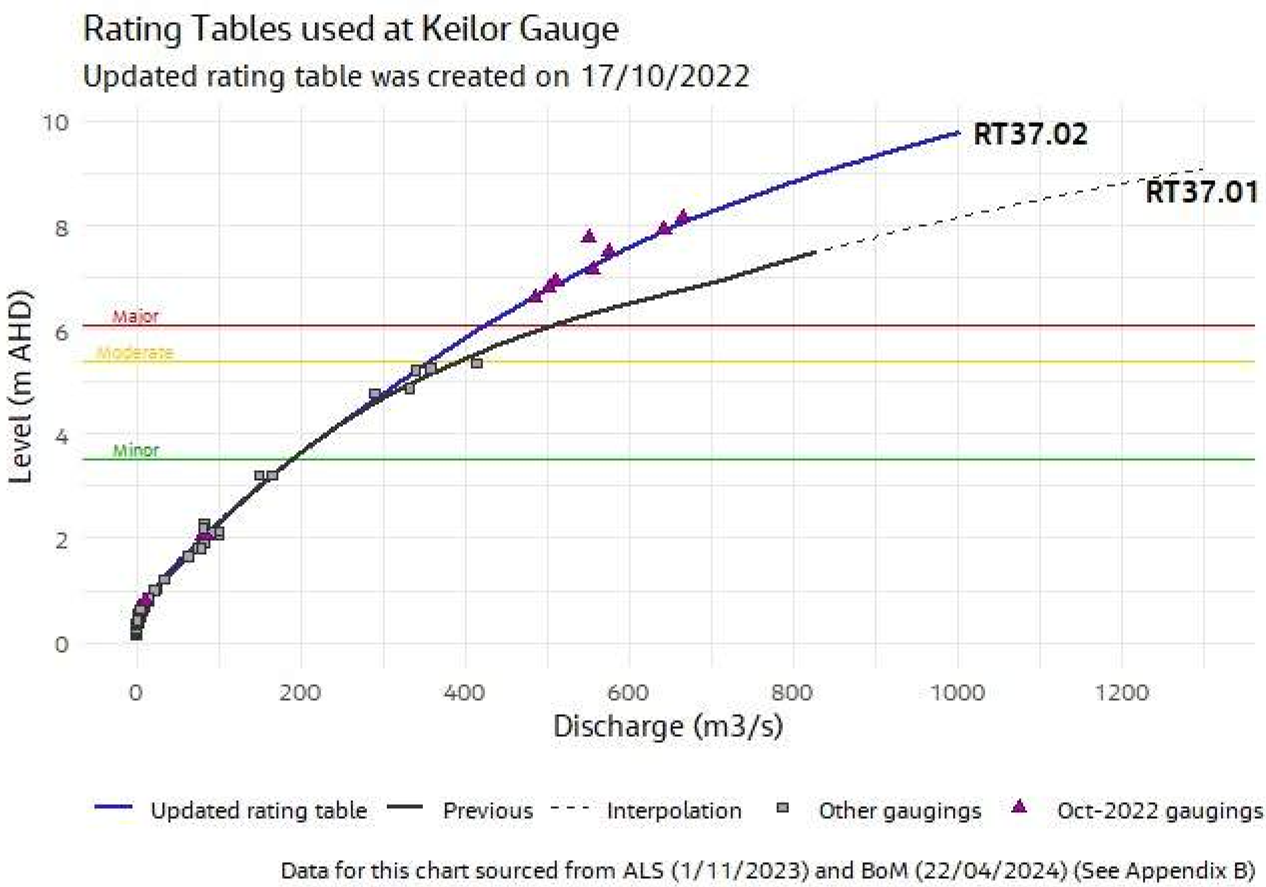

Figure 3-8: Maribyrnong River at Keilor Gauge - rating table comparison between RT37.01 (pre-October 2022) and RT37.02 (post-October 2022). This figure has been produced based on data supplied by ALS (email dated 26/10/2023 - see Appendix B).

The updated rating table (RT32.02) a significant improvement for high stages and suitable for application to historic flood events compared to previous rating table for the following reasons:

- The location of the gauge has not moved since at least 1979; prior to this, there have multiple locations for the Maribyrnong River at Keilor gauge which means the recorded stages between gauges cannot be directly compared. Additionally, the rating table from the current location cannot be applied to stages at a different location.

- A total of eight gaugings were taken on the falling limb of the October 2022 hydrograph (see Table 3-6).
- These gaugings were from a stage of 8.157 to 6.745m compared to the previous highest stage of 5.355m in 1987.
- One gauging was considered to be of lower quality which was excluded from the analysis which can be seen in Figure 3-8 as plotting above the rating curve at around a discharge of 550m^3/s.
- The measured flows are within 2.5% of the updated rating.

Further details on the are available in notes provide by ALS in Appendix B.

Table 3-6: Details of October 2022 ratings at Keilor.

Date	Start Time	End Time	Gauge No.	Start GH (m)	End GH (m)	Mean GH (m)	Gauged Flow (m3/s)	Deviation from T37.01 rating (%)
14/10/2022	0854	0927	213	8.282	8.033	8.157	666.1	-35.1
14/10/2022	0933	1001	214	8.033	7.849	7.941	643.2	-33.2
14/10/2022	1009	1040	215	7.849	7.674	7.762	551.7	-39.5
14/10/2022	1049	1120	216	7.582	7.408	7.495	576.1	-31.2
14/10/2022	1145	1217	217	7.245	7.092	7.169	556.7	-26.4
14/10/2022	1229	1258	218	6.995	6.862	6.929	511.5	-26.9
14/10/2022	1313	1340	219	6.862	6.745	6.804	502.1	-25.2
14/10/2022	1349	1418	220	6.678	6.564	6.621	485.2	-23.0

Based on the above considerations, the October 2022 rating table (RT37.02) is the best available information and is notably an unusually good dataset to determine flow at Keilor for a recorded water stage. It is considered suitable for application to historic events more recent than 1979. The re-rated flows for the selected calibration, validation and verification events are listed in Table 3-7.

Table 3-7: Comparison of original and re-rated peak flow at Maribyrnong River @ Keilor since 1974.

Event	BoM reported peak discharge	Re-rated peak discharge
October 2022	768 m^3/s	768 m^3/s *
January 2011	428 m^3/s	379 m^3/s
September 1993	690 m^3/s	510 m^3/s
October 1983	476 m^3/s	400 m^3/s
May 1974	-	726 m^3/s **

* The 2022 event was re-rated in the Keilor gauge record.

** The 1974 event was not recorded at the same location as the current Keilor gauge so it would be incorrect to apply re-rated table from the current site so this flow rate has been adobpted from the value provided by DELWP (726m^3/s). Given that the 1974 event produced a water level at Maribyrnong township of 4.20m AHD and the 2022 event a level of 4.22m AHD the 1974 peak flow appears reasonable.

3.4.6 Hysteresis

As all the October 2022 gauging data was obtained on the falling limb, the potential for hysteresis needs to be acknowledged. Hysteresis is a term that describes the difference in discharge in the rising limb of a hydrograph compared to the falling limb for the same river stage as illustrated in Figure 3-9. Typically, hysteresis is more pronounced when there is a large floodplain (Kumar, 2011), which is not present at the Keilor gauge. This potential impact was investigated, with initial indications that any changes would be in the order of 5%. Findings were discussed with Melbourne Water external reviewers and in our opinion the influence of hysteresis is unlikely to impact results. Future, programmed flood mapping studies that cover the Keilor gauge should further investigate hysteresis.

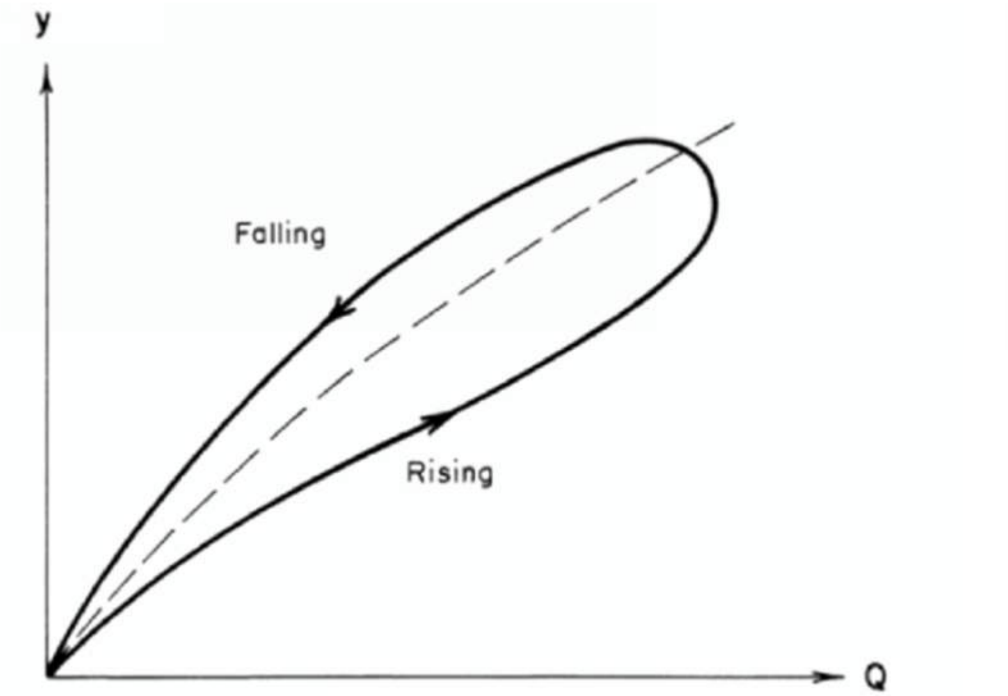

Figure 3-9: Example of hysteresis comparing the discharge on the raising limb of a hydrograph to the falling limb of a hydrograph. Taken from Chaudhry (2008).

3.5 Topography

A comprehensive data acquisition programme has been designed and undertaken specifically for the project, in collaboration with Melbourne Water, to ensure that high quality contemporary topographic data was used in the flood modelling. The project involved a variety of surveying tasks aimed at delivering a high-quality homogeneous dataset across the site extents to support flood modelling and mapping. The data collected was certified by a Licenced Surveyor to meet the accuracy and standard required.

The data acquisition included the following:

- LiDAR commissioned of the study area, was completed in July 2023. This dataset covered 40 km^2 and is comprised of 2 billion points.
- Bathymetry data of the Maribyrnong River was collected in May 2023. This dataset covered 14 km of river and is comprised of 130 million points.
- Terrestrial survey to validate the LiDAR collected covering:
  - Canning Street
  - Maribyrnong Township
  - Other publicly accessible areas

- Cross section data of the Maribyrnong River to validate the bathymetry data.
- Mobile laser scanning of 15 bridges which comprised on more than 1 billion data points.

This data was collected and synthesized into a high-quality terrestrial and bathymetric (below water surface) Digital Elevation Model (DEM) for the flood model. By following best survey practices, Jacobs were able to independently validate all data inputs to the model and detail its completeness and accuracy. Key validation checks and outcomes are summarised in the following sections. Further details can be found in Appendix C.

3.5.1 LiDAR

Jacobs engaged a qualified service provider (Aerometrex) to undertake an airborne LiDAR project across the study area. The survey was carried out on 25/07/2023. A 0.5m DEM was supplied as the main output for use. A summary of the validation exercises and main findings are as follows:

- Jacobs first reviewed the supplied metadata report and found the result of the adjustment to the supplied Ground Control Points had good agreement with a 95% Confidence Interval of ±0.0708m in the vertical component across 65 different observations. This provided confidence that the data was of a high quality.
- Jacobs then conducted an independent assessment using alternative measured points not supplied to Aerometrex for processing. These points were all completed on hard standing areas to ensure an accurate comparison against the LiDAR could be made. The points are spread at 50m intervals along the footpath that runs adjacent the Maribyrnong River through the entire length of the project area (refer Appendix D). Across 453 observations, the data indicated a RMSE of 0.027m and a 95% CI of ±0.054m in the vertical (Figure 3-10). Given that the initial observation accuracies were of an expected tolerance of ±0.030 this was considered a favourable result.

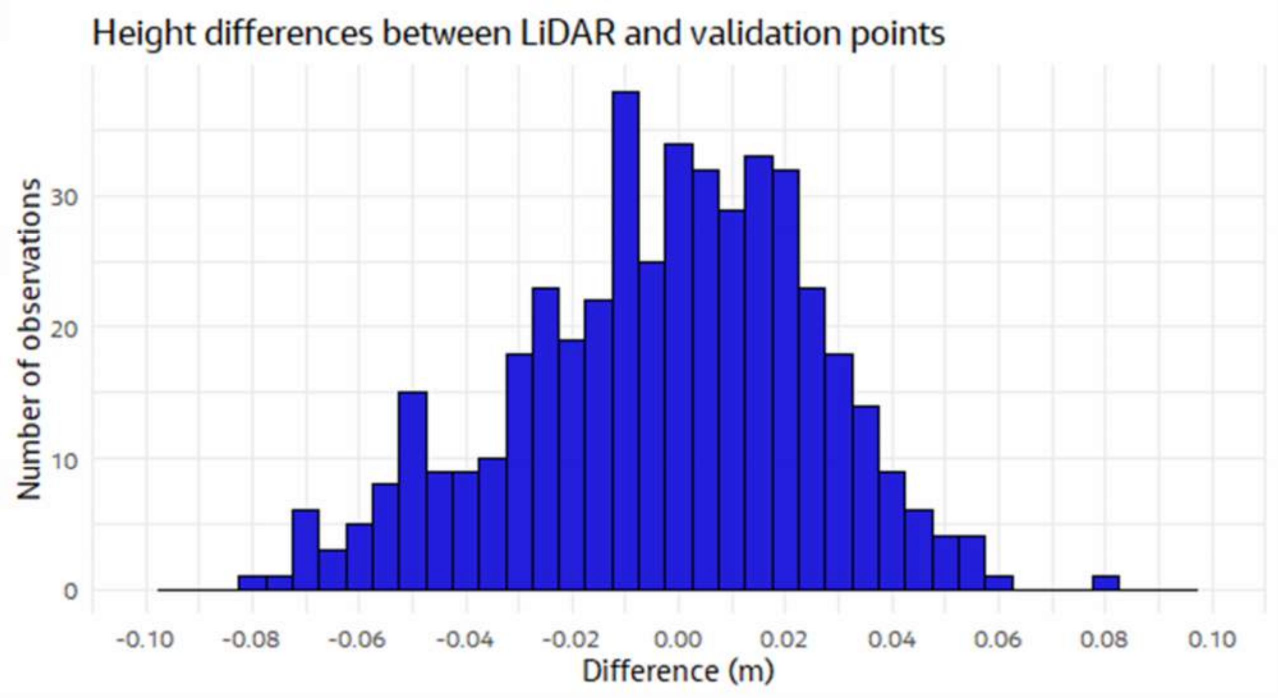

Figure 3-10: Distribution of vertical height differences between the LiDAR and independent validation points.

3.5.2 Bathymetry

Jacobs engaged a sub-contractor (Total Hydrographic) to undertake a hydrographic survey of the Maribyrnong River from the Yarra River confluence to just as far upstream as river conditions would enable the boat to navigate (upstream of Avondale Heights). This survey was undertaken between 24/05/2023 and 26/05/2023. The survey was completed utilising a multibeam echo sounder to build an accurate 3D surface of the riverbed. The survey was approved by a Level 1 (AHSCP CPHS) Hydrographic Surveyor and supplied in a point cloud format. A summary of the validation exercises and main findings are as follows:

- Jacobs reviewed the survey report supplied by Total Hydrographic and collected a total of 358 points across 8 different sites to assess the accuracy of the supplied data.
- A mean difference of 0.031m was found with 85% of the points falling within ±0.100m and a 95% CI of ±0.150m across 311 validation points (Figure 3-11). The riverbed is soft, introducing an expected level of error in both the multibeam echo sounder and the validation methodology. Regardless, the data supplied is of such a high density that it is far superior to any previous dataset used for mapping the riverbed. This greater level of detail provides a much more accurate representation of the riverbed as input to the flood model.
- Some data gaps were identified around project works for the West Gate Tunnel, where only a small section of data could be captured along a short section of the river (150m). To address this, cross-sectional information upstream and downstream of the missing area was used to infill the DEM, to provide a more accurate representation of the riverbed, under the assumption that the river profile would be similar. Other smaller areas of missing data were patched in TUFLOW using the same interpolation principle whereby gaps were infilled using surrounding DEM levels.

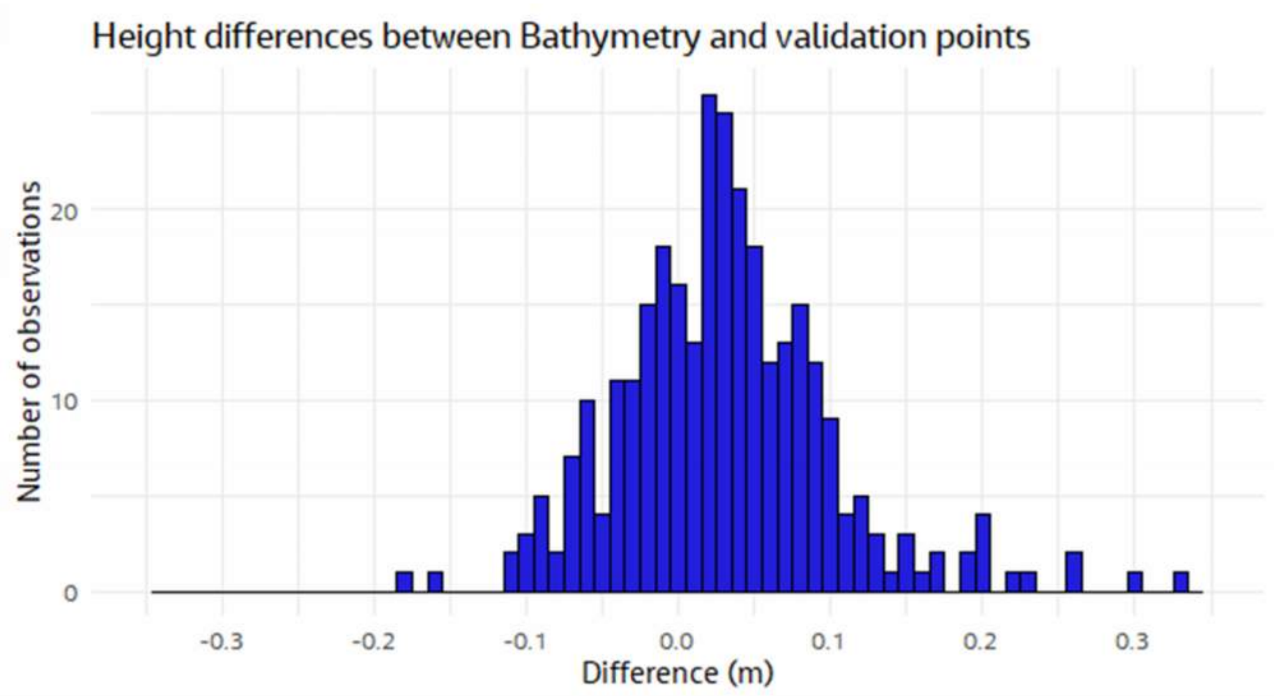

Figure 3-11: Distribution of vertical height differences between the bathymetry data and independent validation points.

3.6 Flood marks

To assist in the calibration of the hydraulic model, post-flood survey marks from the October 2022 event were collected from two different sources:

- SMEC (2022): flood mark surveys centred around Maribyrnong Township, Cannings Street in Avondale Heights and some in Kensington.
- Jacobs (2023): subsequent flood mark surveys were carried out along the length of the mid and lower Maribyrnong River based on flood marks and debris lines and photos taken during the flood event.

Flood photos were also interpreted, and high-water marks identified where possible. In some instances, it was not possible to determine a high-water mark but there was clear evidence that a feature was overtopped. In these cases, the feature was surveyed, and this sets a water level that the flood model must exceed.

All flood marks were reviewed, and spurious data removed (see Appendix A).

In addition to the above, historic observed flood marks from Melbourne Water's database (Historical_Flood_levels) GIS Layer were also used in provided observed flood level data for historic events to assist in the hydraulic model verification and validation process. Historic flood mark data was available for the May 1974 and October 1983 flood events from this database.

3.7 Observed flood extent 2022

For the October 2022 flood event there was a comprehensive set of data with which to reconstruct an observed flood extent that assisted in the calibration of the hydraulic model. This included:

- Aerial photography and video footage provided by Melbourne Water.
- Terrestrial photography provided by:
  - Melbourne Water.
  - Sourced from the public submissions to the Melbourne Water Maribyrnong River Flood Review.
  - Sourced from the private collection of the Jacobs project team.
- Photos and videos sourced from publicly available sources.

3.8 Land Use

Land use data was taken from multiple sources for use on the project. These are listed in Table 3-8.

Table 3-8 Land use data sources

Data	Data Source	Comments on use and/or quality
Victorian Land Use Information System 2014/15	LANDUSE_2014 Title: Victorian Land Use Information System 2014/2015 Anzlic ID: ANZVI0803005388 Custodian: Department of Jobs, Precincts and Regions	Formed the basis of most of the land use categories for the project area.
Next GIS	Obtained from 'NextGis' (https://data.nextgis.com)	Additional topographical data (e.g. river, trees, sand, scrub).
Victorian Spatial Data online portal	Vicmap Property – Road Casement Polygon	This data includes entire road parcels and so covers verges between roads and properties. Formed the basis for the roads layer land use category. The polygons were found to require further definition prior to use in the hydraulic model, including manual adjustment of road extents to delineate the space between the road extent and property boundaries, which was then classified separately using Metromap satellite imagery. For these manual adjustments, priority was given to areas that fell within a maximum flood extent as indicated by initial modelling.
Building footprints taken from project LiDAR	Project LiDAR (see Section 3.5.1)	Building footprints polygons were extracted from the LiDAR collected for this project. This data proved more detailed and up to date than the other available building envelope datasets such as the Melbourne Water dataset and the OpenStreetMap dataset.
Metromap	Metromap aerial imagery	Allowed further delineation of the land use and land use boundaries of the project area, such as noted with the roads layer above. Open pervious areas were manually adjusted using this satellite imagery to increase accuracy in key areas.

3.9 Infrastructure and hydraulic structures

Infrastructure and hydraulic structures across the study area are managed by several stakeholders. The inclusion of this data in modelling is discussed further in the hydraulic modelling section of this report. The data received for use in this study is listed in Table 3-9.

Table 3-9: Infrastructure and hydraulic structures data received for use in the study.

Source	Data	Quality/Comments
Melbourne Water GIS database	▪ Underground drainage network ▪ Waterways/channel network ▪ Retarding basin data (including GIS and as-built data where available) ▪ Levee and embankment data ▪ Melbourne Water owned data of area wide council drainage network	Appropriate for use in study. To be used as input into the flood model.
Melbourne Water	Historic survey of the Flemington Racecourse flood wall (Drawing 10019-V01_REV-C dated 23/04/2013).	Appropriate for use in the study to ensure the correct representation of the flood wall in the flood model.
Melbourne Water	Moonee Valley Council drainage network GIS data provided by Melbourne Water covering Rivervue estate (DR_Council_Pit_AOI_Maribyrnong, and DR_Council_Pit_AOI_Maribyrnong).	Drainage network location and pipe sizes present in the data. Invert levels generally absent, and were infilled using standard assumptions – documented in Section 6.
Melbourne Water	Moonee Valley Council Flood Mapping (2023) TUFLOW model.	TUFLOW drainage network appropriate for use in study. To be used as input into the flood model. The Council model is understood to be in draft status therefore checks and assumptions on the data are documented in Section 6.7.2.

3.9.1 Bridges and structures survey

Survey of key structures was undertaken by Jacobs to capture up-to-date, detailed, information on infrastructure requiring representation in the flood model. The majority of these structures were bridges along the Maribyrnong River, where information such as bridge soffit, deck thickness and pier locations were captured. The survey was undertaken using a terrestrial laser scanner, which has the benefit of capturing a high level of detail, with the point cloud size ranging from 25-110 million points per each bridge depending on the size and scale of the structure. The following structures were surveyed:

- Maribyrnong Pipe Bridge
- Cannings Street Bridge
- Afton Street pedestrian bridge
- Raleigh Road Bridge
- Pipemakers Park Footbridge

- Edgewater Footbridge (North)
- Edgewater Footbridge (South)
- Fisher Parade Bridge
- Rail Culverts at Heavenly Queen Temple
- Lynches Bridge
- Kensington Rail Bridge
- Angliss Stock Bridge
- Rail Bridge (Kensington Road)
- Rail Bridge (Dynon Road)
- Dynon Road Bridge
- Southern Rail Bridge (between Footscray & Dynon)
- Footscray Road Bridge
- Ascot Vale MD Channel
- Flemington Racecourse Flood Wall
- Maribyrnong River (upstream of Medway Golf Course)

Appendix E contains photos of bridge structures. An example of one of the bridge scan point clouds for Footscray Road bridge is shown in Figure 3-12.

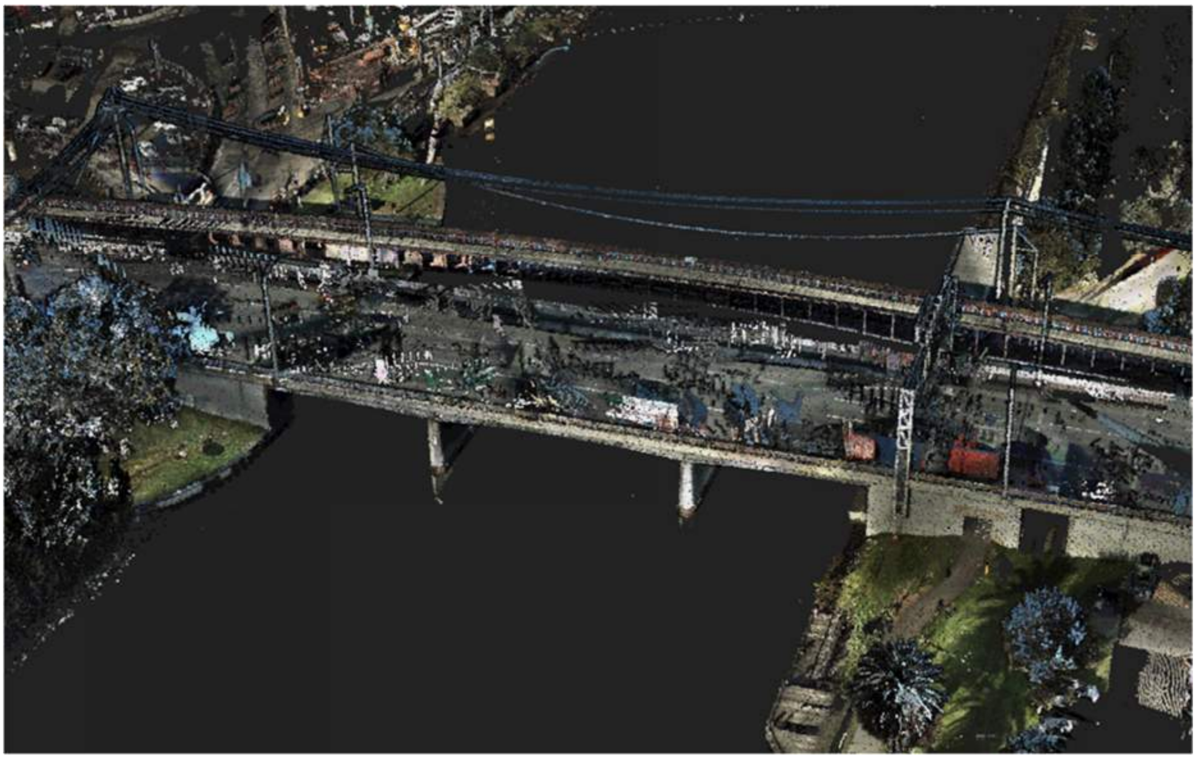

Figure 3-12: Footscray Road bridge point cloud data.

3.9.2 Culverts

There are culverts present at five locations in the study area, including:

- Three circular culverts along Steele Creek under Buckley Street (just north of Steele Creek Reserve) of 4m diameter. Information on these culverts was taken from the Melbourne Water GIS database (Table 3-5). Invert levels were assigned from LiDAR levels immediately up- and downstream of the culverts.
- Three culverts along the drain that runs parallel to Smithfield Road next to the Victoria Racing Club (VRC) / Flemington Racecourse. The most downstream of the three was picked up during the survey of Lynchs Bridge which showed these as 1.6m wide and roughly 1m tall. The other two were assumed to have the same dimensions.
- Five rectangular culverts under Farnsworth Avenue, next to Fisher Parade Bridge. From the project site visit, these were estimated as being approximately 1.8m wide x 1.5m high.
- Twelve rectangular culverts (5.3m wide x 2.8m high) present under the Kensington Rail Bridge embankment, the details of which were collected as part of the project bridges and structures survey.
- Five underpasses under Footscray Road Bridge, the details of which were collected as part of the project bridges and structures survey. Given their standard rectangular shape, these underpasses were represented as culverts in the hydraulic modelling.

3.9.3 History of major infrastructure changes to Lower Maribyrnong

The major infrastructure and other significant features along the Maribyrnong River with relevance to flooding have a history of change and development over the last 50 years. The status of the various infrastructure/features along the river has been reviewed and defined for particular years of interest when a large flood event occurred in recent history (Section 2.1). This information allows the hydraulic model to be adjusted to represent the conditions at the time. Table 3-10 provides the status of major infrastructure and if it was present at key dates when a flood event occurred in the past 50 years.

Table 3-10: Status of major infrastructure and data availability along the Maribyrnong River at key dates when a flood event occurred.

Infrastructure	Description	2022	2011	1993	1983	1974
Culverts						
At Kensington Rail Bridge	12 culverts. 5.3x2.8m. Under the rail embankment. Constructed in 1991 by the Victorian Government Major Project Unit*.	✓	✓	✓	✗	✗
Under Riverside Park Levee	Culvert under levee. Assumptions detailed in Section 6.7.2.1.	✓	✓	✗	✗	✗
Under Farnsworth Avenue	By Fisher Parade Bridge. 5 culverts. 1.8x1.5m. Unsure of date, so assumption made.	✓	✓	✓	✗	✗
Pipes						
Rivervue development	Council pipe network in the Rivervue development.	✓	✗	✗	✗	✗
Bridges						
Westgate	Piers were present in 2022 flood event (Aurecon Jacobs Joint Venture, 2018), but the deck was not yet built	✓	✗	✗	✗	✗
Northern bridge of the Lynchs Bridge pair.	Lynchs Bridge was duplicated in 1991 (GHD, 2003)	✓	✓	✓	✗	✗
Loss reduction works at Footscray Road	Modernisation works at this bridge resulted in lower losses	✓	✓	✗	✗	✗
Levees/Walls						
VRC Racecourse wall	The wall around the Flemington Racecourse was built in 2007.	✓	✓	✗	✗	✗
Levee at Riverside Park	The levee was built as part of works which began in 1991 (GHD, 2003)	✓	✓	✗	✗	✗
Others						
Terrain adjustment at Kensington Railbridge culverts	The path at the downstream end of the culverts under the embankment was lowered from 0.8m AHD to 0.5m AHD to help offset the VRC wall.	✓	✓	✗	✗	✗
Westgate piers	Piers associated with construction of the Westgate tunnel project in Maribyrnong River D/S of Footscray Road.	✓	✗	✗	✗	✗

Infrastructure	Description	2022	2011	1993	1983	1974
Further infrastructure changes and catchment development is understood to have occurred, however, data availability constraints do not permit representation in the hydraulic model.						
Pre-development terrain at Rivervue	Terrain around Rivervue was different prior to the development.	✗	✓	✓	✓	✓
Pre-development terrain at Edgewater	Edgewater development resulted in significant terrain changes.	✗	✗	✓	✓	✓
Pre-development terrain at Kensington	The Kensington Banks development results in significant terrain changes also.	✗	✗	✗	✓	✓
Previous VRC racecourse level**	Before the VRC wall was built	✗	✗	✓	✓	✓

* See Section 3.5 from 'Maribyrnong River Hydraulic Model: Final Report', Melbourne Water, February 2003.

** The granularity on Figure A-2 from 'Flemington Racecourse Flood Protection', GHD, May 2003 is unable to be interpreted with confidence, however, it does indicate that levels across the VRC racecourse may have changed.

3.10 Site visits

A project site visit was undertaken on 2 August 2023, attended by Jacobs and Melbourne Water. Key areas of interest were inspected to confirm hydraulic structures, identify land use types and understand in greater detail the conditions of the catchment and waterway.

Additional project site visits attended by Jacobs are listed in Table 3-11 in addition to specific site surveys detailed in Appendix C.

Table 3-11: Site Visits.

Date	Area Visited
14/10/2022	Avondale Heights, Essendon West, Aberfeldie, Moonee Ponds & Kensington
18/02/2023	Footscray
10/06/2023	Flemington & Maribyrnong
2/08/2023	Avondale Heights, Braybrook, Aberfeldie, Moonee Ponds, Flemington & Footscray
29/10/2023	Maribyrnong
11/11/2023	Aberfeldie, Maribyrnong, Kensington & Footscray
22/01/2024	Kensington

4. Hydrology

The purpose of this section to is describe and outline the approach to determining the flood hydrology of the Lower Maribyrnong River. An event based hydrologic model of the entire Maribyrnong River catchment (see Figure 2-2) to the confluence with the Yarra River was developed for this study. The purpose of the model is to calculate inflow hydrographs at various locations throughout the catchment, including at the upstream inflow to the hydraulic model at Keilor, for the flood magnitudes and probabilities of interest. The inflow hydrographs were applied to the hydraulic model (detailed in Section 6) to develop flood maps and other flood related products for the area. The primary purpose of the project is to determine flood extents and flood levels for the purpose of land use planning. Secondary purposes include emergency management, economic damages assessments and prioritisation for flood risk reduction.

Figure 2-2 demonstrates that the majority of the catchment area and therefore flow that arrives in the Lower Maribyrnong River, is recorded at the Maribyrnong River at Keilor gauge. This is confirmed by the catchment area to the Keilor gauge of 1,300 km^2 compared to the total catchment area at the Yarra River confluence 1,400 km^2. Therefore, this gauge represents the best flow information for this study and will define the flood hydrology. The hydrological analysis involved reviewing the Flood Frequency Analysis (FFA) completed by Jacobs (2023a) for the Keilor gauge. Given the length and quality of the gauged data, the FFA produced the most accurate flood quantiles for the Annual Exceedance Probability (AEP) events of interest. Initially, it was planned for FFA to be completed at a selection of other gauges in the catchment; however, data issues have prevented this and it is recommended that these issues be resolved in future studies.

The hydrological analysis involved reviewing the Flood Frequency Analysis (FFA) completed by Jacobs (2023a) for the Keilor gauge. Given the length and quality of the gauged data, the FFA produced the most accurate flood quantiles for the AEPs of interest. Initially, it was planned for FFA to be completed at a selection of other gauges in the catchment; however, data issues have prevented this and it is recommended that these issues be resolved in future studies.

A new event-based rainfall-runoff (RORB) model of the Maribyrnong River catchment was developed as part of this study. This model was calibration to observed events (e.g. 2022, 2011, etc.) at the Keilor gauge to determine model parameters as well as the FFA results. Once the model was calibrated it was used to develop design event hydrology, that is, hydrographs with a given probability of occurrence expressed as Annual Exceedance Probability (AEP). AEP is the probability or likelihood of an event occurring or being exceeded within any given year, usually expressed as a percentage.

4.1 Approach

The approach to determining the catchment's flood hydrology principally involves defining flood quantiles and hydrographs at the Maribyrnong River at Keilor gauge. Initially, analysis at each of main tributaries of the Maribyrnong River, that is Jacksons Creek, Emu/Bolinda Creek and Deep Creek, was proposed. However, review of the available data raised concerns with some gauges (Emu Creek at Mt Eliza and Deep Creek at Konagaderra) as discussed in Section 3.4.2. Further using the recently updated rating table for the Maribyrnong River at Keilor it became evident that all historic flows should be re-rated (see Section 3.4.5). For these reasons, the flood hydrology was focused on the Keilor gauge.

The FFA analysis produced the flood quantiles (or the magnitude of a flood for a given probability) at the Keilor gauge. This analysis was completed to be consistent with the framework outlined ARR2019 (Kuczera and Franks, 2019) using a Bayesian framework.

The hydrographs for design events with a given probability as opposed to historic events, were determined from the new RORB model created for the catchment. The RORB model was initially developed in accordance with industry practices, such as those outlined in ARR2019 (Ball et al, 2019), the Melbourne Water Technical Specifications and Jacobs' experience. Ultimately, a non-standard approach was adopted to ensure that robust and defensible flood quantiles and hydrographs were generated. The model was calibrated and validated to four historic events (2022, 2011, and 1983 for calibration and 1993 for validation) with a multiple-staged process. The final model parameters were determined through calibration to the expected quantiles of the FFA:

- Initially, the RORB routing parameter was calibrated to historic events at the Maribyrnong River at Keilor gauge. This resulted in an event-based catchment specific k_c.
- The AEP neutral losses (Initial Loss (IL) and Continuing Loss (CL)) parameters were attempted to be determined by adjusting these until there was an acceptable match between the flood quantiles generated by RORB and the FFA quantiles.
- When a good fit could not be found, the constraint of using the k_c from event calibration was removed. The routing parameter k_c and AEP neutral losses were determined through calibration to the FFA quantiles.

As the design hydrographs were ultimately determined by a non-standard approach, the focus in the main body of this report is to present this information with a summary of the traditional calibration approach. Full details of the traditional calibration approach are presented Appendix H of this report, as this information may be useful, in particular for the secondary purposes of this project such as emergency management.

Review of the flow at the Keilor gauge has demonstrated that baseflow is only a minor part of the flood hydrograph at this location. Given this, baseflow will be applied directly to the hydraulic model as the initial flow which will also generate the initial water levels in the Maribyrnong River.

The impact of climate change on flood flows was also considered as outlined in Section 4.3.4.

4.2 Flood frequency analysis

At-site FFA was completed for the Maribyrnong River at Keilor gauge in line with the guidelines provided in Book 3, Chapter 2 of ARR2019 (Kuczera and Franks, 2019). The FFA was undertaken using the TUFLOW Flike software package. Flike provides a Bayesian framework for comprehensive at-site flood frequency estimation that allows the inclusion of ungauged historical events.

This involved the following exercise:

- Extracting the Annual Maximum series for the Calendar Year (January to December).
- Fitting a statistical distribution in Flike (Log Pearson Type 3, Generalised Extreme Value, etc).
- Censoring Low flows.
- Incorporating historical floods (if information available).
- Producing flood quantiles (peak flows vs probability).

The application of the Regional Flood Frequency Estimates (RFFE) model is for catchments less than 1,000km^2 as this was the upper limit of catchment used to develop the RFFE model. Given the area of the catchment (1,300km^2 at Keilor and 1,400km^2 at the outlet), prior parameters for the Log-Pearson Type 3 distribution from the Regional Flood Frequency Estimates model were not used.

4.2.1 Previous Flood Frequency Analysis

There have been a number of studies which have undertaken flood frequency analysis at the Keilor gauge including:

- Water Resources Council (1981)
- MMBW (1986)
- Camp Scott Furphy Pty Ltd (1990)

The resulting flood quantiles from these studies are presented in Table 4-1 as reported by Fluvial Systems (2000). Fluvial Systems states that the MMBW (1986) analysis was the most thorough as it covers a longer period of record, and the authors of this report agree.

The MMBW (1986) Maribyrnong River Flood Mitigation Study completed a flood frequency analysis at the Maribyrnong River at Keilor. The flows at Keilor were based on gauge data available at the time. In this report the Maribyrnong gauge (230106) flows were assumed to have the same peak flows as those at the Keilor gauge, based on the following:

- It was concluded there is little inflow between the Maribyrnong and Keilor gauge.
- The Maribyrnong gauge is influenced by tidal conditions and therefore developing a rating table was difficult.
- The catchment is long and narrow between the two locations.

The MMBW (1986) study assumed that there was no attenuation between Keilor and Maribyrnong Township and this assumption has been investigated in this study. It was found that there was attenuation as detailed in Section 6.5.1. The attenuation was found to be greater for larger flows.

Table 4-1: Results of previous Flood Frequency Analyses for the Maribyrnong River at Keilor as presented in Fluvial System (2000). The date year ranges for the analysis are also listed in the heading.

AEP	WRC (1981) 1871 – 1981 m^3/s	MMBW (1986) 1871 – 1986 m^3/s	Camp Scot Furphy (1990) 1908 – 1933 m^3/s	Camp Scot Furphy (1990) 1956 – 1988 m^3/s
1%	NA	840	725	810
2%	710	710	635	710
5%	520	530	518	571
10%	402	400	430	465
20%	NA	270	340	365
50%	NA	125	220	225

4.2.2 Annual Maximum series

The data for peak flows at Keilor was sourced from:

- Victorian Water Measurement Information System (WMIS) for data from 1908 to 2023.
- Bureau of Meteorology (BoM) Water Data Online for data from 1908 to 2023.
- Blue and Red books (Rural Water Commission of Victoria, 1990).
- MMBW 1986 for historic peak flows from prior to the instrumental records at this site i.e. before 1908.

FFA for the Keilor gauge was recently completed by Jacobs (2023a); however, hydraulic modelling results demonstrated that high flows recorded prior to the October 2022 event at the current site would benefit from re-rating (see Section 3.4.5). Review of the information in the “Blue Books” (Rural Water Commission of Victoria, 1990) indicated that the gauge has moved since it was first established in 1908, to where it is now established, at its current site in 1979. Given this movement of the gauge, the re-rating could only be applied to flow records from 1979 onwards. This resulted in the re-rating of the 2011, 1993, 1987 and 1983 flood peaks. No other changes were made to the annual maximum series from Jacobs (2023a) and the resulting series is presented in Figure 4-1 and the full series in Appendix F (which includes the re-rated values for 2011, 1993 1987 and 1983). This table also outlines which years have been excluded from the analysis and the reasons for this exclusion.

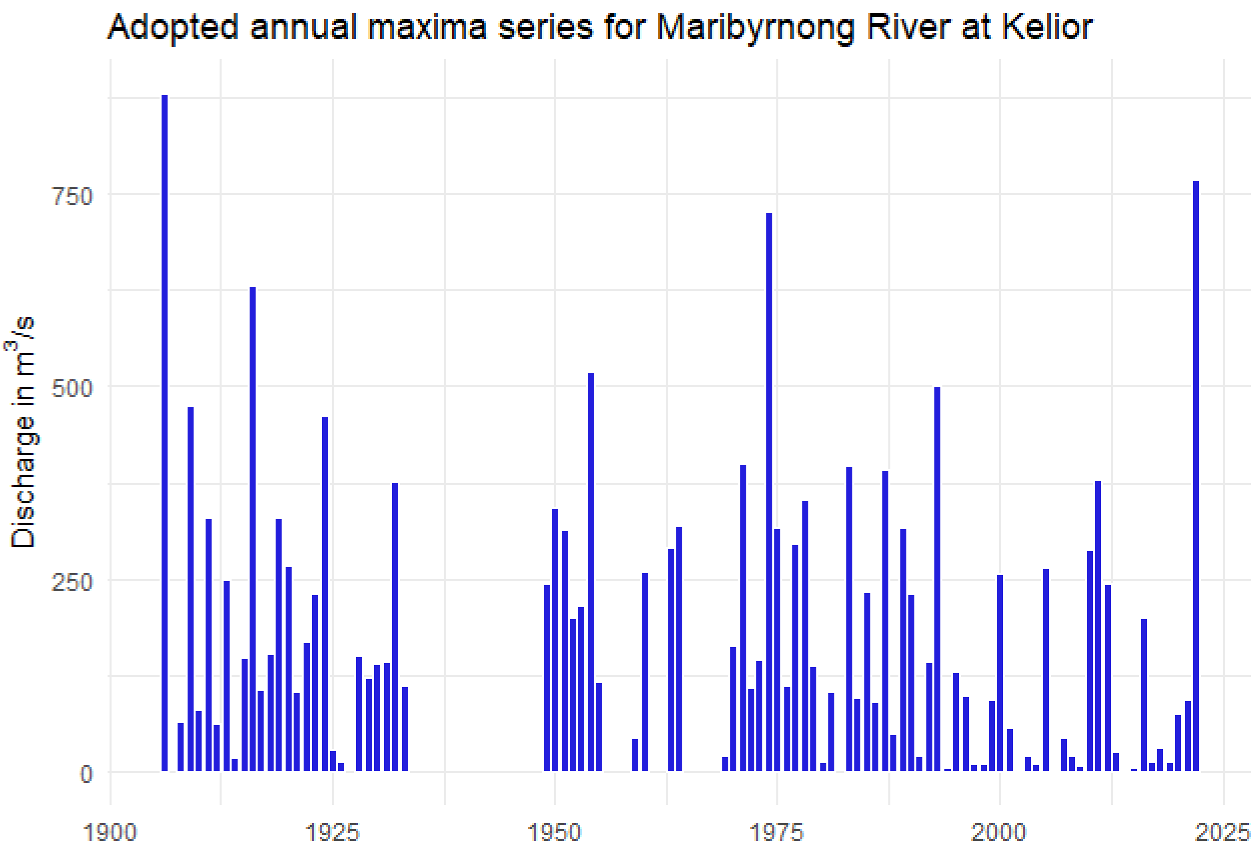

Figure 4-1: Annual maximum series for the Maribyrnong River at Keilor including re-rating of high flows to most recent rating table (RT37.02).

4.2.3 Removal of probable influential low flows

During the period of record there were several low flow years. Low flows were censored from the dataset to ensure that these did not unduly affect the fit of the flood frequency curve. A low flow discharge threshold of 76m^3/s was determined by using the multiple Grubbs-Beck test which resulted in 27 events being censored.

4.2.4 Historic information that pre-dates the instrumental record

Where there is reliable evidence, it is good practice to include historic information that pre-dates the instrumental record. For the Lower Maribyrnong River there is a long history of well documented flooding (see Section 2.1) as well as estimates of peak flow from the MMBW 1986 report.

Following the review of this information, four historic floods were included in the FFA which are listed in Table 4-2. The largest flood occurred in 1906 with a peak flow of 880m^3/s was directly included in the analysis. The other events in Table 4-2 were included as historic or high flow censors in Flike. The peak flow rate of the 1906 event was verified in the hydraulic model as reported in Section 6.10.10. The impact of this peak being underestimated was also investigated. A sensitivity test with the 1906 value being replaced by 1,000m^3/s was completed, and the resulting 1% AEP quantile was around 950m^3/s. However, as the 880m^3/s value was verified in the hydraulic model this value was retained.

The way that the historic data was input into Flike was sensitivity tested in a variety of ways, through including all values as high flow censors, including only one high censor of 320m^3/s and including all directly. The results from these sensitivity tests confirmed that the final adopted approach was appropriate. Summary details of this sensitivity assessment are available in Appendix G.

In addition to the sensitivity testing discussed above, results from TUFLOW Flike were compared to those of Best-Fit (Jacobs, 2023f). Best-Fit is FFA software that also employs a Bayesian framework for estimation of extreme value distribution parameters. The testing found that both TUFLOW Flike and Best-Fit produced the same results (with an acceptable tolerance) for the expected probabilities. However, Best-Fit does not calculate expected quantiles. Given this, the Flike results were adopted for the study.

Table 4-2: Historic floods at Keilor included in the FFA.

Year	MMBW (m^3/s)	Application to Flike	Comments
1871	600	Input as historic censor	There is significant evidence for this flood (see Section 2.1) although the method of calculation is unknown.
1891	560	Input as historic censor	There is significant evidence for this flood (see Section 2.1) although the method of calculation is unknown.
1901	320	Input as historic censor	There is significant evidence for this flood (see Section 2.1) although the method of calculation is unknown.
1906	880	Value input	There is significant evidence for this flood (see Section 2.1) although the method of calculation is unknown.

4.2.5 Keilor Flood Frequency Analysis results

The resulting unbiased flood quantiles as determined by TUFLOW Flike are listed in Table 4-3 and displayed in Figure 4-2. The analysis included the following inputs and processing:

- Annual maxima series as listed in Appendix F.
- Historic information as listed in Table 4-2.
- Low flow censoring threshold of $76m^3/s$, this threshold was determined by the multiple Grubbs Beck test.
- Bayesian inference technique.
- Fitted to the LP3 distribution.

The fit of the LP3 distribution shown in Figure 4-2 is considered to be acceptable as all empirical points (the red dots) fall within the uncertainty bounds.

Table 4-3: Flood quantiles from FFA for the Maribyrnong River @ Keilor.

AEP	Peak flow (m^3/s)	Lower CL (m^3/s)	Upper CL (m^3/s)	Partial series results*	MMBW[9]
0.5% (1 in 200)	1025	788	1412	-	NA
1% (1 in 100)	905	722	1180	-	840
2% (1 in 50)	778	639	982	-	710
5% (1 in 20)	601	508	726	-	530
10% (1 in 10)	463	395	551	452	400
20% (1 in 5)	323	267	386	300	270
50% (1 in 2)	140	114	173	77	125

* Partial series values of the results calculated using Langbein's formulae. For events less frequent than the 10% AEP the annual maxima results are equivalent to the partial series results and hence have not been reported.

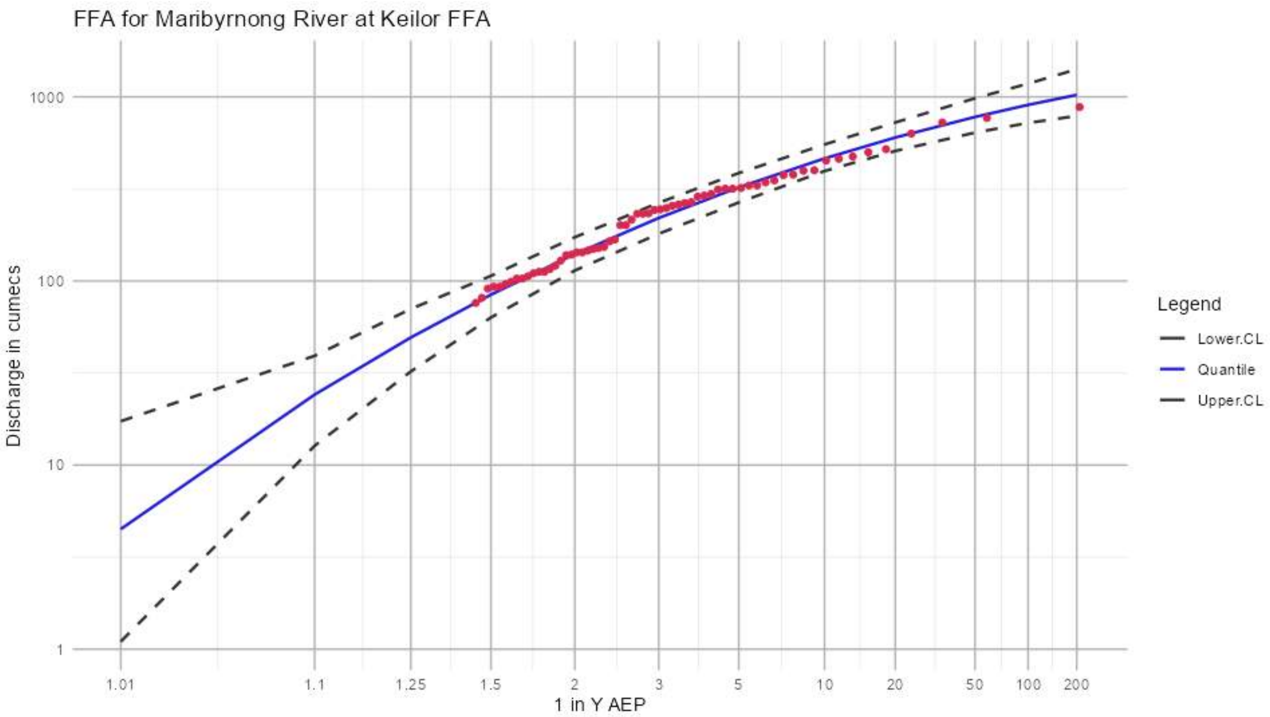

Figure 4-2: Flood frequency curve for the Maribyrnong River at Keilor.

4.2.6 Comparison of flood quantiles with MMBW 1986

The flood quantiles presented above were compared to the flood quantiles estimated by MMBW (1986), as presented in Table 4-3. The estimates produced from the current study are greater than those from the previous work by between 7-15%, with larger differences for smaller flows. This is due to:

- The additional 40 plus years of data.
- More sophisticated analysis techniques.
  - A Bayesian approach vs a method of moment approach.

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[9] Melbourne and Metropolitan Board of Works

- A full series vs a partial series.
- The ability to safely censor low flows.
- The incorporation of historic information.

It is considered that updates, additional data and more advanced techniques have resulted in more robust estimates for flood quantiles and expected probabilities. Thus, the analysis presented in this report represent the best available estimates of flood quantiles.

4.2.7 Reliability of Keilor FFA results

The FFA results at the Keilor gauge form the basis of the hydrology for this study and this section outlines the rationale for this.

FFA is an empirical method of calculating flood quantiles at a streamflow gauge and as such it is reliant on the input data to calculate reliable results. Considerable effort has been made to review and ensure that it is suitable to underpin this study and it was concluded that this record was of high quality and length and therefore suitable for analysis. The basis for this was:

- The annual maxima series have been constructed from a variety of sources with each of the peak flows reviewed against secondary sources, where available. Details of this are provided in Appendix F. With the WMIS database being considered the primary dataset the secondary sources included:
  - BoM Water Data online.
  - Information in the following MMBW reports (1975, 1976 and 1986).
  - Victorian Surface Water Information to 1982 “Red Books” (State Rivers and Water Supply Commission of Victoria, 1984)
  - Victorian Surface Water Information to 1987 “Blue Books” (State Rivers and Water Supply Commission of Victoria, 1990
  - Historic newspaper articles as detailed in Section 2.1.
- The resulting series had an effective length of approximately 150 years with 90 datapoints and 60 years where significant flood events did not occur.
- ARR2019 Book 3, Chapter 2 of ARR2019 (Kuczera and Franks, 2019) does not prescribe strict limits on the extrapolation of a flood frequency curve, in this case, given the length of record, no significant extrapolation was required. The quantiles of interest were effectively interpolated.
- The gauge was re-rated on the basis of data captured during the October 2022 flood event, details of which are provided in Section 3.4.5. This re-rating was applied to previous events at this site which include: 2022, 1993 and 1983 as listed in Table 3-7. The rerating is considered to have significantly reduced the uncertainty in the highest rated flows at this site. This is considered below under the heading *Rating ratio*.
- The largest historical floods (1906 and 1974) were verified in the hydraulic model (see Section 6.10.9 and Section 6.10.10).

These points address the potential disadvantages outlined in Book 3, Chapter 2 of ARR2019 (Kuczera and Franks, 2019) namely:

- The true probability distribution family is unknown. Unfortunately, different models can fit the flood data with similar capability, yet can diverge in the right hand tail when extrapolated beyond the data.
  - Given the length of the there is little extrapolation beyond the data required.
  - For this reason, this disadvantage is not applicable to this project.

- Short records may compromise the utility of flood estimates. Confidence limits inform the practitioner about the credibility of the estimate.
  - For the Keilor gauge the effective length of record is around 150 years and the probabilities of interest for the study are up to the 1% (1 in 100) AEP event, that is, flood quantiles in this instance are essentially interpolated.
  - For this reason, this disadvantage is not applicable to this project.
- It may be difficult or impossible to adjust the data if the catchment conditions under which the flood data were obtained have changed during the period of record, or are different to those applying to the future economic life of a structure or works being designed.
  - Overall, the catchment has not changed its rural nature over the flood history used to inform the FFA. Further, the most significant catchment changes have occurred downstream of the Keilor gauge, and these have been incorporated into the hydraulic model.
  - For this reason, this disadvantage is not applicable to this project.
- Considerable extrapolation of rating curves is necessary to convert recorded stage to discharge for the largest flood peaks at most Australian gauging stations.
  - As outlined under the heading of Rating ratio, significant extrapolation has not been required due to the data capture during the 2022 flood event.
  - For this reason, this disadvantage is not applicable to this project.

Rating ratio[10]

The rating factor is a measure that is an indicator of quality of high flows recorded at a gauge. This ratio of the highest rated discharge to the extrapolated discharge for the highest observed stage (Piggot and Black, 1982). For the Keilor record, at the current location, the rating ratio has been calculated to be 87% greater than the 80% which is considered to be very good but unusual in practice with only three gauges out of 45 in NSW achieving this percentage (Cordery, 2006).

Figure 4-3 presents the inverse of the rating factor, referred to as the rating ratio, noted above for the annual maximum series from the Keilor gauge since 1979. In this figure, ratios above one indicate that the flow calculation has been extrapolated beyond the maximum rated data. In this figure only two flows have been extrapolated: 1993 and 2022. The 1993 peak was extrapolated by 4% and the 2022 peak by 15% both of which are considered to be small and the resulting peaks accurate.

Summary

Multiple lines of evidence have been used to compile an annual maxima series at the Keilor gauge which has taken advantage of the high flow rating during the October 2022 flood event. This annual maxima series is fit for the purpose of providing flood frequency estimates and that the quality of the flow record is in fact unusually good compared to most gauge records.

[10] Rating factor and rating ratio can be used interchangeably; however, in this report they have been defined as the inverse of each other.

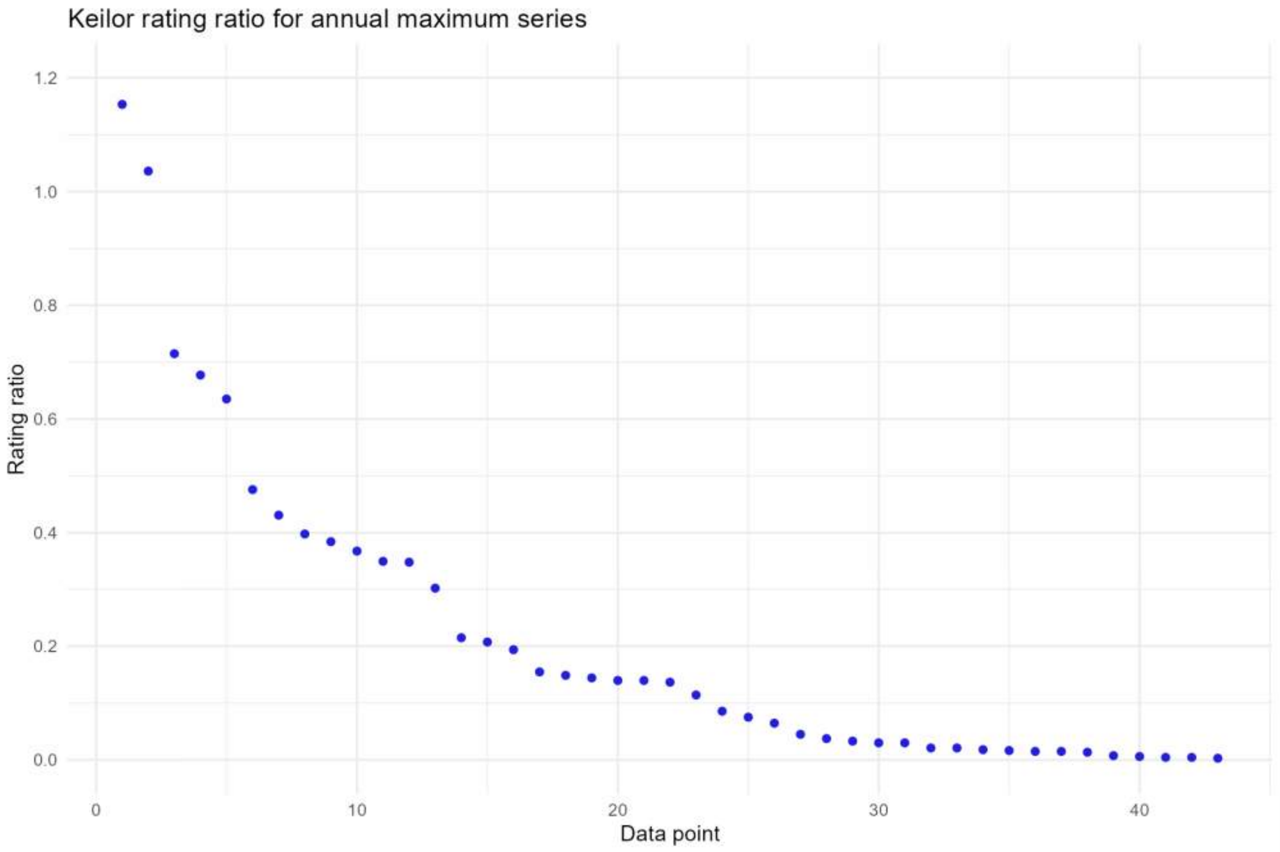


Figure 4-3: Keilor rating ratios for the adopted annual maximum series.

4.3 Event-based flood modelling

A RORB event-based flood model (Laurenson & Mein, 1995; Laurenson, Mein & Nathan, R. J. 2010) was created to represent the Maribyrnong River catchment to its outlet at the tidal section of the Yarra River. Existing RORB models of the Maribyrnong do exist; however, testing demonstrated that these models could not reproduce published results and it was concluded that either the RORB catchment file had changed, or the results had been produced in an earlier version of RORB. Given this a new RORB catchment file was developed.

As noted above, the calibration point for this model was the gauging station at Keilor. The area upstream of Keilor was delineated by the "Interstation area" feature in RORB to allow calibration to this location. Smaller tributaries downstream of Keilor such as Taylors Creek or Steele Creek are represented within the model, but not calibrated to, given the vastly different flood response times between the Maribyrnong River and these tributaries. These tributary flows will be applied as routed hydrographs in the hydraulic model.

The two principal model parameters are k_c and m. The parameter m describes the degree of non-linearity of the catchment's response to rainfall excess, while the parameter k_c describes the delay in the catchment's response to rainfall excess. The value of m is generally kept at a constant value of 0.8. The k_c value is chosen through the process of calibration as outlined in Section 4.3.3 and Section 4.3.3.2.

The remaining model parameters relate to the model representation of the rainfall losses. For this project an initial loss/continuing loss model was used, as recommended in Australian Rainfall and Runoff (ARR, 2019).

Flood quantiles in the RORB model were determined using a Monte Carlo joint probability framework as described in Section 4.3.1 (for a description see Laurenson et al., 2010 or Nathan and Weinmann, 2004). This joint probability approach allows for the inherent variability in flood events to be considered, and includes the sampling of temporal patterns, spatial patterns and initial losses. The inputs required for this approach are described in Section 4.3.4.

4.3.1 Monte Carlo joint-probability framework

The design flood estimates were derived using a Monte Carlo joint-probability framework. The Monte Carlo framework recognises that any design flood characteristics (e.g. peak flow) could result from a variety of combinations of flood producing factors, rather than from a single combination. For example, the same peak flood could result from a moderate storm on a saturated catchment, or a large storm on a dry catchment; in probabilistic terms, a 1% AEP flood could be the result of a 2% AEP rainfall on a very wet catchment, or a 0.5% (1 in 200) AEP rainfall on a dry catchment. Joint probability approaches attempt to mimic “mother nature” in that the influence of all probability distributed inputs are explicitly considered, thereby providing a more realistic representation of the flood generation processes (Nathan et al., 2002).

As shown in Figure 4-4, this approach is consistent with the recommended approaches described in the 2019 release of Australian Rainfall and Runoff (ARR2019) (Nathan and Ball, 2019) for design events of frequency between 20% and 0.2% AEP.

An overview of the joint probability framework adopted is illustrated in Figure 4-5. In essence, the approach involves the undertaking of numerous model simulations where the model inputs are varied in accordance with that observed in nature. The inputs are sampled from statistical distributions that are based on readily available design information. The result of this process are flood quantities at the location(s) of interest.

The following briefly describes the main inputs, and the way these relate to established flood design information:

- Rainfall depth: Rainfall depths are stochastically sampled from the cumulative distribution of rainfall depths. The rainfall depths have been obtained as described in Section 4.3.4.
- Rainfall losses: Rainfall median Initial Losses (IL) and Continuing Losses (CL) were determined as part of the calibration presented in Section 4.3.3.2. IL were stochastically sampled from a non-parametric distribution that was determined from the analysis of a large number of catchments from south-eastern Australia (Hill and Thompson, 2019).
- Rainfall Temporal Patterns: Temporal patterns are randomly selected from a sample of temporal patterns relevant to the catchment area and duration of the storm, details of which are in Section 4.3.4.

Simulations are undertaken using a stratified sampling approach in which the sampling procedure focuses selectively on the probabilistic range of interest. Thus, rather than undertaking many millions of simulations to estimate an event with, say, a 1% probability of exceedance, a reduced number of simulations are undertaken over a specified number of probability intervals. The rainfall frequency curve was divided into 100 intervals uniformly spaced over the standardised normal probability domain, and 100 simulations were undertaken within each division. Thus, a total of 10,000 simulations were undertaken to derive the frequency curve corresponding to each storm duration.

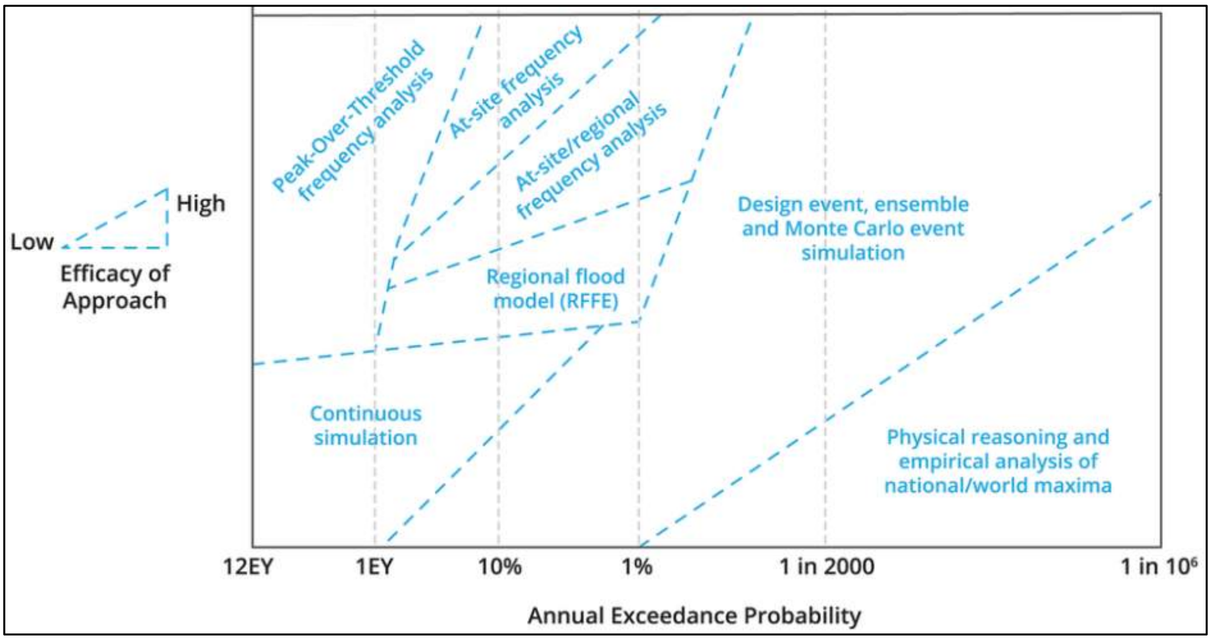


Figure 4-4: Illustration of Relative Efficacy of Different Approaches for the Estimation of Design Floods (Nathan and Ball, 2019).

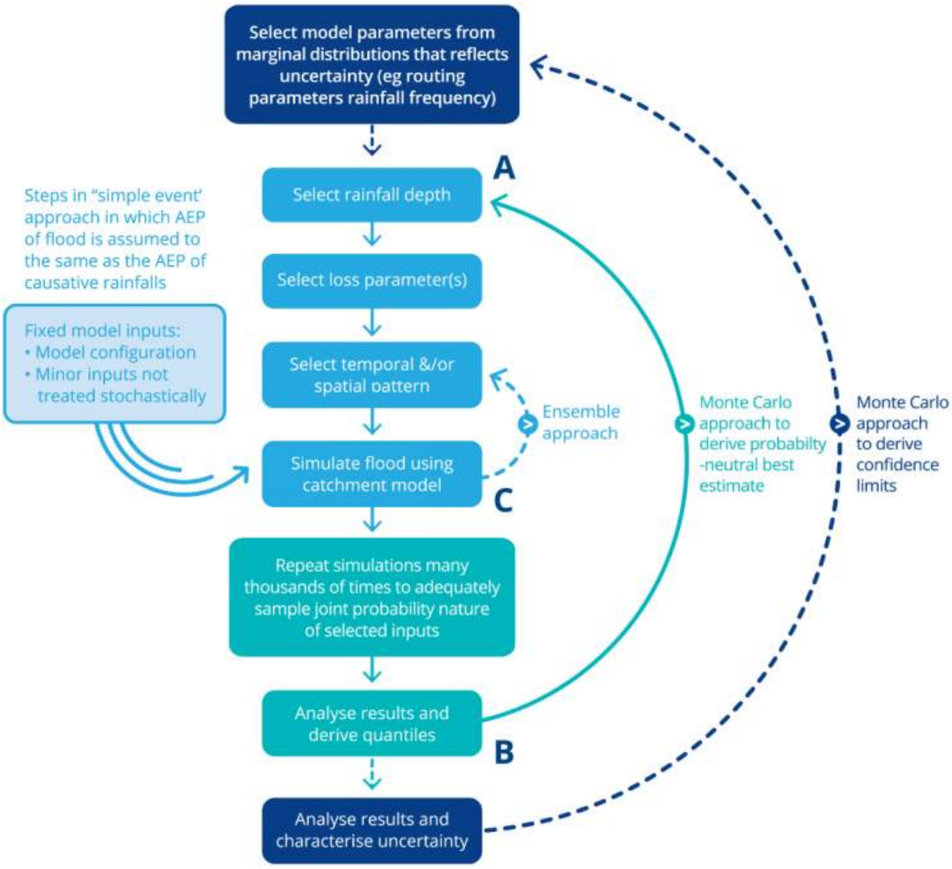


Figure 4-5: Simple Framework for Monte Carlo Simulation for Handling Joint Probabilities Associated with Both Losses and Temporal Patterns (Nathan and Ling, 2019).

4.3.2 RORB Model Setup

The RORB catchment file, which describes the Maribyrnong River catchments geometry and topographic form of sub-catchments, reaches and connectivity, has been specifically developed for this study. The RORB model extends from the upper catchment limits to the confluence of Yarra River (Figure 4-6). The following sub-sections describe the development of the RORB model.

Catchment and sub-catchment delineation

The catchment delineation was determined from the Vicmap™ Elevation DEM 10m (Department of Environment, Land and Planning [11], 2020) with a stated accuracy of +/- 5m. The resulting catchment is displayed in Figure 4-6 and it was generated using the automated routines in ArcHydro plugin in ArcGIS. This boundary was reviewed against topographic maps to ground truth the catchment extents, further it was compared to other existing catchment boundaries and found to align.

Sub-catchments were determined in the same way as the catchment boundary with an additional step to manually disaggregate larger sub-catchment and aggregate sub-catchment considered to be too small. The sub-catchment delineation is displayed in Figure 4-6. This process resulted in 116 sub-catchments with an average area of 12 km^2. It is acknowledged that the number of sub-catchments is at the higher end of the acceptable range; however, this number of sub-catchments was commensurate with the resolution of the RADAR rainfall. The sub-catchments were compared to topographic maps where significant features such as roads were considered, and appropriate adjustments made where required. Sub-catchment outlets were set at topologically logical locations, points of interest and at streamflow gauging stations.

It is of note that a small area in Braybrook was identified, which did not discharge to the Maribyrnong, with an area of approximately 1.6 km^2. This was removed from the respective sub-catchment. This change is of no material impact to the results.

Node-link network

The node-link network is shown in Figure 4-6 and is fundamentally determined using the Vicmap™ Elevation DEM with manual adjustments where required. Where appropriate these were developed to align with the major flow path in the catchment in a 1% AEP event. Links were created using the ArcRORB software package.

Reaches

Stream reaches were also generated in ArcHydro and are displayed in Figure 4-6. These reaches were confirmed against aerial imagery and topographic maps. Reaches were set to:

- Reach Type 1 – Natural channels as appropriate for watercourses; or
- Reach Type 2 - Excavated but unlined for reaches that are predominately drained urban areas such as Sunbury and Gisborne.

Typically, reaches from the sub-catchment to the outlet or junction are calculated from the centroid; however, it was noted that this resulted in a number of very short reaches, shorter than 200m. To manage this, these reaches were altered to be half the length of the longest flow path to provide an objective way to calculate this length.

It is acknowledged that urban areas within the catchment such as Sunbury, Romsey, etc will have grown and therefore, the potential for non-stationarity due to land use change may have an impact on the attribution of reach types. However, these changes are considered to be small in the context of the overall catchment (1,400km^2) and will not affect peak flows for large flood events. The impact of the non-stationarity was investigated by altering the fraction impervious values to Total Impervious Area (TIA) from Effective

[11] Currently the Department of Energy, Environment and Climate Action

Impervious Area (EIA) which resulted in an increase of less than 6m^3/s in the 1% AEP event. Refer to Section 8.8 for sensitivity testing.

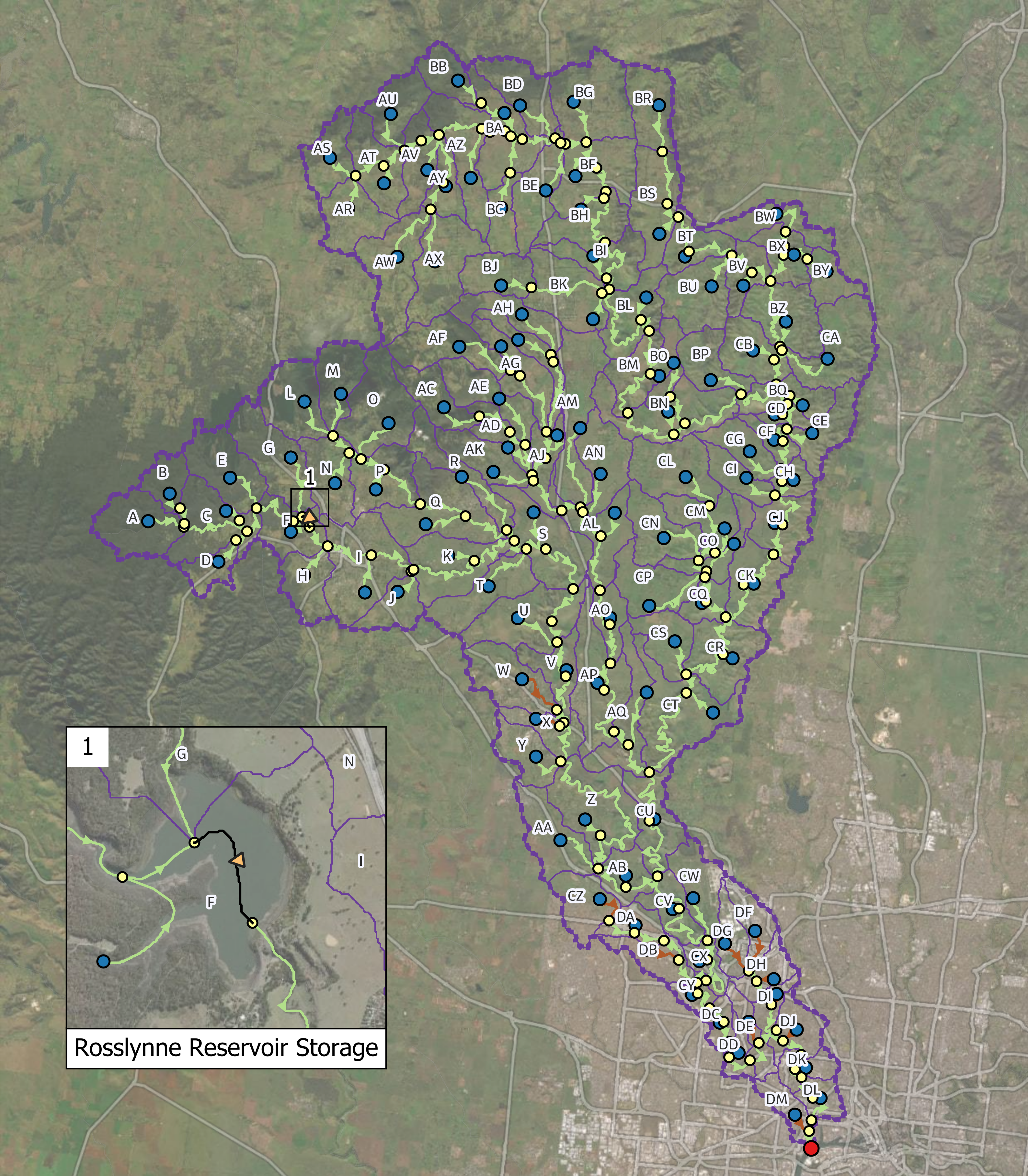
Storages

The only major storage in the catchment was Rosslynne Reservoir which is managed by Southern Rural Water and has a capacity of 25,400ML. The storage is located in the upper reaches of Jacksons Creek (as shown in Figure 4-6) upstream of Gisborne. Details of the storage were obtained from Cardno (2022a) and are shown in Table 4-4. The initial water level of the storage was set to full supply level for all events. Sensitivity testing on the initial water level was undertaken and the results indicated that that flows at Keilor and the Lower Maribyrnong were insensitive (refer Section 8.9).

Table 3-1 Adopted storage-discharge curve for Rosslynne Reservoir

Stage (mAHD)	Storage (ML)	Discharge (m³/s)	Stage (mAHD)	Storage (ML)	Discharge (m³/s)
450.9	0	0	453.2	5010	416.0
451	198	9	453.3	5230	452.0
451.1	398	18	453.4	5450	488.0
451.2	598	27	453.5	5670	524.0
451.3	800	36	453.6	5900	560
451.4	1003	45	453.7	6120	615.0
451.5	1207	55	453.8	6350	670.0
451.6	1413	64	453.9	6580	725.0
451.7	1619	73	454	6810	780.0
451.8	1827	82	454.1	7040	835.0
451.9	2036	91	454.2	7270	890.0
452	2246	100	454.3	7500	945.0
452.1	2457	117	454.4	7730	1000.0
452.2	2670	133	454.5	7970	1055.0
452.3	2883	150	454.6	8200	1110
452.4	3098	167	454.7	8440	1167
452.5	3314	183	454.8	8680	1234.6
452.6	3532	200	454.9	8920	1302.1
452.7	3750	236	455	9150	1369.7
452.8	3970	272	455.1	9400	1437.3
452.9	4191	308	455.2	9640	1504.9
453	4413	344	455.3	9880	1572.4
453.1	4636	380	455.4	10120	1640

Table 4-4: Details of Rosslynne Reservoir obtained from Cardno (2022a).



Legend

- Catchment boundary
- Subcatchment boundaries
- Storage

Nodes

- Sub-Catchment
- Junction
- Outlet

Reaches

- 1. Natural channel
- 2. Excavated but unlined channel
- 3. Lined channel or pipe
- 4. Drowned reach
- 5. Dummy reach

MGA Zone 55

0 5 10 15 km

Jacobs

Figure 4-6: Maribyrnong RORB model layout

Project Number: IA5000NN

FINAL

Diversions

There were no diversions in the catchment relevant to Maribyrnong River flooding.

Fraction impervious

Total impervious area fractions were assigned based on land-use classification layers and guidance from the Melbourne Water flood mapping guidelines (Melbourne Water, 2023). Aerial photography was inspected to ground-truth the assigned fractions. Particular attention was given to land use through the urban areas such as Gisborne, Sunbury and catchment area below Keilor.

ARR 2019 (Ball et al., 2019), Phillips et al. (2014) and the Melbourne Water Technical Specification 2023 identify three types of land use with respect to impervious area, these are:

- Effective Impervious Area (EIA) or Directly Connected Areas (DCA) – these are considered to be impervious areas that are directly connected to a drainage path. These areas have low losses; typically, 1mm for initial loss and 0mm/hr for continuing losses.
- Indirectly connected area (ICA) or other areas – these are considered to be a combination of impervious areas not connected directly to a drainage path and other pervious areas such as gardens etc. Phillips at al. (2014) defines these areas as "*this is a combination of all pervious surfaces and indirectly connected impervious surfaces*". These areas have initial losses that are typically a proportion of 0.6 - 0.8 of pervious initial losses and continuing losses that are between 1 and 3mm/hr.
- Pervious areas (PA) – these are considered to be large open space, rural or forested areas. These areas have losses that are the same as the rural losses.

To determine the impervious fractions, the procedure outlined in the Melbourne Water Technical Specifications was followed. The planning zone mapping layers were obtained for the catchment, and land use types were assigned a Total Impervious Area (TIA) value in-line with those presented in Appendix 14 of the Melbourne Water Technical Specifications. Aerial imagery was used to validate fraction impervious areas particularly in areas such special interest zones or areas that have been recently developed. Sensitivity testing has demonstrated that peak flows are not sensitive to fraction impervious, as seen in Section 8.8.

The EIA was then calculated by factoring the TIA using the relationship specified in the Melbourne Water Technical Specifications, in most cases, EIA = 0.6 x TIA. The EIA values were used as the Fraction Impervious inputs to the RORB catchment file. The following areas were assumed to be pervious with no EIA area:

- Green Wedge Zone
- Public Park and Recreation Zone
- Urban Floodway Zone
- Public Conservation and Resource Zone

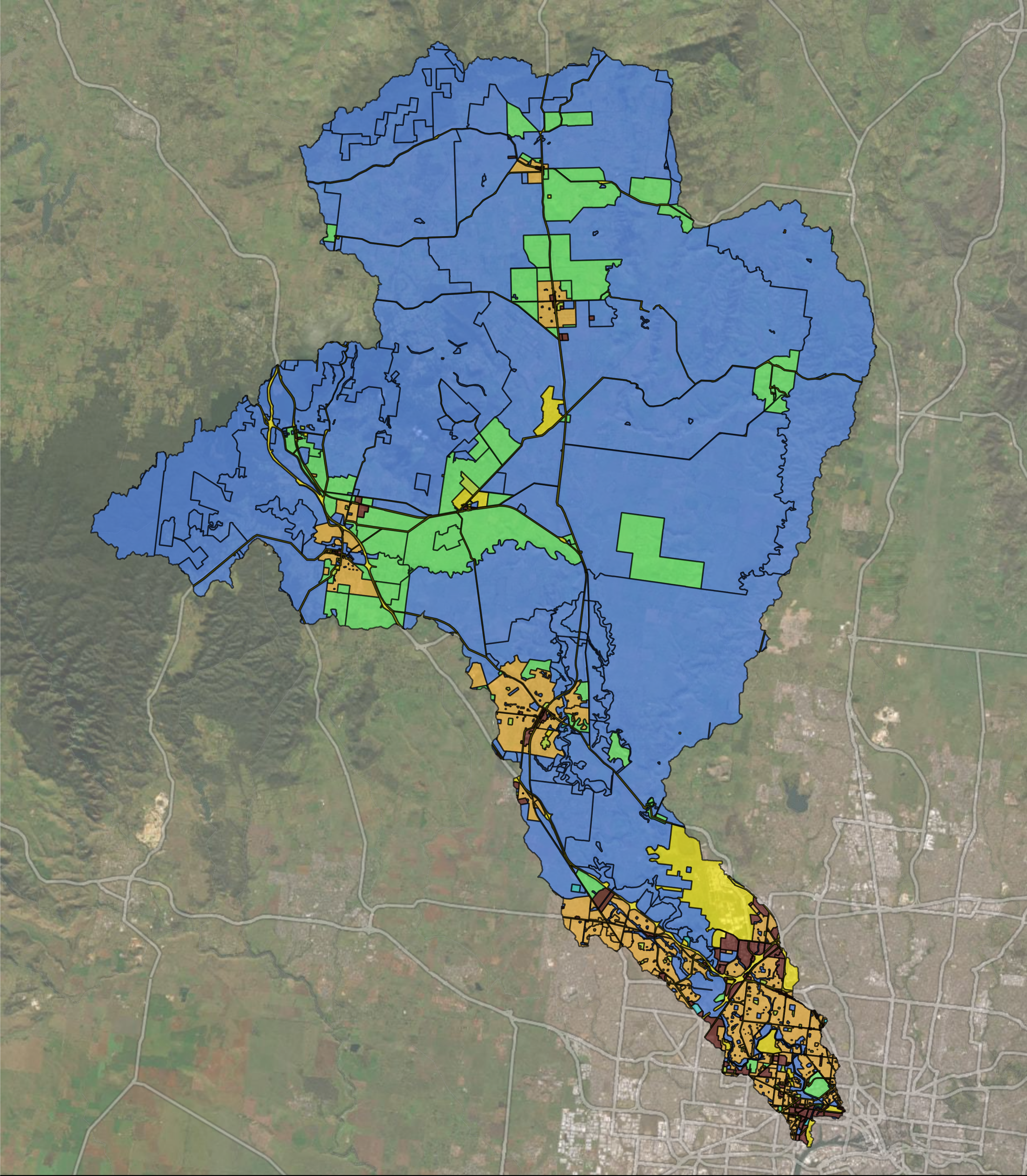
The resulting EIA values are presented in Figure 4-7.

Printout locations

Print statements were added at the Catchment Outlet of the model and at the Maribyrnong River at Keilor gauge (230200D). Additional print locations in the model were located at points of interest and other inflow points.

RORB version

RORB version 6.47 was used for modelling.



Legend

Effective Impervious Area for planning zones

- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.6
- 0.6 - 0.7
- > 0.7

MGA Zone 55

0 5 10 15 km

Jacobs

Figure 4-7: Spatial distribution of Maribyrnong catchment EIA values

Disclaimer: Produced by Jacobs for the Lower Maribyrnong Flood Mapping Study, a Melbourne Water project. Jacobs does not warrant that this document is definitive nor free of errors and does not accept liability for any loss caused or arising from reliance upon information provided herein. This map should be read in conjunction with 2024 Maribyrnong River Flood Model Report. Background imagery from ESRI

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4.3.3 RORB Calibration

Initially, the determination of the calibrated parameters was undertaken in two steps, firstly the k_c parameter was determined by calibrating the RORB model to known flood hydrographs. The second step involved calibrating RORB flood quantiles to the FFA flood quantiles by adjusting the loss values (Initial and Continuing). This approach is referred to as the standard approach. However, the ultimately adopted approach differs from the standard approach (refer to Section 4.3.3.2).

As the design hydrology ultimately did not use the standard approach, only a summary is presented in the main body of the report with details presented in Appendix H. This information may be useful for applications such as flood forecasting and emergency management.

4.3.3.1 Standard calibration

The adjustment of parameters to match observed events or calibration was completed using an automated process followed by manual fine tuning of parameters. The selected automatic calibration was AutoCal (Myers, 2021, Pedruco et al., 2023, Chen et al., 2023). This was applied to three historic events and validated against another historic event using the streamflow, rainfall, and observed data.

Calibration involved adjusting the model k_c parameter until an acceptable fit to the observed hydrographs was achieved. Once the calibration determined the k_c parameter the validation event was run. This involved applying the historic data to the model and evaluating its performance with only changes to the loss parameters, effectively a blind test of the model's performance.

The selection of the calibration and validation events were selected as outlined in Section 3.4.4 and were:

- Calibration events
  - October 2022, January 2011 & October 1983
- Validation event
  - September 1993

To create rainfall data to apply to the RORB model for calibration, information on rainfall depth and the temporal distribution of rainfall or rainfall patterns was required. The approach undertaken in this study was to calculate rainfall depths from gridded dataset and determine rainfall temporal patterns from RADAR or pluviograph data depending on availability. The available data for each event varied. Details of the hyetographs available is presented in Appendix I.

Streamflow data for each of the calibration and validation events was obtained for the Maribyrnong River at Keilor (230105A) with flows being re-rated as discussed in Section 3.4.5. These hydrographs are shown in the calibration plot results.

In order to determine an acceptable k_c parameter, the October 2022, January 2011 and September 1983 events were initially calibrated in tandem in AutoCal. In this automatic calibration, the losses values (Il and CL) were allowed to vary and a single k_c value that produced the best fit in terms of the objective function was determined. The performance for each event was weighted with the 2022 event given the highest weight and the 2011 the least. The results of this process are presented in Table 4-5.

Table 4-5: RORB Calibrated parameters from routing calibration.

Event	k_c	m	IL mm	CL mm/hr
October 2022	51.56	0.8	48	0.37
January 2011	51.56	0.8	135	1.70
September 1983	51.56	0.8	62	0.49
Validation				
October 1993	51.56	0.8	65	0.87

The results of the 2022, 2011 and 1983 calibration events and 1993 validation event in terms of modelled and observed hydrographs are shown in Appendix H. In summary:

- The 2022 calibration event has the best performance as show in Figure 4-8.
- The January 2011 calibration event has the poorest performance (see Figure 4-9), this event is the only summer event in the calibration and validation events that occurred at the end of the millennium drought, and it is possible these factors have also contributed to the poorer performance. This event had the lowest peak and did not cause any significant flood impacts and was considered to be the least influential of the events.
- The 1983 calibration also had a good fit particularly to the peak flows with a poorer fit when volume was considered as shown in Figure 4-10.
- The 1993 validation event is also considered to have a good fit as shown in Figure 4-11.

It is noted that across all calibration and validation events, the model did underestimate hydrograph volumes.

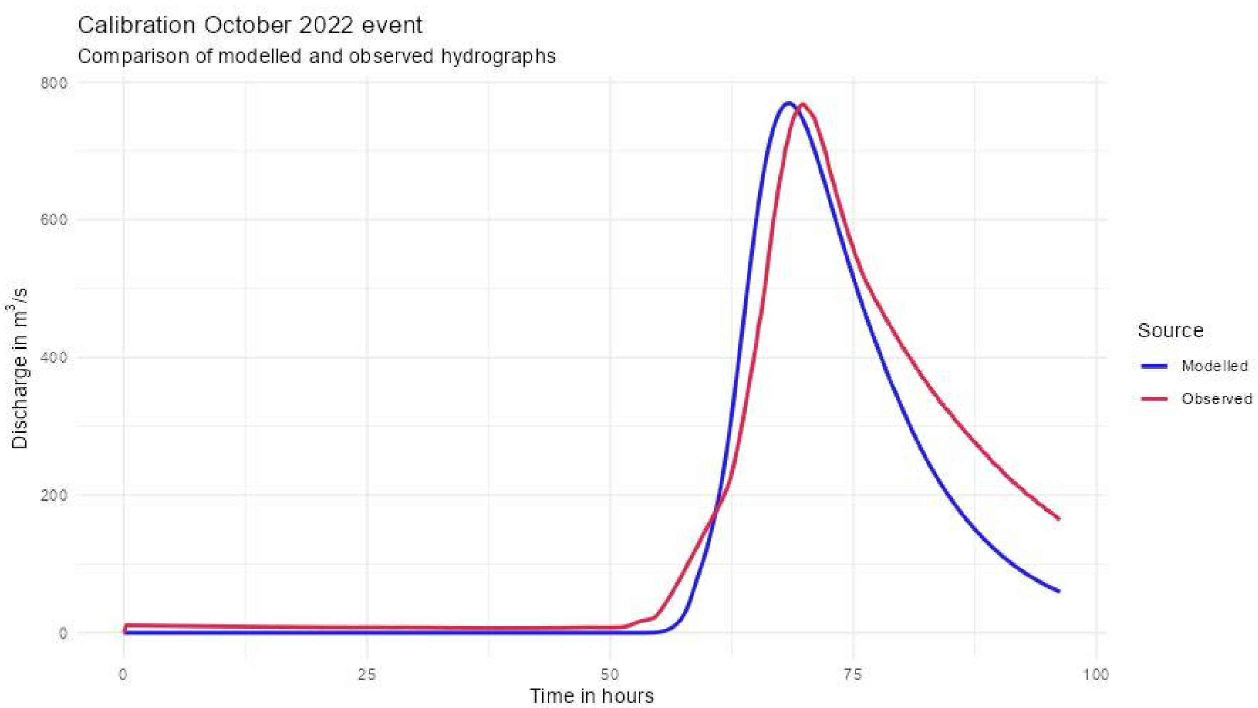


Figure 4-8: October 2022 calibration event hydrographs.

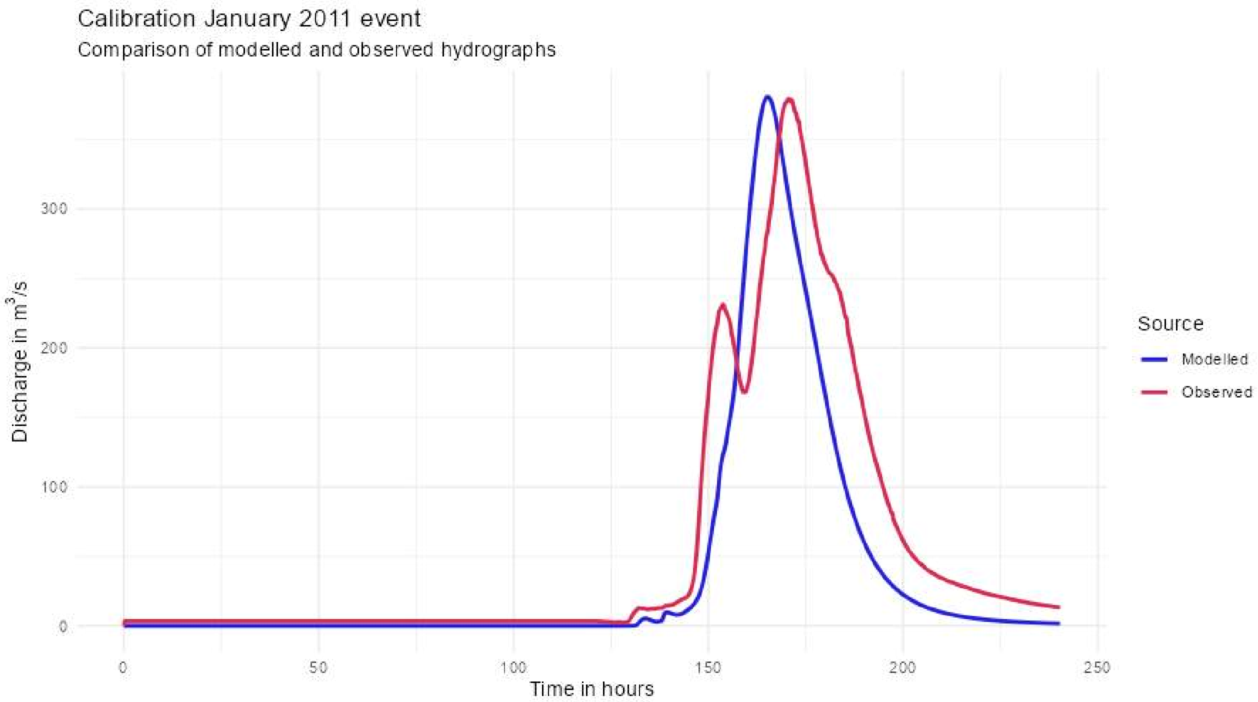


Figure 4-9: January 2011 calibration event.

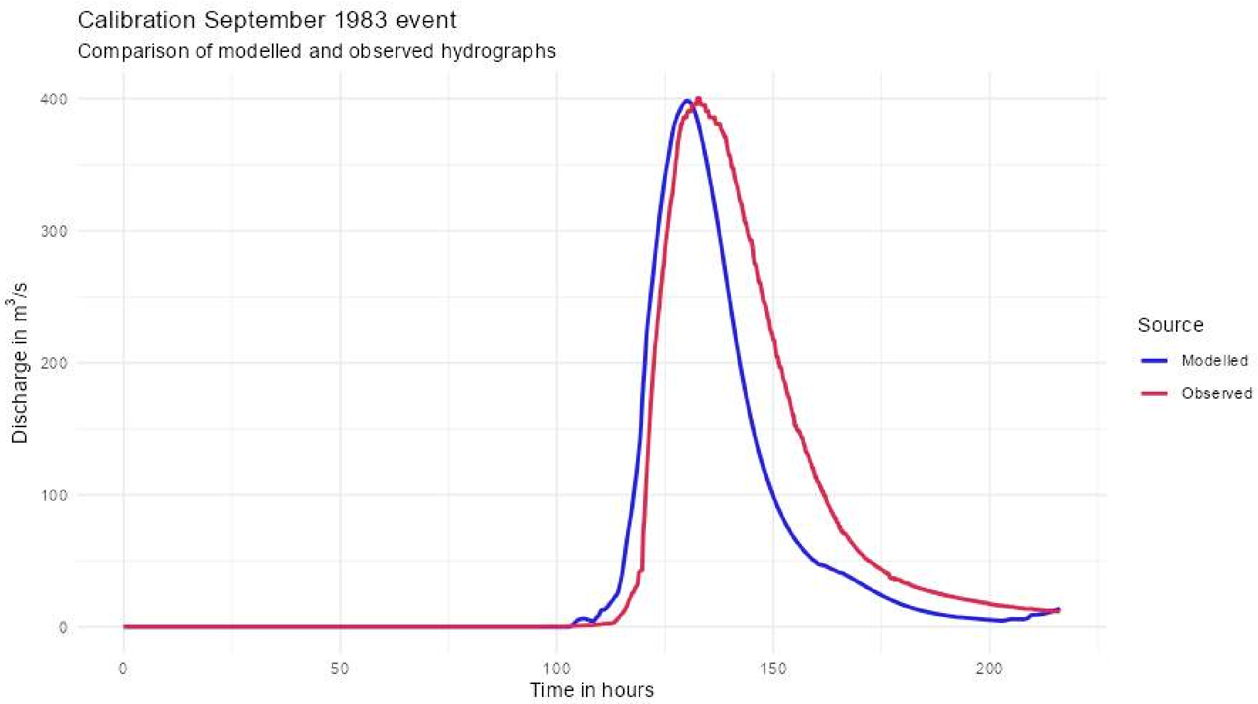


Figure 4-10: September 1983 calibration event.

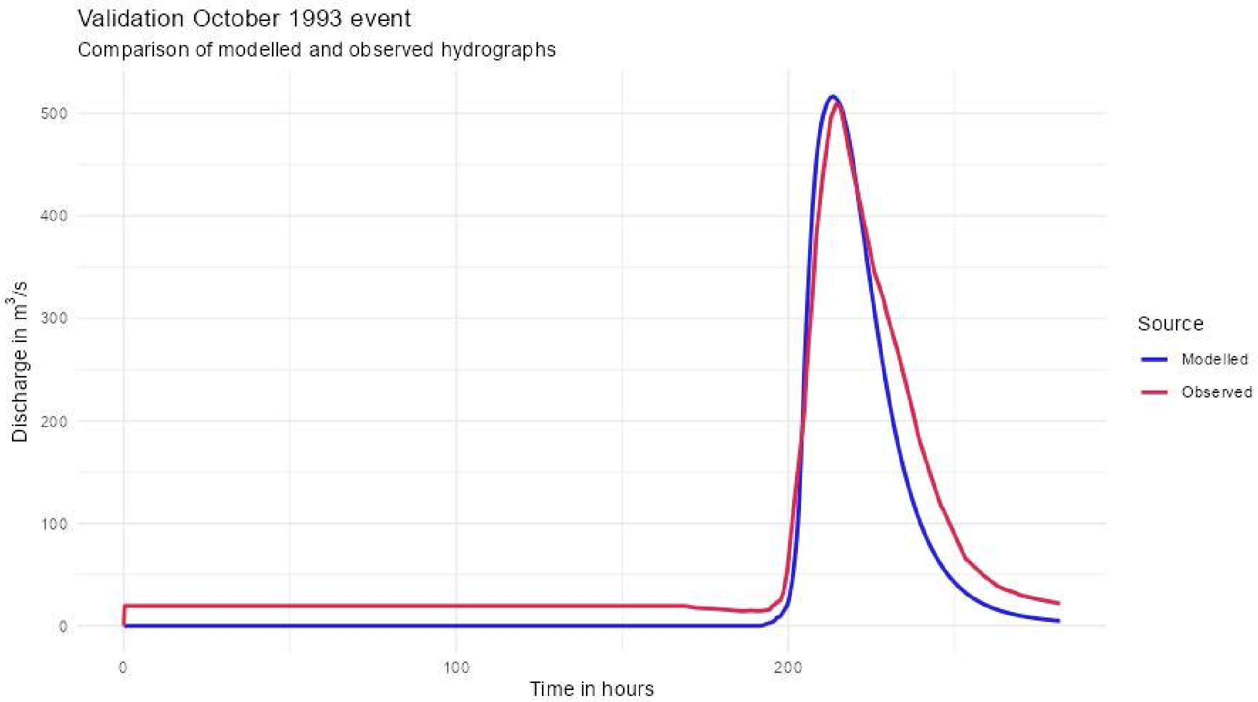


Figure 4-11: October 1993 calibration event.

4.3.3.2 Adopted Calibration

As noted above, the standard approach to determining the design event hydrology did not result in acceptable outcomes. The outcome of this was that the k_c parameter was determined from a different approach as outlined here. Fundamentally, model parameters were determined through calibrating the design RORB flood quantiles to the FFA food quantiles.

In the case of the Lower Maribyrnong River, this was considered appropriate given the high quality and length of the gauge information at Keilor meaning there was a high confidence in the FFA quantiles (as outlined in Section 4.2.7). This was achieved by developing the design RORB model as detailed in Section 4.3.4 and adjusting the k_c, the Initial Loss (IL) and Continuing Loss (CL) until there was an acceptable match.

This approach is the same as the second step in the traditional approach (loss parameter calibration) with the addition of calibrating the k_c parameter. This has the additional benefit of obtaining probability neutral rainfall loss parameters, that is, values that are not biased towards wet antecedent conditions. The value of losses obtained from calibration to large events can be biased towards low loss rates, as large floods are more likely to occur on catchments with wet antecedent conditions. The manner in which loss values vary with rainfall depends on chance, though it would be expected that some systematic variation occurs with season. Thus, while a small sample of historic events can provide useful data for the selection of routing parameters, these few events provide less information about the appropriate values of loss to be used in design flood estimation.

This approach was considered appropriate for the following reasons:

- The FFA at the main gauge (Keilor) has been completed to a long-term runoff series that has been verified to historic records and it is therefore considered to be an accurate representation of the catchments peak flow response.
- Additional analysis of rainfall events would be required to ensure that high rainfall in non-productive parts of the catchment (the lower catchment) did not bias the selection of events.
- The process is a more direct and efficient method to determine the design loss parameters that will produce the FFA quantiles.

- The primary purpose of the study is to inform land use and infrastructure planning where the flood levels and extents are key information, hydrograph shape and timing are secondary considerations.

The Initial loss (in mm) represents the initial rainfall that does not appear as direct runoff, while the continuing loss (in mm/hr) is the average loss rate throughout the remainder of the event.

4.3.3.2.1 Loss Calibration Summary

The purpose of the loss parameter calibration is to ensure that the Maribyrnong RORB model produced design events that are representative of the catchment by fitting Monte Carlo (MC) results to expected quantiles of the FFA. In the vast majority of catchments, the length and quality of the streamflow record means there will be considerable uncertainty in the rarer flood quantiles produced by the FFA. In these circumstances, more weight is given to the event-based rainfall-runoff (RORB) modelling results for rarer quantiles. However, in the case of the Maribyrnong at Keilor, the gauged record is extensive with records extending into the late 1800's and a recently updated rating relationship to high flows. Further the discharge estimate of the largest flood on record (1906 at 880m^3/s) has been verified in the hydraulic model. This means there is high confidence in the gauged record and consequently in the FFA results as discussed in Section 4.2.7. Therefore, in this study the FFA quantiles were considered to produce the most representative flood quantiles of interest. The FFA quantiles were adopted as the peak flows for the design events.

The standard approach for determining probability neutral losses involves fixing routing parameters which have been previously determined through calibration to event hydrographs, then choosing initial and continuing loss values to fit the FFA. This approach was investigated however, it was not possible to achieve an adequate fit to the FFA following this method.

Given that there is high confidence in the FFA, it was necessary to consider alternative approaches to determining the probability neutral losses that reproduced the FFA quantiles. This section outlines the standard and alternative approaches explored to find RORB model parameters that produce a MC result which closely matches the expected quantiles of the FFA. Supporting information is also provided in Appendix J.

Two alternative methods were investigated to determine suitable probability neutral losses:

- Varying the loss parameters (IL and CL) with AEP to match the FFA quantiles.
- Adjusting the k_c value (in combination with IL and CL) to achieve a match to the FFA quantiles.

The first of these approaches was considered but ultimately this method was not adopted for the following reasons:

- While varying losses with AEP will generally result in a close match with FFA quantiles; however, there is little evidence for systematic variation of losses with AEP (Hill & Thompson, 2019). This would limit the ability to extrapolate losses beyond the reliable FFA quantiles, in this case up to the 1% AEP, as there is no guidance to inform loss values for rarer AEPs.
- Given that it is envisaged that modelling developed for this study will be used in the future for other purposes such as flood mitigation and infrastructure design where rarer AEPs may be of interest, this extrapolation would limit the use of the flood model.
- Additionally, this approach could limit the ability to explore the catchment's response to large rainfall events such as those that may result from increased rainfall intensity caused by climate change.

4.3.3.2.2 Standard Approach

Summary of key design inputs into approach:

- **Fixed routing parameters from event calibration**
- **Standard Design Spatial Pattern**

- **75% Pre-burst**

The Standard Approach involved using the fitted k_c routing parameter from calibration event (Section 4.3.3). A design spatial pattern was applied which varied by duration (Appendix K) and the pre-burst ratios applied where the 75% percentile values from the ARR Datahub file (Appendix L).

Trials were completed to fit the RORB MC quantiles to the FFA quantiles by varying the losses and with a fixed routing parameter as determined through event calibration. It was found that, for all attempted loss values, the curve of the MC results was too steep to achieve a satisfactory fit to the expected quantiles (Figure 4-12). Additional plots of the MC results compared with the expected quantiles of the FFA are provided in Appendix J.

The range of parameters explored to fit the MC results to the expected quantiles of the FFA are provided in Table 4-6.

Table 4-6: Parameters used to calibrate losses to expected quantiles of the FFA with a standard approach.

k_c	m	Initial Loss (mm)	Continuing Loss (mm/h)
51.56	0.8	0 - 40	0.00 - 4.00

The closest fit that was found between the MC results and the expected FFA quantiles using the Standard Approach was an initial loss of 10 mm and a continuing loss of 2.3mm/h (Figure 4-12). MC results compared to the FFA results for more frequent (less than the 5% AEP) are acceptable, however, the MC results for the 2% and rarer significantly exceed the FFA results (Table 4-7). MC results for the 1% overpredict the 1% FFA expected quantile by 270m^3/s (Table 4-7). While the MC results generally fall within the uncertainty bounds of the FFA results, the large differences for rarer events means the fit is unacceptable.

Table 4-7: Comparison of expected quantiles of the FFA and Monte Carlo results from the closest fit attained with the standard approach (IL=10, CL=2.3).

AEP	FFA Expected Quantile (m^3/s)	Monte Carlo Results (m^3/s)
50% (1 in 2) AEP	140	101
20% (1 in 5) AEP	323	273
10% (1 in 10) AEP	463	433
5% (1 in 20) AEP	601	624
2% (1 in 50) AEP	778	918
1% (1 in 100) AEP	905	1175
0.5% (1 in 200) AEP	1025	1425

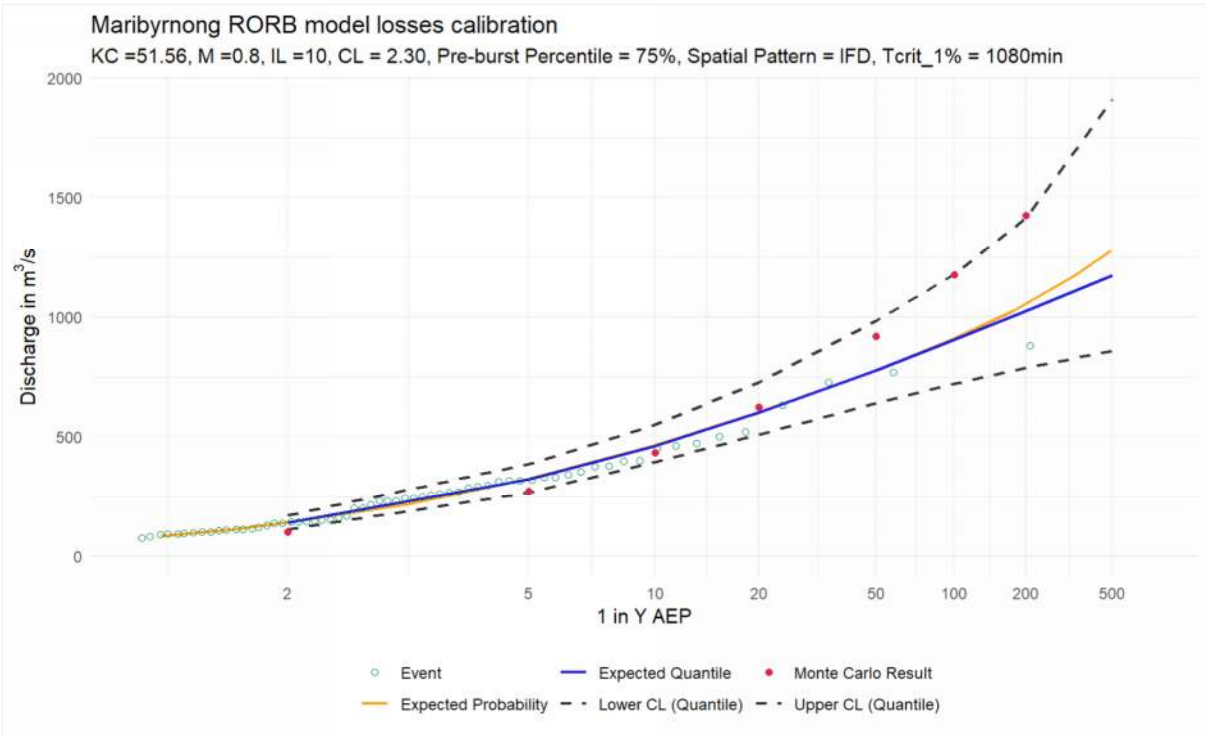


Figure 4-12: Comparison of expected quantiles and probabilities of the FFA and Monte Carlo results from the closest fit attained with the standard approach.

The results for the FFA presented in Figure 4-12 are for both the expected quantiles (results that are neutral with respect to quantiles) and expected probabilities (results that are neutral with respect to probability). This allows direct comparison to the MC results which are expected probabilities. In the case of Keilor FFA results, there is little difference between the expected quantile and expected probability results. Thus, the observations noted above for the FFA expected quantile results remain true for the FFA expected probability results.

As the fit between the MC results and the FFA results was unable to be reconciled by varying loss parameters, alternative approaches were tested. These approaches included:

- Replacing the design spatial pattern with an event spatial pattern.
- Varying the non-linearity *m* parameter.
- Increasing the pre-burst rainfall to the 90th percentile applied.
- Investigating alternative k_c parameters.

The results of these investigations are presented in the following sections.

4.3.3.2.3 Event spatial pattern

- **Fixed routing parameters from event calibration**
- **October 2022 Event Spatial Pattern**
- **75% Pre-burst**

This approach involved using the k_c parameter determined through the event calibration (k_c = 51.56) the design parameters outlined in Section 4.3.3 but with the spatial rainfall pattern being replaced by the October 2022 Event Spatial Pattern.

The change to the spatial pattern did not improve the fit to the FFA quantiles when tested with a series of initial and continuing loss values. Results are provided in Appendix J, and the 2022 event spatial pattern details are provided in Appendix K.

4.3.3.2.4 Varying the *m* parameter

Summary of key design inputs into approach:

- **Fixed routing parameters from event calibration**
- **'*m*' fixed at a value of 0.9 instead of 0.8**
- **Standard Design Spatial Pattern**
- **75% Pre-burst**

This approach involved varying the *m* parameter from 0.8 to 0.9, recalibrating k_c parameter, and using the remaining design parameters outlined in Section 4.3.3. For an *m* value of 0.9, the event calibration process resulted in a k_c of 27.

This pair of routing parameters (m = 0.9, k_c = 27) did not enable an improved fit to the expected quantiles of the FFA when tested with a series of initial and continuing loss values. Results are provided in Appendix J but these results were still not considered an acceptable fit.

4.3.3.2.5 90th percentile pre-burst

- **Fixed routing parameters from event calibration**
- **Standard Design Spatial Pattern**
- **90% Pre-burst**

This approach involved using the calibrated k_c parameter and the design parameters outlined in Section 4.3.3 but with the 75th percentile pre-burst rainfall being replaced by the 90th percentile pre-burst rainfall.

The increase to the pre-burst did not improve the fit to the expected quantiles when tested with a series of initial and continuing loss values. Results are provided in Appendix J, and the 90% Pre-Burst inputs are provided in the ARR Data Hub text file in Appendix L.

4.3.3.2.6 Summary of alternative approaches

The standard approach and three alternative approaches did not produce an acceptable calibration to the expected quantiles of the FFA and the curve of the MC results was steeper than the curve of the expected quantiles of the FFA. The next calibration method that was explored was to remove the constraint of fixing routing parameters based on event calibration.

4.3.3.2.7 Adopted approach: Varying k_c parameter

This approach involved varying the k_c and loss parameters with all other design parameters as outlined in Section 4.3.3. As with the other approaches the aim was to achieve a flatter slope to the Monte Carlo results. This approach found a k_c value that produced Monte Carlo results which were an acceptable fit to the FFA expected quantiles (Figure 4-13). Trials of other k_c and *m* parameters are provided in Appendix J.

The adopted k_c parameter is presented in Table 4-8 and this has been compared to the results presented by Pearse et. al. (2002), similar to the comparison of the calibrated k_c presented in Section 4.3.3. The adopted k_c parameter of 105 expressed as *c* is 1.14 (average distance 92.43 km) which is similar to the Victorian *c* value of 1.25 published by Pearse. This compares with the *c* value of 0.56 that corresponds to a k_c of 51.56 from the historic event calibration. It is worth noting that the area upstream of the Keilor gauge (approximately 1,300km^2) is larger than the majority of catchments sampled within the Pearse et. al. 2002 study.

Table 4-8: Routing parameters chosen to achieve an acceptable calibration to fit to expected quantiles of the FFA.

k_c	m
105	0.8

The range of investigated loss parameters in Appendix J for when k_c is set to 105 was the same as that listed in Table 4-6. The design inputs used to calibrate losses to expected quantiles of the FFA using the standard approach. Results are provided in Appendix J.

The initial and continuing losses that provided the best fit to expected quantiles when k_c is 105 and *m* is 0.8 detailed in Table 4-9.

Table 4-9: Final parameters used in the Maribyrnong RORB model.

k_c	m	Initial Loss (mm)	Continuing Loss (mm/h)
105	0.8	10	0.8

A comparison of the FFA Expected Quantiles and the Monte Carlo results with the adopted parameters is presented in Table 4-10. This table demonstrates the close agreement between the FFA expected quantiles and the Monte Carlo results with the adopted parameters. It is noted that the 0.5% (1 in 200) AEP MC results is closer to FFA expected probability result (Figure 4-13).

Table 4-10: Comparison of expected quantiles and Monte Carlo results after loss calibration with variable routing parameters (IL=10, CL=0.8).

AEP	FFA Expected Quantile (m^3/s)	Monte Carlo Results (m^3/s)
50% (1 in 2) AEP	140	147
20% (1 in 5) AEP	323	303
10% (1 in 10) AEP	463	434
5% (1 in 20) AEP	601	580
2% (1 in 50) AEP	778	779
1% (1 in 100) AEP	905	938
0.5% (1 in 200) AEP	1025	1103

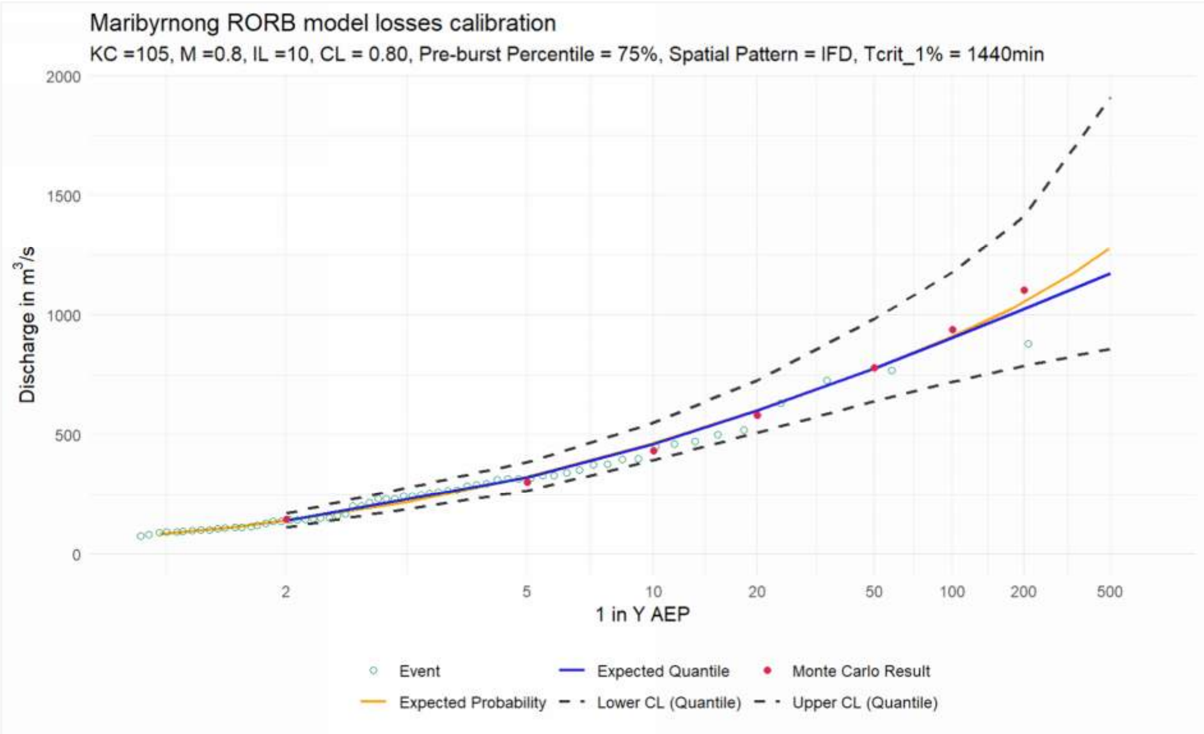


Figure 4-13: Comparison between Monte Carlo results and Expected Quantiles with variable loss and routing parameters.

4.3.3.2.8 Loss Calibration Discussion

The ultimate purpose of the RORB modelling is to determine design event hydrographs for application to the hydraulic model with a given probability to allow the determination of flood risk.

The FFA completed as part of this assessment has been undertaken on a high-quality gauge with long record and the largest flood events being verified through secondary methods; 1906 through hydraulic modelling (see Section 6.10.10) and 2022 through direct rating of the event as well as hydraulic modelling (see Section

6.10.5). Given the multiple lines of evidence and the quality of the input annual maximum series, the results of the FFA are considered to provide the best available information regarding flood quantiles at the Maribyrnong at Keilor gauge. Therefore, the design event RORB modelling should match the FFA results.

The analysis above has demonstrated that the standard approach to determining RORB mode parameters was not able to satisfactorily reproduce the FFA flood quantiles. For this reason, alternative approaches to the design event methodology were investigated. The most successful of these used a different k_c parameter to that determined during the historical event calibration. The approach of varying loss parameters with AEP was considered, however it was acknowledged that the results presented were likely to be used beyond this project where larger flood events would be considered such as for mitigation or climate change. This would require extrapolation of loss values and there is no guidance on which to base this, given this limitation this alternative approach was not considered further.

The adopted approach yielded a k_c parameter of 105 which was close to the value using the relationship determined by Pearse et al. (2002) (k_{c_Pearse} = 115.5). The Pearse et al. (2002) method was based on analysis of 39 Victorian catchments and is considered of particular relevance to this site. Further, it is also noted that a satisfactory fit to the FFA expected quantiles was achieved using standard design inputs including the k_c value, providing further comfort in the results.

The primary purpose of the study is to produce flood levels, extents and other flood properties with a given probability of occurrence to allow the assessment of flood risk and setting of planning levels. Sensitivity testing presented in Section 8.1 has demonstrated that peak flows rather than hydrograph volume are the key driver of flood levels at the Chiefly Drive gauge. Given that the FFA results are considered to produce accurate peak flows (see Section 4.2.7), it follows that matching the peak flows produced by the FFA results result in robust and defensible flood levels in the Lower Maribyrnong River. While it is acknowledged that hydrograph shape and timing are important, the adopted approach has been developed to deliver on the primary outcomes of the study.

While the outcome above is considered suitable for the purposes of the study, there are a number of associated assumptions and limitations of the model with this approach:

- The Maribyrnong RORB model should only be used to derive flows downstream of the Keilor gauge. These flows will also be valid for a short distance upstream.
- The hydraulic results based on the design event hydrology outlined above are conservative with respect to peak flood level compared to those produced using the calibrated k_c values. The design hydrographs produced using higher k_c adopted (105) have a longer time of concentration compared to the calibrated k_c (51.56) as illustrated in Figure 4-14 (hydrograph details provided in Table 4-11). The two hydrographs in this figure are based on the k_c determined from the standard approach and the adopted k_c for the 1% AEP event. The standard approach hydrograph represents the set of parameters that produced the results which most closely matched the FFA results. It is noted that this hydrograph could have been adjusted to match the peak flow through the adjustment of the losses; however, all other events would have underpredicted the FFA results. Regardless, this figure demonstrated the volume difference between the two approaches and this must be carefully considered and applied for applications where volume is sensitive. The adopted approach has been utilised as the better approach for provision of flood extents that correspond to a particular AEP event in the Lower Maribyrnong River, where flood extents and peak water levels are driven by peak flow rates as opposed to hydrograph volume (see Section 8.1).
- A further consequence of using the adopted approach versus the standard approach is that there will be a difference in the timing. The Standard Approach results in a faster peakier hydrograph compared to the adopted approach. For this reason, Maribyrnong RORB model using the alternative approach may not be appropriate for applications where timing is a key consideration such as:
  - Flood forecasting.
  - Live flood events information.
  - Emergency management.

Table 4-11: Design hydrograph details for Figure 4-14.

Parameter	Value where k_c is chosen based on FFA calibration	Value where k_c is chosen based on event calibration
k_c	105	51.56
m	0.80	0.80
Initial Loss (mm)	10	10
Continuing Loss (mm/h)	0.8	2.3
AEP	1% (1 in 100)	1% (1 in 100)
Duration	1440 minutes	1440 minutes
Temporal Pattern	2	2

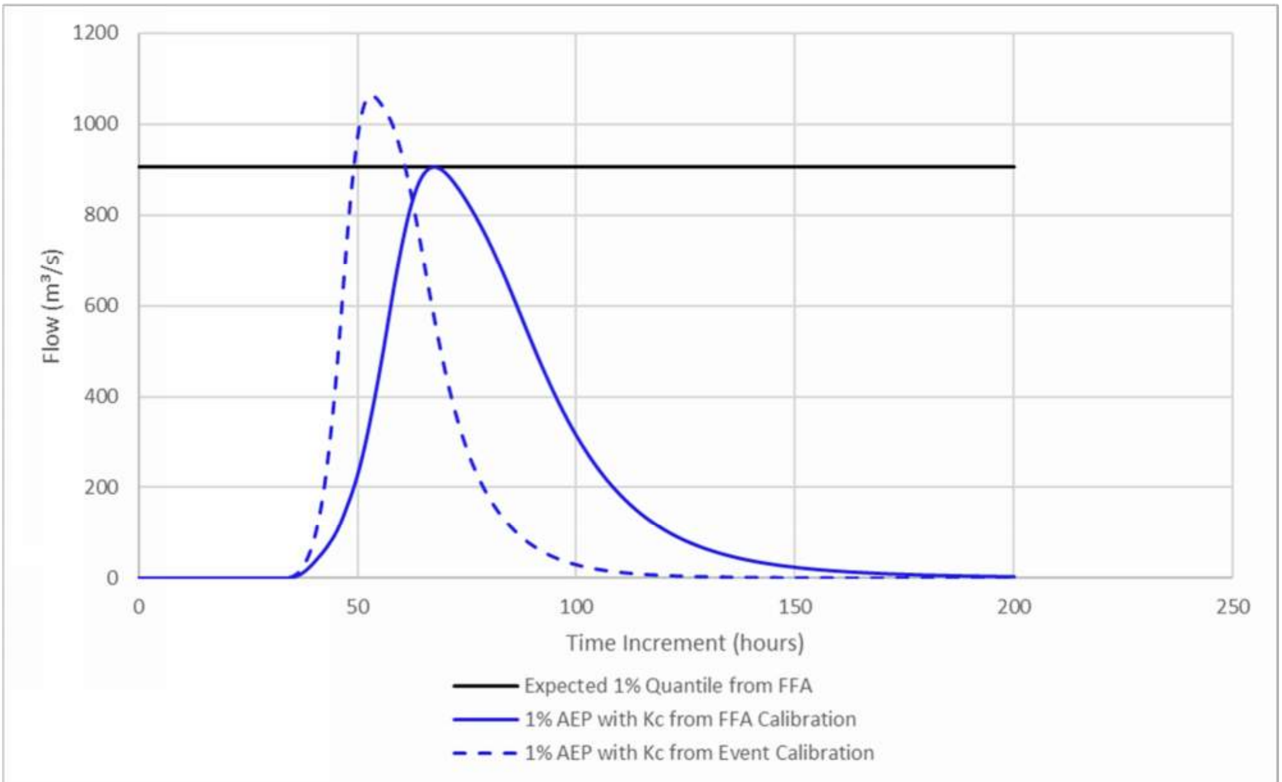


Figure 4-14: Comparison of 1% AEP design hydrograph for event calibrated k_c and FFA calibrated K_c.

4.3.4 Design event modelling

This section outlines the design event modelling completed for the project. Final reporting includes the design event modelling for the Scenarios presented in Table 4-12.

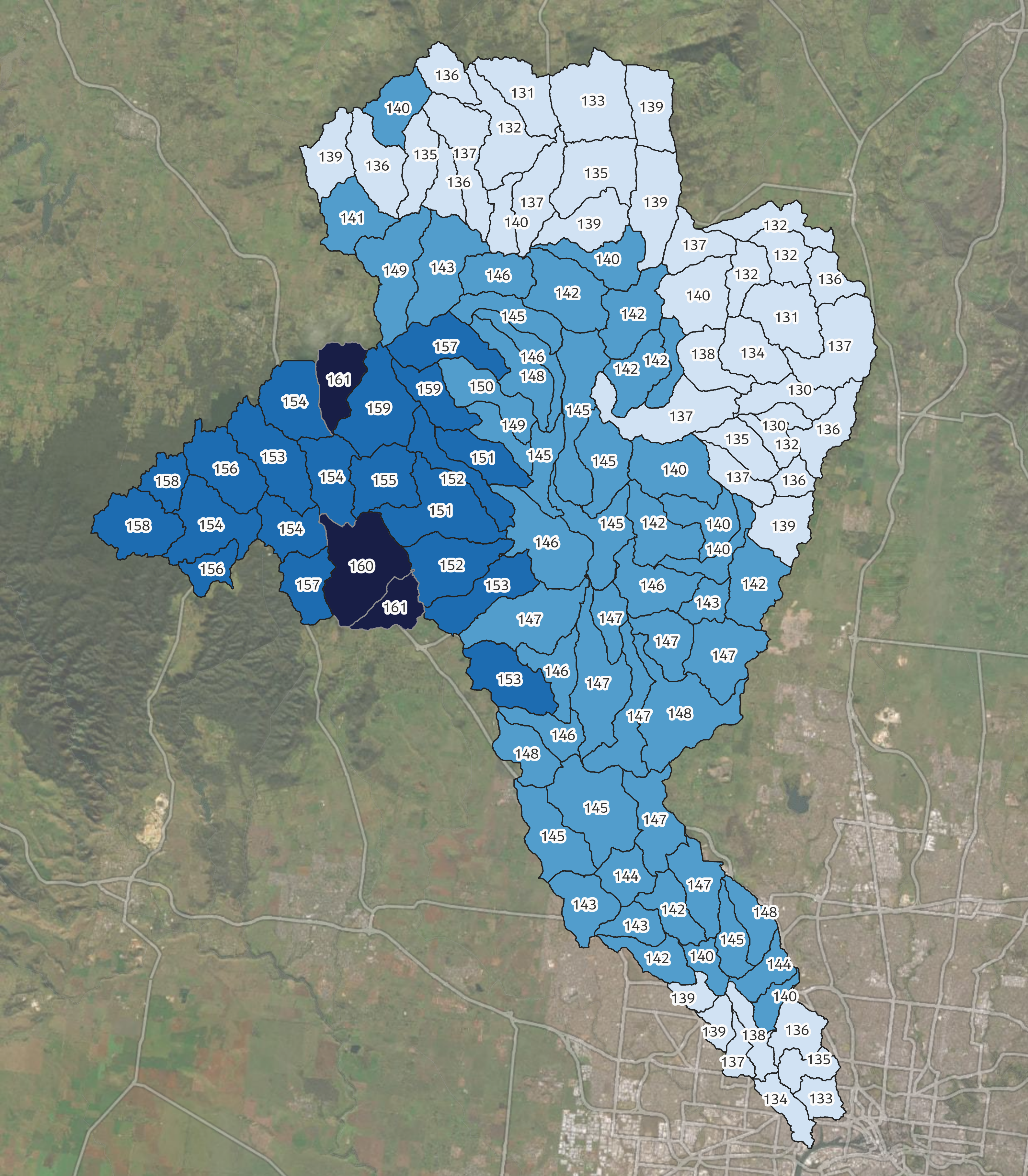
Table 4-12: Scenarios modelled.

AEP	Scenario A: Base Case	Scenario B: Climate Change 1 – Sea level rise	Scenario C: Climate Change 2 – Sea level rise and increase in rainfall intensity	Scenario D: Climate Change 3 - Increase in rainfall intensity
20% AEP	✓		✓	✓
10% AEP	✓		✓	✓
5% AEP	✓			
2% AEP	✓			
1% AEP	✓	✓	✓	✓

The RORB design event modelling was completed as outlined in Table 4-13. Given RORB was calibrated these catchment specific parameters were applied where applicable.

Table 4-13: Design event modelling approach.

Task	Description
ARR Datahub	The ARR datahub was accessed to download the required design modelling information as well as a copy of the metadata a copy of which is in Appendix L.
Design Rainfall	ARR 2019 design rainfalls (IFDs) was sourced from the Bureau of Meteorology's Design Rainfall Data System (2016) for the catchment. Given the size of the catchment, sub-catchment averaged rainfall depths have been applied to the RORB model for design rainfall. The depths have been calculated from the IFD grids using zonal statistics and the distribution of depths for the 1% AEP 24-hour storm are shown in Figure 4-15.
Areal Reduction Factors	Areal Reduction Factors (ARF) were based on ARR 2019 equations and applied using RORB inbuilt function. The area for the ARF calculation was set to the catchment area at the Maribyrnong River at Keilor streamflow gauge of approximately 1,300 km^2.
Temporal Patterns	Temporal patterns were sourced from the DataHub and filtered for embedded bursts. Areal temporal patterns were used given that the catchment area is larger than 75 km^2.
Continuing loss and model time-step	Given the model losses were calibrated using the design rainfall input to the FFA there is no need to adjust the continuing loss for model time-step.
Spatial Patterns	Spatial patterns were applied, and these were determined from the gridded IFD from the BoM. The distribution of rainfall depths for the 1% AEP 24-hour storm are shown in Figure 4-15.
Pre-burst rainfall	Pre-burst can either be applied by reducing the initial loss by the 75th percentile pre-burst, or by pre-pending the pre-burst to the beginning of the design rainfall. Prepending was preferred here using the temporal patterns from Minty and Meighen (1999) and Jordan et al (2005). The Maribyrnong catchment falls within both Zone 2 and Zone 3 of the Victorian Loss Regions as mapped in Benchmarking ARR2019 for Victoria (HARC, et al., 2020). The upper parts of the Maribyrnong catchment fall within Zone 3 which is where the majority of runoff is generated. The Benchmarking report recommends that in ungauged catchments in Zone 3 the 75th percentile pre-burst depths are used in combination with the Data Hub loss values. While this study has determined calibrated loss values, the 75th percentile pre-burst depths were adopted.
Initial and Continuing Loss Values	The Initial Loss and Continuing Loss values determined in the calibration process will be adopted. The IL and CL for the catchment downstream of Keilor will be set to "urban" values to match the land use in this part of the catchment i.e. the calibrated IL were discounted by 70% and CL will be set to 2.0mm/hr.
Calibration/Validation	See Calibration (Section 4.3.3).
Critical Event Selection	Critical duration was undertaken using the Monte Carlo approach and verified with the ensemble simulation.
Climate Change	To assess the impact of climate change, rainfall depths have been factored using the process outlined in the Melbourne Water Technical Specification. This has been undertaken for the year 2100 with an 18.4% increase in rainfall intensity adopted. It is acknowledged that ARR2019 guidance (currently in draft for comment) may differ from this approach (when finalised). It is recommended that climate change rainfall depths and factors are re-evaluated when revised guidance is published.
Storages	The only major storage in the Maribyrnong River catchment is Rosslynne Reservoir which is assumed to be full for design runs. For details see Section 4.3.2 and Table 4-4.



Legend

Event rainfall totals (mm)

- 130
- 140
- 150
- 160

MGA Zone 55

0 5 10 15 km

Figure 4-15: Distribution of depths for the 1% AEP 24-hour storm

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4.3.5 Climate change and updates to current climate representation

A climate change assessment is required for the project which accounts for the increase in rainfall intensity due to climate change, noting that sea level rise is discussed in Section 5.5. This project adopts the approach that is outlined in the Melbourne Water Technical Specifications, of factoring IFD depth. The IFD depths were increased by 18.4% to establish climate change rainfalls.

It is recognised that current guidance is being updated to allow for how global warming has affected extreme rainfalls in the past few decades. A draft of this guideline, Draft update to the Climate Change Considerations chapter in Australian Rainfall and Runoff: A Guide to Flood Estimation (DCCEEW, 2023), has been published for industry comment and it is not expected to be adopted until the third quarter of 2024.

It is recommended that the guidelines are adopted when published and the flood mapping deliverables from this project updated.

4.4 Conclusions

The adopted model parameters for the Maribyrnong RORB model are presented in Table 4-14 and these are suitable for the project purposes.

A non-standard approach to determining RORB model parameters was adopted however it was acknowledged that this approach produced hydrographs with different shapes and larger volumes than the standard approach. Sensitivity testing was undertaken to investigate the implications of this on the outcomes of the project. As the primary aim of the project was to produce flood level and flood extents for land use planning purposes it was considered more important to produce accurate flood levels than to reproduce hydrograph shape and timing. The sensitivity testing in Section 8.1 demonstrates that the peak water levels at Chifley Drive are driven by peak discharges and this approach is considered to be suitable for the project purposes.

Several assumptions and limitations include:

- The Maribyrnong RORB model should only be used to derive flows downstream of the Keilor gauge, although they will also be valid for a short distance upstream.
- The adopted approach has been utilised as it is considered the better approach for provision of flood extents that correspond to a particular AEP event in the Lower Maribyrnong River, where flood extents and peak water levels are driven by peak flow rates as opposed to hydrograph volume (see Section 8.1). A limitation of this approach is that design event hydrograph volumes are generally conservative with respect to volume.
- A further consequence of using the adopted approach is that there will be a difference in the timing. This alternative approach may not be appropriate for applications where timing is a key consideration such as:
    - Flood forecasting.
    - Live flood events information.
    - Emergency management.

Key design hydrographs are presented in Figure 4-16.

For applications beyond the scope of this project, the appropriateness of the Maribyrnong RORB model should be assessed on a case-by-case basis to determine whether revision of the parameter set or model set up is required.

Table 4-14: Chosen model parameters for the Maribyrnong RORB model.

k_c	*m*	Initial Loss (mm)	Continuing Loss (mm/h)
105	0.8	10	0.80

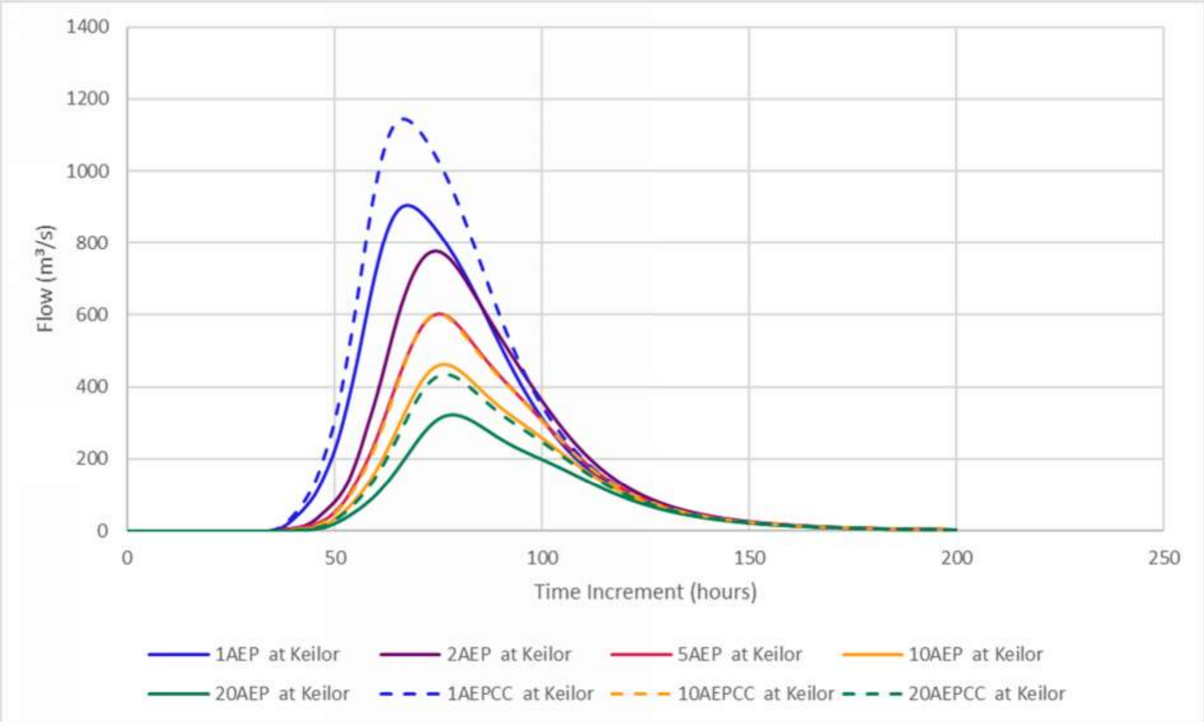


Figure 4-16: Key design hydrographs at the Keilor gauge inflow location.

4.4.1 Recommendations

The hydrology completed for the study has produced robust design hydrographs for application to the TUFLOW hydraulic model of the Lower Maribyrnong River. In completing this work, a number of recommendations for future work have become evident, these are:

- The Keilor gauge rating table should be confirmed and extended using a hydraulic model. The TUFLOW model developed for this study will be suitable for this purpose; however, additional survey and other information together with further development of the model will be required.
- The analysis presented in Section 3.4.2.2 noted that there are a number of upstream streamflow gauges in the catchment that would benefit from rating curves being revised and potentially extended through hydraulic modelling. This should be completed for these gauges in future projects.
- It is recommended that the study modelling is revisited when the update to Climate Change Considerations chapter in Australian Rainfall and Runoff (DCCEEW, 2023) are adopted. This is expected to be in late 2024.
- The rate of urban growth within the Maribyrnong catchment is expected to increase significantly in the future. The Integrated Water Management Plan for the Maribyrnong catchment (DEECA, 2022) estimates that there will be an increase of 26% in runoff volume from urbanised areas by 2050. This increase in runoff is anticipated be limited to increases in volumetric catchment runoff, and any changes to peak flows can be managed through appropriate runoff detention and other interventions. It is noted that the total urban area is small relative to the total catchment size. It is

recommended that the impervious fractions in the RORB model, and Manning's 'n' values in the TUFLOW model be reviewed and revised where appropriate in future modelling. This is of particular importance for climate change modelling.

Assumptions and limitations of the model outlined in Section 4.3.3.2.8 must be considered if the model is to be used in future projects.

4.5 Quality assurance

This project has met the Melbourne Water standards as set by:

- The most recent 1 AM STA 6200 Flood Mapping Projects Specifications August 2023.
- Melbourne Water's Quality Assurance Framework for Flood Models 2021 (QA Framework)

The RORB model has been reviewed in accordance with Melbourne Water's Quality Assurance (QA) Framework spreadsheet. An internal review of the RORB model was completed by a senior hydrologist. Improvements identified by the reviewer were integrated back into the model. Reviews completed by Melbourne Water's reviewer are provided in Appendix M and additional reviews completed by external reviewers can be found in Appendix N.

5. Tidal

A tidal boundary was required for the downstream extent of the model at the confluence of the Yarra River, both for the Maribyrnong River and Moonee Ponds Creek, as water levels at this location are affected by the tides in Port Phillip. The boundary is based on the water level records from the Yarra River at Crown Melbourne Spencer Street Southbank (229663A) tidal gauge (Southbank gauge). This gauge has been selected based on its close proximity to the downstream boundary, as shown in Figure 3-7 and further as the water level accounts for amplification of the tidal signal from Port Phillip. An example for the 2022 event is shown in Figure 5-1.

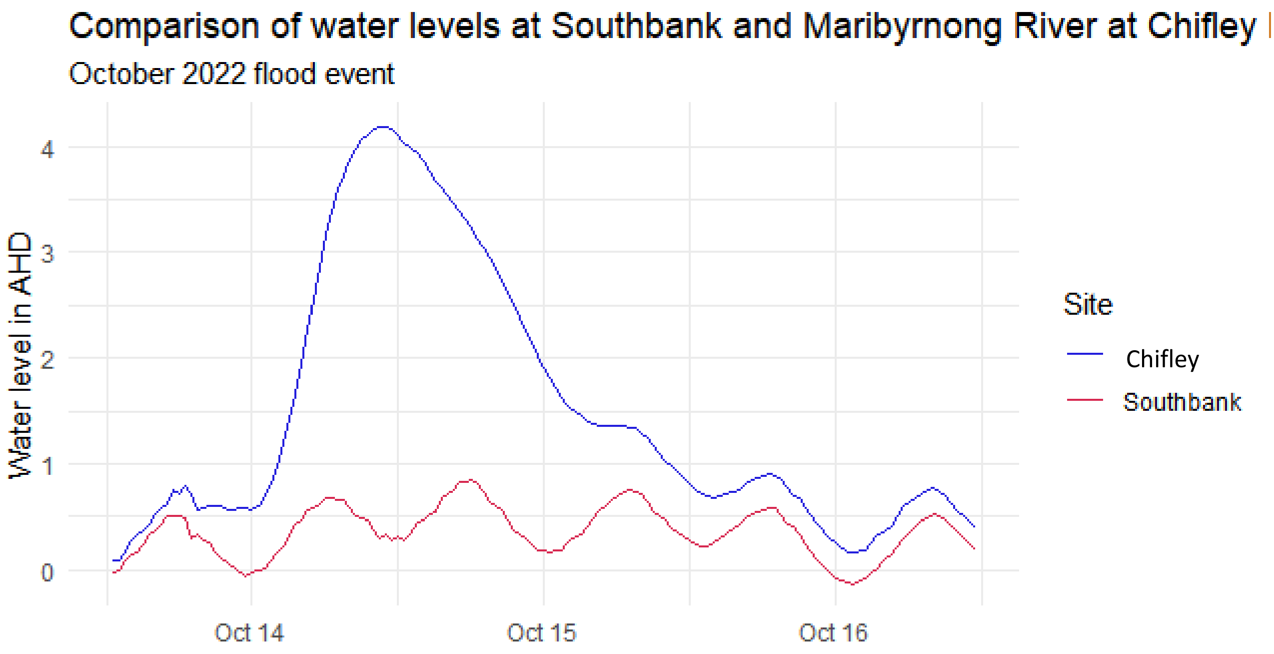


Figure 5-1: Comparison of water level at Southbank and Maribyrnong River at Chifley Drive for the 2022 flood event.

The tidal water levels have also been compared to those produced by the Port Phillip Bay Storm Tide Modelling (Water Technology, 2018).

Downstream boundary conditions were required for both calibration, validation and verification (historic) events as well as design events and two different approaches to determining these boundaries were undertaken as described below.

5.1 Yarra River at Crown Melbourne Spencer Street Southbank gauge

The Southbank gauge is located approximately 5km from the hydraulic model's downstream boundary (Figure 3-7). This gauge has a record length of 41 years from 1979 to 2023 as illustrated in Figure 5-3. Until July 2008, water levels were recorded to a chart datum and since this time the water levels were recorded to m AHD. The full record at this gauge is shown in Figure 5-2 which has had the pre-July 2008 records adjusted down by 0.524m to align it with the Australian Height Datum (AHD).

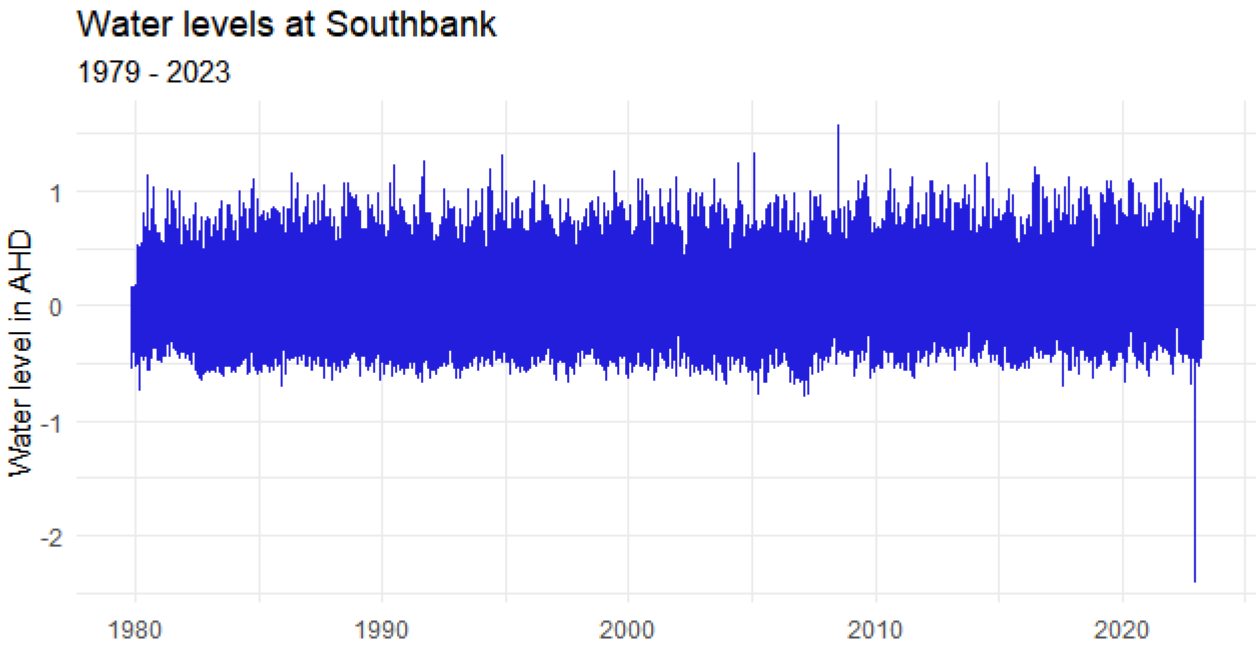


Figure 5-2: Full tidal level dataset at Southbank from 1979 - 2023 with the datum shift pre-July 2008 (-2m AHD data point after 2020 is spurious and has no influence on the analysis presented here).

While the levels at Southbank are predominantly driven by the tidal levels in Port Phillip, there is a small contribution from the Yarra River flows, and any impact was implicitly included in the empirical tidal analysis presented below. The tidal influence at this gauge includes the astronomical tide, atmospheric pressure, wave runup, wind setup as well as amplification of the tidal signature through the estuary (see Section 5.3).

Note there is a small amount of conservatism in the water levels at the Southbank gauge as the gauge is upstream of the confluence of the Yarra and Maribyrnong Rivers. Hence, the water levels at Southbank are expected to be slightly higher than the water levels at the Yarra River confluence. However, this is expected to be less than 50mm and of no meaningful consequence.

In terms of timing, it is expected that water levels would peak slightly earlier in the Maribyrnong River compared to Southbank, but this is considered to be small and insignificant.

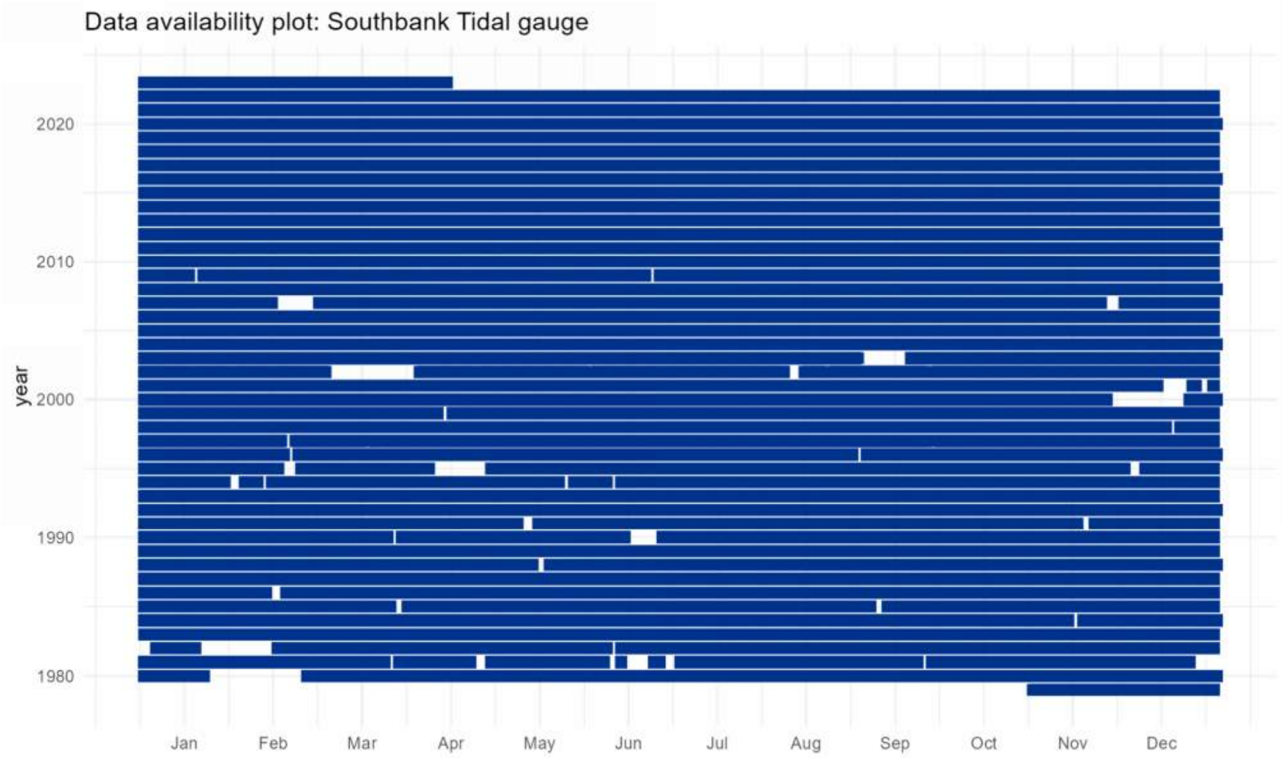


Figure 5-3: Available data plot for the Southbank tidal gauge.

5.2 Historic events downstream boundary

For historic events, the tidal record from Southbank was applied to the downstream boundary with an initial water level in the hydraulic model set to the corresponding initial water level from the gauge. Water levels were applied as a dynamic time series, that is, one where water level varied with time. This was completed for all historic events (1983, 1993, 2011 and 2022) except for 1974 as this event predates the Southbank gauge (see Figure 5-3).

For the 1974 verification event a static level of 0.0m AHD was adopted, as discussed in MMBW (1986). MMBW's predicted tide curves (MMBW, 1975) for the 1974 event based on the best information available at the time are provided in Figure 5-4 for comparison.

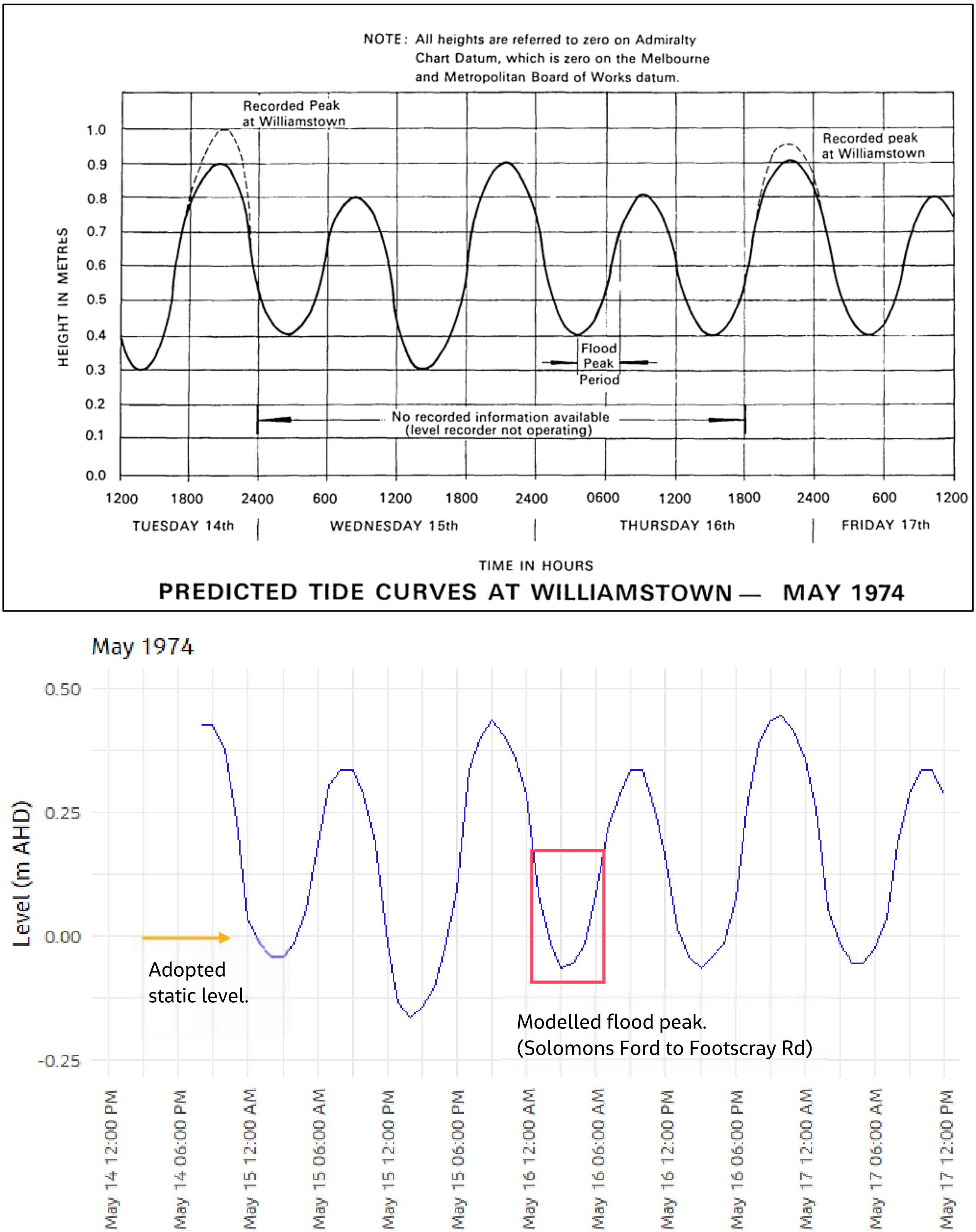


Figure 5-4: MMWB's predictions of Williamstown tidal levels during the 1974 flood event based on their best available knowledge from Figure 16 MMBW 1975 (top) and converted to m AHD (bottom) where AHD is 0.465m lower than Admiralty Chart Datum.

A static level was adopted for the following reasons:

- To calculate a dynamic water level would require building and using a hydrodynamic model of Hobsons Bay and the lower Yarra and Maribyrnong River estuaries. Without modelling there would be uncertainties regarding the timing due to the complex tidal dynamics. This would have been a significant task and would have only had a minimal reduction in uncertainty and the effort was considered disproportionate to the benefit.
- The 1974 event was selected as a verification event given the considerable uncertainties regarding the floodplain topography due to numerous developments. The uncertainty in topography is considered to be greater than the potential uncertainty introduced by using a static tidal boundary.

Sensitivity testing demonstrated that levels upstream of Footscray rail bridge were insensitive to tidal levels due to the blockage at that bridge.

5.3 Design events downstream boundary

For design events a different approach was required to determine the downstream boundary than for historic events. Both Australian and international research has shown that there is a statistical dependence between flood forming rainfall and storm tide (see for instance Hawkes and Svensson, 2006, Zheng et al., 2013, or Westra et al., 2019). For this study, this means that when there is a riverine flood event on the Maribyrnong River, it is necessary to account for any potential storm tide to calculate the expected[12] water levels for a riverine event with a given annual exceedance probability. This is referred to as a joint probability problem and the potential impact of this is conceptually illustrated in Figure 5-5 (from Westra et al., 2019).

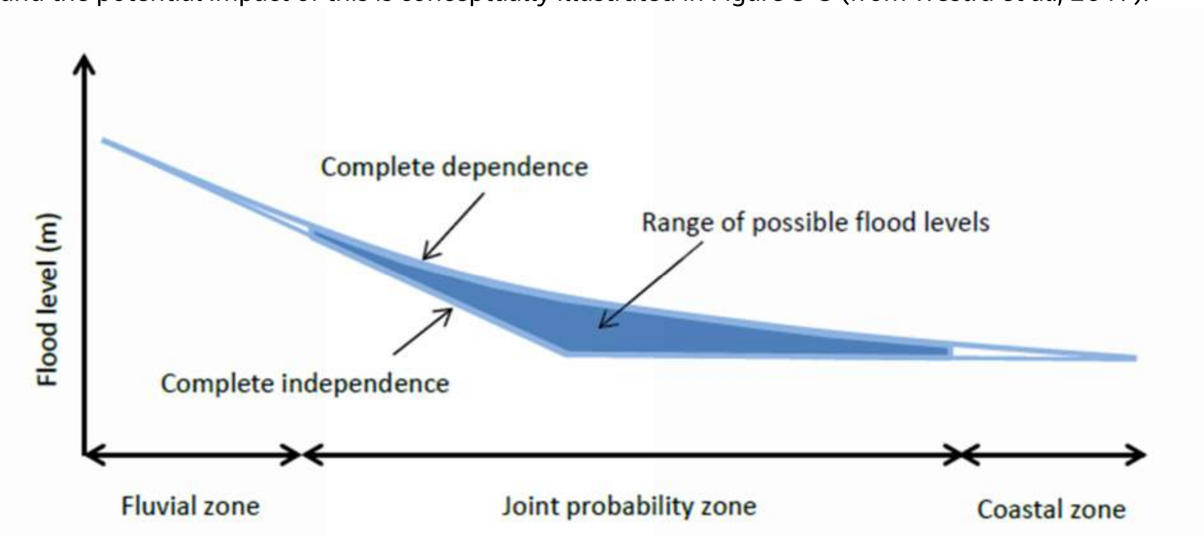


Figure 5-5: Schematic of a longitudinal section of an estuary, which shows two hypothetical water levels: the level obtained by assuming that fluvial floods will always coincide with storm tides of the same exceedance probability (upper curve); and the level assuming fluvial processes and ocean processes are completely independent and thus will almost never coincide (lower curve). From Westra et al. (2019) Figure 6.5.1.

Storm tide is considered a combination of the astronomical tide, storm surge (wind setup, wave runup and atmospheric pressure) and tidal dynamics driven by estuary morphology as shown in Figure 5-6.

[12] The term expected in this context has been used as a measure of central tendency.

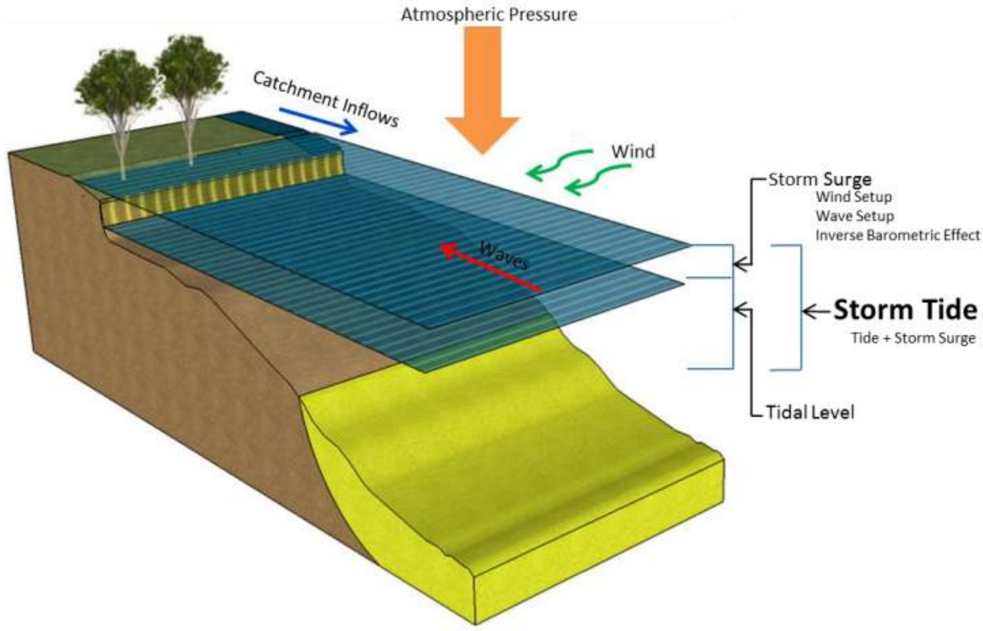


Figure 5-6: Physical Processes Generating Elevated Water Levels in Port Phillip Bay (from Water Technology, 2018, Figure 3-2).

5.4 Approach

The steps applied to determine the coincident (expected) water levels at the Southbank gauge to apply to the downstream boundary, were as follows:

- Investigate the degree of correlation between coincident flood events on the Maribyrnong River at the Keilor gauge and maximum water levels at the Southbank gauge. Note that the water levels were conditioned on the Keilor flows.
- Fit extreme value distributions to the flood and tidal series to calculate quantiles for the Keilor gauge (for discharge) and the Southbank gauge (for water levels). This step allowed the understanding of the frequency concurrent events at the Southbank gauge.
- Fitting of a bivariate normal distribution to transforms of the coincident marginal distributions using a Box-Cox transform and calculating the expected water level at the Southbank gauge.
- Undertaking a MC simulation of the Keilor peak flows and Southbank water levels.
- Determination of expected downstream boundary water levels for Maribyrnong River design events.

5.4.1 Correlation analysis

The initial step in understanding the degree of dependence between floods on the Maribyrnong River and water levels at the Southbank gauge was to calculate correlation coefficients of coincident events. As the purpose of the study was to map flood levels from the riverine Maribyrnong River, water levels at the Southbank gauge were conditioned on Maribyrnong River floods. The following procedure was applied:

- Extract the annual maximum flood at the Keilor gauge.
- Extract the coincident peak water level at the Southbank gauge in the 48 hours following the peak at Keilor. The 48 hours was selected to account for travel time from the Keilor to the Yarra confluence. It is noted that this procedure assumes that the Maribyrnong flood wave and the peak water level at the Yarra confluence coincide which is a conservative assumption.

- Calculate the correlation coefficient between the two series.

The annual maximum for the Keilor gauge was extracted as described in Section 4.2 including adjustments for re-rating. The date and time of the annual maximum was also extracted. The coincident peak water level at the Southbank gauge was extracted for the proceeding 48-hour period which allows for the flood wave to reach the Yarra confluence. The resulting coincident series is listed in Table 5-1 and the following was noted:

- As the Southbank gauge was only available from 1979, only annual maximum for the Keilor gauge since 1979 were used.
- 1979 and 2023 was removed as these were partial years.
- 2002 was removed as there was missing data at the Southbank gauge during the annual maximum flow at Keilor.
- This resulted in a coincident record length of 41 years.

These two series have been plotted in Figure 5-7 in the lower left-hand corner. In the upper right-hand corner of this plot the Pearson correlation coefficient is displayed. On the diagonals, upper left-hand plot and lower right-hand plot, are density plots of the coincident Southbank water levels and Keilor peak discharges.

Figure 5-7 indicates that there is a modest positive correlation (0.222) between discharge and water level; however, if the largest discharge (2022) and the largest water level (2005) are removed the correlation is reduced to 0.097.

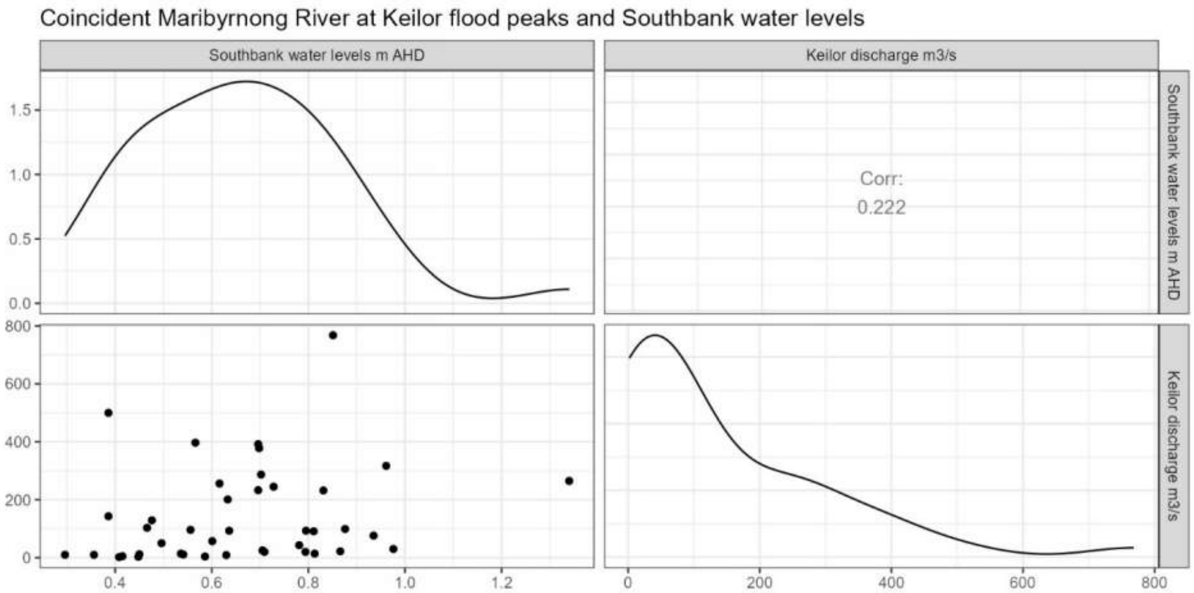


Figure 5-7: Scatter plot matrix of coincident Maribyrnong at Keilor peak discharges and peak water levels at the Southbank gauge. The lower left-hand panel is a scatter plot of the discharges and water levels, the upper right-hand panel is the Pearsons correlations coefficient, the upper right-hand panel is the density plot of the water levels and the lower right-hand plot is the density of the discharges.

Table 5-1: Concurrent Maribyrnong discharge and Southbank tidal series conditioned on Maribyrnong discharge.

Date	Level (m AHD)	Discharge (m^3/s)	Date	Level (m AHD)	Discharge (m^3/s)
23/08/1980	0.536	14	25/08/2003	0.709	20
6/08/1981	0.466	103	11/09/2004	0.541	11
15/10/1983	0.566	400	3/02/2005	1.34	265
3/10/1984	0.556	96	17/07/2006	0.408	2
9/12/1985	0.696	233	22/12/2007	0.781	43
23/10/1986	0.811	91	13/12/2008	0.794	20
31/07/1987	0.696	392	22/11/2009	0.63	9
1/01/1988	0.496	50	31/10/2010	0.702	287
10/06/1989	0.961	317	6/02/2011	0.698	379
18/07/1990	0.831	232	18/08/2012	0.728	245
30/08/1991	0.866	22	19/09/2013	0.705	25
25/09/1992	0.386	143	7/12/2014	0.448	3
16/09/1993	0.386	510	6/11/2015	0.415	5
10/02/1994	0.586	4	31/12/2016	0.633	201
6/11/1995	0.476	129	10/04/2017	0.813	14
1/10/1996	0.876	99	17/06/2018	0.976	30
16/09/1997	0.296	10	12/08/2019	0.45	12
15/11/1998	0.356	10	4/04/2020	0.935	76
28/12/1999	0.636	93	14/11/2021	0.795	93
25/10/2000	0.616	256	14/10/2022	0.851	768
24/04/2001	0.601	57			

5.4.2 Fit extreme value distributions

Extreme value distributions were fitted to the Maribyrnong River at Keilor record and the Southbank gauge tidal record.

Details of fitting the Maribyrnong River at Keilor record were reported in Section 4.2 and the resulting flood quantiles are presented in Table 4-3.

The Southbank gauge record was fitted in a similar way to the Maribyrnong River at Keilor record with the following steps:

- Extract the annual maximum water level.
- Fit extreme value distribution.
- Extract quantiles.

The annual maximum water levels were extracted from the Southbank gauge records with the following years being removed from the results: 1979 and 2023 due to these being incomplete years in the record. Several other years had missing data; however, the amount of missing data was small, and these years were included in the analysis. The resulting annual maximum series is shown in Figure 5-8.

Three procedures were applied to calculating the quantiles for the Southbank gauge:

- Fitting a Generalised Extreme Value (GEV) distribution using a maximum likelihood technique (GEV ML).
- Fitting a GEV distribution using a maximum Bayesian technique (GEV Bayes).
- Fitting a Log Pearson Type 3 (LP3) distribution using a Bayesian technique (LP3 Bayes).

All three analysis produced results that were consistent within 10mm up to the 2% (1 in 50) AEP event with the 2% and 1% AEP water levels from maximum likelihood being 30-40mm less than Bayesian Techniques as shown in Table 5-2. Also included in this table are the results from the Port Phillip Bay Storm Tide Modelling (Water Technology, 2018).

The three analyses on the Southbank gauge maximum water levels produce consistent results and are comparable to the Melbourne Water Technical Specification. For the purposes of reporting the annual exceedance probabilities of Southbank water level results presented in this report the GEV Bayes results have been adopted.

Review of the concurrent tidal series in Table 5-1 shows that all Southbank water levels are less than the adopted 50% AEP water level in Table 5-2 (1.08m AHD) with the exception of the 2005 level.

Table 5-2: Water levels versus annual exceedance probability for the Southbank gauge using various methods as described above and from the Melbourne Water Technical Specification.

AEP	GEV ML	GEV Bayes	LP3 Bayes	Water Technology (2018)
99%	0.86	0.86	0.85	
91%	0.95	0.95	0.94	
80%	1.00	0.99	0.99	
67%	1.04	1.03	1.04	
57%	1.07	1.06	1.06	
50%	1.08	1.08	1.08	
20%	1.18	1.18	1.18	
10%	1.23	1.24	1.24	1.18
5%	1.27	1.29	1.28	
2%	1.31	1.35	1.34	
1%	1.34	1.38	1.37	1.44

There are minor differences between water levels in the tidal analysis completed as part of this project and the water levels calculated by Water Technology (2018). The tidal levels calculated through the statistical analysis presented above are based on historic information only which may be subject to data errors and does not account for physical processes. Further, the more these statistical calculations are extrapolated beyond the length of the record the greater the uncertainty. In the context of this project, the statistical analysis presented in Table 5-2 was only used to characterise the annual exceedance probability of joint tidal levels with fluvial flows. These events tended very frequent to frequent events.

The water levels calculated by Water Technology (2018) have been based on detailed hydrodynamic modelling supported by statistical analysis of numerous input datasets. The hydrodynamic modelling incorporates high quality datasets including bathymetry of Port Phillip. These results are considered to be more robust, however, these results were only available for the 10% and 1% AEP events.

It is of note that the difference between the two techniques is small.

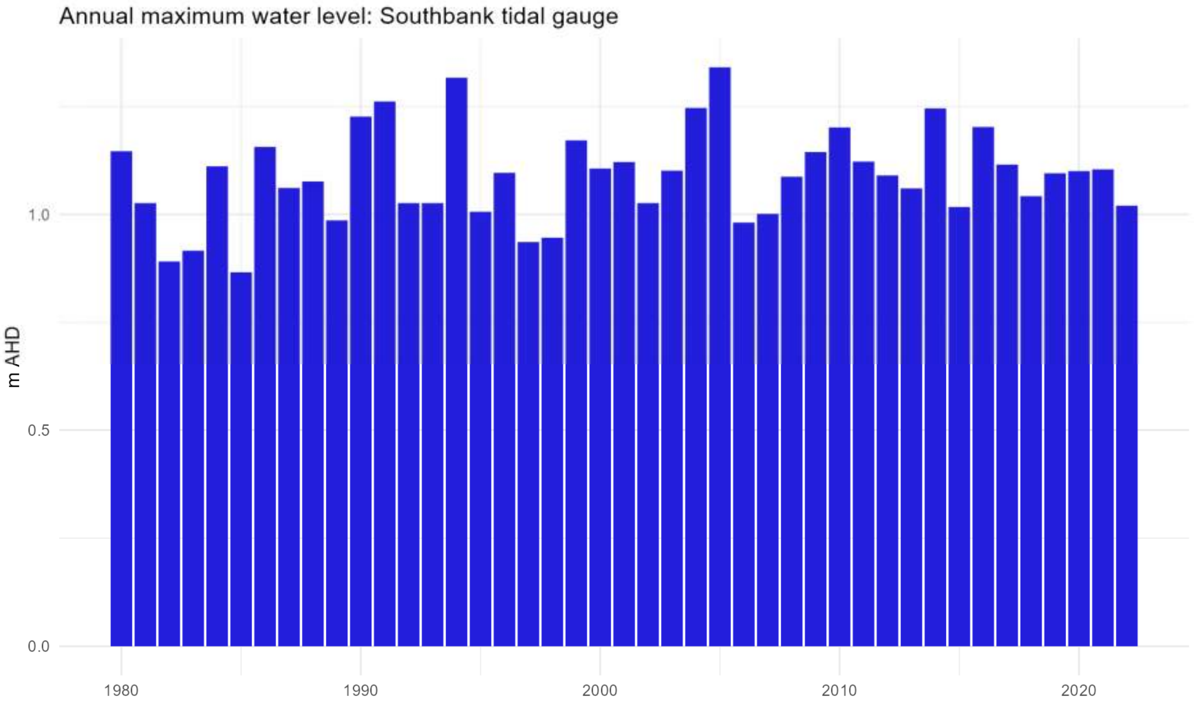


Figure 5-8: Southbank tidal gauge: Annual maximum water level.

5.4.3 Bivariate normal distribution

The bivariate normal distribution is a statistical model that can represent many joint probability processes, such as correlated flow and tidal series, if the two series (or marginal distributions) are normally distributed. This distribution has an analytical solution which can provide the expected quantile in one series given the quantile in another series (Equation 1). A key assumption is that the marginal distributions are normally distributed which can, for many datasets, be achieved through a data transformation.

$$\mu_{y|x} = \mu_y + \rho \frac{\sigma_Y}{\sigma_x}(x - \mu_x)$$

Equation 1: Approximate method for calculating the expected value of one variable given a value on another where the joint distribution can be described by a bivariate normal distribution.

where $\mu_{y|x}$ is the expected water level y given discharge x, ρ is the correlation between discharge and water level, μ_x is the mean discharge, μ_y is the mean water level, σ_x is the mean discharge and σ_y is the mean water level.

This section outlines the procedure undertaken to calculate the expected tidal level for a given Maribyrnong River discharge at Keilor. The procedure applied was:

1. Extract annual maximum series for Maribyrnong River at Keilor – described in Section 4.2 and listed in Table 4-3.

2. Extract concurrent water level records from the Southbank gauge conditioned on the Keilor annual maximum series – described in Section 5.4.1 and listed in Table 5-1.
3. Transform of the Keilor and Southbank to normal distributions.
4. Calculate the expected (transformed) water levels at Southbank given the standard (transformed) Keilor quantiles.
5. Transform the expected transformed water levels calculated in 4) back into actual water levels.

5.4.3.1 Transform to normal distributions

To employ the bivariate normal distribution, it was necessary that the marginal distributions are normally distributed. This transform was achieved through a Box-Cox transform, although initially using the extreme values distribution fitted to each annual maximum series was investigated. The use of extreme values distributions produced unsatisfactory results for the following reasons:

- The FFA for Keilor used low flow censoring, hence flows below 76m^3/s did not produce reliable probabilities and skewed the results.
- The concurrent sample of water levels at Southbank were all less than the 50% AEP event, with the exception of event in 2005. This indicates that concurrent water levels were not a subset of the distribution fitted to the annual maxima series and probabilities returned from the inverse transform were skewed to very frequent events.

For the reasons listed above, a Box-Cox transform was applied with the transform shown in Equation 2.

$$Y = \frac{X^{\lambda} - 1}{\lambda}$$

Equation 2: Box-Cox transform

where *Y* is the transform (normally) series, *X* is the input series and λ is the transform parameter.

A Box-Cox transform was applied to the (concurrent) marginal distributions (Southbank level and Keilor discharge) with l being optimised using Shapiro-Wilk Goodness-of-Fit Statistic[13] as the objective function. The resulting fits for:

- Southbank water levels: The resulting parameters and values are listed in Table 5-3. The Shapiro-Wilk values indicates a good fit to the normal distribution. The resulting quantile-quantile plot and histogram are shown in Figure 5-9. These plots show that there is an acceptable fit with the quantile-quantile plot approximating the 1 to 1 line and the histogram being approximately normally distributed.

[13] The Shapiro–Wilk test (Shapiro and Wilk, 1965) tests for normality with higher values indicate a good fit to the normal distribution.

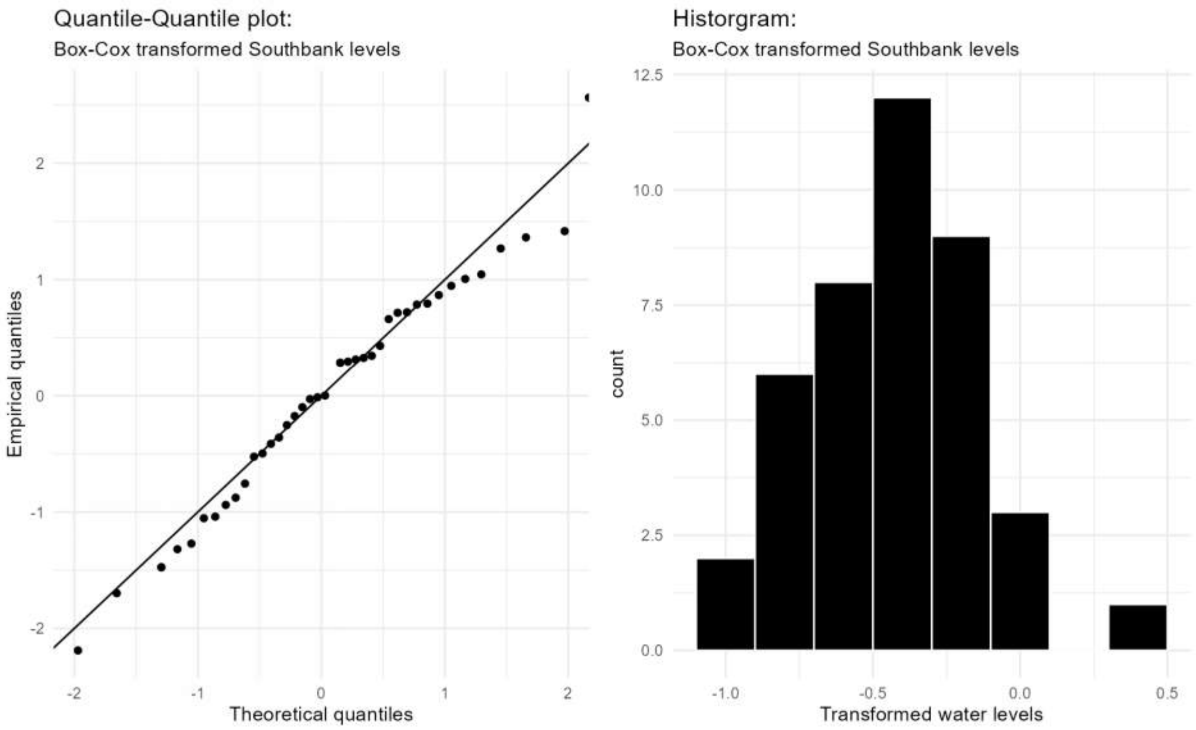


Figure 5-9: Diagnostic plots of the transform of Southbank water levels to normal distribution using a Box-Cox transform.

- Keilor discharge: The resulting parameters and values are listed in Table 5-3. The Shapiro-Wilk values indicates a reasonable fit to the normal distribution. The resulting quantile-quantile plot and histogram are shown in Figure 5-10. These plots show that there is a reasonable fit with the quantile-quantile plot tending to the 1 to 1 line although there are clear correlation waves that are likely due to the relatively small sample size. The histogram is roughly normally distributed although there is high frequency around the bin value of 9 (noting that this is a transformed value).

Table 5-3: Box-Cox transform parameters for Southbank and Keilor.

Parameter	Southbank water level	Keilor discharge
Sample size	41	41
Optimal l	0.242	0.145
Shapiro-Wilk	0.985	0.962
Mean	-0.429	5.811
Standard deviation	0.286	2.791

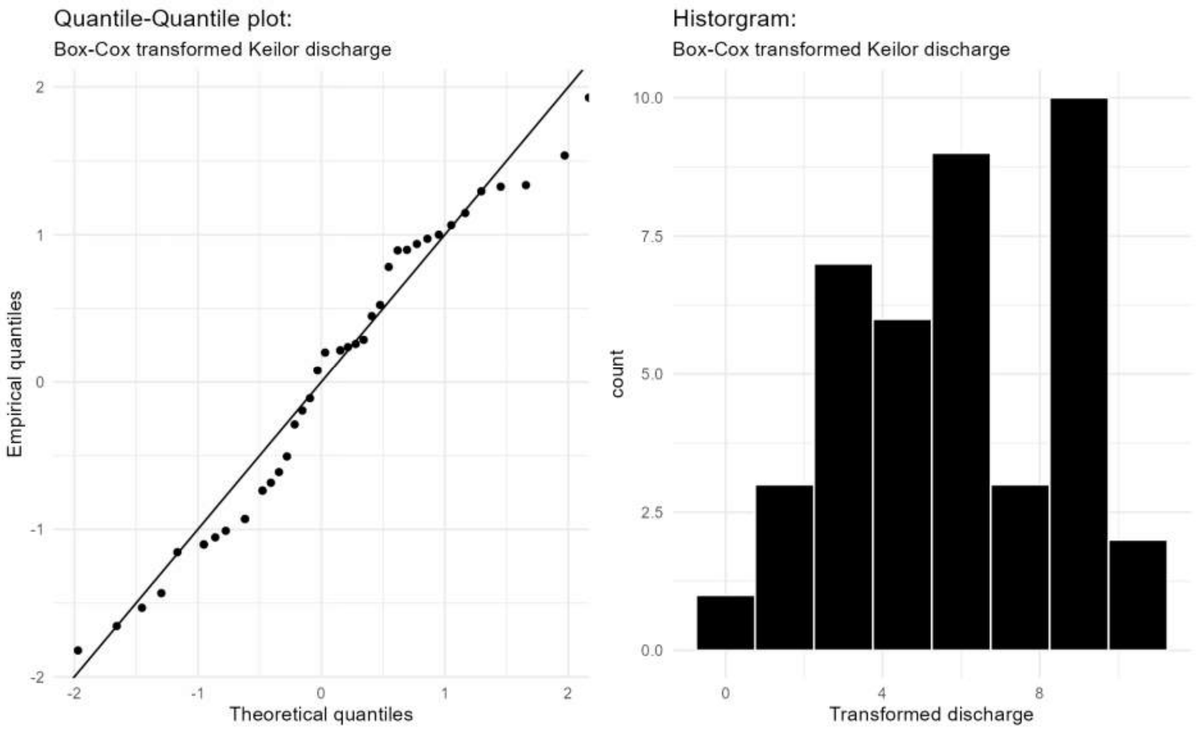


Figure 5-10: Diagnostic plots of the transform of Keilor discharges to normal distribution using a Box-Cox transform.

The resulting concurrent transformed discharge and level series are shown in Figure 5-11 together with the line of best fit. The resulting correlation co-efficient for the concurrent transformed was a modest positive correlation of 0.360 which is slightly stronger than the untransformed value of 0.222. Similar to the untransformed series, the correlation co-efficient is significantly reduced when the largest discharge and water level are removed to 0.097. The largest riverine and tidal events were retained as these were events that had been recorded and inclusion of these data points adds some conservatism to the results.

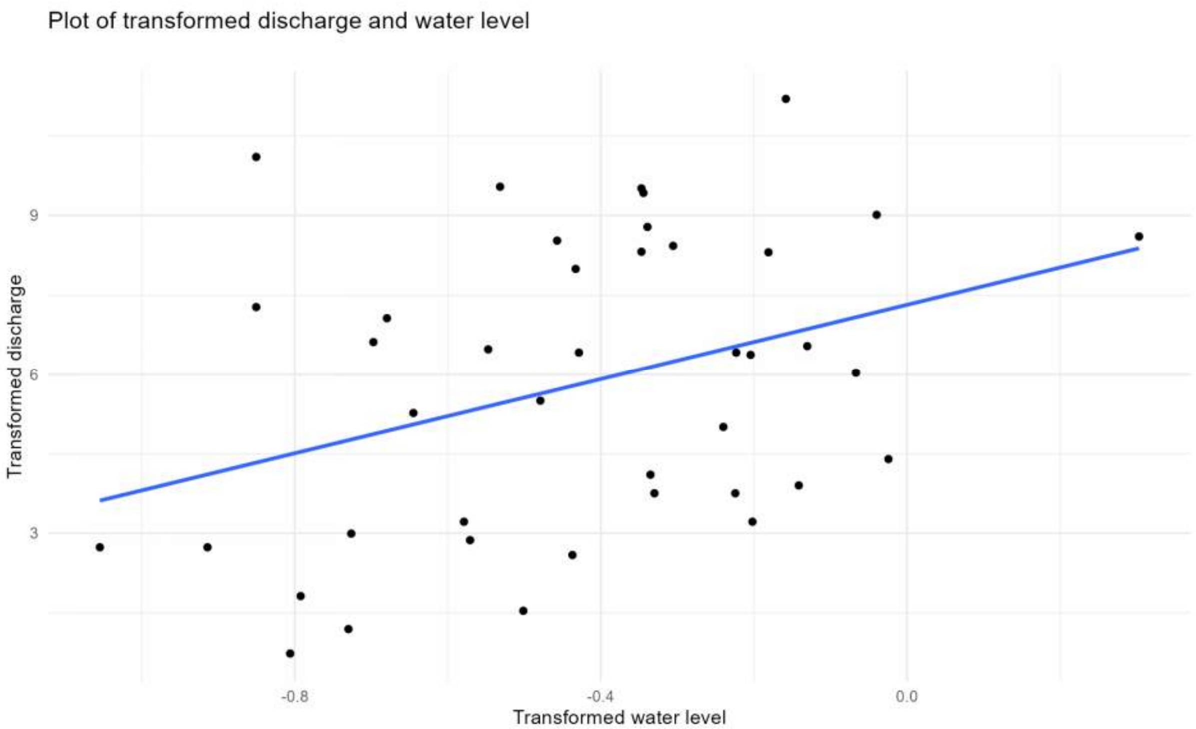


Figure 5-11: Scatter plot of transformed discharged and water levels together with line of best fit.

5.4.3.2 Expected (transformed) water levels at Southbank

The expected values of transformed water level at Southbank were calculated for the annual maximum Maribyrnong River at Keilor probability events listed in Table 5-4. The flowing steps were undertaken:

- Calculate the quantiles of the transformed discharge for the required probabilities using the mean and standard deviation listed Table 5-3. The resulting transformed quantiles are listed Table 5-4.
- Calculated the expected water levels according to Equation 1 and the mean and standard deviation listed in Table 5-3 given the transformed discharge quantiles shown in Table 5-4. The resulting expected transformed water levels are listed in Table 5-4.

5.4.3.3 Transform back to actual water levels from normally transformed water levels

The final step was to transform the expected (normally transformed) water levels back to actual water level in m AHD by inverting the relationship in Equation 2. The results of this are presented in Table 5-4. Comparison of the resulting expected water levels to the annual maxima results for Southbank in Table 5-2 shows that the expected water levels are events that are expected to be equalled or exceeded every year; that is, these events are very frequent. This is consistent with the concurrent series presented in Table 5-1.

Table 5-4: Calculated expected transformed and actual water levels for various Maribyrnong River design events.

Probability % (Keilor event)	Probability 1 in Y (Keilor event)	Transformed discharge quantiles	Expected transformed water levels	Expected water levels
99	1.01	-0.69	-0.668	0.48
91	1.10	2.08	-0.566	0.54
80	1.25	3.46	-0.515	0.58
67	1.50	4.61	-0.473	0.6
57	1.75	5.31	-0.448	0.62
50	2	5.81	-0.429	0.64
20	5	8.16	-0.343	0.7
10	10	9.39	-0.298	0.73
5	20	10.4	-0.260	0.76
2	50	11.54	-0.218	0.8
1	100	12.30	-0.190	0.82
0.5	200	13.00	-0.65	0.85

5.4.4 Monte Carlo assessment

Correlated Monte Carlo (MC) samples were generated from the fitted normal distributions to discharge and water level to allow for:

- The visual comparison of the modelled joint distribution to the correlated samples and expected water levels for discharge for a given probability.
- The determination of the spread of water levels for a given discharge and hence uncertainty.

Using the fitted normal distributions and the calculated correlation coefficient the following procedure (outlined in ARR2019 (Nathan and Wienmann, 2019)):

1. Generate random draws from unit normal distributions as follows:

$$X = N(0,1); Z = N(0,1)$$

2. Generate correlated normal random draw as follows:

$$Y = \rho X + Z\sqrt{1-\rho^2}$$

3. Generate random draws from the fitted normal distributions for the (transformed) discharge and water level from Section 5.4.3.1 using the correlated normal samples from step 2)

$$x = \mu_x + X\sigma_x; \;\; y = \mu_y + Y\sigma_y$$

A sample size of 100,000 was used which was considered adequate to calculate the expected water levels for events with probabilities of 0.5% and more frequent. The resulting 100,000 samples are presented in Figure 5-12 together with the empirical concurrent events between Keilor and Southbank as well as the expected water levels. The resulting MC samples conform to the typical distribution for a tidal rainfall or discharge analysis (see for instance Figure 4.4.5.b from Nathan & Weinmann (2019) (after Westra (2012)).

Figure 5-12 confirms the positive correlation between the Keilor discharge and Southbank water levels and the fit of the bivariate normal distribution to the empirical data.

The numerical analysis of the MC results was undertaken to characterise the spread of the expected water levels for probability. This spread is illustrated in the density plot in Figure 5-13 for the water levels that are coincident with the 1% AEP Keilor flood event. This figure indicates that the Southbank water level could be as low as 0.4m AHD or as high as 1.6m AHD, although these levels are extremely unlikely. The peak of the density plot is around 0.76m AHD with a median value of 0.82m AHD. The empirical analysis of the spread of water levels for standard AEP events are listed in Table 5-5. It is noted that there are small differences between the expected water levels in Table 5-4 and the median values in Table 5-5 (albeit small) due to the skew in the distribution as illustrated in Figure 5-13.

As noted above, the expected water levels are more frequent than the 50% AEP event from the extreme value analysis. Given this an element of conservatism has been incorporated into water levels for design events and the 75% percentiles from Table 5-5 have been adopted.

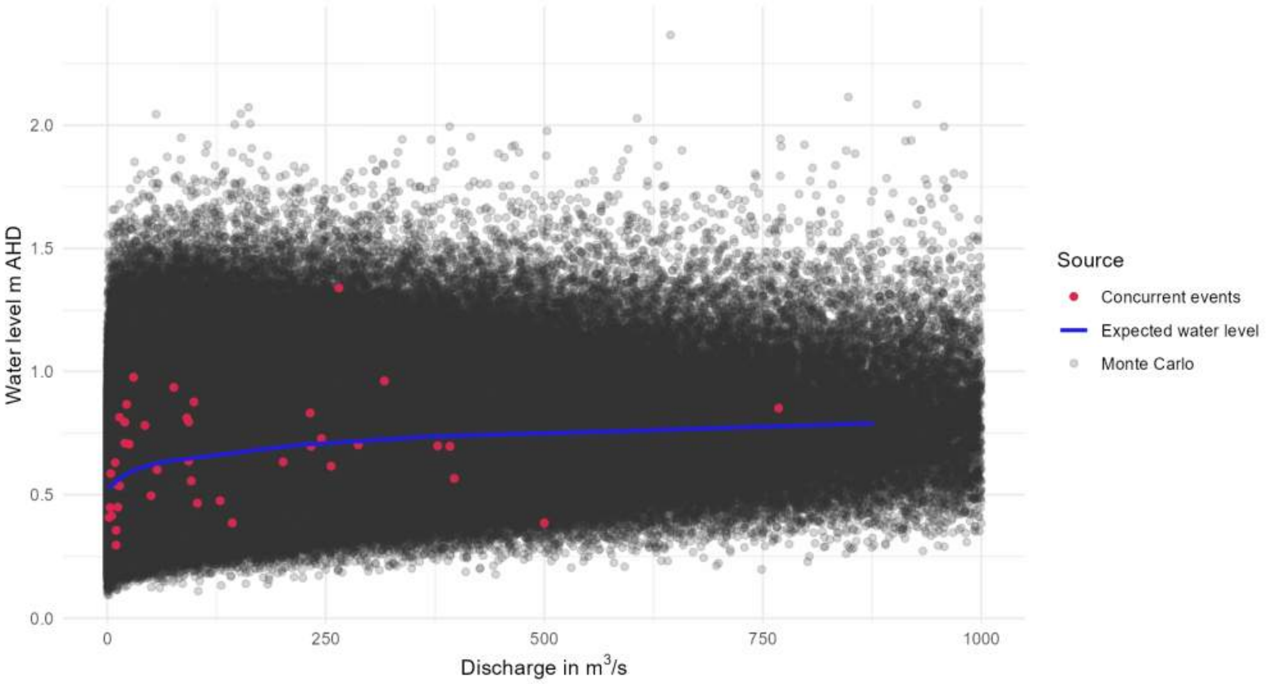


Figure 5-12: Comparison of Monte Carlo samples from fitted bivariate normal distribution to empirical concurrent events and expected water levels.

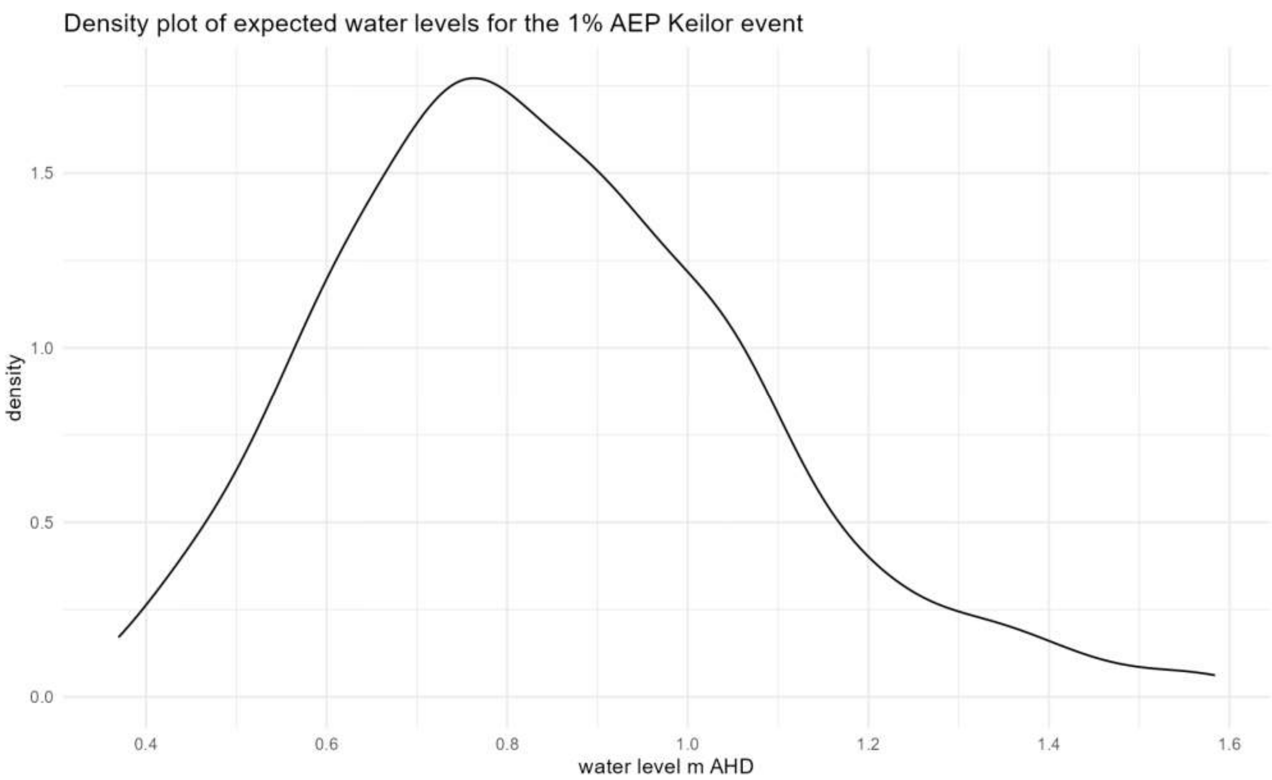


Figure 5-13: Density plot of the modelled water levels for the 1% AEP event at Keilor This plot shows the potential spread of water levels that are coincident with 1% AEP flood.

Table 5-5: Empirical Southbank water level quantiles for water levels for standard AEP events at Keilor.

Probability % (Keilor event)	Probability 1 in Y (Keilor event)	5%	10%	25%	50% median	75%	90%	95%
99	1.01	0.303	0.345	0.425	0.529	**0.650**	0.778	0.862
91	1.10	0.310	0.353	0.434	0.540	**0.663**	0.793	0.878
80	1.25	0.335	0.380	0.463	0.573	**0.700**	0.833	0.921
67	1.50	0.355	0.402	0.490	0.604	**0.737**	0.874	0.965
57	1.75	0.369	0.416	0.506	0.623	**0.758**	0.898	0.988
50	2	0.377	0.426	0.518	0.635	**0.773**	0.915	1.009
20	5	0.425	0.477	0.574	0.701	**0.846**	0.996	1.092
10	10	0.446	0.500	0.601	0.736	**0.891**	1.048	1.146
5	20	0.46	0.521	0.624	0.757	**0.915**	1.077	1.198
2	50	0.487	0.539	0.646	0.790	**0.957**	1.125	1.233
1	100	0.499	0.567	0.675	0.817	**0.987**	1.123	1.271
0.5	200	0.558	0.611	0.723	0.868	**1.053**	1.209	1.296

5.5 Sea level rise

An additional 0.83m was added to the tidal boundary to account for sea level rise. This value is the mean of the difference between 1% AEP tidal level and 1% AEP sea level rise level (at 2100) listed in Table 35 of the Melbourne Water Technical Specification.

5.6 Tidal boundary discussion

An analysis of the tailwater or tidal boundary for the Lower Maribyrnong was completed with the aim of developing appropriate conditions for the various modelling scenarios. These scenarios included historic events and design events. The analysis was completed for the Yarra River at Crown Melbourne Spencer Street Southbank (229663A) tidal gauge (Southbank gauge) as this was the closest gauge to the downstream boundary. This gauge had the advantage of implicitly including amplification of the tidal signature through the Lower Yarra River and any contributions from the Yarra River itself.

The historic events (calibration, validation and verification events) used the dynamic record of the event from the Southbank gauge with the exception of the 1974 event. For the 1974 event information from the Williamstown gauge was transferred to the downstream boundary.

The purpose of design event modelling was to determine flood levels with a given probability of occurrence. As the main source of flood risk in the Lower Maribyrnong is from the river itself an analysis of the coincident peak water levels at Southbank was undertaken, that is, the tidal levels were conditioned on the Keilor floods.

The coincident water levels were generally less than the 50% AEP water levels at Southbank with the only exception of the 2005 event, that is, in the 41 years of available data only once has an annual maximum flood on the Maribyrnong coincided with a tidal event that is likely to be equalled or exceeded less than once every 1.44 years. This empirical data demonstrates that it is unlikely a Maribyrnong flood event will occur at the same time as a significant storm tide.

Analysis of the coincident water levels with the Keilor annual maximum flows were moderately correlated with a correlation coefficient of 0.3 which reduced to 0.09 when largest tidal and largest flood events were removed. The reduction in correlation when the largest events were removed demonstrates the leverage these events have on the analysis; however, these events were retained, the consequence of which is slightly higher water levels which can be considered conservative.

The calculation of the expected water levels at Southbank was completed by fitting of a bivariate normal distribution to transforms of the coincident marginal distributions to normal distributions using a Box-Cox transform. This analysis found that expected water levels were all modest with the coincident expected water level for the 10% AEP event being 0.74m AHD and for the 1% being 0.82m AHD. These compared to equivalent levels in the Melbourne Water Technical Specification of 1.00m AHD and 1.09m AHD.

To incorporate an element of conservatism, the adopted expected water levels were set to the 75% percentiles from the MC analysis where were 0.89m AHD (10% AEP) and the 0.99m AHD (1% AEP).

6. Hydraulics

A calibrated hydraulic model covering the Lower Maribyrnong River has been developed using a 1D/2D linked hydraulic model. This model calculates flood depth, level, velocity and other hydraulic properties for the historic and design event flows. This section details the development of the hydraulic model including its calibration.

6.1 TUFLOW version and solver

The 2023-03-AE release of TUFLOW was used in this study given that it offers up-to-date functionality and bug fixes, with the Heavily Parallelised Compute (HPC) solver adopted and the Sub-Grid Sampling (SGS) functionality enabled. A TUFLOW HPC model was developed that models the Maribyrnong River and the floodplain in 2D, with embedded 1D elements to represent sub-grid scale features.

6.1.1 Quadtree mesh

This model uses the SGS feature together with the Quadtree feature. The Quadtree feature has been used to provide finer resolution results in the urban floodplain such as Maribyrnong Township and other locations where an increased resolution was needed (see Figure 6-1).

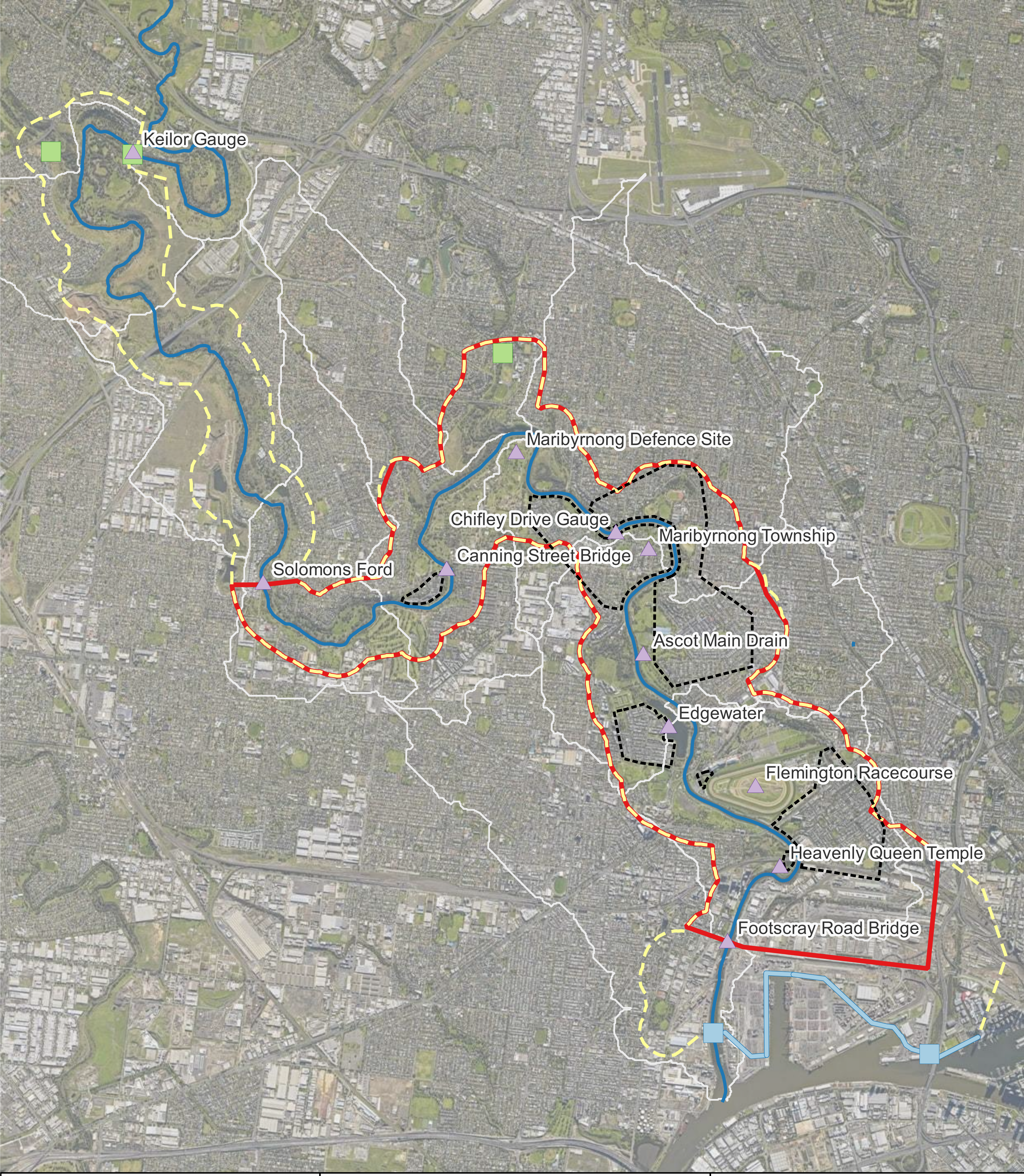
6.2 Model Extents

The TUFLOW hydraulic model extends from Brimbank Park in Keilor to the downstream confluence of the Maribyrnong River and Yarra River as illustrated in Figure 6-1. The hydraulic model extent differs from the flood mapping extent (also shown in Figure 6-1). The mapping extent for this project extends from Solomon Ford to the upstream face of the Footscray Road bridge. The flood mapping area is the area where the model simulation results are considered to be accurate and valid.

The difference between the upstream hydraulic model boundary and the flood mapping boundary is to allow the realistic routing of the flood wave from the Keilor streamflow station to the upstream flood mapping extent. The hydraulic model calculates any attenuation and dispersion of the flood wave which previous studies, including MMBW (1986), GHD (2003a), GHD (2003b) and GHD (2003c) assumed did not occur. The Keilor gauge was selected as the upstream boundary as this gauge captures the majority of the flow to arrive in the Lower Maribyrnong River and also has an updated rating table that is based on high flow gaugings captured during the October 2022 flood event (see Section 3.4.5). Effectively, this decision reduced uncertainties in flow routing in the Maribyrnong River between Keilor and Solomons Ford and included attenuation and dispersion of the flood wave.

Note that the area between the Keilor gauge and Solomons Ford will be mapped following completion of the current study and will include updated land use and infrastructure information as well as survey data, which is yet to be commissioned.

The mapping extent includes areas that are impacted from flooding from the Lower Maribyrnong River including Maribyrnong, Aberfeldie, Kensington, Moonee Ponds, Flemington, Ascot Vale, West Melbourne, Footscray, Essendon West, Avondale Heights, Braybrook and Sunshine North.



Legend

- Mapping extent
- TUFLOW model extent
- Quadtree regions
- Distributed inflow areas
- Points of interest
- TUFLOW outflow boundary (tidal)
- Tuflow outflow boundary (overland)
- TUFLOW inflow boundary
- Maribyrnong River

MGA Zone 55

0 1 2 3 km

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Figure 6-1: TUFLOW model extent, Quadtree area, study mapping limit and points of interest

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6.3 Grid size

The grid size for the TUFLOW model has been selected at 8m based on cell size convergence testing. The following series of grid sizes were tested in an initial hydraulic model: 20m, 16m, 12m, 10m, 8m, 5m and 4m. These results were based on the LiDAR and Bathymetry that was available prior to the commencement of the project. It is not expected that the data acquired as part of this project will alter the results of the grid size convergence testing.

The results of the grid size testing are presented and discussed in the Schematisation Report (Jacobs, 2023) and repeated in Figure 6-3 for information. The results show that:

- Flood levels for all cell sizes are generally well within 100mm of each other.
- Runtimes increased significantly for 5m and 4m runs, which were considered impractical.

On this basis, the 8m grid resolution was adopted as the grid size. However, the 8m grid resolution was not considered to be sufficient for urban areas such as Maribyrnong Township and a higher resolution of 2m was used through the Quadtree feature of TUFLOW in these areas. Figure 6-1 shows the location of the finer (2m) grid resolution Quadtree areas and Figure 6-2 provides an example of the resolution of results in a location in Maribyrnong Township. The quadtree areas represent urban areas that are inundated either in the calibration event or one of the higher-flow design events, or areas that required increased resolution for modelling accuracy reasons.

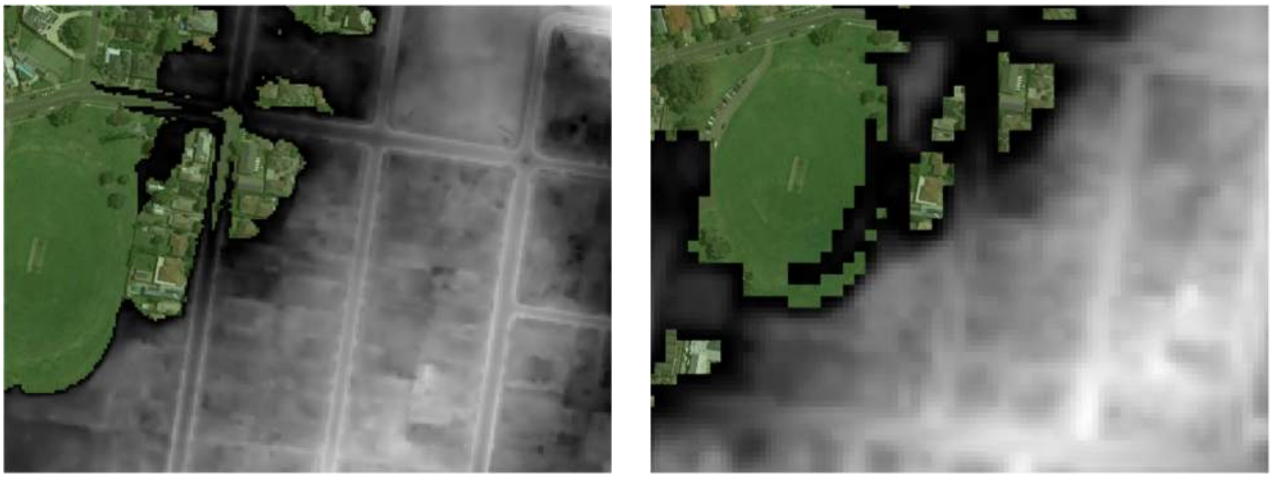


Figure 6-2: Comparison of resolution of results with Quadtree (left) and without (right) in a small part of Maribyrnong Township.

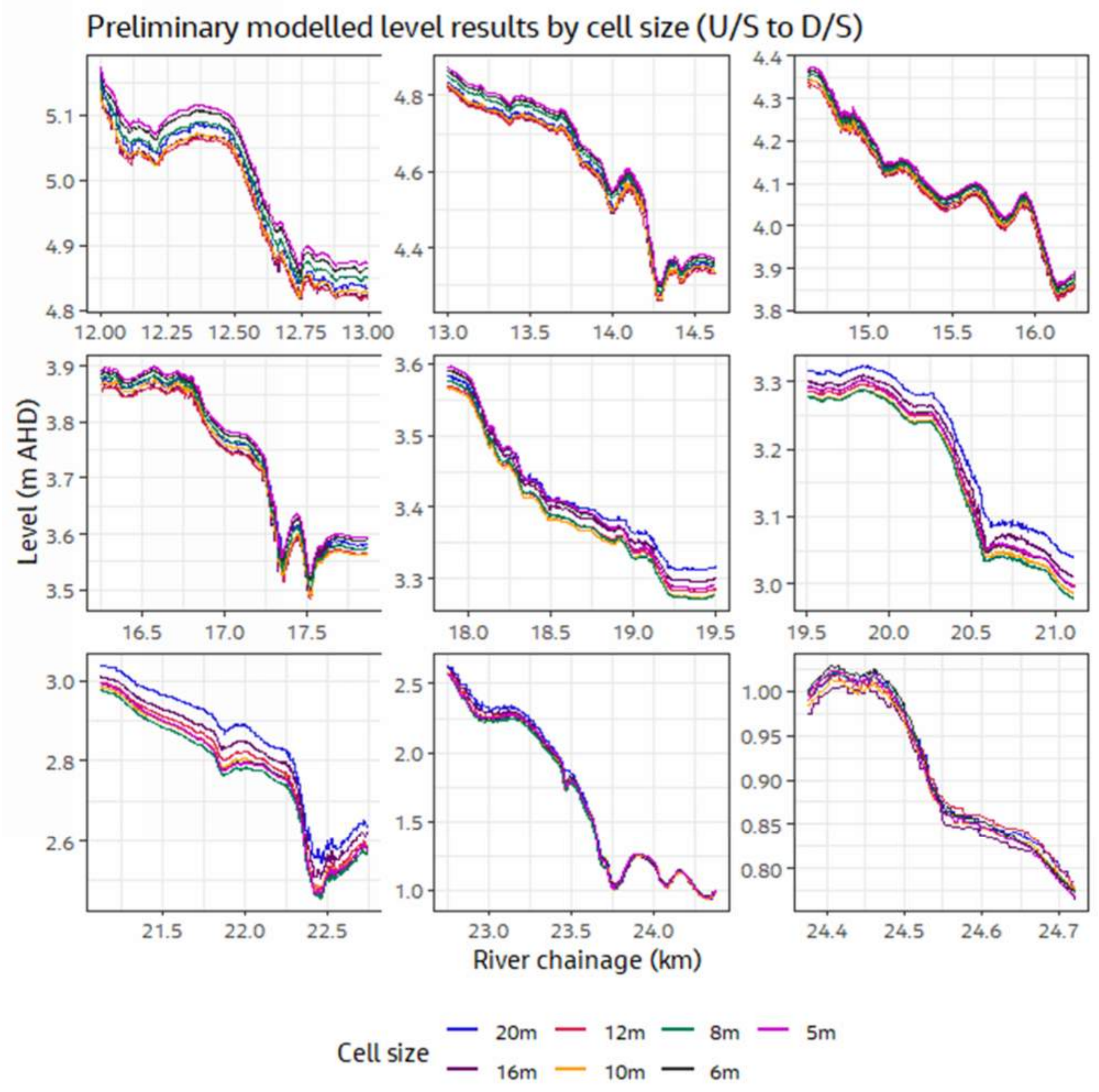


Figure 6-3: Results of cell sized convergence testing using the 2022 flood event using a range of cell sizes between chainage=10 km (Grimes Flat) and chainage=24 km (Footscray Road).

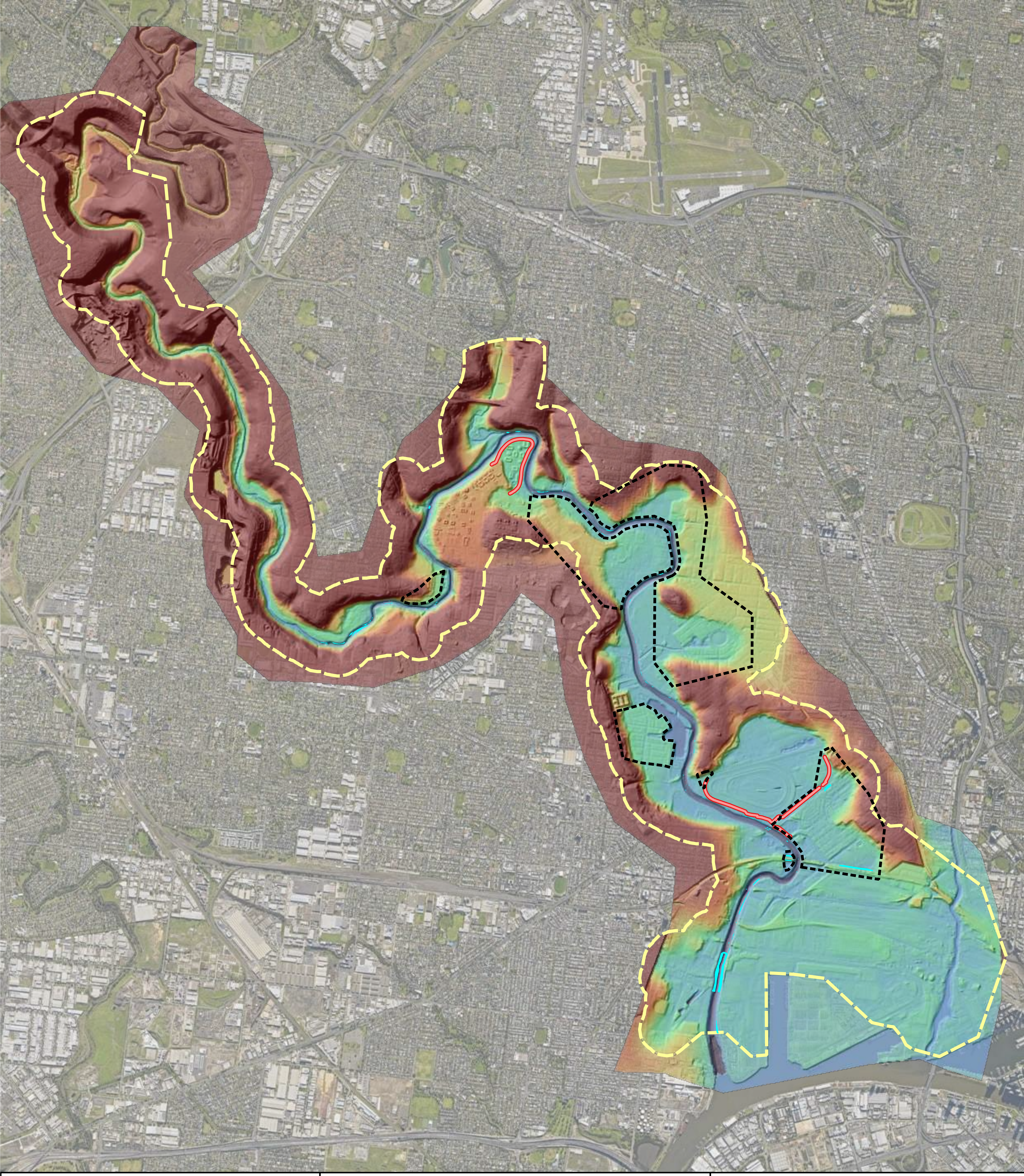
6.4 Terrain

The topography of the TUFLOW model was based on the 2023 LiDAR and bathymetric survey collected for the project (see Section 3.5). The two datasets were synthesised into a high-quality terrestrial and bathymetric DEM with a resolution of 0.5m that was input into the TUFLOW model. The TUFLOW DEM is shown in Figure 6-4. The following sections detail the further definition and/or modifications added to the model terrain.

6.4.1 Levees

There are three levees in the Lower Maribyrnong as shown in Figure 6-4 that were included in the hydraulic model:

- The levee at Maribyrnong Defence site
  - Details were obtained from the LiDAR. Given that this is a defence site, access was limited and it was not feasible to obtain topographic survey of the levee. Further review of the project LiDAR demonstrated that the levee was well represented and suitable for use in the model. The levee was reinforced in the hydraulic model using a "z-shape" line with the level raised to the maximum elevation in the terrain of each grid cell using "z-shape" points. This ensured that there are no artificial sags in the crest of the levee. The crest of the levee varies between 6.09m AHD to 12.52m AHD.
- The flood wall at Flemington Racecourse
  - Given the importance of understanding the potential impact of the flood wall the publicly accessible portion of the flood wall was surveyed as part of the data acquisition programme. This information was used to set the elevation of the wall. There were gaps in the survey data which were infilled using design drawings received from Melbourne Water. The wall was modelled as a z-shape feature in the hydraulic model with elevation of the crest of the wall taken from the survey data listed in Section 3.5.1. The crest of the wall varies between 3.28m AHD to 5.28m AHD.
- The levee at Riverside Park
  - This levee was not surveyed, however the wide crest ensured that levels were recorded by the LiDAR. These levels align with the design drawings in Appendix O. It was modelled using the same approach as the Maribyrnong Defence levee, with the crest of the levee varying between 2.89m AHD to 4.69m AHD.



Legend

TUFLOW model extent

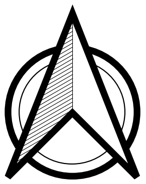
Quadtree regions

Terrain adjustments

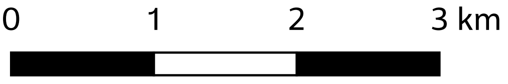
Levee & embankments

Elevation (m AHD)

-5	10
0	15
5	20



MGA Zone 55



Jacobs

Figure 6-4: TUFLOW model terrain and terrain modifications

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6.4.2 Terrain modifications

In some areas, adjustments were required to remove artefacts and/or gaps in the model DEM. This was completed using z-shape polygons and z-shape points using neighbouring elevation data. Figure 6-5 and Figure 6-6 show examples of the DEM modification carried out within TUFLOW. In both examples, there were gaps in the bathymetry that required infilling. The figures show the model processing input terrain DEM data into TUFLOW grids, hence the pixelated nature of the terrain in the images on the right. It can be seen in both examples that the infilled areas have varied depths, clearly showing an interpolation process being applied as intended.

A further terrain modification has been noted as being required on the corner of Smithfield Road and Gatehouse Drive, where a large multi-storey building has been filtered out of the model input DEM incorrectly. Elevated floor levels and a brick wall are understood to be present and therefore a z-shape will be needed to block out the building in the model terrain. The impact on model results were expected to be minor and localised only to the immediate area.

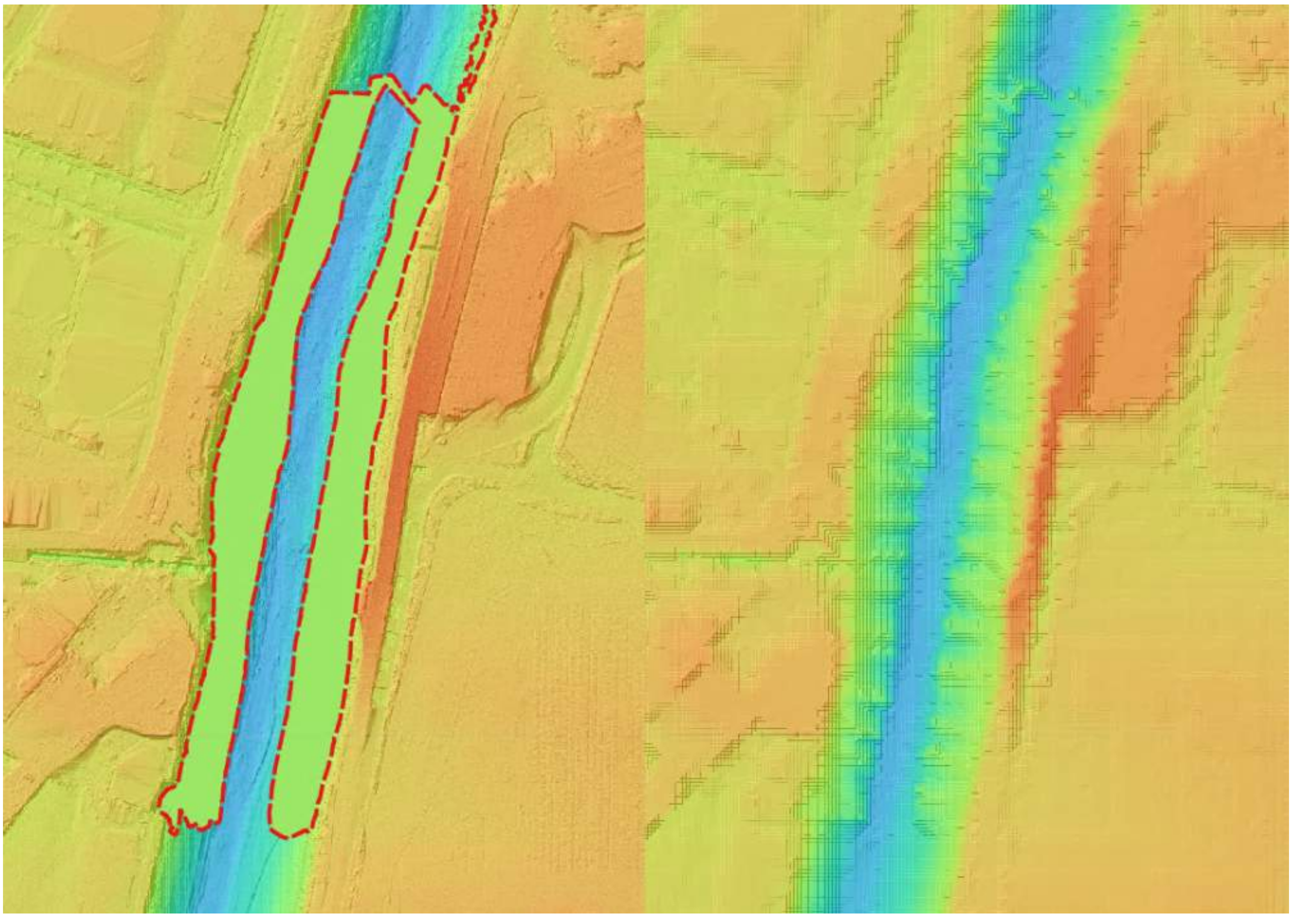


Figure 6-5: An example of a terrain modification within TUFLOW located south of Footscray Road. The area for modification is marked by the red dotted line. Left: the pre-modification raw DEM. Right: the DEM_Z as processed by TUFLOW.

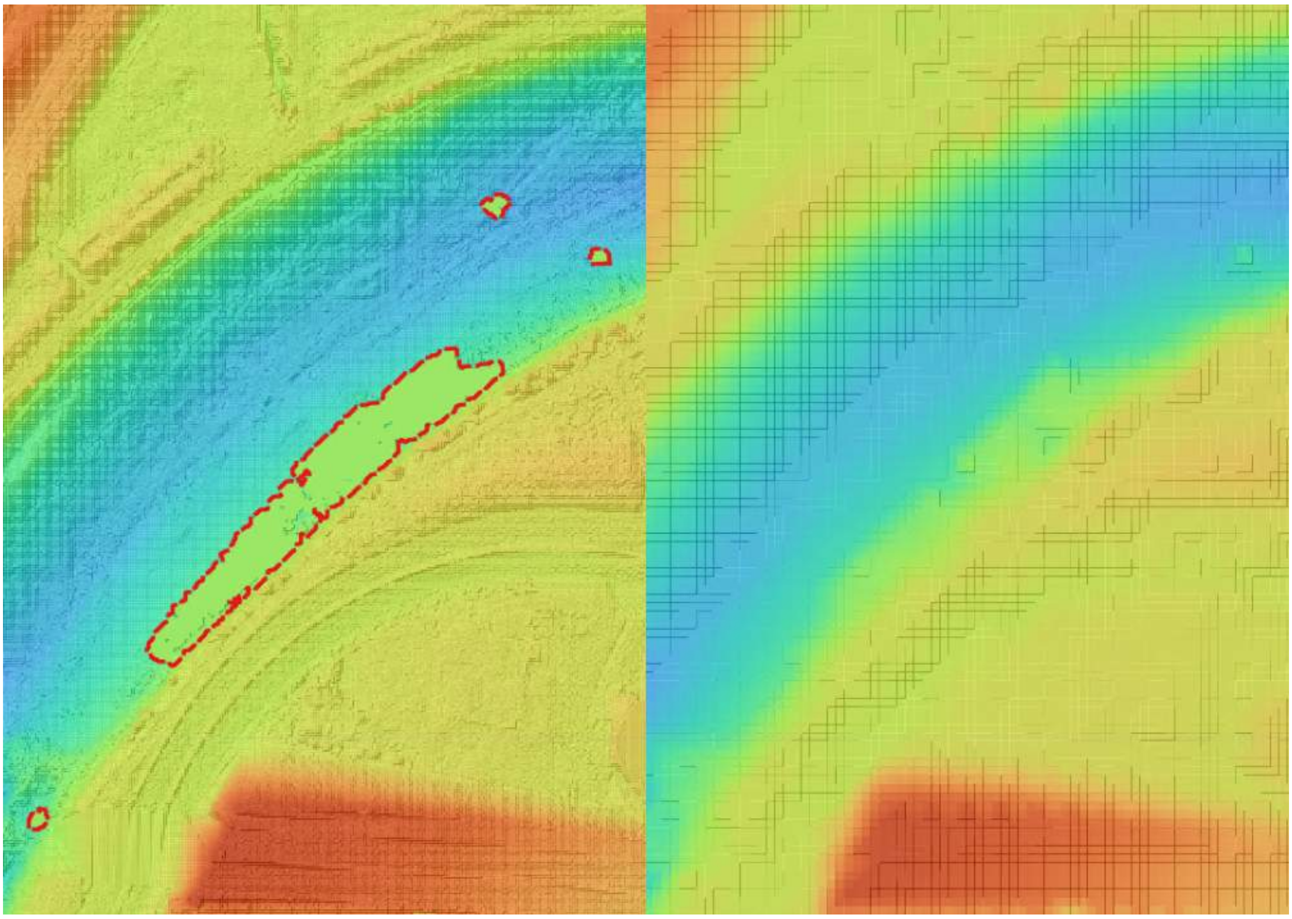


Figure 6-6: An example of a terrain modification within TUFLOW located north of Dynon Road bridge. The areas for modification are marked by red dotted lines. Left: the pre-modification raw DEM. Right: the DEM_Z as processed by TUFLOW.

Additional modifications included:

- Ensuring a small brick wall is represented at the entrance to the VRC stables on Smithfield Road.
- Adjustment to the DEM for the vehicle access on the corner of Smithfield Road and Gatehouse Drive.

These modifications are expected to not influence model calibration but were added to the model both for completeness and due to the relevance to larger design events (1% AEP and higher).

6.5 Boundaries

The hydraulic model boundaries apply water to the model and remove water from the model. In the Lower Maribyrnong TUFLOW model, three types of boundaries, as shown in Figure 6-1, have been used:

- Upstream inflow boundaries on the Maribyrnong River, Taylors Creek and Steele Creek.
- Downstream boundaries to remove water from the model.
- Distributed inflows, representing lateral inflows from land draining to the river typically through adjacent drainage such as Melbourne Water main drains.

Only the Maribyrnong River inflow was considered in the calibration of the hydraulic model given the small contributions from the other sources (Taylors Creek, Steele Creek and lateral inflows) and the short critical durations compared to the riverine catchment of the Maribyrnong River. Such lateral inflows do not contribute to the peak water levels in the river for the calibration event(s). Further details on the impact and influence of lateral inflows on flooding can be found in the Schematisation Report (Jacobs, 2023). Lateral inflows were added for completeness in design event modelling.

6.5.1 Upstream inflow boundaries

The primary upstream inflow boundary representing the Maribyrnong River was applied upstream of the Keilor gauging station for the reasons described in Section 6.2, the location of which is shown in Figure 6-1. This inflow boundary was applied as a flow time series, based on:

- Recorded discharge at Keilor for calibration, validation or verification events that have been re-rated as outlined in Section 3.4.5.
- The results from the hydrological analysis for design events.

Two additional upstream inflow boundaries for Taylors Creek (near Keilor gauge), and Steele Creek (near the Maribyrnong Defence site) as shown in Figure 6-1 were added to the model for the design events. The inflow design hydrographs were calculated in the RORB hydrological model.

As noted above, the selection of the Keilor gauge as the location of the primary upstream boundary allows for the explicit hydraulic calculation of the routing and any potential attenuation and dispersion of the flood wave. Comparison of the initial results demonstrated there was attenuation and dispersion of the flood wave as illustrated in Figure 6-7 and Table 6-1.

Two additional upstream inflow boundaries were added for the design events representing two tributary creeks: Taylors Creek (near Keilor gauge), and Steele Creek (near the defence site). Due to the mismatch in timing between the peak flow discharging from a small catchment such as the Taylors Creek catchment and the peak flow from the greater Maribyrnong catchment, the calibration was not considered sensitive to these additional inflows. They were included in the design events, as an output of the RORB hydrological model, for completeness.

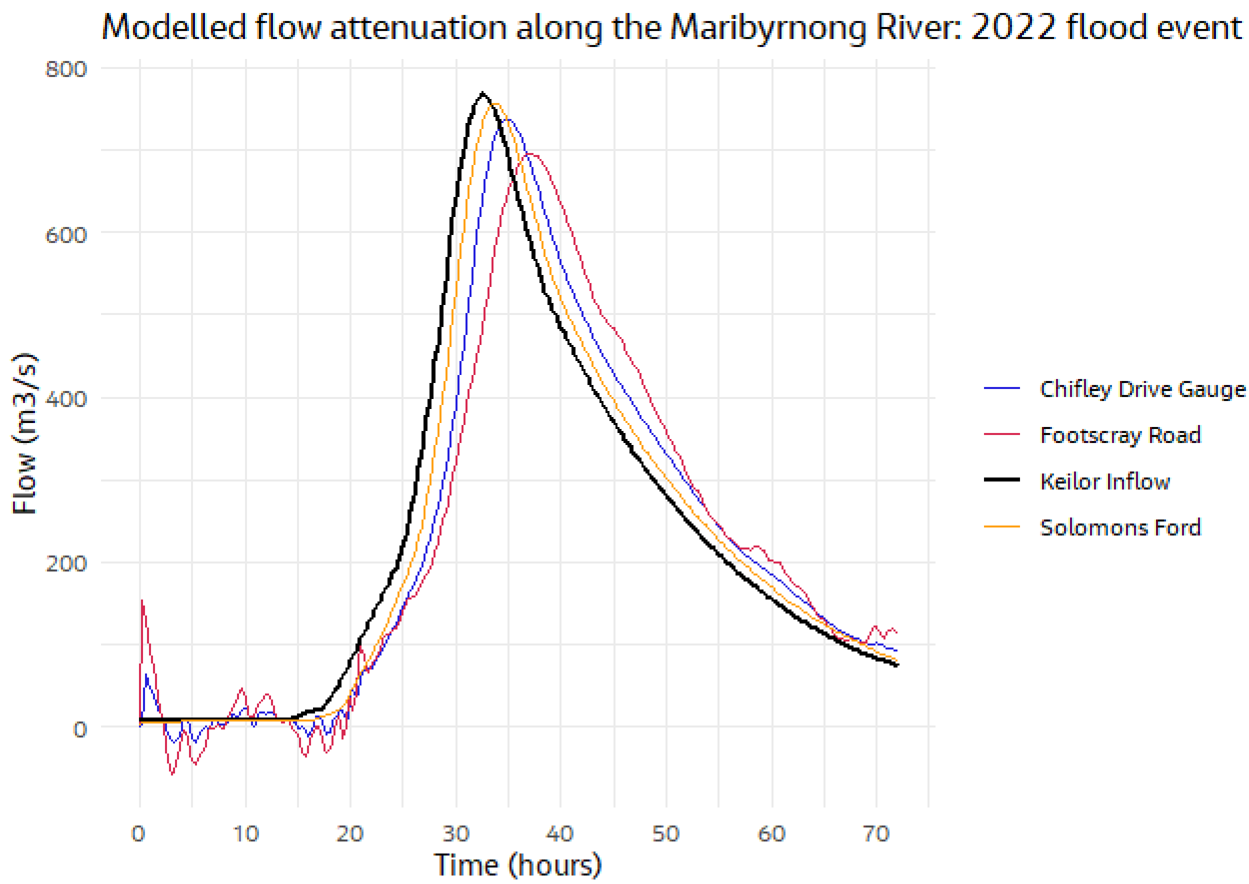


Figure 6-7: Comparison of hydrographs through the Lower Maribyrnong River demonstrating attenuation and dispersion of the flood wave from Keilor.

Table 6-1: Comparison of peak flows through the Lower Maribyrnong River demonstrating attenuation and dispersion of the flood wave from Keilor.

Location	Peak flow (m^3/s)
Keilor inflow	768
Solomons Ford	757
Chifley Drive gauge	737
Footscray Road	695

6.5.2 Downstream boundaries

The downstream boundaries were required to account for flow leaving the model domain as shown on Figure 6-1 from Maribyrnong River. Additionally, cross catchment flow from Maribyrnong River into Moonee Ponds Creek required a downstream boundary where Moonee Ponds Creek discharges into the Yarra River.

Flow through the Dynon Road Tidal Canal and overland flow from Maribyrnong River into Moonee Ponds Creek only occurs in the model in larger design events, which were larger than the 6 historical events discussed in Section 6.10. The Dynon Road Tidal Canal is the flow path between the rivers up to a certain level, beyond which water spills out into the surrounding rail yards.

The downstream boundaries into the Yarra River are represented as tidal water levels and were modelled as:

- Dynamic (level varying with time) boundaries for calibration and validation events.

  - More accurately model the water levels in the lower part of the model.
  - Captures the water level variation at Chifley Drive gauge.
- Static water level for design events (design events).
  - Slightly high (conservative) water level in the lower part of the model.

The rationale behind the tidal boundary levels adopted for each of the calibration, validation, verification and design events is detailed in Section 5.

6.5.3 Distributed inflows

The distributed inflows represent the catchment runoff that flows directly into the Maribyrnong River not via one of the modelled tributaries. These are delineated into segments as per the RORB sub-catchments. These areas are significantly smaller and have a shorter time of concentration than the larger Maribyrnong catchment. As such the modelled flow peaks for these sub-catchments occur early in the model run compared to the inflow hydrograph peak at Keilor. Due to this time delay, the modelled peak flood level is not sensitive to these inflows. For this reason, these distributed flows were not included in the calibration or validation events. For completeness, the distributed inflows have been included in the design model runs. These flows were applied as 2d_SA boundaries which distribute the inflow to an area (or polygon) in the model.

6.6 Initial water levels

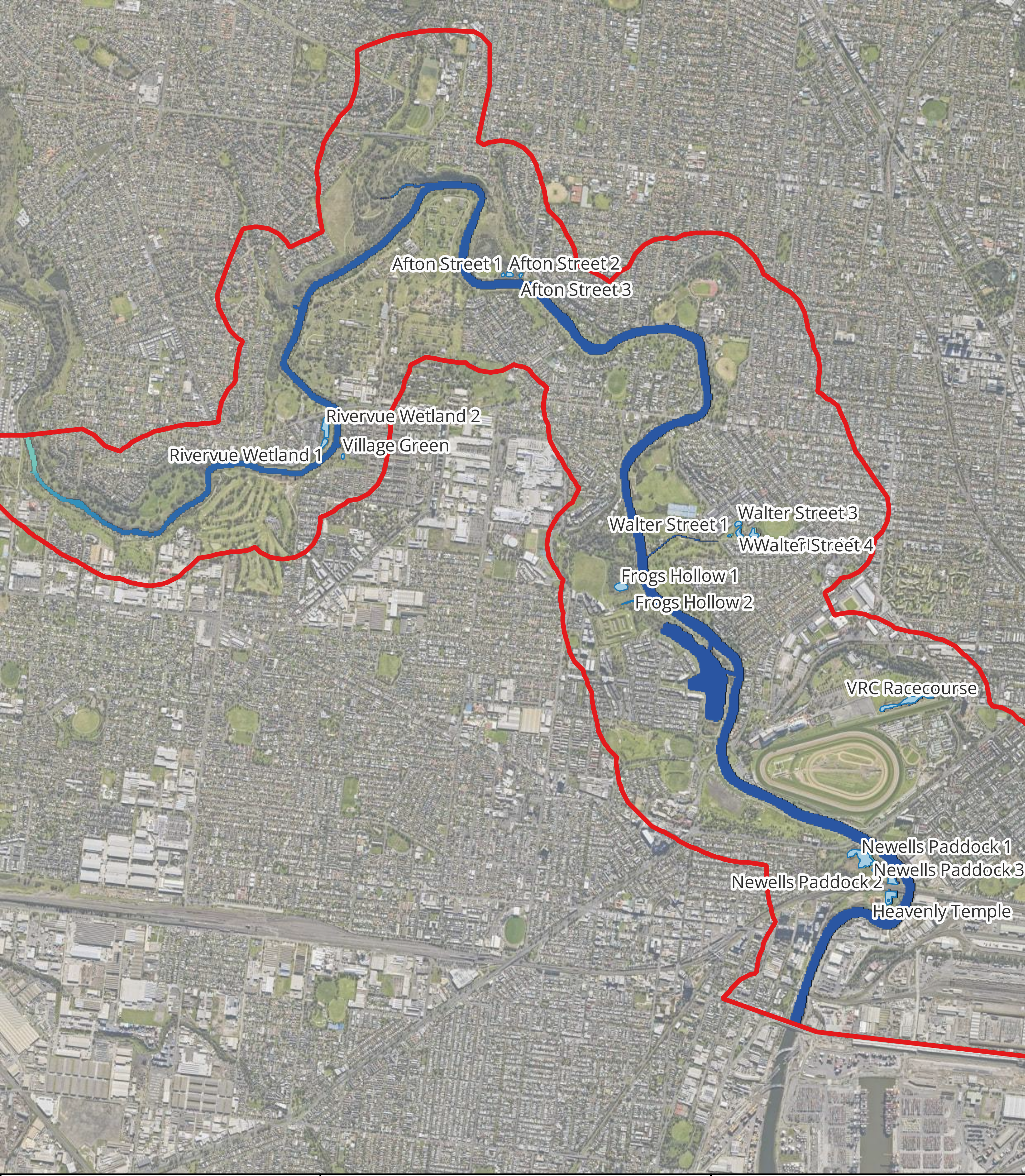
Initial water levels (applied to the Maribyrnong River channel) were set as the water level prior to the inflows being added at Keilor and other locations.

A number of 2D initial water levels were applied where permanent water bodies exist, including lakes and wetlands. As formal water level data was not available, the initial water level of the model's waterbodies was set using engineering judgement to fill storages but not cause them to start spilling. The 2D initial water levels applied are listed in Table 6-2.

Locations for initial water levels used for calibration are shown in Figure 6-8. The validation and design events each have an initial water level which corresponds to the tidal levels observed in the historical events or the design tide level, respectively. These water levels varied through the river to represent the sloping water surface and the downstream boundary initial water level for each historic and design event are listed in Table 7-1.

Table 6-2: Initial water levels in the wetlands represented within the TUFLOW model.

Location	Initial Water Level (m AHD)	Description
Rivervue Wetland 1	3.00	Southernmost wetland of the 2 wetlands at the western, low-lying, end of the Rivervue development.
Rivervue Wetland 2	2.75	Northernmost wetland of the 2 wetlands at Rivervue
Village Green	9.50	Wetland in the park opposite the Rivervue development, on the steep side of the river.
Afton Street 1	2.00	Westernmost wetland of the 3 wetlands near the river in Afton Street Conservation Reserve
Afton Street 2	2.00	Middle wetland of the 3 in Afton Street Conservation Reserve
Afton Street 3	1.75	Easternmost wetland of the 3 in Afton Street Conservation Reserve
Walter Street 1	0.75	Westernmost, and smallest, of the 4 wetlands in Walter Street Reserve, by the Ascot Vale Main Drain.
Walter Street 2	0.75	Middle of the 4 wetlands in Water Street Reserve
Walter Street 3	1.00	Northernmost of the 4 wetlands in Water Street Reserve
Walter Street 4	1.25	Easternmost of the 4 wetlands in Water Street Reserve
Frogs Hollow 1	1.50	The large circular wetland at the southern end of Frogs Hollow, just north of Jacks Magazine
Frogs Hollow 2	1.50	The thin rectangular wetland at the southern end of Frogs Hollow
VRC Racecourse	0.35	The wetland at the north-east corner of Flemington Racecourse
Newells Paddock 1	0.80	The northernmost wetland of the 3 wetlands at Newells Paddocks Wetlands Park, just north of Kensington Railway Bridge.
Newells Paddock 2	0.80	The middle wetland of the 3 at Newells Paddocks Wetlands Park
Newells Paddock 3	0.00	The southernmost wetland of the 3 at Newells Paddocks Wetlands Park
Heavenly Queen Temple	0.40	The wetland next to the Heavenly Queen Temple, just south of Kensington Railway Bridge.



Legend

Mapping extent

Wetlands

Initial Water Level (m AHD)

0.0

0.5

1.0

1.5

MGA Zone 55

0 1 2 km

Jacobs

Figure 6-8: 2022 calibration event initial water level raster and locations of wetlands and lakes with initial water levels applied

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6.7 Infrastructure

This section provides details of the infrastructure input to the hydraulic model.

6.7.1 Bridges

All bridges on the Maribyrnong River within the model boundary were surveyed in detail as described in Section 3.9.1, with the list of bridges presented in Table 6-3 and Figure 6-9. The completed survey scans have the benefit of capturing a high level of detail, with the point cloud size ranging from 25-110 million points per bridge depending on the size and scale of the structure. Photographs of bridges are in Appendix E.

Bridges were modelled as Layered Flow Constrictions, with inputs based on detailed bridge survey scans collected for the purpose of this project. Bridge abutments were added to the TUFLOW model via the use of 2D z-shape polygons where these were missing from the model input DEM.

As of TUFLOW release 2023-03-AB a new bridge modelling approach was made available – Method D. This is the result of a research project between Queensland Department of Transport and Main Roads (DTMR) and BMT (BMT 2023). The method requires the following inputs:

- Pier_pBlockage = The percentage blockage of the pier Layer which will be calculated from the bridge survey data.
- Pier_FLC = Pier layer form loss coefficient which was calculated based on the Brady (1978) "Hydraulics of bridge waterways".
- Deck_Soffit = The elevation of the bridge soffit from bridge survey data.
- Deck_Depth = The thickness of the bridge deck from bridge survey data.
- Deck_Width = The bridge width in the predominant direction of flow from bridge survey data.
- Deck_pBlockage = The percentage blockage of the deck layer. The majority of the bridge decks were a solid bridge deck obstruction and therefore have a value of 100%.
- Rail_Depth = The depth of the guard rail layer from the bridge survey.
- Rail_pBlockage: The percentage blockage of the rail layer from the bridge survey.
- SuperS_FLC: The combined form loss coefficient for the deck and the rail layers. Two layers are treated as a single "super structure" layer in this new bridge method. This was obtained from Table 2 (Collecutt et al. 2022) where the form loss is based on the ratio of the height of the bridge deck (h_b) to bridge deck thickness (T) (h_b/T).
- SuperS_IPf: The inflection point (IP) at which the transition from pressure flow to drowned flow commences. The default value of 1.6 was used.

The parameters and details used in the hydraulic model are listed in Table 6-3.

Pier loss coefficients

The pier loss coefficient was initially calculated using the methodology described in Bradley (1978) which was used as the starting point for modelling calibration. For Lynches Bridge Bradley's dual bridge theory was used to calculate the losses for the downstream set of piers as described by Thorne et al. (2023). As the pier loss coefficient calculation outlined by Bradley is essentially an empirical relationship, it is good practice to calibrate this parameter where there is available calibration data such as for the October 2022 flood event on the Maribyrnong River. Only the pier loss coefficients coloured light blue in Table 6-3 were adjusted through the calibration process.

Table 6-3: Bridge data and loss coefficients from upstream to downstream.

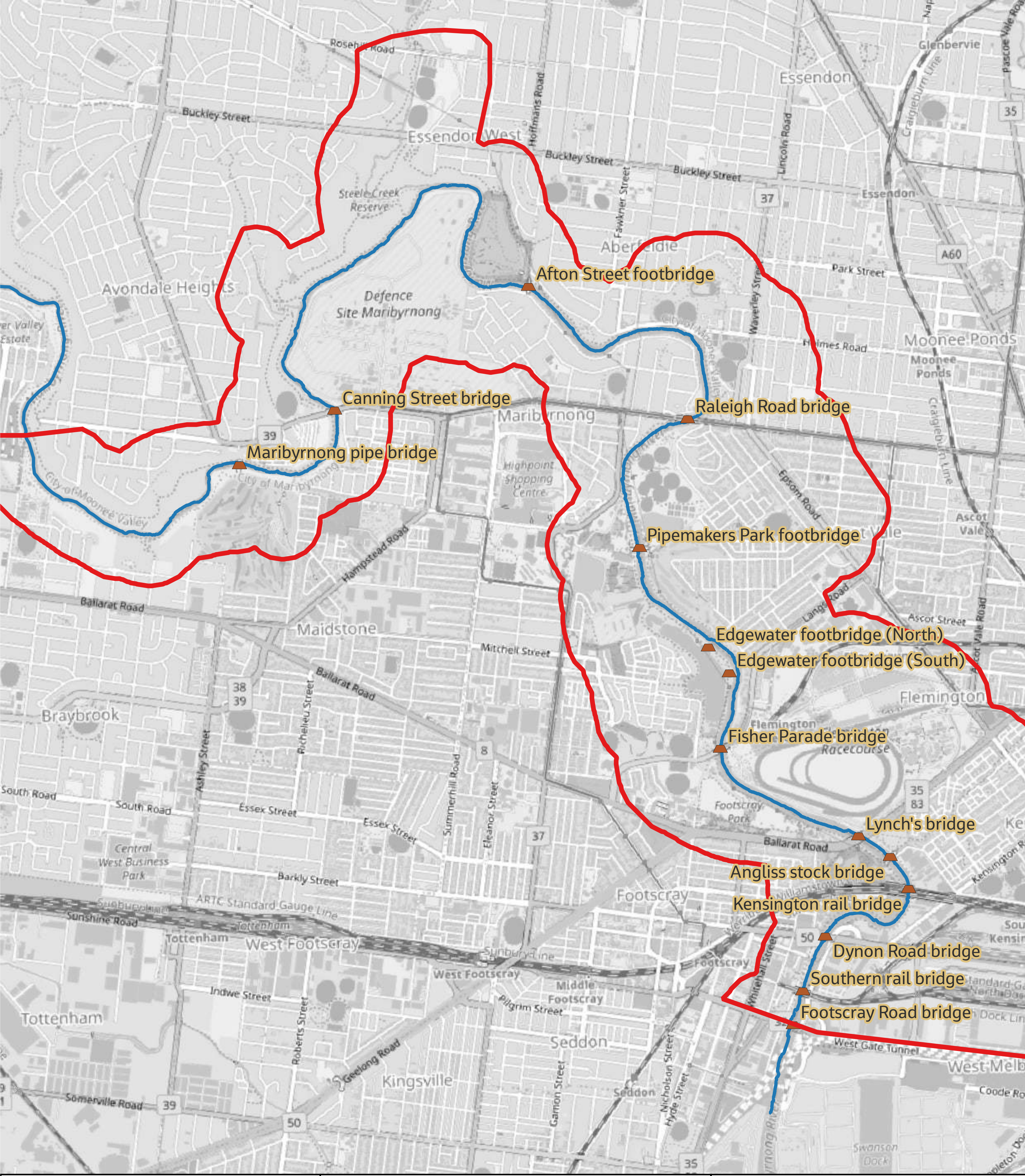
Bridge	Pier type	Pier skew to flow	Pier loss coefficient (Pier_FLC)	Deck engaged in 2022 event	Deck loss coefficient (SuperS_FLC)	Abutments added to model
Maribyrnong pipe bridge	Strip	None	0.05	Yes	0.2	
Canning Street bridge	Strip/circular combined	None	0.08	No	0.2	
Afton Street pedestrian bridge	Circular	N/A (piers not in channel)	0.01	Yes	0.2	
Raleigh Road bridge	Circular x2	None	0.54	No	0.2	
Pipemakers Park footbridge	Strip/circular combined	N/A (piers not in channel)	0.05 around piers 0 otherwise	Yes - ends only (curved deck)	0.2 in middle 0.27 around piers 0.3 at low ends	
Edgewater footbridge (north)	N/A (no piers)	N/A (no piers)	0	Yes	0.34	1 abutment added to each end of bridge
Edgewater footbridge (south)	N/A (no piers)	N/A (no piers)	0	No	0.2	1 abutment added to each end of bridge
Fisher Parade bridge	Strip/circular combined	None	0.15	No	0.2	1 abutment added to western end
Lynchs Bridge north	Strip	None	0.06	No	0.21	1 abutment added to each end of bridge
Lynchs Bridge south	Square x5	None	0.047*	No	0.28	1 abutment added to each end of bridge
Angliss Stock Bridge	Circular x2	None	0.07	No	0.2	
Kensington Rail Bridge north	Strip/circular combined	18° (1 pier only)	0.1	No	0.35	1 abutment added
Kensington Rail Bridge mid	N/A (no piers)	N/A (no piers)	0	No	0.2	2 abutments added
Kensington Rail Bridge south	Circular x5	None	0.1 in channel 0 between 0.07 by culverts	No	0.28 in channel 0.42otherwise	

Bridge	Pier type	Pier skew to flow	Pier loss coefficient (Pier_FLC)	Deck engaged in 2022 event	Deck loss coefficient (SuperS_FLC)	Abutments added to model
Dynon Road bridge	Square x2	None	0.23	No	0.2	
Bunbury St Rail Bridge	Strip	None	0.11	No	0.2	
Footscray Road bridge north	Strip	None	0.11	No	0.2	1 large concrete abutment added to each end of bridge 1 small bluestone abutment on west edge of channel
Footscray Road bridge south	Strip	None	0.03 at edges 0.0 in channel	No	0.2	
Kensington Road Bridge North**	Strip	None	0.09	No	0.3	
Kensington Road Bridge South**	Strip	None	0.03*	No	0.3	

*Note: Bradley's dual bridge theory used to lower downstream bridge pier losses from stand-alone value of 0.14 to ~0.05.

** Kensington Road Bridges Incorporated post calibration for completeness. Is assumed will not impact calibration. A 3rd Kensington Road Bridge is present but was not included as it does not have piers in the flow path and the super structure well above the 1% AEP event.

Blue pier loss coefficients determined through calibration.



Legend

- Mapping extent
- Bridge locations
- Maribyrnong River

MGA Zone 55

0 1 2 km

Jacobs

Figure 6-9: Locations of bridges modelled as layered flow constrictions in the TUFLOW model

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6.7.2 Underground drainage networks

Only pipes that are likely to be affected from the Maribyrnong River have been modelled, with the local pipe network only considered by exception. This means that only pipe networks that can backflow and inundate low lying areas, such as around Ascot Chase and Kensington Banks have been included, along with key culverts that interact with flood events.

For the parts of the drainage network that have been included in the TUFLOW model, the Melbourne Water and council pipe and pit networks have been represented as a 1d_nwk, dynamically linked to the 2D model domain. As noted in Section 3.9, the existing TUFLOW model network from the Moonee Valley Council Flood Mapping model was reviewed and utilised given the 1d_nwk data was deemed suitable.

Key elements of the model pit and pipe network are:

- Only pipes that had the potential to cause inundation from the Maribyrnong River through backflow have been included in the TUFLOW model.
- Pits have been modelled as 'Q' Type and based on a set of standard depth-discharge curves except for junction pits.
- Junction pits are not connected to the 2D domain.
- Standard pipe entry and exit coefficients have been applied and the Engelund loss approach to manholes adopted.

The three areas of the model where the underground drainage network was required to be included according to the above approach were:

- Rivervue Estate as shown in Figure 6-11.
- Aberfeldie Main Drain as shown in Figure 6-12.
- Ascot Vale Main Drain as shown Figure 6-13.

Note that underground drainage data for Kensington has not been incorporated in the current version of the model but may be incorporated into future versions.

The following culverts were included in the model:

- The culvert under Buckley St where Steele Creek flows into Maribyrnong River.
- The culverts under Farnsworth Ave immediately west of the river.
- Three culverts along the South-West – North-East orientated drain that runs parallel to the VRC wall.
- The drain that connects Riverside Park in Kensington Banks to Maribyrnong River has been represented as a 1.2m diameter culvert through the embankment around the park with an intake elevation of 1.5m AHD and a discharge (into the park) elevation of 0.9m AHD. See Section 6.7.2.1 for more information on this piece of infrastructure.
- The culverts under the Footscray Rail embankment and the minor balancing culverts immediately downstream.
- Pedestrian and car tunnels through the concrete embankment associated with Footscray Road bridge are represented as culverts, however these are not materially engaged during any of the modelled flood events.

6.7.2.1 Riverside Park underground drainage

As noted above, there is an underground drain connecting the Maribyrnong River with Riverside Park. Observations from the October 2022 Maribyrnong flood event demonstrate that inundation into the Kensington area was through this drain. For this reason, further details were sought of this pipe and the Riverside Park levee.

Prior to the receipt of these details the model was calibrated with an assumed set up as described above in Section 6.7.2. This representation produced flood extents through Kensington Banks that was consistent with site observations during the 2022 event.

Details of this pipe were recently obtained, including design drawings and a maintenance report from the City of Melbourne (see Appendix O), along with a survey conducted by the Jacobs survey team. However, there was conflicting information with the City of Melbourne plans and the Hobsons Road Trash Rack maintenance report that was not able to be clarified by the survey team due to high water levels in the pipe. For this reason, the actual layout of the pipe under the embankment is unclear. The pipe consists of two segments, with an overflow grate where they join, shown in Figure 6-10, together with a flap-gated valve which is understood to prevent flows from the river backflowing into the park. The large grate on the park-side of the embankment presumably exists to drain water out of the park rather than to allow water in.

Figure 6-10: The pipe under Riverside Park levee in green, with the overflow pit and the discharge pit marked in red. The high point of the levee is marked by the dirt path.

The invert of the obvert of grate in Riverside Park is approximately the 0.9m AHD and would allow the ingress of water from the river during high tides. It is reasonable to assume that the purpose of the flap-gate is to prevent this water ingress. However, since inundation was experienced in Kensington Banks during the 2022 event it is assumed that this flap-gate may not be functioning as intended and did not prevent ingress of river water, or an alternate flow path was found.

It is recommended that the functionality and intended purpose and operation of this flap-gate is further investigated through a comprehensive investigation, which would likely require dewatering, and any additional records sought from the City of Melbourne if possible.

In the current modelling, the setup of this pipe (as described in Section 6.7.2) has been retained, which contradicts some of the additional information that was later made available. The consequence of this assumption is that for events below the 1% AEP with a tidal boundary level greater than 0.9m AHD (i.e. all scenarios with a sea level increase), the sole source of flooding through Kensington is the flap-gate which is assumed does allow tidal inundation. For events equal to and greater than the 2% AEP flow paths develop between Smithfield Road and Kensington, initially through the Hungry Jacks carpark and the carpark behind 13 Smithfield Road. For events equal to and greater than the 1% AEP, flood levels exceed the level of the levee around Riverside Park causing general inundation from the river water.

Sensitivity of this infrastructure was tested under the 2022 calibration event, the results of which are shown in Section 8.6.

Legend

Pipe network

- Rectangular pipe
- Circular pipe

Pits

- Junction/Node pits
- Grates/Side entry pits

MGA Zone 55

0 25 50 75 100 m

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Figure 6-11: TUFLOW model 1D drainage network (Rivervue Estate)

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Figure 6-12: TUFLOW model 1D drainage network (Aberfeldie Main Drain)

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Figure 6-13: TUFLOW model 1D drainage network (Ascot Vale MD)

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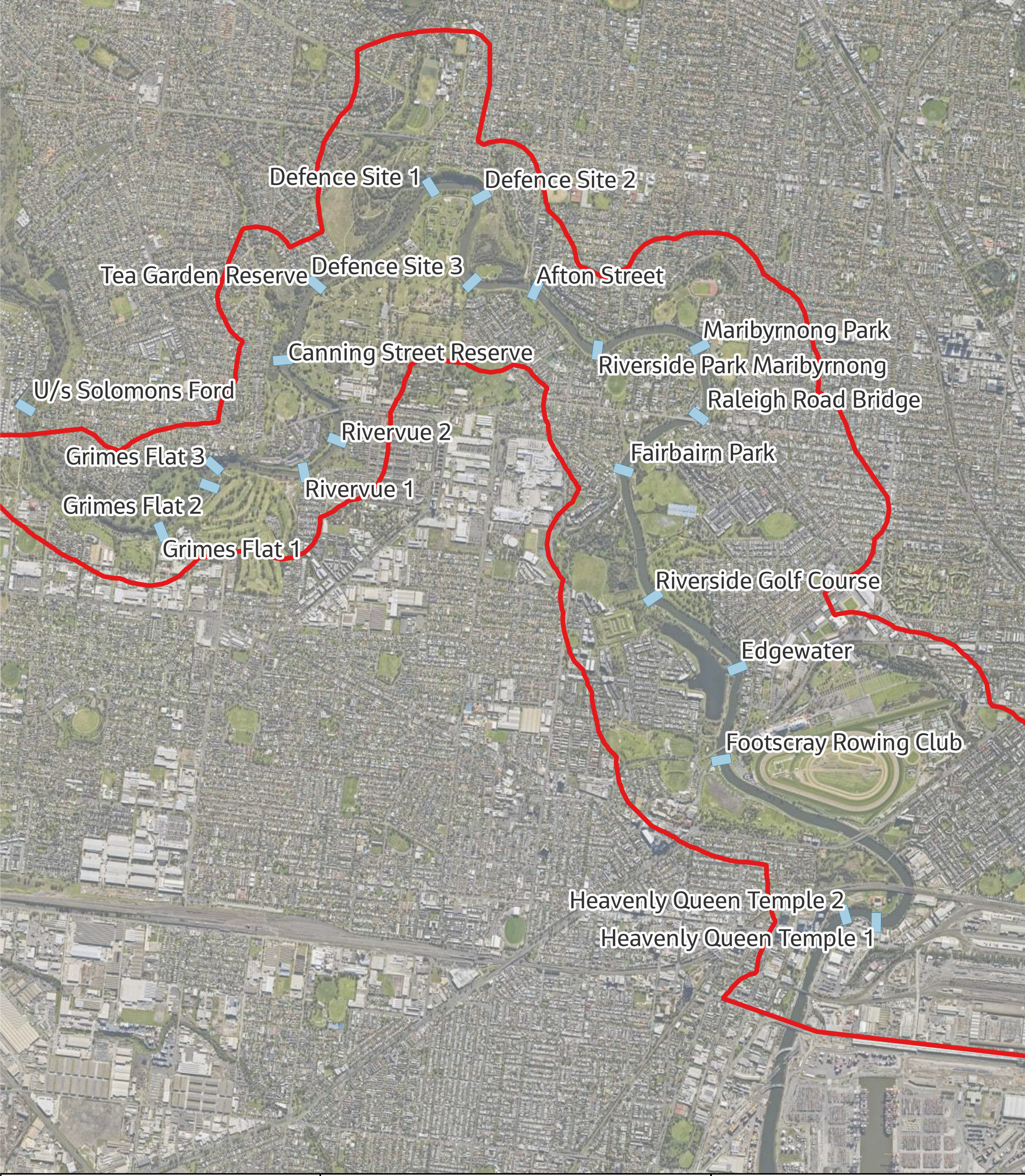
6.8 Bend losses

While 2D hydraulic models, such as the Lower Maribyrnong hydraulic model, do account for hydraulic or energy losses as water flows around bends in 2D and super elevation they do not account for energy losses in the vertical such as helicoidal circulations (Syme, 2015). Hence it is necessary to add additional energy loss at significant bends in the river channel, which are referred to as Bend Losses.

Bend losses were initially applied using the values from Syme (2015); 0.1 for a 45° bend to 0.4 for a 180° bend with values in between calculated by linear interpolation. These values were calibrated with values allowed to change by +/-20%. Table 6-10 provides the calibrated bend losses adopted in the model. These values were checked against a more recent publication from Syme (2021); 0.05 (45°) to 0.15 (90°) to 0.3 (180°).

The location of where bend losses were applied are shown in Figure 6-14.



Legend

Mapping extent

Bend losses

MGA Zone 55

0 1 2 km

Jacobs

Figure 6-14: Location of bend losses

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6.9 Manning's values

The land use information detailed in Section 3.8 was used to create a Manning's roughness (materials) layer, illustrated in Figure 6-15. Table 6-4 shows the standard Manning's values used as the starting point for the calibration as well as the typical range. These values have been obtained from standard text and guidelines such as:

- Chow (1959).
- Australian Rainfall and Runoff reference Table 6.2.2 – note Table 6.2.2 has been preferred over Table 6.2.1. as the latter is for 1D. (Ball et al, 2019).
- Melbourne Water Technical Specification (2023).

Manning's values were the main calibration parameter, as discussed in the hydraulic model calibration section (Section 6.10) which also contains the final parameter values determined through the calibration process.

Table 6-4: List of Manning's values ranges and starting values.

Material number	Description	Manning's value (typical value / starting point)	Typical range
1	Industrial/commercial	0.35	0.20 - 0.50
2	Open pervious areas – minimal vegetation (grass)	0.045	0.03 – 0.05
3	Open pervious areas – moderate vegetation	0.06	0.05 – 0.07
4	Open pervious areas – minimal vegetation (mowed grass)	0.03	0.03 – 0.05
5	Open pervious areas – sand/gravel/dirt	0.06	0.05 – 0.07
6	Open pervious areas – thick vegetation (trees)	0.07	0.07 – 0.12
7	Residential – urban (property parcel)	0.08	0.08 – 0.12
8	Railway line	0.10	0.05 – 0.20
9	Paved surfaces - other	0.025	0.02 – 0.03
10	Paved surfaces - roads	0.025	0.02 – 0.03
11	Wetlands (emergent vegetation)	0.07	0.05 – 0.08
12	Lakes (no emergent vegetation)	0.07	0.015 – 0.35#
13*	Estuaries/Oceans	0.03	0.02 – 0.04
15-21	Waterways/channels	0.03 – 0.05	0.02 – 0.10
22	Road easements/verges	0.03	0.02 – 0.12
23	Building footprints	0.40	0.20 – 0.50

* Value 14 was not used in the final Manning's classification layer due to consolidation of land use types.

The range stated in ARR19 and the Melbourne Water Technical Specifications is between 0.015 and 0.35, however, in our opinion the 0.35 value is a typographic error and should be 0.035. This means that the modelled value of 0.07 is outside of the acceptable range and will need to be adjusted in the next revision. It is unlikely that this change will have a significant impact on the modelled results presented here.

6.9.1 Channel Manning's values

Through multiple site visits (refer Section 3.10), the team's existing local knowledge and review of previous studies including GHD (2003) it was concluded that varying channel Manning's would be a reasonable approach. Review of the photos in Table 6-5 from upstream to downstream demonstrates the change in channel characteristics throughout the reach. The most upstream reach from Solomons Ford to Canning Street Bridge is a natural channel which gradually changes to an engineered channel in the lowest reaches near the confluence with the Yarra River. In addition to the nature of the channel changing, the physical dimension clearly increases in the lower reaches. This information indicates the channel in the upper reaches is rougher and more tortuous suggesting a higher Manning's values and smoother with few bends in the lower section suggesting a lower Manning's value.

The photos in Table 6-5 demonstrate that the physical characteristics of the Lower Maribyrnong River dictate that the Manning's values should be varied through this channel. This was further supported by the sensitivity analysis of Manning's values presented in Section 8.5.

Table 6-5: Change of channel characteristics from upstream to downstream of the Lower Maribyrnong River.

Channel reach	Photo	Comments
Solomons Ford to Canning St Bridge (Channel 18)		Between Solomons Ford and Cannings Street Bridge Manning's = 0.042
Canning St Bridge to Afton St Bridge (Channel 17)		Across to Old Maribyrnong Defence Site Manning's = 0.035

Afton St Bridge to Fisher Bridge (Channel 16)		Looking downstream from Afton Street Bridge Manning's = 0.030
Fisher Bridge to D/S boundary (Channel 15)		Looking upstream towards Footscray Road Bridge Manning's = 0.023

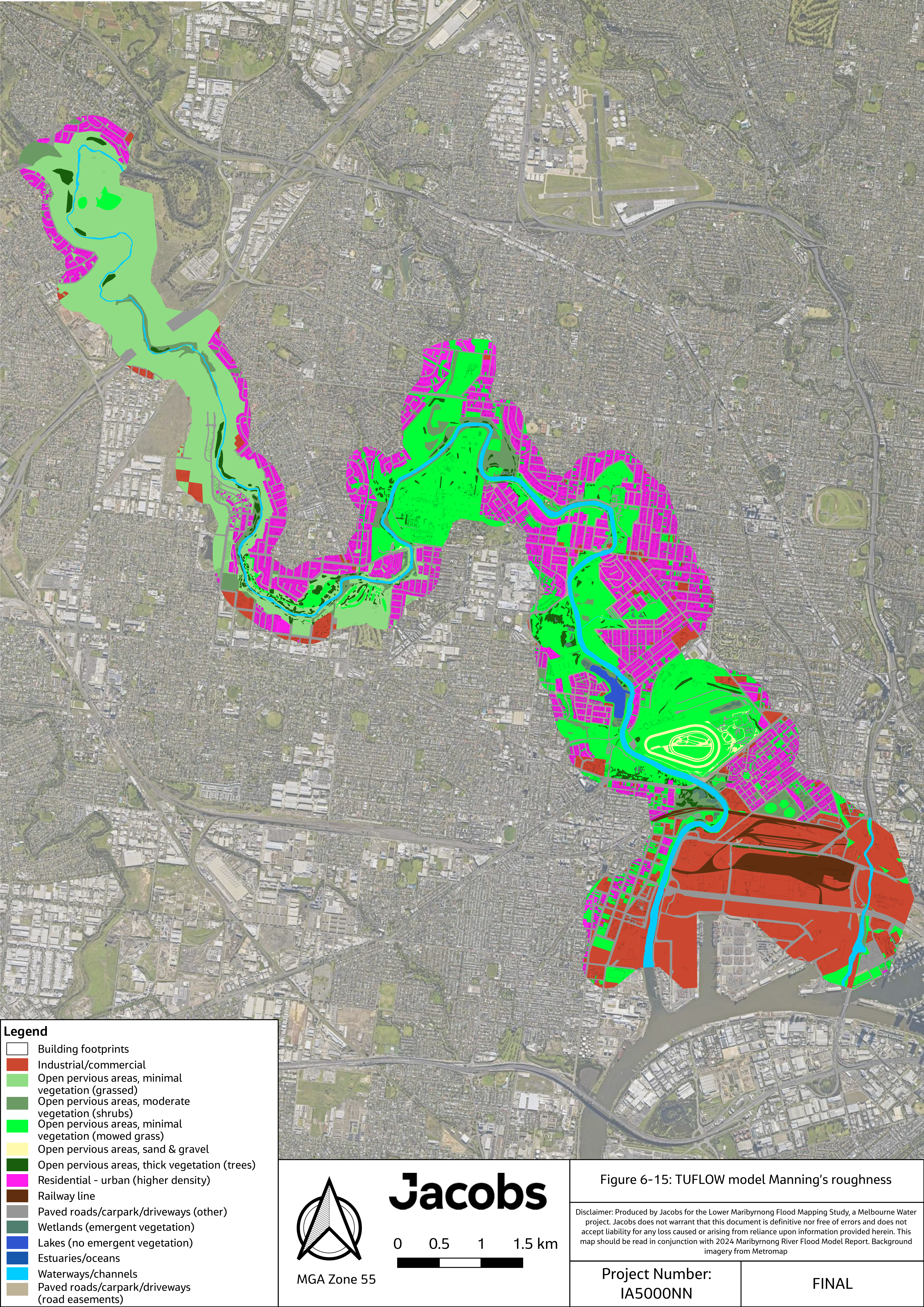

Figure 6-15: TUFLOW model Manning's roughness

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6.10 Calibration and Validation

The hydraulic model of the Lower Maribyrnong River is fundamentally a numerical representation of the river and its floodplain. In the model, these physical relationships include a number of model parameters which together with the underlying mathematical relationships produce the model results. While the model parameters have a basis ether through experimental determination or modeller experience, they should be adjusted to match observed flood data for a given event such as the October 2022 event. This process of adjusting the model parameters is referred to as model calibration, that is, model parameters are adjusted until an acceptable match to observed flood data is achieved. Where flood data exists, it is essential that model calibration is performed.

For the Lower Maribyrnong River, calibration, validation and verification strategy was undertaken. This involved applying the recorded hydrograph at Keilor to the hydraulic model for each of the identified events in Section 6.10.1 and adjusting parameters for the calibration or evaluating model fit for validation and verification as discussed below. For validation and verification events, the hydraulic models were altered only where there was a known change to the floodplain such as the construction of a bridge which is detailed below for each event.

This approach to calibration, validation and verification is considered to be a robust strategy to evaluate model performance, it effectively means that model parameters are first determined through calibration and then these parameters are validated through a blind test of the model. This blind test or validation event involves taking the calibrated model and applying a different historical event and comparing the results to observed flood data. If a model is calibrated and validated well it can be considered suitable for use in determining other outputs such as design flood events.

In addition to validation, model verification was also undertaken. This is similar to validation, though the observed flood data to which it is compared is not as well documented.

The calibration of the hydraulic model was undertaken in two steps. Firstly, sensitivity testing was undertaken of key parameters for calibration to identify which parameters are the most influential; this step avoided wasted computational efforts on uninformative parameters.

The next steps involved calibrating the model by adjusting the parameters determined as the most influential in the sensitivity testing until there was an acceptable match to the observed flood data.

The main calibration parameters were Manning's values for the channel followed by Manning's values for the floodplain. Bridge losses and bend loss parameters were the next most important although the influence of these was generally in the immediate vicinity of application.

6.10.1 Hydraulic model calibration events

The events to select for calibration, validation and verification were based primarily on the level of interest in the event and the available data. On this basis the 2022 flood event was selected as the main calibration event specifically as:

- This event had a significant impact on a number of areas flooded and has received significant stakeholder and community attention.
- There has been a wealth of data collected in relation to this event to calibrate the model including survey flood marks and photographs.
- The data acquisition programme has collected contemporary data to characterise the river channel and floodplain.

Review of data for the other flood events has shown that both the 1974 and 1983 events have a reasonable amount of information, however, there have been substantial changes to the Lower Maribyrnong catchment since these events as outlined in 3.9.3. Given these uncertainties in the catchment, these events were not considered to be suitable for use as calibration events and were instead used as validation (1983) and verification (1974) events. In addition, the hydraulic model was used to investigate the accuracy of the 1906 flow estimate of 880m^3/s given the age of this estimate and the uncertain method used to calculate this flow rate.

For the 1993 and 2011 flood events, the only available data were the recorded water levels at the Maribyrnong River at Chifley Drive gauge. While this is valuable information it is not considered sufficient for model calibration and these events were used as validation events.

In summary:

- The October 2022 flood event was selected as the calibration event.
- The January 2011, September 1993 and October 1983 flood events were selected as validation events.
- The May 1974 flood event was selected as a verification event.
- The 1906 flood event was verified in the hydraulic model.

6.10.2 Calibration procedure

Hydraulic model calibration was completed through both automatic and manual calibration. Automatic calibration was initially performed to understand the sensitivity of model parameters as well as the structural relationship between parameters. Once the automatic calibration was completed, this information was used to inform the manual calibration along with literature and Jacobs' experience.

The automatic calibration was completed using AutoCal (Myers, 2021) as described in Section 4.1. This automatic calibration was completed in a number of steps:

- Calibration of the Maribyrnong River Manning's values. This was prioritised as the channel Manning's roughness was considered to be the main set of calibration parameters.
- Calibration of the floodplain Manning's values.
- Calibration of bridge and bend losses.

The sensitivity of channel Manning's was initially examined to confirm, though a different line of enquiry, that varying the channel Manning's roughness values along the channel was justified.

6.10.3 Selected Calibration, Validation and Verification events

The selected calibration, validation and verification events are outlined in Section 3.4.4, these are:

- Calibration event – October 2022.
- Validation events – January 2011, September 1993 and October 1983.
- Verification event – May 1974.

6.10.4 Calibration data

A variety of calibration data was collected including observed flood marks (Section 3), recorded water levels of the Maribyrnong River at Chifley Drive gauge and available terrestrial and aerial photography. Each of these datasets (where available) have been compared to the model results, as discussed below, for each historic event.

Observed Flood Marks

Observed flood marks were obtained from a variety of sources as outlined in Section 3.6 and can be summarised as follows:

- October 2022:

  - Survey flood marks were obtained immediately following the flood. These marks were concentrated in Rivervue, around Maribyrnong Township and sporadically through Kennington. As discussed in Section 3.6, these flood marks were critically reviewed as part of this project and spurious data removed. In general, these flood marks are considered to be the most relevant.
  - Survey flood marks obtained post October 2022.
    - As part of this project flood marks following the October 2022 were also surveyed. These included debris lines and where peak levels had been noted such as the Footscray City Rowing Club.
    - Observed flood marks from photographs and videos collected during the October 2022 flood event by the project team. These photographs were examined to identify potential features where a reliable flood level could be obtained.
- January 2011:
  - There were no observed flood marks from this event. Given the minor nature of this flood it was not expected that there would be survey flood marks.
- September 1993:
  - No surveyed flood marks were available.
- October 1983:
  - Observed flood marks were available from the Melbourne Water Flood Mark database and also from the MMBW 1986 report.
- May 1974:
  - Observed flood marks were available from the Melbourne Water Flood Mark database and also from the MMBW 1986 report.

Observed flood marks are shown in Figure 6-16.

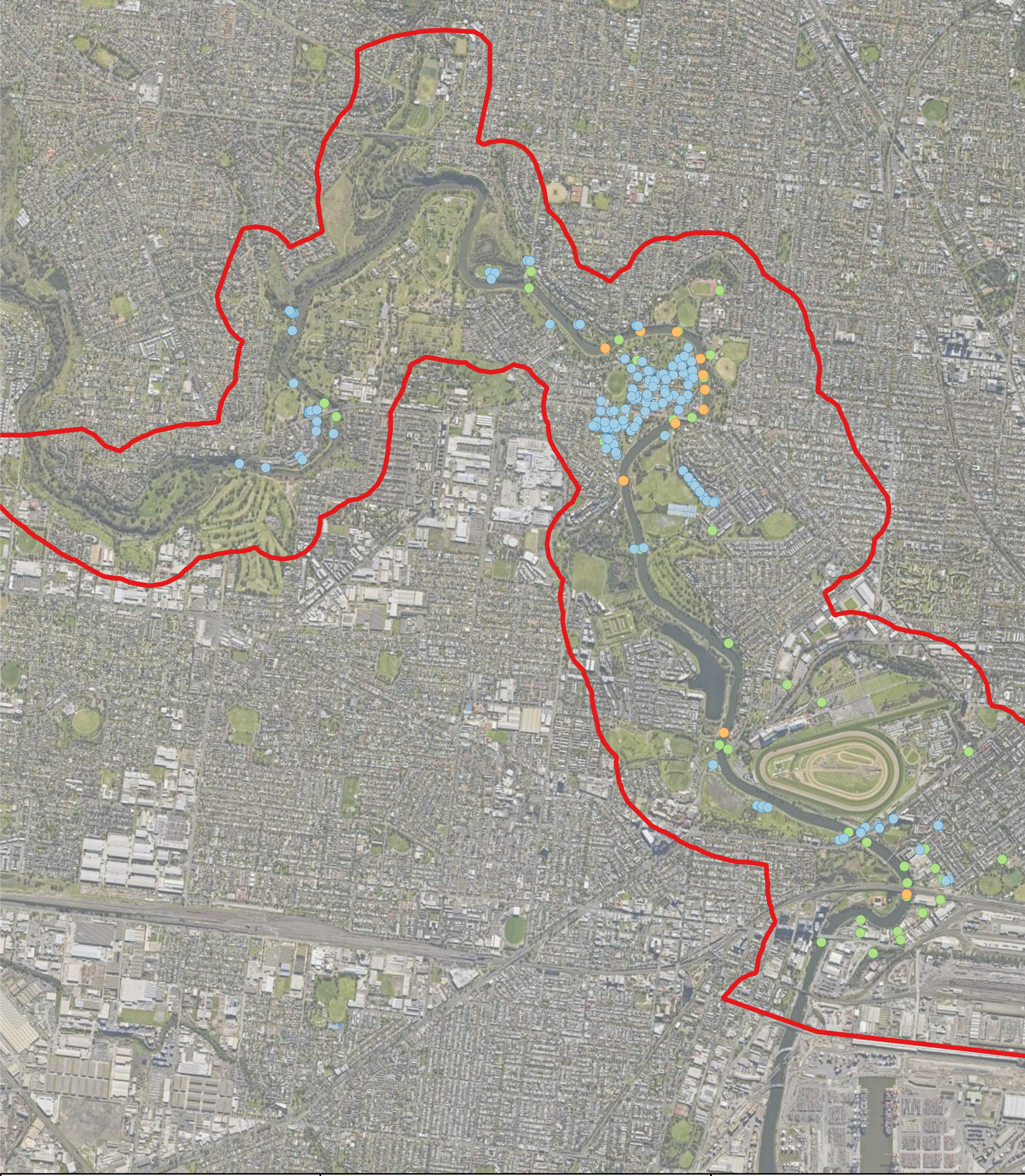
Water Level Gauges

Maribyrnong River at Chifley Drive gauge has data available from 1975, and this gauge has water level records that cover the 1983, 1993, 2011 and 2022 flood events. The 1974 event was not captured at this gauge although the peak water level at this location was recorded (this can be seen on the "Candy" pole shown in Plate 3-3). The recorded peak flows for each event are listed in Table 6-6.

In 2008 the datum of Chifley Drive gauge was altered from chart datum to AHD. This involved a change of 0.524m; hence all values prior to 2008 were reduced by 0.524m when presented in this report to allow direct comparison between recorded water level pre- and post- 2008 and model results (which are produced in m AHD).

Table 6-6: Peak levels at Chifley Drive gauge for calibration, validation and verification

Year	Level (m AHD)
2022	4.22
2011	2.21
1993	3.31
1983	2.85
1974	4.20 (MMBW, 1986)



Legend

- Mapping extent
- 2022 flood event
- 1983 flood event
- 1974 flood event

MGA Zone 55

0 1 2 km

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Figure 6-16: Location of flood marks for 2022, 1983 and 1974 events

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Terrestrial and Aerial Photography

Photography, both ground and aerial, was collected for the calibration, validation and verification events where available:

- October 2022:
  - Third parties such as news agencies, libraries etc as noted in plate and figure titles as well as photos captured by Melbourne Water and the Jacobs' project team. The majority of these were not taken at the peak of the flood event. Examples of terrestrial photography are provided in Table 6-7 and oblique aerial photography in Table 6-8.
- January 2011:
  - There were no observed photos from this event. Given the minor nature of this flood it was not expected that there would be a public record of flood photography.
- September 1993:
  - There were no observed photos from this event, while this event was large on the Maribyrnong River, there was widespread flooding throughout Victoria which dominated the news at the time.
- October 1983:
  - There were no observed photos from this event. Given the minor nature of this flood it was not expected that there would be a public record of flood photography.
- May 1974:
  - Historic flood photography was obtained from The Age archives.

It is noted that further photography, both ground and aerial, are expected to emerge through consultation with stakeholders and the community.

2022 Flood Extents from Photographs

Based on the collected photographs the extent of the October 2022 flood event was digitised. This is presented in Section 6.10.5. The majority of the information used to determine the extent of the 2022 flood event was not taken at the peak of the flood event, hence the extents are slight underestimates of the actual October 2022 flood event.

Table 6-7: Ground photos captured by team members during the October 2022 event, not taken at the peak of the event.

Location	Photo (in order of U/S to D/S)
Pipe Bridge	

Location	Photo (in order of U/S to D/S)
Rivervue	
Canning Reserve	

Location	Photo (in order of U/S to D/S)
Tea Gardens Reserve	
Maribyrnong Defence Site	

Location	Photo (in order of U/S to D/S)
Afton Street Reserve	
Afton Street	

Location	Photo (in order of U/S to D/S)
Riverside Park (Pirate Ship)	
The Blvd/ Vida St	

Location	Photo (in order of U/S to D/S)
Aberfeldie Park	

Location	Photo (in order of U/S to D/S)
Middle Rd (Maribyrnong Reserve)	

Location	Photo (in order of U/S to D/S)
Hobsons Road (Kensington Banks)	
The Crescent (Kensington Banks)	

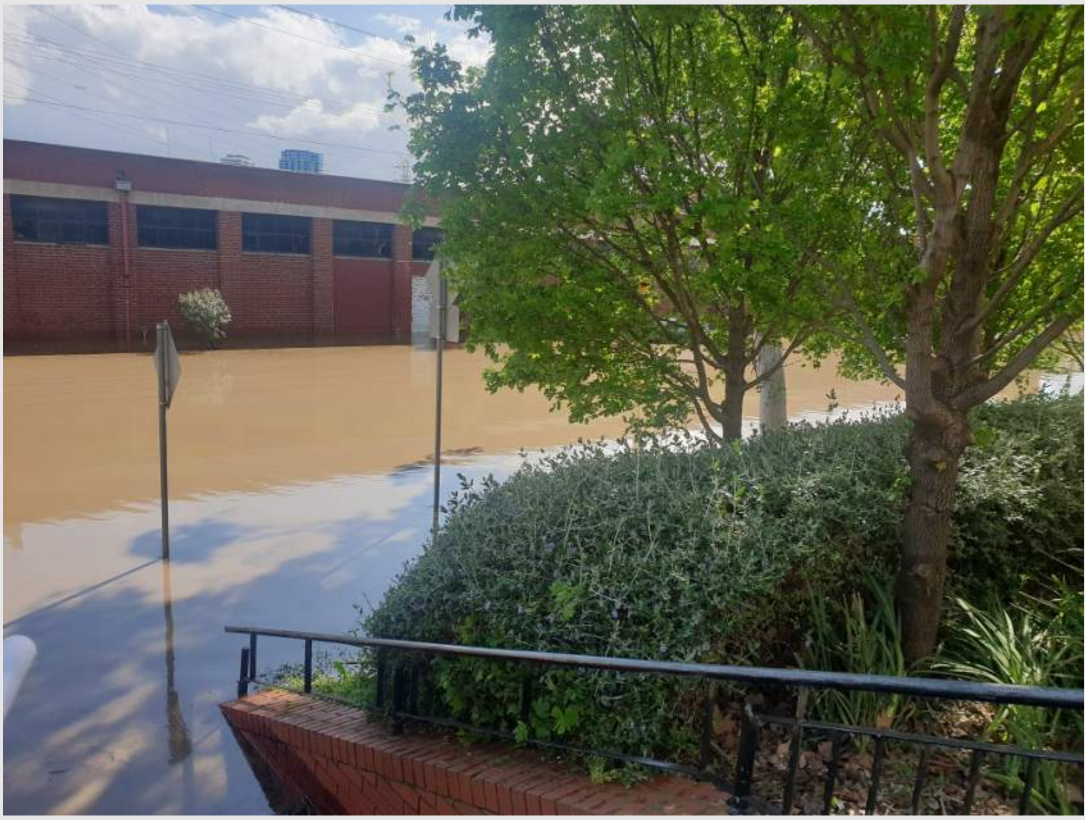
Location	Photo (in order of U/S to D/S)
Hobsons Road	
Kensington Road (JJ Holland Park)	

Table 6-8: Oblique aerial photographs obtained from Melbourne Water, not taken at the peak of the event.

Location	Photo (in order of U/S to D/S)
Maribyrnong Township, with Maribyrnong Reserve on the right, and Aberfeldie Park on the left.	

Location	Photo (in order of U/S to D/S)
Looking west up the Maribyrnong River, with Maribyrnong Park in the foreground, and the Maribyrnong Defence Site further in the distance.	

Location	Photo (in order of U/S to D/S)
Looking south down the Maribyrnong River, with Aberfeldie Park in the foreground and Fairbairn Park further in the distance.	

6.10.5 October 2022 calibration event

The Lower Maribyrnong hydraulic model for the October 2022 event has the same set up as the final design model with the following changes to reflect the configuration of the floodplain at the time of the event:

- The bridge and access ramps associated with the Westgate Tunnel project were only partially constructed at the time of the 2022 flood event. This partial construction was represented in the hydraulic model.
- The October 2022 hydrograph at the Keilor gauge was applied to the model with the flow rate being determined from the most recent rating table at Keilor (RT37.02). This hydrograph is shown in Figure 6-17.

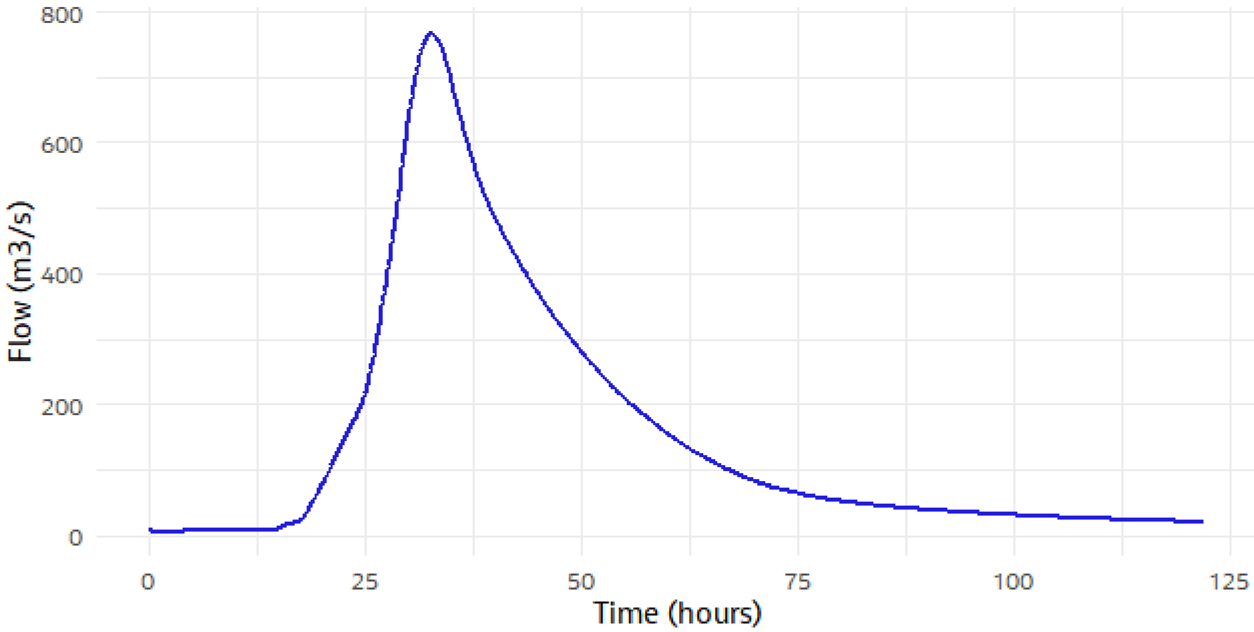


Figure 6-17: Maribyrnong River at Keilor 2022 event inflow hydrograph.

Modelling results for the October 2022 event are presented as follows:

- Figure 6-18 is a comparison between recorded and modelled flood levels at the Chiefly Drive gauge. This figure demonstrates a close agreement between recorded and modelled water level with a difference in peak levels of 41mm.
- Figure 6-19 shows a long section of the modelled peak water level compared to the observed flood marks. This figure demonstrates that the model was able to reproduce observed flood levels throughout the Lower Maribyrnong River with few exceptions. One area where the model overpredicts flood levels is around chainage 12,350m (Tea Gardens Reserve). These flood marks were determined from photographs that were not taken at the peak and hence may underpredict the actual peak and these flood marks could be considered at the minimum flood level that occurred at this location.
- Figure 6-21 shows a histogram of the difference between observed flood marks and the modelled peak water levels. The mean difference between the flood marks and the modelled results was 2mm with 73% falling within +/- 50mm and 90% falling within +/- 100mm.

  While flood marks or surveyed flood debris levels typically represent the best information regarding the height to which a flood reached, there are numerous potential errors in the collection of this data. It is therefore expected that there would be a difference between modelled flood levels, which are static water surfaces, and the observed data. It is therefore expected that scatter or a distribution about an average or mean of zero similar to what is shown Figure 6-21.

  There are various factors which can contribute to these differences such as those listed below. Note that this is not an exhaustive list:

- Debris being caught on the falling limb which would lead to a lower observed flood level.
- Floating debris sitting proud of the water, such as branches, being caught at a higher level.
- Wave action from wind, vehicles and boats can lead to higher flood levels.
- Natural collection error – random error.
- Systematic error such as instrument error or incorrect datum.

  Incorrect identification of flood debris lines.

- Figure 6-22 is a map showing the difference between observed and modelled water levels. In this figure, each flood mark is colour coded with yellow marks being within +/- 50mm, light blue marks being lower than modelled results by between 50 to 100mm, dark blue mark being lower by more than 100mm, light red mark being higher than by between 50 to 100mm and dark red marks being higher by more than 100mm. This figure demonstrates an excellent fit of modelled results to the observed data.
- Figure 6-23 compares the modelled flood extent to the observed flood extent from photography. As noted above, the extents were determined from photography that was not taken at the peak, so it is expected that the modelled flood extents will be slightly larger than the observed. The modelled flood extents are in fact larger than the observed, demonstrating the model is performing well.

Overall, the lower Maribyrnong Flood model can be considered well calibrated. The falling limb is slightly over-estimated, but this is considered conservative. The calibrated Manning's values are presented in Table 6-9, the bend losses are presented in Table 6-10 and the bridge losses are presented in Table 6-3. All hydraulic model parameters are within expected ranges.

The model appears to be adequately replicating the tidal signal at the Chifley gauge. This gives confidence that the in-channel Manning's n values in the reaches below the Chifley gauge are appropriate as the conveyance of a tide upstream into a river is strongly influenced by the Manning's n value but not the form (bend) loss.

The resulting modelling flood depths for the 2022 flood event are shown in Figure 6-24.

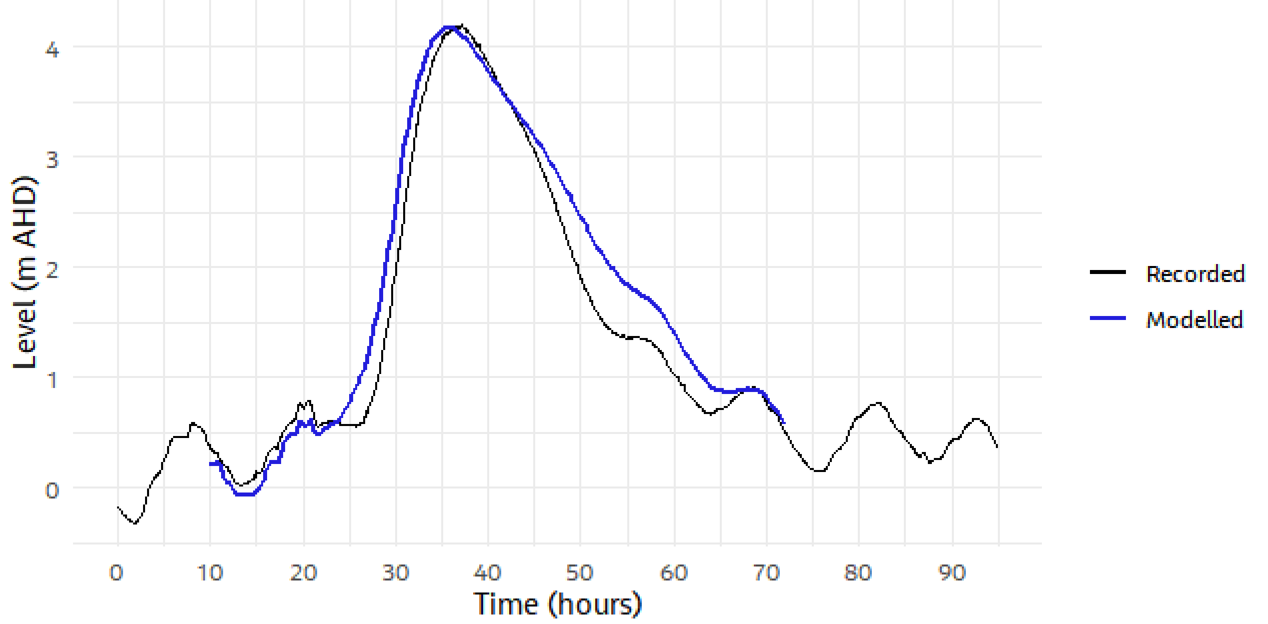


Figure 6-18: 2022 flood event comparison of recorded and modelled water levels at the Chifley Drive gauge.

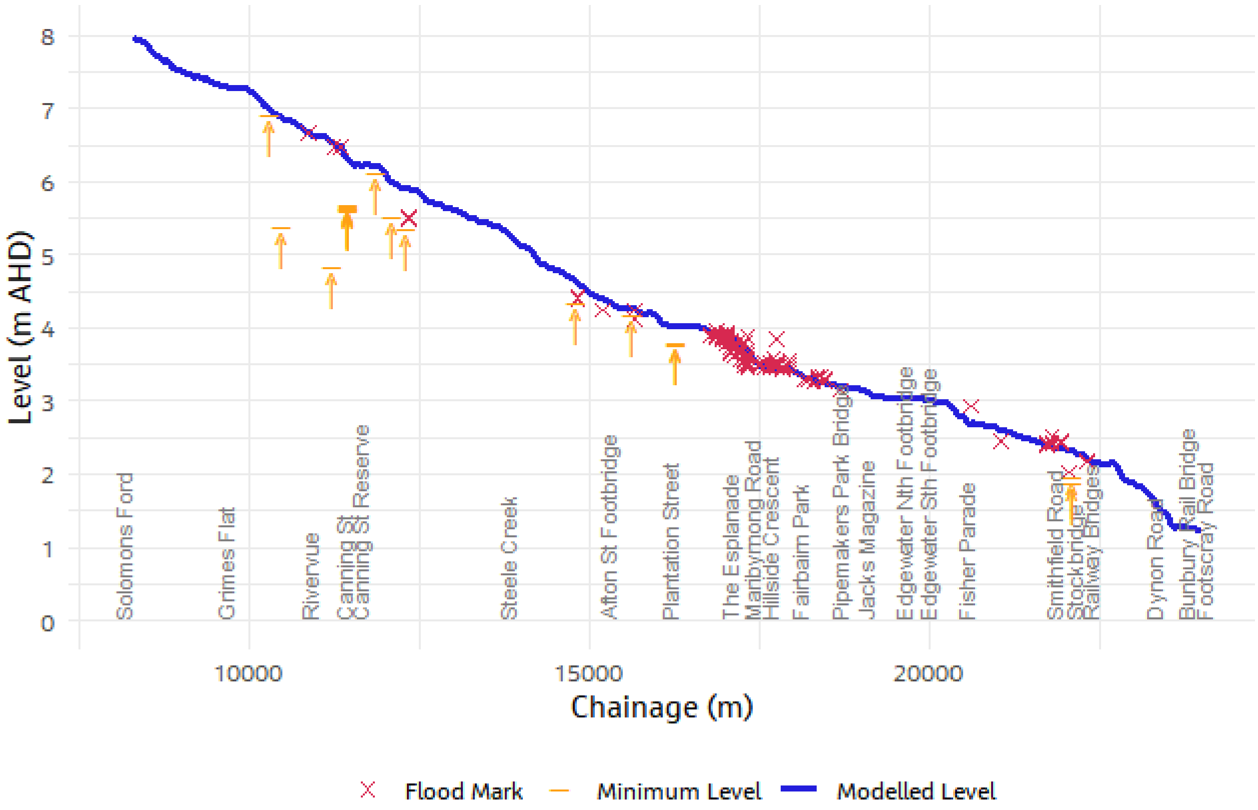


Figure 6-19: Longitudinal section of Lower Maribyrnong River modelled levels during 2022 flood event compared to known flood marks.

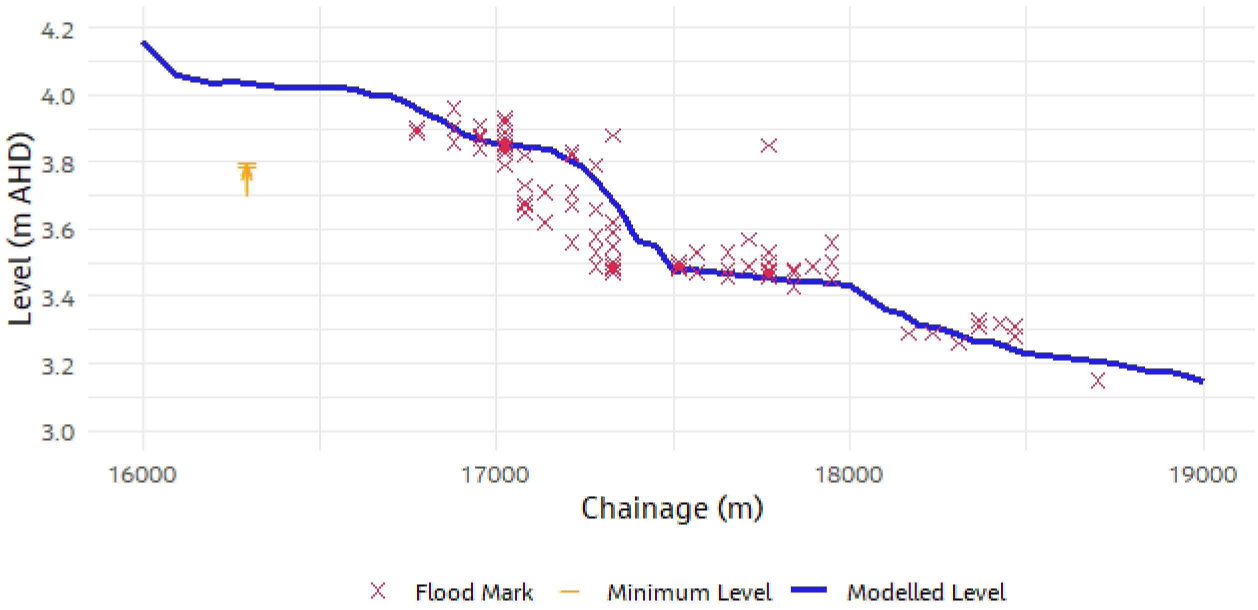


Figure 6-20: Longitudinal section of Lower Maribyrnong River modelled levels during 2022 flood event compared to known flood marks - Maribyrnong Township only.

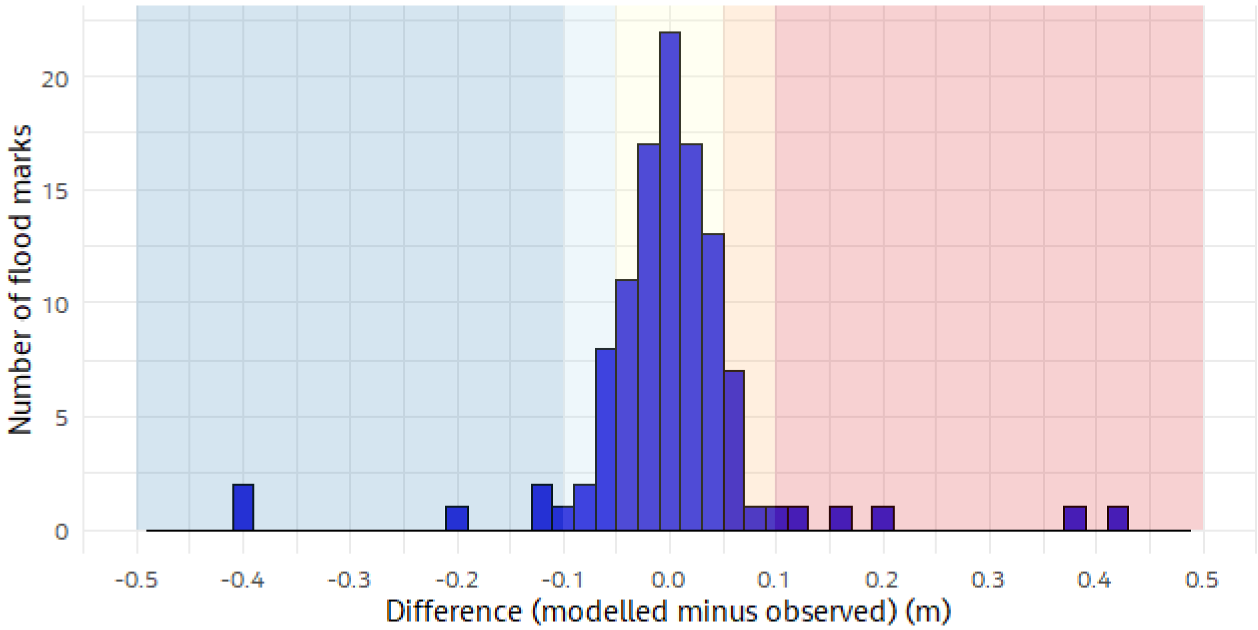
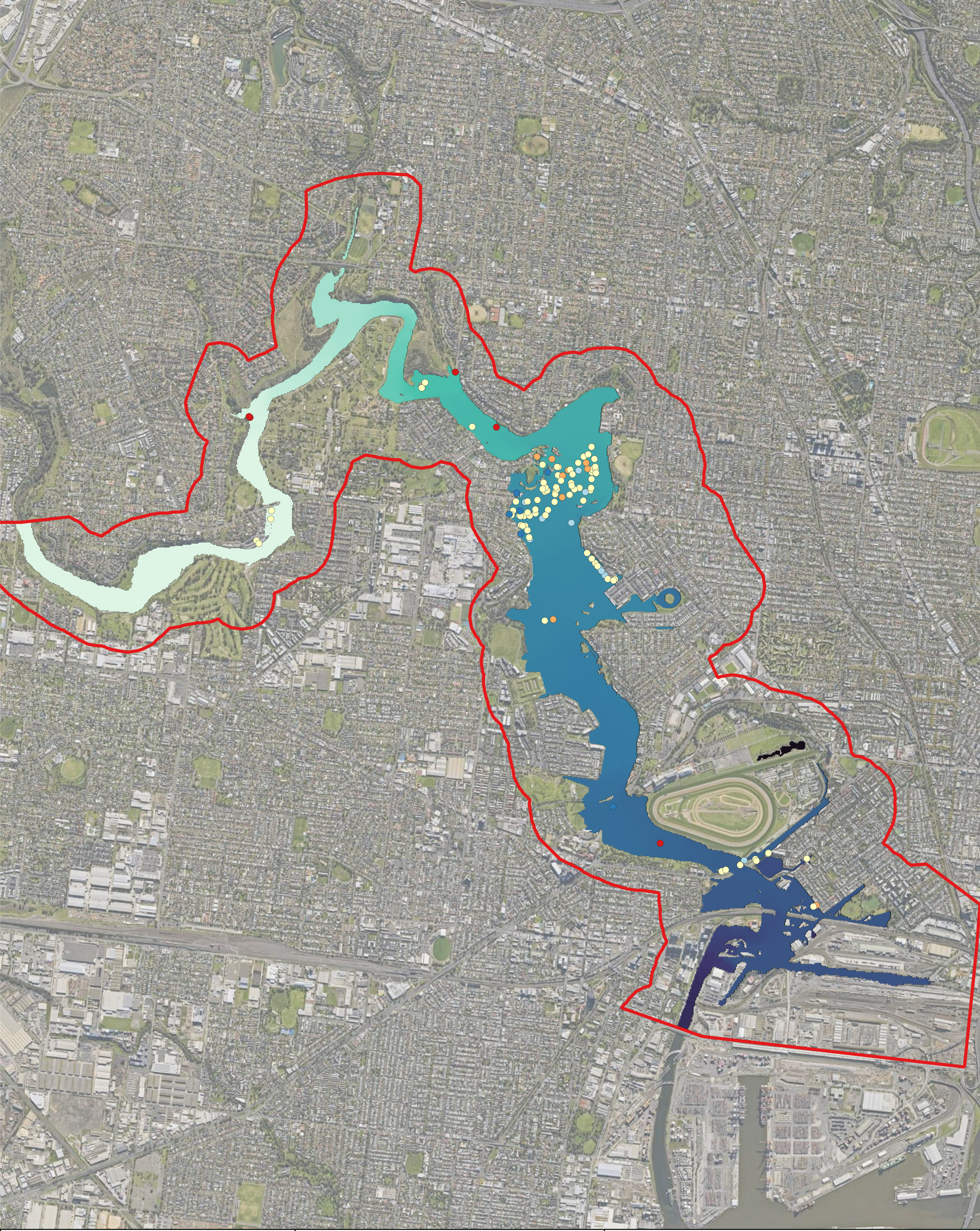


Figure 6-21: Histogram of Lower Maribyrnong River modelled levels of calibrated 2022 flood event.



Legend

Mapping extent

Difference to surveyed flood levels
- < 100mm
- 100 - 50mm below
- +/- 50mm
- 50 - 100mm above
- > 100mm

Modelled levels (m AHD)
- 0.0
- 1.5
- 3.0
- 4.5
- 6.0

MGA Zone 55

Jacobs

0 0.5 1 km

Figure 6-22: 2022 flood level calibration results

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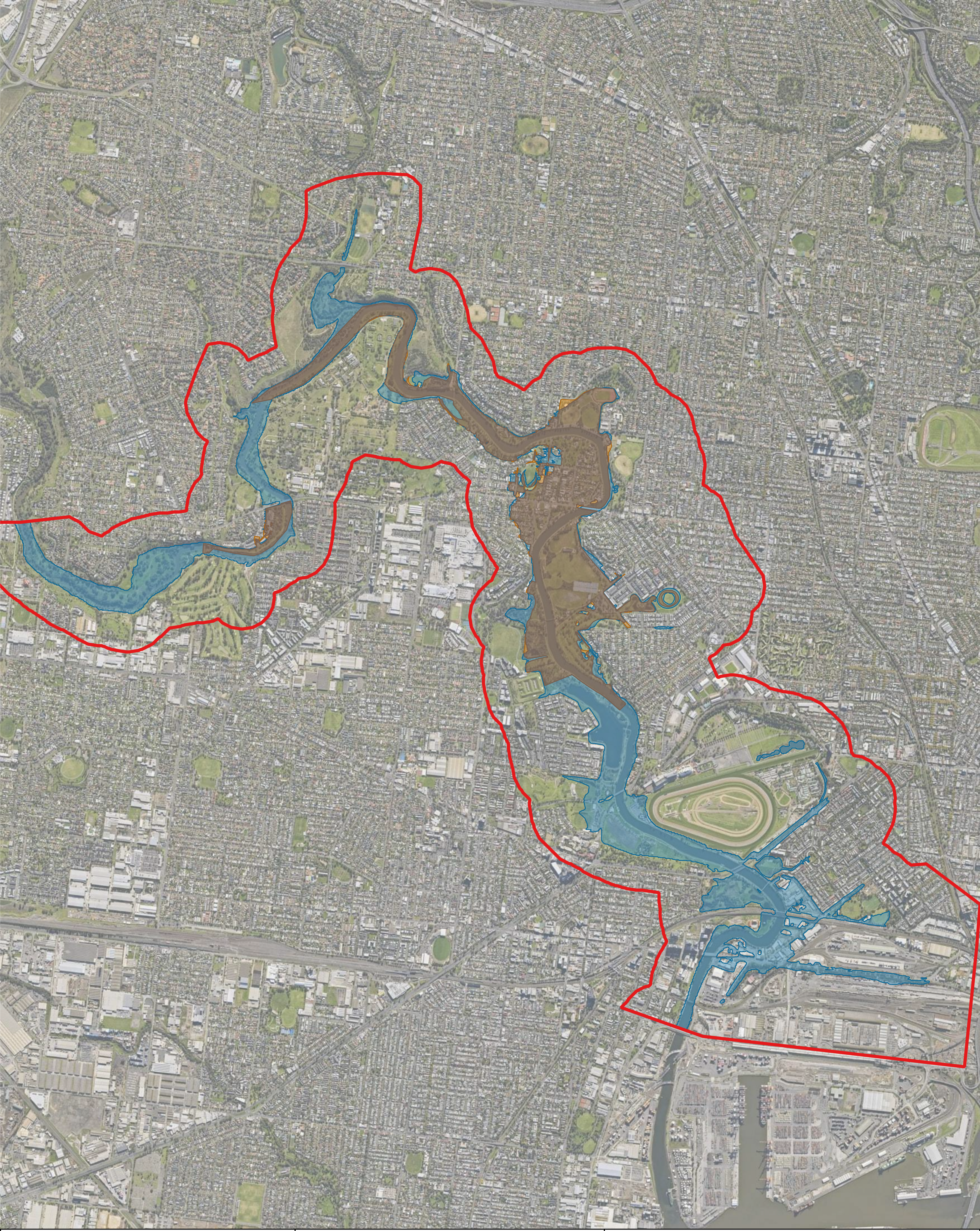


Legend

- Mapping extent
- 2022 modelled flood extent
- Flood event interpreted from photography
- Overlap of the above

MGA Zone 55

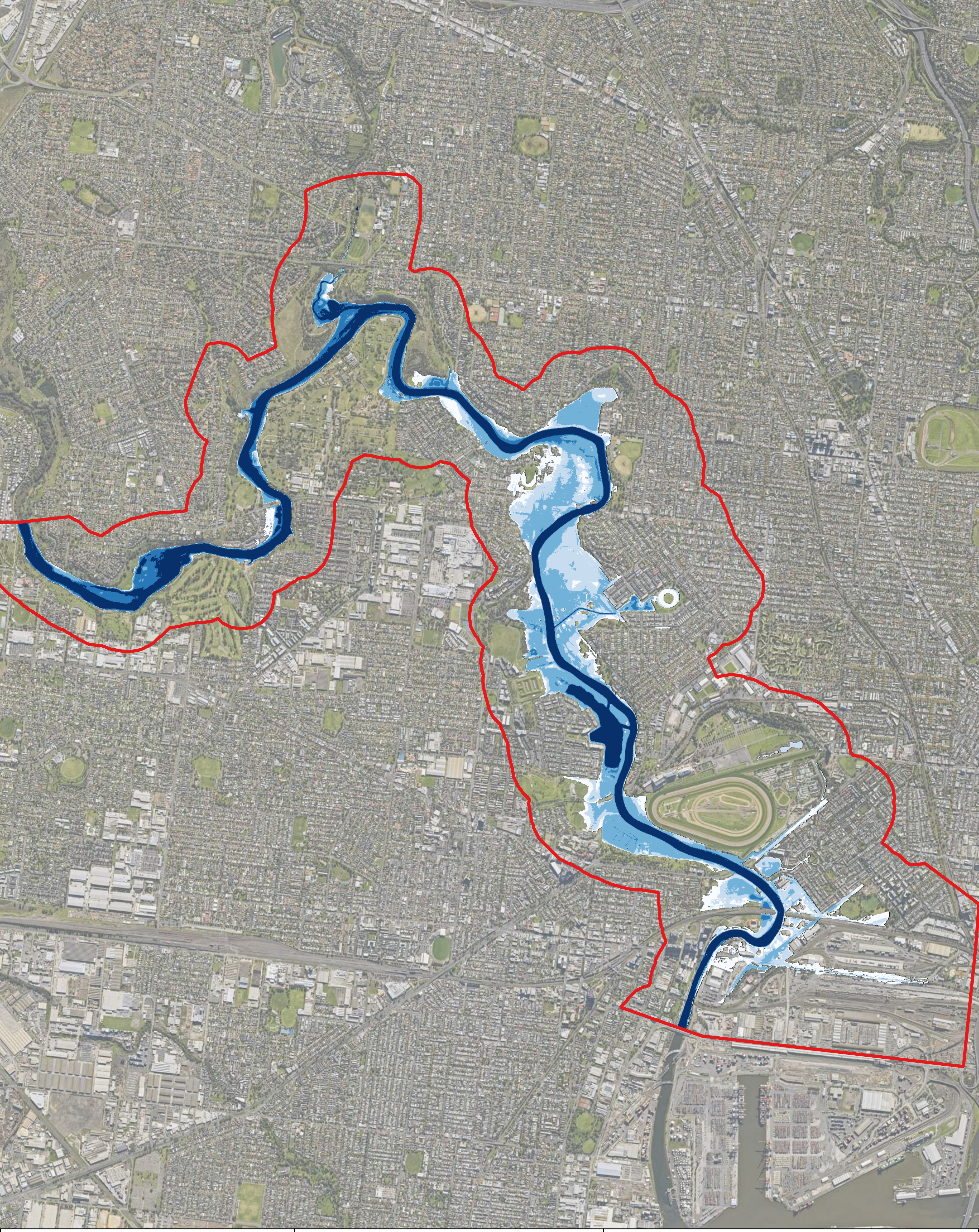
Jacobs

0 0.5 1 km

Figure 6-23: 2022 modelled flood extent compared to extents in photography

Project Number: IA5000NN

FINAL



Legend

Mapping extent

Modelled depths (m)

- <= 0.5m
- 0.5 - 1.0m
- 1.0 - 2.0m
- 2.0 - 3.0m
- > 3.0m

MGA Zone 55

0 0.5 1 km

Figure 6-24: 2022 modelled flood depths

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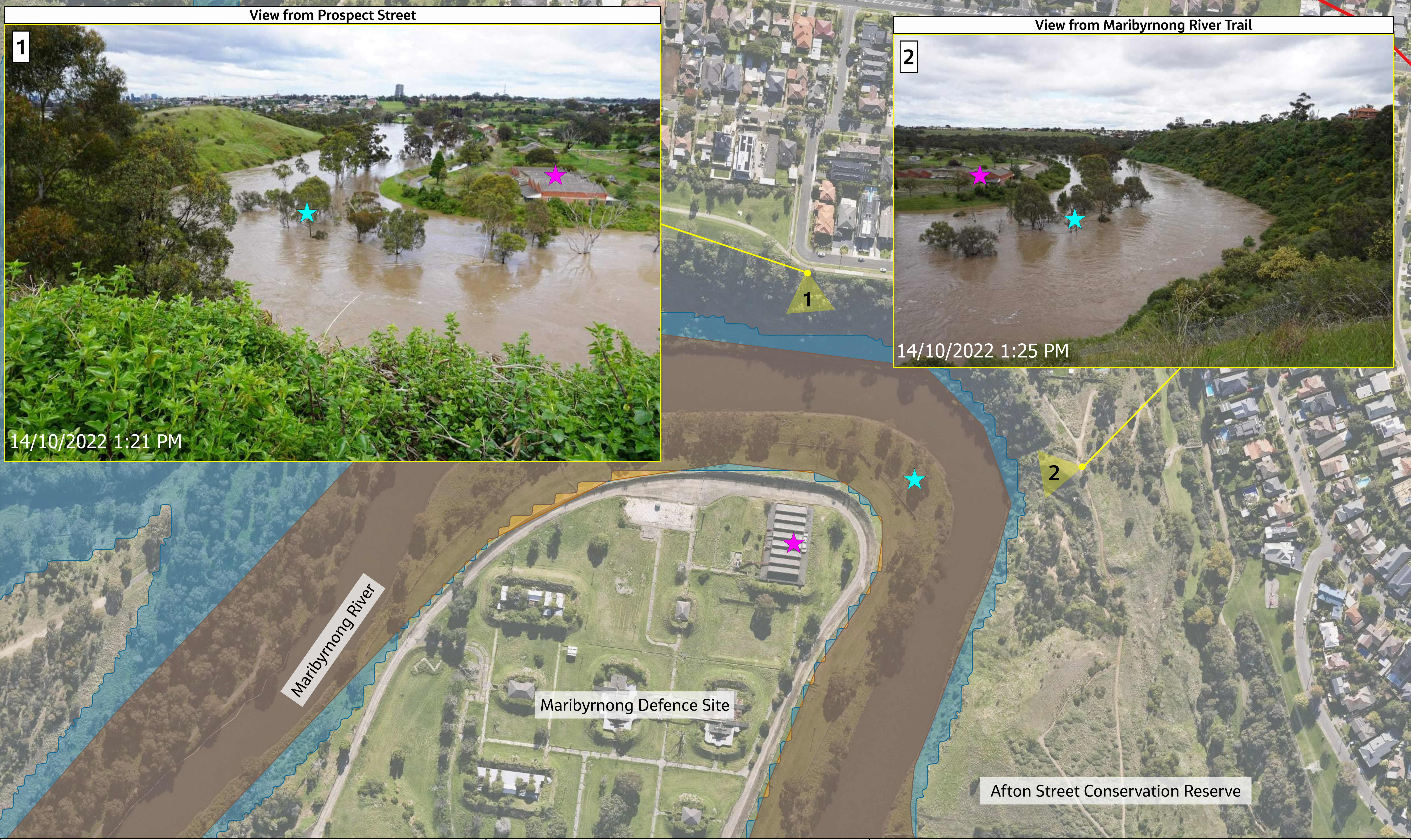

Legend

- 2022 modelled flood extent
- Flood extent interpreted from photography
- Overlap of above
- Vantage point of photograph

MGA Zone 55

Jacobs

0 50 100 150 m

Figure 6-25: Comparison of the 2022 modelled flood extent to photos taken at street level around the Maribyrnong Defence Site

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Legend

- 2022 modelled flood extent
- Flood extent interpreted from photography
- Overlap of above
- Vantage point of photograph

MGA Zone 55

0 50 100 150 m

Figure 6-26: Comparison of the 2022 modelled flood extent to photos taken at street level around Afton Street Conservation Reserve

Project Number: IA5000NN

FINAL

Jacobs

Figure 6-27: Comparison of the 2022 modelled flood extent to aerial photography of the area around Chifley Drive

Project Number: IA5000NN

FINAL

Legend

- 2022 modelled flood extent
- Flood extent interpreted from photography
- Overlap of above
- Vantage point of photograph

MGA Zone 55

Jacobs

0 100 200 300 m

Figure 6-28: Comparison of the 2022 modelled flood extent to photos taken at street level around Maribyrnong Township

Project Number: IA5000NN	FINAL

Table 6-9: Calibrated Manning's values.

Material ID	Description	Manning's value	Comments
1	Industrial/commercial	0.08	Excluding building footprints
2	Open pervious areas – minimal vegetation (grass)	0.042	Upstream of Canning St bridge where vegetation is less 'kept' (e.g. mowed less often)
3	Open pervious areas – moderate vegetation	0.065	More overgrown open pervious areas including scrub and bush
4	Open pervious areas – minimal vegetation (mowed grass)	0.03	Downstream of Canning St bridge where vegetation is more 'kept' (e.g. more likely to be mowed often)
5	Open pervious areas – sand/gravel/dirt	0.06	Dirt paths, golf course sand, racecourse track
6	Open pervious areas – thick vegetation (trees)	0.07	
7	Residential – urban (property parcel)	0.08	Property parcels only, excluding building footprints
8	Railway line	0.1	
9	Paved surfaces - other	0.025	
10	Paved surfaces - roads	0.025	
11	Wetlands (emergent vegetation)	0.07	
12	Lakes (no emergent vegetation)	0.025	
13	Estuaries/Oceans	0.03	Only used in marina area of Edgewater
14			
15	Waterways/channels – Maribyrnong River	0.023	Fisher Bridge to D/S boundary
16		0.03	Afton St Bridge to Fisher Bridge
17		0.035	Canning St Bridge to Afton St Bridge
18		0.042	Solomons Ford to Canning St Bridge
20	Waterways/channels - other	0.02	Ascot Vale Main Drain
21		0.05	Moonee Ponds Creek
22	Road easements/verges	0.03	Grassy verges, driveway entrances
23	Building footprints	0.4	

Table 6-10: Calibrated Bend losses (see Figure 6-14 for locations).

Bend ID	Bend loss (2dp)
U/S Solomons Ford	0.16
Grimes Flat 1	0.11
Grimes Flat 2	0.13
Grimes Flat 3	0.18
Rivervue 1	0.10
Rivervue 2	0.11
Canning Street Reserve	0.14
Tea Garden Reserve	0.09
Defence Site 1	0.16
Defence Site 2	0.24
Defence Site 3	0.21
Afton Street	0.11
Riverside Park Maribyrnong	0.23
Maribyrnong Park	0.11
Raleigh Road Bridge	0.20
Fairbairn Park	0.12
Riverside Golf Course	0.08
Edgewater	0.16
Footscray Rowing Club	0.22
Heavenly Queen Temple 1	0.21
Heavenly Queen Temple 2	0.21

6.10.6 January 2011 validation event

The model setup for the January 2011 flood event was very similar to the setup for the 2022 calibration event, with only the following differences:

- The January 2011 hydrograph at the Keilor gauge was applied to the model with the flow rate being determined from the most recent rating table at Keilor (RT37.02). This hydrograph is shown in Figure 6-29.
- The Rivervue Estate development was not yet built, and the underground pipe (1d) network was removed from this location. It is understood that the ground levels in this location have changed, however, at this stage these have not been altered.
- The piers associated with the Westgate Tunnel construction were not present in 2011.

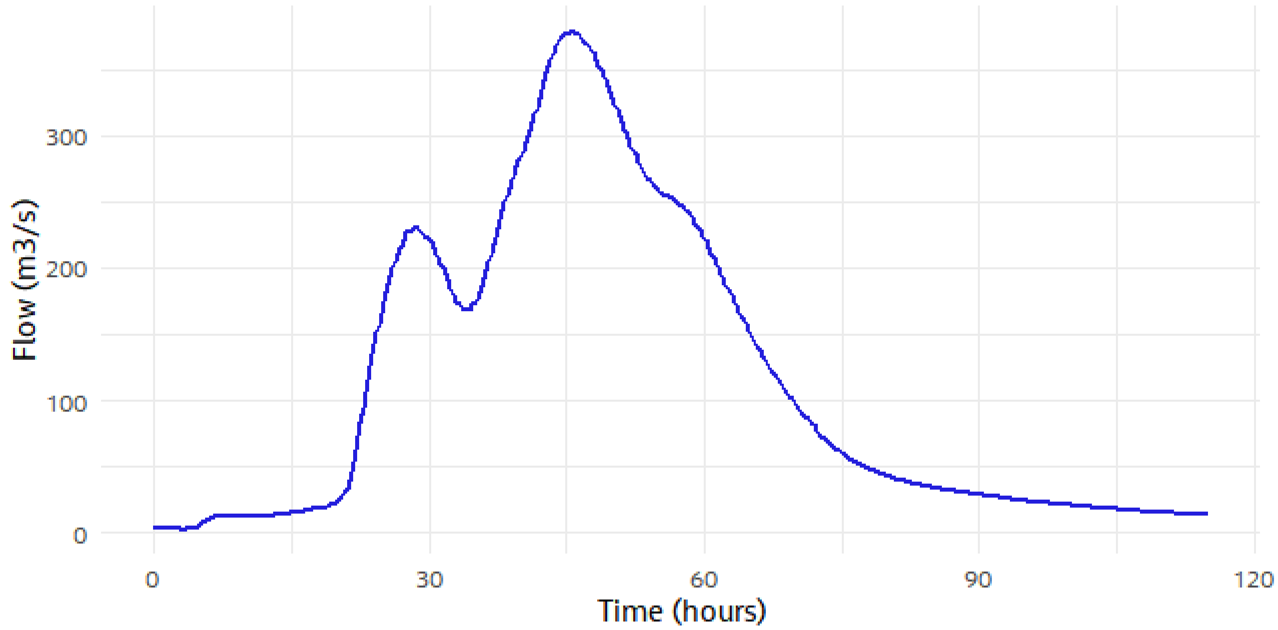


Figure 6-29: Maribyrnong River at Keilor 2011 event inflow hydrograph.

The results for this event are shown in the following figures:

- Figure 6-30 is a comparison between the recorded and modelled flood levels at the Chifley Drive gauge. This figure shows that the model is overpredicting levels at the location of the gauge, with the peak of the event overpredicted by approximately 390mm with a peak modelled level of 2.60m AHD vs a peak observed level of 2.21m AHD.
- Figure 6-31 is a map showing the modelled depth results. Despite the model overpredicting at the Chifley Drive gauge, the model nonetheless shows the wetlands in Rivervue Estate development as inundated, but not the properties, the majority of Maribyrnong township not inundated (notably the Anglers Arms Tavern is inundated), and Kensington Banks is not inundated.

The January 2011 flood event was the smallest historic event modelled and largely in-banks and therefore the least important in terms of replicating flooding conditions. The overprediction is likely to be due to interaction with the rougher channel banks increasing levels. In larger events, this interaction is drowned out and the model produces more accurate results. Given the relatively low importance of this event, potential improvements to results were not further investigated.

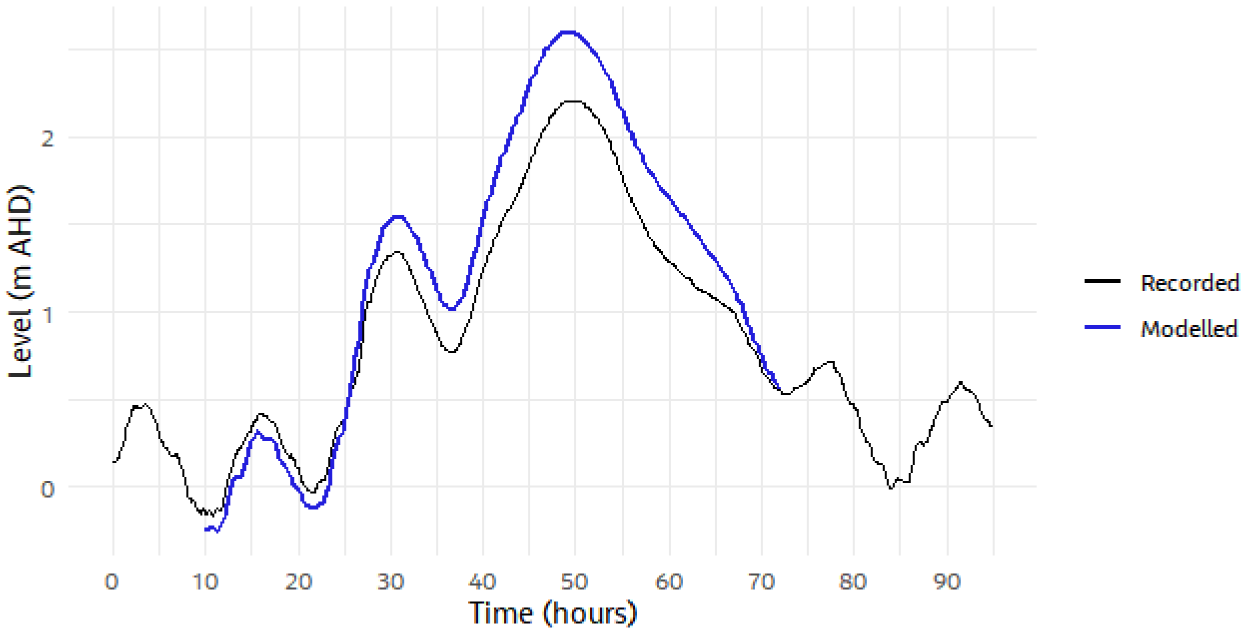
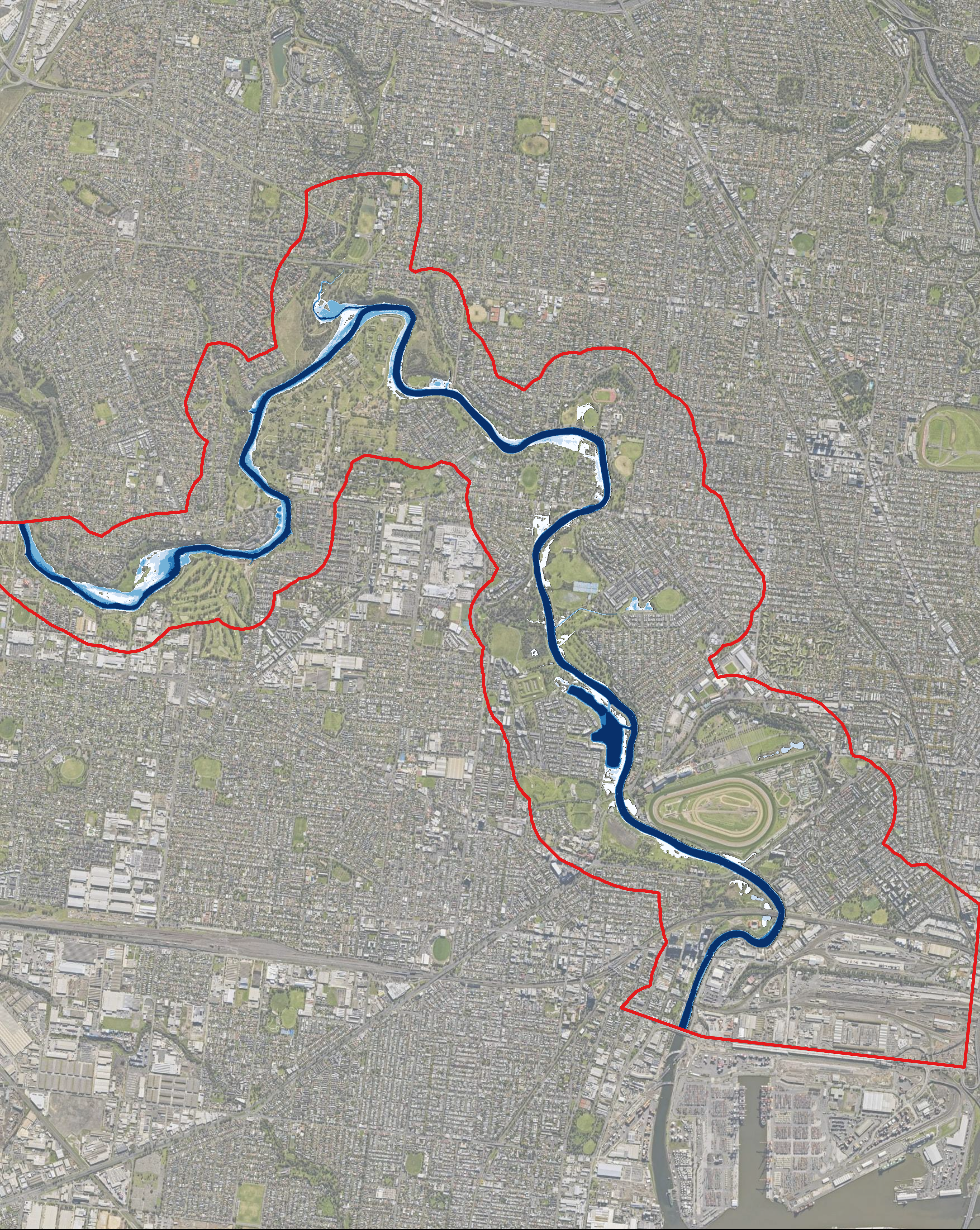


Figure 6-30: 2011 flood event comparison of modelled and observed levels at Chifley Drive gauge.



Legend

Mapping extent

Modelled depth (m)

- <= 0.5m
- 0.5 - 1.0m
- 1.0 - 2.0m
- 2.0 - 3.0m
- > 3.0m

MGA Zone 55

Jacobs

0 0.5 1 km

Figure 6-31: 2011 modelled flood depths

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6.10.7 September 1993 validation event

The September 1993 flood event required the following changes to the model in addition to the changes made for the 2011 event:

- The September 1993 hydrograph at the Keilor gauge was applied to the model with the flow rate being determined from the most recent rating table at Keilor (RT37.02). This hydrograph is shown in Figure 6-32.
- The Riverside Park levee and culvert were removed from the model as these were constructed as part of the Kensington Banks development which was not built in 1993. No other modifications were made to represent any changes to ground levels due to the Kensington Banks development as no details were available.
- The flood wall around Flemington Racecourse was removed as this was constructed circa 2007.
- The form loss on Footscray Road Bridge was increased from its current value to represent the additional abutment that was removed as part mitigation works for the Flemington Racecourse flood wall.
- The level of the road immediately downstream of the Northern Railway culverts was increased to a level of 0.8m AHD to represent the road level prior to its lowering to its current level of 0.5m AHD as part of mitigation works for the Flemington Racecourse flood wall.
- It is of note that the Edgewater development had not yet been completed at the time of the 1993 event.

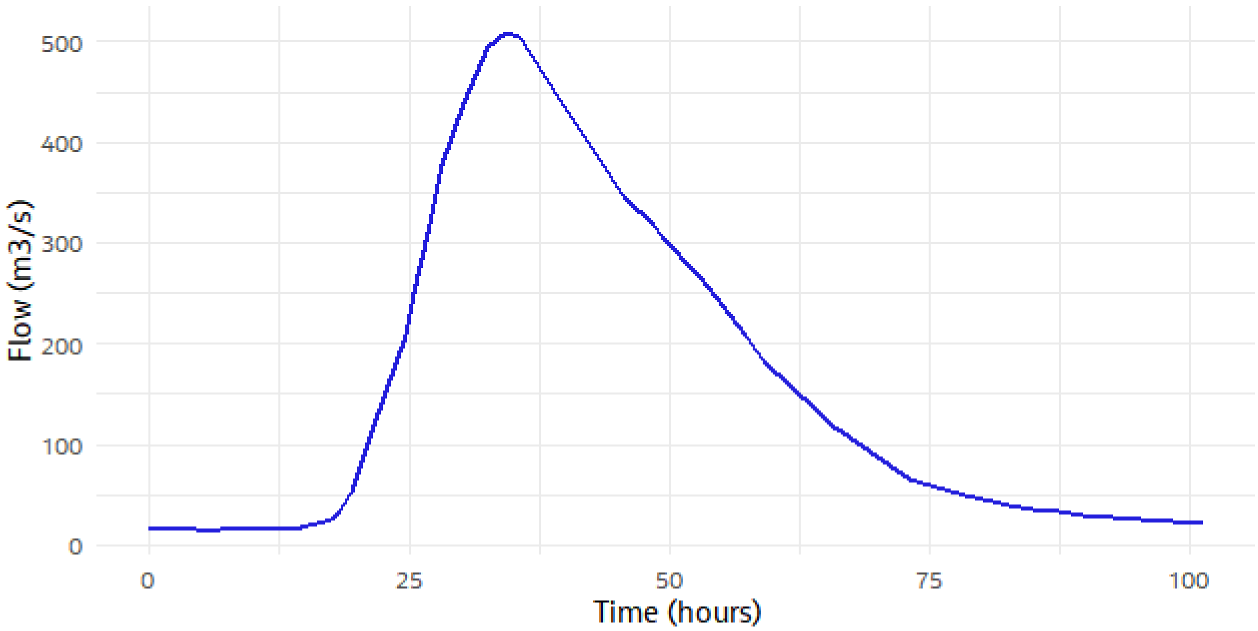


Figure 6-32: Maribyrnong River at Keilor 1993 event inflow hydrograph.

The results for this event are shown in the following figures:

- Figure 6-33 is a comparison between the recorded and modelled flood levels at the Chifley Drive gauge. This figure shows that the model is able to replicate flood levels at this location well. The difference between the modelled peak water level and the recorded water level is 40mm. The modelled water level was 3.35m AHD and the recorded water level was 3.31m AHD. It is of note that the recorded flood level in the timeseries has an unrealistic flat peak, and it is likely that the actual peak was slightly higher than recorded. Regardless, this represents an excellent fit to the observed data.
- Figure 6-34 is a map showing the modelled depth results. This result shows that the model predicts no flooding in the Rivervue development, and much less extensive flooding in Maribyrnong township

compared to the 2022 flood event, although there is still significant inundation. The SES Maribyrnong Local Flood Guide states:

"Anglers Tavern lounge and bistro areas under nearly two metres of water, and a further 50 residences flooded over floor level."

While the source of this information is not stated, the information broadly agrees with the information in Figure 6-34.

While there is only sparse information for the 1993 flood event, the available information provides a strong agreement to the information particularly at the Chifley Drive gauge. Given that this is the second largest historic event the hydraulic model can be considered to be validated.

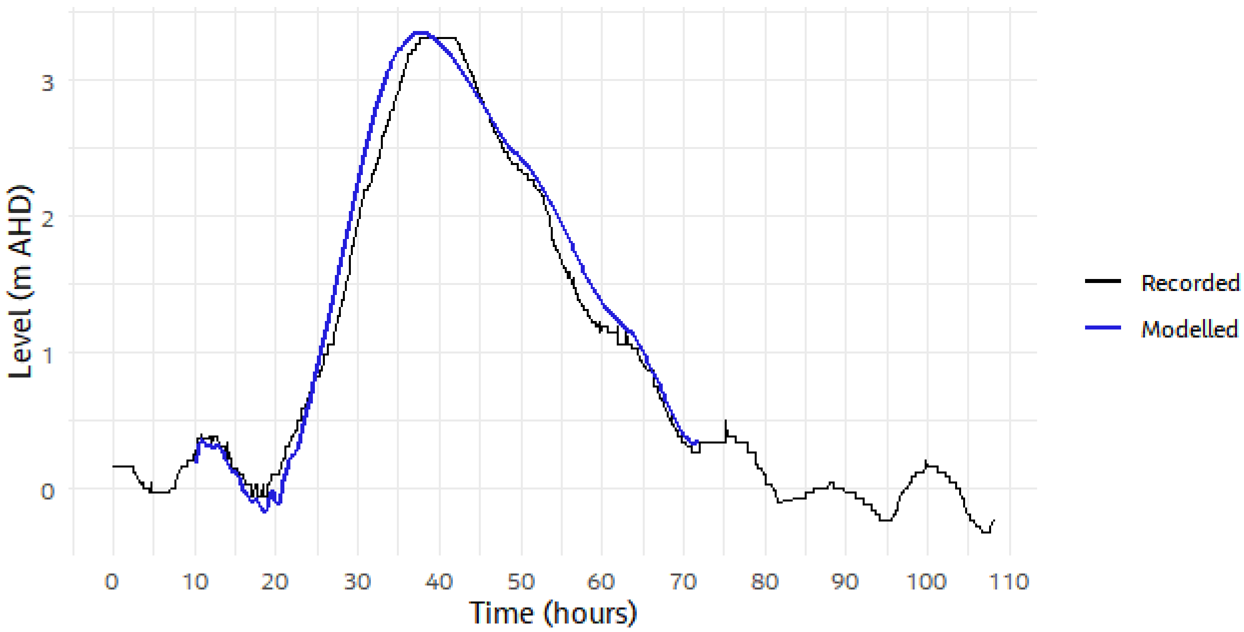
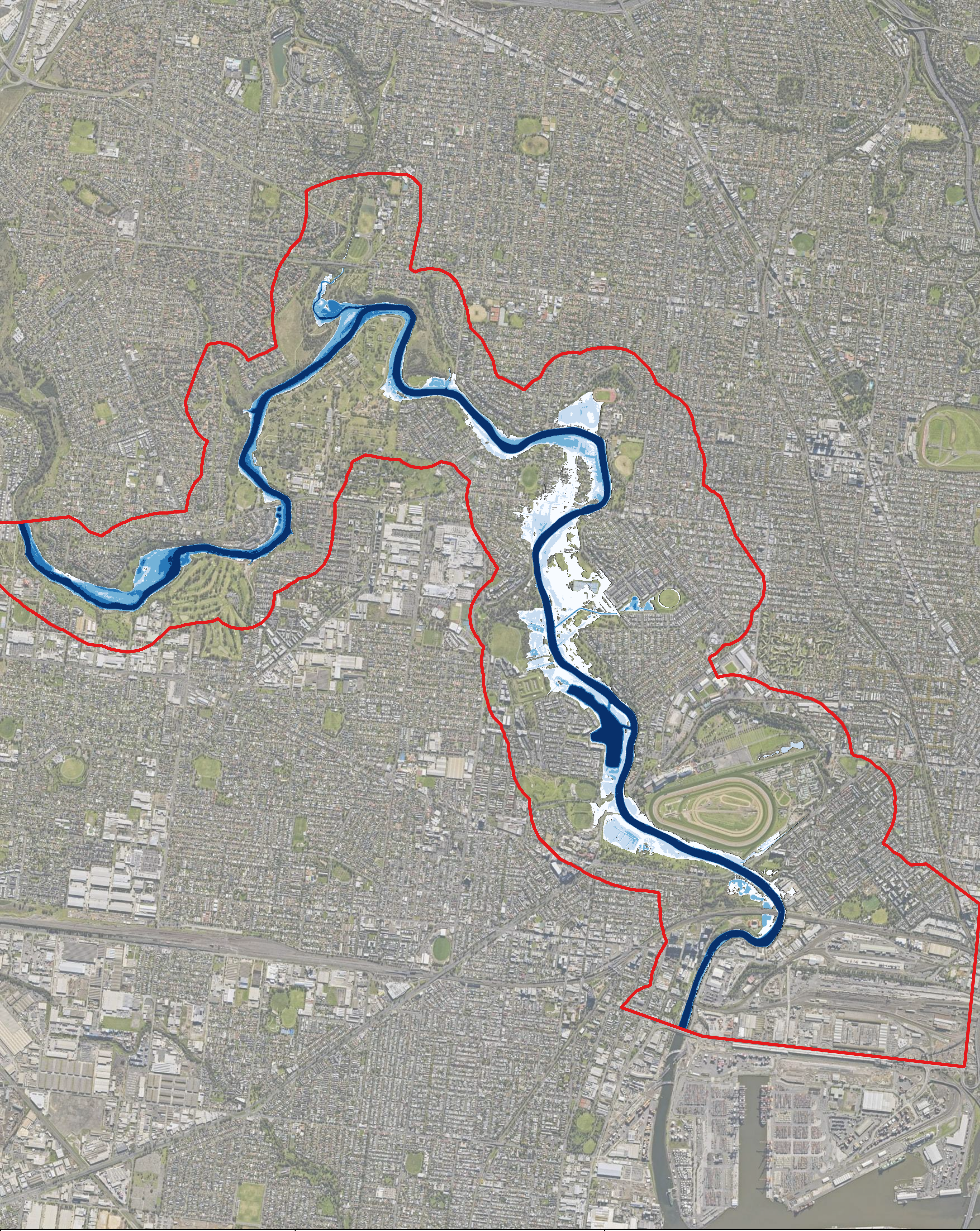


Figure 6-33: Comparison of modelled and observed levels at Chifley Drive gauge during the 1993 flood event.



Legend

Mapping extent

Modelled depth (m)

- <= 0.5m
- 0.5 - 1.0m
- 1.0 - 2.0m
- 2.0 - 3.0m
- > 3.0m

MGA Zone 55

Jacobs

0 0.5 1 km

Figure 6-34: 1993 modelled flood depths

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6.10.8 October 1983 validation event

In addition to the changes for the 1993 and 2011 model set up the following changes were made to the model for the October 1983 flood event:

- The October1983 hydrograph at the Keilor gauge was applied to the model with the flow rate being determined from the most recent rating table at Keilor (RT37.02). This hydrograph is shown in Figure 6-36.
- The culverts under the northern railway embankment by the Kensington Railway Bridge were removed from the model.
- The culverts under Farnsworth Ave, just west of Fisher Bridge, were removed from the model.
- The southernmost bridge of the 3 bridges that make up the Kensington Railway Bridge was removed.
- The northernmost bridge of the pair of bridges that make up Lynchs Bridge was removed.
- Bridge pier losses and %blockage were increased at Maribyrnong Road (Raleigh Road bridge) to account for the effect of the barges that were caught under the bridge during the event, as shown in Figure 6-35.

Figure 6-35: Newspaper accounts at the time of the 1983 reporting on the blockage caused at Maribyrnong Road (Raleigh Road) bridge by two river barges being caught by floodwaters

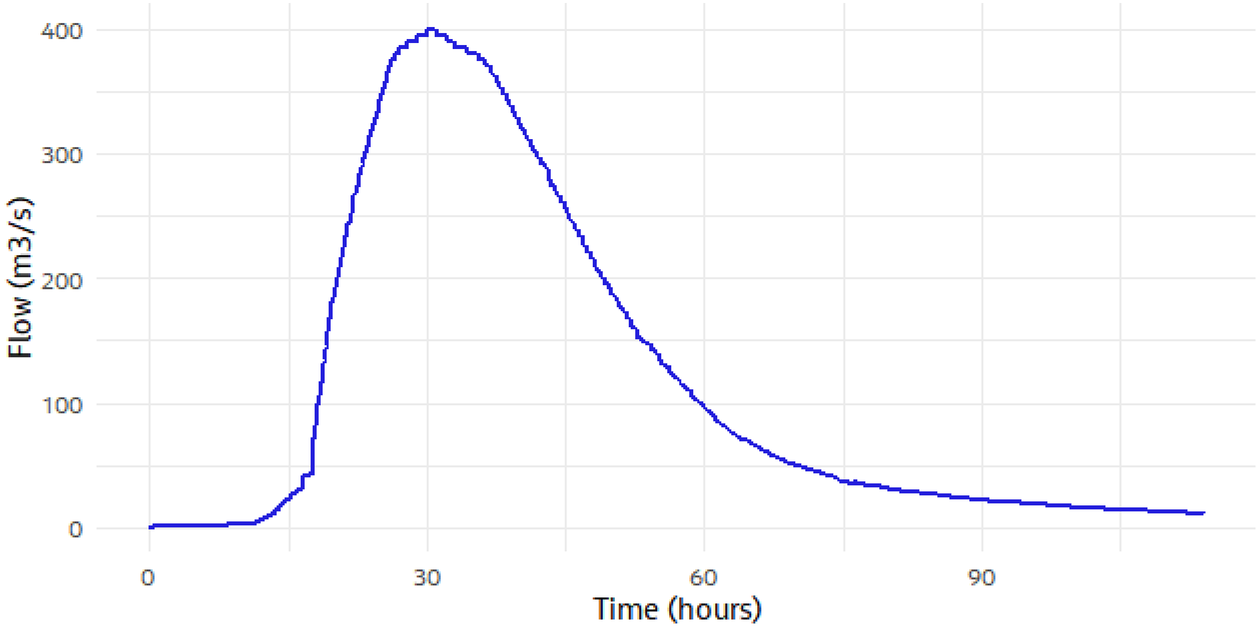


Figure 6-36: Maribyrnong River at Keilor 1983 event inflow hydrograph.

The results for this event are shown in the following figures:

- Figure 6-37 presents a comparison between recorded and modelled flood levels at the Chiefly Drive gauge. This figure demonstrates a good agreement between recorded and modelled peak water levels, with a difference of only 69mm.
- Figure 6-38 shows a long section of the modelled peak water level compared to the observed flood marks. This figure shows that the model reproduces the event well at all flood marks with the exception of the two immediately downstream of the point of the blockage (Maribyrnong Road) and the sole floodmark at the Footscray rail bridge.
- Figure 6-39 shows a histogram of the difference between observed flood marks and the modelled peak water levels. The histogram shows that with the exception of the abovementioned 3 marks, the model is reproducing levels with a good degree of accuracy.
- Figure 6-40 is a map illustrating the difference between observed and modelled water levels. In this figure, each flood mark is colour coded with yellow marks being within +/- 50mm, light blue marks being lower than modelled results by between 50 to 100mm, dark blue mark being lower by more than 100mm, light red mark being higher than by between 50 to 100mm and dark red marks being higher by more than 100mm.

While the 1983 validation overpredicts observed water levels, this is typically by well under 100mm which would generally be considered good model performance. It should also be noted that there has been significant change to the Lower Maribyrnong channel and floodplain which have not been included in the hydraulic model as details are not available.

In addition, it is not known exactly where the flood marks were captured, and water levels are known to vary by 100-200mm from one side of the river to the other due to superelevation.

Taking into account the uncertainties and catchment changes, the hydraulic model can be considered to replicate the 1983 event well.

The resulting modelled flood depths and extents are shown in Figure 6-41.

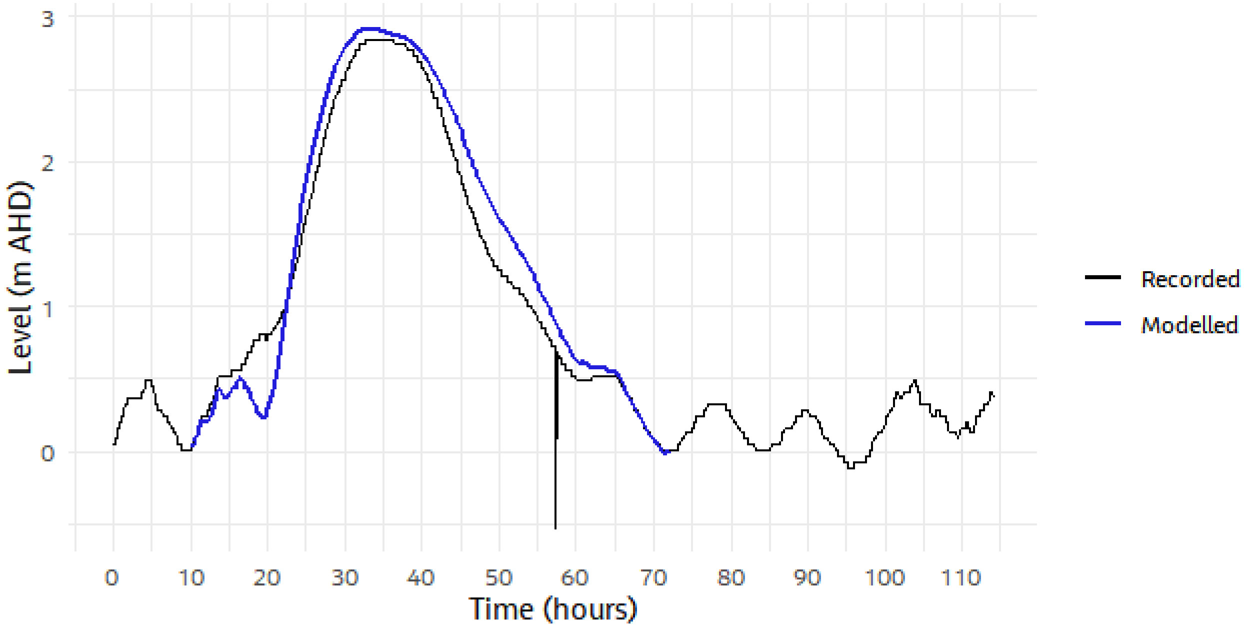


Figure 6-37: Comparison of modelled and observed levels at Chifley Drive gauge during the 1983 flood event.

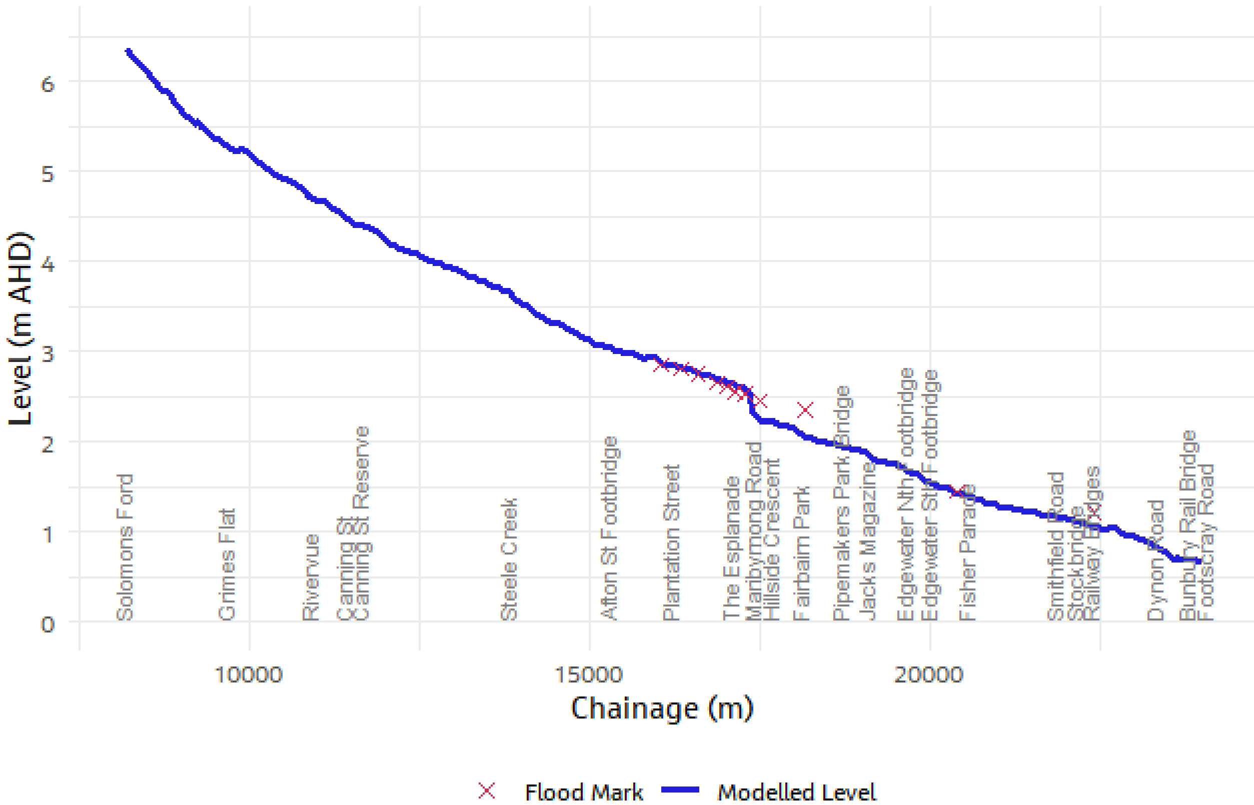


Figure 6-38: Longitudinal section of Lower Maribyrnong River modelled levels during 1983 flood event compared to known flood marks.

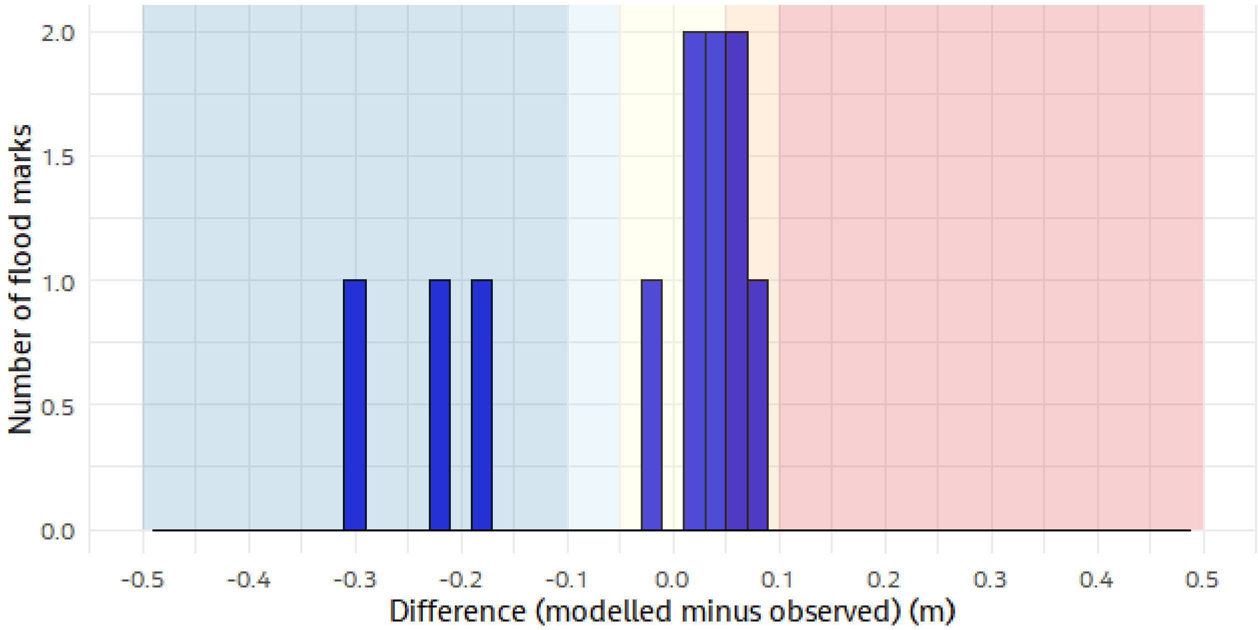
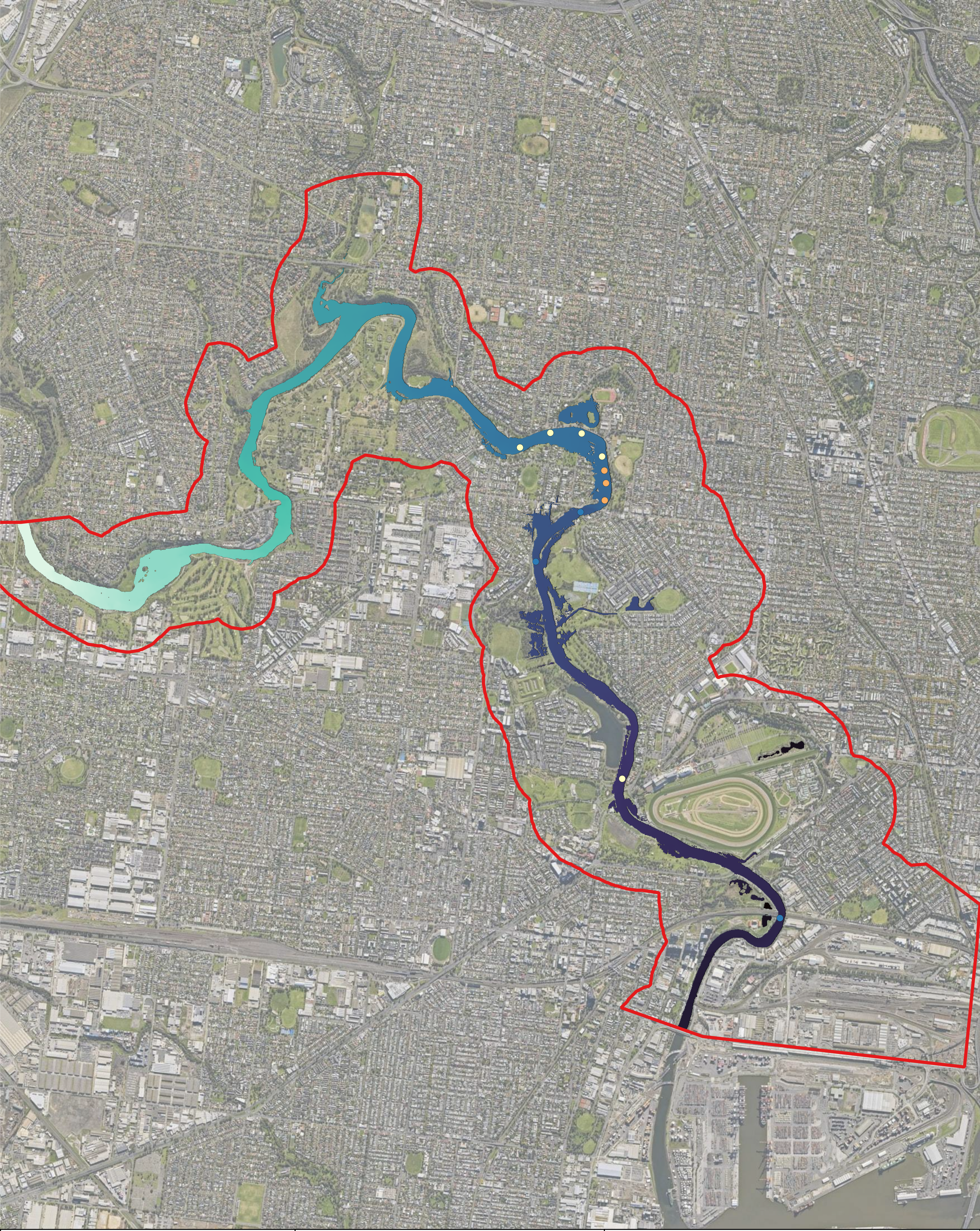


Figure 6-39: Lower Maribyrnong River modelled levels of calibrated 1983 flood event.



Legend

Mapping extent

Difference to surveyed flood levels
- < 100mm
- 100 - 50mm below
- +/- 50mm
- 50 - 100mm above
- > 100mm

Modelled Levels (m AHD)
- 0.0
- 1.5
- 3.0
- 4.5
- 6.0

MGA Zone 55

Jacobs

0 0.5 1 km

Figure 6-40: 1983 levels and flood marks

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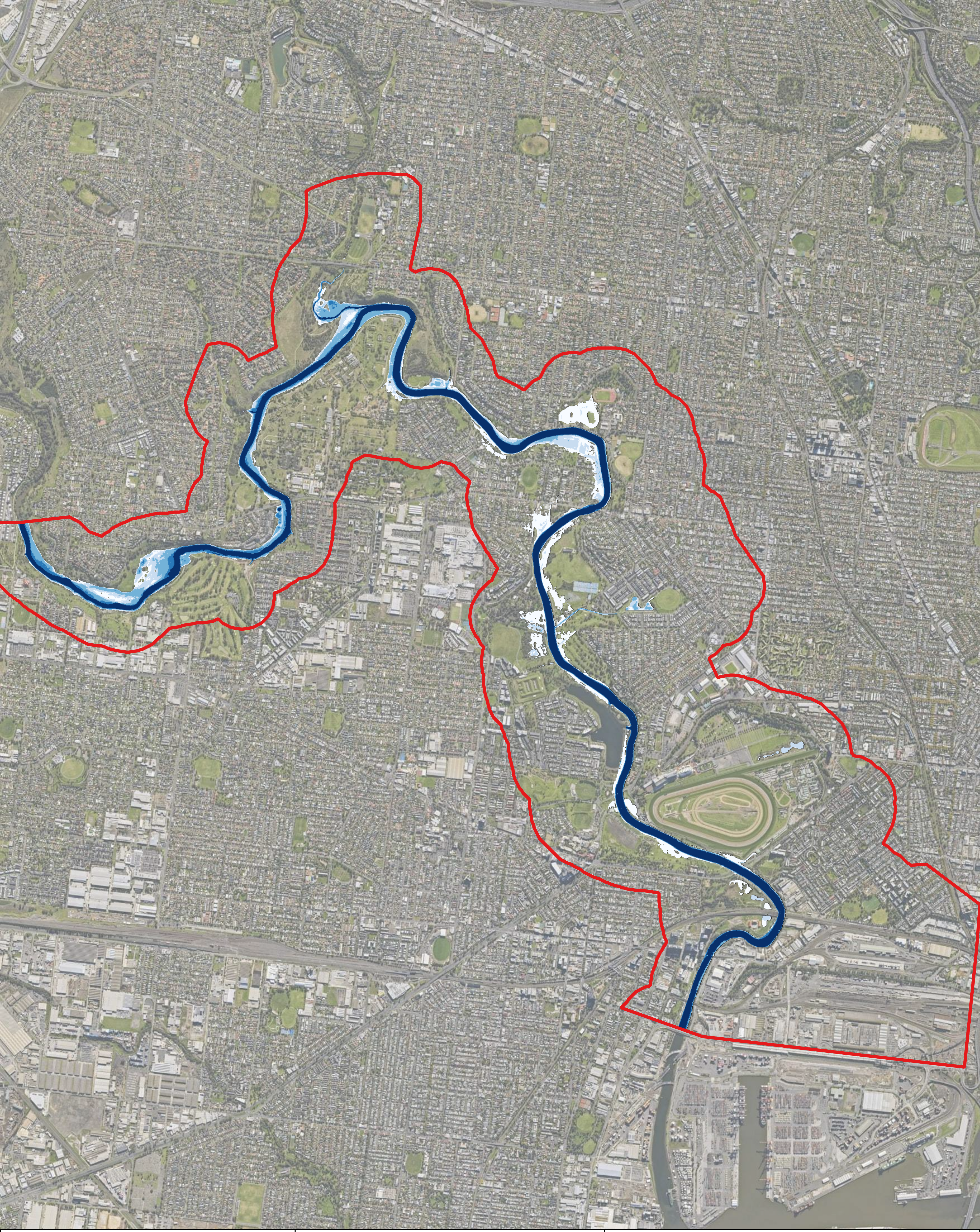

Legend

Mapping extent

Modelled depth (m)

- <= 0.5m
- 0.5 - 1.0m
- 1.0 - 2.0m
- 2.0 - 3.0m
- > 3.0m

MGA Zone 55

Jacobs

0 0.5 1 km

Figure 6-41: 1983 modelled flood depths

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6.10.9 May 1974 verification event

One significant change to the hydraulic model configuration was made for the 1974 event on top of the changes made to the model for the 1983 event. During the 1974 event, cofferdams were in place in the river at Kensington rail bridge, presumably involved in the construction of the most upstream bridge of the 3 that now exist there. This caused significant blockage at the bridge and was blamed for significantly increasing the damage caused by the flood at the time, seen in the text of the newspaper article shown in Figure 6-42. This was applied in the model as a significant cross-section blockage factor in the 2d_bg layer.

The May 1974 hydrograph was applied at the Keilor gauge. This data was obtained from WMIS (https://data.water.vic.gov.au/) and it was noted that the hydrograph from WMIS had a different shape to the hydrograph presented in MMBW (1986) (see Figure 6-44). This hydrograph from WMIS is shown in Figure 6-43.

Northern Regional, May 23, 1974 5

RAILWAYS UNDER FIRE FOR FLOOD

A railways department bridge being built across the Maribyrnong River has been blamed for flood damage amounting to thousands of dollars in Kensington.

Hobsons Road, beside the river, was the hardest area hit by the floodwaters in Kensington.

Factory owners believe a railway bridge under construction across the river blocked the flow of the rising waters last Wednesday, Thursday and Friday.

Mr. Harold Davis, manager of a meat works in Hobson's Road, said this week the flood waters reached 4 ft. 6 in. around his factory.

"Our factory has been here since 1936 and we've never had floods this bad before," he said.

"It's definitely happened because the bridge works have blocked almost half the river."

Mr. G. Duncan, a director of Dodd and Co., wool scourers, in nearby Kensington Road, said damage to his factory and its contents could run as high as half a million dollars.

Cr. Leslie Fox, of Melbourne Council, who has a factory in Hobson's Road, said this week he also believed the bridge works had blocked half the river.

"During the floods torrents of water gushed through the open section of the river, but most of the water banked back and flooded the factories," he said.

Cr. Fox, the council's representative on the Maribyrnong Valley River Works Committee, said he would seek a report on the damage.

He said he would also organise a meeting of factory owners this week to discuss means of obtaining compensation from the Victorian Railways.

Open

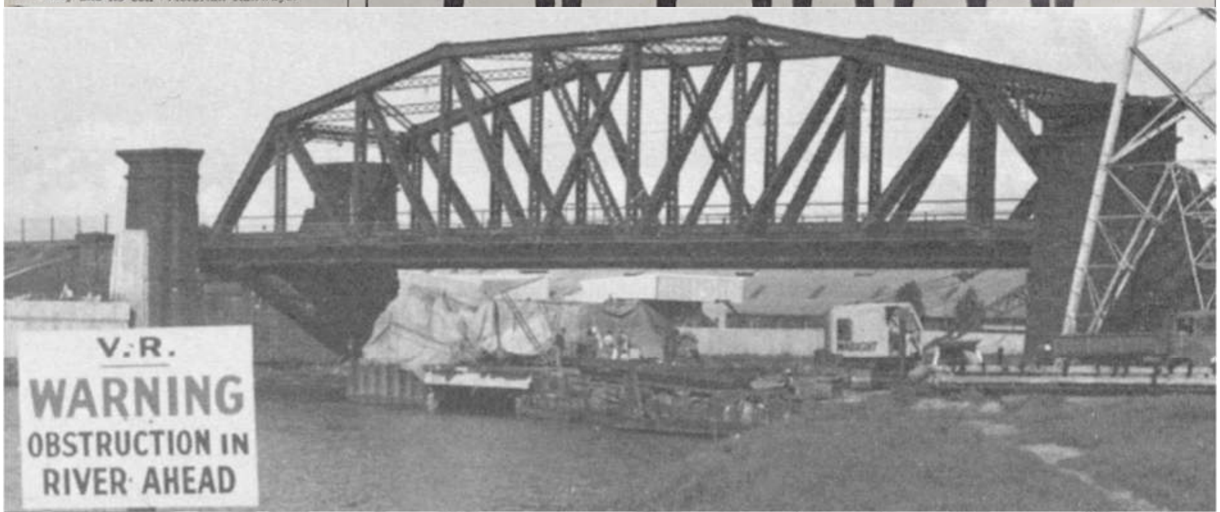


Figure 6-42: Newspaper reports and photos taken in the aftermath of the 1974 flood event around the cofferdam in the river at the Kensington rail bridge obstructing the flowpath thereby likely exacerbating the flood.

The other change for this event was the use of a static water level for the downstream boundary. This was done as the Southbank tidal gauge did not have date that covered this event.

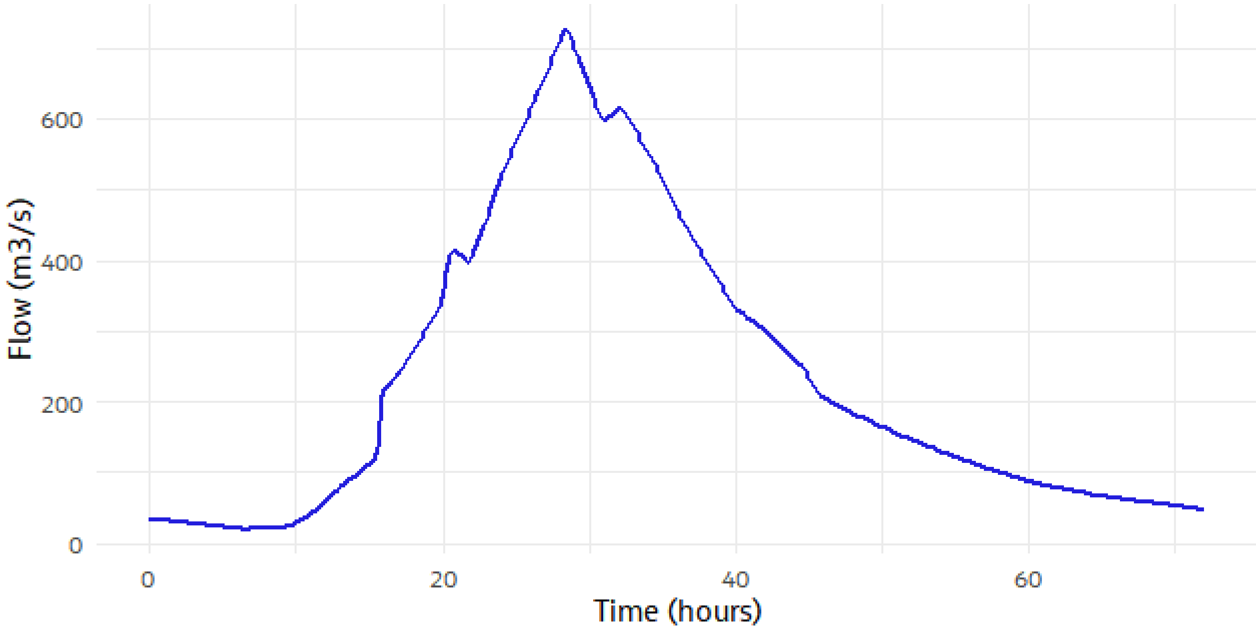


Figure 6-43: Maribyrnong River at Keilor 1974 event inflow hydrograph source WMIS.

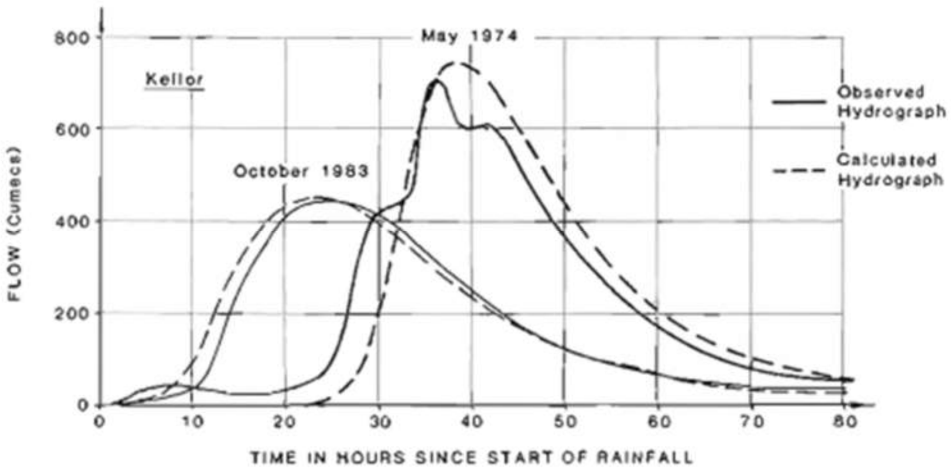


Figure 6-44: Maribyrnong River at Keilor 1974 hydrograph source MMBW 1986.

The results for this event were:

- The modelled flood level was 4.07m AHD compared to the observed flood level at Maribyrnong Township of 4.20m AHD (a difference of 130mm). It has been assumed that the 1974 flood level was determined at the same location as the Chiefly Drive gauge.
- Figure 6-45 shows a long section of the modelled peak water level compared to the observed flood marks. This figure shows that the model performs better in the upper reaches around Maribyrnong Township (Hillside Crescent) compared to the more downstream reaches. In the downstream reaches the model systematically underpredicts flood levels.
- The modelled underprediction in the lower reaches are likely due to the representation of the downstream tidal boundary where there is no recorded data and the level interpolated from the Williamstown gauge as discussed in Section 5.2.

- Figure 6-46 shows a histogram of the difference between observed flood marks and the modelled peak water levels. The histogram shows that the model is generally underpredicting levels but there is a reasonable distribution.
- Figure 6-47 is a map showing the difference between observed and modelled water levels. In this figure, each flood mark is colour coded with yellow marks being within +/- 50mm, light blue marks being lower than modelled results by between 50 to 100mm, dark blue mark being lower by more than 100mm, light red mark being higher than by between 50 to 100mm and dark red marks being higher by more than 100mm.

While the 1974 verification event does not perform as well as the other calibration and validation events, with the exception of 2011, it is still considered an acceptable result when the channel and floodplain changes are considered. Furthermore, there has been a considerable passage of time since the 1974 event. The systematic underprediction in the lower reaches are likely to have been caused by the downstream boundary assumption which has been made in the absence of recorded data.

In addition, it is not known exactly where the flood marks were captured, and water levels are known to vary by 100-200mm from one side of the river to the other due to superelevation.

The resulting modelled flood depths and extents are shown in Figure 6-48. Figure 6-49 and Figure 6-50 provide an illustration of modelled flood extents compared to photographs.

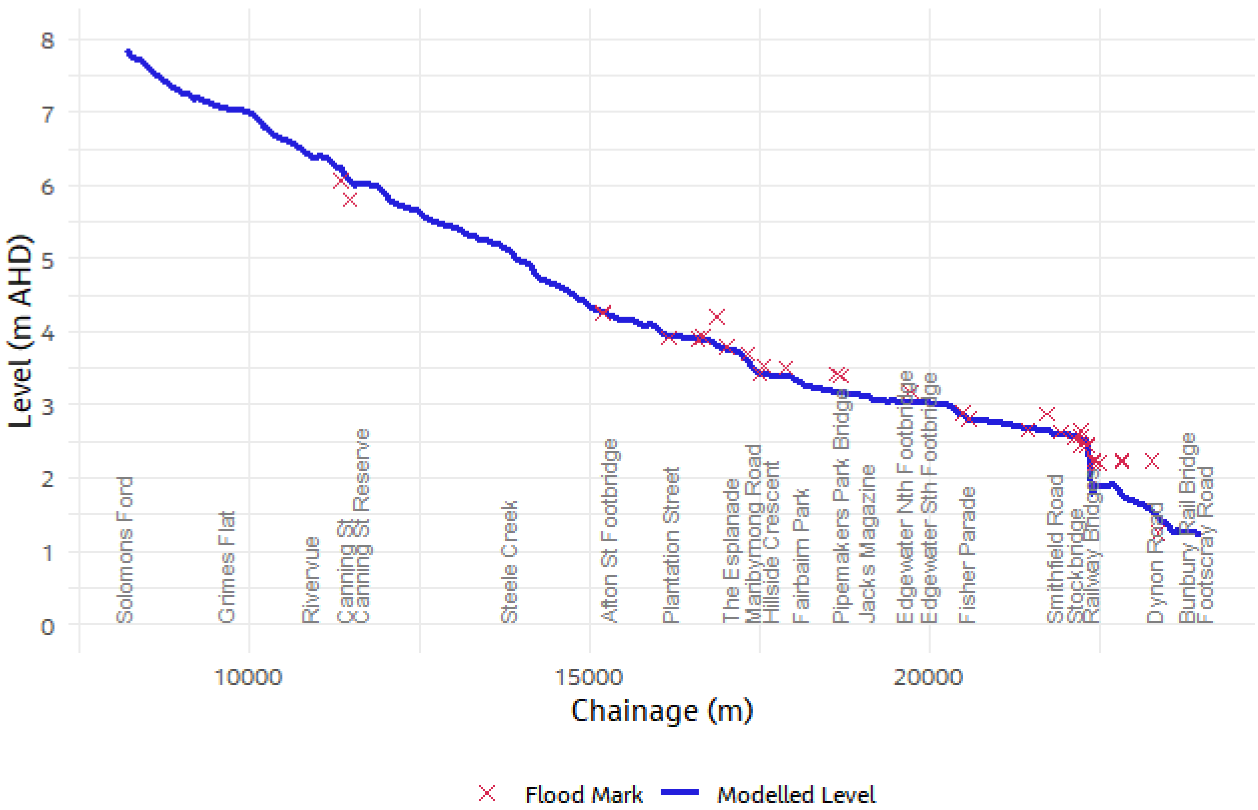


Figure 6-45: Longitudinal section of Lower Maribyrnong River modelled levels during 1974 flood event compared to known flood marks.

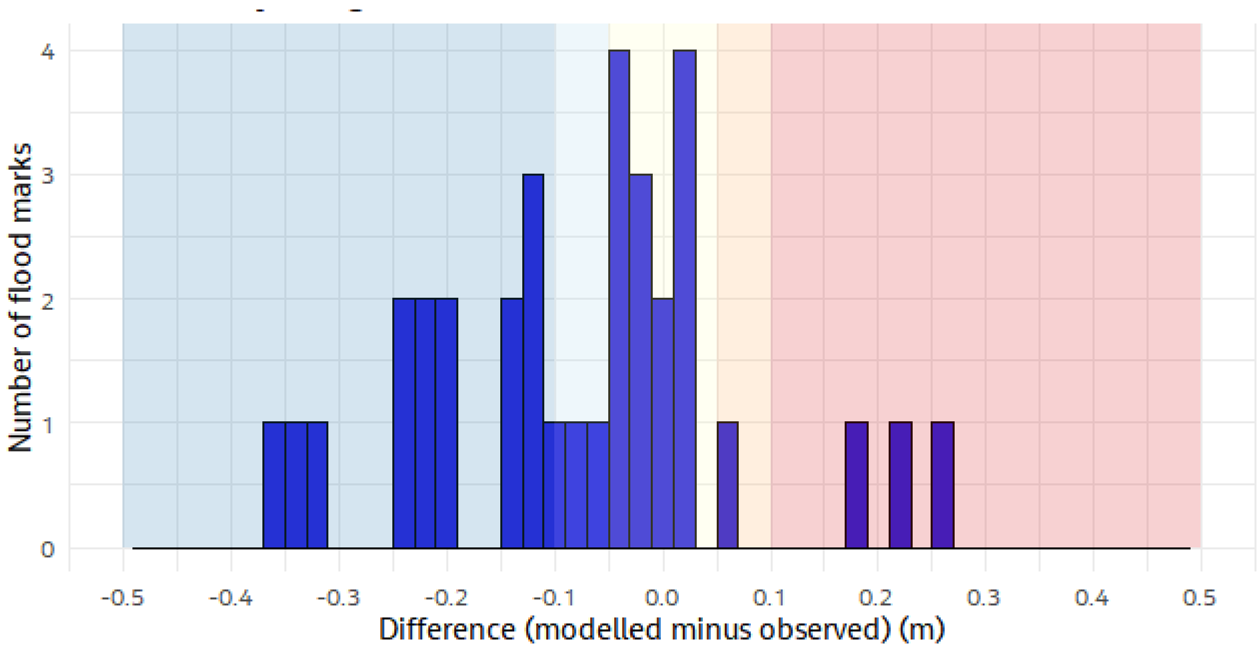
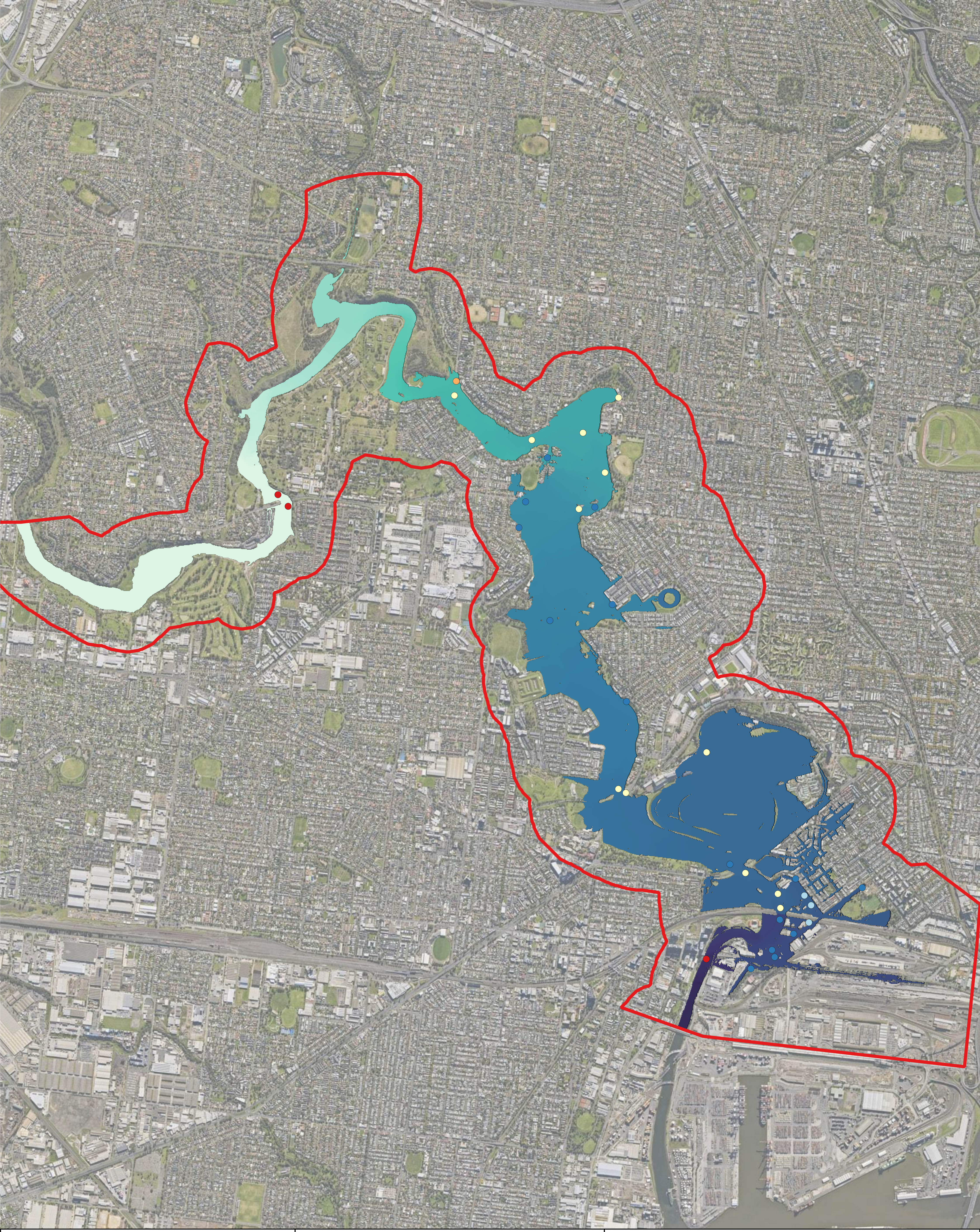


Figure 6-46: Lower Maribyrnong River modelled levels of calibrated 1974 flood event



Legend

Mapping extent

Difference to surveyed flood levels
- < 100mm
- 100 - 50mm below
- +/- 50mm
- 50 - 100mm above
- > 100mm

Modelled Levels (m AHD)
- 0.0
- 1.5
- 3.0
- 4.5
- 6.0

MGA Zone 55

Jacobs

0 0.5 1 km

Figure 6-47: 1974 modelled levels and flood marks

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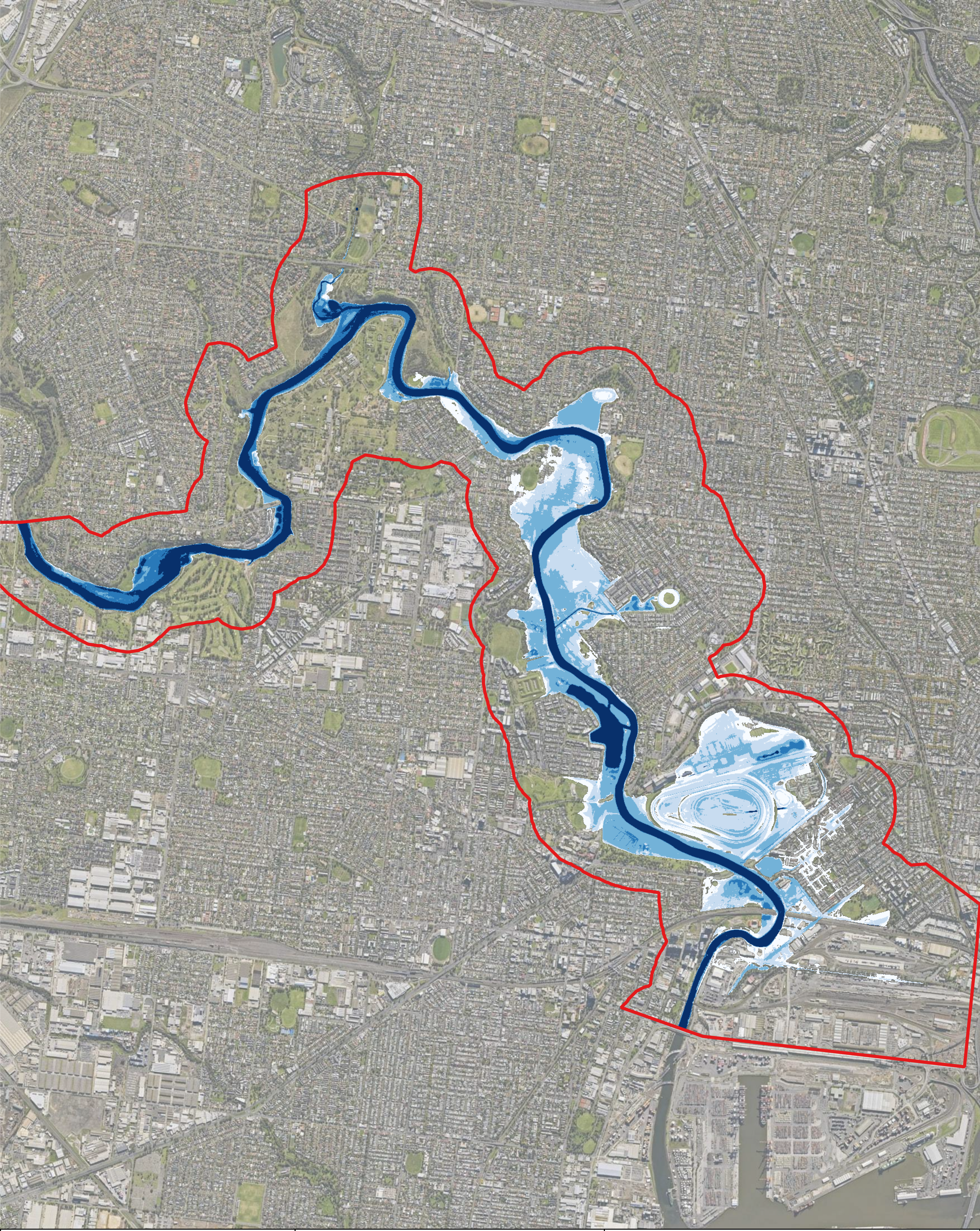

Legend

Mapping extent

Modelled depth (m)

- <= 0.5m
- 0.5 - 1.0m
- 1.0 - 2.0m
- 2.0 - 3.0m
- > 3.0m

MGA Zone 55

Jacobs

0 0.5 1 km

Figure 6-48: 1974 modelled flood depths

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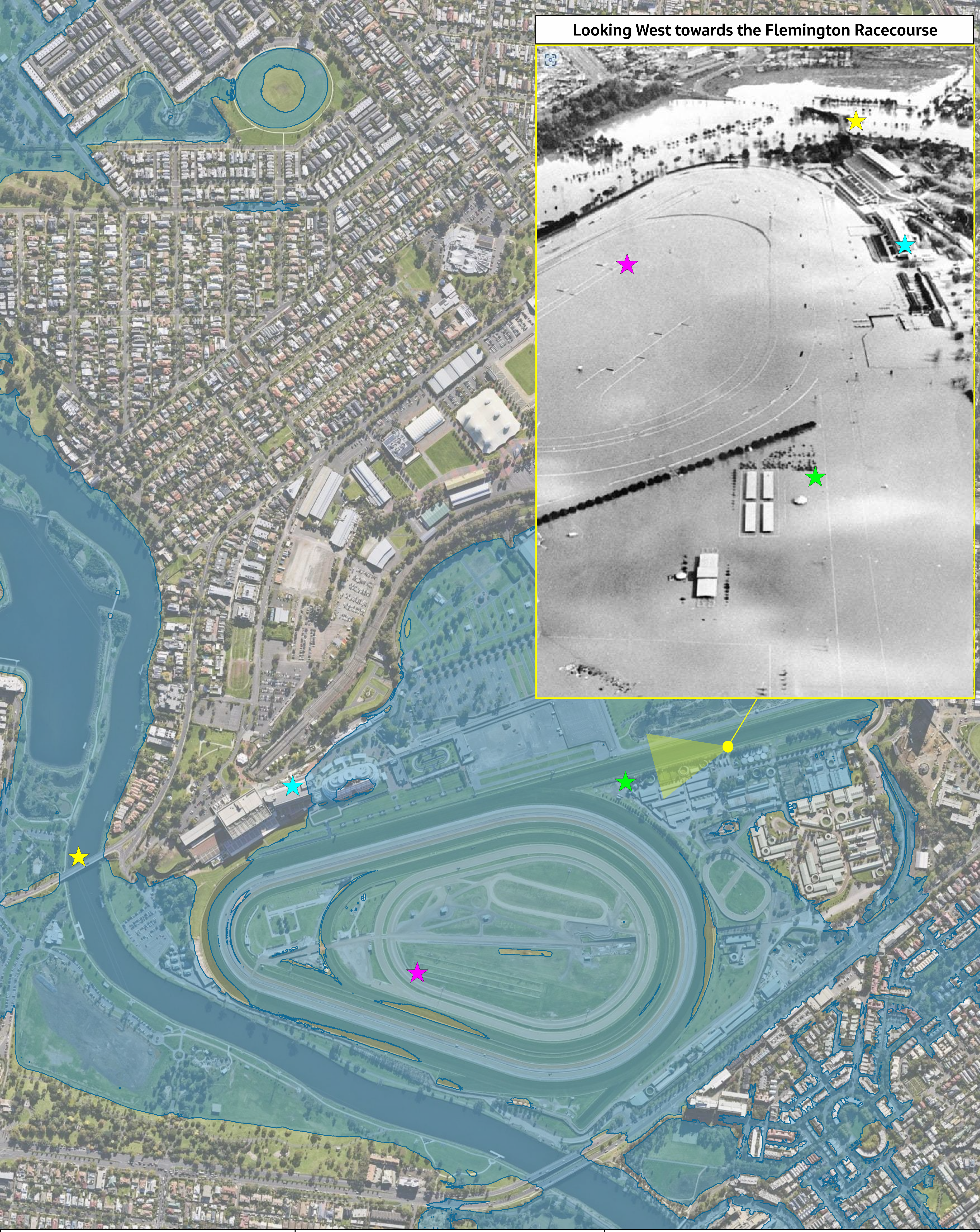

Legend

- Flood extent
- Vantage point of photograph

MGA Zone 55

Jacobs

0 100 200 m

Figure 6-49: 1974 modelled flood extent compared to photograph over Maribyrnong township

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Legend

- Flood extent
- Vantage point of photograph

MGA Zone 55

0 100 200 m

Figure 6-50: 1974 modelled flood extent compared to photograph over Maribyrnong township

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Project Number: IA5000NN	FINAL

6.10.10 1906 verification event

The 1906 event is the largest event in terms of reported flow rate (880m^3/s) and water level at Maribyrnong Township (4.5m AHD) and is therefore one of, if not, the most important event. For this reason, the event was investigated in the calibrated hydraulic model. It is acknowledged that there have been significant catchment changes since 1906, although the most significant have been downstream of Maribyrnong Township.

The purpose of this assessment was not to define the absolute flood level from this event, but rather to confirm the reasonableness of the peak discharge estimate for the event. To investigate this, two peak flows, 880m^3/s and 1,000m^3/s, were applied to the hydraulic model using the following procedure:

- Two hydrographs were prepared; the 2022 hydrograph at Keilor was scaled to 880m^3/s and 1,000m^3/s. These were applied to Keilor. No other inflows were applied as it was considered that these would be insignificant compared to the flooding from the river.
- Infrastructure that was not in place was removed from the model, this included:
  - Afton Street pedestrian bridge was removed.
  - The Raleigh (Maribyrnong) Road bridge was retained to approximate the existing bridge in this location in 1906 (see Plate 6-1).
  - Footbridges in Edgewater were removed.
  - Lynchs Bridge (both) were removed.
  - 2 of the 3 Footscray Rail bridges were removed.
  - The VRC Flood Wall was removed.
  - The Riverside Park levee (in Kensington) was removed.
  - The mitigation works associated with the VRC Flood Wall were removed.
- Manning's values were not adjusted given that there was no evidence to base this on; however, a report from 1803 indicated there were very few trees in the Flemington area (Maddigan and Frost, 1995). Plate 6-2 from 1895 shows the Ascot Vale and Maribyrnong areas with few trees. This suggests that the channel Manning's are naturally low for the Maribyrnong River and floodplain values would also be low.

The water level results at Chiefly Drive were extracted for both scenarios with the following results:

- 880m^3/s resulted in a level of 4.47m AHD.
- 1,000m^3/s resulted in a level of 4.75m AHD.

The 880m^3/s result was close to the reported 1906 water level at Maribyrnong whereas the 1,000m^3/s overestimated the 1906 level by 300mm. While it is not possible to determine the exact catchment conditions such as blockage to the Raleigh Road bridge, these results support the published flow rate of 880m^3/s at Keilor for the 1906 flood event.

Plate 6-1: Maribyrnong flood 1906 at Raleigh Road bridge with Anglers Hotel on the left (from Maddigan and Frost, 1995).

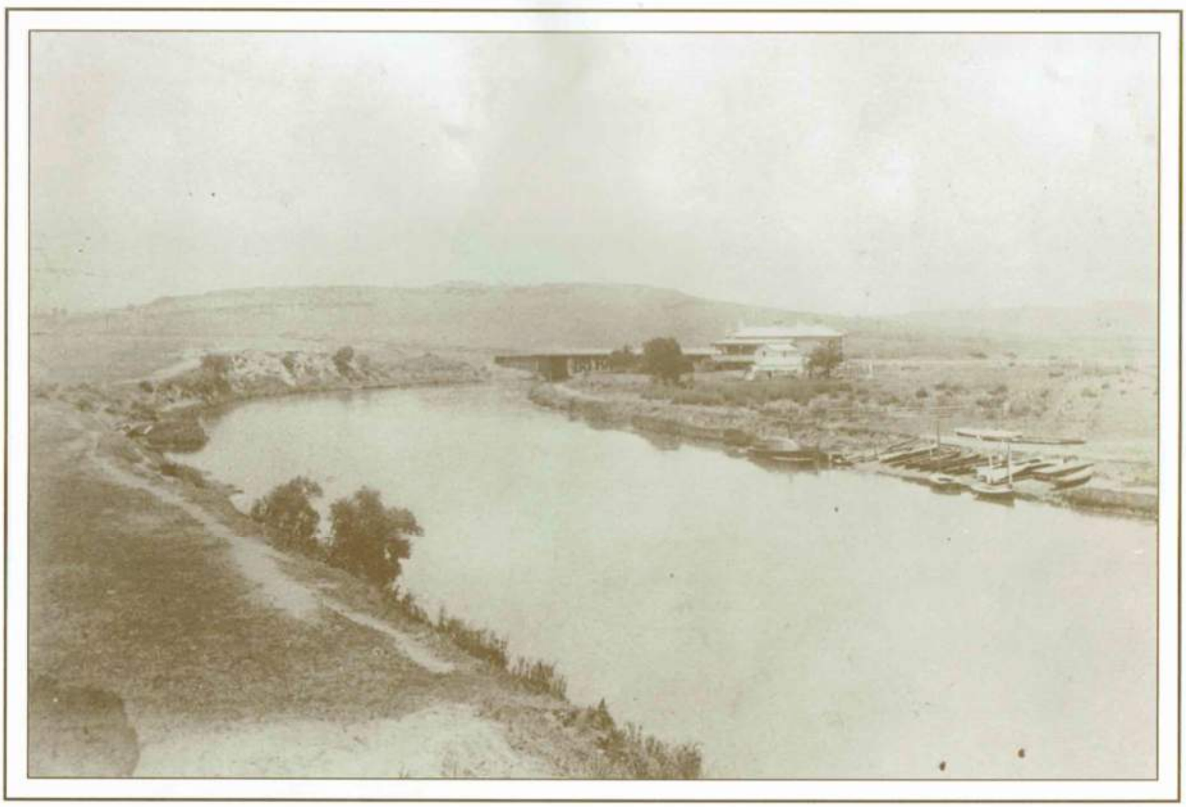

Plate 6-2: View towards Raleigh Road bridge with Anglers Hotel on the left (from Maddigan and Frost, 1995).

6.10.11 Calibration, validation and verification conclusions

The Lower Maribyrnong River hydraulic model has been calibrated to the October 2022 flood event, validated to a further three events and verified to the 1974 flood event. The calibration to the October 2022 flood event is excellent and the validation to the 1993 and 1983 event is considered to be good.

While the validation to the 2011 event is not as strong as other events, this was the smallest flood event and was the first flood event post the millennium drought. It is therefore possible that the catchment characteristics in 2011 were not representative of typical conditions. This reasoning, coupled with the fact that this was the smallest event means these validation results were given the least weight.

The verification using the 1974 event indicated the flood levels upstream of Maribyrnong Township were well represented, whereas downstream there was a systematic underprediction of water levels. This underprediction is likely to be due to the representation of the downstream tidal boundary, catchment changes or the blockage of the Kensington Rail Bridge. Given this, the model is considered to replicate the 1974 event reasonably well.

The hydraulic model was also used to verify the 1906 peak flow rate with results indicating that the reported value of 880m^3/s was reasonable.

The calibration, validation and verification results presented here demonstrate the Lower Maribyrnong River hydraulic model is suitable for design flood event modelling and is a useful tool for floodplain management.

6.11 Recommendations

There are a number of limitations and recommendations which are acknowledged and proposed to be addressed in future phases, including:

- Further work to understand any interaction between tides and Riverside Park, as well as the condition and/or operations of the flap-gate and the interaction with underground drainage.
- Results have not yet been communicated to stakeholders and the wider community. It is envisaged that when these results are communicated there will be feedback from the community. This feedback could provide valuable information to enhance the confidence in the results or highlight areas for improvement. It is strongly recommended that this process is undertaken.
- Should further details become available of the pre-existing conditions of key development such as Rivervue, Edgewater and Kensington Banks it is recommended that these are incorporated into modelling of historic events. However, this is not considered critical to the outcomes of the study as the hydraulic model is considered to be well calibrated.
- It is clear that the land use across the Lower Maribyrnong River floodplain has changed over the historic flood events however, at this stage, no alteration for floodplain Manning’s values have been made. It is recommended that floodplain Manning's values for future events be altered when new climate change guidelines are released.
- A procedure is developed by Melbourne Water to rapidly capture flood data following a significant flood event.

7. Hydraulic modelling and results

7.1 Design events

The design event modelling (discussed in Section 4.3.4) is summarised again below in Table 7-1.

Table 7-1: Design events modelled.

AEP	Scenario A: Base Case	Scenario B: Climate Change 1 – Sea level rise	Scenario C: Climate Change 2 – Sea level rise and increase in rainfall intensity	Scenario D: Climate Change 3 - Increase in rainfall intensity
20% AEP	✓		✓	✓
10% AEP	✓		✓	✓
5% AEP	✓			
2% AEP	✓			
1% AEP	✓	✓	✓	✓

Key information in each design event is summarised in Table 7-2.

Table 7-2: Peak inflows @Keilor, water levels @Chifley and downstream boundary water level for each design event.

Design Event (for (climate change scenarios, have a suffix "CC_X" after the identification of AEP where "X" refers to the modelling scenario)	Upstream Inflow Peak Flow (m^3/s) @Keilor	Water Level (m AHD) @Chifley	Downstream Boundary Water Level (m AHD) @ Maribyrnong River & Moonee Ponds Creek (see Figure 6-1)
20% AEP_A	322	2.44	0.85
20% AEP_CC_C	433	3.28	1.68
20% AEP_CC_D	433	3.08	0.85
10% AEP_A	463	3.24	0.89
10% AEP_CC_C	603	3.91	1.72
10% AEP_CC_D	603	3.80	0.89
5% AEP_A	601	3.80	0.92
2% AEP_A	778	4.38	0.96
1% AEP_A	905	4.74	0.99
1% AEP_CC_B	905	4.80	1.82
1% AEP_CC_C	1142	5.34	1.82
1% AEP_CC_D	1142	5.30	0.99
2022 Historical Event	768	4.17	Dynamic / varying (max 0.851)

7.1.1 Design event hydrographs

Figure 7-1 presents the inflow hydrographs at Keilor for various design events (including those with increased rainfall intensity - Scenario C & D).

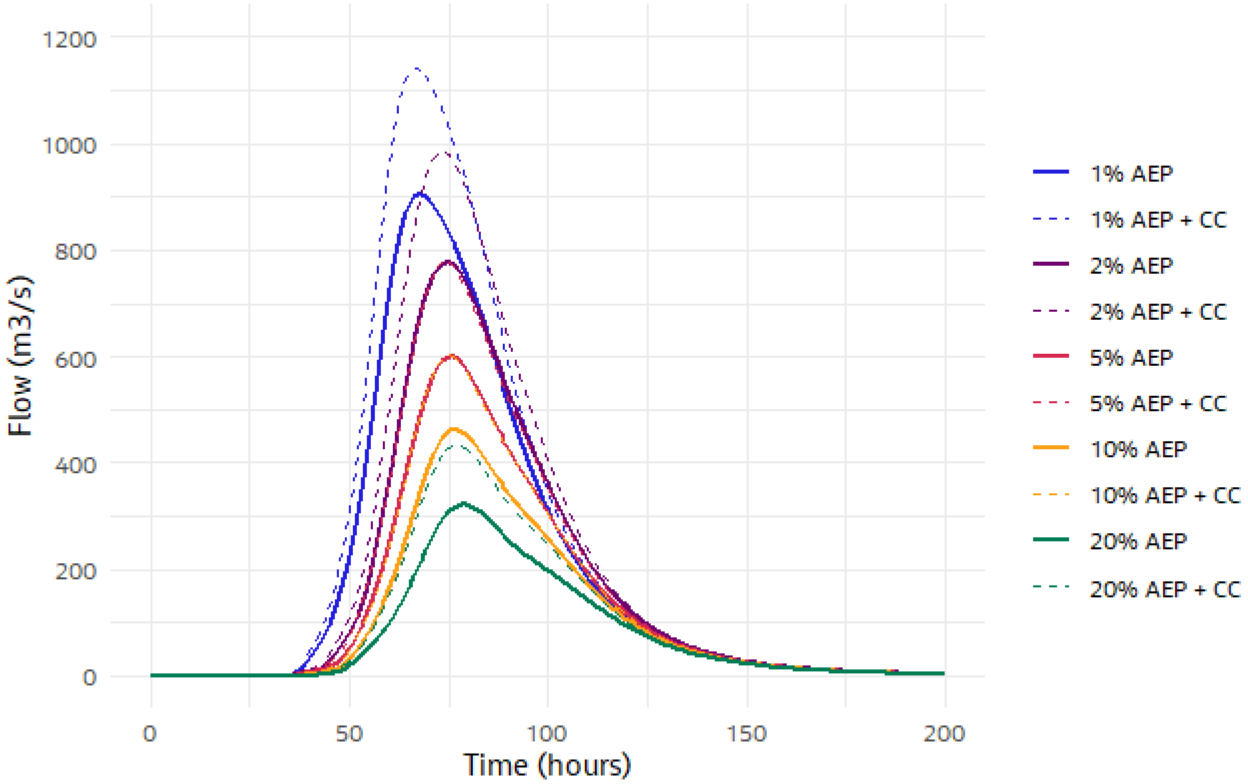

Figure 7-1: Hydrographs applied at the model upstream boundary for all design events including the 5 exceedance probabilities and climate change (the increased rainfall intensity associated with Scenario C & D).

Figure 7-2 presents the inflow hydrographs at Steele Creek for various design events (including those with increased rainfall intensity - Scenario C & D). Both the x and the y-axis for Figure 7-2, Figure 7-3 and Figure 7-4 have been left consistent with Figure 7-1 to enable a direct comparison of the order of magnitude of each of the inflow hydrographs.

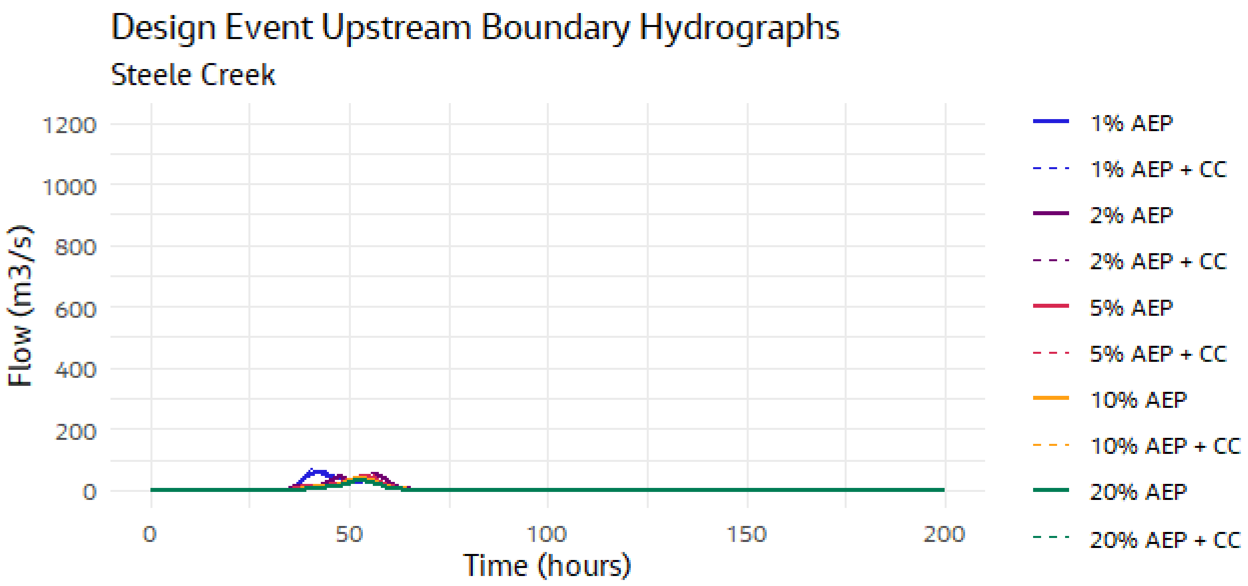

Figure 7-2: Hydrographs applied at Steele Creek upstream boundary for the same 10 design events

Figure 7-3 presents the inflow hydrographs at Taylors Creek for various design events (including those with increased rainfall intensity - Scenario C & D).

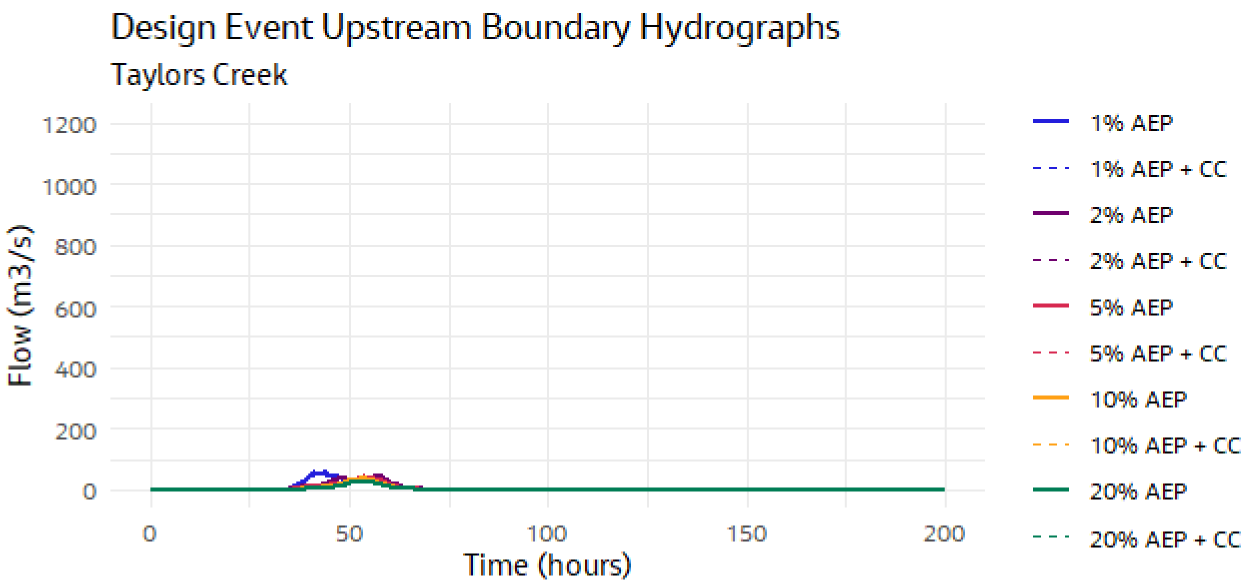

Figure 7-3: Hydrographs applied at Taylors Creek upstream boundary for the same 10 design events

Figure 7-4 presents an example of the distributed inflows, from Edgewater to Footscray Road, for various design events (including those with increased rainfall intensity - Scenario C & D).

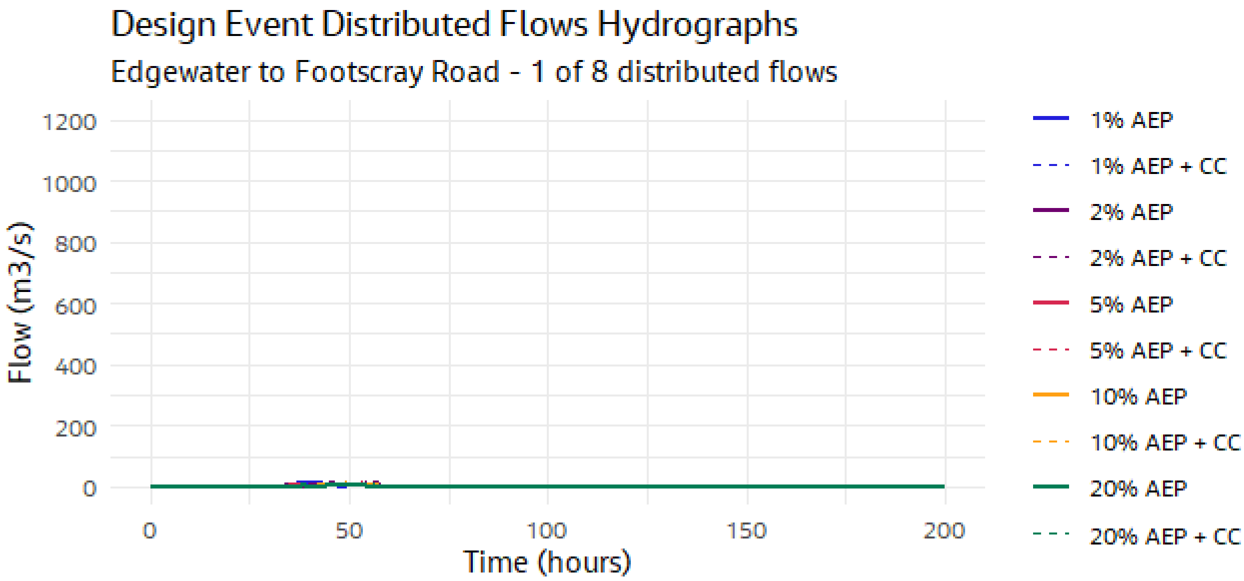

Figure 7-4: Hydrographs for the same 10 design events distributed along the stretch of river between Edgewater and Footscray Road – one of sets of 8 distributed flows in the model

7.2 Results processing

For each of the AEP events and scenarios the TUFLOW results from the flood model were post processed as per Melbourne Water's filtering guidelines:

Table 7-3: Results Processing Process.

Process	Description
Depth Filtering	Consistent with Melbourne Water Technical Specifications (August 2023) results were filtered to remove any cells where the depth of flooding is less than 0.05m.
Area Filtering	Isolated areas of flooding less than 100 m^2 were removed from the flood extent. Isolated dry 'holes' in the flood extent less than 100 m^2 were removed from the flood extent. Diagonal connections between adjacent grids are considered connected for the purposes of filtering areas.
Smoothing	Extent smoothed has been undertaken using a python script that has been developed using the same parameters and process as the feature manipulation engine (FME) tool provided by Melbourne Water.
Trim to Mapping Extent	The results are then trimmed to the mapping extent identified in Figure 6-1.
Manual Adjustments (1% AEP and 1% AEP with Climate Change - Scenario C)	The flood extents were then reviewed based on: Consideration of the area of the parcel that has flood extents intersecting is less than 2% of the parcel area and if the road frontage of the parcel is that has flood extents intersecting is less than 25% of the road frontage of the parcel. Engineering judgement and site understanding consideration were then applied to manually adjust flood extents for the 1% and 1% climate change (Scenario C).
Output	Grid cells which remain within the post-processed flood extent are extracted to provide flood modelling results

The flood extents for the 1% AEP and 1% AEP with Climate Change - Scenario C have subsequently had additional manual adjustments and refined to:

- Represent the Flemington Racecourse (Victorian Racing Club (VRC)) flood wall as dry cells during events where it is not overtopped. The width of the flood wall is smaller than the grid sizes and the hydraulic model representation results in connected flood extents on either side of the wall when the process above is applied to the results.
- Connect some of the discontinuous areas of the flood extent, where the model identifies that the disconnected areas are connected by wet cells with a depth of less than 50mm. An example of where this can occur is if ponded water is dropping off a ledge, flowing down a very steep embankment or overtopping a road the depth can reduce to less than 50mm but the flow path is still continuous.
- Flood extents that have been adjusted based on the above have subsequently undergone a final, manual, check to ensure that where adjustments have been made on the 1% AEP with climate change (Scenario C) these adjusted extents are then compared to the 1% AEP to ensure any adjustments are logical and consistent.

7.3 Results figures & findings

The flood extent and depth for the 1% AEP (Base Case- Scenario A) and 1% AEP including climate change (Scenario C) are presented below in this section as key outputs for this flood mapping project. The historical 2022 flood extent is also presented as an additional output of this project.

A full list of deliverables that have been provided to Melbourne Water are listed in Section 7.5. Flood extents for each AEP event and scenario modelled can be found in Appendix P.

7.3.1 1% AEP results

Figure 7-5 presents the 1% AEP event flood extent. This figure indicates that during a 1% AEP event several sections of the lower catchment would be inundated. Impacted areas include:

- Rivervue indicates some flooding in areas in proximity to the Maribyrnong River.
- The Maribyrnong Defence site, which is on the opposite side of the Maribyrnong River from Lily Reserve/Avondale Heights Parklands, indicates small areas of inundation adjacent to the Maribyrnong River. As this area is Commonwealth land it is not subject to Victorian planning conditions and is not considered further.
- Maribyrnong Township which is a known area that is prone to flooding and several previous flood events have been identified (See Section 2.1).
- Ascot Vale which has flooding primarily limited to roads and public open spaces.
- Edgewater indicates no flood extents in urbanised areas.
- Flemington Racecourse exhibits flooding across the site with flow paths indicated from both the west and from Smithfield Road to the south-east.
- Kensington Banks where flooding is indicated in various locations. Flow paths are seen from Riverside Park infrastructure (see Section 8.6) as well as several flow paths from the north-west from Smithfield Road and Hobsons Road to the south.
- The area south of Kensington and south of Dynon Road, east of the Maribyrnong River, which is primarily an industrial and commercial precinct, indicates flooding in various locations. This area contains several rail lines and rail yards as well as the Dynon Road Tidal Canal. It is acknowledged that there is limited information about drainage infrastructure in this location and the area was not a focus point for consideration in this study (see Section 9).
- The remainder of flooding is primarily limited to public open spaces, wetlands, parks and road reserves, particularly those areas adjacent to the river.

Figure 7-6 presents the 1% AEP event flood depths. Notable information visible on Figure 7-6 includes:

- The deepest areas of flooding are within the Maribyrnong River itself and adjacent wetlands, lakes and connecting creeks.
- Flooded areas of Rivervue generally indicates depths less than 1m.
- Maribyrnong Township has a range of flood depths ranging from less than 0.5m in the north-west area of the Township to greater than 2m in Burton Crescent Reserve south of Raleigh Road.
- Walter Street Reserve in Ascot Vale begins to act as a flood storage location but the limited duration and inflow flow rate to this low point in topography during the 1% AEP means the full storage area is not utilised.
- Flemington Racecourse, similar to Walter Street Reserve, acts as a flood storage location but the limited duration and inflow flow rate to area during the 1% AEP means the storage is fully utilised and depths are generally limited to less than 1m.

- Kensington Banks has a range of flood depths ranging from approximately 2m around Hobsons Road in the south to less than 0.5m in the north.
- The industrial area south of Kensington and south of Dynon Road has a variety of flood depths, the largest being greater than 2m at the Dynon Road Tidal Canal and at a topographic low point near Kensington Road and Dynon Road.

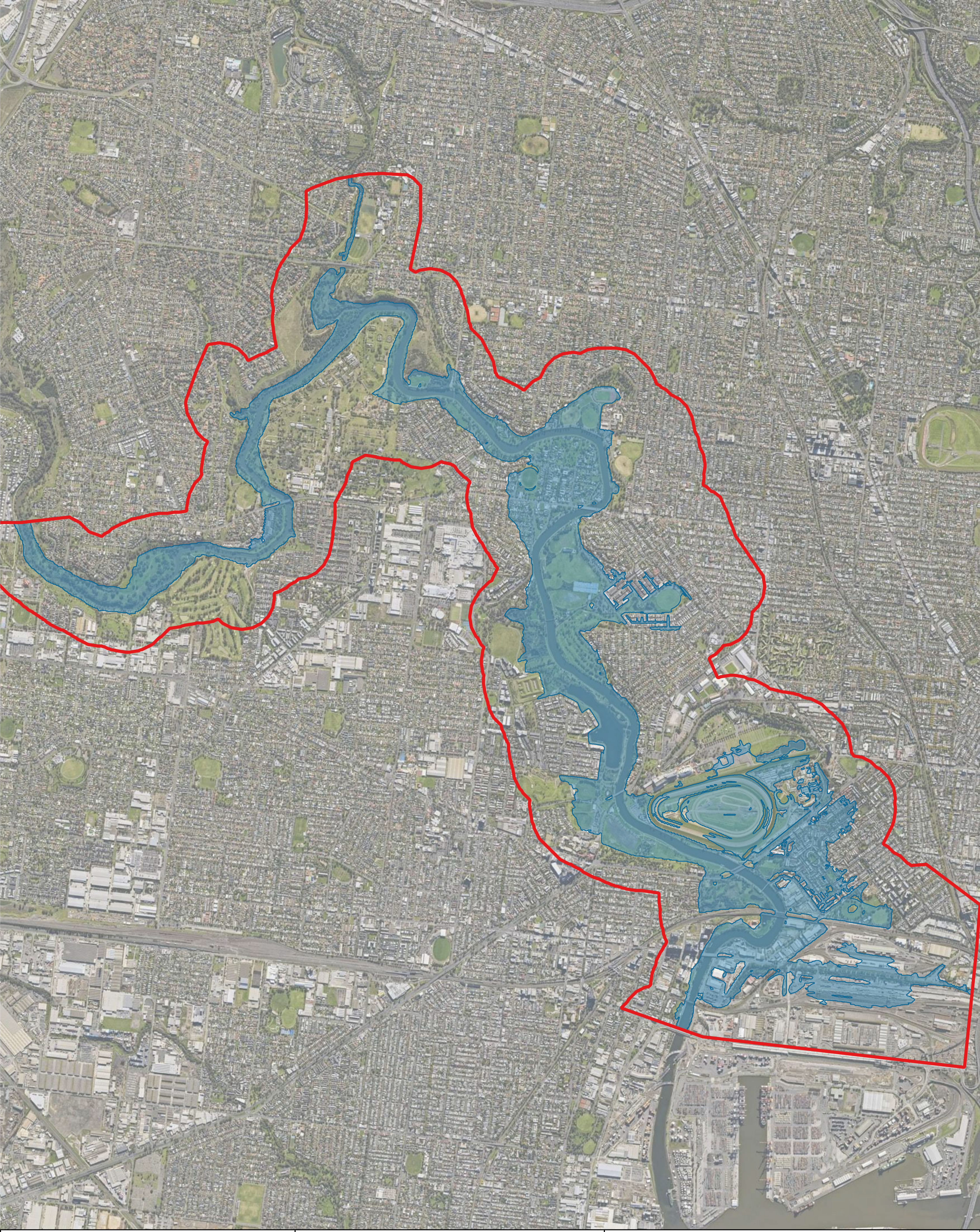

Figure 7-5: 1% AEP event modelled flood extent

Legend

- Mapping extent
- Flood extent

MGA Zone 55

Jacobs

0 0.5 1 km

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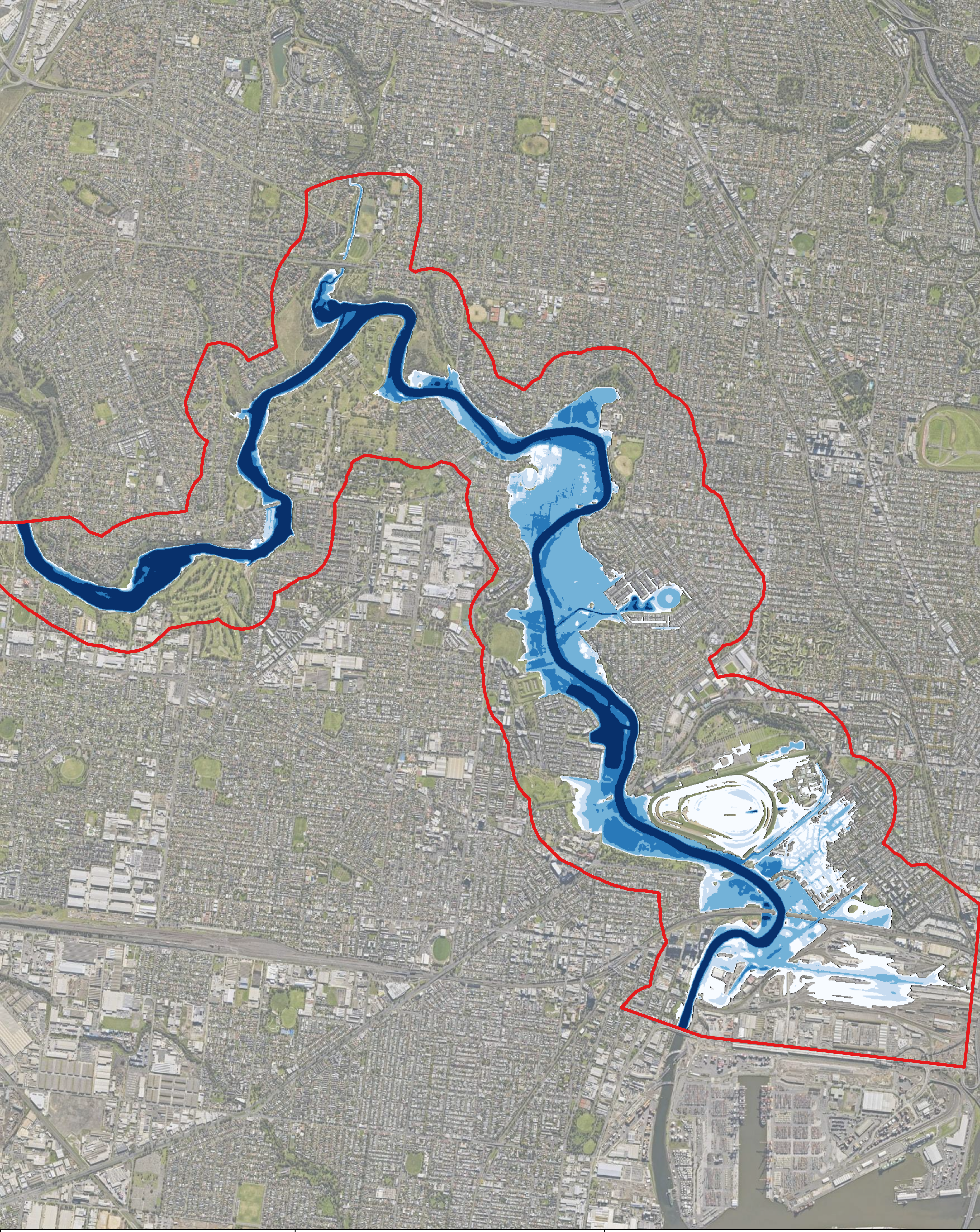

Legend

Mapping extent

Flood Depth

<= 0.5m

0.5 - 1.0m

1.0 - 2.0m

2.0 - 3.0m

> 3.0m

MGA Zone 55

Jacobs

0 0.5 1 km

Figure 7-6: 1% AEP event modelled flood depth

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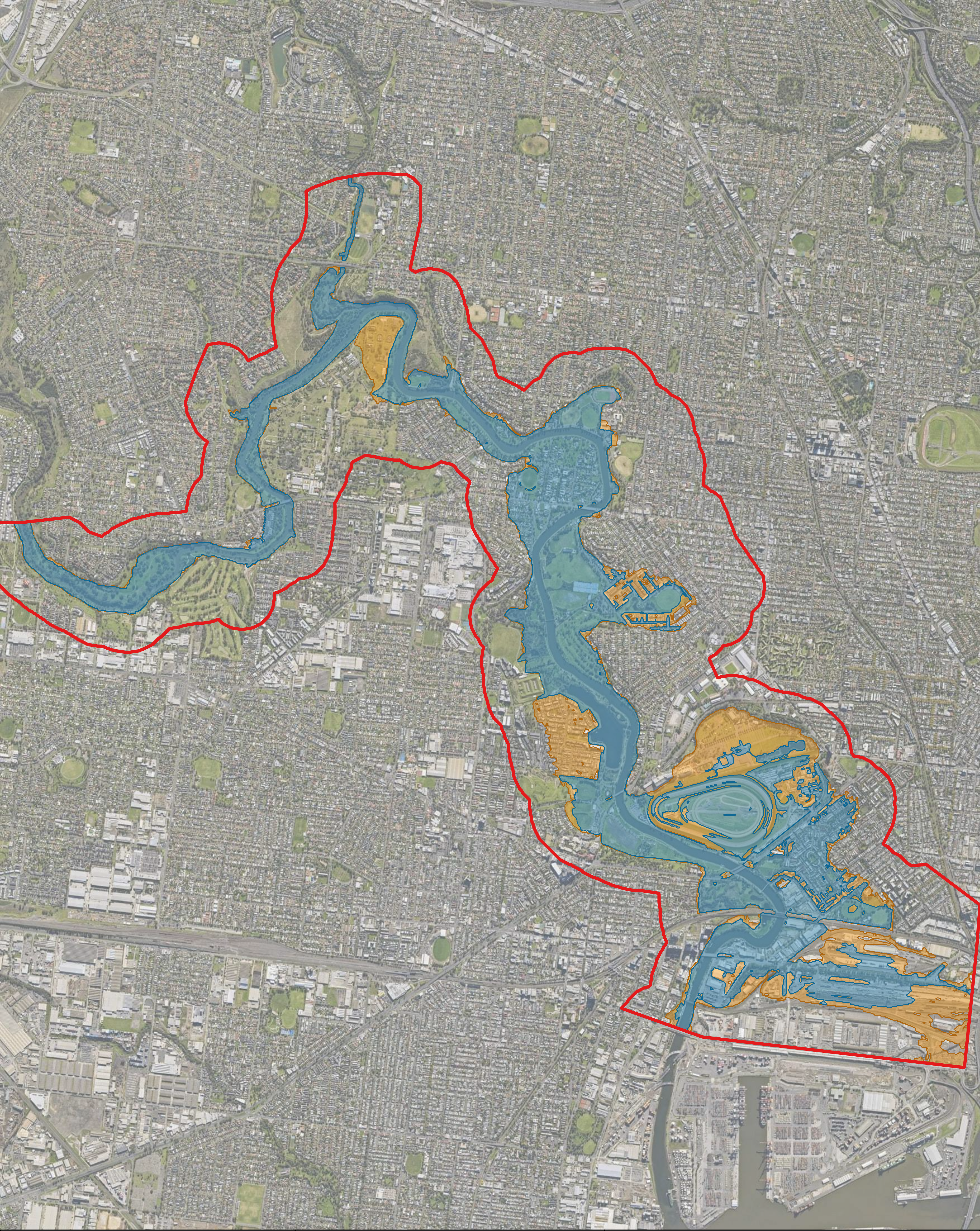
7.3.2 1% AEP including climate change results

Figure 7-7 presents the 1% AEP event with climate change (Scenario C), that is, increased rainfall together with sea level rise. Figure 7-7 indicates that there are several sections of the lower catchment that would be inundated as a result of climate change. Notable changes in extents include:

- The Maribyrnong Defence site is a new area of inundation. As this area is Commonwealth land it is not subject to Victorian planning conditions and is not considered further.
- The flood extents in Ascot Chase have increased as a result of climate change. Flood extents are visible as having extended in the area around Ascot Chase Wetland and Walter Street Reserve.
- Edgewater which previously had no flooding in urbanised areas during the 1%AEP event is now visible as having flood extents during the 1% AEP with climate change.
- Kensington has a visible increase in flood extents particularly around JJ Holland Park.
- The industrial area south of Kensington around Dynon Road, east of the Maribyrnong River, indicates additional flooding in various locations. There are increased flood extents around the rail yards north and south of Dynon Road. It is acknowledged that there is limited information about drainage infrastructure in this location and the area was not a focus point for consideration in this study (see Section 9).

Figure 7-8 presents the 1% AEP event with climate change (Scenario C) flood depths. Comparison of Figure 7-8 with Figure 7-6 is similar to the comparison of flood extents (Figure 7-7). Notable additional information visible on Figure 7-8 includes:

- Flood depths have increased across most of the mapping extent.
- Maribyrnong Township now has a larger area that is now indicated as greater than 2m flood depth as a result of climate change.
- Flemington Racecourse has a flood depth of greater than 2m due to climate change. This indicates this area acting as a storage area and the top water level is similar to that of the Maribyrnong River.
- Kensington in the northern section in proximity to Flemington Racecourse has flood depths ranging from 2m to less than 0.5m.
- Kensington in the southern area around Dynon Road has increased flood depths across the rail yards broadly ranging from 0.5m to 2m.
- As expected, the change in flood extents due to climate change have resulted in new flood depth areas at the Maribyrnong Defence site (not considered further), Ascot Vale (less than 0.5m in new extents) and Edgewater (ranging from approximately 1m in road reserves to less than 0.5m in other areas).



Legend

- 1% AEP flood extent
- 1% AEP with climate change (Scenario C) flood extent
- Mapping extent

MGA Zone 55

Jacobs

0 0.5 1 km

Figure 7-7: 1% AEP and 1% AEP with climate change (Scenario C) modelled flood extent

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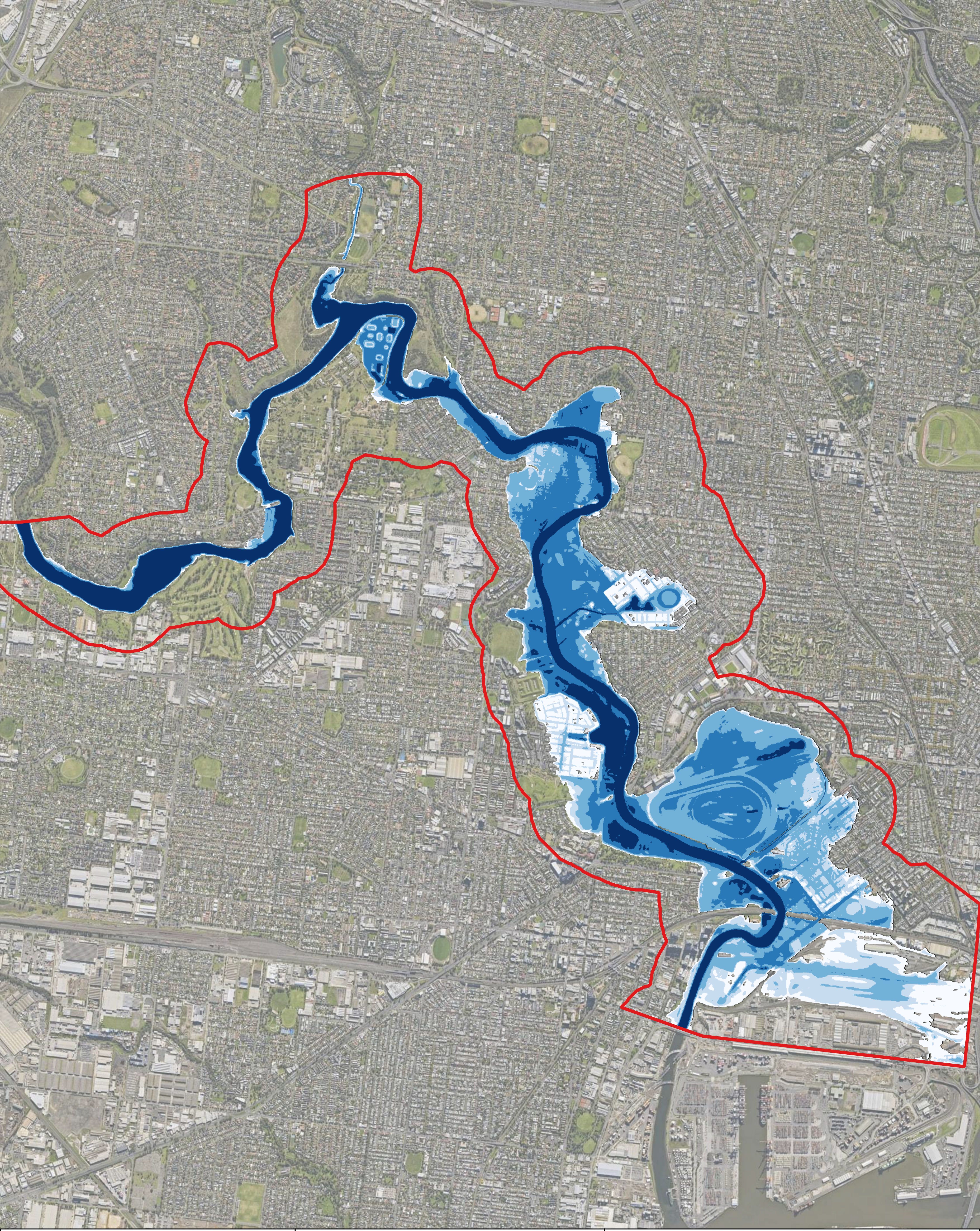
Project Number: IA5000NN	FINAL



Legend

Mapping extent

Flood Depth

- <= 0.5m
- 0.5 - 1.0m
- 1.0 - 2.0m
- 2.0 - 3.0m
- > 3.0m

MGA Zone 55

Jacobs

0 0.5 1 km

Figure 7-8: 1% AEP event with climate change (Scenario C) modelled flood depth

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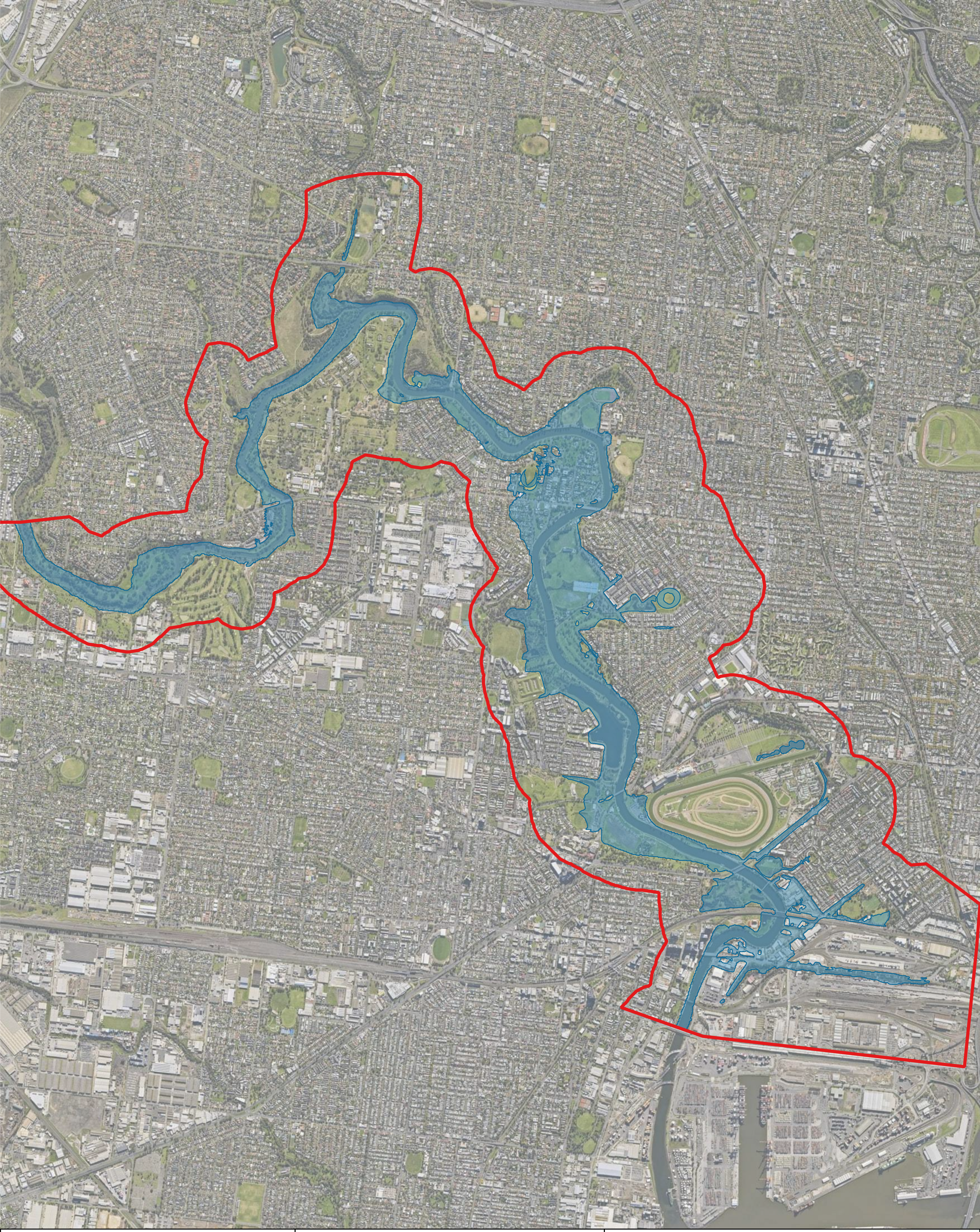
7.3.3 October 2022 modelled results

Figure 7-9 presents the historical 2022 event modelled flood extent. These results indicate that during the October 2022 event several sections of the lower catchment were inundated. Impacted areas include:

- Rivervue indicates flooding of properties in proximity to the Maribyrnong River.
- The Maribyrnong Defence site with small areas of inundation adjacent to the Maribyrnong River. As this area is Commonwealth land it is not subject to Victorian planning conditions and is not considered further.
- Maribyrnong Township which is a known area that is prone to flooding and several previous flood events have been identified (See Section 2.1).
- Ascot Vale which has flooding primarily limited to roads and public open spaces.
- Edgewater indicates no flood extents in urbanised areas.
- Flemington Racecourse exhibits no flooding inside the site. There is also evident flooding along Smithfield Road to the south-east.
- Kensington Banks has flooding in various locations. Flow paths are seen from Riverside Park infrastructure (see Section 8.6) but the flooding from this point appears to be limited to public open spaces and road reserves. There is an additional flow path from the south along Hobsons Road which inundates the areas near the Maribyrnong River and extends along road reserves and public open spaces to the east.
- The area south of Kensington, near and along Dynon Road, east of the Maribyrnong River, which is primarily an industrial and commercial precinct, indicates flooding in various locations. This area contains several rail lines, rail yards as well as the Dynon Road Tidal Canal. It is acknowledged that there is limited information about drainage infrastructure in this location and the area was not a focus point for consideration in this study (see Section 9).
- The remainder of flooding is primarily limited to public open spaces, wetlands, parks and road reserves, particularly those areas adjacent to the river.



Legend

Mapping extent

Flood extent

MGA Zone 55

Jacobs

0 0.5 1 km

Figure 7-9: October 2022 historical event modelled flood extent

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7.4 Quality assurance

The TUFLOW model has been reviewed in accordance with Melbourne Water's Quality Assurance (QA) Framework spreadsheet. An internal review of the TUFLOW model was completed by a senior engineer. Improvements identified by the reviewer were integrated back into the model. The remaining TUFLOW model warnings and checks are summarised in Table 7-4. They have been assessed as not likely to adversely affect the model results. Reviews completed by Melbourne Water's reviewer are provided in Appendix M and reviews completed by additional external reviewers can be found in Appendix N.

Table 7-4: TUFLOW Warnings and Checks (from the 1% AEP event).

Warning/Check	Comment	Occurrences	Justification
1100	The WARNING is issued where a 1D structure's invert/bed lies below the invert/bed of the primary upstream and/or downstream channel.	13	Pipe inverts change due to steepness of underlying terrain
1401	When applying the Engelhund loss approach for manholes (see Section 4.5.2 of the 2010 TUFLOW manual), if an incoming culvert enters above the obvert of the highest outlet, the culvert is not included in the manhole loss calculations. See also point 48(b) in the release notes.	25	Model results not significantly impacted by 1d network
1402	When applying the Engelhund loss approach for manholes (see Section 4.5.2 of the 2010 TUFLOW manual), if an incoming culvert enters above the obvert of the highest outlet, the culvert is not included in the manhole loss calculations. If there is only 1 incoming pipe with the invert above the obvert of the outlet culvert, the incoming culvert is ignored and with no inlet culvert to the node a manhole is not possible. See also point 48(b) in the release notes	8	As above
2118	Lowered SX ZC Zpt to 1D node bed level.	62	All terrain lowering mostly below 0.5m. A few points of greater than 0.5 m occur in wetlands or at the start of Ascot Main Drain and are not significant to model results.
2210	For layered Flow Constriction (2d_lfcsh) object the obvert of the	78	Some instances where bridge polygons are positioned slightly past the bank. Does not impact results.

	lowest layer (e.g. soffit of bridge deck) is below ground level.		
2218	Manning's n value is unusually low or high.	1	Placeholder Manning's value not used.
2470	LFC approach hasn't been specified and is defaulting to Portion approach.	174	PORTION approach is used by default, no impact.
2583	The Wu eddy viscosity formulation is based on bed friction velocity, which in turn is dependent on manning's number. High manning's numbers produce very high viscosity values, which in turn can limit the model timestep through the diffusion or Peclet number (reported as "Nd" in the HPC output). In general, in areas where very high manning's numbers are used (for example the slowing effect of buildings may be represented as increased surface roughness), the flow velocity is much slower and the elevated viscosity has little effect, other than to slow the simulation down. An upper limit to the manning's number used in the Wu viscosity calculation was introduced in the 2023-03-AA release to limit the computed viscosity in regions of unusually high roughness. Note that this only affects the viscosity calculation, the momentum equation will continue to use the original roughness value (or lookup table) as defined in the materials file. This warning message indicates that one or more of the manning's values used exceed the limit imposed for Wu viscosity calculation. The default limit is 0.1.	2	Only applies to the building envelopes (n = 0.4) and the placeholder 'empty' land use which is not in the land use layer.
2815	WARNING 2815 - Write PO Online not yet supported in Quadtree.	1	Warning only regarding use of quadtree, does not impact model results.

7.4.1 Model mass balance

The volume error for this model throughout development has been negligibly low. This is presumably due to the fact that this is a riverine model with large flows confined mostly to the channel and open space floodplains. Volume error is usually associated with comprehensive 1d drainage networks which do not feature heavily in this model. For the 1% AEP event model run, the total volume error was 226 m^3, representing 0.00% (rounded) of the total volume.

7.5 Deliverables

In accordance with Melbourne Water's requirements flood mapping outputs have been delivered to Melbourne Water for all AEP events and scenarios modelled. The data has been delivered in MGA2020 Zone 55 Grid and AHD using the Ausgeoid2020 geoid. MapInfo tables and GIS shapefiles have been provided for the deliverables. Data provided is summarised in Table 7-5.

Table 7-5: Deliverables.

Deliverable	Comment
Hydrology model	The RORB model including the setup files and outputs have been provided to Melbourne Water.
Hydraulic model	The TUFLOW model build files and results (zipped) have been provided to Melbourne Water. Post processing grids of the results (i.e., the calculation of the max-max grid for each AEP) has also been provided).
GIS deliverable files	Refer to Table 7-6.
Flood Maps	Flood extents for the simulated AEP events are provided in Appendix P.

Table 7-6: GIS Deliverables.

Deliverable	Comment
RORB Tables	ESRI feature class format GIS information has been provided for the RORB reaches, nodes, subareas and catchment area.
Grid Points (1m)	Raw and trimmed grid points at 1m resolution have been provided for each AEP event and each Scenario.
Model Gird Points	Raw and trimmed grid points at 1m resolution have been provided for each AEP event and each Scenario.
Gauging Stations	ESRI feature class GIS information has been provided for Maribyrnong River at Chifley Drive Maribyrnong (230106A).
Plot Output Lines	Flow values were extracted from the plot output lines from TUFLOW for each AEP.

Deliverable	Comment
Flow Values	Flow values at the Plot Output Lines have been provided as above. The drainage infrastructure included in the Lower Maribyrnong TUFLOW model was incorporated solely to examine backwater effects from the Maribyrnong River and flow rates at these locations would only produce spurious results, so these were not included.
Flood Extents	The TUFLOW results for each AEP event and each Scenario. As per Melbourne Water's requirements the results were processed as outlined in Section 7.2.
Flood Contours	Flood contours were produced at 0.5m intervals based on the maximum water levels (h max) grid for each AEP event and each Scenario. The contours were smoothed with discontinuous and circular sections removed with additional adjustments also applied in alignment with requirements.
Level of Service	Not Applicable. The drainage infrastructure included in the Lower Maribyrnong TUFLOW model was incorporated solely to examine backwater effects from the Maribyrnong River and level of service information at these locations would only produce spurious results.
Digital Terrain Model (DTM) and Digital Elevation Model (DEM)	The DEM has been provided as part of the TUFLOW model delivery above. For this study the DTM is the same as the DEM.
Flood Study area	The flood study area was produced based on the 1% AEP event and the 1% AEP with climate change (Scenario C).
Parcels Flooded	Flooded parcels were determined by intersecting the provided parcels layer with the 1% AEP and 1% AEP with climate change (Scenario C) flood extents within the mapping extents.
Buildings Flooded	Flooded buildings were determined by intersecting the provided buildings layer with the 1% AEP and 1% AEP with climate change (Scenario C) flood extents within the mapping extents. The buildings dataset used to identify buildings flooded was supplemented with additional survey (see Section 7.5.1).

7.5.1 Building floor levels

Jacobs were engaged in March 2024 to undertake Mobile Laser Scanning (MLS) to capture data across the following areas:

- Kensington.
- Ascot Vale.
- Edgewater.

Details of the MLS survey can be found in Appendix C. The MLS capture generates a Pointcloud dataset from which floor levels are identified and extracted from door frames visible in the Pointcloud. A total of 1353 building floor levels were measured as part of the MLS and 72 locations validated. This information was then incorporated into the Buildings GIS layer that was provided by Melbourne Water for the purposes of generating building impacts GIS deliverables.

No missing/incomplete floor levels were infilled via traditional surveying methods which means while Melbourne Water's GIS building floor level dataset will be significantly improved it may still be incomplete.

Table 7-7: List of GIS Flood Mapping Deliverables (found in MW_LMAR.gdb)

Flood Mapping Deliverables (Refer to 2023 Melbourne Water Flood Mapping Guidelines)	File Naming Convention (<AEP> is presented as the numerical percentage of the AEP with a PCT suffix to denote percentage e.g. the 1% AEP event is named "1PCT") (for climate change scenarios "CC_X_" is a prefix where "X" refers to the modelling scenario as well as a suffix denoting the year of at which this climate scenario begins e.g. 2100)	Historical Events	Modelling Scenario A: Base Case					Scenario B: Climate Change 1 – Sea level rise	Scenario C: Climate Change 2 – Sea level rise and increase in rainfall intensity			Scenario D: Climate Change 3 - Increase in rainfall intensity		
		2022	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	1% AEP	20% AEP	10% AEP	1% AEP	20% AEP	10% AEP	1% AEP
Grid Points (1m) – Raw and Trimmed	POINTS_1M_<AEP>_RAW POINTS_1M_<AEP>		✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓
Grid Points (model resolution) – Raw and Trimmed	POINTS_ MODELGRID _<AEP>_RAW POINTS_MODELGRID_<AEP>		✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓
Plot Output (PO) Lines	PLOT_OUTPUT_LINE						✓	✓			✓			✓
Flow Rate	FLOW_RATE						✓	✓			✓			✓
Gauging Stations	GAUGE_STATION_<AEP>		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Flood Extent	FLOOD_EXTENT_<AEP>_WATERWAYS [historical provided separately as shp file]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Flood Study Area	FLOOD_STUDY						✓	✓			✓			✓
Flood Contours	FLOOD_CONTOUR_<AEP>_WATERWAYS		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Flood Affected Parcels	PARCEL_FLOODED_WATERWAYS						✓	✓			✓			✓
Flood Affected Building Footprints	BUILDING_FOOTPRINT_WATERWAYS						✓	✓			✓			✓

8. Sensitivity analysis

8.1 Volume sensitivity analysis

This section investigates the sensitivity of water levels in the Lower Maribyrnong River to peak flows and hydrograph volumes. An understanding of this is important as a consequence of the adopted approach to determining the design hydrology is that the hydrograph volume is greater than using the standard approach. To investigate this the peak flow, volume and peak water level change at Chifley Drive were appraised and are presented in Figure 8-1.

This analysis used the following events and synthetic hydrographs which were applied to the TUFLOW hydraulic model:

- Historic events: 2022, 2011, 1993 and 1983.
- Current conditions design events: 1%, 2%, 5%, 10% and 20% AEP.
- Rainfall climate change design event (i.e. Scenarios C and D).
- A set of synthetic volume sensitivity hydrographs. The 24-hour hydrograph, for the design runs, were modified to conduct volumetric sensitivity analysis and are shown in Figure 8-2. This was done by modifying the timesteps as follows:
  - The timestep was reduced from hourly to half-hourly (i.e. same flows in each timestep as the 24-hour hydrograph but the duration of each timestep reduced). This is referred to as the 12-hour time base.
  - The timestep was not changed. This is referred to as the 24-hour time base.
  - A time-based 48-hour hydrograph was produced by increasing the timestep of the 24-hour hydrograph from hourly to 2-hourly. This is referred to as the 48-hour time base.
  - A time-based 72-hour hydrograph was produced by increasing the timestep of the 24-hour hydrograph from hourly to 3-hourly. This is referred to as the 72-hour time base.

The purpose of these synthetic hydrographs was to test the impact on flood levels at Chifley Drive from different volume events with the same peak.

The peak flows and volumes were measured at the Keilor gauge and the peak level at the Chiefly Drive gauge. The peak flows and volumes for the historic events were calculated from the recorded data whereas for design events and sensitivity hydrograph these metrics were calculated from the RORB or modified RORB hydrographs. All levels were modelled results to use a consistent data source.

The results plotted in Figure 8-1 show:

- That peak water levels increase with peak discharge with little scatter about the line of best fit. The outlier is the 1993 historic event. It is noted that the tailwater for this event (tidal boundary) was reasonably low compared to the other calibration and validation events (see the results in Section 6.10). This may have contributed to the lower peak water level.
- Peak water levels tend to increase with volume, although this is considerably more scattered compared to the level-discharge plot in the left-hand panel. Further, the historic events tend to have lower volumes than design events as expected.
- The sensitivity hydrographs produce similar peak water levels despite having vastly different volumes.

The results presented in Figure 8-1 and Table 8-1 demonstrate that the peak water levels at Chifley Drive are driven by peak discharges at Keilor rather than hydrograph volume. This indicates that the adopted approach to determining the design hydrology does not significantly impact on peak water levels.

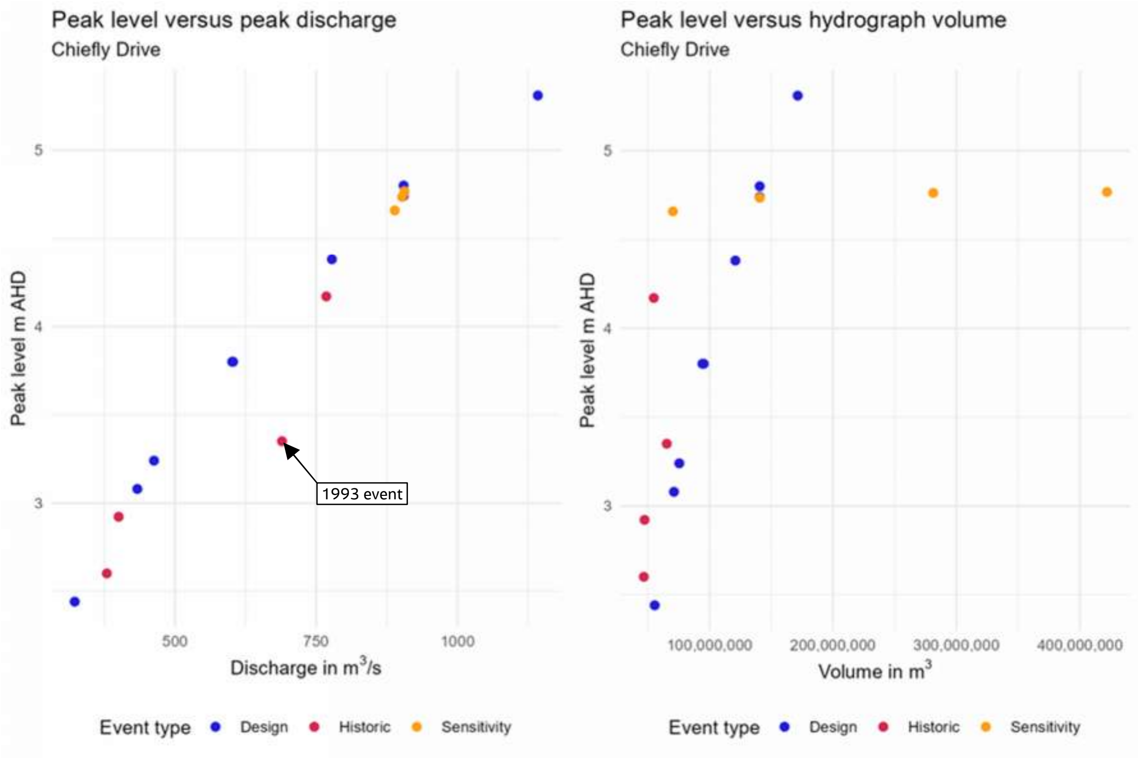


Figure 8-1: Plot of peak level at Chiefly Drive versus peak discharge on the left-hand panel and versus hydrograph volume on the right-hand panel. Three groups have been plotted Design events, Historic events and Sensitivity events.

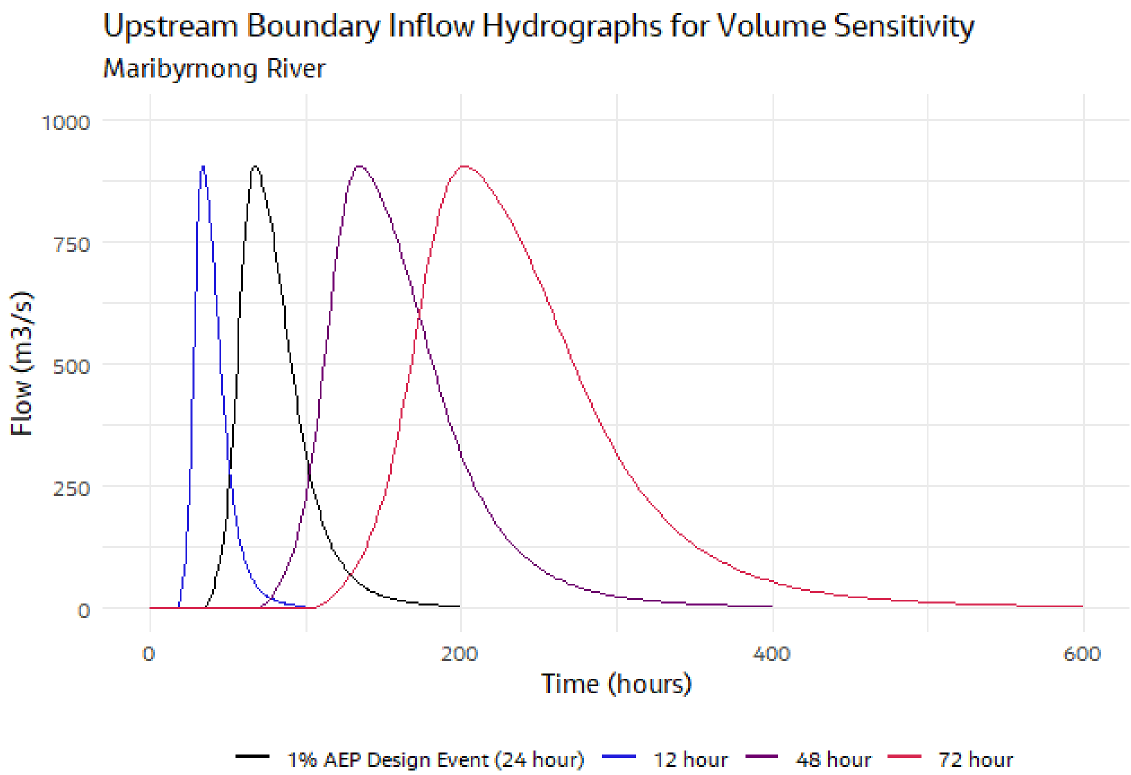


Figure 8-2: Inflow Hydrographs at the Maribyrnong River upstream boundary used in the 4 volume sensitivity model runs.

Table 8-1: Chifley Drive Gauge levels and event volumes for 4 different event duration model runs.

1% AEP Event Duration	Peak Flow (m^3/s) at upstream boundary (Keilor)	Peak Level (m AHD) at Chifley Drive Gauge	U/S boundary inflow volume (ML)
12-hour time based	889	4.66	70,300
24-hour event	902	4.74	140,600
48-hour time based	906	4.76	281,200
72-hour time based	906	4.77	421,800

8.2 Control factor sensitivity

The control factor is 1 by default in TUFLOW. A sensitivity run was conducted using a value of 0.5 and the results indicated limited sensitivity as seen in Figure 8-3. A control factor of 1 was adopted.

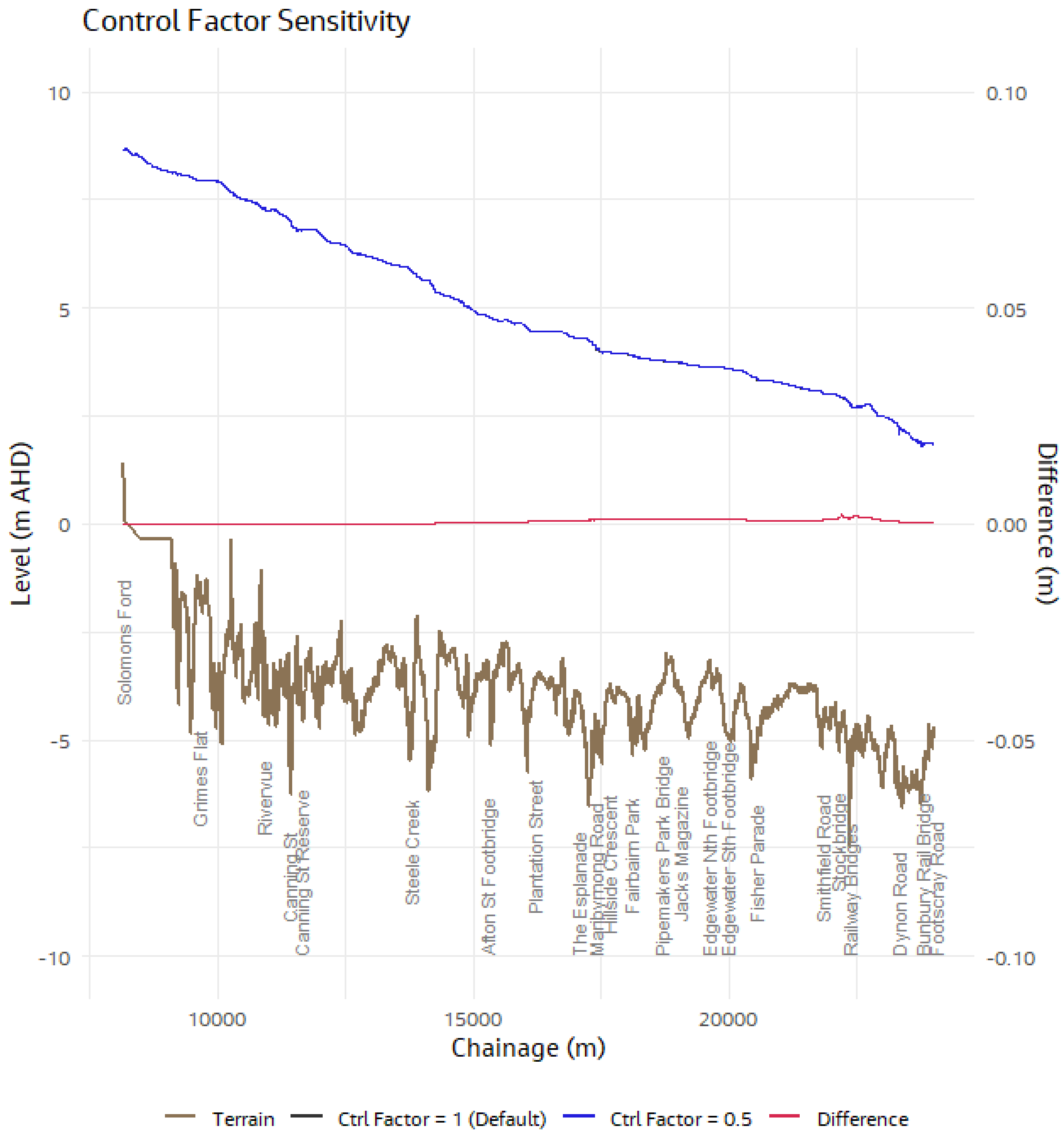


Figure 8-3: Longitudinal section comparing the default control factor of 1.0 and a sensitivity run of 0.5.

8.3 Tidal level

Tidal sensitivity was tested using five combinations of inflow and tidal events, the result of which are shown in Figure 8-4. These sensitivity tests were undertaken before full design hydrographs and tidal levels were derived, so the values used were intended to be indicative only. Three inflow hydrographs were used:

- A high nominally 0.5% AEP event, with a peak flow of 1,070m^3/s.
- A nominal 1% AEP event, with a peak flow of 890m^3/s.
- A nominal 50% AEP event, with a peak flow of 122m^3.

The 1% AEP event was paired with three different tidal levels:

- A high level, approximating the 1% AEP peak tide level.
- A lower level, approximating the 10% AEP peak tide level.
- A much lower level, approximately representing a 55% AEP peak tide level.

The 1%, 10% levels for the Yarra River were adopted (1.417m AHD and 1.168m AHD respectively) from Table 35 of the Melbourne Water Technical Specifications. A tidal level corresponding to less than the 10% AEP was not available from Table 35 so to capture a lower tidal peak level at the Maribyrnong River downstream boundary, the 55% AEP level at St Kilda (Table 34) was scaled by the ratio of the 10% AEP tidal level at St Kilda (from Table 34) to the 10% AEP tidal level at Yarra River (Table 35) – a 97.3% ratio. The 55% AEP tidal level at St Kilda Marina (0.9m AHD) was then adjusted by this ratio for an adopted level of 0.876m AHD.

Figure 8-4 indicates that under the 1% AEP, any difference in modelled flood levels due to the three different tidal boundary levels is indiscernible in proximity to Maribyrnong Township, and not significant upstream of Kensington rail bridge. Downstream of this bridge, as expected due to the closer proximity to the downstream boundary, there is greater sensitivity to the tidal boundary level.

The greater influence of the tidal boundary downstream of Kensington rail bridge is reinforced by the 0.5% AEP event, which shows consistently higher levels than the other events until proximity to the Kensington rail bridges, where the influence of lower tidal levels results in a modelled flood level similar to the other events.

The 50% AEP event shows that the modelled flood levels are overall much more sensitive to the inflow hydrograph than to the tidal levels, with the pairing to the relatively high 1% AEP tidal level still producing modelled peak flood levels lower than in any other sensitivity run at the downstream boundary.

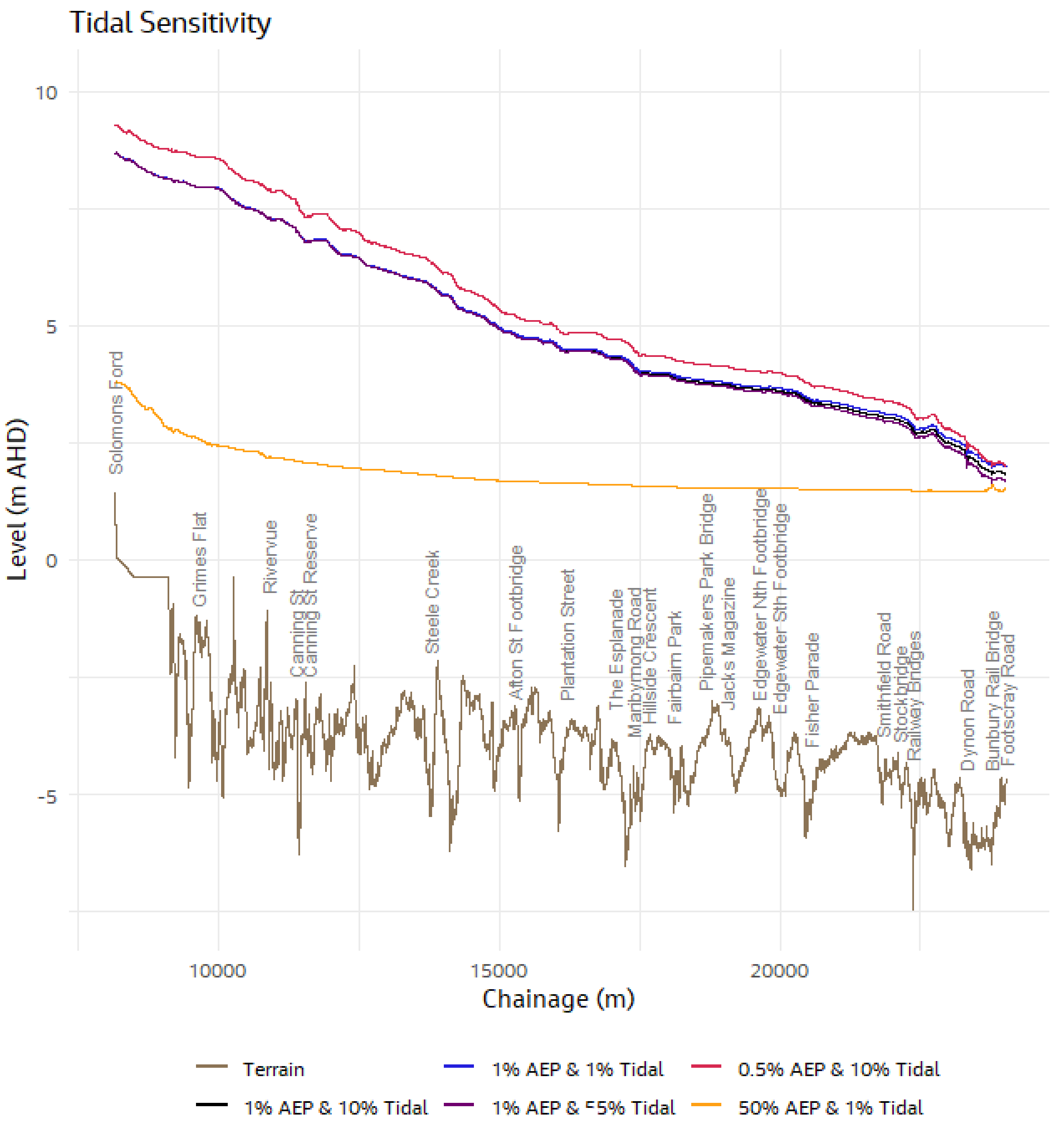


Figure 8-4: Longitudinal sections showing modelled flood levels under various combinations of inflow and tidal events.

8.4 Grid orientation sensitivity

A north-south orientation was used in this model. The direction of flow varies from Keilor to the downstream boundary meaning there is no overarching general direction of flow different to the north-south orientation of the Maribyrnong catchment. The sensitivity of this was tested by comparing the regular north-south grid to a roughly 45 degree-orientated grid using a 2d_loc line, the results of which are shown in Figure 8-5. The results show that there is minor sensitivity to this model setup. The downstream reaches of the river indicate up to approximately 100mm in sensitivity , reducing to less than 50mm for the majority of the length of the river. The model was calibrated to a north-south grid.

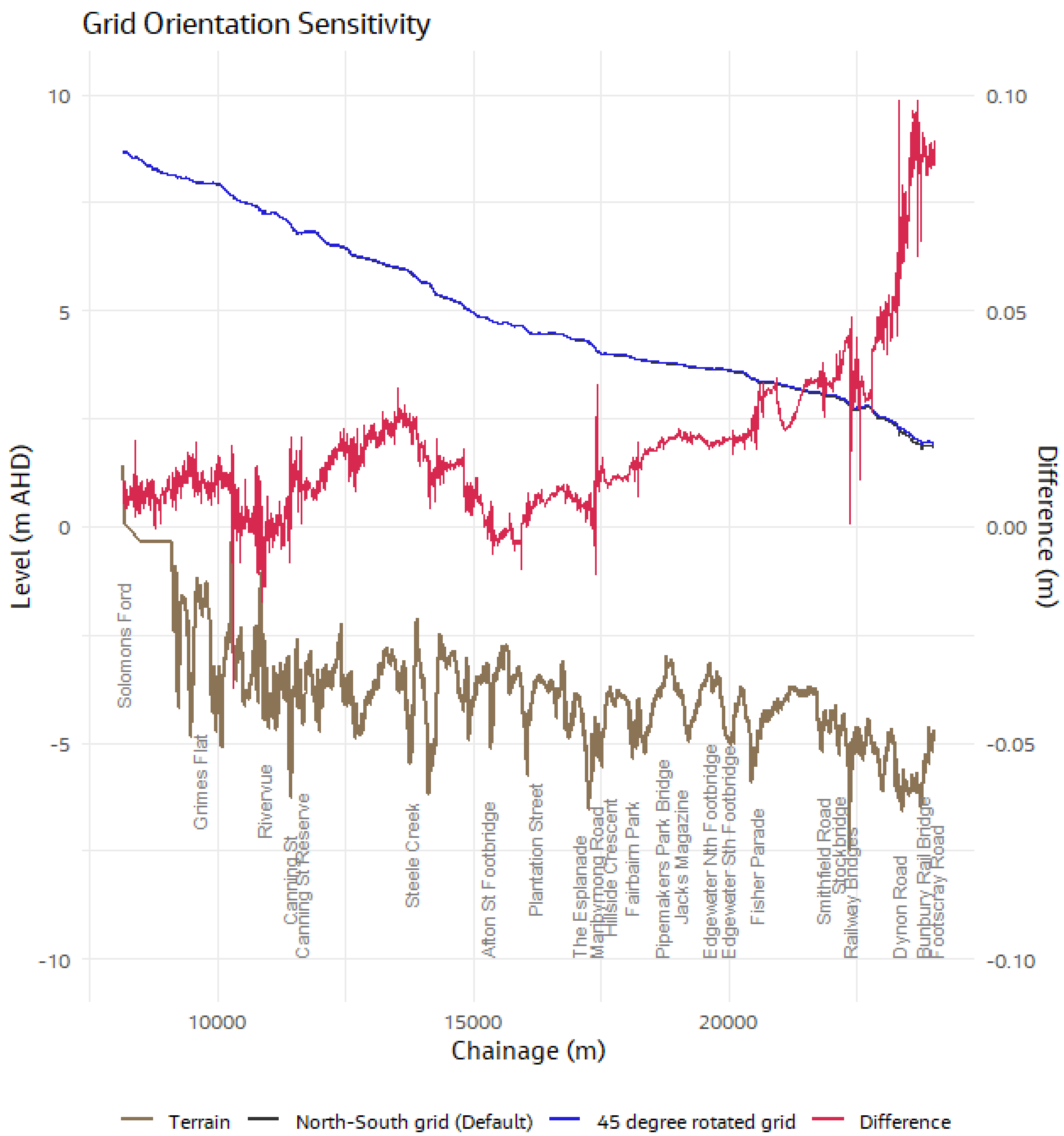


Figure 8-5: Longitudinal section of the model default North-South grid and a sensitivity run using a 45-degree-rotated grid orientation.

8.5 Channel roughness

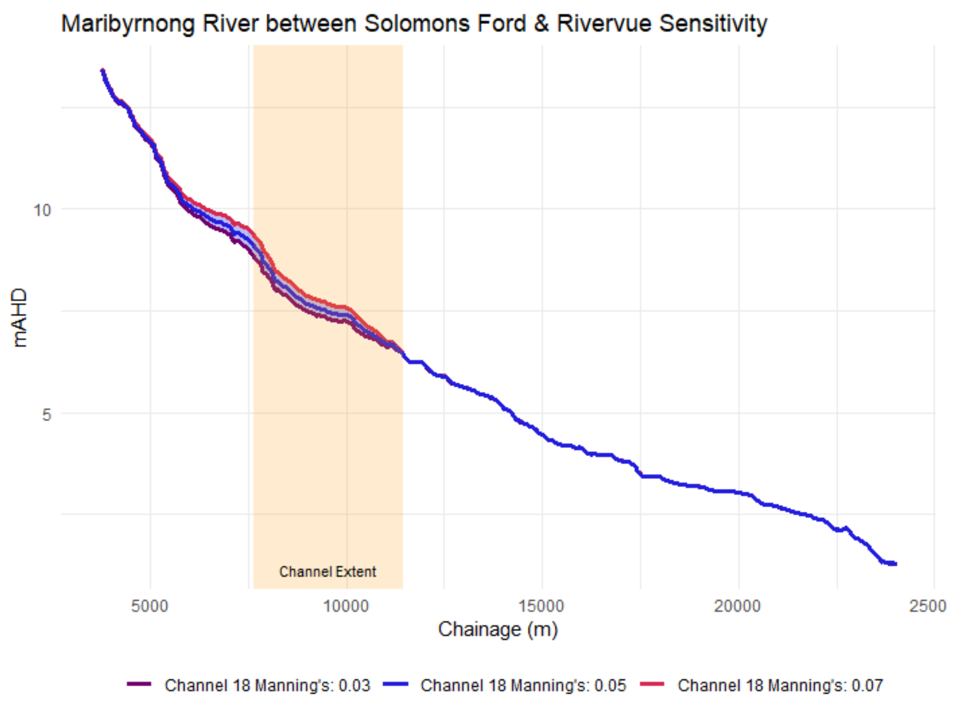
The Manning's roughness coefficient used in the channel was the main calibration parameter.

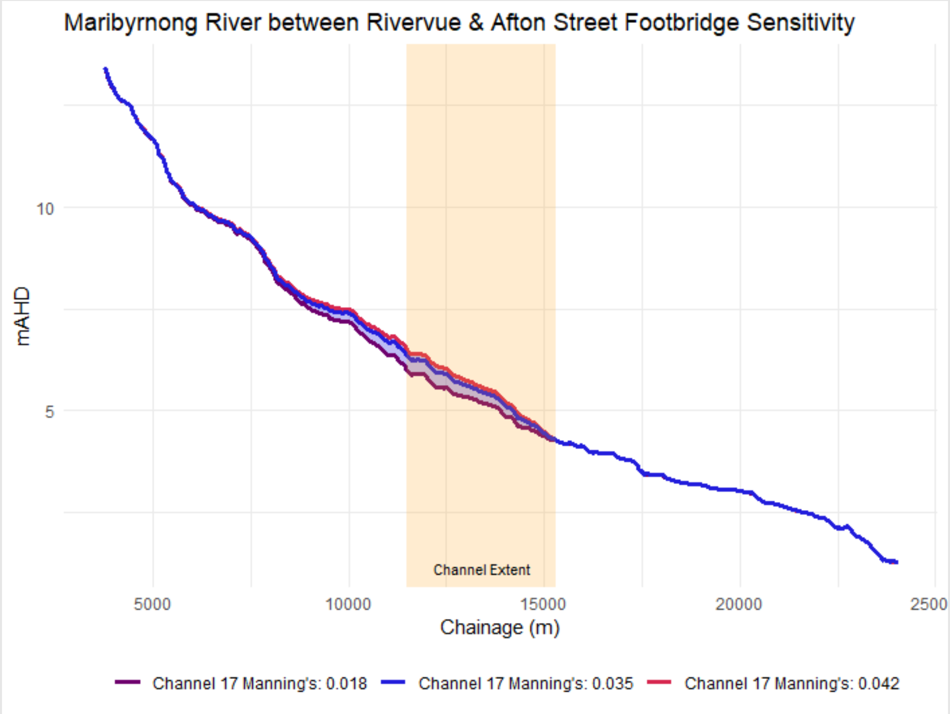
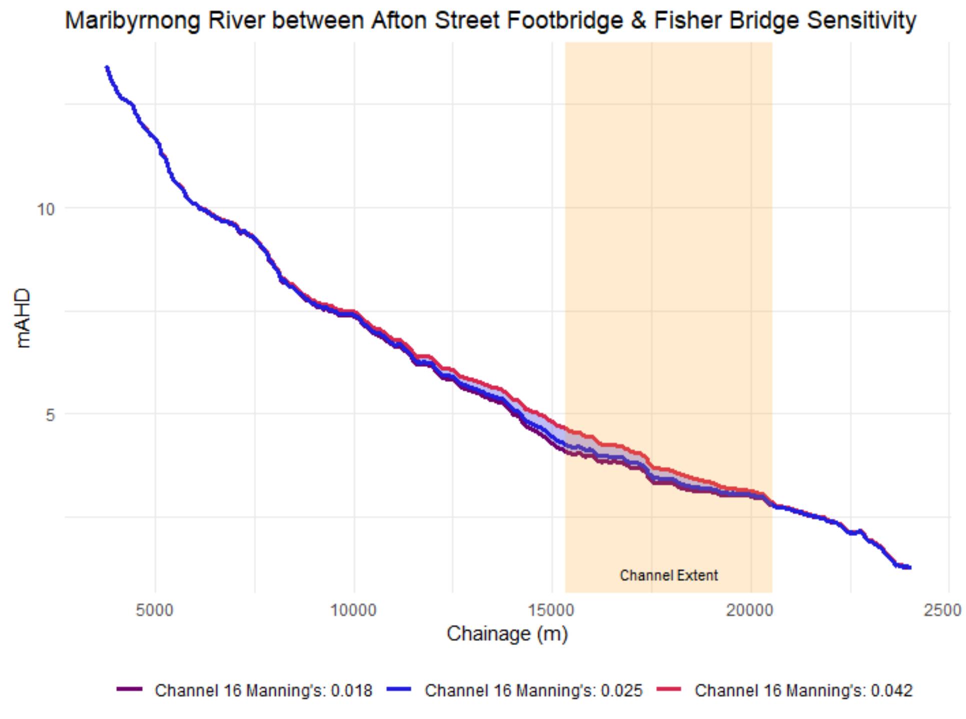
For the purposes of representing channel Manning's roughness, the channel was split into four segments (refer Section 6.9.1). To test sensitivity, the model was run with a higher, a lower and a mid- manning's roughness coefficient for each segment of channel. At the time this sensitivity was carried out the calibrated roughness values had not yet been adopted, so these values do not necessarily align with the final calibrated values.

Table 8-2 shows levels along the length of the model, from the Albion Viaduct (at approximate chainage 5000) to the downstream boundary (further upstream to Keilor gauge is not shown due to lack of sensitivity). The sensitivity of channel roughness to modelled peak flood levels can be seen in the difference between the three model runs on each graph.

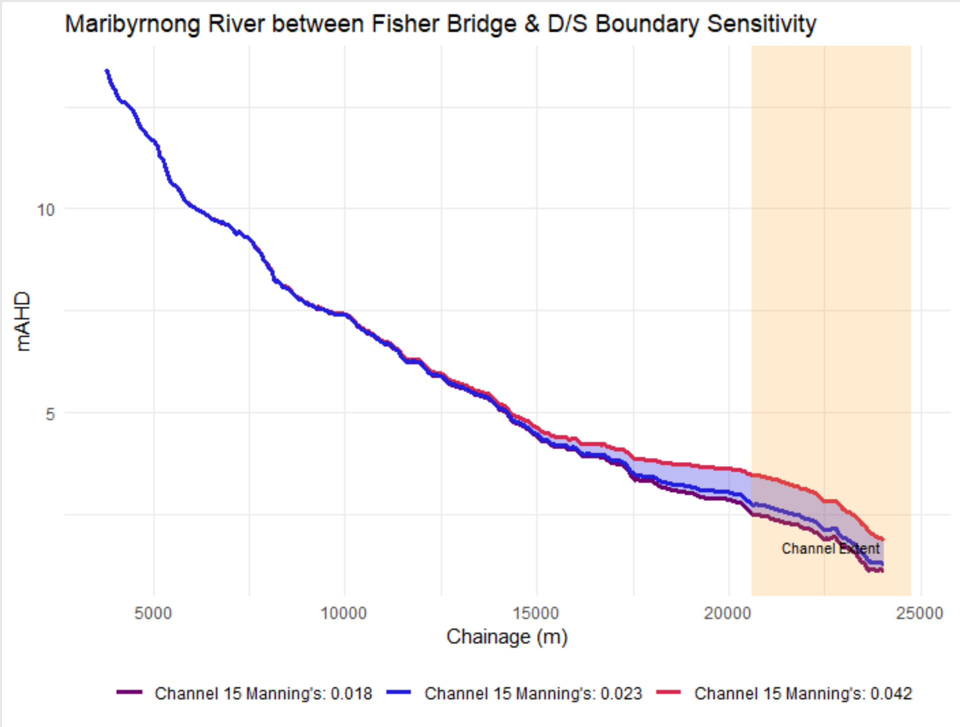
The sensitivity of water levels to Manning's roughness is clearly evident in the segments of the channel where the roughness parameter is varied, with less discernible sensitivity upstream and limited discernible impact seen downstream. The magnitude of the impact in the reach between Solomons Ford and Rivervue is lower because the channel is comparatively narrow through that segment. Further downstream, the difference in modelled peak flood levels between the lower and the higher Manning's values increases in relation to channel width and reaches above 1m near the downstream boundary, confirming that the model is highly sensitive to this parameter and confirming the need for this parameter to be used as a key calibration parameter.

Table 8-2: Longitudinal sections showing channel Manning's (roughness) sensitivity

Channel segment	Longitudinal Section
18: Between Solomons Ford & Rivervue	

17: Between Rivervue & Afton Street Footbridge	
16: Between Afton Street Footbridge & Fisher Bridge	

15: Between Fisher Bridge & D/S Boundary



8.6 Riverside Park infrastructure

As discussed in Section 6.7.2 and Section 6.7.2.1, additional information was received regarding the infrastructure and levee in proximity to Riverside Park (see Appendix O). Sensitivity analysis was undertaken using the following configuration of this infrastructure:

- Two 1d pipe elements, with dimensions as per the plans shown in Appendix O
- An overflow pit where these two pipes meet, with the ground level of this pit informed by the DEM/LiDAR.
- The location of the outlet (inlet from the Maribyrnong River) and invert was informed by a combination of the drawings in Appendix O and the bathymetric survey.
- A two-thirds blockage applied to the next pipe upstream, to represent the gate-flap as only partially functional.

The sensitivity was tested using the 2022 calibration event. The result of this sensitivity test was an increase in the extent of flooding through Kensington Banks, shown in Figure 8-6. The following can be concluded from this sensitivity analysis:

- The extent of flooding through Kensington Banks is sensitive to the representation of this piece of infrastructure in smaller, more frequent, events when alternate flow paths do not develop (i.e. events equal to or less than the 2% AEP as discussed in Section 6.7.2.1).
- A 66% blockage at the flap-gate is not sufficient to restrict flow through the pipes.

The final adopted model configuration for design events (refer Section 6.7.2.1) was utilised because:

- The configuration calibrated well to the understanding of flooding in Kensington Banks.
- The flooding of this area is expected to be insensitive in larger events (greater than 2% AEP) due to multiple flow paths into Kensington).
- Survey was attempted at this location but due what appears to be tidal ingress and debris, the pits and pipes were submerged and unable to be accurately surveyed.
- There is uncertainty in the functionality of the flap-gate and the actual infrastructure configurations at this outlet due to differing information on drawings, reports and the limited survey that could be undertaken.

Refer to Section 9 for recommendations about future treatment of this area.

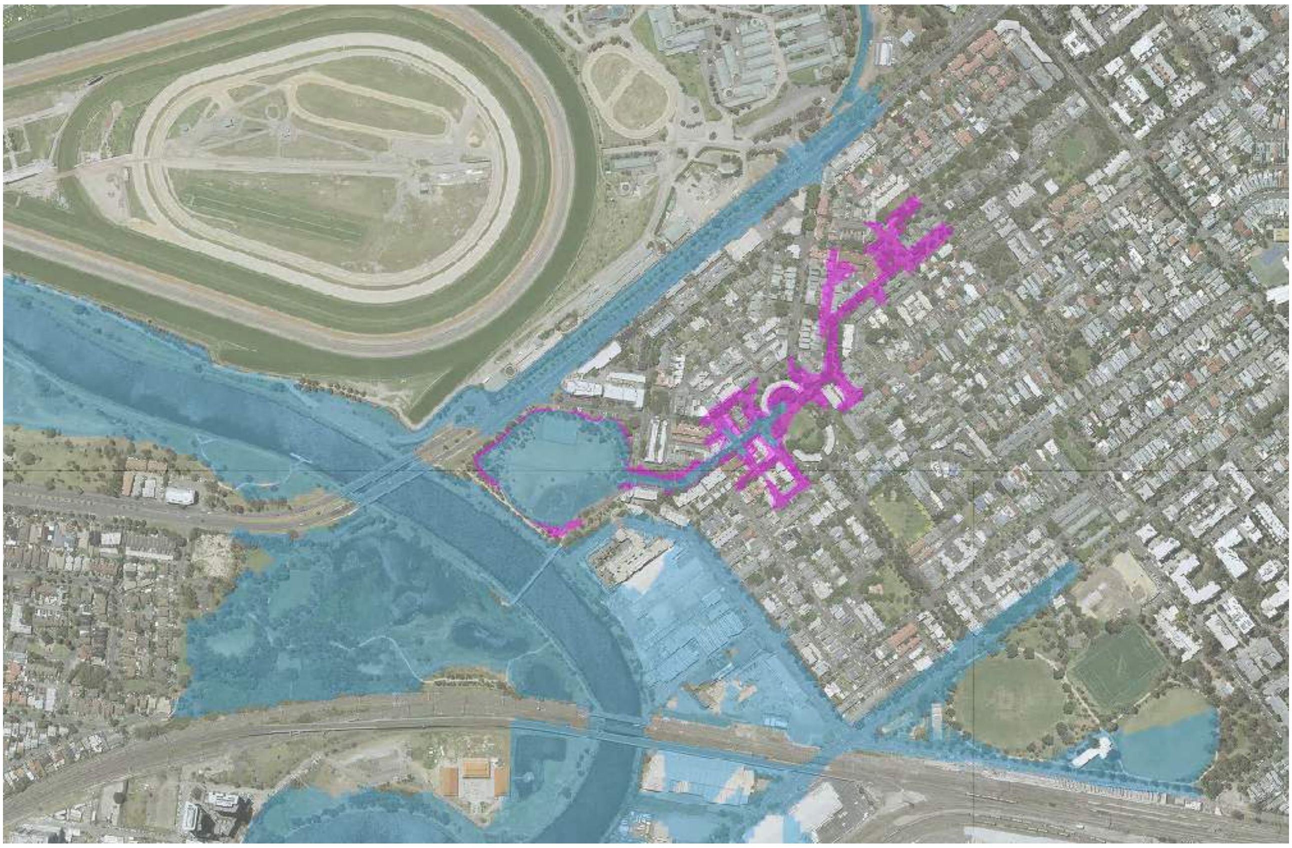


Figure 8-6: Modelled flood extent under the 2022 calibration event, with the calibrated flood extent shown in blue, and the extra flood extent under the sensitivity run shown in pink.

8.7 Blockage assessment

The upper Maribyrnong River catchment is predominantly rural, agricultural, grasslands and woodlands. There are numerous crossings upstream of the project defined mapping extents which will limit the potential for blockage. Within the mapping extents there are several major crossings of the Maribyrnong River but only three have limited freeboard to the bridge soffit during the 1% AEP event. Additionally, the clear span width of the bridges is generally greater than 50m so the risk of blockage was considered low.

During the 1974 event there was a construction-related constriction in the Maribyrnong River at Kensington Rail Bridge. There is also evidence of two barges causing a blockage at Raleigh Road bridge during the 1983 event. Table 8-3 presents a blockage analysis and recommendations.

Table 8-3: Blockage Assessment.

Analysis Type	Comment	Recommended Blockage Scenario
Urban Network	The urban network that has been applied to this model has been incorporated to analyse the backwater flooding impacts from the Maribyrnong River. It was considered that blockage factor analysis on these networks would produce spurious results in the context of this study. As noted in Section 6.7.2.1 there was limited information available to be incorporated into the model in the Riverside Park/Kensington area. Sensitivity analysis was undertaken of this drainage infrastructure (see Section 8.6). There is a recommendation that future phases of work consider a comprehensive survey, including confirmation of the functionality of a flap-gate, of this location (see Section 9).	Yes (future phases when survey and functionality is confirmed)
Major Waterway Crossings	The upper Maribyrnong catchment is predominantly rural, agricultural, grasslands and woodlands. There are numerous crossings upstream of the of the mapping extents which will limit the potential for blockage. Within the mapping extents there are several major crossings of the Maribyrnong River but of these crossings the pipe bridge, the edges of Afton St footbridge and Raleigh Rd bridge have limited freeboard to the bridge soffit during the 1% AEP event. Additionally, the clear span width of the bridges is generally greater than 50 m so the risk of blockage was considered low. During the 1974 event there was a construction-related constriction in the Maribyrnong River at Kensington Rail Bridge. It is assumed that this scenario is not credible to be run as a sensitivity test if contemporary construction and planning methods are followed. The model could be used during planning and investigation stages of proposed construction to examine flood risk and potential mitigation measures but until a specific scenario is identified this is considered unnecessary. There is also evidence of two barges causing a blockage at Raleigh Road bridge during the 1983 event. It has been assumed this is not a realistic contemporary scenario to be considered further.	No (to be revisited if specific bridge blockage scenario is identified)

8.8 Non-stationarity

Urban areas within the catchment such as Sunbury, Romsey, etc will have grown and therefore, the potential for non-stationarity due to land use change may have an impact on the attribution of reach types. However, these changes are considered to be small in the context of the overall catchment (1,400 km^2) and will not affect peak flows for large flood events.

The impact of the non-stationarity was investigated by altering the fraction impervious values to Total Impervious Area (TIA) from Effective Impervious Area (EIA) which resulted in an increase of less than 6m^3/s at the Keilor gauge interstation area in the 1% AEP event. This is equivalent to about 0.6% of the peak inflow applied to the hydraulic model.

It is expected that urbanisation will significantly increase in the catchment over the next 50 years and it is recommended that this is investigated in future revisions to the flood model.

8.9 Storages

Flooding often occurs during wet periods, and this correlates to when water supply storages are near capacity, and this was the case for the flooding event of October 2022. Therefore, the initial water level of the storage of Rosslynne Reservoir was set to full supply level for all events in the design event modelling.

A sensitivity test on the initial water level was undertaken by modelling an initial drawdown of 12,700ML (half the reservoir capacity). This sensitivity test resulted in no outflow from the reservoir being modelled for a 1% AEP event.

The results indicated that that flows at Keilor and the Lower Maribyrnong were not heavily affected by the capacity of the reservoir. The peak flow at the Keilor Gauge reduced by 44m^3/s which is less than 5% of the total flow.

8.10 Calibrated 2022 RORB hydrograph applied to TUFLOW

The hydraulic model was calibrated to observed data and to investigate how the RORB and TUFLOW model were preforming jointly the hydrograph from calibrated RORB model for the 2022 event was applied to the TUFLOW model. Specifically, the setup of this sensitivity analysis was:

- The upstream inflow was the calibrated RORB hydrograph at the Keilor gauge using the parameters detailed in Appendix H.
- This hydrograph was applied to the 2022 setup of the TUFLOW model as described in Section 6.10.5.

The results of this are presented in Figure **8-7**. These results are similar to those presented in Figure 6-22 with the modelled level timeseries closely tracing the recorded levels; the peak level difference is about 10mm. This result indicated that the hydrology and hydraulic models i.e. the flood model, is working well.

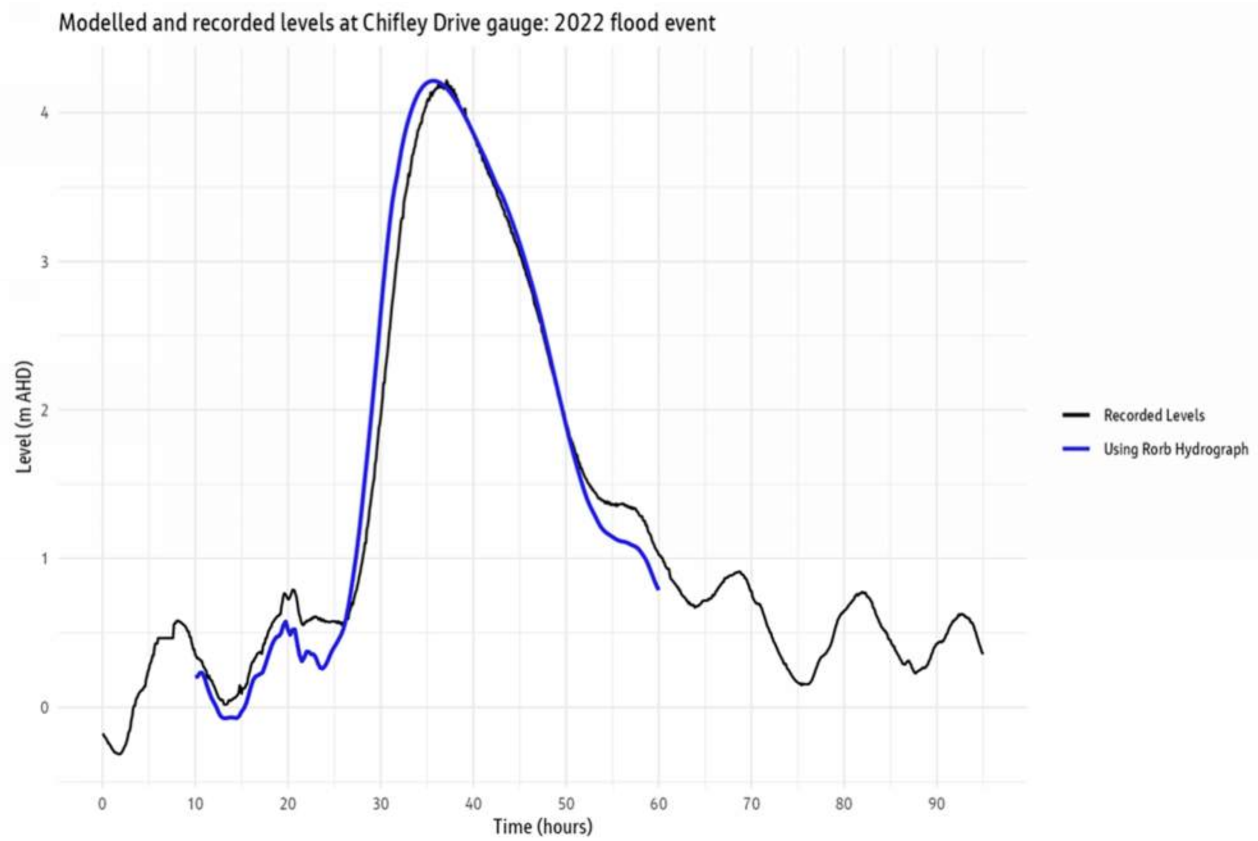


Figure 8-7: Comparison of 2022 calibration event using the calibrated RORB 2022 hydrograph as an input to the TUFLOW model.

9. Recommendations

The flood model developed as part of this study represents the most up-to-date information with regard to flood data in the Lower Maribyrnong catchment. This model and the associated datasets should be used to update and inform floodplain management activities that naturally follow a flood mapping study. Further, this study has highlighted that there are a number of areas that could be enhanced through further data collection, infilling of knowledge gaps and additional analysis that is beyond the scope of this study. These areas for future work are outlined below.

9.1 Flood history review

The data collection and analysis has found a minor discrepancy between the flow rates at Keilor and the resulting levels at Maribyrnong Township, that is, the flows and levels have variable correspondence between the two locations (i.e. different ranks of the flows at Keilor compared to the ranks of the levels at Maribyrnong Township). The work detailed within this report has been undertaken to ensure that this discrepancy did not have a material effect on modelling results. The most notable discrepancy is the 1916 event which is the 5th highest flow rate at Keilor, but the 2nd highest water level at Chifley Drive. It is recommended that this discrepancy is further investigated noting that there are numerous possibilities for consideration, such as:

- There have been significant changes to the Lower Maribyrnong River in the early part of the 19th Century such as the creation of Coode Island and other channel works on the Lower Maribyrnong and Yarra Rivers.
- The presence of numerous low-lying bridges which were reported to have contributed to flooding.
- There could have been localised blockages that could have affected flood levels in Maribyrnong Township. Further the exact location of the reported flood level is not known.
- The location of the Keilor gauging station has moved overtime which means gauged heights for this gauge cannot be directly compared without a datum correction.
- The method of calculating discharge for historic events is currently unknown.

9.2 Data recommendations

- Currently there is a minimum of three potential sources of flow gauge data for the Maribyrnong catchment: Melbourne Water's online repository, the Bureau of Meteorology (BoM) and Victoria's Water Measurement Information System (WMIS). There is often conflicting information between the gauges, and a consolidated single source of information would prove valuable for future projects. It is acknowledged and should be pointed out that the Melbourne Water system is live data and is utilised for immediate observational purposes whereas BoM and WMIS data are generally verified prior to publication. This; however, can lead to confusion from stakeholders.
- Currently when major flood events occur there is no systematic approach to data collection which can mean that valuable flood data is not captured. It is important to ensure data collection during this time is maximised to best inform modelling calibration and verification and in turn enhance stakeholder confidence and acceptance with the flood modelling results. It is recommended that a procedure be developed for capturing flood data immediately following flood events. It is envisaged that this would include capturing social media feeds, newspaper articles, SES call out records, road closures, information collected by Council as well as data collection such as flood marks, aerial photography (oblique and plan), drone survey etc.

9.3 Stakeholder communication

- It is recommended that the results of this study should be communicated to stakeholders and the wider community. It is envisaged that when these results are communicated there will be feedback from the community. This feedback could provide valuable information to enhance the confidence in the results or highlight areas for improvement. It is strongly recommended that this process is undertaken. It would also be beneficial to provide these results in an online platform to allow rapid dissemination of this information.

9.4 Hydrology recommendations

- The Keilor gauge rating table accuracy should be confirmed and extended for higher flood flows using a hydraulic model. The TUFLOW model developed for this study will be suitable for this purpose; however, additional survey and other information together with further development of the model will be required.
- The analysis presented in Section 3.4.2.2 noted that there are a number of upstream flow gauges in the catchment that would benefit from rating curves being revised and potentially extended through hydraulic modelling. This should be completed for these gauges in future projects along with further investigation of upper catchment hydrology.
- Once the revision and update of upstream gauging stations has been completed, it is recommended that the hydrology assessment is revisited. In particular, the event-based rainfall-runoff model calibration. This new information may allow the standard calibration approach to be applied successfully increasing the utility and function of the RORB model; however, these revisions will not impact the design flood levels and extents presented in this report for the reasons outlined in Section 4.3.3.2.8. These changes would mean the model could be used in situations where the hydrograph timing and volume were of key concern such as informing floodplain management interventions and flood emergency management response plans.

9.5 Hydraulics recommendations:

- Further work to understand any interaction between tides and Riverside Park, as well as the condition and/or operations of the flap-gate and the interaction with underground drainage. This would include an intrusive survey of the flap-gate and surrounding drainage infrastructure. This will enable the backwater, tidal related, representation of flooding during higher frequency events in Kensington to be verified but is unlikely to impact larger, less frequent, events (2% AEP and above).
- Should further details become available of the pre-existing conditions of key development such as Rivervue, Edgewater and Kensington Banks it is recommended that these are incorporated into modelling of historic events. However, this is not considered critical to the outcomes of the study as the hydraulic model is considered to be well calibrated.
- It is clear that the land use across the Lower Maribyrnong River floodplain has changed over the historic flood events however, at this stage, no alteration for floodplain Manning’s values have been made. It is recommended that floodplain Manning's values for future events be altered when new climate change guidelines are released.
- Extension of the flood model presented here to cover the area between Solomons Ford and upstream of the Keilor gauge.
- Future work should consider collection and incorporation of any available water or flood management plans for the Flemington Racecourse. During model development, in the absence of specific information, it was assumed that there are no additional (other than those captured in this reporting) flood defence measures (such plans for deployment of temporary flood barriers or emergency sandbag procedures) in place for the Flemington Racecourse and only the passive wall and associated topography are incorporated. As a result, larger, less frequent, flood events have a flow path into the Racecourse area, from the embankment wall to the north-west and via Stables Drive from Smithfield Road. Future work should confirm this assumption.

9.6 Revised climate change guidelines

- It is recommended that the study modelling is revisited when the update to Climate Change Considerations chapter in Australian Rainfall and Runoff (DCCEEW, 2023) are adopted. This is expected to be in late 2024.

- The rate of urban growth within the Maribyrnong catchment is expected to increase significantly in the future. The Integrated Water Management Plan for the Maribyrnong catchment (DEECA, 2022) estimates that there will be an increase of 26% in runoff volume from urbanised areas by 2050. This increase in runoff is anticipated be limited to increases in volumetric catchment runoff, and any changes to peak flows can be managed through appropriate runoff detention and other interventions. It is recommended that the impervious fractions in the RORB model, and Manning's 'n' values in the TUFLOW model be reviewed and revised where appropriate in future modelling. This is of particular importance for climate change modelling.

9.7 Floodplain management

On completion of a major flood mapping study such as the Lower Maribyrnong, it is typical that further floodplain management studies are undertaken, using the new information. It would be irresponsible to commence these studies without the new information, as this information dictates the direction of these future studies such as the required data collection. Specifically, it is recommended that:

- The relevant Victorian SES flood guides are revised and updated taking into account the new information generated from this study. In interpreting this information care should be taken to take into account the limitations outlined in Section 4.3.3.2.8.
- The Flood sub-plan of the Municipal Emergency Management Plan for relevant Councils should be updated using the information generated from this study. In interpreting this information care should be taken to take into account the limitations outlined in Section 4.3.3.2.8.
- The results from this study should be used to update the planning scheme, in particular, the Land Subject to Inundation Overlay (LSIO).
- The results of this study and the associated flood modelling could be used to calculate the economic flood damages in the study area. This can take into account the most recent flood damages curve, such as the one published by the NSW government in 2023. This would result in an understanding of the average annual damages ($/year) due to flooding from the Maribyrnong River. In turn, this information can then be used to determine economically viable flood mitigation for the catchment.
- A flood mitigation study be undertaken to inform developing a program of works and measures for reducing flood risk in the study area. This would occur as part of Melbourne Water’s on-going flood risk reduction programming. This study should use the calibrated flood model developed for this study. This and the flood damages assessment could be delivered as part of a floodplain management plan for the study area.
- It is recommended that modelling be revised every 5 years, or sooner if a major flood event occurs. Revisions to modelling should also adhere to new guidance on climate change, flood hydrology and flood hydraulics.

The model results have highlighted areas for additional detailed studies, these are:

- Kensington: through the study it has become evident that Kensington is at risk of flooding from the Maribyrnong River. While the study has identified the majority of the flooding mechanisms, there is some uncertainty regarding the potential flow path through the culverts under Riverside Park. Further, Melbourne Water has recently received (April 2024) further and more detailed information regarding the topographic levels in and around this area. These details should be incorporated into the flood model to further investigate flooding in this area.
- It is acknowledged that a limitation of this model is the uncertainty in the modelled results in the industrial area between Moonee Ponds Creek and Maribyrnong River, in South Kensington. This area contains rail yards, where data availability has limited the ability to incorporate drainage infrastructure in this area. There is also a joint-probability consideration of Moonee Ponds Creek and the Dynon Road Tidal Canal, and the influence these may have on flood metrics, that has not been included in this model. Future work should consider additional data collection and detailed survey of these areas and include Moonee Ponds Creek in future analysis.

- The results of this study indicate that the Ascot Chase and Edgewater areas are likely to have increased flood risk into the future with climate change. It is recommended that detailed studies similar to that proposed for Kensington are undertaken using the recently obtained (April 2024) topographic datasets.

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Appendix A. Flood Mark Review

Note: Due to privacy considerations, identification of exact locations of flood markers has been removed.

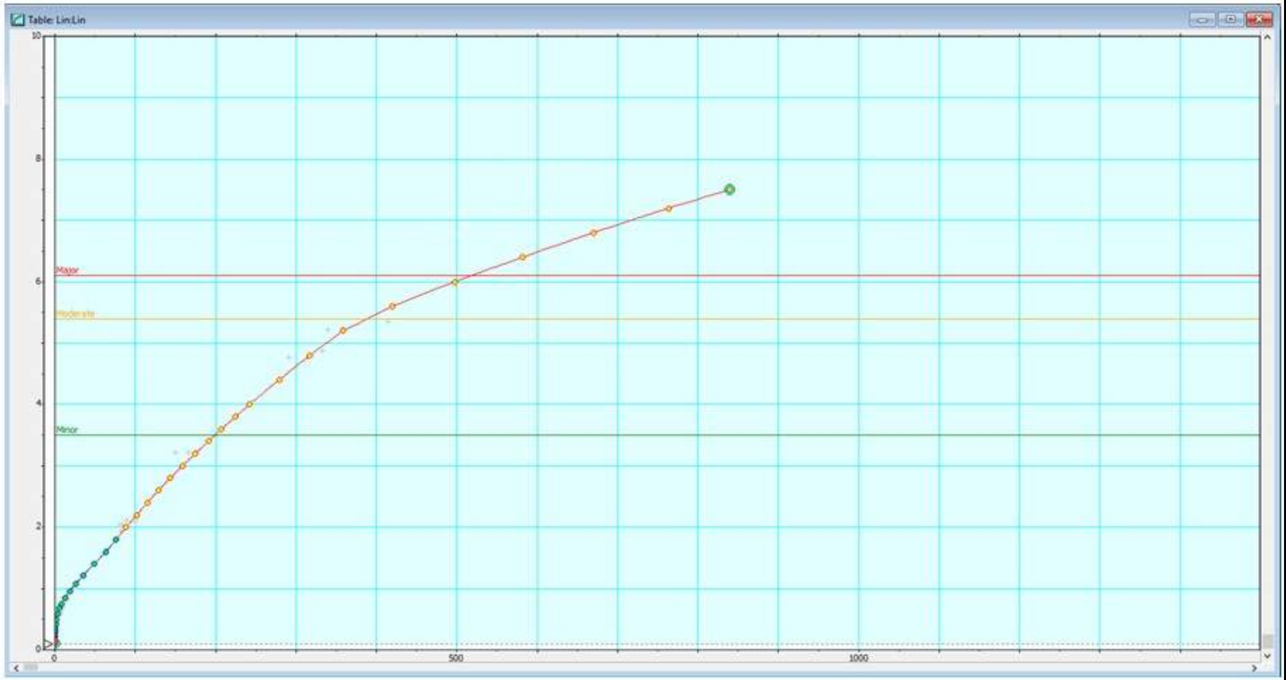
Jacobs Rating	Jacobs Comment
Moderate	Height seems OK, although the mark is not clear
Low	Photo shows clear mark - but no level recorded
Moderate	Photo shows 9 roller door segments which are around 85mm, so 765mm Natural Surface Level + 765mm = Flood level
Low	Photo states advised by owner but no Flood level
Moderate	Suggest another mark + 100mm in photo
Moderate	Faint Flood mark
High	Clear Flood mark on window
Moderate	Clear Flood mark, but seems a little high + two levels provided seems to be two different locations
Low	Appears to be high on fence would expect more than 1.2m, debris line faint
High	
Low	Cannot identify Flood mark in photo
Low	Edit on photo suggests this should be 15 - transferred to 15
Moderate	Could be slightly low looking at photo - water near to top of low part of fence which could be more than 1.5m high
High	Clearly identified Flood mark
High	7-8 weather boards = 150 * 7.5 = 1.2m
High	
Moderate	Advised by owner - but not Natural Surface Level
Moderate	Clear mark in the photo, but no Natural Surface Level
Low	11 brick (min) = 946mm, could be incorrectly labelled with 27

Jacobs Rating	Jacobs Comment
Moderate	Clear mark but no Natural Surface Level
High	18 roller door segments = 1.5
Moderate	4 (ish) bricks high = 86 * 4 = 344mm (slightly low)
Low	Owner photo could be used to calc depth using other photos
Moderate	Faint Flood mark
High	3 bricks
Low	Clear Flood Levelled mark but no level
Moderate	Questionable Flood Levelled mark
High	Seems reasonable from photo
Moderate	Additional information in photo + owner supplied
Low	Mark is 150 - 200mm above Flood Livedoor Level
Low	Debris clearly identified but no surveyed Flood Levelled level
Moderate	4 bricks but not relatable to Flood Level or Natural Surface Level
Moderate	Compatible with photo - at least 10 bricks from Natural Surface Level 860mm
High	Compatible with photo panel on door ~ 6
Moderate	Difficult to id Flood Levelled mark, no info to confirm
Moderate	Compatible with fence height
Moderate	Compatible with photo
High	Consistent with photo 1.5 bricks = 130mm
High	3 weatherboards = 450mm from Flood Level
Moderate	Consistent with neighbour
Low	No context in photo to verify

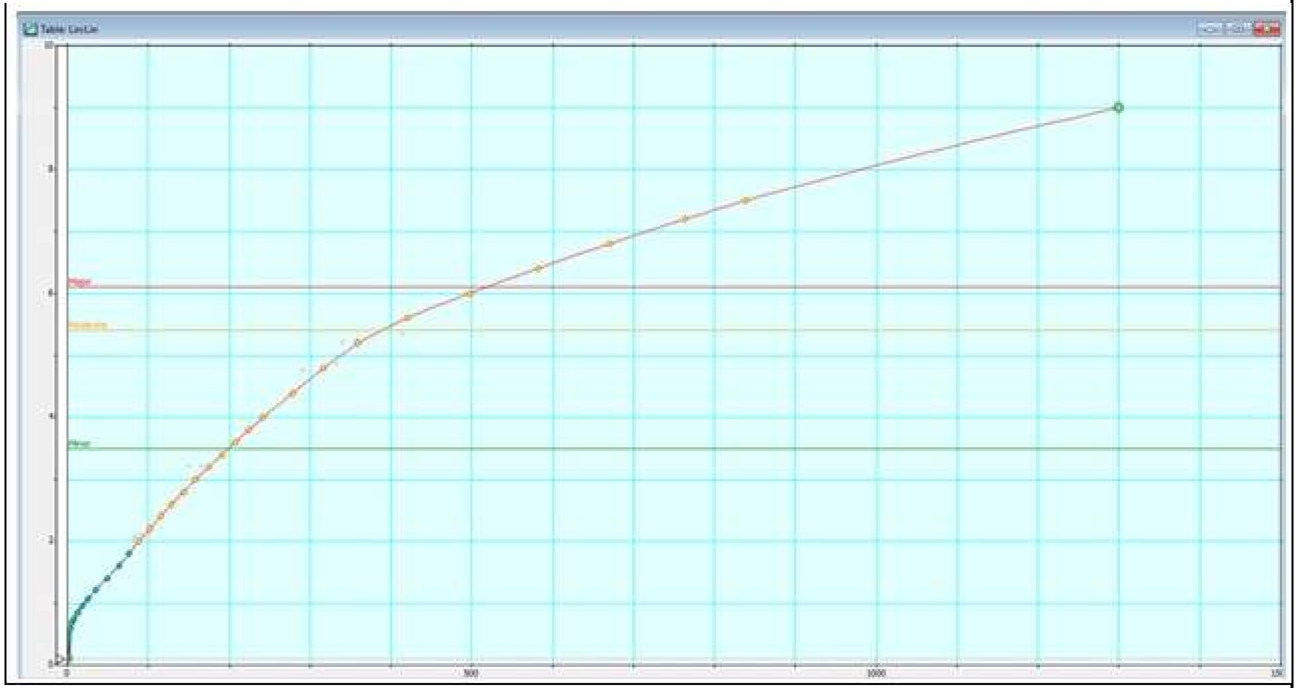
Jacobs Rating	Jacobs Comment
Low	Not compatible with photo estimated should be 600mm above Flood Level
Moderate	Consistent with neighbour
Low	9 bricks = 774mm not consistent with levels
Moderate	Perhaps 100mm low - 4 weatherboards @ 150mm = 600mm
Low	Photo of Flood Mark but no level
Low	Not able to verify but seems low
High	consistent with photo and neighbours
Low	Faint Flood mark & far too low
Low	Levels seem strange like Flood Level 100 above Natural Surface Level
High	Flood mark near door handle ~ 1m
High	Level consistent with photo
Low	Multiple marks identified, overall levels seem low
Moderate	Confirmed with weatherboards
Moderate	Compatible with photo
Low	4 bricks high = 86 * 4 = 344mm - Flood mark could have been higher
Moderate	Clear Flood mark
Low	Seems low compared to neighbours
High	Consistent with expectations and matches photo 5 bricks = 440mm
Low	No Flood level but clear level in photo at least 1m above Natural Surface Level
Moderate	No information to verify
Moderate	Faint Flood mark on fence, second photo also faint

Appendix B. Keilor rating table details from ALS

Table B-1: Keilor rating table details from ALS in email dated 26/10/2023.

Historic (Old) rating <u>RT 37.00 active until 11/10/2022</u> 	Rating extrapolation maximum 7.500m (839cumecs) this extrapolation had been in place since 2001.

New release <u>RT37.01 active from 11/10/2022 to 17/10/2022</u>



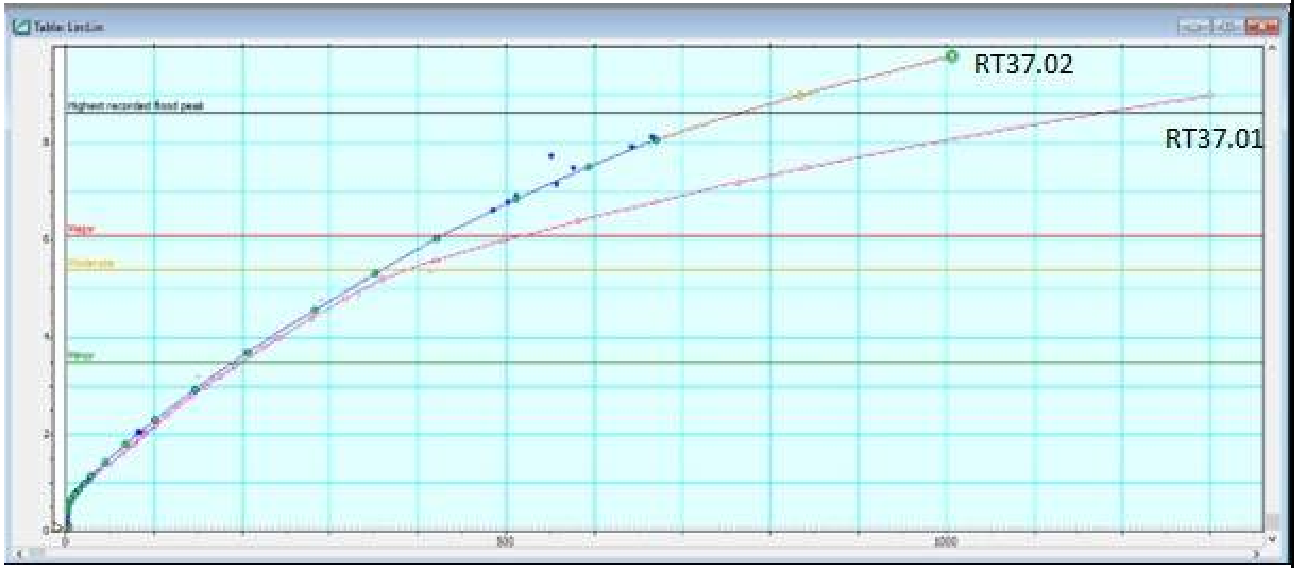
Amidst the forecast preceding the October 2022 event, Melbourne Water requested that ALS extrapolate the rating table from its previous maximum range of **<u>7.5m (which as above existed historically) to 9.0m</u>**

This was completed by ALS on 11/10/2022, with the new rating release T37.01 logarithmically extrapolated to the upper range of **<u>9.0m (1300cumecs)</u>**.

As communicated by ALS to Melbourne Water, the uncertainty in extrapolating the rating to the 9.0m stage range would have **<u>unknown error</u>**. Due to the criticality of the Keilor site and the predicted flow range, ALS clarified to Melbourne Water that this had been done beyond ALS' peer-review procedure. (refer to email sent from ALS 11/10/2022). Although all due care is taken when extrapolating any rating curve the likelihood that the extrapolation had the potential to produce significant errors was discussed, and that this uncertainty needed to be documented within relevant Melbourne Water systems.

ALS also highlighted that per AS3778.2.3 – the logarithmic extrapolation completed should have seen the table extend no higher than 6.5m. This limit of reasonable extrapolation was derived from section 6.9 of the Standard (AS3778), which recommends that the extrapolation be extended not more than 1.5 times the maximum flow rate measured through gauging.

Table 37.02 was created on 17/10/2022



The site was gauged throughout the morning and the early afternoon of October 14th (summary below) verifying a negative shift on the RT37.01, in the stage range of 6.6m to 8.1m measured.

Note that gauging #215 was observed by the ALS field crew to be a less reliable gauging and had applied a reduced quality code to this gauging (QC32 Fair measurement) , due to the pitch of the hydroboard across some measuring stations. ALS did not consider this gauging in the subsequent rating adjustment that developed RT37.02

Table 37.02 was created on 17/10/2022 and was drafted and reviewed based on gaugings collected above. The comparison of this revised rating against T37.01 during the flood is below (RT37.01 pink)

Following this rating adjustment, each of the flood gaugings (aside from #215) plotted within 2.5% of the rating. The new rating extrapolation follows AS3778.2.3 to comply with 1.5 times the maximum gauging per the AS3778.2.3. This saw the new table maximum sit at 9.8m (1007cumecs), and quality coded (QC149 – Rating extrapolated within 1.5XMaxQ) above the maximum gauging to reflect uncertainty in this logarithmic extrapolation.

Appendix C. Survey Report

Jacobs

SURVEY REPORT

Lower Maribyrnong Flood Mapping Study

IA5000NN_REP_001_Survey_Report_Maribyrnong_River_Flood_Modelling_001 | E

22 April 2024

Melbourne Water Corporation

SURVEY REPORT

Project No:	IA5000NN
Document Title:	Maribyrnong River Flood Modelling
Document No.:	IA5000NN_REP_001_Survey_Report_Maribyrnong_River_Flood_Modelling_001
Revision:	E
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Author:	Phillip Nixon
File Name:	IA5000NN_Survey_Control_Report_.docx

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Document history and status

Revision	Date	Description	Author	Checked	Reviewed	Approved
A	12/05/2023	Initial Issue	PN	BS		
B	23/08/2023	Data Validation included	PN/BS	PN		
C	13/11/2023	Conclusion added. Sent to JM for review	BS	PN	JM	JM
D	9/1/2024	Minor amendments on independent review	BS			
E	22/4/2024	Added Drainage and Floor Level Survey Sections	BS	PN	LC	LC

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Executive Summary

The following report is a Survey Report for Project IA5000NN – Lower Maribyrnong Flood Mapping Study. The project involved a variety of surveying tasks aimed at delivering a high-quality homogeneous dataset across the site extents to support flood modelling and mapping. It involved undertaking and verifying a variety of survey including:

- Establishment of Australian Heigh Datum (AHD) across the project site (including analysis of published values)
- Analysis of existing survey data collected.
- Survey of flood levels/markers identified from the 2022 floods.
- Commission an airborne LiDAR survey of the Project site and validate its accuracy.
- Commission a bathymetry survey of the Lower Maribyrnong River by a suitably qualified hydrographic survey and validate is accuracy.
- Survey of up to twenty (20) structures of relevance to the flood modelling (bridges/culverts/walls)
- Combine the various datasets into a single source of truth across the project site.
- Drainage investigations
- Floor Level survey

By following best survey practices Jacobs were able to independently validate all data incoming to the model and detail its completeness and accuracy. The following report details the methodology undertaken and the accuracy results of our analysis.

The data outlined in this report (either captured by or supplied to Jacobs) meets the requirements for its desired use – A Flood Model of the Lower Maribyrnong River. Data should be assessed for suitability before used for any alternative purposes.

I Phillip Nixon LS, certify that the data herewith meets the accuracies and standards outlined in this report.

……………………………………………
Licensed Surveyor, Surveying Act 2004

1. Project Overview

The Project Site is the lower Maribyrnong River system as detailed in the below Figure 1.

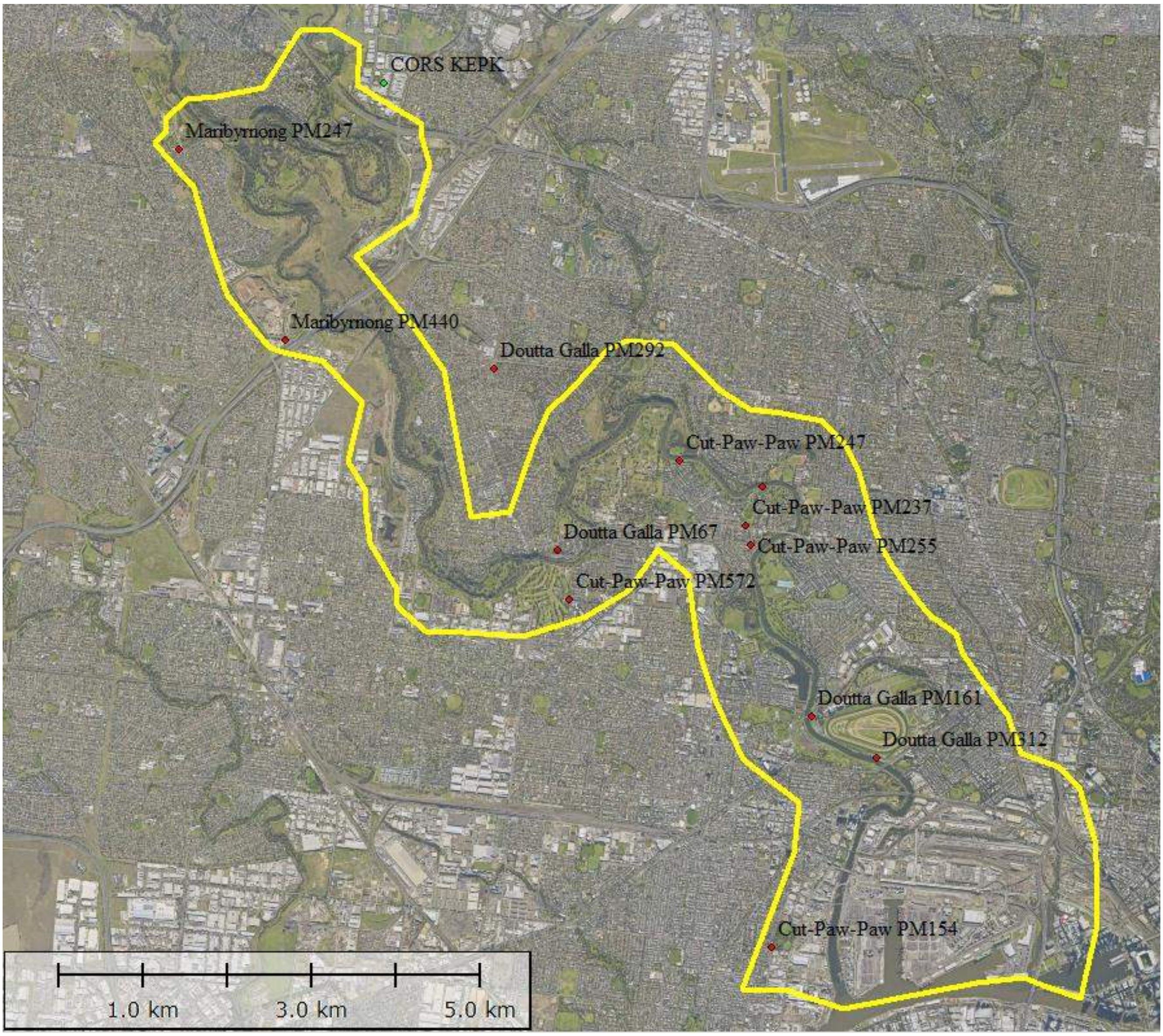

Figure 1 – Project Site extents for the Lower Maribyrnong Project including location of primary Permanent Mark Network (source: MetroMap)

1.1 Survey Equipment & Survey Team

This project involved many people and included sub-contractors. Below is a list of relevant personnel across the project.

JACOBS Contacts

Joanna Margariti
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Table 1 – List of surveyors and the relevant equipment/software utilised.

Equipment used	Leica GS18 series GNSS Leica GS15 Series GNSS
Name of Survey party leader:	Phillip Nixon
Name of assisting surveyors:	Laura Hevey, Brett Sheehan, Daniel Vodicar
Software Used	Leica Geomatics Office (v8.0) Leica Infinity 3.3.0 Havoc/Triglev

Airborne LiDAR Survey

Jacobs engaged Aerometrix Pty Ltd to capture the entire Project area with airborne LiDAR.

Hydrographic Survey

Jacobs engaged Total Hydrographic to complete the Bathymetry Survey of the project site.

2. Survey Control

The coordinates calculated are in MGA2020 Zone 55 Grid and AHD using the Ausgeoid2020 geoid.

Static GNSS baselines were observed between Maribyrnong PM247, Maribyrnong PM440, Doutta Galla PM292, Doutta Galla PM67, Cut-Paw-Paw PM572, Cut-Paw-Paw PM247, Cut-Paw-Paw PM237, Cut-Paw-Paw PM255, Cut-Paw-Paw PM251, Cut-Paw-Paw PM154, Doutta Galla PM161, Doutta Galla PM312, COS PKVL, CORS CBG2, CORS KEPK and CORS CRKM.

Additional checks were made by Smartnet RTK (IMAX) to Doutta Galla PM270, Maribyrnong PM248, Maribyrnong PM141, Cut-Paw-Paw PM256 and Cut-Paw-Paw PM257

2.1 Horizontal Position

GNSS Baselines were reduced and processed in a network adjustment in both Leica Infinity and Havoc holding CORS KEPK fixed. The minimum observation interval was set to 20minutes resulting in 83 baselines. These baselines were then adjusted using least squares in both using Leica Infinity and Havoc with similar results obtained from both packages. The maximum standard deviation calculated was 4mm.

2.2 Vertical Position

CORS KEPK transmitted value was held fixed in the Network Adjustment but after analysis was adjusted to RL84.547 based on results on the other 3 CORS stations and checks to higher quality PM's. GNSS Baselines were reduced and processed in a network adjustment in both Leica Infinity and Havoc holding CORS KEPK fixed. These baselines were then adjusted using least squares in both using Leica Infinity and Triglev with similar results obtained from both packages. The maximum standard deviation calculated was 5mm.

2.3 Additional Checks

While surveying GCP's, additional PM's were surveyed via a 60 second single Smartnet (Imax) RTK observation. We would expect the results of these points to be +/-40mm.

Additional static observations made to SGV levelled values in the area on another project were also analysed to further confirm CORS station adoptions.

3. Survey Control Analysis

Along the area surveyed there are two types of AHD, marks surveyed and adjusted by the Surveyor General of Victoria's office (SGV), and those surveyed by the Melbourne Water Corporation (MWC). The marks surveyed by SGV are part of the levelling network adjustment, while the MWC marks are just a listing of published RL's. As a result, there is the possibility for there to be a difference between marks which are quite close together depending on the source.

Most of the marks from the SGV agreed well with each other and the SMES published values (sourced 23/05/2023), with the values mostly being within 15mm of the adopted adjustment. The exception being Cut-Paw-Paw PM572, which shows a 53mm difference. This was addressed with the SGV who informed Jacobs that PM572 was part of a level network which had been based on a disturbed Victorian levelling network mark that was currently being revised, the new value was 29.553 which is within 1mm of our value.

The MWC values appear to show a trend of around 50mm lower than published values.

Table 2 – Summary of Control Coordinates and their difference to the quoted values (vertical)

	HAVOC/TRIGLEV HOLDING KEPK				SMES/TRANSMITTED				
HAVOC/TRIGLEV HOLDING KEPK	EASTING	NORTHING	HEIGHT(AHD)	SURVEYED METHOD	EASTING	NORTHING	HEIGHT(AHD)	DIFFERENCE	SMES SOURCE
Maribyrnong PM247	307889.859	5822170.09	67.629	STATIC NETWORK	307889.858	5822170.079	67.606	0.023	SGV
Maribyrnong PM440	309154.839	5819897.266	60.887	STATIC NETWORK	309154.845	5819897.260	60.882	0.005	SGV
Doutta Galla PM292	311626.424	5819571.736	53.918	STATIC NETWORK	311626.432	5819571.724	53.905	0.013	SGV
Doutta Galla PM67	312377.075	5817418.094	19.396	STATIC NETWORK	312377.078	5817418.096	19.355	0.041	MWC
Cut-Paw-Paw PM572	312523.928	5816824.455	29.552	STATIC NETWORK	312523.930	5816824.439	29.605	-0.053	SGV
Cut-Paw-Paw PM247	313820.07	5818479.382	2.644	STATIC NETWORK	313820.079	5818479.327	2.625	0.019	MWC
Cut-Paw-Paw PM237	314610.444	5817705.651	2.976	STATIC NETWORK			2.991	-0.015	SGV
Cut-Paw-Paw PM255	314669.48	5817468.701	1.591	STATIC NETWORK	314669.482	5817468.691	1.585	0.006	MWC
Cut-Paw-Paw PM251	314811.241	5818173.491	1.288	STATIC NETWORK	314811.254	5818173.488	1.343	-0.055	MWC
Cut-Paw-Paw PM154	314918.57	5812706.919	9.325	STATIC NETWORK	314918.574	5812706.907	9.331	-0.006	SGV
Doutta Galla PM161	315392.296	5815441.563	6.043	STATIC NETWORK	315392.320	5815441.540	6.100	-0.057	MWC
Doutta Galla PM312	316155.375	5814948.659	1.315	STATIC NETWORK	316155.385	5814948.673	1.340	-0.025	SGV GPS
CORS CRKM	315782.443	5811517.955	14.773	STATIC NETWORK	315782.441	5811517.946	14.774	-0.001	TRANSMITTED
CORS PKVL	320479.048	5814437.795	62.589	STATIC NETWORK	320479.056	5814437.771	62.588	0.001	TRANSMITTED
CORS CBG2	321446.424	5821156.04	58.627	STATIC NETWORK	321446.432	5821156.038	58.625	0.002	TRANSMITTED
CORS KEPK	310323.991	5822953.135	84.547	STATIC NETWORK	310323.991	5822953.135	84.537	0.010	TRANSMITTED

1

Table 3 – Additional Smartnet RTK observations against additional marks. Table 2 – Summary of Control Coordinates and their difference to the quoted values (vertical)

BY SMARNET RTK (IMAX)									
Maribyrnong PM141	308521.0936	5822912.328	70.821	SMARTNET RTK (IMAX)	308521.069	5822912.310	70.936	-0.115	SGV
Maribyrnong PM248	308490.8682	5822559.086	63.8714	SMARTNET RTK (IMAX)	308490.912	5822559.071	63.915	-0.044	SGV
Cut-Paw-Paw PM256	315462.7167	5815164.843	1.0631	SMARTNET RTK (IMAX)	315462.709	5815164.833	1.085	-0.022	MWC
Cut-Paw-Paw PM257	315674.0954	5815068.68	0.7651	SMARTNET RTK (IMAX)	315674.081	5815068.679	0.846	-0.081	MWC
Doutta Galla PM270	309684.313	5820138.146	17.8945	SMARTNET RTK (IMAX)	309684.321	5820138.146	17.895	0.000	SGV
Doutta Galla PM65	312440.951	5817562.529	16.715	SMARTNET RTK (IMAX)	312440.928	5817562.507	16.715	0.000	MWC
CHECKS FROM MAR CORRIDOR PROJECT (KEPK)									
Doutta Galla PM168	313,231.95	5823613.343	78.42	STATIC SINGLE BASE	313231.945	5823613.355	78.417	0.003	SGV
Maribynong PM263	308272.718	5818797.893	55.422	STATIC SINGLE BASE	308272.721	5818797.881	55.443	-0.021	SGV
Doutta Galla PM39	311799.866	5822130.265	67.297	STATIC SINGLE BASE			67.307	-0.010	SGV
Doutta Galla PM167	312184.916	5822574.542	43.776	STATIC SINGLE BASE	312184.913	5822574.540	43.765	0.011	SGV
Tullamarine PM145	313111.305	5825469.642	95.776	STATIC SINGLE BASE	313111.308	5825469.629	95.764	0.012	SGV
Tullamarine PM138	311424.357	5824678.348	79.515	STATIC SINGLE BASE	311424.357	5824678.344	79.497	0.018	SGV

Based on this analysis we are satisfied that the transmitted MGA2020/AHD values of CORS stations KEPK, CRKM, PKVL and CBG2 are suitable to define AHD over the area of interested and no adjustment is necessary to localise to site AHD. The adjustment reports can be found in appendix A.

4. Check on SMEC Data

A series of marks were issued from SMEC who measured flood level marks on surrounding houses. Smartnet RTK checks and 2 static observations to Doutta Galla PM251 and PM255. While the control file "Control.csv" appears to be in MGA94 and the accompanying drawings appear to be in MGA2020, the heights are in good agreement with the heights measured by Jacobs to a standard deviation of 18mm.

Table 4 – Vertical data checks against supplied SMEC control surveys information

Point ID	JACOBS RL	SMEC RL	DIFFERNCE
NLC24	1.987	1.98	0.007
NLC32	2.173	2.17	0.003
NLC34	2.459	2.44	0.019
NLC37	2.713	2.71	0.003
NLC39	2.283	2.28	0.003
NLC48	2.198	2.24	-0.042
NLC50	2.490	2.5	-0.010
NLC51	2.365	2.33	0.035
NLC65	4.599	4.61	-0.011
NLC72	4.200	4.2	0.000
NLC74	3.540	3.54	0.000
NLC75	3.066	3.07	-0.004
NLC77	3.520	3.49	0.029
RVTC27	2.013	2.04	-0.027
RVTC52	1.661	1.65	0.011
RVTC55	4.026	4.02	0.006
RVTC70	4.326	4.31	0.016
RVTK1	6.080	6.06	0.020
PM255	1.591	1.6	-0.009
PM65	16.715	16.69	0.024

5. Additional Control for Structure Surveys

A number of additional control surveys were measured for coordinating the structure surveys. These were observed by minimum 40minutes static GNSS and 4 set reciprocally trigonometrically levelled total station observations. Results show standard deviations of less than 15mm in horizontal and vertical position.

POINT	EAST	NORTH	HEIGHT	TYPE	SOURCE	STRUCTURE
JA06	312751.678	5817674.760	3.386	RIVET IN PYLON	TPS	CANNING
JA04	312701.551	5817709.559	3.082	SPIKE	TPS	CANNING
JA05	312762.660	5817610.247	2.708	SPIKE	GNSS	CANNING
JA07	312551.253	5817637.055	9.873	RIVET IN CONC	TPS	CANNING
DG PM65	312440.934	5817562.500	16.717	PM	GNSS	CANNING
JA08	312452.966	5817495.878	19.817	RIVET IN CONC KERB	TPS	CANNING
DG PM66	312439.096	5817456.056	20.398	PM	TPS	CANNING
DG PM67	312377.080	5817418.069	19.392	PM	TPS	CANNING
JA09	314838.125	5816766.370	2.162	RIVET IN BITUMEN	TPS (GNSS ORIENT)	PIPEMAKERS
DG PM24	314922.829	5816491.207	1.441	PM	TPS	PIPEMAKERS
DG PM23	314836.252	5816839.166	1.762	PM	TPS	PIPEMAKERS
JA10	314709.713	5816783.231	1.650	RIVET IN CONC PATH	GNSS	PIPEMAKERS
DG PM312	316155.375	5814948.659	1.315	PM	GNSS	LYNCHES TO FLEM RD AND STH KEN
JA03	316236.671	5814819.070	1.605	RIVET IN CONC PATH	TPS	LYNCHES TO FLEM RD AND STH KEN
DG PM162	316340.417	5814903.282	3.127	PM	TPS	LYNCHES TO FLEM RD AND STH KEN
JA01	316317.661	5814866.901	1.044	RIVET IN BITUMEN	TPS	LYNCHES TO FLEM RD AND STH KEN
P001	317395.154	5814415.512	3.042	RIVET(NOW GONE)	TPS	LYNCHES TO FLEM RD AND STH KEN
JA02	316486.063	5814734.399	1.180	SPIKE	TPS	LYNCHES TO FLEM RD AND STH KEN
SK33	317396.154	5814526.470	2.144	RIVET	TPS	LYNCHES TO FLEM RD AND STH KEN
JR07	316522.821	5814557.840	4.623	RETRO	TPS	LYNCHES TO FLEM RD AND STH KEN
DG PM317	316480.696	5814780.176	5.887	PM	GNSS	LYNCHES TO FLEM RD AND STH KEN
JA39	316527.139	5814560.158	1.322	RIVET IN CONC PATH	TPS	LYNCHES TO FLEM RD AND STH KEN
SK34	317231.514	5814443.072	2.056	RIVET(NOW GONE)	TPS	LYNCHES TO FLEM RD AND STH KEN
SK38	316488.455	5814747.166	1.355	STARPICEKT(NOW GONE)	TPS	LYNCHES TO FLEM RD AND STH KEN
DG PM171	316463.171	5814763.470	1.229	PM(NOW GONE)	TPS	LYNCHES TO FLEM RD AND STH KEN
J178	316566.523	5814816.849	1.437	SURVEY NAIL	TPS	LYNCHES TO FLEM RD AND STH KEN
SK35	316909.793	5814496.868	1.748	RIVET (NOW GONE)	TPS	LYNCHES TO FLEM RD AND STH KEN
SK37	316650.553	5814797.444	1.238	RIVET	TPS	LYNCHES TO FLEM RD AND STH KEN
DG PM334	316870.303	5814507.748	1.429	PM RIVET	TPS	LYNCHES TO FLEM RD AND STH KEN
SK36	316837.282	5814553.696	1.467	RIVET(NOW GONE)	TPS	LYNCHES TO FLEM RD AND STH KEN
JR05	316903.945	5814492.408	5.788	RETRO(NOW GONE)	TPS	LYNCHES TO FLEM RD AND STH KEN
JR06	316897.800	5814493.268	5.400	RETRO(NOW GONE)	TPS	LYNCHES TO FLEM RD AND STH KEN
JA20	316588.929	5814477.693	1.480	RIVET IN CONC PATH	TPS	LYNCHES TO FLEM RD AND STH KEN
JA21	316402.729	5814348.078	1.194	RIVET IN CONC PATH	TPS	LYNCHES TO FLEM RD AND STH KEN
JA22	316102.547	5814373.765	1.404	RIVET IN CONC PATH	TPS	LYNCHES TO FLEM RD AND STH KEN
JA23	315957.147	5814007.959	1.109	RIVET IN CONC PATH	TPS	LYNCHES TO FLEM RD AND STH KEN
JA24	315797.885	5813743.076	1.729	RIVET IN CONC PATH	TPS	LYNCHES TO FLEM RD AND STH KEN
1104	315744.790	5813614.921	2.263	RIVET IN CONC PATH	TPS	LYNCHES TO FLEM RD AND STH KEN
360M1	315756.300	5813627.162	5.234	MINI360 PRISM ON COLUMN	TPS	LYNCHES TO FLEM RD AND STH KEN
DG PM767	316041.625	5814186.653	1.471	PM	TPS	LYNCHES TO FLEM RD AND STH KEN
DG PM768	316060.640	5814221.269	7.893	PM	TPS	LYNCHES TO FLEM RD AND STH KEN

DG PM769	316311.631	5814187.552	1.636	PM	TPS	LYNCHES TO FLEM RD AND STH KEN
DG PM770	316661.672	5814120.131	1.651	PM	TPS	LYNCHES TO FLEM RD AND STH KEN
DG PM343	315942.836	5813899.744	2.219	PM RIVET IN KERB	GNSS	LYNCHES TO FLEM RD AND STH KEN
JA11	315111.578	5817686.661	3.194	RIVET IN CONCRETE	TPS	RALEIGH
JA12	315038.266	5817649.495	5.072	HILTI IN BITUMEN	GNSS	RALEIGH
JA13	314953.404	5817611.324	1.950	RIVET IN CONCRETE	TPS	RALEIGH
JA14	314894.408	5817649.728	2.383	RIVET IN CONCRETE	TPS	RALEIGH
JA15	314609.341	5817702.361	3.031	RIVET IN CONCRETE	TPS	RALEIGH
CPP PM237	314610.446	5817705.649	2.991	PM	GNSS	RALEIGH
JA17	312146.983	5817269.650	9.419	SPIKE	GNSS	PIPE BRIDGE
JA18	312136.943	5817355.225	4.117	SPIKE	GNSS	PIPE BRIDGE
JA19	312158.950	5817366.605	10.115	RIVET	TPS	PIPE BRIDGE
DG PM245	314072.253	5818742.876	8.907	PM	TPS	AFTON
JA16	314032.815	5818542.087	2.484	SPIKE	GNSS	AFTON
CPP PM248	314037.819	5818363.782	3.448	PM	TPS	AFTON
CPP PM247	313820.077	5818479.373	2.624	PM	GNSS	AFTON
DG PM161	315392.297	5815441.556	6.043	PM	GNSS	FISHER PDE
CPP PM256	315462.715	5815164.844	1.071	PM	GNSS	FISHER PDE

6. Airborne LiDAR

Jacobs engaged a suitable qualified supplier (Aerometrix) to undertake an airborne LiDAR project across the site extents. Aerometrix used it RIEGL VQ-780ii Sensor to carry out the survey on 25th July 2023. The data supplied included:

- Colourised .las tiles (classified)
- 0.5m Digital Elevation Model (DEM)
- Metadata and Reports (Appendix B)

Jacobs surveyed Ground Control Points for both Horizontal and Vertical control using 10 second Smartnet observations based on the guide - *Aerometrix Control Survey Guidelines 2022.pdf*. Half of these points were issued to Aerometrix to be utilised within their processing workflow; the remainder being used to confirm that suitable accuracy had been obtained from the LiDAR. Additionally, vertical control points were obtained for the entire length of the Maribyrnong River to Brimbank Park approximately every 50m using a 3 second Smartnet observations.

The extent of the LiDAR captured is detailed in Figure 1. As LiDAR capture methodology cannot penetrate water bodies, no return was received. For the DEM it was identified that in these areas where water was present, the DEM values were flattened across the river as per the nearest available dataset point (and not NULL). This information was noted and passed onto the flood modelling team to ensure it was treated appropriately.

6.1 Data Validation

Jacobs initially reviewed the Aerometrix supplied metadata report (Appendix B) and found the result of the adjustment to the supplied Ground Control Points found relatively good agreement with a 95% Confidence Interval of ±0.071m in the vertical component across 65 different observations.

Jacobs conducted an independent assessment using alternative measured points not supplied to Aerometrix for processing. These points were all completed on hard standing areas to ensure an accurate comparison against the LiDAR could be made. The points are spread at approximately 50m intervals along the footpath that runs adjacent the Maribyrnong River through the entire length of the project area. Across 453 observations, the difference between control points averaged -0.003m ±0.054 at 95% Confidence Interval. The full results can be seen in Appendix C.

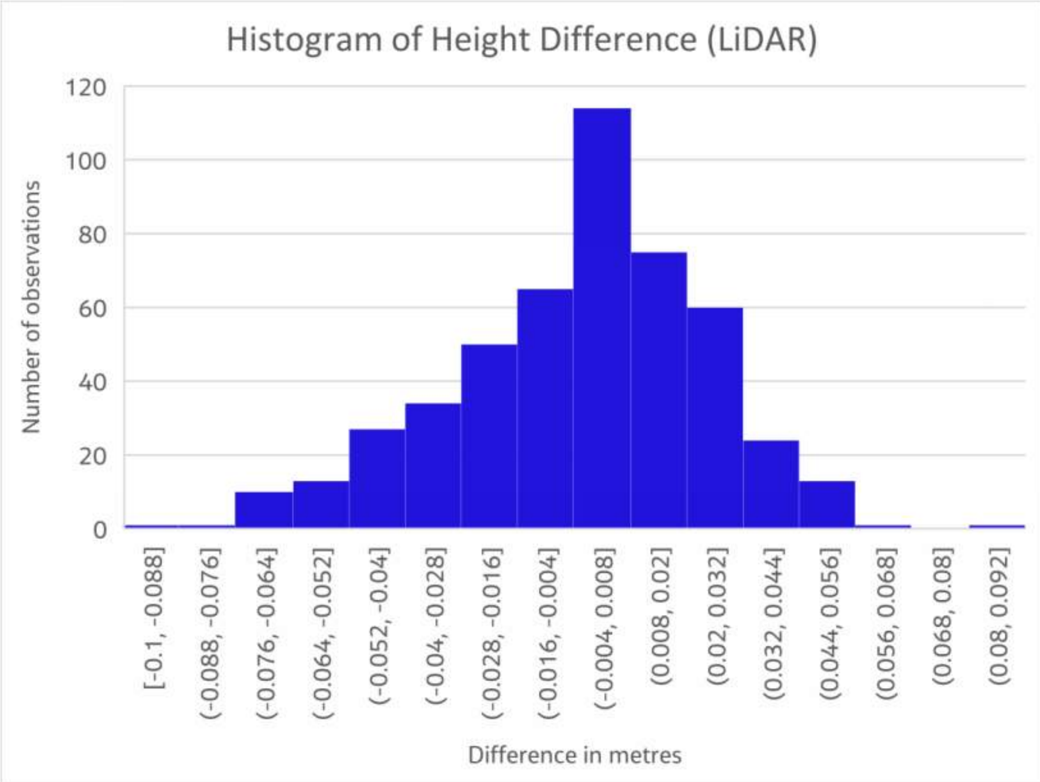

Figure 2 – Distribution of vertical height differences between the LiDAR and independent validation points

The LiDAR data was also uploaded to a 3D visualisation platform Pointerra to conduct various checks on the LiDAR classification and ensure the ground points were accurately classified as this has a direct impact on the derived DEM. Reviewing the point cloud demonstrated that ground points were classified correctly with a very high level of confidence in line with the quoted accuracy of 98%.

7. Bathymetry Survey

Jacobs engaged a sub-contractor (Total Hydrographic) to undertake a hydrographic Survey of the Maribyrnong River from the Yarra River Junction as far upstream as river conditions would enable the boat to continue. The survey was completed from the 24th – 26th May 2023 utilising a multibeam echo sounder to build an accurate 3D surface of the Riverbed. The survey was signed off by Level 1 (AHSCP CPHS) Hydrographic Surveyor Tim Williams (See Appendix D) and supplied in a point cloud (.las) format.

Some gaps were identified within initial analysis of the data specifically in and around project works for the West Gate Tunnel where only a small section of data could be captured along the river (150m). As opposed to patching within the flood model, cross-sectional information upstream and downstream of the missing area was used to infill the DEM under the assumption that the river profile would be similar and provide a more accurate representation of the riverbed. Other smaller areas of missing data were patched using TUFLOW using the same interpolation principle whereby gaps were infilled using surrounding DEM levels.

7.1 Data Validation

Jacobs reviewed the supplied survey report supplied by Total Hydrographic and determined that the Jacobs supplied control points provided insufficient detail on the accuracy of the dataset. Initially control points were only captured from wharfs and boat ramps allowing depth measurements to be observed but Jacobs then collected a total of 358 points across 8 different sites to assess the accuracy of the supplied data.

The method for collecting these validation points utilising an RTK receiver and a lead-line, while rudimentary, was deemed appropriate given the soft base of the riverbed and the general flatness throughout the centre channels. In total, once points on steep gradients were removed and gross errors discarded, we found a mean difference of 0.031m with 85% of the points falling within ±0.100m and a 95% CI of ±0.150m across 311 validation points. The full results can be seen in Appendix E.

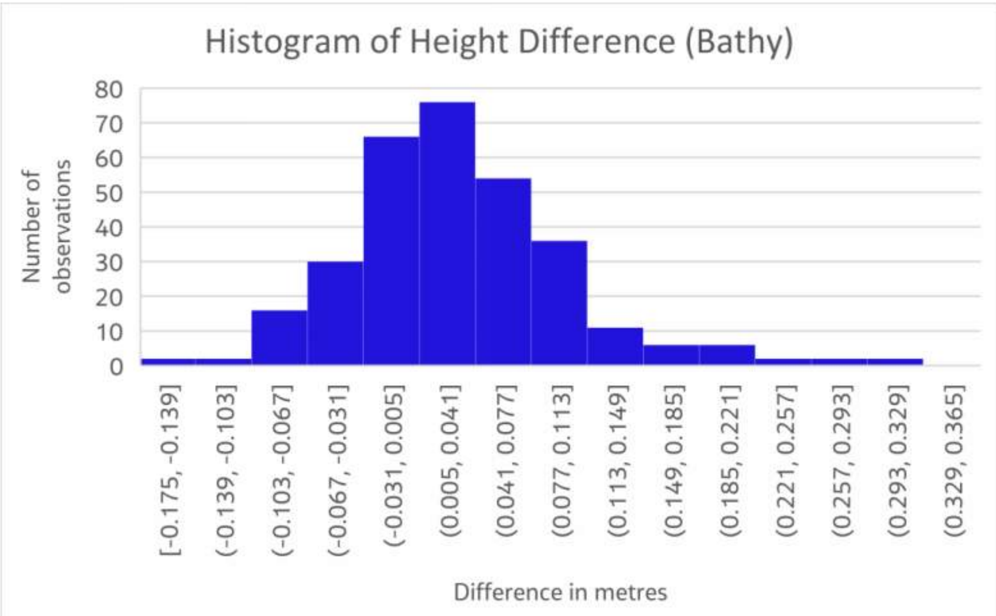

Figure 3 – Distribution of vertical height differences between the Bathymetry Data and independent validation points

While the overall accuracy is inferior to the airborne LiDAR, some variability is to be expected in the validation results. The riverbed is soft, introducing an expected level of error in both the multibeam echo sounder and the validation methodology. Regardless, the data supplied is of such a high density that it is far superior to any previous dataset used for mapping the riverbed previously. This greater level of detail provides a much more accurate representation of the riverbed as input into the flood model.

Additional analysis of the point cloud included viewing the data within Pointerra. Jacobs QA/QC looked for areas of misalignment between passes (upstream vs downstream) and any locations that didn't align with the expectations of the data. The high level of detail of the dataset was of note, with an unexpected by-product of the survey identifying as many as 70 vehicles and 2 boats along the riverbed.

8. Flood Level Markers

To assist the calibration of the flood model, Jacobs surveyed a series of known flood mark levels from the 2022 flooding event and measured their respective AHD value using Smartnet (Imax) RTK observations. In all a total of 50 flood marks were surveyed. These varied from debris identified in trees to text marks on structures that coincided with the peak of the flood as seen on flood photos. All will prove invaluable in helping calibrate the flood model.

Figure 4 – Example of the flood marker surveyed with its associated horizontal position and AHD value to be utilised to help calibrate the flood model.

9. Feature Survey

An additional input for flood modelling was the requirement to capture information at key structures across the Project Site. These structures were predominantly bridges where information about bridge soffit, deck thickness and pier locations were surveyed using Terrestrial Laser Scanners. Addition areas of interest such as the Flemington flood wall, Ascot Vale MD channel, various culverts and the river upstream of Medway golf course was also surveyed using Smartnet (Imax) RTK observations. A list of the various locations can be found below:

- Pipe Bridge
- Cannings Street Bridge
- Afton Street pedestrian bridge
- Raleigh Road Bridge
- Pipemakers Park Footbridge
- Edgewater Footbridge (North)
- Edgewater Footbridge (South)
- Fisher Parade Bridge
- Rail Culverts at Heavenly Queen Temple
- Lynches Bridge
- Kensington Rail Bridge
- Angliss Stock Bridge
- Rail Bridge (Kensington Road)
- Rail Bridge (Dynon Road)
- Dynon Road Bridge
- Southern Rail Bridge (between Footscray & Dynon)
- Footscray Road Bridge
- Ascot Vale MD Channel
- Flemington Racecourse Flood Wall
- Maribyrnong River (upstream of Medway Golf Course)

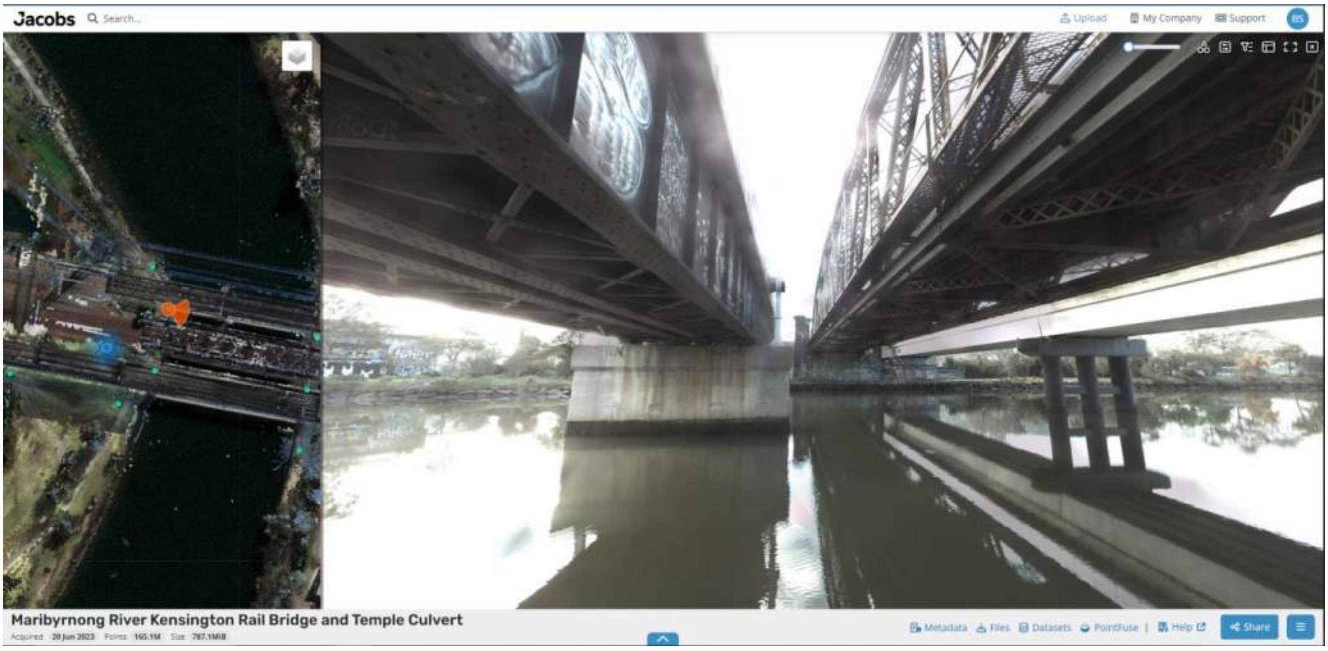

Figure 5 – Pointerra viewer of point cloud and panoramic imagery of Kensington Rail Bridge

10. Drainage Asset Investigation

In January and February 2024, Jacobs Survey Team completed additional drainage investigations in the Kensington area. The investigation focussed on the drainage assets within the Kensington estate which was bounded by the Maribyrnong River, Princess Highway, Epson Road, and Kensington Road (Figure 6).

The drainage investigation scope was developed with time and cost considerations and no traffic management, pit ingress or dewatering of submerged infrastructure assets was part of the scope. Much of the drainage network is maintained by the City of Melbourne and BYDA provided minimal detail. Results shown in Figure 6 highlight the limited assets that could be confirmed on site.

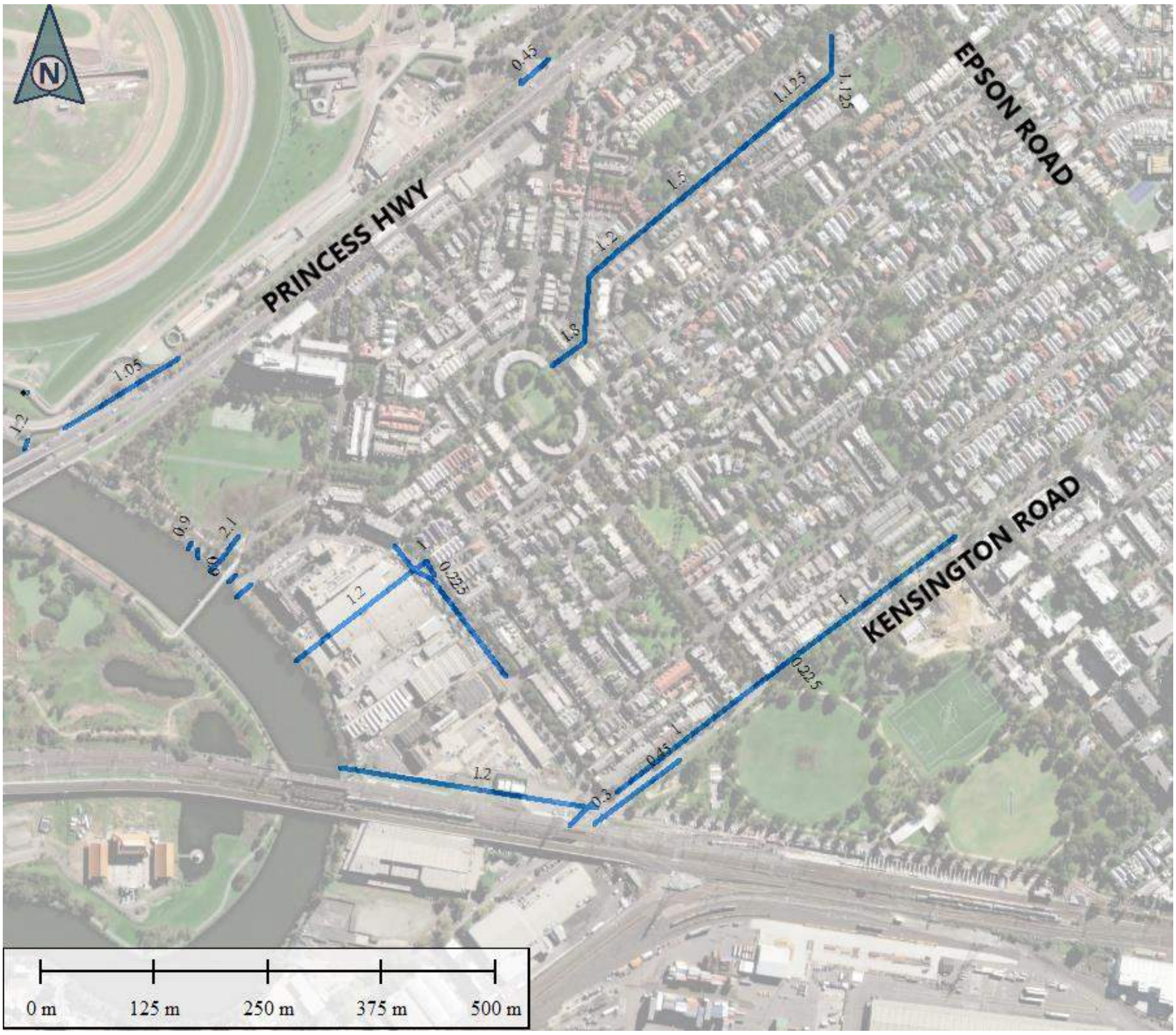

Figure 6. A snapshot of the confirmed assets located on site by Jacobs surveyors.

It was noted on site that there were significant drainage network upgrades along Childers Street which may associated with the construction of the Metro Tunnel project which were not reflected in the BYDA results. Jacobs recommends additional investigation be undertaken to improve the completeness of the critical drainage assets.

11. Floor Level Survey

As part of this Flood Study, it was identified a Floor Level Survey would help supplement flood analysis through provision of updated flood level data for buildings. Considering compressed timelines, a floor level survey was completed by Jacobs utilising an innovative Mobile Laser Scanning (MLS) technology approach. This method had the added benefit of not requiring communications to landowners as data is captured without accessing any private property. In late March and early April Jacobs conducted the MLS in the suburbs of Kensington, Edgewater and Ascot Vale as outlined in Figure 7, generating a point cloud that was constrained by the aerial LiDAR detailed in Section 6. Given this, the MLS accuracy was expected to mirror the results seen from the airborne LiDAR survey.

Figure 7 – Floor Level Survey extents in Kensington, Edgewater, and Ascot Vale

From the generated point cloud Jacobs were able to extract floor levels. Those points were then linked to building data and delivered within a shape file to be included in flood mapping analysis.

11.1 Data Validation

The method detailed in Section 11 has limitations. Firstly, it was known that the MLS would not be able to capture all floor levels as not all front doors will be able to be seen from the road (where the data is captured from) due to high fences, vegetation, or other obstructions. Jacobs had initially estimated approximately 75% of Flood Levels would be captured in the suburbs required.

From Table 6 is it clear that the method did not capture the expected number of property floor levels as initially expected. Reasons for the lower-than-expected number include:

- Higher density properties with private driveways.
- Kensington had significant number of properties fronting parkland as opposed to roads (Kensington).
- Large, heavily vegetated front yards where the front door is quite far from the road (Ascot Vale)

Suburb	*Floor Levels Located*	*Total Parcels*	*% Complete*
Kensington	608	1147	53%
Edgewater	359	492	73%
Ascot Vale	386	787	49%
Total	**1353**	**2426**	**56%**

Table 6 – A summary table for completeness of Floor Levels Surveyed. While good results were seen in Edgewater, Ascot Vale and Kensington had lower than expected completeness.

A secondary problem was the requirement to validate the accuracy of the data that was captured. While the Airborne LiDAR was used to constrain the MLS point cloud, an independent check on the accuracy of the Floor Levels was also completed to provide an assessment of their accuracy. To complete this, 90 properties had their floor level independently surveyed across nine streets in the three different suburbs. The method used a Total Station to measure the floor levels from the roadway with AHD established via Static GNSS from existing site survey control.

From the 90 properties surveyed, 72 were able to be seen in the point cloud with an average elevation difference of -0.015m ±0.058 @ 95% Confidence Interval. A full summary of results can be found in Appendix F. While the results do not meet Melbourne Water Survey Standards for Floor Level Surveys (±0.040m), given the time and project constraints, the Floor Levels surveyed were able to provide a large amount (1352 buildings) of valuable information in a short period of time at low cost and in a non-invasive manner with minimal stakeholder disturbance.

12. Conclusion

With the various number of datasets input into the final model it is important to document how they were integrated. A 0.5m DEM of the bathymetric data was created from the point cloud and combined into the supplied Aerial LiDAR DEM from Aerometrix. This task was completed in FME workbench, and a single output created.

The Terrestrial Laser scan point cloud was used to digitise important inputs into the flood model including bridge pier locations, bridge soffits, bridge deck, culverts, and other relevant features. Overall, this report demonstrates the quality and scale of data captured to form the basis of the flood model. All data integrity checks and reviews transparently illustrate the high standard of the data that is available for use by the flood model on this project.

Appendix A - Network Adjustment Results

Horizontal Adjustment

PROGRAM: HAVOC G77-3.6 11-11-2015 16-May-2023

MARI
*** OPTIONS SELECTED ***
Zone number is 55
Ellipsoid to grid reduction is required
Reduction of distances to the ellipsoid is required
Direction (C-O) limit is 350 minutes
Distance (C-O) limit is 100 metres
Required stage of processing is 4
Storage of information in station file is required
Number of iterations is 4
Analysis option is 2
Scaling of error ellipses by variance factor is required
Centering standard deviation is 0.3 centimetres
Variance factor limit for stage 3 output is 5.0
Adjustment report is required
All observed distances reduced by 4.7 ppm

SEPARW210913PNT
GEOCENTRIC DATUM OF AUSTRALIA ZONE 55 - METRES

LIST OF STATIONS

NUMBER	LABEL	NAME	EASTING	NORTHING	HEIGHT		N(GRS80)
5	M_PM247		307889.859	5822170.090	67.618		4.904
2	CPP_PM247		313820.070	5818479.382	2.621		4.836
15	PM440		309154.839	5819897.266	60.875		4.829
4	KEPK		310323.991	5822953.135	84.537	FIXED	4.944
7	PM67		312377.075	5817418.094	19.348		4.784
9	PM161		315392.296	5815441.563	6.096		4.754
1	CBG2		321446.424	5821156.040	58.644		5.045
3	CRKM		315782.443	5811517.955	14.792		4.624
6	PKVL		320479.048	5814437.795	62.604		4.802
13	PM292		311626.424	5819571.736	53.926		4.849
11	PM251		314811.241	5818173.491	1.336		4.843
12	PM255		314669.480	5817468.701	1.579		4.815
10	PM237		314610.444	5817705.651	3.003		4.823
14	PM321		316155.375	5814948.659	1.339		4.749
8	PM154		314918.570	5812706.919	9.360		4.656
16	PM572		312523.928	5816824.455	29.601		4.764

LIST OF AZIMUTH AND BEARING OBSERVATIONS

OBS. NO.	FROM	TO	AZIMUTH / ARC-CHD. CONVERGENCE / SECONDS / PLANE BEARING		COMPUTED PLANE BEARING	(C-O) SECONDS	STD DEV	WEIGHT
1	CBG2	KEPK	279 10 41.4	C	279 10 41.5	0.0	0.5	3.938
2	CBG2	PKVL	188 11 37.8	C	188 11 37.8	0.0	0.6	3.139
3	CBG2	CRKM	210 26 28.8	C	210 26 28.8	0.0	0.5	3.923
4	CPP_PM247	CBG2	70 39 36.7	C	70 39 36.8	0.0	0.5	3.429
5	CPP_PM247	PKVL	121 15 18.6	C	121 15 18.6	0.0	0.5	3.368
6	CPP_PM247	PM440	286 54 19.3	C	286 54 19.3	0.0	0.6	2.568
7	CPP_PM247	CRKM	164 15 26.2	C	164 15 26.2	-0.1	0.6	3.250
8	CPP_PM247	KEPK	321 59 37.1	C	321 59 37.1	0.0	0.6	2.837
9	CRKM	PKVL	58 07 52.0	C	58 07 52.0	0.0	0.6	2.790
10	CRKM	KEPK	334 28 59.0	C	334 28 59.0	0.0	0.5	4.095
11	KEPK	PKVL	129 58 51.3	C	129 58 51.3	0.0	0.5	4.161
12	M_PM247	PM440	150 54 03.9	C	150 54 04.0	0.1	0.8	1.529
13	M_PM247	KEPK	72 10 02.3	C	72 10 02.4	0.1	0.8	1.504
14	M_PM247	PKVL	121 33 29.9	C	121 33 29.9	0.0	0.5	4.297
15	M_PM247	CRKM	143 27 49.7	C	143 27 49.7	0.0	0.5	4.161
16	PM67	PM292	340 47 02.6	C	340 47 02.5	-0.1	0.9	1.339
17	PM67	PM440	307 34 28.3	C	307 34 28.2	-0.1	0.7	2.254
18	PM67	KEPK	339 38 56.2	C	339 38 56.2	0.0	0.6	2.903
19	PM67	CRKM	150 00 28.4	C	150 00 28.3	-0.1	0.6	3.150
20	PM67	PKVL	110 11 45.5	C	110 11 45.5	0.0	0.5	3.530
21	PM67	CBG2	67 36 03.3	C	67 36 03.3	0.0	0.5	3.733
22	PM154	KEPK	335 50 51.8	C	335 50 51.8	-0.1	0.5	3.938
23	PM154	CRKM	143 59 55.5	C	143 59 55.6	0.1	1.1	0.805
24	PM154	CBG2	37 41 23.8	C	37 41 23.8	0.0	0.5	3.863
25	PM154	PM237	356 28 21.6	C	356 28 21.7	0.1	0.6	2.617
26	PM154	PM321	28 53 10.6	C	28 53 10.4	-0.1	0.8	1.504
27	PM154	PKVL	72 42 34.3	C	72 42 34.5	0.2	0.6	2.874
28	PM161	CRKM	174 19 17.1	C	174 19 17.1	0.0	0.7	2.202
29	PM161	PM321	122 51 36.0	C	122 51 36.2	0.1	1.5	0.417
30	PM161	CBG2	46 39 11.3	C	46 39 11.3	0.0	0.5	3.479
31	PM161	PM154	189 49 40.5	C	189 49 40.4	-0.1	0.8	1.626
32	PM161	PKVL	101 09 45.8	C	101 09 45.9	0.0	0.6	2.676
33	PM161	PM237	340 56 55.7	C	340 56 55.7	0.0	0.8	1.408
34	PM161	KEPK	325 59 28.2	C	325 59 28.2	0.0	0.5	3.609
35	PM237	PM292	302 01 12.6	C	302 01 12.6	0.1	0.7	2.012
36	PM237	KEPK	320 45 21.7	C	320 45 21.7	0.0	0.6	3.139
37	PM237	CBG2	63 13 05.3	C	63 13 05.2	0.0	0.5	3.344
38	PM237	PM321	150 44 06.3	C	150 44 06.4	0.1	0.7	1.830
39	PM237	CRKM	169 16 29.2	C	169 16 29.2	0.1	0.6	3.012

40	PM237	PKVL	119 06 38.4	C	119 06 38.4	0.0	0.6	3.117
41	PM251	KEPK	316 48 26.0	C	316 48 26.0	0.0	0.6	3.074
42	PM251	PKVL	123 23 21.2	C	123 23 21.1	-0.1	0.6	3.139
43	PM251	PM321	157 22 23.9	C	157 22 23.8	-0.2	0.7	1.995
44	PM251	PM237	203 13 44.6	C	203 13 44.5	-0.2	2.4	0.168
45	PM251	PM292	293 42 11.1	C	293 42 11.3	0.1	0.7	1.989
46	PM251	CBG2	65 47 45.2	C	65 47 45.0	-0.2	0.6	3.250
47	PM251	CRKM	171 41 52.0	C	171 41 52.0	0.0	0.6	3.128
48	PM255	CRKM	169 24 23.0	C	169 24 23.1	0.1	0.6	2.942
49	PM255	PKVL	117 33 05.3	C	117 33 05.3	0.0	0.6	3.074
50	PM255	KEPK	321 36 32.9	C	321 36 32.8	-0.1	0.6	3.194
51	PM255	PM237	346 00 34.8	C	346 00 35.0	0.2	4.6	0.047
52	PM255	CBG2	61 26 57.7	C	61 26 57.7	0.0	0.5	3.356
53	PM255	PM292	304 38 53.1	C	304 38 53.1	0.0	0.7	2.092
54	PM255	PM321	149 28 30.2	C	149 28 30.3	0.0	0.8	1.710
55	PM292	KEPK	338 56 04.3	C	338 56 04.3	0.0	0.7	2.057
56	PM292	PKVL	120 06 39.3	C	120 06 39.3	0.0	0.5	3.790
57	PM292	CBG2	80 50 06.7	C	80 50 06.7	0.0	0.5	3.747
58	PM292	PM440	277 30 11.4	C	277 30 11.5	0.0	0.8	1.465
59	PM292	CRKM	152 42 17.2	C	152 42 17.1	0.0	0.5	3.609
60	PM321	CRKM	186 12 14.1	C	186 12 14.2	0.1	0.7	1.979
61	PM321	CBG2	40 26 37.0	C	40 26 37.0	0.0	0.5	3.441
62	PM321	KEPK	323 55 33.9	C	323 55 33.9	0.0	0.5	3.747
63	PM321	PKVL	96 44 18.7	C	96 44 18.8	0.1	0.6	2.371
64	PM440	PKVL	115 44 20.4	C	115 44 20.4	0.0	0.5	4.095
65	PM440	KEPK	20 56 11.2	C	20 56 11.3	0.1	0.7	1.889
66	PM440	CBG2	84 09 09.9	C	84 09 09.9	0.0	0.5	4.063
67	PM440	CRKM	141 39 28.2	C	141 39 28.2	-0.1	0.5	3.863
68	PM572	CRKM	148 26 51.1	C	148 26 51.1	0.0	0.6	2.992
69	PM572	KEPK	340 15 14.5	C	340 15 14.4	0.0	0.6	3.064
70	PM572	PM292	341 54 30.4	C	341 54 30.2	-0.2	0.8	1.689
71	PM572	CBG2	64 06 17.7	C	64 06 17.7	0.0	0.5	3.747
72	PM572	PKVL	106 42 00.2	C	106 42 00.2	0.0	0.5	3.466
73	PM572	PM237	67 06 15.2	C	67 06 15.3	0.1	0.9	1.327

LIST OF DISTANCE OBSERVATIONS

OBS. NO.	FROM	TO	OBSERVED DISTANCE	SCALED DISTANCE	LINE SCALE FACTOR	RED. PLANE DISTANCE	COMP PLANE DISTANCE	(C-O)	STD. DEV. CONST	PPM
74	CBG2	KEPK	11266.488E	11266.488	1.00001767	11266.687 C	11266.680	-0.007	0.5	2.0
75	CBG2	PKVL	6787.575E	6787.575	0.99999483	6787.540 C	6787.535	-0.005	0.5	2.0
76	CBG2	CRKM	11179.098E	11179.098	1.00000528	11179.157 C	11179.150	-0.007	0.5	2.0
77	CPP_PM247	CBG2	8082.366E	8082.366	1.00000971	8082.444 C	8082.436	-0.008	0.5	2.0
78	CPP_PM247	PKVL	7789.420E	7789.420	1.00001187	7789.512 C	7789.506	-0.006	0.5	2.0
79	CPP_PM247	PM440	4875.759E	4875.759	1.00003775	4875.943 C	4875.938	-0.004	0.5	2.0
80	CPP_PM247	CRKM	7232.573E	7232.573	1.00002247	7232.736 C	7232.730	-0.006	0.5	2.0
81	CPP_PM247	KEPK	5677.571E	5677.571	1.00003503	5677.770 C	5677.766	-0.003	0.5	2.0
82	CRKM	PKVL	5530.204E	5530.204	1.00000743	5530.245 C	5530.242	-0.004	0.5	2.0
83	CRKM	KEPK	12670.771E	12670.771	1.00003051	12671.158 C	12671.150	-0.007	0.5	2.0
84	KEPK	PKVL	13252.526E	13252.526	1.00001984	13252.789 C	13252.780	-0.009	0.5	2.0
85	M_PM247	PM440	2601.002E	2601.002	1.00005161	2601.136 C	2601.135	-0.001	0.5	2.0
86	M_PM247	KEPK	2556.855E	2556.855	1.00004886	2556.980 C	2556.982	0.002	0.5	2.0
87	M_PM247	PKVL	14773.796E	14773.796	1.00002545	14774.172 C	14774.168	-0.004	0.5	2.0
88	M_PM247	CRKM	13257.010E	13257.010	1.00003617	13257.490 C	13257.483	-0.006	0.5	2.0
89	PM67	PM292	2280.633E	2280.633	1.00003534	2280.713 C	2280.713	0.000	0.5	2.0
90	PM67	PM440	4065.431E	4065.431	1.00004109	4065.598 C	4065.599	0.001	0.5	2.0
91	PM67	KEPK	5903.317E	5903.317	1.00003837	5903.544 C	5903.544	0.000	0.5	2.0
92	PM67	CRKM	6812.181E	6812.181	1.00002578	6812.356 C	6812.354	-0.002	0.5	2.0
93	PM67	PKVL	8632.602E	8632.602	1.00001515	8632.733 C	8632.737	0.004	0.5	2.0
94	PM67	CBG2	9809.319E	9809.319	1.00001298	9809.446 C	9809.452	0.006	0.5	2.0
95	PM154	KEPK	11228.825E	11228.825	1.00003250	11229.190 C	11229.208	0.018	0.5	2.0
96	PM154	CRKM	1469.632E	1469.632	1.00001996	1469.662 C	1469.664	0.002	0.5	2.0
97	PM154	CBG2	10677.024E	10677.024	1.00000723	10677.101 C	10677.103	0.002	0.5	2.0
98	PM154	PM237	5008.105E	5008.105	1.00002264	5008.219 C	5008.220	0.001	0.5	2.0
99	PM154	PM321	2560.243E	2560.243	1.00001912	2560.292 C	2560.290	-0.001	0.5	2.0
100	PM154	PKVL	5823.586E	5823.586	1.00000938	5823.641 C	5823.645	0.005	0.5	2.0
101	PM161	CRKM	3942.881E	3942.881	1.00001889	3942.955 C	3942.958	0.002	0.5	2.0
102	PM161	PM321	908.414E	908.414	1.00001804	908.430 C	908.429	-0.001	0.5	2.0
103	PM161	CBG2	8325.071E	8325.071	1.00000616	8325.122 C	8325.126	0.004	0.5	2.0
104	PM161	PM154	2775.313E	2775.313	1.00002085	2775.371 C	2775.373	0.002	0.5	2.0
105	PM161	PKVL	5184.795E	5184.795	1.00000831	5184.838 C	5184.843	0.004	0.5	2.0
106	PM161	PM237	2395.231E	2395.231	1.00002156	2395.282 C	2395.285	0.002	0.5	2.0
107	PM161	KEPK	9061.243E	9061.243	1.00003141	9061.528 C	9061.536	0.008	0.5	2.0
108	PM237	PM292	3519.362E	3519.362	1.00003019	3519.468 C	3519.468	-0.001	0.5	2.0
109	PM237	KEPK	6775.446E	6775.446	1.00003321	6775.671 C	6775.675	0.003	0.5	2.0
110	PM237	CBG2	7657.336E	7657.336	1.00000792	7657.397 C	7657.402	0.006	0.5	2.0
111	PM237	PM321	3160.286E	3160.286	1.00001982	3160.348 C	3160.350	0.002	0.5	2.0
112	PM237	CRKM	6297.576E	6297.576	1.00002067	6297.706 C	6297.711	0.006	0.5	2.0
113	PM237	PKVL	6717.026E	6717.026	1.00001008	6717.094 C	6717.097	0.003	0.5	2.0
114	PM251	KEPK	6555.724E	6555.724	1.00003275	6555.938 C	6555.945	0.006	0.5	2.0
115	PM251	PKVL	6788.120E	6788.120	1.00000963	6788.185 C	6788.185	0.000	0.5	2.0
116	PM251	PM321	3493.677E	3493.677	1.00001936	3493.744 C	3493.743	-0.002	0.5	2.0
117	PM251	PM237	509.096E	509.096	1.00002288	509.108 C	509.111	0.003	0.5	2.0
118	PM251	PM292	3478.136E	3478.136	1.00002973	3478.240 C	3478.240	0.000	0.5	2.0
119	PM251	CBG2	7274.639E	7274.639	1.00000747	7274.693 C	7274.700	0.006	0.5	2.0
120	PM251	CRKM	6725.887E	6725.887	1.00002021	6726.023 C	6726.024	0.001	0.5	2.0
121	PM255	CRKM	6053.803E	6053.803	1.00002053	6053.927 C	6053.930	0.003	0.5	2.0
122	PM255	PKVL	6552.602E	6552.602	1.00000995	6552.667 C	6552.669	0.002	0.5	2.0
123	PM255	KEPK	6997.071E	6997.071	1.00003307	6997.302 C	6997.306	0.003	0.5	2.0
124	PM255	PM237	244.187E	244.187	1.00002321	244.193 C	244.193	0.001	0.5	2.0
125	PM255	CBG2	7715.080E	7715.080	1.00000779	7715.140 C	7715.144	0.004	0.5	2.0
126	PM255	PM292	3698.935E	3698.935	1.00003006	3699.046 C	3699.047	0.000	0.5	2.0
127	PM255	PM321	2925.432E	2925.432	1.00001969	2925.490 C	2925.491	0.001	0.5	2.0

128	PM292	KEPK	3623.418E	3623.418	1.00004011	3623.563 C	3623.561	-0.002	0.5	2.0
129	PM292	PKVL	10233.422E	10233.422	1.00001686	10233.594 C	10233.587	-0.007	0.5	2.0
130	PM292	CBG2	9946.843E	9946.843	1.00001469	9946.989 C	9946.981	-0.008	0.5	2.0
131	PM292	PM440	2492.823E	2492.823	1.00004284	2492.930 C	2492.930	0.000	0.5	2.0
132	PM292	CRKM	9062.640E	9062.640	1.00002751	9062.890 C	9062.885	-0.004	0.5	2.0
133	PM321	CRKM	3450.857E	3450.857	1.00001716	3450.916 C	3450.915	-0.001	0.5	2.0
134	PM321	CBG2	8156.364E	8156.364	1.00000445	8156.400 C	8156.395	-0.005	0.5	2.0
135	PM321	KEPK	9903.074E	9903.074	1.00002966	9903.368 C	9903.367	-0.001	0.5	2.0
136	PM321	PKVL	4353.723E	4353.723	1.00000660	4353.752 C	4353.749	-0.003	0.5	2.0
137	PM440	PKVL	12571.260E	12571.260	1.00002253	12571.543 C	12571.536	-0.007	0.5	2.0
138	PM440	KEPK	3271.740E	3271.740	1.00004589	3271.890 C	3271.888	-0.002	0.5	2.0
139	PM440	CBG2	12355.628E	12355.628	1.00002035	12355.879 C	12355.872	-0.007	0.5	2.0
140	PM440	CRKM	10683.188E	10683.188	1.00003322	10683.543 C	10683.538	-0.005	0.5	2.0
141	PM572	CRKM	6226.949E	6226.949	1.00002544	6227.107 C	6227.107	-0.001	0.5	2.0
142	PM572	KEPK	6511.313E	6511.313	1.00003803	6511.560 C	6511.563	0.002	0.5	2.0
143	PM572	PM292	2890.067E	2890.067	1.00003500	2890.168 C	2890.168	0.000	0.5	2.0
144	PM572	CBG2	9918.216E	9918.216	1.00001265	9918.341 C	9918.345	0.004	0.5	2.0
145	PM572	PKVL	8305.300E	8305.300	1.00001481	8305.423 C	8305.424	0.002	0.5	2.0
146	PM572	PM237	2264.897E	2264.897	1.00002812	2264.961 C	2264.963	0.002	0.5	2.0

Number of stations : 16
Number of fixed stations : 1
Number of azimuths : 73
Number of directions : 0
Number of distances : 73

Number of observation equations : 146
Matrix size : 30
Band width : 20
Number of terms in normal equations : 420

LIST OF RESIDUALS

OBS.NO.	FROM		TO	RESIDUAL	STD. RES.	DISTANCE	OFFSET
1	CBG2	*	KEPK	0.0	0.023	11267	0.001
2	CBG2		PKVL	0.0	0.037	6788	0.001
3	CBG2		CRKM	0.0	0.027	11179	0.001
4	CPP_PM247		CBG2	0.0	0.058	8082	0.001
5	CPP_PM247		PKVL	0.0	0.022	7790	0.000
6	CPP_PM247		PM440	0.0	0.013	4876	0.000
7	CPP_PM247		CRKM	-0.1	-0.115	7233	-0.002
8	CPP_PM247	*	KEPK	0.0	0.020	5678	0.000
9	CRKM		PKVL	0.0	0.021	5530	0.000
10	CRKM	*	KEPK	0.0	0.014	12671	0.000
11 *	KEPK		PKVL	0.0	0.013	13253	0.000
12	M_PM247		PM440	0.1	0.150	2601	0.002
13	M_PM247	*	KEPK	0.1	0.129	2557	0.001
14	M_PM247		PKVL	0.0	-0.097	14774	-0.003
15	M_PM247		CRKM	0.0	0.012	13257	0.000
16	PM67		PM292	-0.1	-0.115	2281	-0.001
17	PM67		PM440	-0.1	-0.119	4066	-0.002
18	PM67	*	KEPK	0.0	0.011	5904	0.000
19	PM67		CRKM	-0.1	-0.129	6812	-0.002
20	PM67		PKVL	0.0	-0.017	8633	0.000
21	PM67		CBG2	0.0	0.086	9809	0.002
22	PM154	*	KEPK	-0.1	-0.122	11229	-0.003
23	PM154		CRKM	0.1	0.094	1470	0.001
24	PM154		CBG2	0.0	0.068	10677	0.002
25	PM154		PM237	0.1	0.229	5008	0.003
26	PM154		PM321	-0.1	-0.168	2560	-0.002
27	PM154		PKVL	0.2	0.324	5824	0.005
28	PM161		CRKM	0.0	0.036	3943	0.000
29	PM161		PM321	0.1	0.079	908	0.001
30	PM161		CBG2	0.0	0.066	8325	0.001
31	PM161		PM154	-0.1	-0.178	2775	-0.002
32	PM161		PKVL	0.0	0.077	5185	0.001
33	PM161		PM237	0.0	0.045	2395	0.000
34	PM161	*	KEPK	0.0	-0.031	9062	-0.001
35	PM237		PM292	0.1	0.122	3519	0.001
36	PM237	*	KEPK	0.0	-0.059	6776	-0.001
37	PM237		CBG2	0.0	-0.074	7657	-0.001
38	PM237		PM321	0.1	0.123	3160	0.001
39	PM237		CRKM	0.1	0.101	6298	0.002
40	PM237		PKVL	0.0	-0.003	6717	0.000
41	PM251	*	KEPK	0.0	0.016	6556	0.000
42	PM251		PKVL	-0.1	-0.183	6788	-0.003
43	PM251		PM321	-0.2	-0.247	3494	-0.003
44	PM251		PM237	-0.2	-0.063	509	0.000
45	PM251		PM292	0.1	0.166	3478	0.002
46	PM251		CBG2	-0.2	-0.304	7275	-0.006
47	PM251		CRKM	0.0	-0.005	6726	0.000
48	PM255		CRKM	0.1	0.122	6054	0.002
49	PM255		PKVL	0.0	0.004	6553	0.000
50	PM255	*	KEPK	-0.1	-0.151	6997	-0.003
51	PM255		PM237	0.2	0.038	244	0.000
52	PM255		CBG2	0.0	0.055	7715	0.001
53	PM255		PM292	0.0	-0.029	3699	0.000
54	PM255		PM321	0.0	0.029	2925	0.000
55	PM292	*	KEPK	0.0	-0.042	3624	-0.001
56	PM292		PKVL	0.0	0.032	10234	0.001
57	PM292		CBG2	0.0	-0.045	9947	-0.001
58	PM292		PM440	0.0	0.056	2493	0.001
59	PM292		CRKM	0.0	-0.063	9063	-0.001

60	PM321	CRKM	0.1	0.105	3451	0.001
61	PM321	CBG2	0.0	0.012	8156	0.000
62	PM321	* KEPK	0.0	0.096	9903	0.002
63	PM321	PKVL	0.1	0.141	4354	0.002
64	PM440	PKVL	0.0	-0.025	12572	-0.001
65	PM440	* KEPK	0.1	0.135	3272	0.002
66	PM440	CBG2	0.0	-0.015	12356	0.000
67	PM440	CRKM	-0.1	-0.144	10684	-0.004
68	PM572	CRKM	0.0	0.004	6227	0.000
69	PM572	* KEPK	0.0	-0.071	6512	-0.001
70	PM572	PM292	-0.2	-0.279	2890	-0.003
71	PM572	CBG2	0.0	0.003	9918	0.000
72	PM572	PKVL	0.0	-0.019	8305	0.000
73	PM572	PM237	0.1	0.071	2265	0.001

OBS.NO.	FROM	TO	RESIDUAL	STD. RES.	DISTANCE	PPM
74	CBG2	* KEPK	-0.007	-0.272	11267	-0.7
75	CBG2	PKVL	-0.005	-0.265	6788	-0.7
76	CBG2	CRKM	-0.007	-0.253	11179	-0.6
77	CPP_PM247	CBG2	-0.008	-0.388	8082	-1.0
78	CPP_PM247	PKVL	-0.006	-0.297	7790	-0.8
79	CPP_PM247	PM440	-0.004	-0.292	4876	-0.9
80	CPP_PM247	CRKM	-0.006	-0.287	7233	-0.8
81	CPP_PM247	* KEPK	-0.003	-0.197	5678	-0.6
82	CRKM	PKVL	-0.004	-0.220	5530	-0.6
83	CRKM	* KEPK	-0.007	-0.244	12671	-0.6
84 *	KEPK	PKVL	-0.009	-0.277	13253	-0.7
85	M_PM247	PM440	-0.001	-0.057	2601	-0.2
86	M_PM247	* KEPK	0.002	0.181	2557	0.7
87	M_PM247	PKVL	-0.004	-0.111	14774	-0.3
88	M_PM247	CRKM	-0.006	-0.200	13257	-0.5
89	PM67	PM292	0.000	-0.017	2281	-0.1
90	PM67	PM440	0.001	0.086	4066	0.3
91	PM67	* KEPK	0.000	0.028	5904	0.1
92	PM67	CRKM	-0.002	-0.109	6812	-0.3
93	PM67	PKVL	0.004	0.180	8633	0.5
94	PM67	CBG2	0.006	0.247	9809	0.6
95	PM154	* KEPK	0.018	0.657	11229	1.6
96	PM154	CRKM	0.002	0.232	1470	1.3
97	PM154	CBG2	0.002	0.087	10677	0.2
98	PM154	PM237	0.001	0.090	5008	0.3
99	PM154	PM321	-0.001	-0.126	2560	-0.5
100	PM154	PKVL	0.005	0.277	5824	0.8
101	PM161	CRKM	0.002	0.178	3943	0.6
102	PM161	PM321	-0.001	-0.142	908	-1.1
103	PM161	CBG2	0.004	0.186	8325	0.5
104	PM161	PM154	0.002	0.174	2775	0.7
105	PM161	PKVL	0.004	0.272	5185	0.8
106	PM161	PM237	0.002	0.232	2395	0.9
107	PM161	* KEPK	0.008	0.365	9062	0.9
108	PM237	PM292	-0.001	-0.053	3519	-0.2
109	PM237	* KEPK	0.003	0.186	6776	0.5
110	PM237	CBG2	0.006	0.274	7657	0.7
111	PM237	PM321	0.002	0.183	3160	0.7
112	PM237	CRKM	0.006	0.319	6298	0.9
113	PM237	PKVL	0.003	0.158	6717	0.4
114	PM251	* KEPK	0.006	0.345	6556	1.0
115	PM251	PKVL	0.000	-0.027	6788	-0.1
116	PM251	PM321	-0.002	-0.157	3494	-0.5
117	PM251	PM237	0.003	0.455	509	5.4
118	PM251	PM292	0.000	0.011	3478	0.0
119	PM251	CBG2	0.006	0.325	7275	0.9
120	PM251	CRKM	0.001	0.075	6726	0.2
121	PM255	CRKM	0.003	0.171	6054	0.5
122	PM255	PKVL	0.002	0.123	6553	0.3
123	PM255	* KEPK	0.003	0.174	6997	0.5
124	PM255	PM237	0.001	0.109	244	2.4
125	PM255	CBG2	0.004	0.191	7715	0.5
126	PM255	PM292	0.000	0.024	3699	0.1
127	PM255	PM321	0.001	0.107	2925	0.4
128	PM292	* KEPK	-0.002	-0.199	3624	-0.7
129	PM292	PKVL	-0.007	-0.292	10234	-0.7
130	PM292	CBG2	-0.008	-0.314	9947	-0.8
131	PM292	PM440	0.000	0.024	2493	0.1
132	PM292	CRKM	-0.004	-0.192	9063	-0.5
133	PM321	CRKM	-0.001	-0.062	3451	-0.2
134	PM321	CBG2	-0.005	-0.248	8156	-0.6
135	PM321	* KEPK	-0.001	-0.046	9903	-0.1
136	PM321	PKVL	-0.003	-0.233	4354	-0.7
137	PM440	PKVL	-0.007	-0.231	12572	-0.6
138	PM440	* KEPK	-0.002	-0.164	3272	-0.6
139	PM440	CBG2	-0.007	-0.234	12356	-0.6
140	PM440	CRKM	-0.005	-0.192	10684	-0.5
141	PM572	CRKM	-0.001	-0.037	6227	-0.1
142	PM572	* KEPK	0.002	0.121	6512	0.3
143	PM572	PM292	0.000	-0.026	2890	-0.1
144	PM572	CBG2	0.004	0.170	9918	0.4
145	PM572	PKVL	0.002	0.077	8305	0.2
146	PM572	PM237	0.002	0.190	2265	0.8

(PVV) = 4.405

(PLV) = -4.405

Estimate of variance factor = 0.038

Azimuth component = 0.015

Distance component = 0.061
Number of redundant observations = 116
Average redundancy number = 0.795

RESIDUAL ANALYSIS

STANDARD RESIDUAL DISTRIBUTION

< -4	-4 TO -3	-3 TO -2	-2 TO -1	-1 TO 0	0 TO 1	1 TO 2	2 TO 3	3 TO 4	> 4
0	0	0	0	64	82	0	0	0	0

Maximum = 0.657 (Observation 95)
Minimum = -0.388 (Observation 77)
Mean = 0.007 Standard deviation = 0.174
Total = 146

AZIMUTH RESIDUAL DISTRIBUTION (SECONDS)

< -4	-4 TO -3	-3 TO -2	-2 TO -1	-1 TO 0	0 TO 1	1 TO 2	2 TO 3	3 TO 4	> 4
0	0	0	0	29	44	0	0	0	0

Maximum = 0.191 (Observation 27)
Minimum = -0.215 (Observation 70)
Mean = 0.004 Standard deviation = 0.079
Total = 73

DISTANCE RESIDUAL DISTRIBUTION (CENTIMETRES)

< -4	-4 TO -3	-3 TO -2	-2 TO -1	-1 TO 0	0 TO 1	1 TO 2	2 TO 3	3 TO 4	> 4
0	0	0	0	35	37	1	0	0	0

DISTANCE RESIDUAL DISTRIBUTION (PPM)

< -8	-8 TO -6	-6 TO -4	-4 TO -2	-2 TO 0	0 TO 2	2 TO 4	4 TO 6	6 TO 8	> 8
0	0	0	0	35	36	1	1	0	0

Maximum = 0.018 metres (Observation 95)
5.379 ppm (Observation 117)
Minimum = -0.009 metres (Observation 84)
-1.066 ppm (Observation 102)
Mean = 0.000 metres Standard deviation = 0.005 metres
0.131 ppm 0.921 ppm
Total = 73

LABEL	NAME	E (APPROX.)	N	CORRECTIONS E	CORRECTIONS N	E (ADJUSTED)	N
M_PM247		307889.859	5822170.090	0.000	0.000	307889.859	5822170.090
CPP_PM247		313820.070	5818479.382	0.000	0.000	313820.070	5818479.382
PM440		309154.839	5819897.266	0.000	0.000	309154.839	5819897.266
KEPK	FIXED STATION					310323.991	5822953.135
PM67		312377.075	5817418.094	0.000	0.000	312377.075	5817418.094
PM161		315392.296	5815441.563	0.000	0.000	315392.296	5815441.563
CBG2		321446.424	5821156.040	0.000	0.000	321446.424	5821156.040
CRKM		315782.443	5811517.955	0.000	0.000	315782.443	5811517.955
PKVL		320479.048	5814437.795	0.000	0.000	320479.048	5814437.795
PM292		311626.424	5819571.736	0.000	0.000	311626.424	5819571.736
PM251		314811.241	5818173.491	0.000	0.000	314811.241	5818173.491
PM255		314669.480	5817468.701	0.000	0.000	314669.480	5817468.701
PM237		314610.444	5817705.651	0.000	0.000	314610.444	5817705.651
PM321		316155.375	5814948.659	0.000	0.000	316155.375	5814948.659
PM154		314918.570	5812706.919	0.000	0.000	314918.570	5812706.919
PM572		312523.928	5816824.455	0.000	0.000	312523.928	5816824.455

ERROR ELLIPSE INFORMATION FOR LINES OBSERVED

VARIANCE FACTOR USED: 0.038 STANDARD DEVIATIONS ARE IN METRES AND SECONDS * INDICATES FIXED STATION
ADJ. VARIANCE FACTOR: 0.038

95% CONFIDENCE REGION (FACTOR= 2.45)

LINE			REL. CO-ORD. PRECISION			RELATIVE ELLIPSE				LINE PRECISION		
FROM		TO	DE	DN	COV.	S.MAJ.	S.MIN.	ORIENT.	MAJ/MIN	DIST.	PPM	BEAR.
CBG2	*	KEPK	0.001	0.001	0.000	0.004	0.004	34	1.0	0.004	0.3	0.1
CBG2		PKVL	0.001	0.001	0.000	0.004	0.004	32	1.0	0.004	0.5	0.1
CBG2		CRKM	0.001	0.001	0.000	0.004	0.004	14	1.0	0.004	0.3	0.1
CPP_PM247		CBG2	0.002	0.002	0.000	0.005	0.005	153	1.0	0.005	0.6	0.1
CPP_PM247		PKVL	0.002	0.002	0.000	0.004	0.004	157	1.0	0.004	0.6	0.1
CPP_PM247		PM440	0.002	0.002	0.000	0.004	0.004	149	1.0	0.004	0.9	0.2
CPP_PM247		CRKM	0.002	0.002	0.000	0.004	0.004	156	1.0	0.004	0.6	0.1
CPP_PM247	*	KEPK	0.002	0.002	0.000	0.004	0.004	148	1.0	0.004	0.7	0.2
CRKM		PKVL	0.001	0.001	0.000	0.003	0.003	23	1.0	0.003	0.5	0.1
CRKM	*	KEPK	0.001	0.001	0.000	0.003	0.003	161	1.0	0.003	0.2	0.1
* KEPK		PKVL	0.001	0.001	0.000	0.003	0.003	22	1.0	0.003	0.3	0.1
M_PM247		PM440	0.001	0.001	0.000	0.004	0.004	145	1.0	0.004	1.4	0.3
M_PM247	*	KEPK	0.001	0.001	0.000	0.004	0.004	79	1.0	0.004	1.4	0.3
M_PM247		PKVL	0.002	0.002	0.000	0.004	0.004	78	1.0	0.004	0.3	0.1
M_PM247		CRKM	0.002	0.002	0.000	0.004	0.004	130	1.0	0.004	0.3	0.1
PM67		PM292	0.001	0.001	0.000	0.003	0.003	158	1.0	0.003	1.4	0.3
PM67		PM440	0.001	0.001	0.000	0.004	0.004	150	1.0	0.004	0.9	0.2
PM67	*	KEPK	0.001	0.001	0.000	0.004	0.004	157	1.0	0.004	0.6	0.1
PM67		CRKM	0.002	0.002	0.000	0.004	0.004	157	1.0	0.004	0.5	0.1
PM67		PKVL	0.002	0.002	0.000	0.004	0.004	169	1.0	0.004	0.4	0.1
PM67		CBG2	0.002	0.002	0.000	0.004	0.004	162	1.0	0.004	0.4	0.1
PM154	*	KEPK	0.001	0.001	0.000	0.003	0.003	157	1.0	0.003	0.3	0.1
PM154		CRKM	0.001	0.001	0.000	0.003	0.003	172	1.0	0.003	1.8	0.4
PM154		CBG2	0.002	0.002	0.000	0.004	0.004	20	1.0	0.004	0.3	0.1
PM154		PM237	0.001	0.001	0.000	0.003	0.003	170	1.0	0.003	0.6	0.1
PM154		PM321	0.001	0.001	0.000	0.003	0.003	165	1.0	0.003	1.1	0.2
PM154		PKVL	0.001	0.001	0.000	0.003	0.003	8	1.0	0.003	0.6	0.1
PM161		CRKM	0.001	0.001	0.000	0.003	0.003	176	1.0	0.003	0.7	0.1
PM161		PM321	0.001	0.001	0.000	0.002	0.002	2	1.0	0.002	2.6	0.5
PM161		CBG2	0.001	0.001	0.000	0.004	0.004	30	1.0	0.004	0.4	0.1
PM161		PM154	0.001	0.001	0.000	0.003	0.003	162	1.0	0.003	1.0	0.2

PM161		PKVL	0.001	0.001	0.000	0.003	0.003	20	1.0	0.003	0.6	0.1
PM161		PM237	0.001	0.001	0.000	0.003	0.003	169	1.0	0.003	1.1	0.2
PM161	*	KEPK	0.001	0.001	0.000	0.003	0.003	157	1.0	0.003	0.4	0.1
PM237		PM292	0.001	0.001	0.000	0.003	0.003	131	1.0	0.003	0.7	0.1
PM237	*	KEPK	0.001	0.001	0.000	0.003	0.003	138	1.0	0.003	0.4	0.1
PM237		CBG2	0.001	0.001	0.000	0.003	0.003	36	1.0	0.003	0.4	0.1
PM237		PM321	0.001	0.001	0.000	0.002	0.002	26	1.0	0.002	0.7	0.2
PM237		CRKM	0.001	0.001	0.000	0.003	0.003	174	1.0	0.003	0.4	0.1
PM237		PKVL	0.001	0.001	0.000	0.003	0.003	25	1.0	0.003	0.4	0.1
PM251	*	KEPK	0.001	0.001	0.000	0.003	0.003	44	1.0	0.003	0.5	0.1
PM251		PKVL	0.001	0.001	0.000	0.003	0.003	28	1.0	0.003	0.5	0.1
PM251		PM321	0.001	0.001	0.000	0.003	0.003	53	1.0	0.003	0.8	0.2
PM251		PM237	0.001	0.001	0.000	0.002	0.002	109	1.0	0.002	4.4	0.9
PM251		PM292	0.001	0.001	0.000	0.003	0.003	132	1.0	0.003	0.8	0.2
PM251		CBG2	0.001	0.001	0.000	0.004	0.004	11	1.0	0.004	0.5	0.1
PM251		CRKM	0.001	0.001	0.000	0.003	0.003	177	1.0	0.003	0.4	0.1
PM255		CRKM	0.001	0.001	0.000	0.003	0.003	172	1.0	0.003	0.5	0.1
PM255		PKVL	0.001	0.001	0.000	0.003	0.003	22	1.0	0.003	0.5	0.1
PM255	*	KEPK	0.001	0.001	0.000	0.003	0.003	147	1.0	0.003	0.4	0.1
PM255		PM237	0.001	0.001	0.000	0.002	0.002	164	1.0	0.002	8.6	1.8
PM255		CBG2	0.001	0.001	0.000	0.004	0.004	38	1.0	0.004	0.5	0.1
PM255		PM292	0.001	0.001	0.000	0.003	0.003	145	1.0	0.003	0.8	0.2
PM255		PM321	0.001	0.001	0.000	0.003	0.003	161	1.0	0.003	0.9	0.2
PM292	*	KEPK	0.001	0.001	0.000	0.003	0.003	114	1.0	0.003	0.8	0.2
PM292		PKVL	0.001	0.001	0.000	0.003	0.003	22	1.0	0.003	0.3	0.1
PM292		CBG2	0.001	0.001	0.000	0.004	0.004	6	1.0	0.004	0.4	0.1
PM292		PM440	0.001	0.001	0.000	0.003	0.003	138	1.0	0.003	1.2	0.2
PM292		CRKM	0.001	0.001	0.000	0.003	0.003	161	1.0	0.003	0.3	0.1
PM321		CRKM	0.001	0.001	0.000	0.003	0.003	2	1.0	0.003	0.8	0.2
PM321		CBG2	0.001	0.001	0.000	0.003	0.003	35	1.0	0.003	0.4	0.1
PM321	*	KEPK	0.001	0.001	0.000	0.003	0.003	153	1.0	0.003	0.3	0.1
PM321		PKVL	0.001	0.001	0.000	0.003	0.003	27	1.0	0.003	0.7	0.1
PM440		PKVL	0.001	0.001	0.000	0.004	0.004	175	1.0	0.004	0.3	0.1
PM440	*	KEPK	0.001	0.001	0.000	0.003	0.003	159	1.0	0.003	0.9	0.2
PM440		CBG2	0.002	0.002	0.000	0.004	0.004	164	1.0	0.004	0.3	0.1
PM440		CRKM	0.001	0.001	0.000	0.003	0.003	153	1.0	0.003	0.3	0.1
PM572		CRKM	0.001	0.001	0.000	0.003	0.003	177	1.0	0.003	0.6	0.1
PM572	*	KEPK	0.001	0.001	0.000	0.004	0.004	66	1.0	0.004	0.5	0.1
PM572		PM292	0.001	0.001	0.000	0.003	0.003	73	1.0	0.003	1.1	0.2
PM572		CBG2	0.002	0.002	0.000	0.004	0.004	17	1.0	0.004	0.4	0.1
PM572		PKVL	0.001	0.001	0.000	0.004	0.004	21	1.0	0.004	0.4	0.1
PM572		PM237	0.001	0.001	0.000	0.003	0.003	163	1.0	0.003	1.3	0.3

POINT ERROR ELLIPSE INFORMATION

VARIANCE FACTOR USED: 0.038 STANDARD DEVIATIONS ARE IN METRES

ADJ. VARIANCE FACTOR: 0.038

	CO-ORD. PRECISION			95% CONFIDENCE POINT ELLIPSE			
STATION	EAST	NORTH	COV.	S.MAJ.	S.MIN.	ORIENT.	MAJ/MIN
M_PM247	0.001	0.001	0.000	0.004	0.004	79	1.0
CPP_PM247	0.002	0.002	0.000	0.004	0.004	148	1.0
PM440	0.001	0.001	0.000	0.003	0.003	159	1.0
PM67	0.001	0.001	0.000	0.004	0.004	157	1.0
PM161	0.001	0.001	0.000	0.003	0.003	157	1.0
CBG2	0.001	0.001	0.000	0.004	0.004	34	1.0
CRKM	0.001	0.001	0.000	0.003	0.003	161	1.0
PKVL	0.001	0.001	0.000	0.003	0.003	22	1.0
PM292	0.001	0.001	0.000	0.003	0.003	114	1.0
PM251	0.001	0.001	0.000	0.003	0.003	44	1.0
PM255	0.001	0.001	0.000	0.003	0.003	147	1.0
PM237	0.001	0.001	0.000	0.003	0.003	138	1.0
PM321	0.001	0.001	0.000	0.003	0.003	153	1.0
PM154	0.001	0.001	0.000	0.003	0.003	157	1.0
PM572	0.001	0.001	0.000	0.004	0.004	66	1.0

ADJUSTED CO-ORDINATES

LABEL	NAME	LATITUDE	LONGITUDE	ZONE	EASTING	NORTHING	GRID CONVERGENCE	POINT SCALE FACTOR
CBG2		S37 44 22.14177	E144 58 24.79212	55	321446.424	5821156.040	-1 14 26.37	0.99999270
CRKM		S37 49 30.62531	E144 54 24.70474	55	315782.443	5811517.955	-1 17 02.35	1.00001800
KEPK *		S37 43 15.81708	E144 50 52.33325	55	310323.991	5822953.135	-1 19 01.57	1.00004315
PKVL		S37 47 59.31396	E144 57 39.30841	55	320479.048	5814437.795	-1 15 00.34	0.99999696
PM67		S37 46 16.81520	E144 52 10.99672	55	312377.075	5817418.094	-1 18 18.72	1.00003360
PM154		S37 48 51.44320	E144 53 50.48465	55	314918.570	5812706.919	-1 17 22.22	1.00002193
PM161		S37 47 23.11566	E144 54 12.35533	55	315392.296	5815441.563	-1 17 06.24	1.00001977
PM237		S37 46 09.13108	E144 53 42.49221	55	314610.444	5817705.651	-1 17 22.41	1.00002334
PM251		S37 45 54.10747	E144 53 51.12408	55	314811.241	5818173.491	-1 17 16.68	1.00002242
PM255		S37 46 16.85745	E144 53 44.68588	55	314669.480	5817468.701	-1 17 21.29	1.00002307
PM292		S37 45 06.42746	E144 51 42.34521	55	311626.424	5819571.736	-1 18 34.21	1.00003708
PM321		S37 47 39.65245	E144 54 43.08460	55	316155.375	5814948.659	-1 16 47.87	1.00001631
PM440		S37 44 54.02833	E144 50 01.72065	55	309154.839	5819897.266	-1 19 35.50	1.00004863
PM572		S37 46 36.17253	E144 52 16.44335	55	312523.928	5816824.455	-1 18 15.95	1.00003292
M_PM247		S37 43 39.38057	E144 49 12.22782	55	307889.859	5822170.090	-1 20 03.58	1.00005460
CPP_PM247		S37 45 43.46424	E144 53 10.92143	55	313820.070	5818479.382	-1 17 41.02	1.00002696

Vertical Adjustment

Zone number is 55
Refraction option is 0
Zenith distance (C-O) limit is 350 seconds
Height difference (C-O) limit is 100 metres
Use of geoid separation model is required
Default value for refraction is 0.0650
Refraction standard deviation is 0.0100
Required stage of processing is 4
Number of iterations is 4
Analysis option is 2
Centering standard deviation is 0.3 centimetres

GEOCENTRIC DATUM OF AUSTRALIA ZONE 55 - METRES
LIST OF STATIONS

NUMBER	LABEL	NAME	EASTING	NORTHING	HEIGHT		N (GRS80)
1	M_PM247		307889.859	5822170.090	67.629		4.904
2	CPP_PM247		313820.070	5818479.382	2.644		4.836
3	PM440		309154.839	5819897.266	60.887		4.829
4	KEPK		310323.991	5822953.135	84.547	FIXED	4.944
5	PM67		312377.075	5817418.094	19.396		4.784
6	PM161		315392.296	5815441.563	6.043		4.754
7	CBG2		321446.424	5821156.040	58.627		5.045
8	CRKM		315782.443	5811517.955	14.773		4.624
9	PKVL		320479.048	5814437.795	62.589		4.802
10	PM292		311626.424	5819571.736	53.918		4.849
11	PM251		314811.241	5818173.491	1.288		4.843
12	PM255		314669.480	5817468.701	1.591		4.815
13	PM237		314610.444	5817705.651	2.976		4.823
14	PM321		316155.375	5814948.659	1.315		4.749
15	PM154		314918.570	5812706.919	9.325		4.656
16	PM572		312523.928	5816824.455	29.552		4.764

HEIGHT DIFFERENCE OBSERVATIONS

OBS. NO.	FROM	TO	OBSERVED HT DIFF	HEIGHT OF INSTR	TARGET	REDUCED HT DIFF	COMPUTED HT DIFF	(C-O) DEV	STD	WEIGHT
1	CBG2	KEPK	25.918C	0.000	0.000	25.918	25.920	0.002	0.0500	400.0
2	CBG2	PKVL	3.963C	0.000	0.000	3.963	3.962	-0.001	0.0500	400.0
3	CBG2	CRKM	-43.856C	0.000	0.000	-43.856	-43.854	0.002	0.0500	400.0
4	CPP_PM247	CBG2	55.982C	0.000	0.000	55.982	55.983	0.001	0.0500	400.0
5	CPP_PM247	PKVL	59.950C	0.000	0.000	59.950	59.945	-0.005	0.0500	400.0
6	CPP_PM247	PM440	58.241C	0.000	0.000	58.241	58.243	0.002	0.0500	400.0
7	CPP_PM247	CRKM	12.135C	0.000	0.000	12.135	12.129	-0.006	0.0500	400.0
8	CPP_PM247	KEPK	81.896C	0.000	0.000	81.896	81.903	0.008	0.0500	400.0
9	CRKM	PKVL	47.818C	0.000	0.000	47.818	47.816	-0.003	0.0500	400.0
10	CRKM	KEPK	69.772C	0.000	0.000	69.772	69.774	0.002	0.0500	400.0
11	KEPK	PKVL	-21.956C	0.000	0.000	-21.956	-21.958	-0.002	0.0500	400.0
12	M_PM247	PM440	-6.746C	0.000	0.000	-6.746	-6.742	0.003	0.0500	400.0
13	M_PM247	KEPK	16.915C	0.000	0.000	16.915	16.918	0.003	0.0500	400.0
14	M_PM247	PKVL	-5.038C	0.000	0.000	-5.038	-5.040	-0.002	0.0500	400.0
15	M_PM247	CRKM	-52.851C	0.000	0.000	-52.851	-52.856	-0.005	0.0500	400.0
16	PM67	PM292	34.525C	0.000	0.000	34.525	34.522	-0.003	0.0500	400.0
17	PM67	PM440	41.492C	0.000	0.000	41.492	41.491	-0.001	0.0500	400.0
18	PM67	KEPK	65.150C	0.000	0.000	65.150	65.151	0.001	0.0500	400.0
19	PM67	CRKM	-4.618C	0.000	0.000	-4.618	-4.623	-0.005	0.0500	400.0
20	PM67	PKVL	43.193C	0.000	0.000	43.193	43.193	0.000	0.0500	400.0
21	PM67	CBG2	39.224C	0.000	0.000	39.224	39.231	0.007	0.0500	400.0
22	PM154	KEPK	75.232C	0.000	0.000	75.232	75.222	-0.011	0.0500	400.0
23	PM154	CRKM	5.439C	0.000	0.000	5.439	5.448	0.009	0.0500	400.0
24	PM154	CBG2	49.310C	0.000	0.000	49.310	49.302	-0.008	0.0500	400.0
25	PM154	PM237	-6.348C	0.000	0.000	-6.348	-6.349	0.000	0.0500	400.0
26	PM154	PM321	-8.011C	0.000	0.000	-8.011	-8.010	0.001	0.0500	400.0
27	PM154	PKVL	53.256C	0.000	0.000	53.256	53.263	0.008	0.0500	400.0
28	PM161	CRKM	8.725C	0.000	0.000	8.725	8.730	0.005	0.0500	400.0
29	PM161	PM321	-4.728C	0.000	0.000	-4.728	-4.728	0.001	0.0500	400.0
30	PM161	CBG2	52.589C	0.000	0.000	52.589	52.584	-0.005	0.0500	400.0
31	PM161	PM154	3.285C	0.000	0.000	3.285	3.282	-0.002	0.0500	400.0
32	PM161	PKVL	56.544C	0.000	0.000	56.544	56.546	0.002	0.0500	400.0
33	PM161	PM237	-3.067C	0.000	0.000	-3.067	-3.066	0.001	0.0500	400.0
34	PM161	KEPK	78.506C	0.000	0.000	78.506	78.504	-0.002	0.0500	400.0
35	PM237	PM292	50.946C	0.000	0.000	50.946	50.941	-0.005	0.0500	400.0
36	PM237	KEPK	81.575C	0.000	0.000	81.575	81.571	-0.004	0.0500	400.0
37	PM237	CBG2	55.651C	0.000	0.000	55.651	55.651	0.000	0.0500	400.0
38	PM237	PM321	-1.662C	0.000	0.000	-1.662	-1.661	0.001	0.0500	400.0
39	PM237	CRKM	11.791C	0.000	0.000	11.791	11.797	0.006	0.0500	400.0
40	PM237	PKVL	59.607C	0.000	0.000	59.607	59.612	0.005	0.0500	400.0
41	PM251	KEPK	83.261C	0.000	0.000	83.261	83.259	-0.002	0.0500	400.0
42	PM251	PKVL	61.300C	0.000	0.000	61.300	61.301	0.001	0.0500	400.0
43	PM251	PM321	0.029C	0.000	0.000	0.029	0.027	-0.002	0.0500	400.0
44	PM251	PM237	1.689C	0.000	0.000	1.689	1.689	0.000	0.0500	400.0
45	PM251	PM292	52.629C	0.000	0.000	52.629	52.630	0.001	0.0500	400.0
46	PM251	CBG2	57.334C	0.000	0.000	57.334	57.339	0.005	0.0500	400.0
47	PM251	CRKM	13.488C	0.000	0.000	13.488	13.485	-0.003	0.0500	400.0
48	PM255	CRKM	13.175C	0.000	0.000	13.175	13.182	0.006	0.0500	400.0
49	PM255	PKVL	60.997C	0.000	0.000	60.997	60.997	0.001	0.0500	400.0
50	PM255	KEPK	82.958C	0.000	0.000	82.958	82.956	-0.002	0.0500	400.0
51	PM255	PM237	1.384C	0.000	0.000	1.384	1.385	0.001	0.0500	400.0
52	PM255	CBG2	57.040C	0.000	0.000	57.040	57.036	-0.004	0.0500	400.0
53	PM255	PM292	52.326C	0.000	0.000	52.326	52.326	0.000	0.0500	400.0

54	PM255	PM321	-0.274C	0.000	0.000	-0.274	-0.276	-0.002	0.0500	400.0
55	PM292	KEPK	30.628C	0.000	0.000	30.628	30.629	0.001	0.0500	400.0
56	PM292	PKVL	8.675C	0.000	0.000	8.675	8.671	-0.004	0.0500	400.0
57	PM292	CBG2	4.707C	0.000	0.000	4.707	4.710	0.003	0.0500	400.0
58	PM292	PM440	6.973C	0.000	0.000	6.973	6.969	-0.004	0.0500	400.0
59	PM292	CRKM	-39.141C	0.000	0.000	-39.141	-39.145	-0.004	0.0500	400.0
60	PM321	CRKM	13.457C	0.000	0.000	13.457	13.458	0.001	0.0500	400.0
61	PM321	CBG2	57.315C	0.000	0.000	57.315	57.312	-0.003	0.0500	400.0
62	PM321	KEPK	83.231C	0.000	0.000	83.231	83.232	0.001	0.0500	400.0
63	PM321	PKVL	61.274C	0.000	0.000	61.274	61.274	-0.001	0.0500	400.0
64	PM440	PKVL	1.704C	0.000	0.000	1.704	1.702	-0.002	0.0500	400.0
65	PM440	KEPK	23.658C	0.000	0.000	23.658	23.660	0.003	0.0500	400.0
66	PM440	CBG2	-2.265C	0.000	0.000	-2.265	-2.259	0.005	0.0500	400.0
67	PM440	CRKM	-46.108C	0.000	0.000	-46.108	-46.113	-0.005	0.0500	400.0
68	PM572	CRKM	-14.775C	0.000	0.000	-14.775	-14.779	-0.004	0.0500	400.0
69	PM572	KEPK	54.998C	0.000	0.000	54.998	54.995	-0.003	0.0500	400.0
70	PM572	PM292	24.367C	0.000	0.000	24.367	24.366	-0.001	0.0500	400.0
71	PM572	CBG2	29.072C	0.000	0.000	29.072	29.075	0.004	0.0500	400.0
72	PM572	PKVL	33.033C	0.000	0.000	33.033	33.037	0.004	0.0500	400.0
73	PM572	PM237	-26.576C	0.000	0.000	-26.576	-26.575	0.000	0.0500	400.0

Number of stations : 16
Number of fixed stations : 1
Number of zenith distances : 0
Number of refraction observations : 0
Number of height differences : 73
Number of observation equations : 73
Matrix size : 15
Band width : 10
Number of terms in normal equations : 110

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STAGE ONE COMPLETE

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LIST OF RESIDUALS

OBS.NO.	FROM		TO	RESIDUAL	STD. RES.	DISTANCE	Z.D. RES.
1	CBG2	*	KEPK	0.002	0.048	11267	0.0
2	CBG2		PKVL	-0.001	-0.022	6788	0.0
3	CBG2		CRKM	0.002	0.047	11179	0.0
4	CPP_PM247		CBG2	0.001	0.017	8082	0.0
5	CPP_PM247		PKVL	-0.005	-0.095	7790	-0.1
6	CPP_PM247		PM440	0.002	0.038	4876	0.1
7	CPP_PM247		CRKM	-0.006	-0.110	7233	-0.2
8	CPP_PM247	*	KEPK	0.008	0.151	5678	0.3
9	CRKM		PKVL	-0.003	-0.058	5530	-0.1
10	CRKM	*	KEPK	0.002	0.043	12671	0.0
11 *	KEPK		PKVL	-0.002	-0.045	13253	0.0
12	M_PM247		PM440	0.003	0.068	2601	0.3
13	M_PM247	*	KEPK	0.003	0.068	2557	0.3
14	M_PM247		PKVL	-0.002	-0.037	14774	0.0
15	M_PM247		CRKM	-0.005	-0.099	13257	-0.1
16	PM67		PM292	-0.003	-0.055	2281	-0.2
17	PM67		PM440	-0.001	-0.015	4066	0.0
18	PM67	*	KEPK	0.001	0.026	5904	0.0
19	PM67		CRKM	-0.005	-0.095	6812	-0.1
20	PM67		PKVL	0.000	-0.007	8633	0.0
21	PM67		CBG2	0.007	0.147	9809	0.2
22	PM154	*	KEPK	-0.011	-0.214	11229	-0.2
23	PM154		CRKM	0.009	0.172	1470	1.2
24	PM154		CBG2	-0.008	-0.170	10677	-0.2
25	PM154		PM237	0.000	-0.010	5008	0.0
26	PM154		PM321	0.001	0.025	2560	0.1
27	PM154		PKVL	0.008	0.150	5824	0.3
28	PM161		CRKM	0.005	0.107	3943	0.3
29	PM161		PM321	0.001	0.011	908	0.1
30	PM161		CBG2	-0.005	-0.102	8325	-0.1
31	PM161		PM154	-0.002	-0.046	2775	-0.2
32	PM161		PKVL	0.002	0.044	5185	0.1
33	PM161		PM237	0.001	0.021	2395	0.1
34	PM161	*	KEPK	-0.002	-0.036	9062	0.0
35	PM237		PM292	-0.005	-0.104	3519	-0.3
36	PM237	*	KEPK	-0.004	-0.085	6776	-0.1
37	PM237		CBG2	0.000	-0.009	7657	0.0
38	PM237		PM321	0.001	0.015	3160	0.0
39	PM237		CRKM	0.006	0.120	6298	0.2
40	PM237		PKVL	0.005	0.099	6717	0.2
41	PM251	*	KEPK	-0.002	-0.044	6556	-0.1
42	PM251		PKVL	0.001	0.021	6788	0.0
43	PM251		PM321	-0.002	-0.042	3494	-0.1
44	PM251		PM237	0.000	-0.001	509	0.0
45	PM251		PM292	0.001	0.021	3478	0.1
46	PM251		CBG2	0.005	0.101	7275	0.1
47	PM251		CRKM	-0.003	-0.056	6726	-0.1
48	PM255		CRKM	0.006	0.126	6054	0.2
49	PM255		PKVL	0.001	0.013	6553	0.0
50	PM255	*	KEPK	-0.002	-0.043	6997	-0.1
51	PM255		PM237	0.001	0.021	244	0.9
52	PM255		CBG2	-0.004	-0.080	7715	-0.1
53	PM255		PM292	0.000	0.007	3699	0.0
54	PM255		PM321	-0.002	-0.044	2925	-0.2

55	PM292	*	KEPK	0.001	0.023	3624	0.1
56	PM292		PKVL	-0.004	-0.081	10234	-0.1
57	PM292		CBG2	0.003	0.054	9947	0.1
58	PM292		PM440	-0.004	-0.075	2493	-0.3
59	PM292		CRKM	-0.004	-0.072	9063	-0.1
60	PM321		CRKM	0.001	0.018	3451	0.1
61	PM321		CBG2	-0.003	-0.063	8156	-0.1
62	PM321	*	KEPK	0.001	0.023	9903	0.0
63	PM321		PKVL	-0.001	-0.014	4354	0.0
64	PM440		PKVL	-0.002	-0.040	12572	0.0
65	PM440	*	KEPK	0.003	0.051	3272	0.2
66	PM440		CBG2	0.005	0.107	12356	0.1
67	PM440		CRKM	-0.005	-0.103	10684	-0.1
68	PM572		CRKM	-0.004	-0.070	6227	-0.1
69	PM572	*	KEPK	-0.003	-0.058	6512	-0.1
70	PM572		PM292	-0.001	-0.021	2890	-0.1
71	PM572		CBG2	0.004	0.072	9918	0.1
72	PM572		PKVL	0.004	0.072	8305	0.1
73	PM572		PM237	0.000	0.005	2265	0.0

(PVV) = 0.427
(PLV) = -0.427
Estimate of variance factor = 0.007
Height difference component = 0.007

Number of redundant observations = 58
Average redundancy number = 0.795

RESIDUAL ANALYSIS

STANDARD RESIDUAL DISTRIBUTION

< -4	-4 TO -3	-3 TO -2	-2 TO -1	-1 TO 0	0 TO 1	1 TO 2	2 TO 3	3 TO 4	> 4
0	0	0	0	37	36	0	0	0	0

Maximum = 0.172 (Observation 23)
Minimum = -0.214 (Observation 22)
Mean = -0.002 Standard deviation = 0.077
Total = 73

HEIGHT DIFFERENCE RESIDUAL DISTRIBUTION (MILLIMETRES)

< -4	-4 TO -3	-3 TO -2	-2 TO -1	-1 TO 0	0 TO 1	1 TO 2	2 TO 3	3 TO 4	> 4
11	5	11	4	6	7	9	6	4	10

Maximum = 0.009 metres (Observation 23)
Minimum = -0.011 metres (Observation 22)
Mean = 0.000 Standard deviation = 0.004
Total = 73

ADJUSTED VALUES

HEIGHT

LABEL	NAME	PROVISIONAL	CORRN.	ADJUSTED
M_PM247		67.629	0.000	67.629
CPP_PM247		2.644	0.000	2.644
PM440		60.887	0.000	60.887
KEPK		FIXED STATION		84.547
PM67		19.396	0.000	19.396
PM161		6.043	0.000	6.043
CBG2		58.627	0.000	58.627
CRKM		14.773	0.000	14.773
PKVL		62.589	0.000	62.589
PM292		53.918	0.000	53.918
PM251		1.288	0.000	1.288
PM255		1.591	0.000	1.591
PM237		2.976	0.000	2.976
PM321		1.315	0.000	1.315
PM154		9.325	0.000	9.325
PM572		29.552	0.000	29.552

PRECISION ANALYSIS

VARIANCE FACTOR USED: 0.007

LABEL	NAME	ADJ. HEIGHT	STD. DEV.	ADJ. K VALUE	STD. DEV.
M_PM247		67.629	0.002		
CPP_PM247		2.644	0.002		
PM440		60.887	0.002		
KEPK		84.547	FIXED		
PM67		19.396	0.002		
PM161		6.043	0.002		
CBG2		58.627	0.002		
CRKM		14.773	0.002		
PKVL		62.589	0.002		
PM292		53.918	0.002		
PM251		1.288	0.002		
PM255		1.591	0.002		
PM237		2.976	0.002		
PM321		1.315	0.002		
PM154		9.325	0.002		
PM572		29.552	0.002		

RELATIVE HEIGHT ANALYSIS

VARIANCE FACTOR USED: 0.007

FROM		TO	DISTANCE	STANDARD DEVIATION (95%)	CLASS
CBG2	*	KEPK	11266.679	0.003	3A
CBG2		PKVL	6787.535	0.004	3A
CBG2		CRKM	11179.149	0.004	3A
CPP_PM247		CBG2	8082.436	0.005	3A
CPP_PM247		PKVL	7789.507	0.005	3A
CPP_PM247		PM440	4875.938	0.006	3A
CPP_PM247		CRKM	7232.729	0.005	3A
CPP_PM247	*	KEPK	5677.767	0.004	3A
CRKM		PKVL	5530.241	0.004	3A
CRKM	*	KEPK	12671.150	0.003	3A
* KEPK		PKVL	13252.781	0.003	3A
M_PM247		PM440	2601.135	0.006	2A
M_PM247	*	KEPK	2556.982	0.005	3A
M_PM247		PKVL	14774.169	0.005	3A
M_PM247		CRKM	13257.483	0.005	3A
PM67		PM292	2280.713	0.005	2A
PM67		PM440	4065.599	0.005	3A
PM67	*	KEPK	5903.544	0.004	3A
PM67		CRKM	6812.354	0.005	3A
PM67		PKVL	8632.737	0.005	3A
PM67		CBG2	9809.451	0.005	3A
PM154	*	KEPK	11229.207	0.004	3A
PM154		CRKM	1469.664	0.005	2A
PM154		CBG2	10677.103	0.005	3A
PM154		PM237	5008.220	0.005	3A
PM154		PM321	2560.290	0.005	3A
PM154		PKVL	5823.646	0.005	3A
PM161		CRKM	3942.958	0.005	3A
PM161		PM321	908.429	0.005	2A
PM161		CBG2	8325.125	0.005	3A
PM161		PM154	2775.373	0.005	3A
PM161		PKVL	5184.843	0.005	3A
PM161		PM237	2395.284	0.005	3A
PM161	*	KEPK	9061.536	0.004	3A
PM237		PM292	3519.467	0.005	3A
PM237	*	KEPK	6775.675	0.003	3A
PM237		CBG2	7657.402	0.004	3A
PM237		PM321	3160.351	0.005	3A
PM237		CRKM	6297.711	0.004	3A
PM237		PKVL	6717.097	0.004	3A
PM251	*	KEPK	6555.945	0.004	3A
PM251		PKVL	6788.185	0.005	3A
PM251		PM321	3493.743	0.005	3A
PM251		PM237	509.111	0.005	A
PM251		PM292	3478.239	0.005	3A
PM251		CBG2	7274.699	0.005	3A
PM251		CRKM	6726.024	0.005	3A
PM255		CRKM	6053.930	0.005	3A
PM255		PKVL	6552.669	0.005	3A
PM255	*	KEPK	6997.306	0.004	3A
PM255		PM237	244.194	0.005	A
PM255		CBG2	7715.143	0.005	3A
PM255		PM292	3699.047	0.005	3A
PM255		PM321	2925.491	0.005	3A
PM292	*	KEPK	3623.561	0.003	3A
PM292		PKVL	10233.587	0.004	3A
PM292		CBG2	9946.980	0.005	3A
PM292		PM440	2492.930	0.005	3A
PM292		CRKM	9062.885	0.004	3A
PM321		CRKM	3450.914	0.005	3A
PM321		CBG2	8156.395	0.005	3A
PM321	*	KEPK	9903.367	0.003	3A
PM321		PKVL	4353.749	0.005	3A
PM440		PKVL	12571.537	0.005	3A
PM440	*	KEPK	3271.888	0.004	3A
PM440		CBG2	12355.872	0.005	3A
PM440		CRKM	10683.538	0.005	3A
PM572		CRKM	6227.107	0.005	3A
PM572	*	KEPK	6511.562	0.004	3A
PM572		PM292	2890.167	0.005	3A
PM572		CBG2	9918.345	0.005	3A
PM572		PKVL	8305.425	0.005	3A
PM572		PM237	2264.963	0.005	2A

WM220802PNT

LIST OF STATIONS ADJUSTED

STATION	ADJ. HEIGHT	STD DEV (95%)
M_PM247	67.629	0.005
CPP_PM247	2.644	0.004
PM440	60.887	0.004
PM67	19.396	0.004
PM161	6.043	0.004
CBG2	58.627	0.003
CRKM	14.773	0.003
PKVL	62.589	0.003
PM292	53.918	0.003
PM251	1.288	0.004
PM255	1.591	0.004
PM237	2.976	0.003

PM321	1.315	0.003
PM154	9.325	0.004
PM572	29.552	0.004

WM220802PNT

LIST OF STATIONS HELD FIXED

STATION	HEIGHT
KEPK	84.547

Appendix B - Aerometrix Vertical Control Report

aerometrex

Aerometrex Project Statistical Summary Report

Date : **07/08/23**

Project : **OP-005762**

Area : **Maribyrnong_River**

Quality : **Accepted**

Control File :94_hc.txt

Method Used:

Point to Tin

This report was generated by comparing supplied ground control points (GCPs) to a Triangulated Irregular Network (TIN) generated from LiDAR points classified as ground. Points with vertical Standard Deviation of greater than or less than 0.1m from the Average Vertical Difference have been rejected from analysis. The shifts values and statistics shown in this report are suitable for adjusting the LiDAR point cloud. RMSE and CI95 values shown are calculated after average shifts were applied.

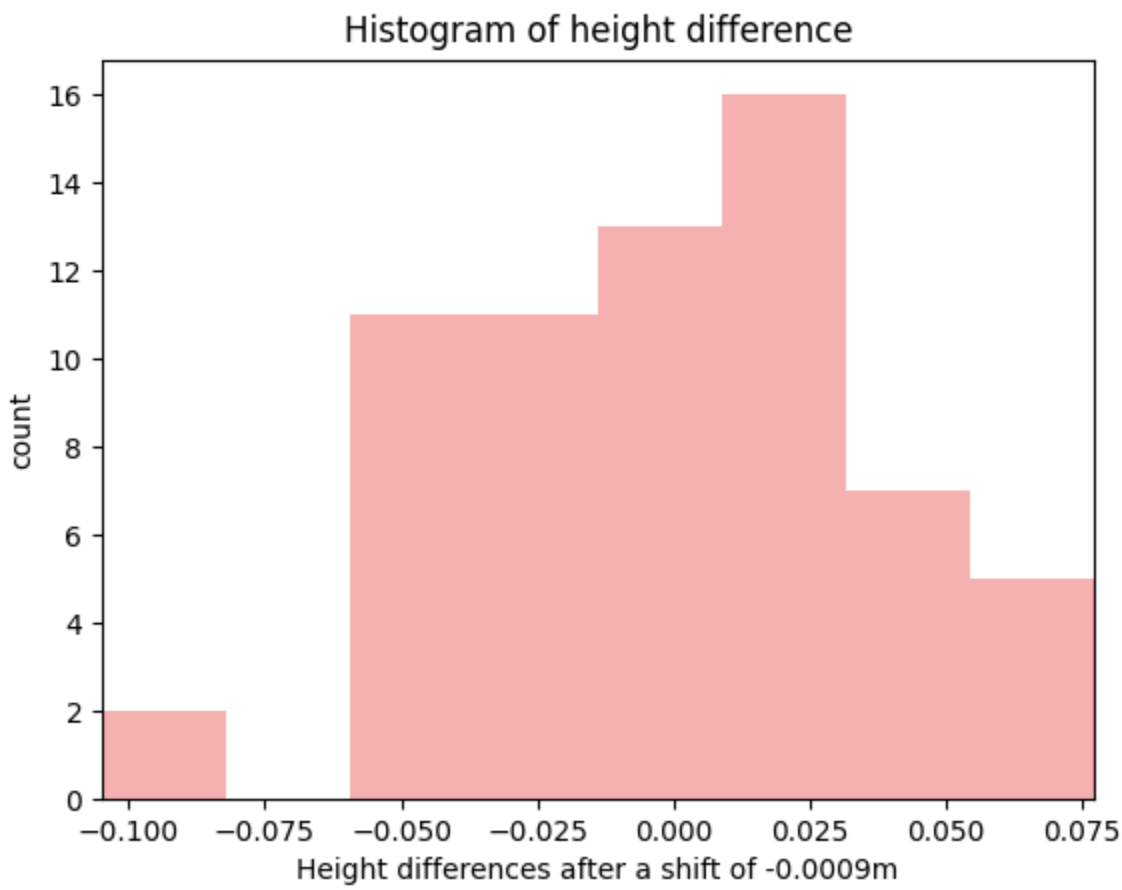
Absolute Corrections

Description	Value
East :	0.0 m
North :	0.0 m
Height :	-0.0009 m

Summary of Heights

Description	Value
GCP points sampled :	65
GCP points accepted :	65 (100.0 %)
GCP points rejected :	0 (0.0 %)
Out of Range :	0 (0.0 %)
Mean Average:	0.0009
RMSE after z shift applied :	0.0361
CI95 after z shift applied:	0.0708

Height difference distribution



Summary of points

	index	x	y	controlz	lidarz	dz	dz after shift
0	1	307687.241	5822573.204	68.837	68.8643	0.027	0.0261
1	2	307684.047	5822580.759	68.898	68.9263	0.028	0.0271
2	3	307682.522	5822587.973	68.927	68.9491	0.022	0.0211
3	4	307686.584	5822589.54	68.874	68.8856	0.012	0.0111
4	5	307687.281	5822583.95	68.899	68.946	0.047	0.0461
5	6	309269.857	5823020.148	31.54	31.5738	0.034	0.0331
6	7	309271.557	5823022.889	31.531	31.5431	0.012	0.0111
7	8	309265.003	5823027.513	31.579	31.6056	0.027	0.0261
8	9	309257.949	5823030.079	31.577	31.5744	-0.003	-0.0039
9	10	309263.007	5823024.897	31.602	31.6221	0.020	0.0191
10	11	308992.531	5821811.528	18.321	18.3245	0.004	0.0031
11	12	308992.747	5821815.67	18.297	18.2551	-0.042	-0.0429
12	13	308987.572	5821815.87	18.221	18.2002	-0.021	-0.0219
13	14	308987.353	5821811.057	18.265	18.2231	-0.042	-0.0429
14	15	308999.174	5821813.421	18.371	18.3632	-0.008	-0.0089
15	16	309001.218	5821827.797	18.261	18.2704	0.009	0.0081
16	17	308998.607	5821832.961	18.09	18.1571	0.067	0.0661
17	18	308996.094	5821827.744	18.204	18.1773	-0.027	-0.0279
18	19	308770.308	5820002.025	59.96	59.9942	0.034	0.0331
19	20	308773.597	5820004.446	60.015	60.0438	0.029	0.0281
20	21	308769.36	5820010.495	60.142	60.1669	0.025	0.0241
21	22	308765.702	5820007.985	60.122	60.141	0.019	0.0181
22	23	308761.277	5820014.426	60.134	60.1521	0.018	0.0171
23	24	308764.812	5820016.98	60.201	60.2378	0.037	0.0361
24	25	312571.347	5817711.803	9.238	9.23391	-0.004	-0.0049
25	26	312568.991	5817704.166	9.339	9.32666	-0.012	-0.0129
26	27	312566.72	5817696.63	9.379	9.36851	-0.010	-0.0109
27	28	312574.16	5817695.675	9.248	9.24106	-0.007	-0.0079
28	29	312580.743	5817704.198	9.179	9.19864	0.020	0.0191
29	30	314129.736	5819574.38	30.097	30.1458	0.049	0.0481
30	31	314123.375	5819575.176	30.317	30.3437	0.027	0.0261
31	32	314114.44	5819529.436	27.584	27.6078	0.024	0.0231
32	33	314111.085	5819529.917	27.543	27.6001	0.057	0.0561
33	34	314111.534	5819536.868	27.907	27.95	0.043	0.0421
34	35	314115.762	5819536.534	27.903	27.9351	0.032	0.0311
35	36	315159.857	5812817.911	3.023	3.10085	0.078	0.0771
36	37	315158.065	5812811.489	2.986	3.04641	0.060	0.0591
37	38	315156.186	5812804.097	2.993	3.0605	0.067	0.0661

	index	x	y	controlz	lidarz	dz	dz after shift
38	39	315153.947	5812797.095	3.03	3.06094	0.031	0.0301
39	40	315163.461	5812792.862	2.939	2.98388	0.045	0.0441
40	41	314983.351	5815511.939	3.088	3.08598	-0.002	-0.0029
41	42	314979.81	5815499.505	3.238	3.21677	-0.021	-0.0219
42	43	314973.284	5815485.836	3.517	3.51863	0.002	0.0011
43	44	314961.817	5815484.596	3.86	3.85456	-0.005	-0.0059
44	45	314963.471	5815497.407	3.669	3.66866	-0.000	-0.0009
45	46	314968.058	5815514.963	3.456	3.45273	-0.003	-0.0039
46	47	318549.654	5814774.369	2.677	2.59451	-0.082	-0.0829
47	48	318319.928	5814838.466	2.558	2.51144	-0.047	-0.0479
48	49	318321.435	5814823.159	2.492	2.45374	-0.038	-0.0389
49	50	318323.104	5814807.5	2.5	2.46834	-0.032	-0.0329
50	51	318326.571	5814786.734	2.5	2.39557	-0.104	-0.1049
51	52	318329.63	5814761.923	2.449	2.41273	-0.036	-0.0369
52	53	318317.149	5814742.987	2.325	2.30711	-0.018	-0.0189
53	54	318312.685	5814768.456	2.474	2.42583	-0.048	-0.0489
54	55	318308.427	5814804.201	2.43	2.38128	-0.049	-0.0499
55	56	318307.195	5814813.729	2.406	2.36799	-0.038	-0.0389
56	57	318304.062	5814843.041	2.57	2.52778	-0.042	-0.0429
57	58	318388.957	5813749.416	2.288	2.24853	-0.039	-0.0399
58	59	318385.902	5813745.6	2.546	2.52067	-0.025	-0.0259
59	60	318394.133	5813745.937	2.203	2.18794	-0.015	-0.0159
60	61	318395.657	5813747.006	2.182	2.15622	-0.026	-0.0269
61	62	318414.076	5813740.962	1.913	1.89784	-0.015	-0.0159
62	63	318429.722	5813732.474	1.983	1.95158	-0.031	-0.0319
63	64	318444.694	5813725.657	2.198	2.15829	-0.040	-0.0409
64	65	318450.004	5813724.013	2.288	2.27492	-0.013	-0.0139

Appendix C - LiDAR Validataion

Index	Point	Easting	Northing	Elevation	Abs(Deviation Z)	Deviation Z
0	2000	315319.714	5815302.761	1.432	0.006	-0.006
1	2001	315327.593	5815287.964	2.022	0.048	-0.048
2	2002	315357.951	5815246.112	1.262	0.025	-0.025
3	2003	315392.695	5815214.832	1.324	0.03	-0.03
4	2004	315435.429	5815186.674	1.383	0.028	-0.028
5	2005	315479.906	5815159.728	1.253	0.014	-0.014
6	2006	315520.678	5815140.491	1.078	0.021	-0.021
7	2007	315565.808	5815123.843	1.129	0.022	-0.022
8	2008	315611.816	5815104.14	1.167	0.041	-0.041
9	2009	315656.709	5815083.414	1.029	0.038	-0.038
10	2011	315708.414	5815049.601	1.034	0.044	-0.044
11	2012	315749.358	5815025.327	0.953	0.031	-0.031
12	2013	315787.767	5814996.796	1.212	0.066	-0.066
13	2014	315830.9	5814976.982	1.137	0.053	-0.053
14	2015	315875.521	5814959.799	1.17	0.072	-0.072
15	2016	315920.996	5814945.802	1.147	0.051	-0.051
16	2017	315966.768	5814935.899	1.13	0.035	-0.035
17	2018	316009.803	5814922.543	1.184	0.049	-0.049
18	2019	316052.171	5814907.805	1.417	0.052	-0.052
19	2020	316095.582	5814894.394	1.384	0.049	-0.049
20	2021	316134.753	5814876.559	1.284	0.062	-0.062
21	2022	316166.374	5814861.24	1.432	0.079	-0.079
22	2023	316223.264	5814828.949	1.229	0.047	-0.047
23	2024	316260.811	5814802.264	1.746	0.051	-0.051
24	2025	316309.847	5814769.654	1.574	0.054	-0.054
25	2026	316341.958	5814748.08	1.631	0.045	-0.045
26	2027	316379.38	5814730.892	1.547	0.053	-0.053
27	2028	316405.844	5814708.435	1.663	0.068	-0.068
28	2029	316436.618	5814678.33	1.339	0.038	-0.038
29	2030	316455.903	5814658.024	1.318	0.025	-0.025
30	2031	316491.698	5814614.577	1.323	0.06	-0.06
31	2032	316512.02	5814581.664	1.453	#N/A	Not Enough Data
32	2033	316524.995	5814495.678	1.446	0.049	-0.049
33	2034	316497.243	5814453.938	1.375	0.025	-0.025
34	2035	316474.462	5814426.824	1.233	0.038	-0.038
35	2036	316455.781	5814388.102	1.131	0.024	-0.024
36	2037	316419.95	5814359.131	1.238	0.056	-0.056
37	2038	316377.715	5814346.767	1.27	0.047	-0.047
38	2039	316338.724	5814370.876	1.464	0.047	-0.047
39	2040	316303.696	5814394.352	1.545	0.036	-0.036
40	2041	316260.572	5814407.886	1.741	#N/A	Not Enough Data
41	2042	316219.91	5814409.986	1.557	0.056	-0.056
42	2043	316184.91	5814407.283	1.583	0.034	-0.034
43	2044	316134.069	5814391.509	1.344	0.062	-0.062
44	2045	316100.925	5814374.194	1.407	0.062	-0.062
45	2046	316056.057	5814338.671	1.534	0.05	-0.05

46	2047	316028.574	5814311.673	1.691	0.068	-0.068
47	2048	315996.601	5814255.178	1.87	0.041	-0.041
48	2049	315986.429	5814237.439	2.065	0.044	-0.044
49	2050	315967.986	5814196.561	1.843	0.036	-0.036
50	2051	315941.31	5814148.775	1.92	0.072	-0.072
51	2052	315912.048	5814109.804	2.06	0.027	-0.027
52	2053	315912.045	5814109.823	2.068	0.038	-0.038
53	2054	315906.835	5814071.771	2.072	0.018	-0.018
54	2055	315893.604	5814031.707	1.923	#N/A	Not Enough Data
55	2056	315879.865	5813993.803	1.875	0.03	-0.03
56	2057	315859.767	5813949.055	1.977	0.053	-0.053
57	2058	315853.235	5813924.294	2.03	0.009	-0.009
58	2059	315843.013	5813895.022	1.954	0.026	-0.026
59	2060	315823.336	5813838.353	2.035	0.062	-0.062
60	2061	315809.8	5813794.405	1.832	0.03	-0.03
61	2062	315793.088	5813749.294	1.809	0.002	-0.002
62	2063	315778.835	5813693.153	1.733	0.011	-0.011
63	2064	315763.14	5813663.043	2.627	0.026	-0.026
64	2065	315748.399	5813620.937	2.405	0.025	0.025
65	2066	315734.764	5813606.212	2.297	0.002	-0.002
66	2067	315715.441	5813552.508	2.375	0.009	-0.009
67	2068	315691.525	5813530	1.7	0.01	0.01
68	2069	315653.775	5813437.167	1.657	0.023	0.023
69	2070	315644.131	5813401.644	1.921	0.059	0.059
70	2071	315630.86	5813363.288	2.008	0.046	0.046
71	2072	315621.853	5813326.382	2.141	0.01	0.01
72	2073	315604.368	5813282.171	2.6	0.037	0.037
73	2074	315537.078	5813259.535	2.399	0.029	0.029
74	2075	315492.799	5813263.077	2.244	0.03	0.03
75	2076	315452.032	5813271.781	2.497	0.005	0.005
76	2077	315414.059	5813284.835	2.504	0.026	0.026
77	2078	315375.457	5813298.484	2.427	0.022	0.022
78	2079	315380.094	5813245.806	2.338	0.042	0.042
79	2080	315415.98	5813234.701	2.093	0.008	0.008
80	2081	315461.211	5813217.493	1.953	0.054	0.054
81	2082	315523.929	5813192.853	2.022	0.026	0.026
82	2083	315515.42	5813166.917	2.264	0.042	0.042
83	2084	315478.085	5813162.925	1.672	0.019	0.019
84	2085	315398.408	5813189.985	1.932	0.017	0.017
85	3000	310793.857	5817511.076	4.561	0.02	0.02
86	3001	310774.919	5817552.391	3.739	0.031	-0.031
87	3003	310760.686	5817582.188	3.564	0.003	-0.003
88	3004	310753.612	5817633.325	4.271	0.023	-0.023
89	3005	310763.433	5817676.788	4.538	0.007	-0.007
90	3006	310786.612	5817724.421	4.923	0.014	-0.014
91	3007	310813.79	5817760.759	4.501	0.003	-0.003
92	3008	310843.583	5817789.428	4.093	0.002	0.002
93	3009	310875.542	5817807.407	5.5	#N/A	Not Enough Data
94	3010	310912.607	5817848.053	4.203	0.013	-0.013
95	3011	310940.187	5817890.789	4.065	0.022	-0.022

96	3012	310965.259	5817945.72	3.878	0.012	-0.012
97	3013	310984.06	5817989.544	3.838	0.036	-0.036
98	3014	311005.707	5818033.382	4.832	0.025	-0.025
99	3015	311015.11	5818109.253	4.525	0.002	-0.002
100	3016	311021.036	5818169.866	4.462	0.007	0.007
101	3017	311010.888	5818209.304	4.62	0.018	0.018
102	3018	310997.838	5818261.064	5.05	0.04	0.04
103	3019	310986.404	5818298.645	4.908	0.027	0.027
104	3020	310988.182	5818345.167	8.34	0.052	-0.052
105	3021	310977.8	5818390.164	10.634	0.016	0.016
106	3022	310945.481	5818435.954	9.998	0.002	0.002
107	3023	310894.64	5818414.956	6.575	0.003	-0.003
108	3024	310852.834	5818417.718	7.164	0.006	0.006
109	3025	310815.252	5818423.87	4.426	0.021	0.021
110	3026	310782.122	5818453.846	4.285	0.01	-0.01
111	3027	310755.238	5818482.104	4.182	0.023	0.023
112	3028	310715.824	5818506.015	4.148	0.066	-0.066
113	3029	310661.264	5818547.343	4.155	0.025	0.025
114	3030	310631.652	5818569.937	4.076	0.027	0.027
115	3034	310604.552	5818595.626	4.304	0.01	0.01
116	3035	310587.701	5818613.775	4.735	0.015	0.015
117	3036	310550.17	5818643.771	5.353	#N/A	Not Enough Data
118	3037	310518.972	5818687.968	4.77	0.016	0.016
119	3038	310508.373	5818745.46	4.46	0.019	0.019
120	3039	310521.932	5818838.2	4.176	0.031	0.031
121	3043	310530.441	5818895.614	5.326	0.022	0.022
122	3044	310546.563	5818942.743	5.651	0.01	0.01
123	3045	310560.5	5819004.615	5.603	0.01	0.01
124	3046	310567.57	5819061.051	5.638	0.03	0.03
125	3047	310572.795	5819111	5.488	0.021	0.021
126	3048	310579.968	5819173.624	5.202	0.03	-0.03
127	3049	310585.393	5819240.632	7.696	0.039	0.039
128	3050	310581.086	5819274.836	7.608	0.047	0.047
129	3051	310557	5819319.36	5.778	0.017	-0.017
130	3052	310545.963	5819366.913	6.771	0.009	-0.009
131	3053	310529.506	5819426.25	6.124	0.01	-0.01
132	3054	310516.61	5819469.326	6.652	0	0
133	3055	310498.88	5819513.487	6.1	0.057	-0.057
134	3057	310486.443	5819575.967	6.249	0.01	-0.01
135	3058	310469.892	5819619.112	6.462	0.012	-0.012
136	3059	310467.14	5819656.478	8.966	0.053	0.053
137	3060	310444.887	5819685.641	6.371	0.011	0.011
138	3061	310431.569	5819735.217	8.443	0.02	0.02
139	3062	310396.976	5819778.513	6.113	#N/A	Not Enough Data
140	3063	310377.362	5819839.08	6.434	0.007	0.007
141	3064	310355.644	5819886.77	7.109	0.064	-0.064
142	3065	310338.279	5819921.77	7.182	0.027	-0.027
143	3066	310329.241	5819960.776	9.831	0.012	-0.012
144	3067	310300.392	5819995.326	7.685	0.003	-0.003
145	3068	310276.483	5820016.079	7.099	0.009	0.009

146	3069	310235.773	5820060.05	8.376	0.028	-0.028
147	3070	310208.802	5820088.082	8	0.007	0.007
148	3071	310163.305	5820133.8	12.473	0.032	-0.032
149	3072	310141.924	5820143.533	12.811	0.014	-0.014
150	3074	310096.769	5820148.14	15.79	0.05	-0.05
151	3075	310050.669	5820142.682	17.299	0.016	-0.016
152	3076	310006.569	5820129.712	15.212	0.008	-0.008
153	3078	309970.608	5820120.119	13.866	0.021	0.021
154	3079	309924.709	5820097.524	9.687	0.004	-0.004
155	3080	309882.279	5820087.209	10.258	0.019	-0.019
156	3081	309830.151	5820059.371	9.637	0.001	-0.001
157	3082	309770.776	5820040.579	8.496	0.024	-0.024
158	3083	309732.999	5820040.618	8.792	0.018	0.018
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160	3087	309628.557	5820200.159	9.232	#N/A	Not Enough Data
161	3088	309613.797	5820268.339	8.884	0.031	-0.031
162	3089	309606.369	5820316.365	8.675	0.036	-0.036
163	3090	309597.103	5820381.145	7.83	0.003	0.003
164	3091	309596.493	5820429.746	7.949	0.016	-0.016
165	3092	309589.067	5820484.825	9.562	0.043	-0.043
166	3093	309563.13	5820539.243	10.03	0.017	-0.017
167	3094	309534.975	5820587.377	11.351	0.004	-0.004
168	3095	309514.364	5820617.333	11.263	0.001	-0.001
169	3096	309483.75	5820647.73	9.662	0.007	-0.007
170	3097	309458.999	5820679.704	10.76	0.05	-0.05
171	3098	309408.598	5820717.268	10.903	0.05	-0.05
172	3099	309370.562	5820694.771	10.476	0.001	0.001
173	3101	309325.913	5820677.981	10.187	0.03	-0.03
174	3102	309279.502	5820672.54	10.311	0.069	-0.069
175	3103	309196.157	5820664.966	10.954	0.012	-0.012
176	3104	309143.54	5820684.561	11.695	0.056	-0.056
177	3105	309115.015	5820706.259	11.158	0.007	-0.007
178	3106	309096.112	5820774.386	11.809	0.005	-0.005
179	3107	309086.705	5820816.982	9.27	0.007	-0.007
180	3108	309117.734	5820859.228	9.422	0.017	-0.017
181	3109	309163.419	5820895.057	9.596	0.025	-0.025
182	3110	309206.378	5820933.34	9.817	0.037	-0.037
183	3111	309242.926	5820975.641	9.787	0.011	0.011
184	3112	309277.018	5821015.243	9.775	0.007	-0.007
185	3113	309312.447	5821056.569	9.815	0.025	-0.025
186	3114	309355.854	5821105.557	9.605	0.018	0.018
187	3115	309395.066	5821136.317	9.942	0.01	-0.01
188	3116	309432.237	5821182.181	11.019	0.021	-0.021
189	3121	309443.526	5821244.537	10.795	0.01	-0.01
190	3122	309449.785	5821293.617	10.501	0.029	-0.029
191	3123	309456.706	5821338.657	11.154	0.019	-0.019
192	3124	309447.639	5821386.705	11.496	0.009	-0.009
193	3126	309420.301	5821421.501	10.952	0.068	-0.068
194	3127	309372.769	5821475.131	13.563	0.021	-0.021
195	3128	309329.946	5821489.505	14.275	0.049	-0.049

196	3129	309279.106	5821483.571	14.367	0.039	-0.039
197	3130	309223.22	5821458.526	14.441	0.008	-0.008
198	3132	309172.95	5821447.64	14.866	0.005	0.005
199	3133	309125.541	5821440.484	14.797	0.032	-0.032
200	3134	309088.74	5821435.795	14.716	0.011	-0.011
201	3135	309037.575	5821451.018	17.653	0.004	0.004
202	3136	309004.153	5821445.733	17.842	0.028	-0.028
203	3137	308958.16	5821449.978	18.717	0.021	-0.021
204	3138	308906.674	5821462.557	20.539	0.025	0.025
205	3139	308863.27	5821482.995	20.598	#N/A	Not Enough Data
206	3140	308831.399	5821499.574	20.578	0.016	0.016
207	3141	308770.596	5821530.921	15.826	0.003	0.003
208	3142	308758.653	5821571.334	12.721	0.003	0.003
209	3143	308772.412	5821619.117	12.694	0.024	0.024
210	3144	308778.768	5821658.631	13.044	0.004	-0.004
211	3145	308774.529	5821689.471	13.253	0.025	-0.025
212	3146	308768.024	5821730.808	13.327	0.04	0.04
213	3147	308772.167	5821774.824	13.62	#N/A	Not Enough Data
214	3148	308783.108	5821819.538	13.743	#N/A	Not Enough Data
215	3149	308800.75	5821864.773	13.681	0.023	-0.023
216	3150	308809.324	5821908.852	13.803	0.038	0.038
217	3151	308812.429	5821966.716	13.902	0.1	-0.1
218	3152	308844.343	5822030.289	14.778	0.011	0.011
219	3153	308861.885	5822074.003	14.753	0.046	0.046
220	3154	308859.667	5822130.427	14.934	#N/A	Not Enough Data
221	3155	308858.117	5822173.17	15.905	0.01	-0.01
222	3156	308868.19	5822223.18	16.685	0.024	-0.024
223	3158	308824.763	5822219.58	13.179	0.055	0.055
224	3159	308822.844	5822186.812	12.706	0.053	0.053
225	3161	308790.444	5822168.682	9.611	0.074	-0.074
226	3162	308743.691	5822106.697	14.259	0.025	-0.025
227	3163	308740.089	5822160.636	19.75	0.033	0.033
228	3164	308724.655	5822201.916	22.129	0	0
229	3165	308657.967	5822219.295	19.982	0.036	-0.036
230	3166	308610.794	5822231.63	19.184	0.051	0.051
231	3167	308578.055	5822237.81	19.881	0.014	-0.014
232	3168	308528.287	5822246.536	19.937	0.014	0.014
233	3169	308573.527	5822301.392	26.495	0.028	0.028
234	3170	308581.819	5822343.532	32.095	0.019	0.019
235	3171	308569.14	5822376.148	36.513	0.001	0.001
236	3172	308532.818	5822415.66	42.524	0.021	0.021
237	3173	308502.627	5822448.231	47.18	0.016	0.016
238	3174	308468.476	5822487.786	52.114	0.023	0.023
239	3176	308506.79	5822475.48	55.382	0.008	-0.008
240	3177	308498.724	5822524.665	61.796	0.009	-0.009
241	3178	308507.871	5822550.631	64.028	0.001	-0.001
242	3179	308507.82	5822606.181	66.567	0.023	0.023
243	3180	308513.764	5822653.776	67.813	0.005	0.005
244	3181	308519.782	5822700.448	68.8	0.035	0.035
245	3183	308525.71	5822749.431	69.632	0.002	0.002

246	3184	308533.998	5822814.26	70.178	0.001	0.001
247	3185	308539.565	5822855.672	70.451	#N/A	Not Enough Data
248	3186	308544.318	5822899.895	70.603	#N/A	Not Enough Data
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250	3189	308494.484	5822851.201	70.311	#N/A	Not Enough Data
251	3190	308490.004	5822814.499	70.188	0.02	0.02
252	3191	308484.476	5822770.868	69.662	0.014	0.014
253	3192	308480.608	5822738.536	69.245	#N/A	Not Enough Data
254	3193	308474.178	5822685.508	68.208	#N/A	Not Enough Data
255	3194	308468.962	5822645.883	66.948	0.017	0.017
256	3195	308463.564	5822603.625	64.493	0.006	-0.006
257	3196	308426.144	5822607.45	64.594	0.009	0.009
258	3197	308372.313	5822614.053	64.96	#N/A	Not Enough Data
259	3198	308338.917	5822627.979	65.372	0.01	-0.01
260	3199	308303.425	5822664.836	65.877	0.009	0.009
261	3200	308268.375	5822701.113	66.89	0.004	0.004
262	3201	308241.1	5822729.494	67.581	0.029	0.029
263	3202	308213.76	5822758.674	67.971	0.028	-0.028
264	4000	314965.585	5818177.896	2.273	0.013	0.013
265	4001	315010.073	5818172.936	2.249	0.047	0.047
266	4002	315058.697	5818156.854	2.379	0.082	0.082
267	4003	315099.966	5818135.871	2.751	0.02	0.02
268	4004	315141.903	5818104.012	2.458	0.032	0.032
269	4005	315153.06	5818052.52	2.31	0.027	0.027
270	4006	315164.529	5817996.933	2.216	0.002	0.002
271	4007	315182.711	5817897.259	2.015	0.018	0.018
272	4008	315173.041	5817826.323	2.011	0.049	-0.049
273	4009	315141.463	5817774.991	2.391	0.014	0.014
274	4010	315109.929	5817725.926	2.684	0.052	-0.052
275	4011	315100.891	5817666.273	3.473	0.024	0.024
276	4012	315212.164	5817591.093	6.128	0.002	0.002
277	4013	315168.664	5817575.129	4.881	0.022	0.022
278	4014	315121.801	5817551.006	5.999	0.008	-0.008
279	4015	315080.303	5817525.78	11.044	0.014	-0.014
280	4016	315037.668	5817504.351	8.506	0.025	-0.025
281	4017	314992.057	5817503.341	2.433	#N/A	Not Enough Data
282	4018	314946.775	5817498.304	2.113	0.022	-0.022
283	4019	314894.636	5817485.861	1.986	0.023	0.023
284	4020	314845.076	5817446.531	2.018	0.006	-0.006
285	4021	314801.681	5817407.098	2.107	0.008	0.008
286	4022	314766.993	5817371.776	2.048	0.011	-0.011
287	4023	314743.722	5817333.681	2.076	0.003	0.003
288	4024	314721.027	5817291.465	2.058	0.006	0.006
289	4025	314714.486	5817243.065	1.94	#N/A	Not Enough Data
290	4026	314720.155	5817194.742	1.681	0.047	-0.047
291	4027	314727.87	5817135.242	1.626	0.038	-0.038
292	4028	314735.113	5817088.2	1.633	0.005	0.005
293	4029	314751.746	5817032.624	1.917	0.013	-0.013
294	4030	314770.629	5816989.87	1.97	0.005	-0.005
295	4031	314792.189	5816943.003	2.347	0.01	-0.01

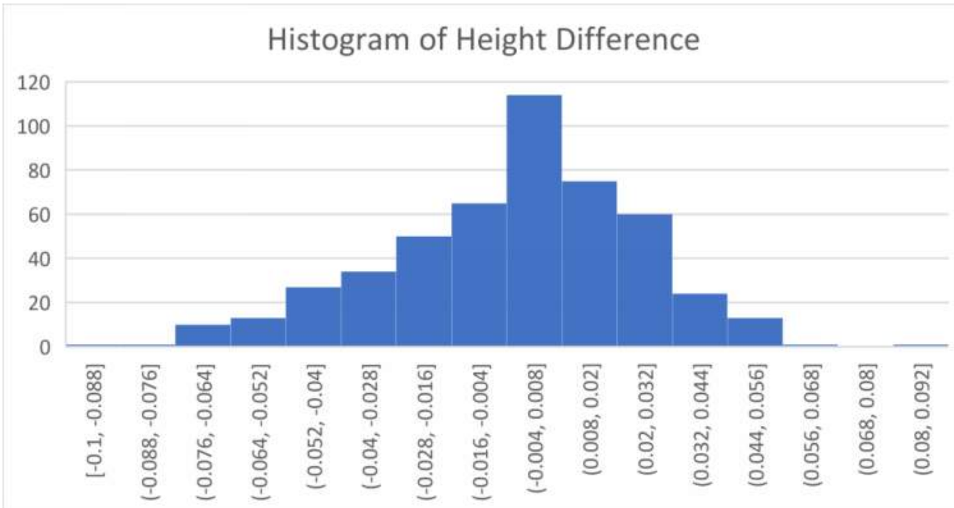
296	4032	314804.025	5816899.133	2.418	0.002	0.002
297	4033	314826.004	5816829.979	2.133	0.016	0.016
313	4049	314918.194	5816205.264	2.047	0.028	0.028
314	4050	314964.982	5816189.785	1.553	0.004	0.004
315	4051	315008.22	5816161.233	1.672	0.021	0.021
316	4052	315039.959	5816133.416	1.678	0.025	0.025
317	4053	315083.668	5816111.814	1.692	0.001	0.001
318	4054	315118.585	5816083.997	1.761	0.002	0.002
319	4055	315150.947	5816053.731	1.676	0.028	0.028
320	4056	315171.202	5816012.944	1.778	0.002	0.002
321	4057	315182.752	5815959.376	1.67	0.001	-0.001
322	4058	315142.915	5815933.275	1.951	0.034	-0.034
323	4059	315100.841	5815905.881	2	0.019	0.019
324	4060	315101.201	5815861.218	2.108	0.018	-0.018
325	4061	315130.92	5815837.239	1.426	0.011	0.011
326	4062	315177.82	5815828.985	1.423	0.049	0.049
327	4063	315221.373	5815809.64	1.328	0	0
328	4064	315219.464	5815763.725	1.623	0.017	0.017
329	4065	315217.366	5815719.141	1.506	0.014	-0.014
330	4066	315214.135	5815675.775	1.476	0.016	-0.016
331	4067	315208.912	5815624.214	1.636	0.042	-0.042
332	4068	315196.439	5815581.762	2.077	0.012	0.012
333	4069	315216.935	5815540.033	1.762	0.017	-0.017
334	4070	315254.685	5815537.157	1.673	0.01	0.01
335	4071	315300.259	5815516.281	1.079	0.013	0.013
336	4072	315290.475	5815465.27	1.272	#N/A	Not Enough Data
337	4073	315291.351	5815414.264	1.337	0.015	-0.015
338	4074	315299.392	5815369.625	1.398	0.024	-0.024
339	4075	315314.452	5815318.523	1.255	0.016	-0.016
340	4076	314981.621	5818255.463	3.097	0.045	0.045
341	4077	314933.161	5818254.276	3.204	0.014	0.014
342	4078	314892.118	5818249.143	3.18	0.048	0.048
343	4079	314830.463	5818243.642	3.277	0.023	0.023
344	4080	314790.502	5818239.317	3.497	0.037	0.037
345	4081	314731.603	5818224.335	3.73	0.033	0.033
346	4082	314684.027	5818208.772	4.169	0.021	0.021
347	4083	314621.518	5818175.245	2.619	0.037	0.037
348	4084	314570.434	5818142.075	1.538	0.037	0.037
349	4085	314518.248	5818123.16	1.398	0.039	0.039
350	4086	314475.878	5818138.137	1.805	0.031	0.031
351	4087	314429.749	5818161.56	1.814	0.031	0.031
352	4088	314395.552	5818201.107	1.889	0.011	0.011
353	4089	314371.178	5818241.967	2.191	0.023	0.023
354	4090	314335.799	5818290.938	2.393	0.016	0.016
355	4091	314299.935	5818324.519	2.294	0.007	0.007
356	4092	314269.962	5818352.215	2.62	0.035	0.035
357	4093	314237.435	5818386.523	2.657	0.009	0.009
358	4094	314191.236	5818432.173	2.541	0.043	0.043
359	4095	314162.031	5818466.272	2.327	0.003	0.003
360	4096	314128.24	5818505.758	2.856	#N/A	Not Enough Data

361	4097	314092.795	5818530.804	2.559	0.033	0.033
362	4098	314049.974	5818579.128	2.944	0.035	0.035
363	4099	314012.791	5818595.682	2.366	0.001	0.001
364	4100	313973.824	5818615.322	2.765	0.015	0.015
365	4101	313909.129	5818635.067	3.458	0.003	-0.003
366	4102	313854.818	5818651.767	4.55	0.017	0.017
367	4103	313812.431	5818673.595	4.959	0.012	-0.012
368	4104	313767.084	5818674.593	4.308	0.001	-0.001
369	4105	313729.838	5818661.638	5.088	0.011	0.011
370	4106	313684.047	5818645.419	7.166	0.016	0.016
371	4107	313685.681	5818680.3	9.243	0.016	0.016
372	4108	313698.593	5818723.759	10.653	0.031	-0.031
373	4109	313711.329	5818764.335	11.337	0.012	-0.012
374	4110	313734.576	5818805.172	13.274	0.011	0.011
375	4111	313779.154	5818825.306	19.309	0.021	-0.021
376	4112	313821.99	5818822.152	26.147	0.006	0.006
377	4113	313849.953	5818818.474	28.219	0.016	0.016
378	4114	313851.374	5818864.766	27.161	0.02	0.02
379	4115	313848.693	5818910.091	25.626	#N/A	Not Enough Data
380	4116	313846.214	5818954.051	23.699	0.005	0.005
381	4117	313849.912	5818989.701	22.302	0.016	0.016
382	4118	313835.811	5819047.515	27.108	0.037	0.037
383	4119	313824.417	5819094.821	26.282	0.019	0.019
384	4120	313808.257	5819137.991	27.717	0.01	0.01
385	4121	313781.116	5819173.945	30.639	0.002	-0.002
386	4122	313748.8	5819206.393	32.993	0.014	0.014
387	4123	313713.847	5819234.13	36.878	0.011	0.011
388	4124	313669.41	5819242.609	40.552	0.008	0.008
389	4125	313612.381	5819257.413	42.207	0.016	0.016
390	4126	313572.38	5819280.465	43.173	0.007	0.007
391	4127	313527.957	5819288.903	43.449	0.009	0.009
392	4128	313482.574	5819289.445	43.507	0.017	0.017
393	4129	313450.187	5819259.059	42.007	0.013	0.013
394	4130	313408.238	5819236.171	39.369	0.018	0.018
395	4131	313353.059	5819258.094	40.717	0.005	-0.005
396	4132	313312.904	5819280.849	39.356	0.01	-0.01
397	4133	313278.382	5819312.839	36.764	0.002	-0.002
398	4134	313288.107	5819356.127	36.114	0.006	0.006
399	4135	313319.981	5819391.614	35.296	0.006	0.006
400	4136	313336.961	5819424.799	33.329	0	0
401	4137	313298.956	5819397.677	31.224	0.001	0.001
402	4138	313239.597	5819336.531	29.735	0.011	-0.011
403	4139	313263.896	5819388.056	25.824	0.023	-0.023
404	4140	313290.867	5819429.73	22.249	0	0
405	4141	313272.925	5819452.426	16.441	0.004	-0.004
406	4142	313235.906	5819422.783	14.082	0.018	-0.018
407	4143	313210.067	5819383.183	13.526	0.005	0.005
408	4144	313189.058	5819339.746	12.437	0.001	-0.001
409	4145	313167.567	5819291.64	8.238	0.008	-0.008
410	4146	313142.253	5819257.181	6.941	0.013	-0.013

411	4147	313101.335	5819236.317	4.571	0.028	0.028
412	4148	313085.175	5819199.626	3.105	0.004	0.004
413	4149	313058.366	5819161.687	2.685	#N/A	Not Enough Data
414	4150	313015.82	5819104.477	2.846	#N/A	Not Enough Data
415	4151	313006.855	5819060.779	3.891	0.018	-0.018
416	4152	313019.03	5819014.955	5.018	0.027	-0.027
417	4153	312998.181	5818979.132	9.245	0.013	-0.013
418	4154	312962.194	5818960.937	11.373	0.026	-0.026
419	4155	312912.798	5818941.089	13.471	0.031	0.031
420	4156	312891.168	5818900.501	16.225	0.022	0.022
421	4157	312867.279	5818862.187	20.605	0.051	0.051
422	4158	312846.553	5818819.991	26.607	0.042	0.042
423	4159	312847.508	5818772.573	30.644	0.017	0.017
424	4160	312839.294	5818722.448	33.668	0.02	0.02
425	4161	312802.297	5818696.46	35.766	0.03	0.03
426	4162	312759.383	5818677.82	35.665	0.018	0.018
427	4163	312718.27	5818657.731	36.559	0.031	0.031
428	4164	312677.442	5818630.815	36.018	0.003	0.003
429	4165	312632.788	5818621.374	35.742	0.024	0.024
430	4166	312591.33	5818598.504	36.769	0.006	0.006
431	4167	312555.781	5818567.481	37.208	0.033	0.033
432	4168	312523.537	5818535.108	37.255	0.03	0.03
433	4169	312479.935	5818531.409	37.852	0.012	0.012
434	4170	312432.268	5818543.921	36.416	0.036	0.036
435	4171	312405.072	5818504.584	29.454	0.028	0.028
436	4172	312404.872	5818462.857	22.092	0.008	-0.008
437	4173	312420.385	5818425.505	15.701	0.024	0.024
438	4174	312424.518	5818377.862	9.935	0.034	0.034
439	4175	312446.171	5818351.461	4.549	0.047	-0.047
440	4176	312492.233	5818341.037	4.73	0.024	-0.024
441	4177	312508.769	5818293.203	3.731	0.002	0.002
442	4178	312500.549	5818236.431	4.165	0.035	-0.035
443	4179	312487.52	5818193.801	5.256	0.018	0.018
444	4180	312459.037	5818133.846	6.05	#N/A	Not Enough Data
445	4181	312430.26	5818074.535	6.833	0.032	0.032
446	4182	312404.502	5817972.363	5.747	#N/A	Not Enough Data
447	4183	312424.616	5817928.603	4.305	#N/A	Not Enough Data
448	4184	312475.198	5817875.9	4.117	#N/A	Not Enough Data
449	4185	312505.958	5817845.234	4.176	0.013	-0.013
450	4186	312539.735	5817808.863	4.389	0.015	-0.015
451	4187	312562.114	5817770.663	6.155	0.012	-0.012
452	4188	312603.434	5817752.42	4.592	0.004	0.004
453	4189	312647.022	5817723.231	3.864	0.006	0.006
454	4190	312702.976	5817706.564	3.11	0.004	0.004
455	4191	312762.103	5817636.479	3.107	#N/A	Not Enough Data
456	4192	312767.405	5817589.176	2.291	0.024	0.024
457	4193	312769.082	5817534.407	2.372	0.019	-0.019
458	4194	312755.286	5817469.159	2.637	#N/A	Not Enough Data
459	4195	312732.267	5817431.448	3.196	0.014	-0.014
460	4196	312698.061	5817395.49	2.581	0.021	0.021

461	4197	312659.711	5817368.901	2.872	0.02	0.02
462	4198	312609.148	5817329.74	2.742	0.01	-0.01
463	4199	312569.601	5817306.238	2.381	0.006	-0.006
464	4200	312527.612	5817288.159	2.278	0.021	0.021
465	4201	312481.875	5817295.791	2.298	0.006	0.006
466	4202	312436.003	5817302.859	3.044	0.018	0.018
467	4203	312362.327	5817308.842	2.736	0.006	-0.006
468	4204	312305.525	5817316.459	3.12	0.012	-0.012
469	4205	312249.396	5817334.088	3.834	0.02	-0.02
470	4206	312198.142	5817351.052	4.319	0.003	-0.003
471	4207	312136.425	5817357.602	4.283	0.012	0.012
472	4208	312087.403	5817352.432	3.889	0.008	-0.008
473	4209	312036.386	5817342.517	2.829	0.007	0.007
474	4210	311984.129	5817332.882	2.102	0.003	-0.003
475	4211	311884.708	5817302.245	3.8	#N/A	Not Enough Data
476	4212	311827.091	5817282.373	4.202	0.012	-0.012
477	4213	311785.335	5817270.272	4.345	0.009	-0.009
478	4214	311754.213	5817237.027	4.141	0.012	0.012
479	4215	311734.16	5817187.77	4.77	0.002	-0.002
480	4216	311715.343	5817143.054	5.12	0.009	0.009
481	4217	311649.802	5817118.343	4.543	0.009	-0.009
482	4218	311617.231	5817085.552	5.092	0.016	0.016
483	4219	311623.732	5817024.443	4.809	0.014	0.014
484	4220	311583.19	5816986.332	4.051	#N/A	Not Enough Data
485	4221	311529.099	5816981.668	4.139	#N/A	Not Enough Data
486	4222	311474.583	5816988.213	4.097	#N/A	Not Enough Data
487	4223	311398.988	5816997.56	4.284	#N/A	Not Enough Data
488	4224	311353.491	5817009.107	4.38	0.013	0.013
489	4225	311296.167	5817028.425	4.41	0.01	0.01
490	4226	311232.42	5817056.677	5.261	0.013	0.013
491	4227	311200.165	5817076.326	5.518	0.014	0.014
492	4228	311142.032	5817105.336	6.108	0.016	0.016
493	4229	311070.681	5817149.718	7.264	0.019	-0.019
494	4230	311014.932	5817161.85	6.404	0.023	0.023
495	4231	310953.721	5817194.719	4.312	0.003	-0.003
496	4232	310918.101	5817224.388	4.391	0.018	-0.018
497	4233	310893.822	5817273.961	4.682	0.03	-0.03
498	4234	310855.001	5817333.041	4.538	0.018	-0.018
499	4235	310839.27	5817376.613	4.986	0.031	-0.031
500	4236	310817.31	5817435.927	4.627	0.01	-0.01
501	4237	310797.895	5817505.209	4.731	0.024	0.024
502	4238	310814.608	5817550.457	9.497	0.039	0.039
503	4239	310836.849	5817587.195	14.871	0.002	0.002

AVG	-0.0031
RMSE	0.0274
95% CI	0.054
Within Tolerance (%)	100



Histogram of Height Difference
120
100
80
60
40
20
0
[-0.1, -0.088]
(-0.088, -0.076]
(-0.076, -0.064]
(-0.064, -0.052]
(-0.052, -0.04]
(-0.04, -0.028]
(-0.028, -0.016]
(-0.016, -0.004]
(-0.004, 0.008]
(0.008, 0.02]
(0.02, 0.032]
(0.032, 0.044]
(0.044, 0.056]
(0.056, 0.068]
(0.068, 0.08]
(0.08, 0.092]

Appendix D - Total Hydrographic Survey Report

Bathymetric Survey of Maribynong River

Report of Survey

Report compiled by: Steph Morrish
Date: 13/06/2023
Revision: 1.0

www.totalhydrographic.com.au

REPORT OF SURVEY

Purpose of the Survey
Multibeam Bathymetric Survey and Mobile Laser Scanning Survey of Maribynong River

General

Survey and ID		Project Locality	
JAC0001		Maribynong	
Survey Authority/Client		Client Contact	
Jacobs		Brett Sheehan	
Hydrographic Surveyor (Supervising)		Certification or Qualification	
Tim Williams		AHSCP CPHS - Level 1	
Hydrographic Surveyor (Assisting)		Certification or Qualification	
Tim Williams		AHSCP CPHS - Level 1	
Start date of Survey	24/05/2023	End Date of Survey	26/05/2023
Number of field days	2	Class of Survey	IHO Special Order
Survey Platform/Vessel Name		Survey Platform/Vessel Name	
Total 2 - 4.0m Monohull			
Survey Report Completed by		Steph Morrish	
Date of Survey Report Completion		13/06/2023	

Details of Survey Execution

The following positioning systems were used:		
Positioning System 1	POS MV INS	
Positioning System 2	-	
Base station (if applicable)	-	
The following sounding systems were used:		
	Model/System Details	Frequency (kHz)
Echosounder 1	Norbit Winghead	400 Khz
Echosounder 2		
Motion reference unit	-	-
Towed Side Scan Sonar	-	-
Hull mounted Side Scan Sonar	-	-
Logging and processing systems used, and Versions:		
Logging	Hypack 2022	
Processing	Hypack 2022	
Survey Plan line spacing	N/A	
Has data been thinned from that collected	No	
Data - thinning	N/A	
Survey Plan - thinning method and bin size	N/A	

TOTAL HYDROGRAPHIC

REPORT OF SURVEY

Horizontal Control

Soundings are on the following datum	
Datum	GDA2020
Spheroid	GRS80
Projection and Zone	MGA Zone 55
How was the positioning system validated	RTK GNSS against Client Control
THU - Total Horizontal Uncertainty. Estimated Accuracy of soundings at 2.45 Sigma (95%) confidence level	**0.75m**

Vertical Control

Tides Applied	RTK GNSS Tides
Sounding datum	Australian Height Datum (AHD)
Geoid details if using GNSS tides	AusGeoid2020
AHD Separation Value	-
Tide Board/Gauge 1	-
Tide Board/Gauge 2	-
Survey Mark used for datum connection	Jacobs Provided Control
Survey Mark used for datum connection	-
Survey Mark used for datum connection	-
Method for Sound Velocity correction	Sound Velocity Profile
Temperature and Salinity values used	N/A
Tide Model comments (if applicable)	
The following table contains the Survey Control marks used and their associated coordinate uncertainties	

TVU - Total vertical uncertainty. Estimated vertical accuracy of soundings at 1.96 Sigma (95%) confidence level	**0.25m**

INTERNATIONAL HYDROGRAPHIC ORGANIZATION (IHO) SPECIFICATIONS

The International Hydrographic Organization

The International Hydrographic Office (IHO) aims to provide a set of standards for hydrographic surveys primarily used to compile navigational charts essential for the safety of navigation, knowledge and the protection of the marine environment. It's S-44 6E publication describes and outlines the minimum standards for the orders of safety of naviation surveys which are considered acceptable by hydrographic offices or authorities to generate navigational products and services that allow surface vessels to navigate safely. Requirements vary with water depth, geophysical properties, and expected shipping types, five different orders of survey are defined; each designed to cater to a range of needs.

The five orders are described below along with a description of the inteded area(s) of usage. It should be noted that for hydrographic offices or authorities responsible for acquiring surveys should select the order of survey that is most appropriate for the requirements for saftey of navigation in the area. A single order of survey may not be appropriate for the entire area to be survedyed, and in these cases, the different orders should be explicitly defined through the survey area.

Order 1B

Intended for areas where a general depiction of the bottom is considered adequate. As a minimum, an evenly distributed bathymetric coverage of 5% is required. Some features will not be detected, although the distance between areas of bathymetric coverage will limit the size of those features. This order of survey is only recommended where underkeel clearance is considered not to be an issue.

Order 1A

Intended for areas where features on the bottom may become a concern for the type of surface traffic expected to transit the area but where the underkeel clearance is considered not to be critical. A 100% feature search is required in order to detect features of a specified size. Bathymetric coverage less than or equal to 100% is appropriate as long as the least depths over all signifcant features are obtained and the bathymetry provides an adequate depiction of the nature of the bottom topography.

Special Order

Intended for those areas where underkeel clearance is critical. Therefore, 100% feature search and 100% bathymetric coverage are required and the size of the features to be detected by this search is deliberately more demanding than for Order 1A. Examples of areas that may require Special Order surveys are: berthing areas, harbours, and critical areas of fairways and shipping channels.

Exclusive Order

An extension of IHO Special Order with more stringent uncertainty and data coverage requirements. For this order, a 200% feature search and a 200% bathymetric coverage are required. The size of features to be detected is deliberately more demanding than for Special Order. Use is intended for shallow water areas (harbours, berthing areas and critical areas of fairways and channels) where there is an exceptional and optimal use of the water column and where specific critical areas with minimum underkeel clearance and bottom characteristics are potentially hazardous to vessels.

Table 1 - Minimum Bathymetric Standards for Safety of Navigation Hydrographic Surveys

The table on the following page has been taken from the IHO S-44 6E publication, as stated above the table it is to be read in conjunction with the rest of the publication which can be found in the below hyperlink.

7.3 TABLE 1 - Minimum Bathymetry Standards for Safety of Navigation Hydrographic Surveys

To be read in conjunction with the full text set out in this document, m = metres, all uncertainties at 95% confidence level, * = Matrix Reference.

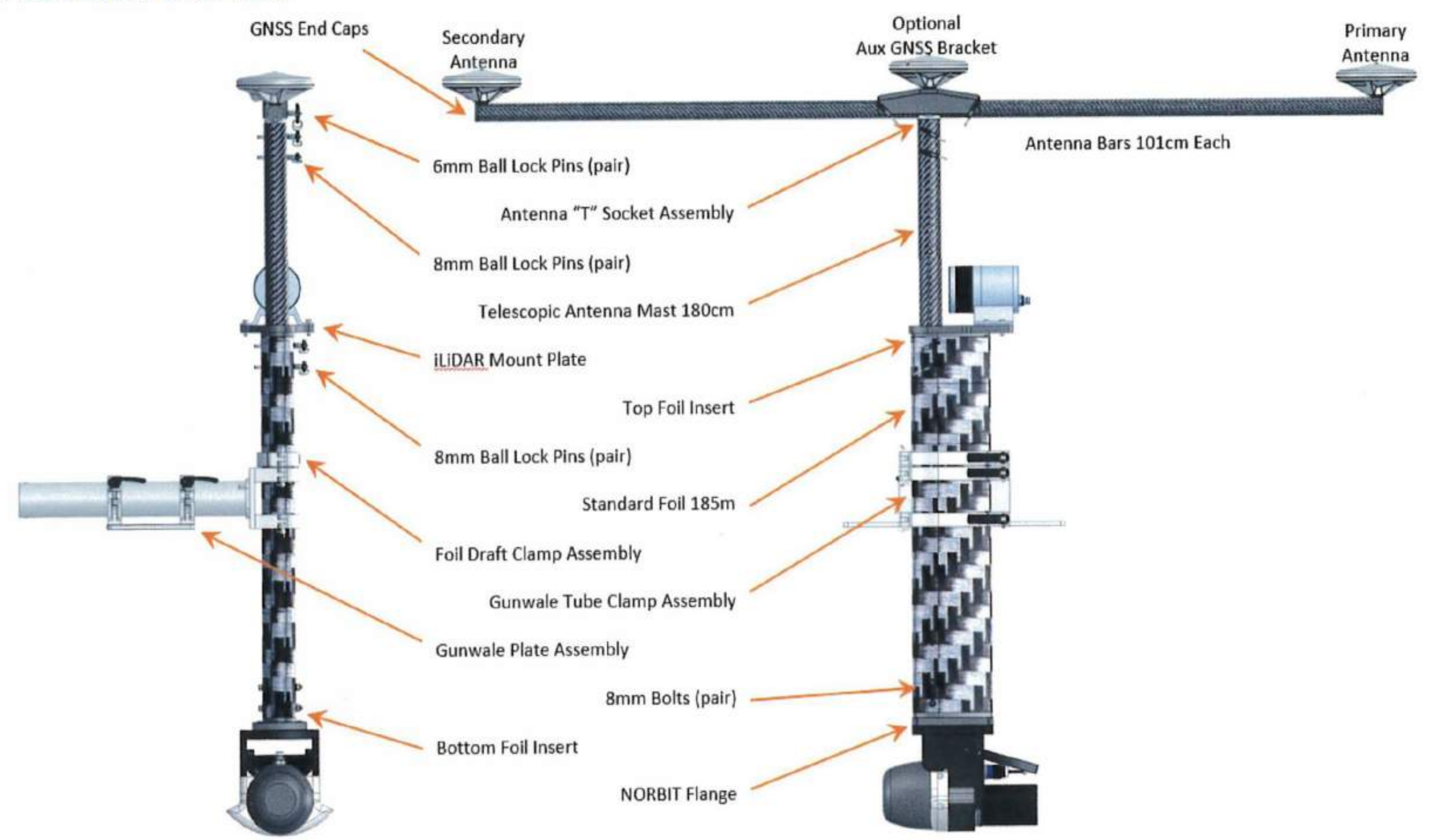
Reference	Criteria	Order 2	Order 1b	Order 1a	Special Order	Exclusive Order
Chapter 1	**Area description** (Generally)	Areas where a general description of the sea floor is considered adequate.	Areas where underkeel clearance is not considered to be an issue for the type of surface shipping expected to transit the area.	Areas where underkeel clearance is considered not to be critical but features of concern to surface shipping may exist.	Areas where underkeel clearance is critical	Areas where there is strict minimum underkeel clearance and manoeuvrability criteria
Section 2.6	**Depth THU** [m] + [% of Depth]	20 m + 10% of depth *Ba5, Bb2	5 m + 5% of depth *Ba8, Bb3	5 m + 5% of depth *Ba8, Bb3	2 m *Ba9	1 m *Ba10
Section 2.6 Section 3.2 Section 3.2.3	**Depth TVU** (a) [m] and (b)	a = 1.0 m b = 0.023 *Bc7, Bd4	a = 0.5 m b = 0.013 *Bc8, Bd6	a = 0.5 m b = 0.013 *Bc8, Bd6	a = 0.25 m b = 0.0075 *Bc10, Bd8	a = 0.15 m b = 0.0075 *Bc12, Bd8
Section 3.3	**Feature Detection** [m] or [% of Depth]	Not Specified	Not Specified	Cubic features > 2 m, in depths down to 40 m; 10% of depth beyond 40 m *Be5, Bf3 beyond 40m	Cubic features > 1 m *Be6	Cubic features > 0.5 m *Be9
Section 3.4	**Feature Search** [%]	Recommended but Not Required	Recommended but Not Required	100% *Bg9	100% *Bg9	200% *Bg12
Section 3.5	**Bathymetric Coverage** [%]	5% *Bh3	5% *Bh3	≤ 100% *≤ Bh9	100% *Bh9	200% *Bh12

NORBIT SYSTEM MOBILISATION
DIMENSIONAL CONTROL

Norbit Dimenisonal Control

The Norbit Winghead i77h Multi Beam Echosounder (MBES) survey system, utilises the Norbit Portus Pole Mount; a purpose built expeditionary mounting kit that can be transferred across vessels. The portus pole incoporates a 3-position telescopic mast with known offsets from the manufacturer, therefore an independent dimensional control survey was not needed.

Assembled Overview



Lever Arm Offsets – Primary Antenna is Aft – Antenna Separation = 2.001m

Standard Sonar Foil (1.850m)	**+Fwd**	**+Stbd**	**+Dwn Full extension**	**+Dwn Mid Extension**	**+Dwn No Extension**
Bttm Center Sonar Flange to Bttm *Aft* Ant.	-0.955	0.000	-3.632	-2.887	-2.137
Bttm Center Sonar Flange to top GNSS Aux	-0.045	0.000	-3.656	-2.911	-2.161
Bttm Center Sonar Flange to LiDAR Center	0.031	0.00	-1.900		

Lidar

	+Fwd	**+Stbd**	**+Dwn**
Bttm Center Sonar Flange to LiDAR Center	-0.031	0.00	-1.900
Top Center of Bracket to WBMS-Narrow Ref	-0.172	0.00	0.070
Sonar/INS Ref to LiDAR Center	**0.141**	**0.00**	**-1.970**

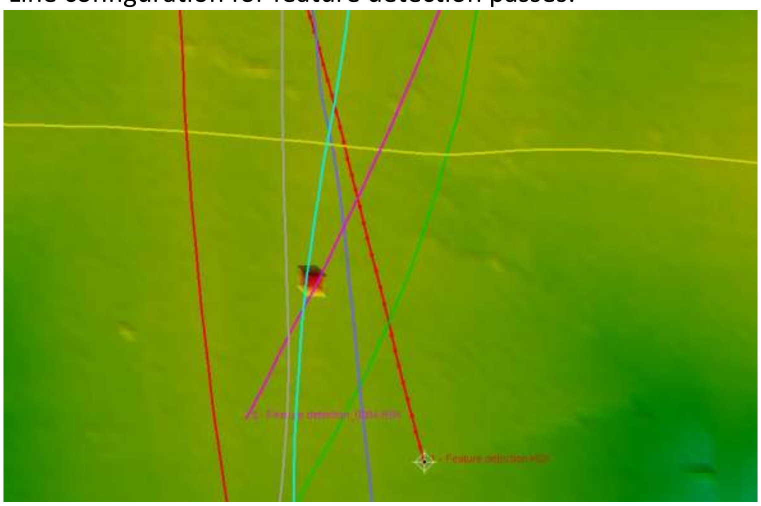
NORBIT SYSTEM MOBILISATION
FEATURE DETECTION VALIDATION

Norbit Winghead i77h Feature Detection Validation

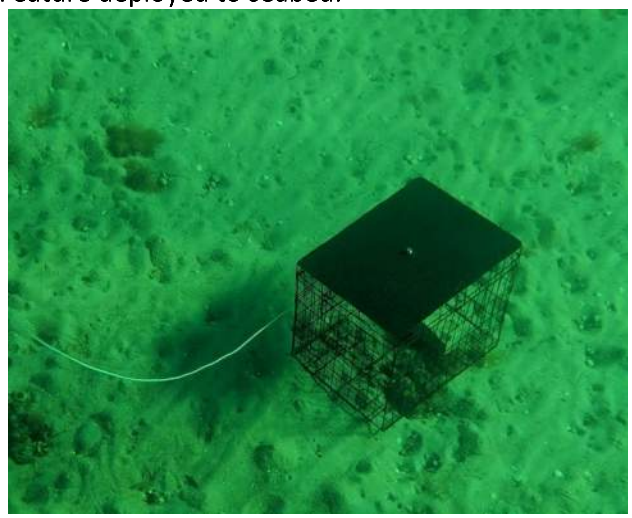
Total Hydrographic's Norbit Winghead i77h MBES system has been tested for its feature detection capability. The system was put under the most stringent specification, the IHO Exclusive Order survey, this states that a cubic feature >0.5m needs to be detected by the system. The density of samples that were to be collected on a feature to be considered detected was set at a minimum of 9 soundings.

Methodology			
Date	20/10/2021	Time	14:15
Location	Altona, VIC	Cubic Feature (m)	0.6 X 0.45 X 0.5
Water Depth (m)	12m	Swath Width	140°
Survey Speed	7knots	Number of Passes	2

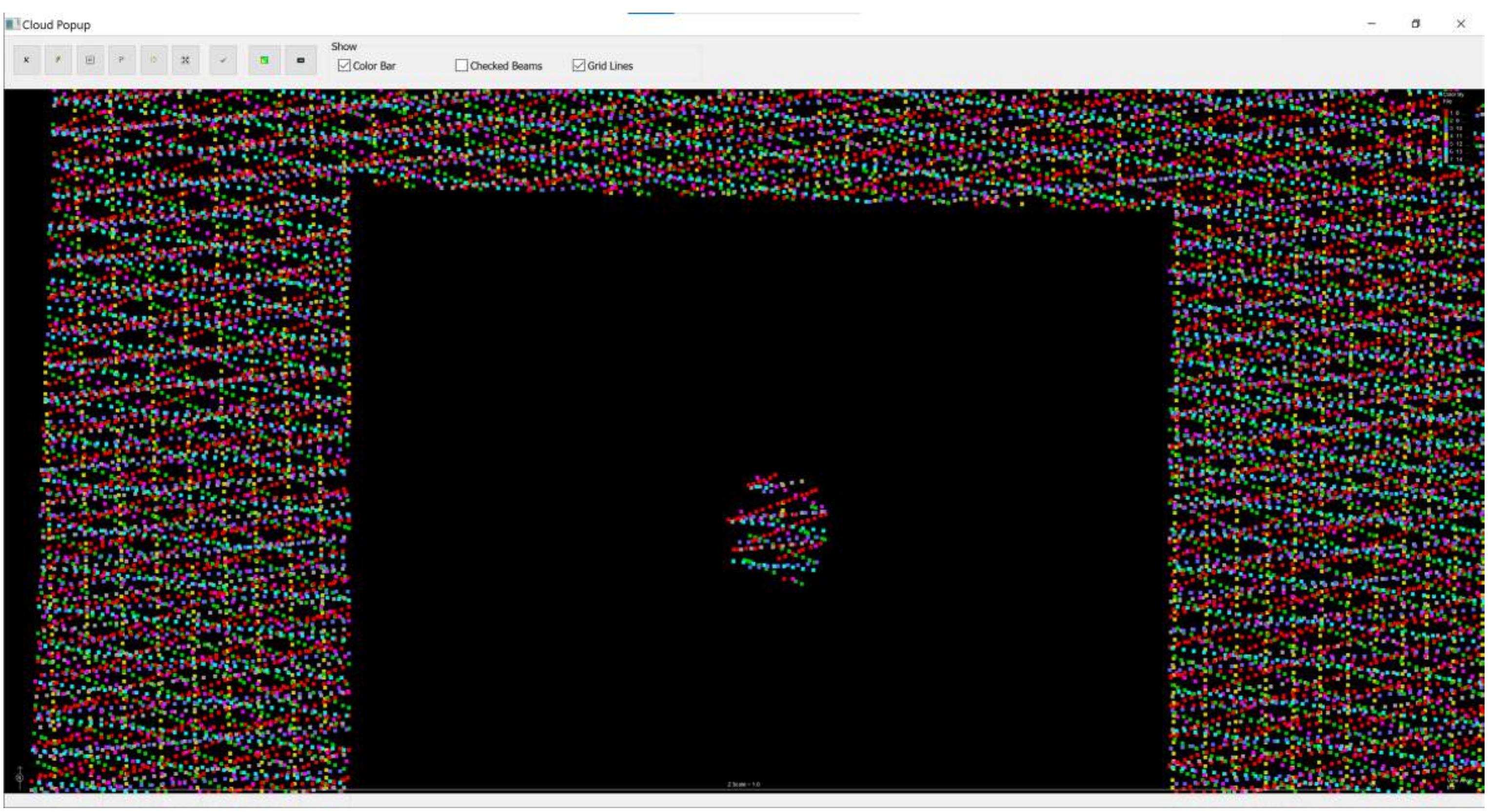
Line configuration for feature detection passes:



Feature deployed to seabed:

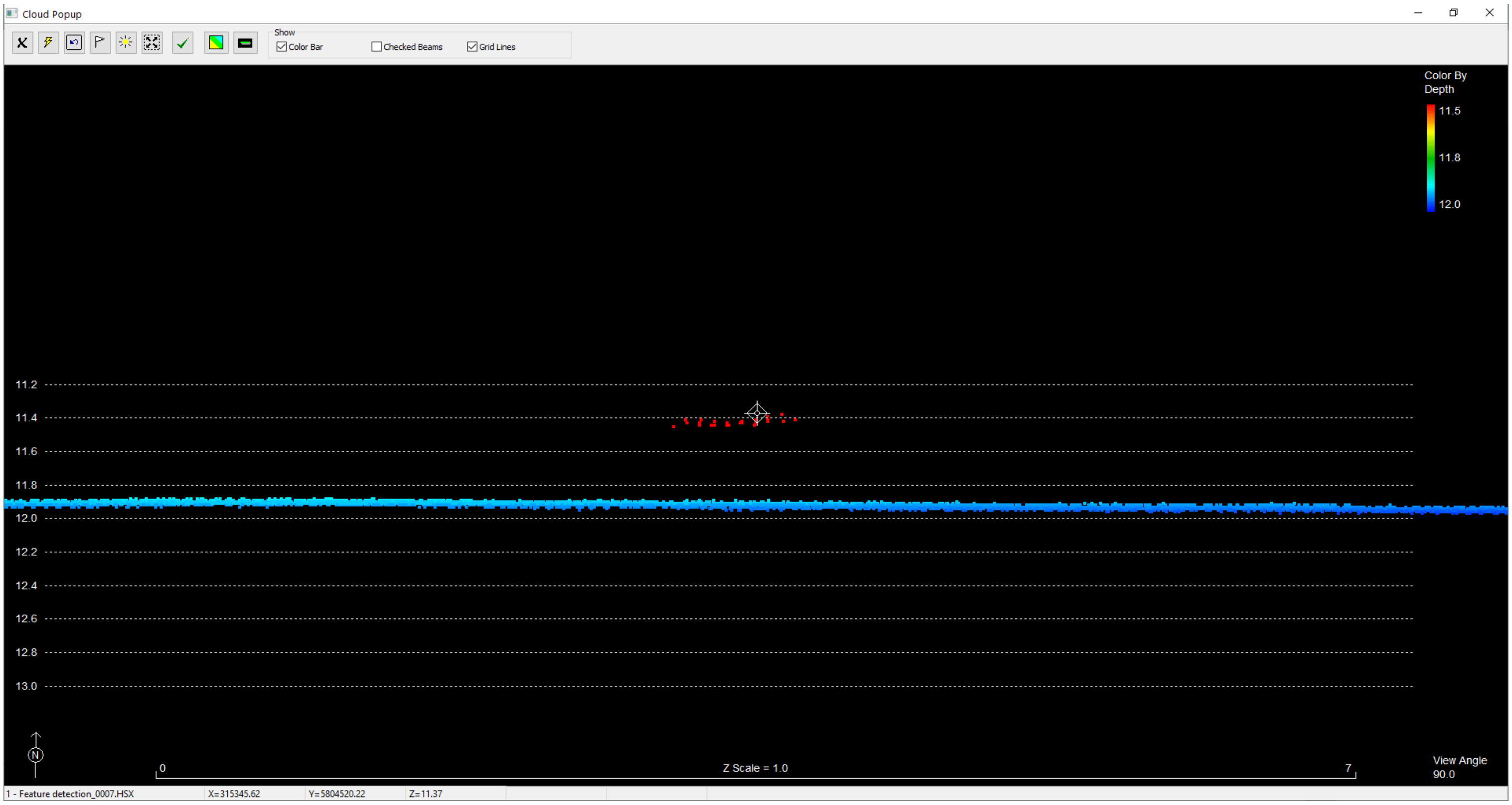


Detections on feature with seabed remove - shows consistent positioning of feature:

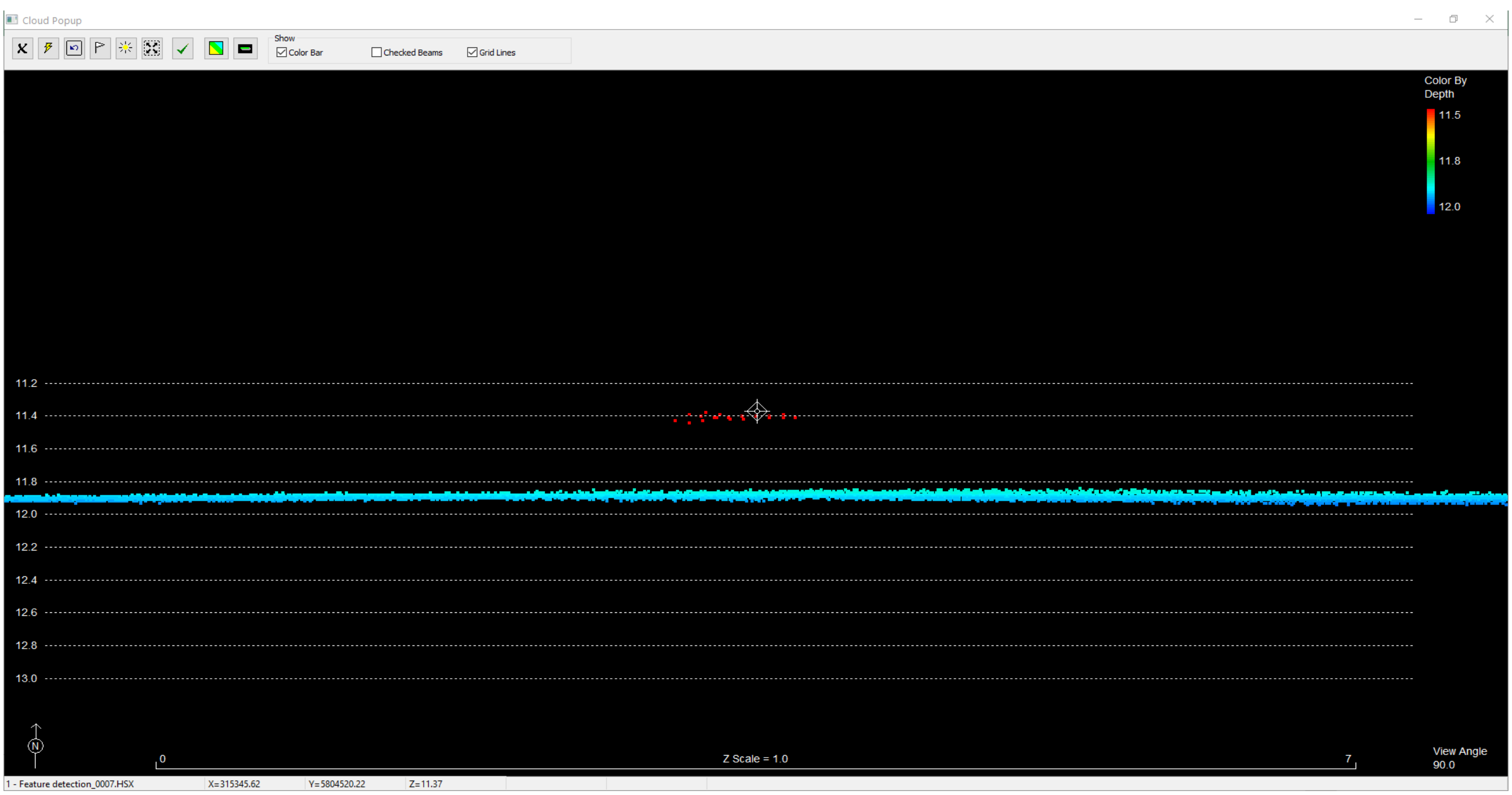


NORBIT SYSTEM MOBILISATION
FEATURE DETECTION VALIDATION

Pass 1 - 7 Knots with a 140° swath via Norbit Winghead i77h



Pass 2 - 7 Knots with a 140° swath via Norbit Winghead i77h



Final Comment: Feature was detected

NORBIT SYSTEM MOBILISATION
STATIC POSITION VALIDATION

To validate the positioning system onboard Total Hydrographic's Survey vessel Total 2, a Static Position validation was

A point was marked out on the ground

RTK GNSS observation was captured on the point

RTK GNSS and POS MV observations are taken over the same

The MBES is then moved over the same point on the ground and observations of the MBES's positioning are recorded and compared to the RTK GNSS observation of the same point.

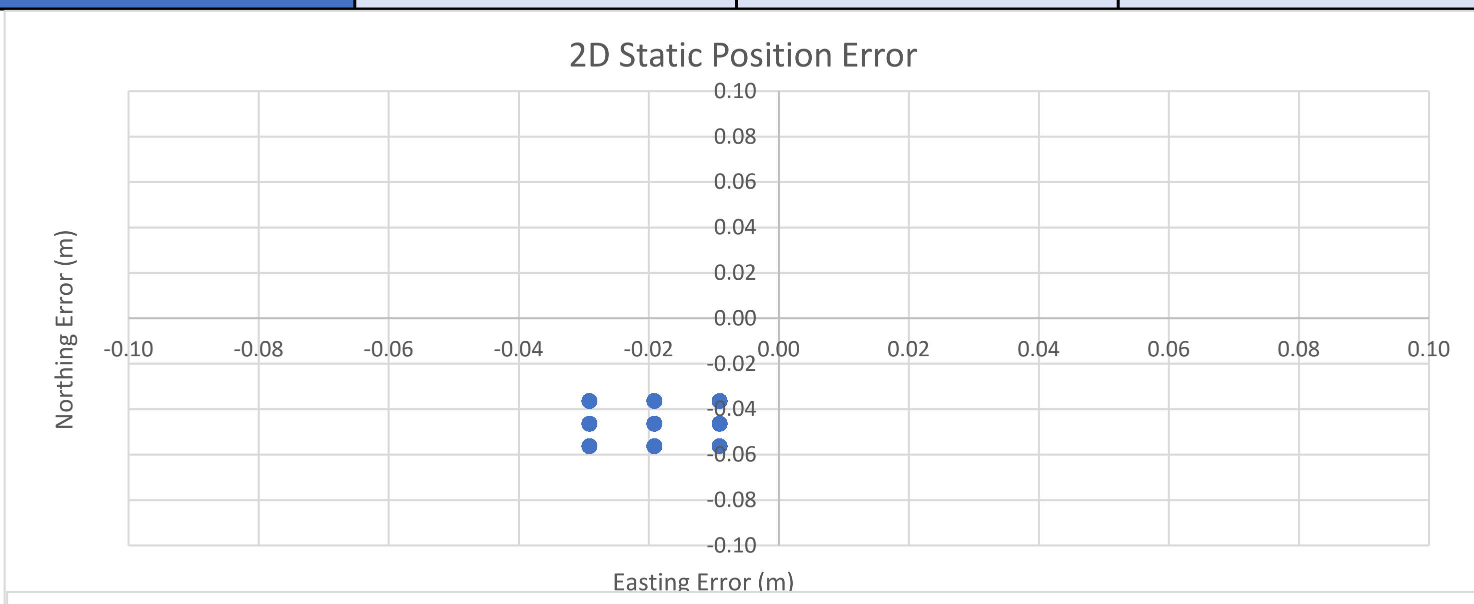
NORBIT MOBILISATION
STATIC POSITION VALIDATION

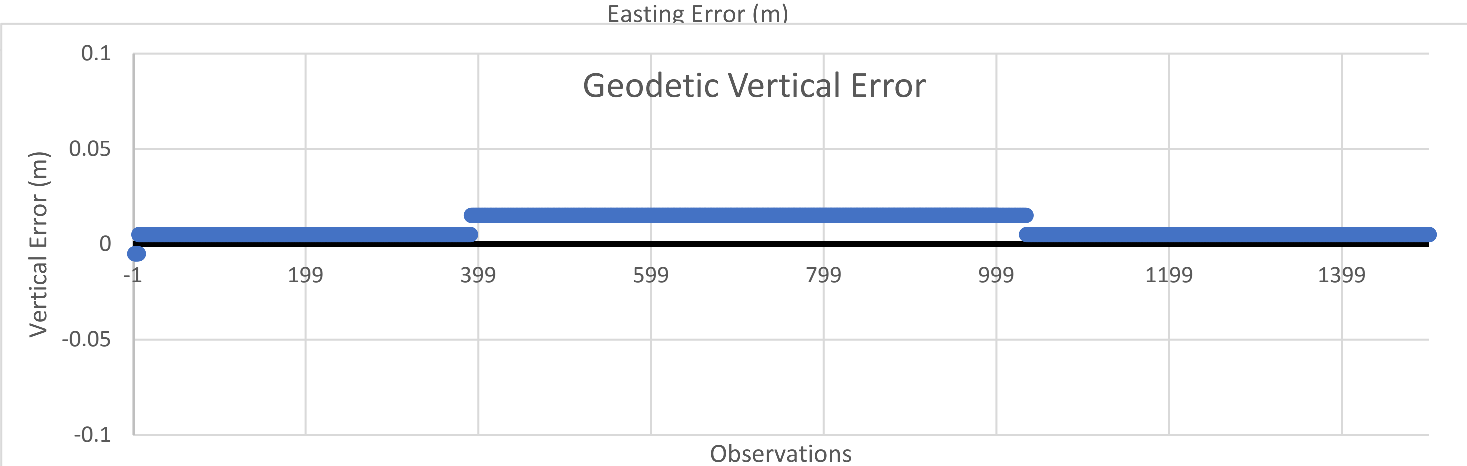
Date	8/07/2021	Project	CLOT0003
Time: (AEST)	14:30	Project Locality	Apollo Bay
Vertical Datum	Chart Datum	AHD Separation	1.140
Horizontal Datum	GDA2020	Map Projection	MGA Zone 54

Static Position Node	Ground beneath sonar	Validation Location	Apollo Bay
GNSS Device	Leica GS14	Surveyor	Tim Williams
Correction	SNA iMax (2020)	Duration of RTK Observations	120s
# IMU Z Observations	10770	# Baseline Distance	NA

Results

	Easting	Northing	Orthometric Height
IMU Z (RTK GNSS)	732626.651	5706485.244	2.575
RTK Rover Uncertainty	0.015		0.079
POSMV Observation	732626.671	5706485.290	2.569
Standard Deviation	0.005	0.006	0.008
POSMV Uncertainty	0.011		0.016
Variation	**-0.020**	**-0.046**	**0.006**





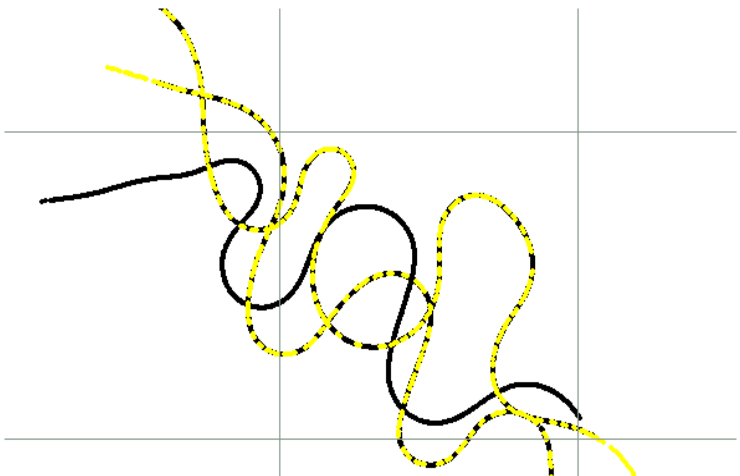
Final Comments: Static Position observations reduced to AHD for comparison

NORBIT MOBILISATION
DYNAMIC POSITION VALIDATION

Date	1/11/2021	Project	VEN0001
Time: (AEST)	9:00	Project Locality	Point Wilson, Vic
Vertical Datum	Chart Datum - Outer Harbour	AHD Separation	-0.524
Horizontal Datum	GDA2020	Map Projection	MGA Zone 55

Dynamic Position Node	AUX GNSS Bracket	Validation Location	Point Wilson, VIC
GNSS Device	Emlid Reach RS2	Surveyor	Louis Bennett
Correction	SNA iMax (2020)	Duration of RTK Observations	3 minutes
Duration of IMU Observations	3 minutes	# Baseline Distance	-

Dynamic position checks were undertaken to validate horizontal position performance of the MBES system whilst in motion. A dynamic position check whilst underway was carried out using an independent RTK GNSS rover and making a comparison to the positioning from the POSMV INS. The RTK unit was placed on the Portus Pole Auxillary GNSS Antenna bracket that has a known offset relating it back to a central reference point of the MBES system.



A random sample of 20 locations along the dynamic position line was taken and the off-track error distance was measured between the RTK GNSS and the POSMV positions. The results from this can be seen in the table below

Sample	Off Track Error	Sample	Off Track Error
1	0.02	11	0.05
2	0.06	12	0.04
3	0.02	13	0.04
4	0.04	14	0.03
5	0.10	15	0.03
6	0.09	16	0.02
7	0.08	17	0.08
8	0.03	18	0.04
9	0.02	19	0.09
10	0.08	20	0.09

	(m)
Average	0.05
Standard Deviation	0.03
95% Confidence	0.05

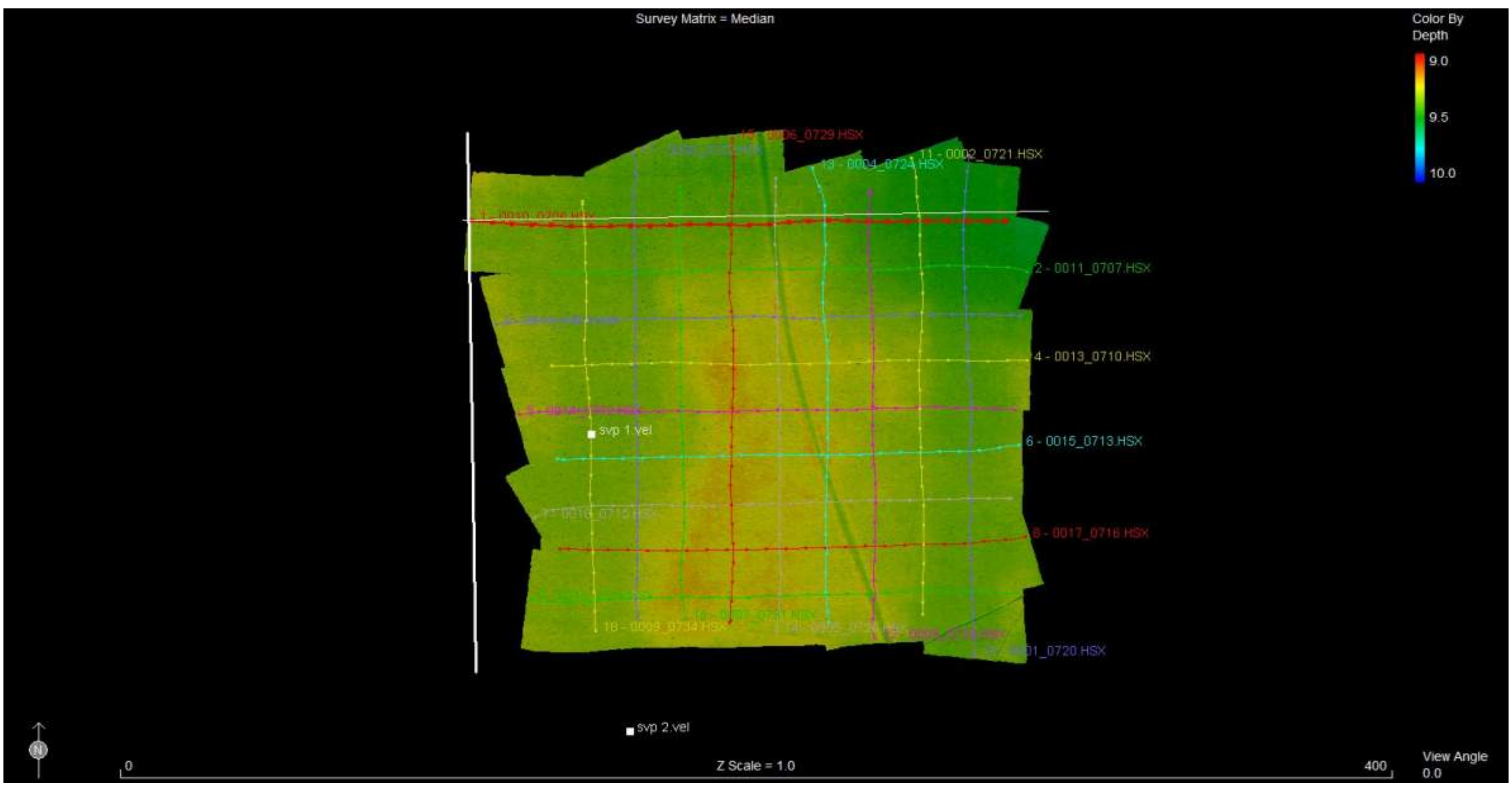
NORBIT SYSTEM MOBILISATION
SYSTEM PERFORMANCE TEST

Date	1/11/2021	Time	7:00
Location	Point Wilson, VIC	Survey System	Norbit Winghead
Water Depth	9 - 10m	Survey Speed	6.5 knots
Cross Line Swath Width	125^{o}, 130^{o} & 140^{o}	Number of Cross Lines	3

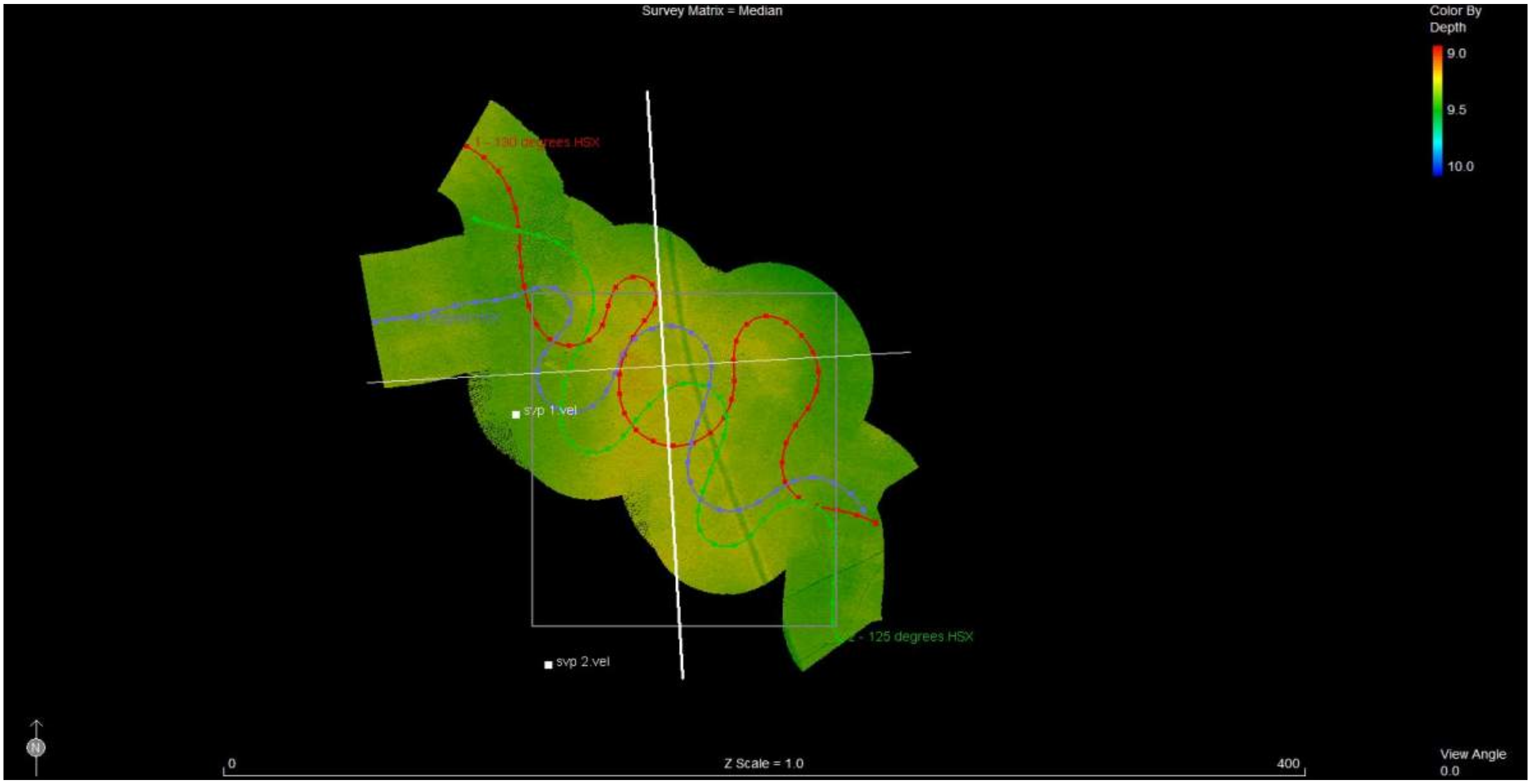
A beam angle test was undertaken to assess the performance of the MBES system across the entire 1024 beams of the Norbit Winghead i77h MBES survey system. Each beam/beam angle was analysed in Hypack 2021 to assess how the MBES system performs relative to its most reliable beams at Nadir.
The process involved capturing a high denisity/high confidence 'reference surface' using a reduced swath in a region of 9-10m water depth.

> 7 parallel lines were captured over a bearing of 0 degrees/180 degrees
> 7 parallel lines were captured over a bearing of 90 degrees/270 degrees
> MBES swath width when capturing reference surface was restrictred to 120 degree swath and a minimum swath overlap of 200% was maintained throughout.
> Vessel maintained a speed of >5.5 knots

The reference surface was generated from this dataset using a 0.25m median sounding cell export.



Three passes were run over the reference surface, with each path the vessel was induced to sharp cornering and turns to induce a dynamic vessel motion and put the system under stress that could be found in the field. Each pass was also run at 6.5 - 7 knots. The first pass the swath was open to 125 degrees, the second 130 degrees and the final pass at 140 degrees so as to best determine the operational capacity of the system for differing scenarios.

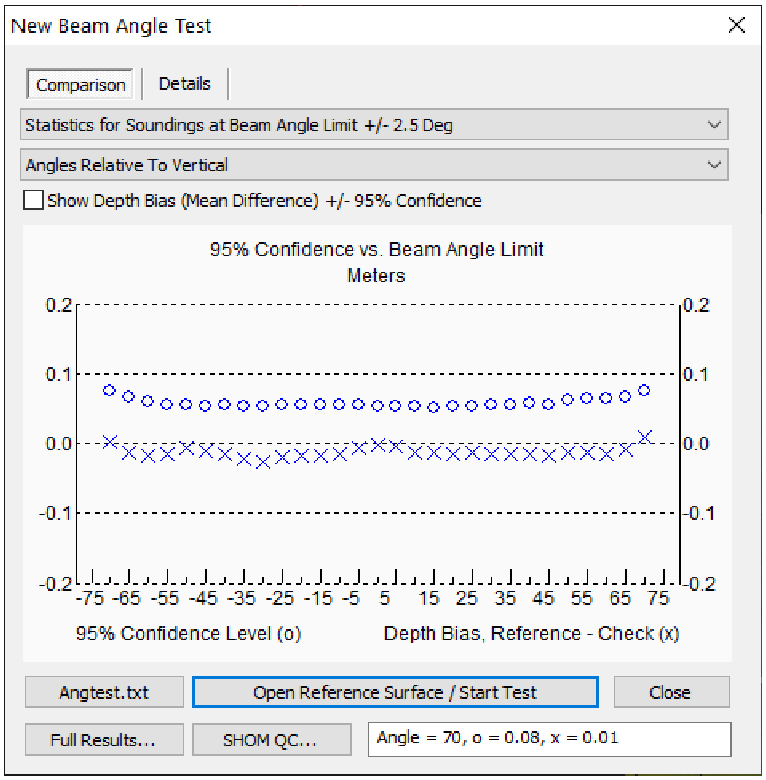


NORBIT SYSTEM MOBILISATION
SYSTEM PERFORMANCE TEST

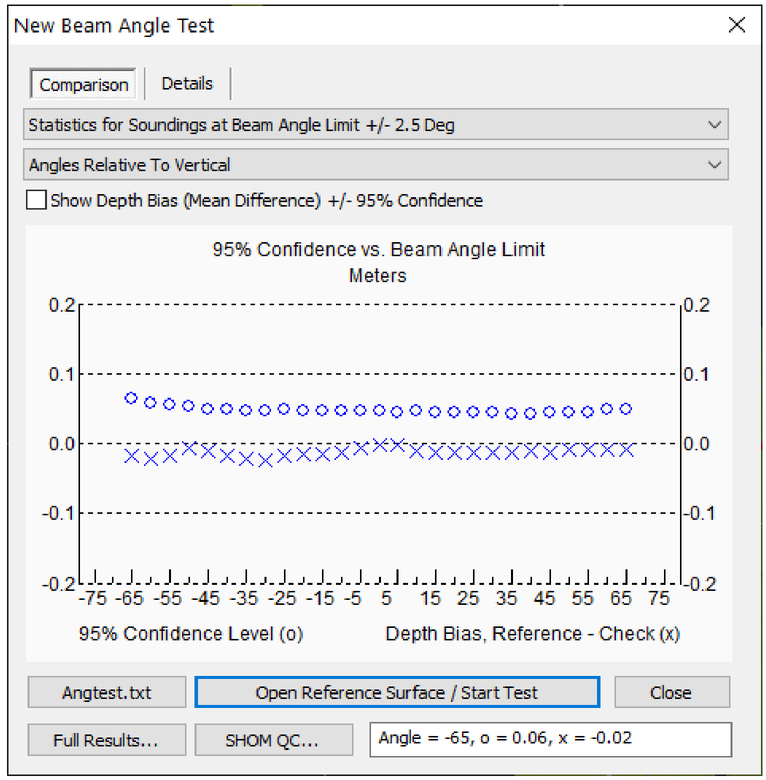
BEAM ANGLE TEST RESULTS

The beam angle test assessed the uncertainty of soundings during the dynamic check lines across the entire 1024 beams per sonar head. A graph was generated assessing total uncertainty assigned across the entire swath.

The results show the data deteriorates beyond the 70 degrees (140 degree swath) however despite this, the system exceeded IHO Exclusive Order specification vertical uncertainty across the entire MBES swath.



140 Degree Swath



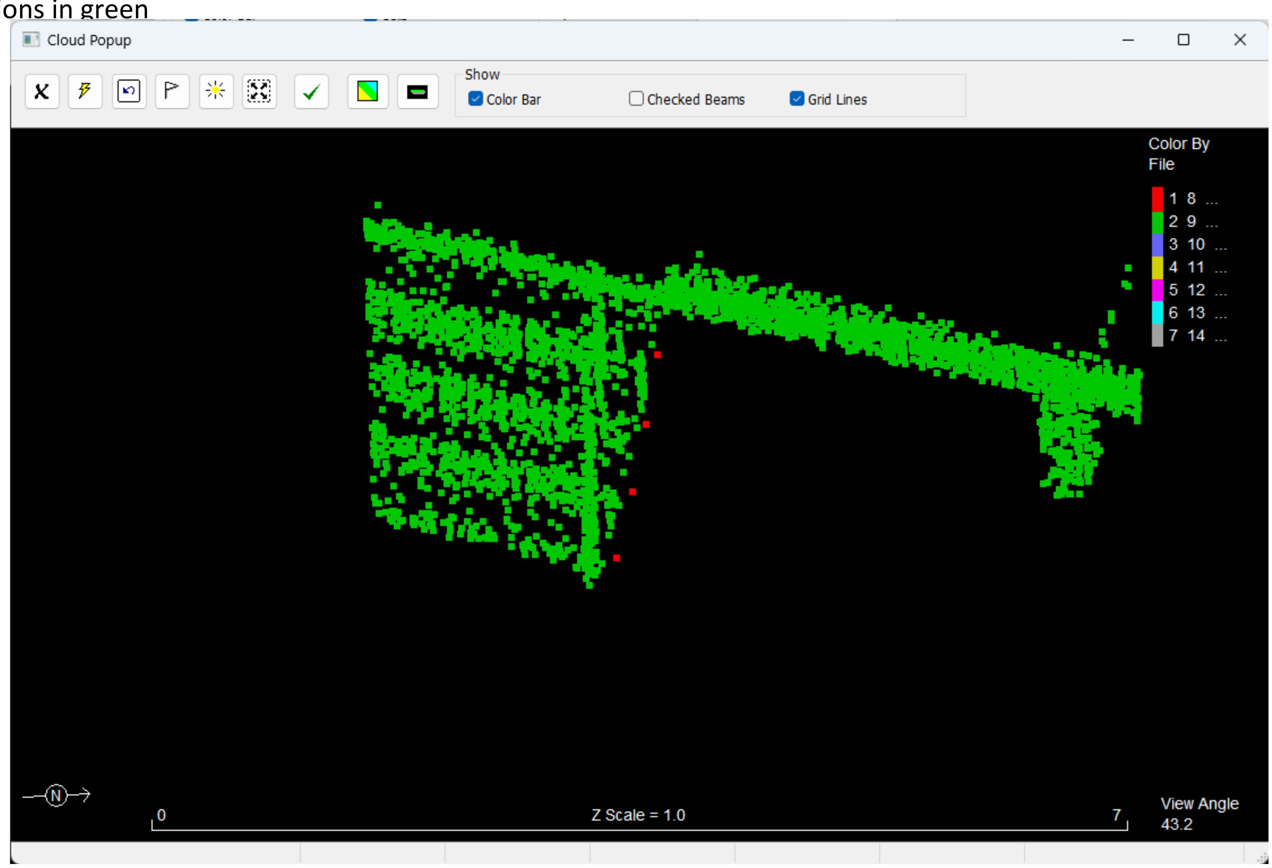
130 Degree Swath

The conclusion of this test is that the system performs well and meets IHO Exclusive Order out to 70 degrees either side of nadir (140 degree swath). Beyond this where the system starts to deteriorate and may fail to meet IHO Exclusive Order (however further testing would need to be undertaken to conclude this). As a result, the maximum swath used to capture IHO Exclusive ORder survey data is 140 degrees. Any data used beyond this will be for feature detection purposes only.

TOTAL HYDROGRAPHIC

GROUND TRUTH VALIDATION

A ground truth validation has been undertaken at a structure on site. RTK GNSS observations were captured by Jacobs on the above water structure and the river bed below. These points were there compared to the point cloud observations captured by the MLS and the MBES systems. The example image below shows the RTK GNSS observations in red and the MLS observations in green



RESULTS SUMMARY (MLS)			
	Easting (MLS)	Northing (MLS)	Orthometric Height
Average Variation	0.030	0.051	0.003
RMS of Variation	0.149		0.054
95% Confidence Level	**0.365**		**0.107**

RESULTS SUMMARY (MBES)			
	Easting	Northing	Orthometric Height
Average Variation	#VALUE!	#VALUE!	-0.022
RMS of Variation	NA		0.073
95% Confidence Level	**NA**		**0.145**

The 95% confidence uncertainty above is then propogated with the vertical Survey Datum Uncertainty to calculate an absolute uncertainty of the survey system at the 95% confidence level

Absolute Uncertainty at 95% confidence level	N/A	**0.131**

Comments:

MLS VALIDATION OBSERVATIONS

MLS VALIDATION #1			
Date	26/05/2023	Time	NA
	Easting	Northing	Orthometric Height
GNSS Rover	315880.450	5813957.490	0.930
Sounding	315880.400	5813957.360	0.920
Variation	**0.139**		**0.010**

MLS VALIDATION #2			
Date	26/05/2023	Time	NA
	Easting	Northing	Orthometric Height
GNSS Rover	315880.100	5813957.590	1.280
Sounding	315880.100	5813957.440	1.190
Variation	**0.150**		**0.090**

MLS VALIDATION #3			
Date	26/05/2023	Time	NA
	Easting	Northing	Orthometric Height
GNSS Rover	315880.780	5813957.380	0.580
Sounding	315880.730	5813957.200	0.570
Variation	**0.187**		**0.010**

MLS VALIDATION #4			
Date	26/05/2023	Time	NA
	Easting	Northing	Orthometric Height
GNSS Rover	315881.100	5813957.260	0.240
Sounding	315881.080	5813957.020	0.330
Variation	**0.241**		**-0.090**

MLS VALIDATION #5			
Date	26/05/2023	Time	NA
	Easting	Northing	Orthometric Height
GNSS Rover	315881.100	5813957.260	0.240
Sounding	315881.080	5813957.020	0.330
Variation	**0.241**		**-0.090**

MLS VALIDATION #6			
Date	26/05/2023	Time	NA
	Easting	Northing	Orthometric Height
GNSS Rover	316368.660	5814823.920	0.570
Sounding	316368.650	5814824.030	0.500
Variation	**0.110**		**0.070**

MLS VALIDATION OBSERVATIONS

MLS VALIDATION #7			
Date	26/05/2023	Time	NA
	Easting	Northing	Orthometric Height
GNSS Rover	316364.300	5814826.520	0.720
Sounding	316364.280	5814826.630	0.750
Variation	**0.112**		**-0.030**

MLS VALIDATION #8			
Date	26/05/2023	Time	NA
	Easting	Northing	Orthometric Height
GNSS Rover	316363.530	5814827.030	1.150
Sounding	316363.480	5814827.040	1.120
Variation	**0.051**		**0.030**

MLS VALIDATION #9			
Date	26/05/2023	Time	NA
	Easting	Northing	Orthometric Height
GNSS Rover	316364.300	5814826.520	0.720
Sounding	316364.210	5814826.630	0.710
Variation	**0.142**		**0.010**

MLS VALIDATION #10			
Date	26/05/2023	Time	NA
	Easting	Northing	Orthometric Height
GNSS Rover	316363.530	5814827.030	1.150
Sounding	316363.480	5814827.040	1.120
Variation	**0.051**		**0.030**

MLS VALIDATION #11			
Date	26/05/2023	Time	NA
	Easting	Northing	Orthometric Height
GNSS Rover	316357.700	5814830.520	1.140
Sounding	316357.730	5814830.550	1.150
Variation	**0.042**		**-0.010**

MBES VALIDATION OBSERVATIONS

MBES VALIDATION #1			
Date	26/05/2023	Time	NA
	Easting	Northing	Orthometric Height
GNSS Rover	NA	NA	-1.760
Sounding	NA	NA	-1.850
Variation	**NA**		**0.090**

MBES VALIDATION #2			
Date	26/05/2023	Time	NA
	Easting	Northing	Orthometric Height
GNSS Rover	NA	NA	-2.920
Sounding	NA	NA	-2.950
Variation	**NA**		**0.030**

MBES VALIDATION #3			
Date	26/05/2023	Time	NA
	Easting	Northing	Orthometric Height
GNSS Rover	NA	NA	-3.040
Sounding	NA	NA	-2.970
Variation	**NA**		**-0.070**

MBES VALIDATION #4			
Date	26/05/2023	Time	NA
	Easting	Northing	Orthometric Height
GNSS Rover	NA	NA	-3.040
Sounding	NA	NA	-2.970
Variation	**NA**		**-0.070**

MBES VALIDATION #5			
Date	26/05/2023	Time	NA
	Easting	Northing	Orthometric Height
GNSS Rover	NA	NA	-1.720
Sounding	NA	NA	-1.630
Variation	**NA**		**-0.090**

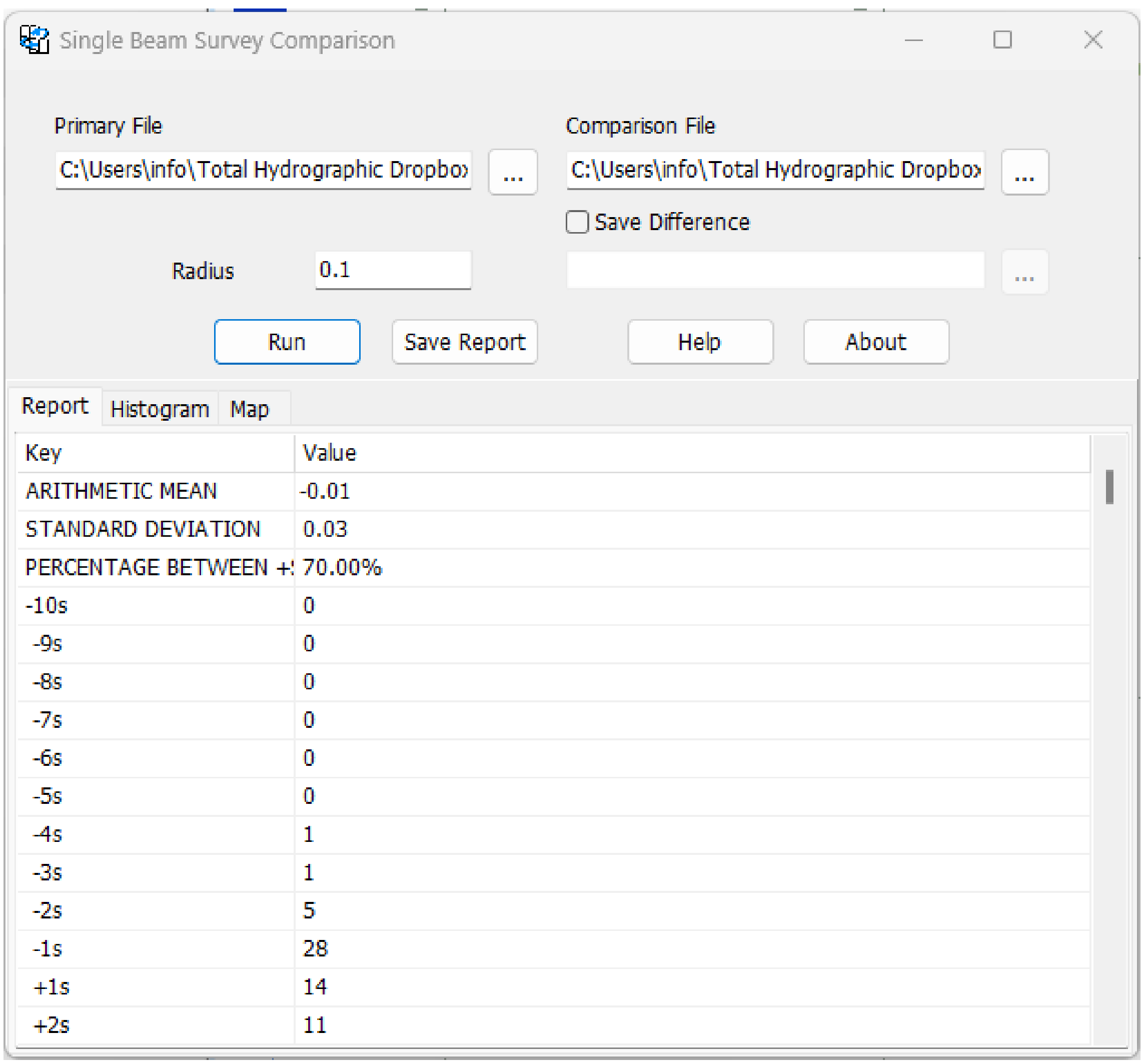
CROSS LINE STATISTICAL ANALYSIS

Date	11/10/2022	Project Locality	Maribynong
Project	JAC0001	AHD Separation	-
Vertical Datum	Australian Height Datum (AHD)	Map Projection	MGA
Horizontal Datum	GDA2020	Number of Cross Lines	2

Cross Line Statistics Results

	Mean Difference (m)	Standard Deviation	95% Confidence (1.96σ)
Crossline 1	-0.010	0.030	0.059
Crossline 2	0.010	0.040	0.078
RMS	**-**	**0.035**	**0.069**

SCREEN GRABS OF CROSS LINE STASTICS APPLICATION



MBES PATCH TEST REPORT

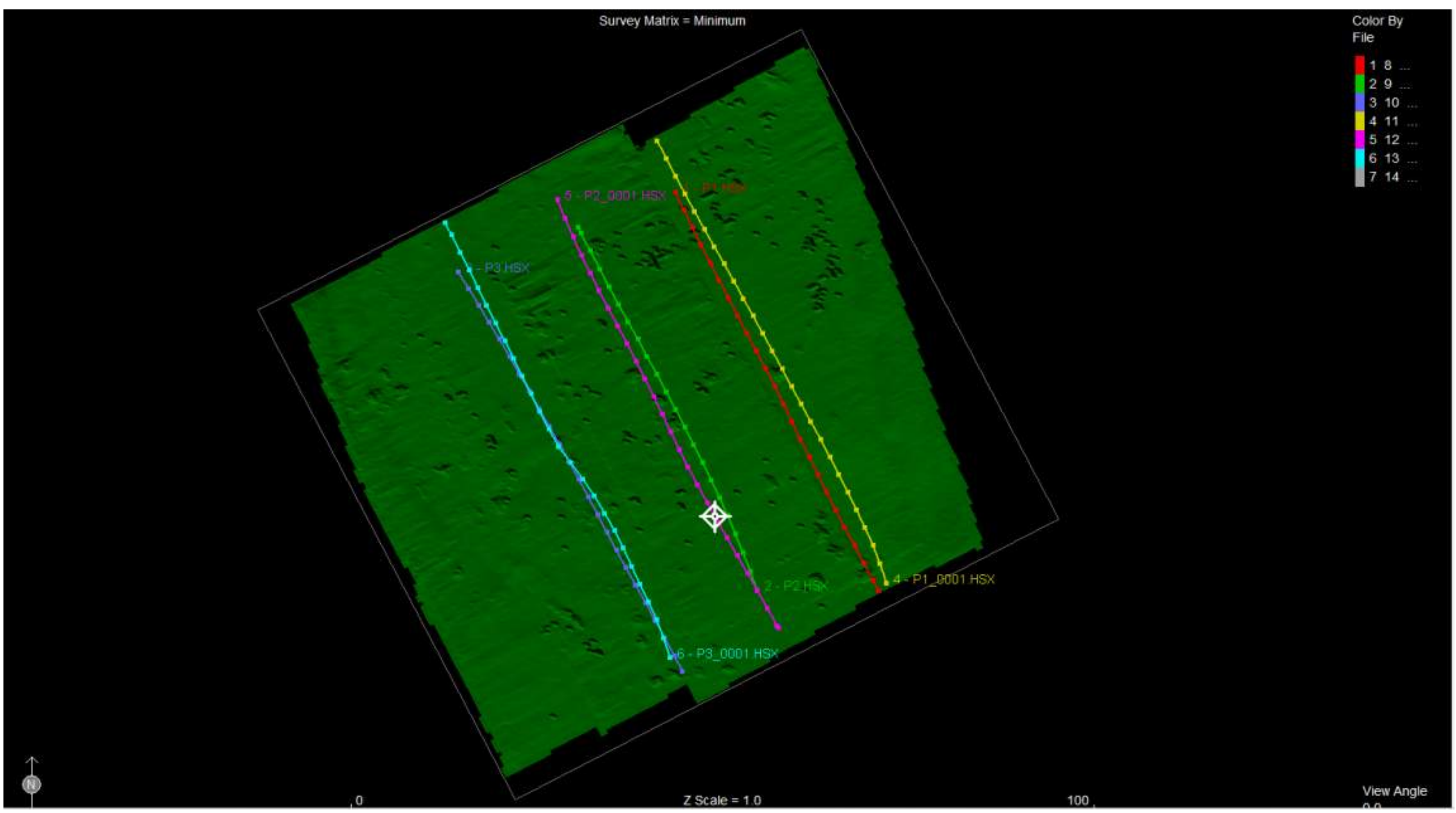
Date	26/05/2023	Project	JAC0001
Time: (AEST)	10:30	Project Locality	Maribynong
Survey System	: Winghead with POSMV OceanM	Positioning System	POS MV INS

Surveyors	Tim Williams	Vessel Speed (knots)	5 knots
Water Depth (m)	11.4m	Swath Width	148°
Feature	Seabed mound		

Calibration of the MBES system was conducted at a typical patch test site throughout the duration of the project. The calibration procedure enables the system's reference angle errors to be identified and corrected within the system. After the initial calibration as part of the system mobilisation the same procedure was undertaken as a system validation of the pre-determined parameters.

PATCH TEST RESULTS SUMMARY			
	Calibration Value	Validation Result	Status
Roll	0.04	0.04	OK
Pitch	0.20	0.20	OK
Yaw	-1.00	-1.00	OK

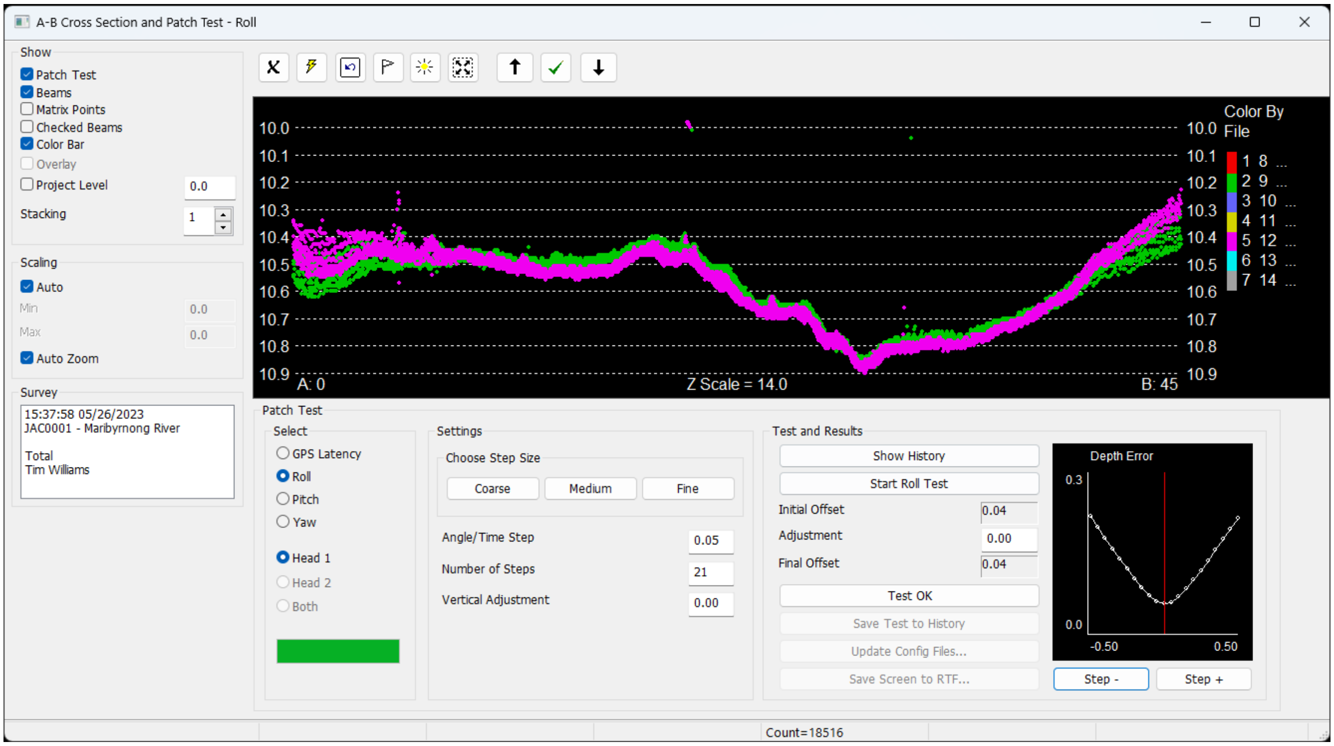
PATCH TEST LINE CONFIGURATION OVERVIEW



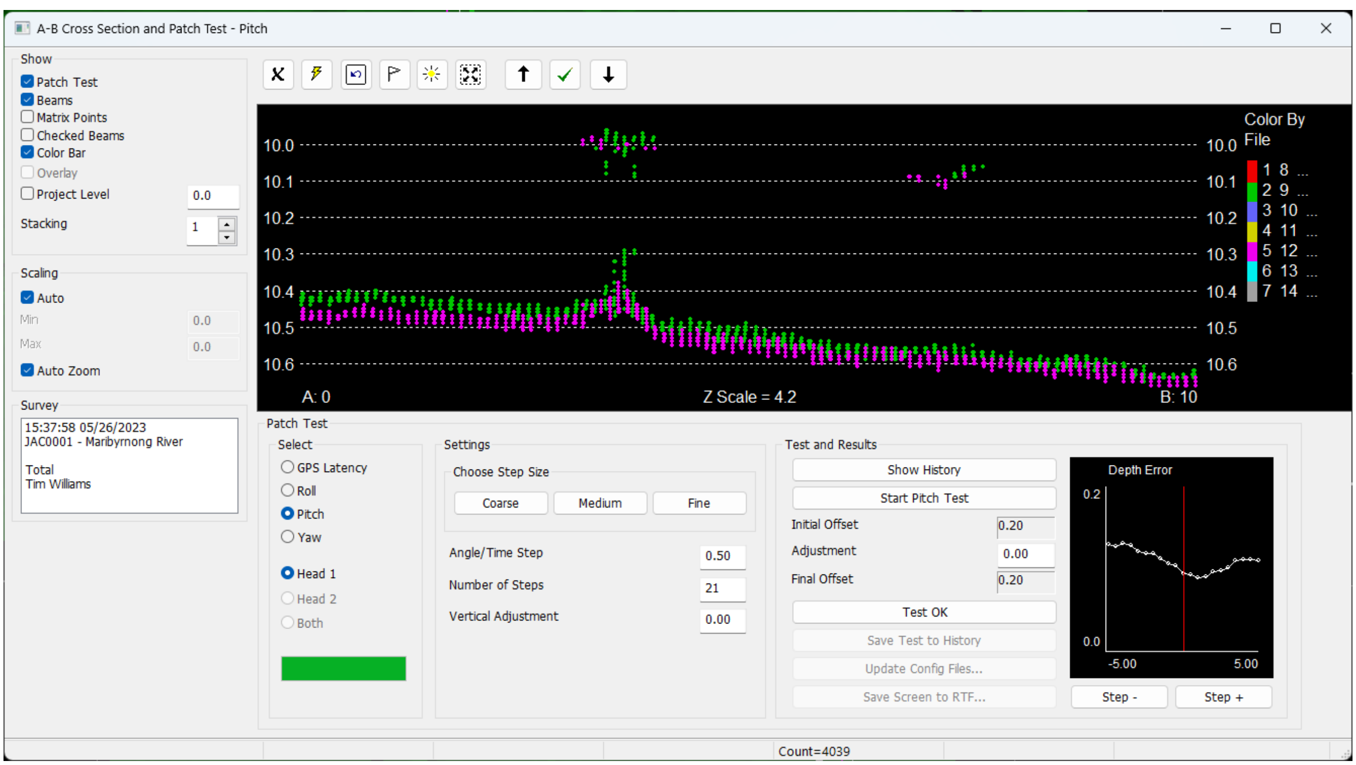
Final Comments:

MBES PATCH TEST - ROLL AND PITCH

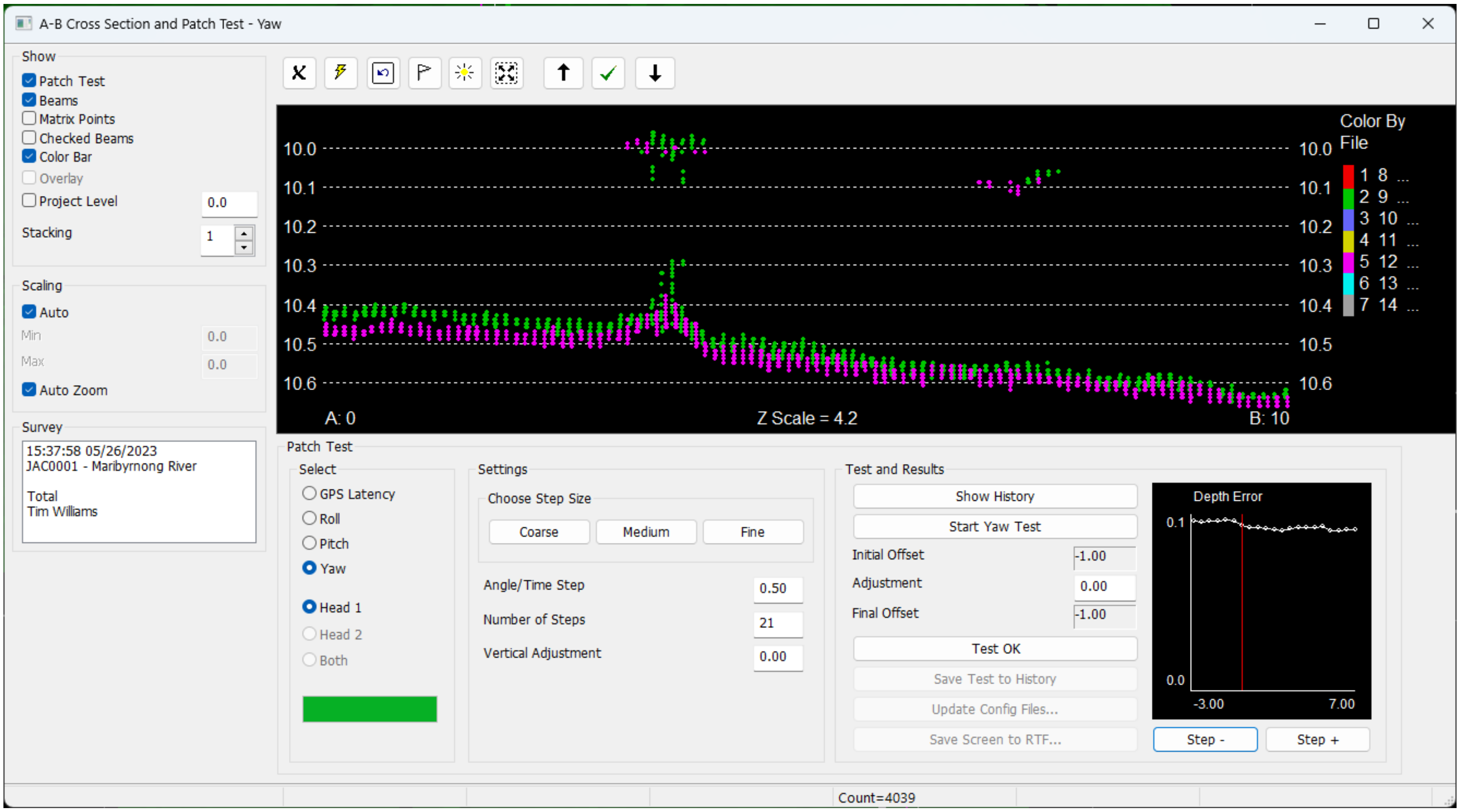
SCREEN GRABS OF ROLL VALIDATION



SCREEN GRABS OF PITCH VALIDATION

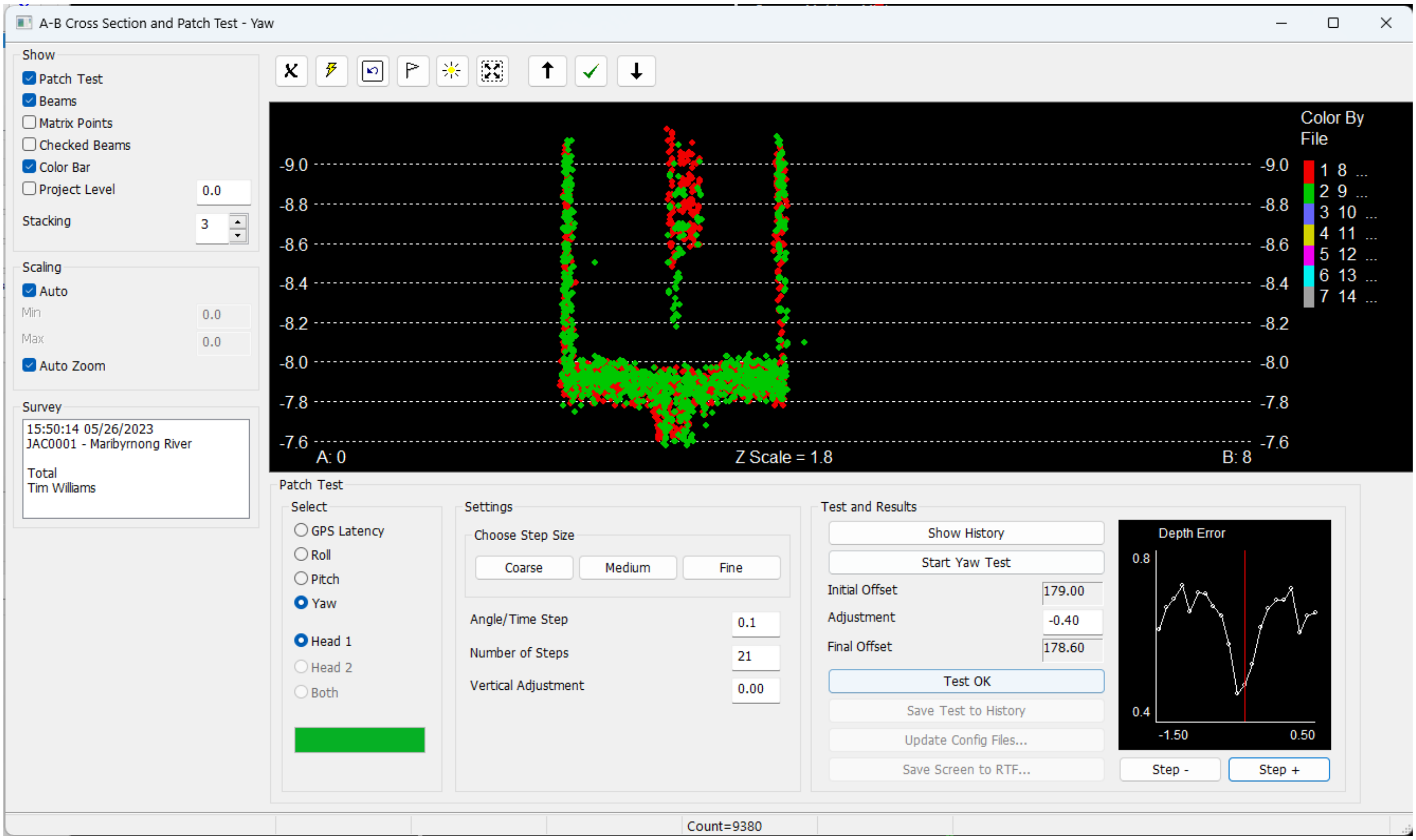


SCREEN GRABS OF YAW VALIDATION



MLS PATCH TEST - YAW

SCREEN GRABS OF YAW VALIDATION



TOTAL HORIZONTAL UNCERTAINTY (THU)

Horizontal Datum	GDA2020	Project Locality	Maribynong
Survey System	Norbit Winghead	Map Projection	MGA

Total Horizontal Uncertainty has been calculated using all of the following observations. All of these observation values are at a 95% confidence interval. SMES Uncertainties for PSM's have been supplied at the 95% horizontal confidence interval.

The propagation of error sources was computed to give an A Posteriori assessment of Total Horizontal Uncertainty

$$\sigma_z = \sqrt{(\sigma_x)^2 + (\sigma_y)^2}$$

Summary of Horizontal Components of Survey Accuracy

Absolute Accuracy Sources of Error	Validation	95% Confidence (m)
Geodetic Control to Datum (Estimate)	Geodetic Control	0.050
POSMV Positional Uncertainty	Static Position Validation	N/A
POSMV Uncertainty to Datum	*Propagation of above*	NA
Final Sounding Accuracy to Datum	Ground Truth	0.365
Absolute Accuracy	***Calculated Value***	***0.365***

Relative Accuracy Sources of Error	Validation	95% Confidence (m)
Repeatability between passes over feature. Test undertaken on 25/05/2022 in 30m of water.	Relative Horizontal Accuracy Assessment	0.180
Relative Accuracy	***Calculated Value***	***0.180***

Propagation of Errors

Error Source		95% Confidence Value
Absolute Accuracy		0.365
Relative Accuracy		0.180
Sounding Accuracy	**Absolute & Relative**	**0.407**

Total Horizontal Uncertainty (THU)	0.75m

Comments:

Final THU rounded up to allow for additional error sources that were not considered in this calculation.

TOTAL VERTICAL UNCERTAINTY (TVU)

Date	11/10/2022	Project	JAC0001
Vertical Datum	Australian Height Datum (AHD)	Project Locality	Maribynong
Horizontal Datum	GDA2020	AHD Separation	-
Survey System	Winghead with POSMV OceanM	Map Projection	MGA

Total Vertical Uncertainty has been calculated using all of the following observations. All of these observation values are at a 95% confidence interval. SMES Uncertainties for PSM's have been supplied at the 95% confidence interval.

The propagation of error sources was computed to give an A Posteriori assessment of Total Vertical Uncertainty

$$\sigma_z = \sqrt{(\sigma_x)^2 + (\sigma_y)^2}$$

Summary of Vertical Components of Accuracy

Absolute Accuracy Sources of Error	Validation	95% Confidence (m)
Geodetic Control to Datum (Estimate)	Geodetic Control	0.050
Positional Uncertainty	Static Position Validation	N/A
Bar check	Bar Check Validation	N/A

Absolute Uncertainty Assessment	Ground Truth	0.131

Absolute Accuracy	***RMS of above assessments***	***0.131***

Relative Accuracy Sources of Error	Validation	95% Confidence (m)
Relative system repeatability - Entire Swath	Cross Line Statistics	0.069
Relative Accuracy	***Calculated Value***	***0.069***

Propagation of Errors

Error Source		**95% Confidence Value**
Absolute Accuracy		0.131
Relative Accuracy		0.069
Sounding Accuracy	**Absolute & Relative**	**0.148**

The final A Posteriori TVU was rounded up to allow for additional error sources that were not considered in this calculation.

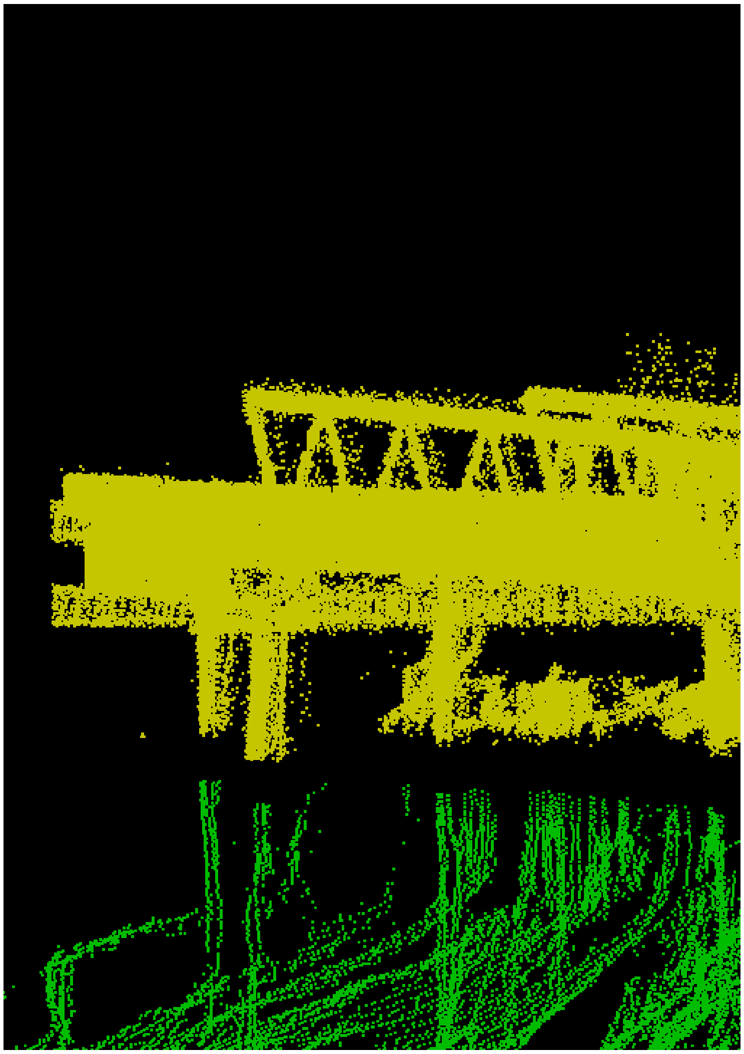
Total Vertical Uncertainty (TVU)	0.25m

Comments:

CONCLUSION

Final Survey comments

A horizontal validation of MBES was not undertaken. However, MLS aligns horizontally with Multibeam as seen in pile in image below. Multibeam data is shown in green and MLS shown in yellow.



Deliverables

JAC0001 - Report of Survey

JAC0001 MLS MGA2020 Z55 AHD.las

JAC0001 MBES MGA2020 Z55 AHD.las

Tim Williams | Principal Hydrographer

Certified Professional Hydrographic Surveyor – Level 1 (CPHS1)

Appendix E - Bathymetric Survey Validation

Index	Point	Easting	Northing	Elevation	Abs(Deviation Z)	Deviation Z
0	1000	315342.743	5815434.678	-4.828	0.021	-0.021
4	1004	315328.177	5815433.896	-4.917	0.034	0.034
5	1005	315323.5	5815433.259	-4.522	0.039	-0.039
6	1006	315317.971	5815431.135	-3.481	0.094	0.094
7	1007	315313.827	5815429.483	-3.349	0.07	0.07
8	1008	315310.858	5815426.356	-3.443	0.098	0.098
9	1009	315307.285	5815422.511	-3.286	0.022	0.022
10	1010	315303.826	5815421.271	-2.849	0.023	0.023
13	1013	315325.809	5815415.479	-3.427	0.061	0.061
14	1014	315328.856	5815408.342	-4.34	0.048	0.048
15	1015	315331.584	5815399.516	-4.573	0.073	0.073
17	1017	315335.941	5815385.961	-4.544	0.054	0.054
18	1018	315339.243	5815379.066	-4.949	0.128	0.128
19	1019	315340.825	5815366.921	-4.743	#N/A	Not Enough Data
20	1020	315339.75	5815359.16	-4.315	0.046	-0.046
21	1021	315340.85	5815349.735	-4.396	0.109	0.109
22	1022	315345.683	5815341.573	-4.052	0.041	-0.041
23	1023	315351.388	5815333.267	-4.167	0.005	-0.005
24	1024	315352.813	5815327.664	-4.23	0.037	0.037
25	1025	315355.217	5815324.359	-4.222	0.055	0.055
26	1026	315362.613	5815313.283	-4.139	0.035	-0.035
27	1027	315384.847	5815286.097	-4.222	0.071	-0.071
28	1028	315393.339	5815273.76	-4.377	0.047	-0.047
29	1029	315404.289	5815257.829	-4.322	0.06	-0.06
30	1030	315416.209	5815242.514	-4.289	0.071	0.071
31	1031	315427.558	5815236.165	-4.299	0.049	0.049
32	1032	315433.841	5815230.781	-4.377	0.019	0.019
33	1033	315439.631	5815227.741	-4.313	0.023	0.023
35	1035	315454.663	5815239.673	-2.464	0.106	-0.106
36	1036	315454.786	5815221.922	-4.162	0.01	0.01
37	1037	315451.942	5815216.4	-4.309	0.027	0.027
38	1038	315448.773	5815209.238	-3.889	0.039	0.039
39	1039	315446.757	5815204.157	-3.698	0.048	0.048
40	1040	315445.456	5815198.905	-3.586	0.031	0.031
43	1043	315415.161	5815214.453	-3.097	0.006	0.006
44	1044	315388.741	5815237.803	-2.98	0.021	0.021
46	1046	315351.992	5815281.06	-2.33	0.09	-0.09
47	1047	315340.28	5815296.405	-2.937	0.057	0.057
48	1048	315331.5	5815307.406	-2.326	#N/A	Not Enough Data
49	1049	312622.551	5817793.905	-2.551	0.102	-0.102
50	1050	312624.354	5817786.113	-3.468	0.029	-0.029
52	1052	312637.738	5817773.902	-3.835	0.088	0.088
53	1053	312650.911	5817769.542	-2.979	0.008	0.008
54	1054	312662.83	5817761.783	-2.635	0.032	-0.032
55	1055	312673.939	5817755.068	-2.825	0.027	-0.027
56	1056	312688.693	5817749.047	-3.569	0.088	-0.088

57	1057	312704.118	5817743.093	-3.601	0.032	-0.032
58	1058	312723.785	5817737.417	-3.705	0.069	-0.069
59	1059	312733.542	5817729.496	-3.997	0.021	-0.021
61	1061	312748.227	5817714.343	-5.39	0.097	0.097
62	1062	312763.176	5817710.765	-5.868	0.033	0.033
63	1063	312798.516	5817659.558	-3.365	0.073	0.073
64	1064	312797.349	5817639.088	-3.706	0.058	-0.058
65	1065	312798.247	5817625.471	-3.769	0.019	-0.019
66	1066	312800.198	5817618.956	-3.478	0.043	-0.043
67	1067	312802.872	5817608.225	-3.151	0.023	-0.023
68	1068	312801.386	5817592.089	-3.404	0.047	0.047
69	1069	312803.219	5817575.646	-3.106	0.204	0.204
70	1070	312803.734	5817564.525	-3.007	0.052	0.052
71	1071	312804.934	5817548.819	-2.6	0.098	0.098
72	1072	312802.954	5817538.587	-2.865	0.09	0.09
73	1073	312800.474	5817522.681	-3.564	0.055	-0.055
75	1075	312798.302	5817492.22	-3.349	0.041	0.041
76	1076	312796.201	5817477.208	-3.493	0.135	0.135
77	1077	312787.888	5817445.079	-3.149	0.052	0.052
78	1078	312779.982	5817440.304	-3.217	0.055	-0.055
79	1079	312763.108	5817423.812	-3.696	0.04	-0.04
80	1080	312755.754	5817415.495	-3.376	0.071	-0.071
81	1081	312746.088	5817399.393	-3.543	0.063	0.063
82	1082	312736.404	5817385.498	-3.925	0.062	0.062
83	1083	312716.083	5817372.258	-3.93	0.057	-0.057
85	1085	312690.159	5817347.433	-3.52	0.09	0.09
86	1086	312674.462	5817334.152	-3.731	0.173	0.173
87	1087	312666.324	5817327.872	-2.663	0.089	0.089
89	1089	312683.586	5817359.376	-3.062	0.009	-0.009
90	1090	312691.006	5817357.595	-3.983	0.008	0.008
91	1091	312695.641	5817355.82	-4.462	0.195	0.195
92	1092	312698.682	5817353.744	-3.191	0.04	0.04
94	1094	312709.025	5817382.701	-2.914	0.032	0.032
96	1096	312737.779	5817402.968	-2.721	0.037	0.037
97	1097	312748.189	5817414.474	-3.244	0.015	0.015
98	1098	312755.605	5817427.431	-2.819	0.149	0.149
100	1100	312770.695	5817448.537	-2.185	0.077	0.077
101	1101	312776.695	5817455.072	-2.481	0.051	0.051
102	1102	312782.268	5817462.075	-2.926	0.055	0.055
103	1103	312784.566	5817475.833	-3.238	0.078	0.078
104	1104	312786.14	5817488.187	-3.467	0.018	-0.018
105	1105	312786.821	5817499.794	-3.491	0.034	0.034
106	1106	312786.715	5817512.843	-2.825	0.031	0.031
107	1107	312788.305	5817530.755	-3.048	0.089	0.089
108	1108	312791.014	5817552.051	-3.209	0.123	0.123
109	1109	312791.682	5817564.095	-3.436	0.191	0.191
110	1110	312790.492	5817577.125	-2.647	0.037	0.037
111	1111	312787.532	5817593.044	-3.354	0.011	0.011
112	1112	312788.957	5817604.93	-3.526	0.057	0.057
113	1113	312787.975	5817618.35	-3.643	0.022	0.022

114	1114	312789.42	5817630.602	-3.556	0.071	0.071
116	1116	312784.206	5817657.382	-2.743	0.033	0.033
118	1118	312750.847	5817711.318	-5.093	0.033	0.033
119	1119	312738.015	5817712.126	-4.654	0.019	0.019
121	1121	312718.33	5817724.437	-3.554	0.085	-0.085
122	1122	312706.329	5817730.773	-2.919	0.096	-0.096
123	1123	312690.091	5817734.674	-2.098	0.038	0.038
124	1124	312674.101	5817742.206	-2.081	0.031	0.031
125	1125	312661.953	5817754.435	-2.815	0.09	0.09
126	1126	312652.613	5817763.064	-3.334	0.073	0.073
127	1127	312641.508	5817770.366	-4.099	0.004	-0.004
128	1128	312628.161	5817780.826	-3.658	0.008	-0.008
129	1129	312618.619	5817786.362	-3.963	0.015	-0.015
130	1130	312636.32	5817790.661	-2.44	0.067	-0.067
131	1131	312632.517	5817788.249	-3.006	0.05	0.05
132	1132	312628.493	5817785.496	-3.276	0.094	0.094
133	1133	312623.983	5817782.607	-3.687	0.034	-0.034
136	1136	314032.546	5818519.48	-3.175	0.089	0.089
137	1137	314020.531	5818518.548	-3.031	0.016	0.016
138	1138	313999.726	5818525.026	-3.097	0.201	0.201
139	1139	313984.494	5818519.365	-3.165	0.204	0.204
140	1140	313965.964	5818525.464	-2.886	0.078	0.078
141	1141	313944.099	5818529.419	-2.943	0.222	0.222
142	1143	313930.087	5818535.056	-2.22	0.083	0.083
143	1144	313907.915	5818526.286	-3.228	0.115	0.115
144	1146	313887.765	5818516.87	-3.107	0.002	-0.002
145	1147	313912.532	5818514.555	-3.462	0.005	-0.005
146	1148	313931.702	5818514.726	-3.53	0.014	0.014
147	1149	313950.207	5818511.286	-3.574	0.058	0.058
148	1150	313962.463	5818508.198	-3.454	0.029	-0.029
149	1151	313975.013	5818507.453	-3.507	0.089	0.089
150	1152	313988.733	5818508.788	-3.481	0.05	0.05
151	1153	314001.133	5818507.342	-3.396	0.097	0.097
152	1154	314012.055	5818501.95	-3.31	0.149	0.149
153	1155	314025.385	5818499.782	-3.254	0.027	0.027
154	1156	314037.255	5818494.932	-3.247	0.058	-0.058
156	1158	314038.344	5818488.13	-2.977	0.117	0.117
157	1159	314040.68	5818501.049	-3.003	0.014	0.014
158	1160	314043.733	5818514.135	-3.066	0.006	0.006
159	1161	314043.103	5818525.883	-2.155	0.11	-0.11
160	1162	314056.867	5818518.808	-2.831	0.002	0.002
161	1163	314078.023	5818509.024	-2.945	0.025	0.025
162	1164	314089.968	5818500.775	-2.97	0.021	0.021
163	1165	314099.925	5818495.519	-2.905	0.037	0.037
164	1166	314111.56	5818488.009	-2.786	0.016	0.016
165	1167	314115.974	5818477.781	-3.171	0.009	-0.009
166	1168	314097.514	5818462.315	-2.678	0.066	-0.066
167	1169	314077.089	5818473.093	-2.791	0.028	-0.028
169	1171	314931.453	5817523.421	-1.221	#N/A	Not Enough Data
170	1172	314924.422	5817526.786	-2.669	0.069	0.069

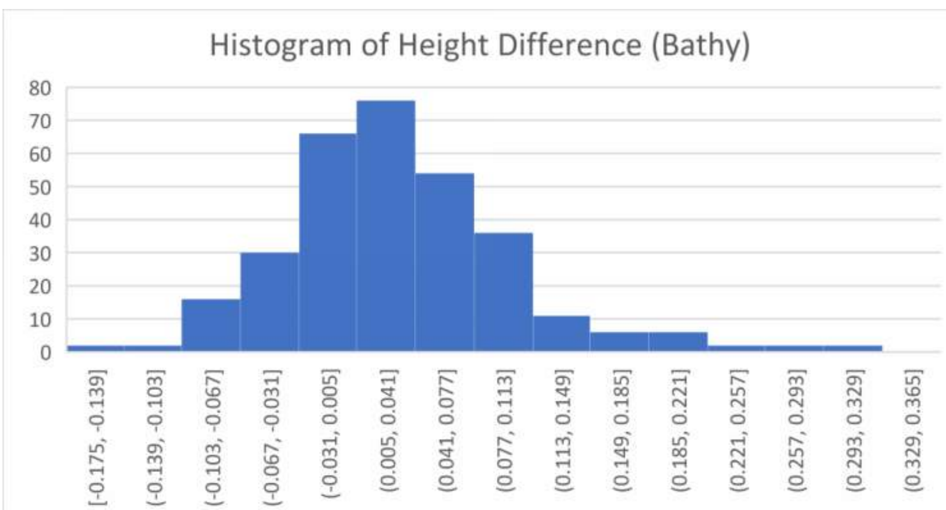
171	1173	314917.002	5817535.541	-3.524	0.265	0.265
173	1175	314906.037	5817557.223	-3.33	0.018	-0.018
176	1178	314937.773	5817564.008	-3.865	0.021	-0.021
177	1179	314948.143	5817573.51	-4.051	0.023	-0.023
178	1180	314964.353	5817581.999	-4.251	0.059	-0.059
179	1181	314979.223	5817590.464	-4.654	0.087	-0.087
180	1182	315004.669	5817594.616	-4.797	0.015	-0.015
181	1183	315018.605	5817602.778	-4.754	0.039	-0.039
182	1184	315041.936	5817609.878	-4.463	0.175	-0.175
183	1185	315063.511	5817612.16	-4.432	0.043	0.043
184	1186	315110.565	5817645.876	-2.548	0.004	0.004
185	1187	315151.035	5817645.341	-4.762	0.04	-0.04
186	1188	315175.995	5817652.27	-4.779	0.071	0.071
187	1189	315192.042	5817663.126	-5.687	0.034	-0.034
188	1190	315205.406	5817673.461	-6.134	0.094	0.094
189	1191	315215.857	5817686.57	-5.907	0.103	0.103
190	1192	315222.153	5817700.04	-6.348	0.04	-0.04
191	1193	315226.968	5817715.807	-5.26	0.058	0.058
192	1194	315238.512	5817726.124	-3.871	0.079	0.079
194	1196	315237.62	5817758.897	-4.953	0.081	0.081
195	1197	315234.63	5817778.685	-4.385	0.023	-0.023
196	1198	315235.981	5817798.851	-4.28	0.008	0.008
197	1199	315235.776	5817810.341	-4.228	0.036	0.036
198	1200	315231.303	5817828.798	-3.92	0.014	-0.014
199	1201	315226.645	5817844.611	-3.813	0.003	-0.003
200	1202	315225.367	5817854.745	-3.794	0.001	0.001
201	1203	315224.579	5817871.407	-3.762	0.01	-0.01
202	1204	315221.43	5817886.355	-3.681	0.03	-0.03
203	1205	315219.86	5817907.337	-3.721	0.03	0.03
204	1206	315219.256	5817923.861	-3.849	0.012	-0.012
205	1207	315213.769	5817942.016	-4.447	0.079	0.079
206	1208	315206.119	5817965.529	-3.788	0.032	0.032
207	1209	315200.146	5817988.059	-3.573	0.02	-0.02
208	1210	315193.431	5818011.858	-3.091	0.012	-0.012
209	1211	315187.963	5818033.843	-2.592	0.032	0.032
210	1212	315192.288	5818058.955	-3.454	0.048	-0.048
211	1213	315182.485	5818075.57	-2.813	0.055	-0.055
213	1215	315177.738	5818095.797	-3.202	0.062	0.062
214	1216	315184.674	5818095.989	-4.809	0.037	0.037
215	1217	315195.067	5818091.251	-4.303	0.075	0.075
216	1218	315199.669	5818094.59	-4.315	0.152	0.152
217	1219	314800.57	5816646.125	-3.163	0.034	0.034
218	1220	314800.975	5816621.165	-3.129	0.104	0.104
219	1221	314802.032	5816605.538	-2.848	0.022	-0.022
220	1222	314803.95	5816590.697	-3.079	0.027	0.027
221	1223	314808.695	5816569.143	-3.239	0.002	0.002
222	1224	314815.985	5816553.633	-3.347	0.024	-0.024
223	1225	314827.212	5816535.922	-3.428	0.001	-0.001
224	1226	314836.406	5816520.818	-3.534	0.084	0.084
225	1227	314843.616	5816507.05	-3.466	0.014	-0.014

226	1228	314850.712	5816489.082	-3.47	0	0
227	1229	314859.926	5816475.266	-3.572	#N/A	Not Enough Data
228	1230	314848.391	5816453.566	-1.541	0.069	-0.069
229	1231	314852.118	5816456.241	-3.193	0.043	0.043
230	1232	314859.349	5816460.844	-4.039	0.106	0.106
231	1233	314867.178	5816464.962	-3.571	#N/A	Not Enough Data
232	1234	314876.635	5816467.993	-3.262	0.083	0.083
233	1235	314888.903	5816469.152	-2.839	0.124	0.124
234	1236	314898.821	5816470.771	-1.67	#N/A	Not Enough Data
235	1237	314888.278	5816479.562	-2.163	0.157	-0.157
236	1238	314870.173	5816494.955	-3.019	0.024	0.024
238	1240	314860.666	5816525.629	-2.47	0.055	-0.055
240	1242	314849.026	5816559.148	-2.354	0.037	-0.037
242	1244	314843.094	5816584.796	-2.087	0.084	-0.084
243	1245	314835.639	5816601.703	-2.549	0.002	-0.002
244	1246	314830.926	5816617.814	-2.792	0.022	0.022
245	1247	314827.714	5816631.129	-2.818	0.008	-0.008
246	1248	314824.18	5816648.213	-2.898	0	0
247	1249	314821.649	5816668.566	-2.893	0.02	0.02
248	1250	314823.262	5816683.267	-2.299	0.036	-0.036
249	1251	314821.803	5816699.215	-1.995	0.014	-0.014
250	1253	315286.95	5815675.798	-1.75	0.047	0.047
251	1254	315293.632	5815687.262	-1.759	0.003	0.003
252	1255	315299.404	5815704.856	-1.88	0.03	0.03
253	1256	315305.807	5815727.197	-1.984	0.004	0.004
254	1257	315304.234	5815746.544	-1.975	0.073	-0.073
255	1258	315304.016	5815772.623	-2.064	0.096	-0.096
256	1259	315305.668	5815805.809	-2.076	#N/A	Not Enough Data
257	1260	315306.896	5815831.565	-2.072	0.022	0.022
258	1261	315304.58	5815861.011	-1.97	0	0
259	1262	315300.113	5815893.149	-1.989	0.072	0.072
260	1263	315295.381	5815925.23	-1.941	#N/A	Not Enough Data
261	1264	315289.381	5815956.561	-2.084	0.043	0.043
262	1265	315268.109	5815993.241	-2.052	0.032	0.032
263	1266	315241.808	5816023.654	-1.637	0.067	0.067
264	1267	315222.86	5816038.135	-1.454	0.023	-0.023
266	1269	315260.946	5816058.002	-1.535	0.035	0.035
267	1270	315249.669	5816047.893	-1.715	0.04	0.04
268	1271	315230.485	5816030.159	-1.684	0.084	0.084
269	1272	315217.932	5816017.878	-1.415	0.011	0.011
270	1273	315206.345	5816005.683	-1.397	0.116	0.116
271	1275	315194.191	5815981.631	-1.453	0.03	0.03
273	1277	315197.244	5815956.852	-1.524	0.043	0.043
274	1278	315202.696	5815926.806	-1.803	0.049	0.049
275	1279	315210.77	5815892.073	-1.705	0.088	-0.088
276	1280	315215.279	5815867.162	-1.834	0.004	0.004
277	1281	315216.673	5815851.56	-1.806	0.011	0.011
279	1283	316213.913	5814892.975	-4.412	0.019	0.019
280	1284	316281.369	5814861.045	-4.625	0.011	-0.011
281	1285	316324.457	5814837.045	-4.31	0.035	-0.035

282	1286	316344.429	5814823.39	-4.308	0.002	-0.002
283	1287	316373.587	5814805.011	-4.197	0.082	-0.082
284	1288	316399.061	5814785.28	-4.237	0.032	0.032
285	1289	316429.622	5814759.34	-4.301	0.043	0.043
286	1290	316465.158	5814734.564	-3.86	0.017	0.017
288	1292	316481.257	5814713.449	-3.574	0.032	0.032
289	1293	316476.139	5814703.3	-5.1	0.16	0.16
290	1294	316467.635	5814686.968	-4.04	0.263	0.263
293	1297	316452.675	5814684.635	-2.8	0.02	0.02
294	1298	316439.846	5814702.324	-3.174	0.058	0.058
295	1299	316413.169	5814725.063	-2.897	0.017	0.017
296	1300	316397.857	5814741.297	-3.147	0.097	0.097
297	1301	316382.685	5814754.539	-3.063	0.076	0.076
298	1302	316362.08	5814770.703	-3.221	0.043	0.043
299	1303	316344.947	5814784.834	-3.386	0.033	0.033
301	1305	316297.574	5814814.352	-3.654	0.018	0.018
302	1306	316281.012	5814824.664	-3.677	0.02	0.02
303	1307	316257.484	5814837.905	-3.993	0.055	0.055
304	1308	316182.37	5814875.742	-3.306	0.057	0.057
305	1309	316172.374	5814887.24	-3.503	0.055	0.055
307	1311	316165.48	5814879.85	-3.01	0.078	0.078
308	1312	316171.33	5814886.438	-3.485	0.08	0.08
309	1313	316179.278	5814891.338	-3.841	0.233	0.233
310	1314	316187.076	5814899.464	-4.115	0.329	0.329
311	1315	316196.717	5814906.141	-4.532	0.117	0.117
313	1317	315882.223	5813920.873	-5.658	0.026	-0.026
314	1318	315884.65	5813935.352	-5.513	0.057	0.057
315	1319	315889.527	5813952.847	-5.065	0.046	-0.046
316	1320	315895.64	5813973.904	-5.021	0.013	-0.013
317	1321	315900.086	5813994.754	-4.267	0.032	0.032
318	1322	315906.221	5814012.361	-4.422	0.144	0.144
319	1323	315913.479	5814032.846	-3.873	0.023	0.023
320	1324	315920.679	5814057.588	-3.674	0.039	0.039
321	1325	315934.991	5814078.969	-4.916	0.014	0.014
322	1326	315948.453	5814102.115	-5.571	0.042	0.042
323	1327	315958.339	5814125.756	-5.317	0.012	-0.012
324	1328	315964.317	5814145.62	-4.472	0.06	-0.06
326	1330	315965.651	5814148.976	-4.578	0.169	0.169
327	1331	315972.68	5814146.716	-5.567	0.098	0.098
328	1332	315983.667	5814142.416	-6.051	0.202	0.202
329	1333	315994.586	5814139.679	-3.701	0.084	0.084
330	1334	316003.02	5814136.821	-2.38	#N/A	Not Enough Data
331	1335	316005.596	5814134.657	-1.393	#N/A	Not Enough Data
332	1336	315988.194	5814125.491	-3.551	0.098	0.098
333	1337	315977.959	5814102.311	-3.132	0.026	-0.026
334	1338	315968.308	5814078.506	-2.943	0.017	0.017
335	1339	315955.492	5814052.201	-2.71	0.007	-0.007
336	1340	315940.122	5814025.287	-3.303	0.047	0.047
337	1341	315929.566	5814000.484	-3.379	0.018	0.018
338	1342	315917.387	5813967.434	-3.514	0.115	0.115

339	1343	315906.339	5813938.002	-3.487	0.02	0.02
340	1344	315896.583	5813906.767	-3.67	0.028	0.028
341	1345	315886.237	5813880.163	-4.094	0.023	0.023
342	1346	315875	5813835.129	-4.429	0.299	0.299
343	1347	315866.96	5813804.608	-3.734	0.06	0.06
344	1348	315857.325	5813767.691	-3.781	0.085	0.085
349	1354	315829.672	5813705.093	-4.809	0.069	0.069
350	1355	315816.507	5813709.649	-5.152	0.092	0.092
351	1356	315804.314	5813713.836	-3.718	0.128	0.128
352	1357	315795.63	5813716.034	-0.53	0.04	0.04
353	1358	315813.448	5813736.031	-3.866	0.044	0.044
354	1359	315829.143	5813759.888	-4.73	0.05	0.05
355	1360	315834.659	5813784.468	-4.757	0.006	-0.006
356	1361	315844.749	5813807.261	-5.326	0.071	0.071
357	1362	315855.615	5813831.968	-5.698	0.009	-0.009

AVG	0.0314
RMSE	0.0761
95% CI	0.149156
Within Tolerance (%)	84.57



Appendix F - Floor Level Survey Validation

AREA	ID	RL	MLS RL	Difference
EDGEWATER	TS0001	4.117	N/A	
EDGEWATER	TS0004	4.211	4.201	-0.010
EDGEWATER	TS0007	4.173	N/A	
EDGEWATER	TS0010	4.122	4.141	0.019
EDGEWATER	TS0013	4.231	4.229	-0.002
EDGEWATER	TS0017	4.220	4.217	-0.003
EDGEWATER	TS0021	4.197	4.188	-0.009
EDGEWATER	TS0024	4.168	4.138	-0.030
EDGEWATER	TS0027	4.227	4.214	-0.013
EDGEWATER	TS0030	4.185	N/A	
EDGEWATER	TS0033	4.339	4.322	-0.016
EDGEWATER	TS0036	4.323	4.318	-0.005
EDGEWATER	TS0039	4.283	4.269	-0.014
EDGEWATER	TS0042	4.173	4.17	-0.003
EDGEWATER	TS0045	4.206	N/A	
EDGEWATER	TS0048	4.141	4.212	0.071
EDGEWATER	TS0051	4.447	4.437	-0.010
EDGEWATER	TS0053	4.670	4.665	-0.005
EDGEWATER	TS0056	4.384	4.372	-0.012
EDGEWATER	TS0059	4.442	N/A	
EDGEWATER	TS0062	4.327	4.319	-0.008
EDGEWATER	TS0065	4.429	4.411	-0.018
EDGEWATER	TS0068	4.201	N/A	
EDGEWATER	TS0073	4.336	4.311	-0.025
EDGEWATER	TS0077	4.327	4.327	0.000
EDGEWATER	TS0080	4.578	N/A	
EDGEWATER	TS0083	4.338	4.324	-0.014
EDGEWATER	TS0086	4.421	4.419	-0.002
EDGEWATER	TS0100	4.435	4.431	-0.004
EDGEWATER	TS0103	4.420	4.428	0.008
EDGEWATER	TS0106	4.340	4.345	0.005
EDGEWATER	TS0109	4.480	4.482	0.002
EDGEWATER	TS0112	4.247	4.247	0.000
EDGEWATER	TS0115	4.473	N/A	
EDGEWATER	TS0118	4.350	4.344	-0.006
KENSINGTON	TS0001	3.202	3.165	-0.037
KENSINGTON	TS0005	3.301	N/A	
KENSINGTON	TS0008	3.152	N/A	
KENSINGTON	TS0011	3.413	3.382	-0.031
KENSINGTON	TS0014	3.635	3.599	-0.036

KENSINGTON	TS0017	3.420	N/A	
KENSINGTON	TS0020	3.523	N/A	
KENSINGTON	TS0023	3.504	3.463	-0.040
KENSINGTON	TS0026	3.426	3.398	-0.028
KENSINGTON	TS0029	3.487	3.444	-0.043
KENSINGTON	TS0032	3.580	3.537	-0.043
KENSINGTON	TS0035	3.447	3.406	-0.041
KENSINGTON	TS0038	3.265	3.241	-0.024
KENSINGTON	TS0041	3.286	3.253	-0.032
KENSINGTON	TS0044	3.279	3.246	-0.033
KENSINGTON	TS0047	3.310	3.285	-0.025
KENSINGTON	TS0050	3.312	3.287	-0.025
KENSINGTON	TS0053	3.332	3.342	0.010
KENSINGTON	TS0056	3.337	3.317	-0.019
KENSINGTON	TS0100	3.132	N/A	
KENSINGTON	TS0103	3.155	3.107	-0.048
KENSINGTON	TS0106	3.114	3.037	-0.077
KENSINGTON	TS0109	3.123	N/A	
KENSINGTON	TS0112	3.106	3.05	-0.056
KENSINGTON	TS0115	3.073	3.003	-0.070
KENSINGTON	TS0118	3.053	3.016	-0.037
KENSINGTON	TS0121	3.057	2.993	-0.064
KENSINGTON	TS0124	3.089	3.032	-0.057
KENSINGTON	TS0127	3.129	3.073	-0.056
ASCOT VALE	TS0001	4.457	4.45	-0.007
ASCOT VALE	TS0004	4.474	4.472	-0.001
ASCOT VALE	TS0007	4.649	4.638	-0.011
ASCOT VALE	TS0010	4.567	4.529	-0.038
ASCOT VALE	TS0013	4.489	4.479	-0.010
ASCOT VALE	TS0016	4.390	4.379	-0.011
ASCOT VALE	TS0019	4.574	N/A	
ASCOT VALE	TS0022	4.609	4.596	-0.013
ASCOT VALE	TS0025	4.432	N/A	
ASCOT VALE	TS0028	4.582	N/A	
ASCOT VALE	TS0031	4.456	4.436	-0.020
ASCOT VALE	TS0034	4.518	4.511	-0.007
ASCOT VALE	TS0040	5.958	6.007	0.049
ASCOT VALE	TS0043	5.682	5.723	0.041
ASCOT VALE	TS0046	5.043	5.104	-0.061
ASCOT VALE	TS0049	4.955	4.918	0.037
ASCOT VALE	TS0052	5.032	N/A	
ASCOT VALE	TS0055	5.043	4.995	0.048
ASCOT VALE	TS0058	4.900	N/A	
ASCOT VALE	TS0061	4.919	N/A	

ASCOT VALE	TS0070	4.443	N/A	
ASCOT VALE	TS0073	4.459	4.452	-0.007
ASCOT VALE	TS0076	4.484	4.458	-0.026
ASCOT VALE	TS0079	4.498	4.481	-0.017
ASCOT VALE	TS0082	4.489	4.572	0.083
ASCOT VALE	TS0086	4.509	4.476	-0.032
ASCOT VALE	TS0089	4.469	4.454	-0.015

Floor Levels Located	AVE	-0.015
Total Properties	1STD	0.029
% Complete	95% CI	0.058

Suburb	*% Complete*
Kensington	53%
Edgewater	73%
Ascot Vale	49%
Total	**56%**

Appendix G - Survey Data Transmittal

Survey Data Transfer

Date: 22 April 2024
Company: Melbourne Water Corporation
Prepared by: Brett Sheehan
Project name: Lower Maribyrnong Flood Mapping Study
Project no: IA5000NN

Floor 13, 452 Flinders Street
Melbourne, VIC 3000
PO Box 312, Flinders Lane
Melbourne, VIC 8009
Australia
T +61 3 8668 3000
F +61 3 8668 3001
www.jacobs.com

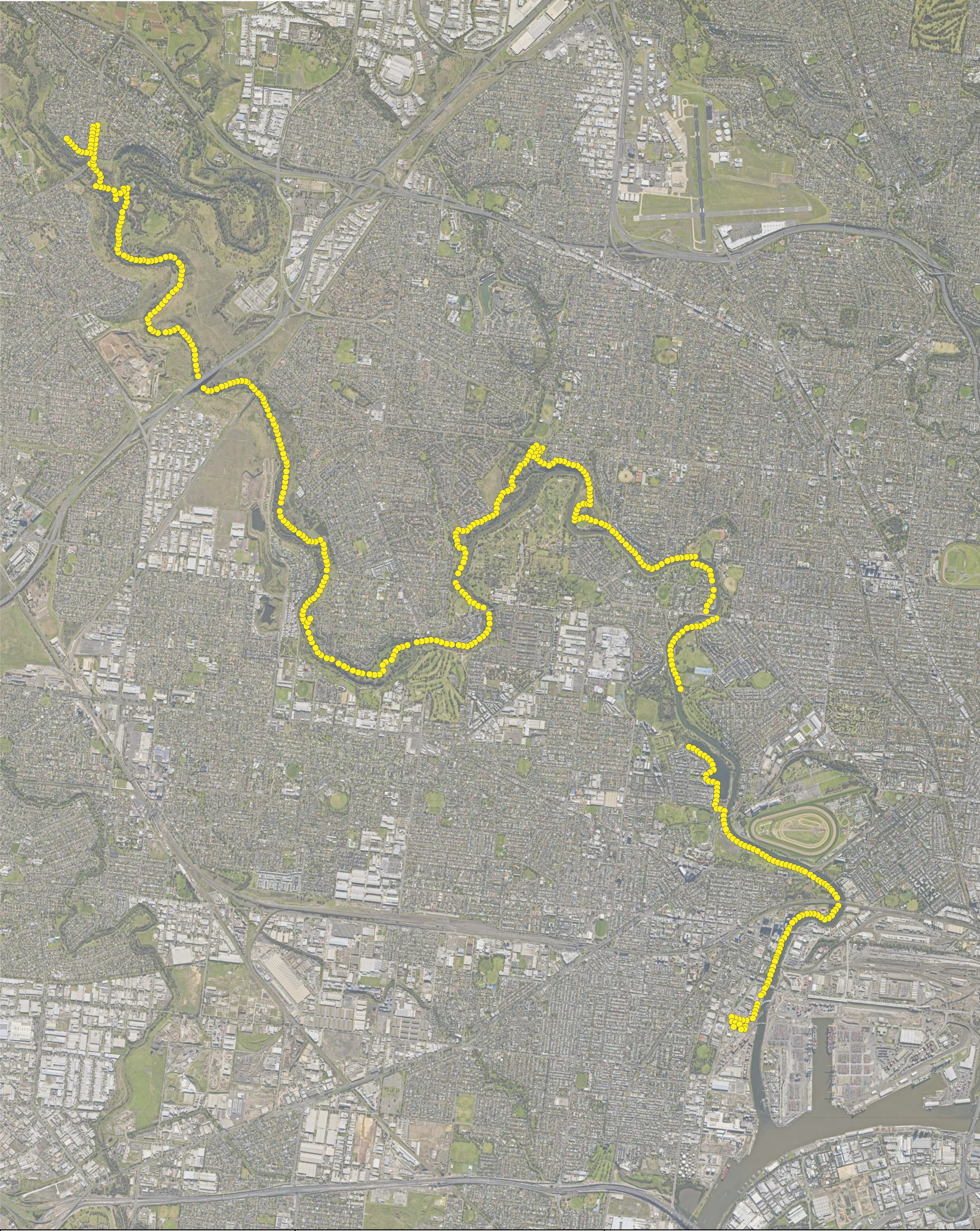
Data Enclosed:

- Airborne LiDAR (supplied by Aerometrex).
  - Colourised Point Cloud Tiles for project area (.laz).
  - 0.5m DEM for project area.
  - Tile Reference (shp).
- Bathymetry Data (supplied by Total Hydrographic).
  - Point Cloud File (laz).
- Drainage Infrastructure (Jacobs).
  - Points, Lines & attributes (shp).
- Floor Level Survey (Jacobs).
  - Point Cloud (Not Supplied*).
  - Points & attributes (shp).
- Feature Survey (Jacobs).
  - Infrastructure Surveys (dwg).
  - Associated photos (.jpg).

*Jacobs did not supply 100Gb Point Cloud for the suburbs captured with Mobile Laser Scanning the Floor Levels were derived from. This can be provided upon request.

The sole purpose of the topographic LiDAR and bathymetric survey data, collected by third parties on behalf of Melbourne Water, the drainage infrastructure data, the floor level survey and the Feature Survey collected by Jacobs, was to assist Jacobs to undertake a flooding assessment for the Lower Maribyrnong, in accordance with and limited by the scope of services set out in the contract between Jacobs and Melbourne Water ("MW" / "the Client"). Jacobs accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this data by any third party. No warranty or guarantee, whether express or implied, is made as to the data, to the extent permitted by law.

Appendix D. Hardstand Survey Validation Points



Legend

Measured Points

MGA Zone 55

Jacobs

0 0.5 1 1.5 km

Measured Hardstand Points for Independent LiDAR Validation

Disclaimer: Produced by Jacobs for the Lower Maribyrnong Flood Mapping Project, a Melbourne Water project. Jacobs does not warrant that this document is definitive nor free of errors and does not accept liability for any loss caused or arising from reliance upon information provided herein. This map should be read in conjunction with Lower Maribyrnong Flood Model Report
Satellite imagery from Metromap

Project Number: IA5000NN

FINAL

Appendix E. Bridge Photos

Bridge	Photo
Pipe bridge	
Canning St bridge	

Afton St footbridge	
Raleigh Rd bridge	
Pipe-makers Park footbridge	

Fisher Parade bridge	
Lynchs bridge (U/S of the two)	

Lynchs bridge (D/S of the two)	
Angliss stock bridge	

Kensington rail bridge (U/S of the three)	
Kensington rail bridge (middle of the three)	
Kensington rail bridge (D/S of the three)	

Dynon Road (Hopetoun) bridge	
Bunbury St rail bridge	

Footscray Road (Shepherd) bridge	
Westgate 1	

Westgate 2	

Appendix F. Annual Maxima Series Review

Table F-1: Annual maxima series for each data source, details on data gaps and justification on adopted values.

Year	Adopted AMAX (m^3/s)	DELWP (m^3/s)	MMBW (m^3/s)	BoM (m^3/s)	DELWP no. missing days	Comments
1871	input as historic		600			Prior to commencement of DELWP gauging - MMBW value adopted
1891	input as historic		560			
1901	input as historic		320			
1906	880		880			
1907	Excl					Missing year of WMIS data - excluded
1908	66	66			110	
1909	474	474	495		57	
1910	81	81			39	
1911	330	330	329		0	
1912	62	62			0	
1913	249	249	253		0	
1914	17	17			6	
1915	149	149			22	
1916	632	632	642		0	
1917	106	106			0	
1918	153	153			0	
1919	330	330	329		28	
1920	268	268	269		51	
1921	103	103			0	
1922	168	168			0	
1923	232	232			105	
1924	461	461	462		5	
1925	28	28			11	
1926	13	13			99	
1927	Excl	9			206	Incomplete WMIS data - excluded
1928	151	151			66	
1929	121	121			100	
1930	139	139			38	
1931	143	143			0	
1932	376	376	380		33	
1933	112	112			47	
1934	Excl				365	

Year	Adopted AMAX (m^3/s)	DELWP (m^3/s)	MMBW (m^3/s)	BoM (m^3/s)	DELWP no. missing days	Comments
1935	Excl				365	Missing years of data in all records - excluded
1936	Excl				366	
1937	Excl				365	
1938	Excl				365	
1939	Excl				365	
1940	Excl				366	
1941	Excl				365	
1942	Excl				365	
1943	Excl				365	
1944	Excl				366	
1945	Excl				365	
1946	Excl				365	
1947	Excl				364	
1948	Excl	17			63	Incomplete WMIS data - excluded
1949	243	243			80	
1950	343	343			15	
1951	314	314			106	
1952	201	201			46	
1953	215	215			67	
1954	520	343	520		199	WMIS records missing part of year - MMBW value adopted
1955	116	116			66	
1956	Excl	99			219	Incomplete WMIS data - excluded
1957	Excl				365	Missing year of WMIS data - excluded
1958	Excl	47			276	Incomplete WMIS data - excluded
1959	43	43			32	
1960	260	156	260		57	WMIS records missing part of year - MMBW value adopted
1961	Excl	24			69	Incomplete WMIS data - excluded
1962	Excl	53			153	Incomplete WMIS data - excluded
1963	291	223	291		27	WMIS records missing part of year - MMBW value adopted
1964	320		320		366	WMIS records missing year - adopt MMBW value
1965	Excl				365	Missing year of WMIS data - excluded
1966	Excl	39			136	Incomplete WMIS data - excluded
1967	Excl	6			186	Incomplete WMIS data - excluded
1968	Excl	73			155	Incomplete WMIS data - excluded

Year	Adopted AMAX (m^3/s)	DELWP (m^3/s)	MMBW (m^3/s)	BoM (m^3/s)	DELWP no. missing days	Comments
1969	22	22			58	
1970	164	164			1	
1971	399	399	407		0	
1972	110	110			14	
1973	146	146			22	
1974	726	726	714		1	
1975	324	288	320	324	0	BoM value adopted given this was nearer to the MMBW value
1976	112	112		135	0	
1977	297	297	296	310	0	
1978	352	352	358	356	0	
1979	138	138		141	0	Significant BoM rating change in 1979 - assumed the rating pre-1979 is correct
1980	14	14		14	0	
1981	103	103		94	0	
1982	Excl	2		1	67	Incomplete WMIS data - excluded
1983	400	476	456	464	0	Re-rate to RT37.02 original value 476
1984	96	96		97	0	
1985	233	233		233	0	
1986	91	91		91	0	
1987	451	451		451	0	
1988	50	50		50	0	
1989	317	317		317	0	
1990	232	232		232	0	
1991	22	22		22	0	
1992	143	143		143	0	
1993	510	690		690	0	Re-rate to RT37.02 original value 690
1994	4	4		4	0	
1995	129	129		129	0	
1996	99	99		99	0	
1997	10	10		10	0	
1998	10	10		10	0	
1999	93	93		93	0	
2000	256	256		256	0	
2001	57	57		57	0	
2002	3	3		3	0	
2003	20	20		20	38	
2004	11	11		11	1	

Year	Adopted AMAX (m^3/s)	DELWP (m^3/s)	MMBW (m^3/s)	BoM (m^3/s)	DELWP no. missing days	Comments
2005	265	265		254	0	
2006	2	2		2	0	
2007	43	43		32	52	
2008	20	20		20	3	
2009	9	9		9	62	
2010	287	287		33	0	
2011	379	423		428	0	Re-rate to RT37.02 original value 423
2012	245	245		87	0	
2013	25	25		25	0	
2014	3	3		3	0	
2015	5	5		5	0	
2016	201	201		17	0	
2017	14	14		14	0	
2018	30	30		30	0	
2019	12	12		12	0	
2020	76	76		76	0	
2021	93	93		93	0	
2022	768	768		766	0	

Appendix G. FFA sensitivity testing

A number of sensitivity tests were while undertaking the develop of the Flood Frequency Analysis, these were:

1. Bayesian fit of the LP3 distribution with no historic, no PILF or prior information.
2. Bayesian fit of the LP3 distribution with historic information (as per final fit), PILF (as per final fit) and priors from the RFFE model.
3. Bayesian fit of the LP3 distribution with infilling of the gaps in the annual maxima record with a random drawn from LP3 distribution with parameters from a previous FFA fit that were less than 250m3/s (a flow understood not to lead cause impacts that would be reported which matches the flood history).
4. Bayesian fit of the GEV distribution with PILF and historic information.
5. Higher order LH moments fitting of the GEV distribution.

The results of these tests are presented in Table G-1. Overall, the results of the sensitivity test presented in Table G-1 are comparable to the adopted results in Table 4-3.

Table G-1. Results of FFA sensitivity testing.

AEP	Test 1 (m^3/s)	Test 2 (m^3/s)	Test 3 (m^3/s)	Test 4 (m^3/s)	Test 5 (m^3/s)
2	141	135	122	140	146
5	326	298	286	221	325
10	466	454	422	326	449
20	602	646	565	468	572
50	773	964	762	609	737
100	894	1,261	916	917	865

Appendix H. RORB Calibration: Standard Approach

This appendix presents the calibration of the RORB model to historic events using the standard approach, specifically the calibration of the routing parameter k_c is discussed. While this approach was ultimately not used to determine the design event hydrographs for application to the TUFLOW hydraulic model, this analysis may contain useful information for purposes that are sensitive to hydrograph shape and timing such as emergency management and flood forecasting.

H.1 Approach

The RORB model was calibrated to three historic events and validated against another historic event using the streamflow, rainfall, and observed data. The number of events were determined by the available data available for each event.

Calibration involved adjusting the model k_c parameter until an acceptable fit to the observed hydrographs was achieved. Once the calibration determined the k_c parameter the validation event was run. This involved applying the historic data to the model and evaluating its performance with only changes to the loss parameters, effectively a blind test of the model's performance. It is noted that the resulting k_c from the process was not ultimately used.

The calibration was completed using an automated process followed by manual fine tuning of parameters. The automatic calibration was completed using AutoCal (Myers, 2021, Pedruco et al., 2023, Chen et al., 2023). AutoCal is a surrogate optimiser that uses machine learning to create a response surface from model runs. An optimisation was completed using the response surface to determine the optimal set of parameters.

H.2 Historic event selection

The selection of the calibration and validation events were selected as outlined in Section 3.4.4 and were:

- Calibration events
  - October 2022, January 2011 & October 1983
- Validation event
  - September 1993

The range of calibration parameters for testing was based on standard ranges from well-known regional RORB k_c relationships such as Pearse et al (2002). Ranges for Initial Loss and Continuing Loss were selected based on the ranges set out in Australian Rainfall and Runoff (Hill & Thomson, 2019) and Jacobs's experience.

H.3 Rainfall for calibration

To create rainfall data to apply to the RORB model for calibration required information on rainfall depth and the temporal distribution of rainfall or rainfall patterns. The approach undertaken in this study was to calculate rainfall depths from gridded dataset and determine rainfall temporal patterns from RADAR or pluviograph data depending on availability.

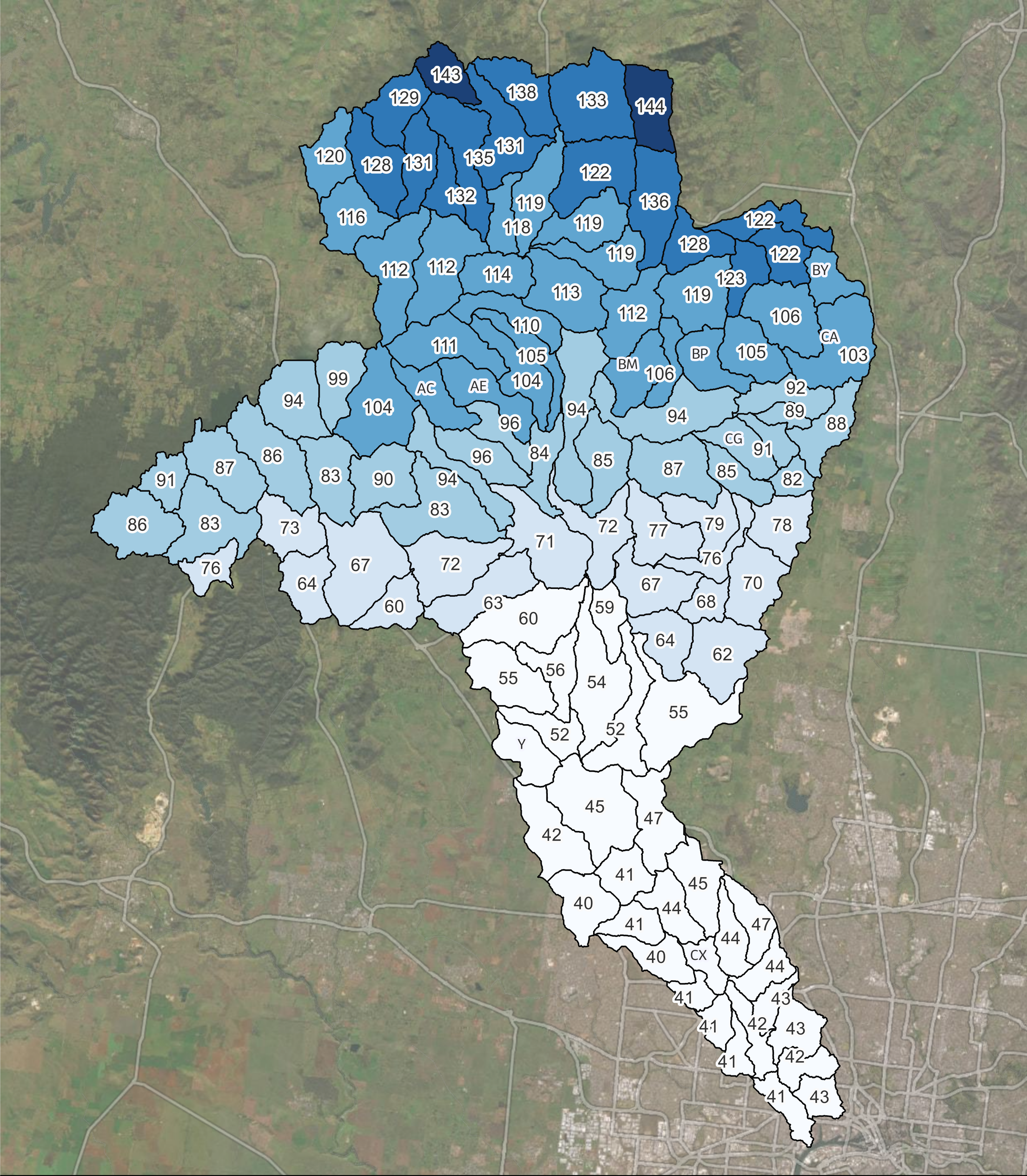
Rainfall data for calibration of the RORB model has been obtained from the following:

- Bureau of Meteorology – daily rainfall data. A list of Bureau of Meteorology stations is provided in Table 3-1.
- Melbourne Water – daily rainfall and pluviograph data. A list of Melbourne Water stations is provided in Table 3-1.

- Gridded rainfall datasets as listed in Table 3-2. Testing has demonstrated that AWAP dataset is the most suitable gridded dataset which has been adopted for calibration rainfall depths.
- RADAR datasets at listed in Table 3-2. This data was only available for the October 2022 event.

The available data for each event varied and the following was used to determine the input rainfall into each calibration and validation event:

- October 2022
  - Rainfall depth from AWAP data as shown in Figure H-1.
  - Temporal patterns from RADAR data generated for each sub-catchment (see example in Figure H-2) and verified against the pluviograph data shown in Figure H-3.
  - The resulting hyetographs for this event are shown in Appendix I.
- January 2011
  - Rainfall depth from AWAP data as shown in Figure H-4.
  - Temporal patterns from available pluviograph stations (as shown in Figure H-5) with temporal patterns allocated to sub-catchment by Veroni (or Thiessen) polygons.
  - The resulting hyetographs for this event are shown in Appendix I.
- September 1983
  - Rainfall depth from AWAP data as shown in Figure H-6.
  - Temporal patterns from available pluviography stations (as shown in Figure H-7) with temporal patterns from pluviographs allocated to sub-catchment by Veroni polygons.
  - The resulting hyetographs for this event are shown in Appendix I.
- October1993
  - Rainfall depth from AWAP data as shown in Figure H-8.
  - Temporal patterns from available pluviography stations (as shown in Figure H-9) with temporal patterns from pluviographs allocated to sub-catchment by Veroni polygons.
  - The resulting hyetographs for this event are shown in Appendix I.



Legend

Subcatchment Boundaries

Event rainfall totals (mm)

- 40
- 60
- 80
- 100
- 120
- 140

MGA Zone 55

0 5 10 15 km

Jacobs

Figure H-1: October 2022 rainfall depth distribution by sub-catchment

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Project Number: IA5000NN

FINAL

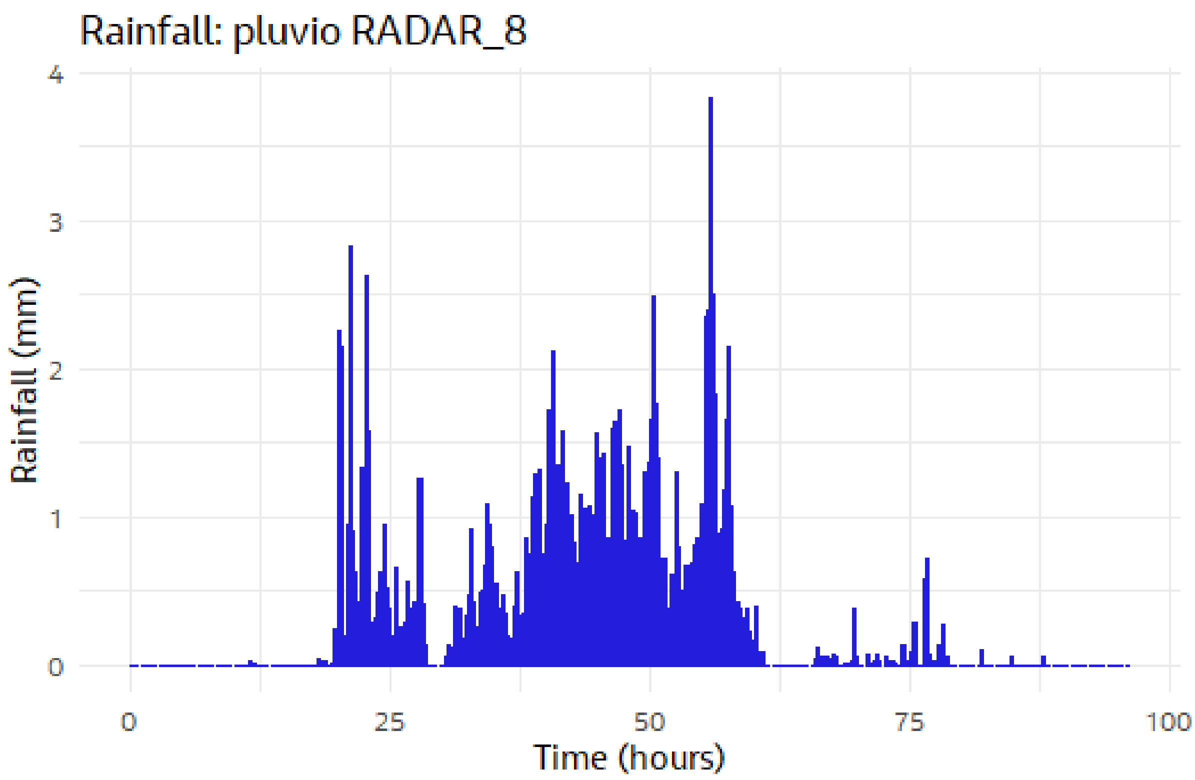


Figure H-2: October 2022 example hyetograph.

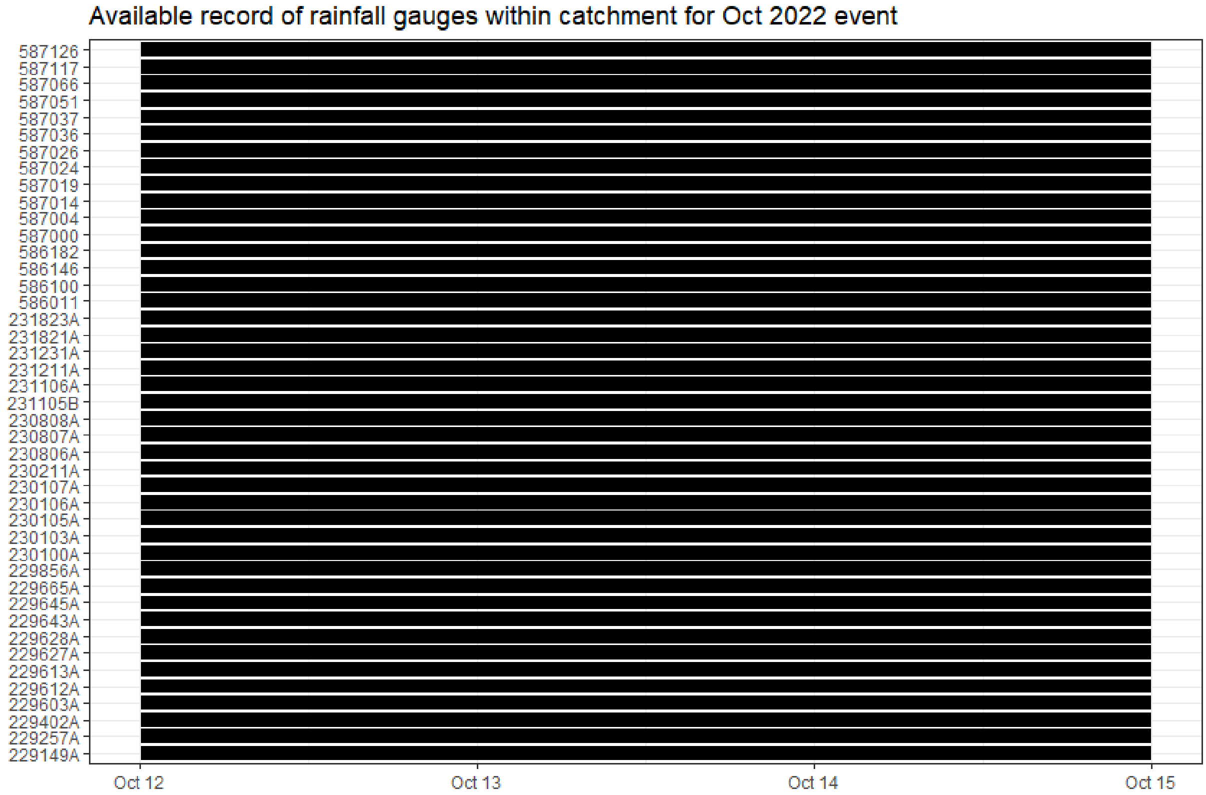
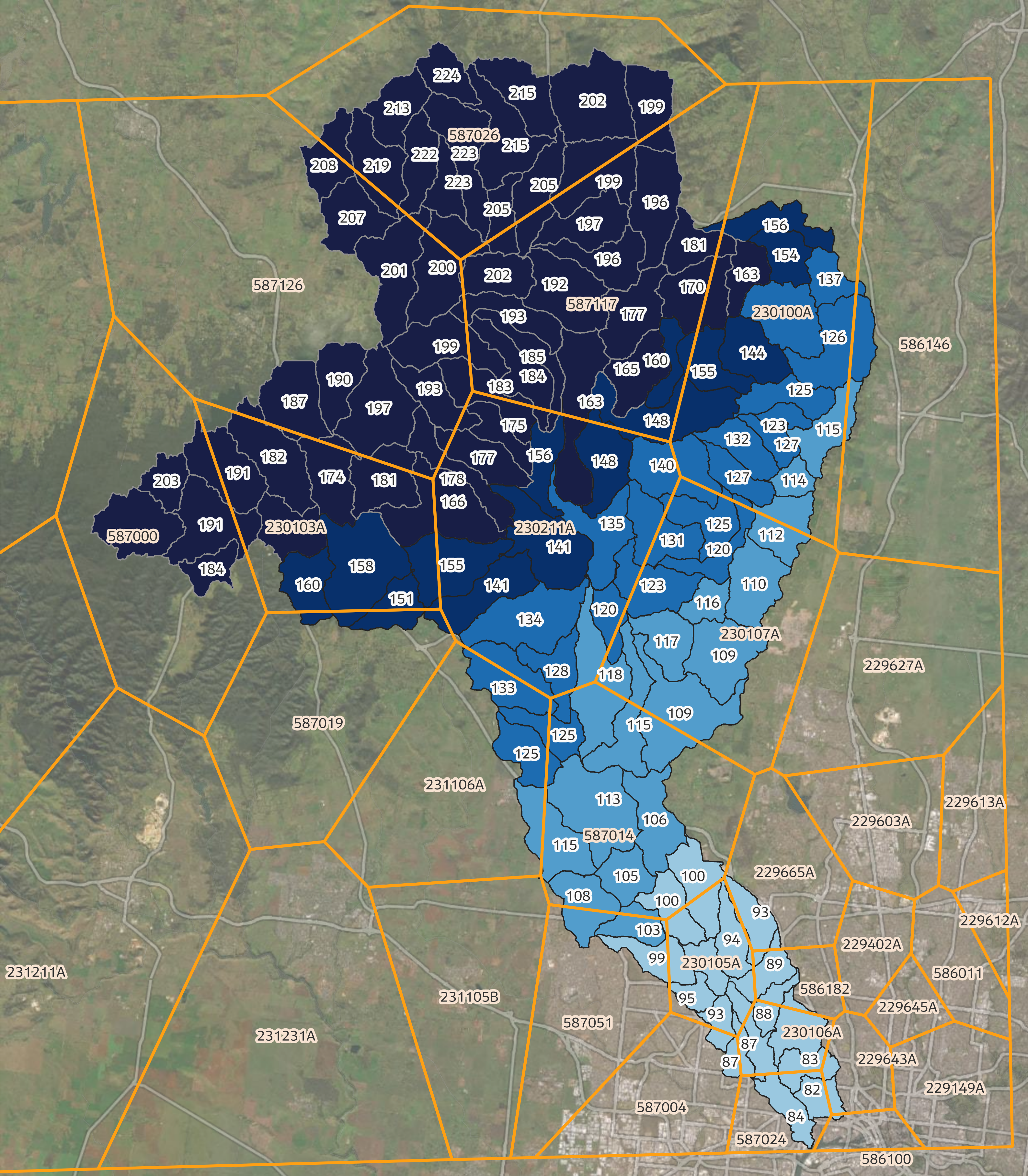


Figure H-3: Pluviographs available for the 2022 event (and used for verification of RADAR data).



Legend

Voronoi polygons (pluviograph temporal patterns applied)

Event rainfall totals (mm)

- 40
- 60
- 80
- 100
- 120
- 140
- 160

MGA Zone 55

0 5 10 15 km

Jacobs

Figure H-4: January 2011 rainfall depth distribution by sub-catchment

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Project Number: IA5000NN

FINAL

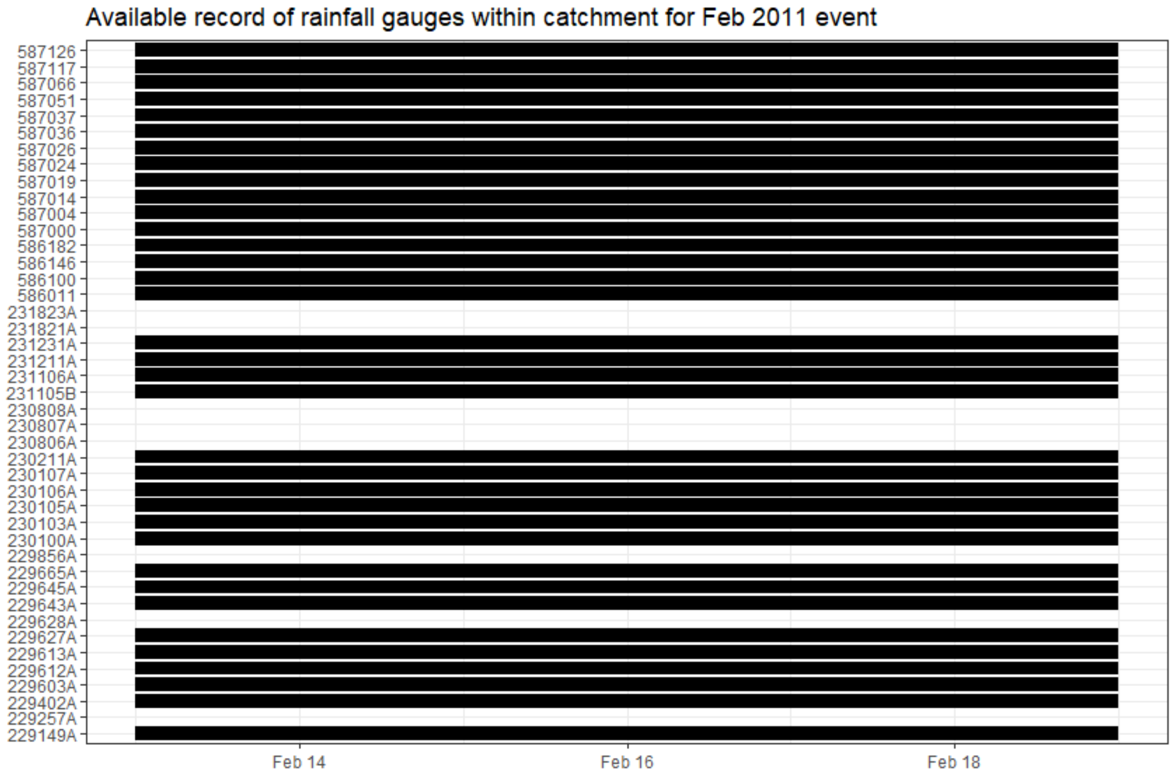
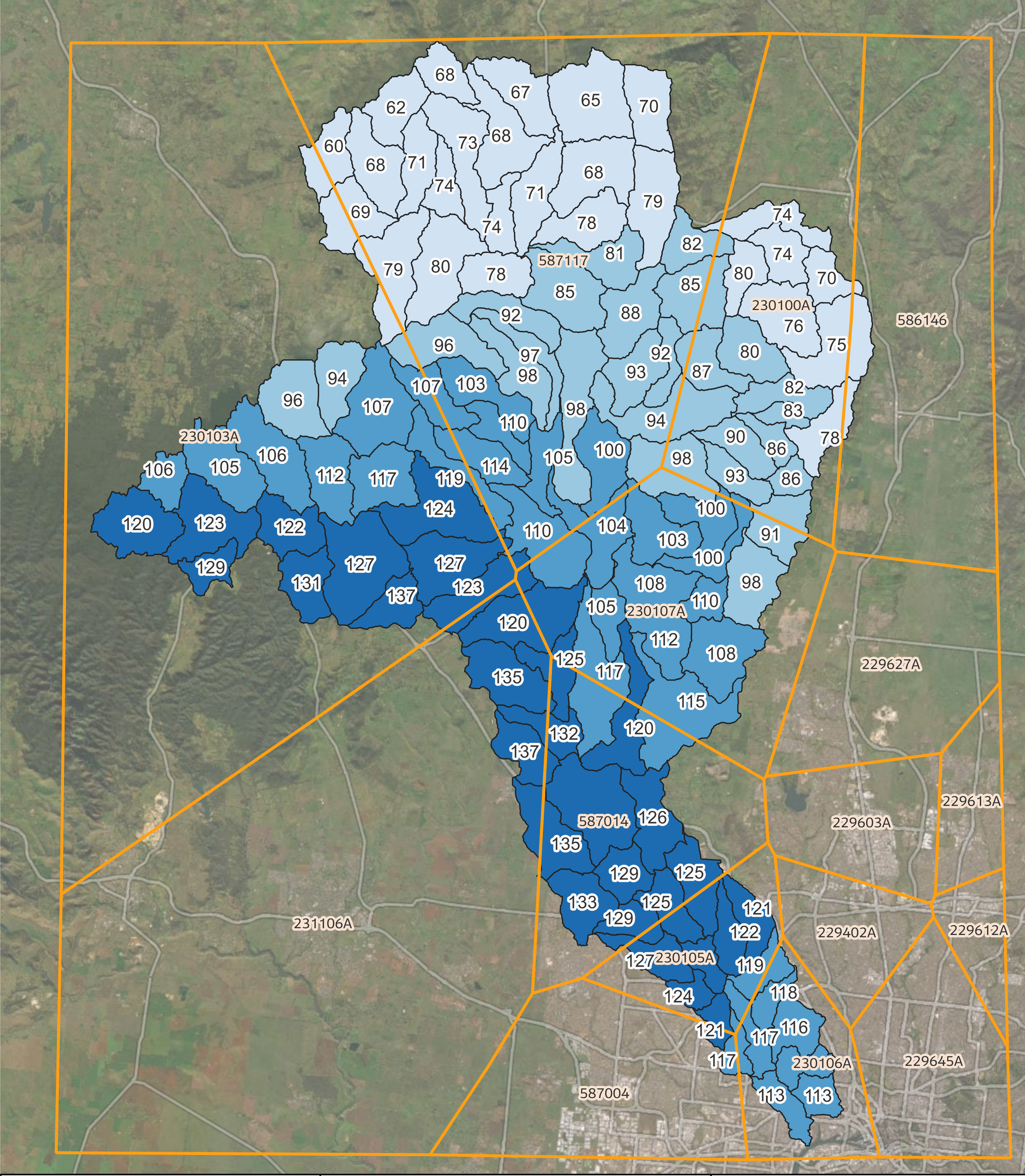


Figure H-5: Pluviographs available for the 2011 event.



Legend

Voronoi polygons (pluviograph temporal patterns applied)

Event Rainfall Totals (mm)

- 40
- 60
- 80
- 100
- 120
- 140

MGA Zone 55

0 5 10 15 km

Jacobs

Figure H-6: September 1983 rainfall depth distribution by sub-catchment

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Project Number: IA5000NN

FINAL

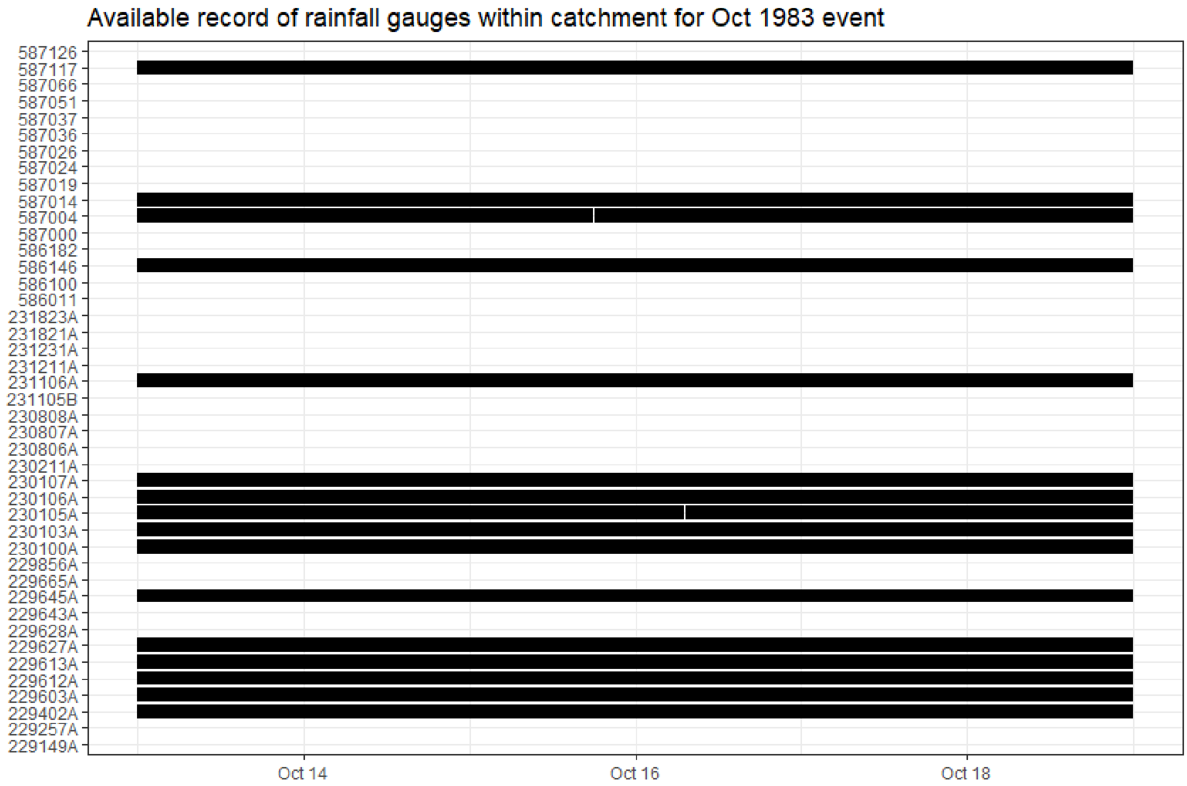
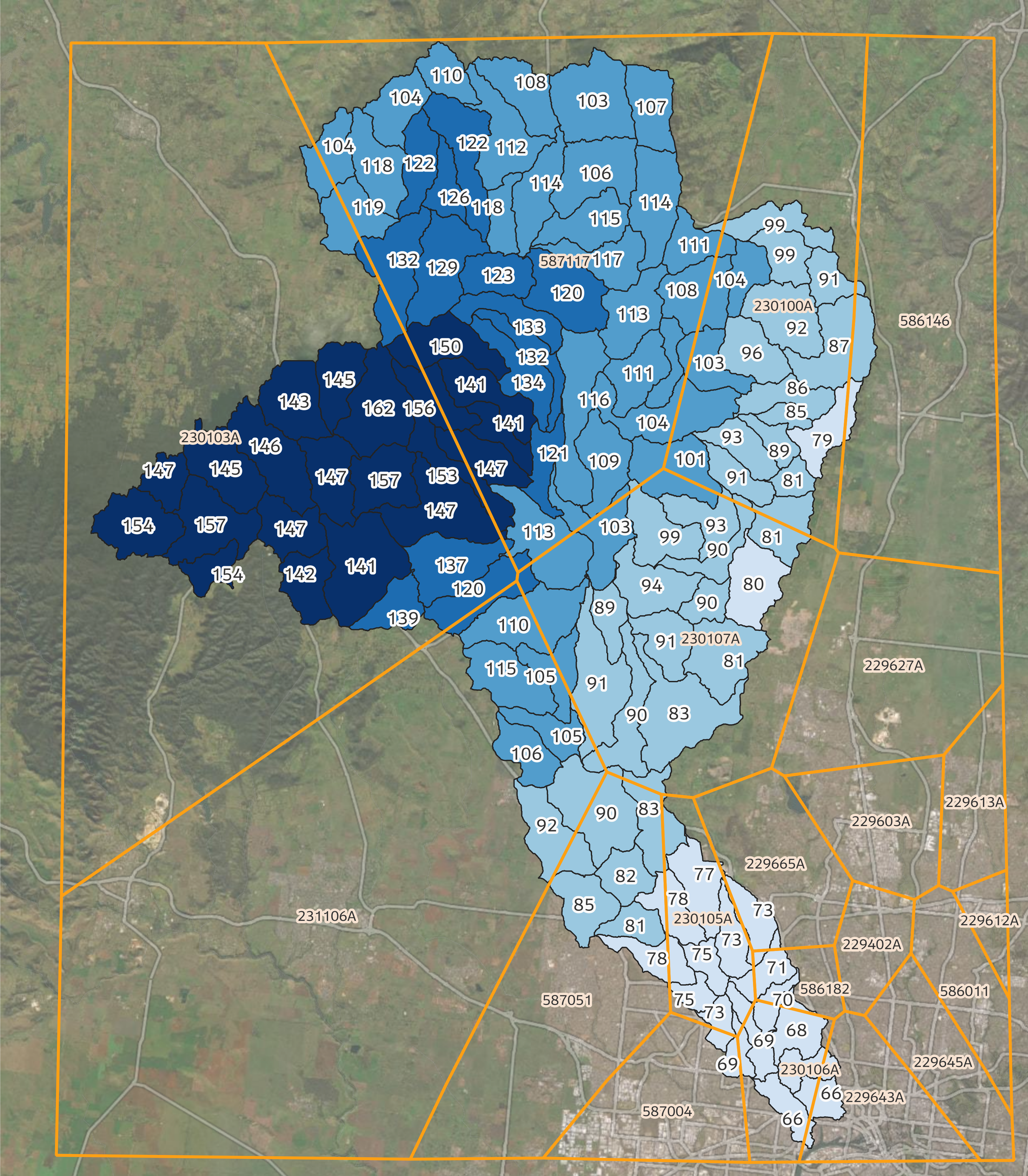


Figure H-7: Pluviographs available for the 1983 event.



Legend

Voronoi polygons (pluviograph temporal patterns applied)

Event rainfall totals (mm)

- 40
- 60
- 80
- 100
- 120
- 140

MGA Zone 55

0 5 10 15 km

Jacobs

Figure H-8: October 1993 rainfall depth distribution by sub-catchment

Project Number: IA5000NN

FINAL

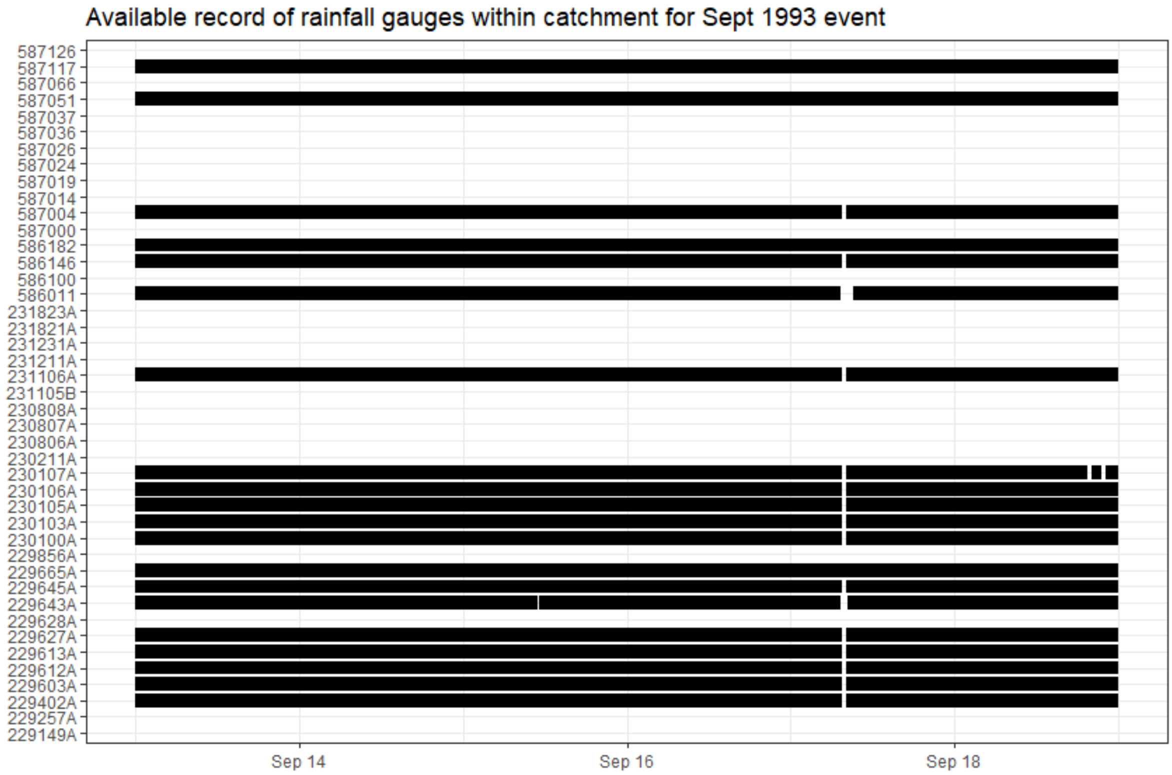


Figure H-9: Pluviographs available for the 1993 event.

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H.4 Streamflow data for calibration and validation

Streamflow data for each of the calibration and validation events was obtained for the Maribyrnong River at Keilor (230105A). These hydrographs are shown in the calibration plot results.

H.5 Assessment of calibration or goodness-of-fit

To assess the performance of the model calibration goodness-of-fit statistics were calculated. These statistics help guide the selection of best model parameters and are described below. The statistical analysis includes a comparison of peak flow, peak stage and the difference in the timing of peaks as well as goodness-of-fit metrics. The goodness-of-fit metrics were:

- PBIAS - Percent Bias is the percentage difference between modelled and observed in the area under the curve or mass, if this is a hydrograph this metric would measure the difference in volume.
- NSE - Nash-Sutcliffe Efficiency (-Inf <= NSE <= 1). The Nash-Sutcliffe efficiency (NSE) is a statistic describes the amount of variance explained by the model (Nash and Sutcliffe, 1970). This metric is particularly affected by timing errors. One indicates a perfect fit. A value of 0 is the value that would be achieved for the average of the observed series, that means, the model is preforming as well as the mean. A value of less than 0 indicates that the model is preforming worse than the average against this statistic.
- r - Pearson Correlation coefficient (-1 <= r <= 1). This statistic is a measure of linear correlation between the modelled and observed series. A value of 1 suggests a perfect correlation and a value of 0 indicates no correlation between the modelled and observed series.
- R^2 - Coefficient of Determination ($0 <= R^2 <= 1$) - Gives the proportion of the variance of one variable that is predictable from the other variable. A value of 1 suggests a perfect fit and value of 0 suggest a poor relationship between modelled and observed series.
- KGE - Kling-Gupta efficiency (Gupta et al., 2009) between modelled and observed (0 <= KGE <= 1). The KGE is a decomposition of the NSE that is considered to be more balanced, has been widely used for calibration and evaluation hydrological models in recent years. The interpretation of the value is similar to the NSE.
- VE Volumetric efficiency between modelled and observed (-Inf <= VE <= 1). One indicates a perfect fit and 0 the average of the observed series. Volumetric efficiency was proposed in order to circumvent some problems associated to the Nash-Sutcliffe efficiency. It represents the fraction of water delivered at the proper time; its compliment represents the fractional volumetric mismatch (Criss and Winston, 2008). The interpretation of the value is similar to the NSE.

Further interpretation of the NSE statistics in relation to hydrological models can be found in Moriasi (2007) and listed in Table H-1. Moriasi developed these interpretations for long term discharge series and not specifically for event based models such as those presented here; however, this schema still provides a valuable interpretation of event based model results.

It must be noted that these goodness-of-fit statistics have been specifically developed for hydrologic (discharge) models and there is a wide body of research to support interpretation of these statistics in this context. This report has also applied these to water levels and while the generally interpretations listed above remain true, there are only limited examples of application to water level. In particular, it can be reasonably expected that given the lower variance in both the modelled and observed water level series the efficiency statistics (NSE, KGE and VE) will naturally perform better than when these are applied to discharge.

Table H-1. NSE model performance criteria (adapted from Moriasi (2007).

Classification	NSE Calibration	NSE Validation
Excellent	> 0.93	> 0.93
Good	0.8 – 0.93	0.8 – 0.93
Satisfactory	0.7 - 0.8	0.6 - 0.8
Passable	0.6 – 0.7	0.3 – 0.6
Poor	< 0.6	< 0.3

H.6 2022, 2011 and 1983 kc calibration

In order to determine an acceptable k_c parameter, the October 2022, January 2011 and September 1983 events were initially calibrated in tandem in AutoCal. In this automatic calibration, the losses values (Il and CL) were allowed to vary and a single k_c value that produced the best fit in terms of the objective function was determined. The performance for each event was weighted with the 2022 event given the highest weight and the 2011 the least; this resulted in weighting of 3 (2022), 2 (1983) and 1 (2011). The objective function was the difference between:

- Modelled and observed peak flow.
- Modelled and observed hydrograph volume.
- Modelled and observed time of peak.

Once the initial parameters were optimised by AutoCal they were manually fine-tuned with the results presented Table H-2. The k_c parameter was 51.56 and expressed as *c* is 0.56 (average distance 92.43km) which fall within +/- 2 standard deviations of the mean of the ranges presented by Pearse et al. (2002) from three different sets of data (Victoria, Yu (1989) and CRCCH (Dyer et al., 1994)). Although this *c* value is more than 1 standard deviation from the mean, the calibration and validation results presented below represent a good fit to the observed data with this parameter.

AutoCal also provides a distribution of candidate parameters which provides a number of insights namely how readily identifiable a parameter is, and it can also provide uncertainty bounds for parameters. A plot for the the k_c parameter (for all calibration events) are presented in Figure H-10.

Table H-2: RORB Calibrated parameters from routing calibration.

Event	k_c	m	IL mm	CL mm/hr
October 2022	51.56	0.8	48	0.37
January 2011	51.56	0.8	135	1.70
September 1983	51.56	0.8	62	0.49
Validation				
October 1993	51.56	0.8	65	0.87

Table H-3: Range of c (kc/dav) parameter values from Pearse at al. (2002).

c parameter	Victorian	Yu	CRCCH	$k_{c\_Victorian}$ (d_{av}=92.43km)
+ 2 standard deviation	3.420	3.926	3.972	316
+ 1 standard deviation	2.065	1.941	2.128	191
mean	1.247	0.959	1.140	115
- 1 standard deviation	0.753	0.474	0.611	70
- 2 standard deviation	0.455	0.234	0.327	43

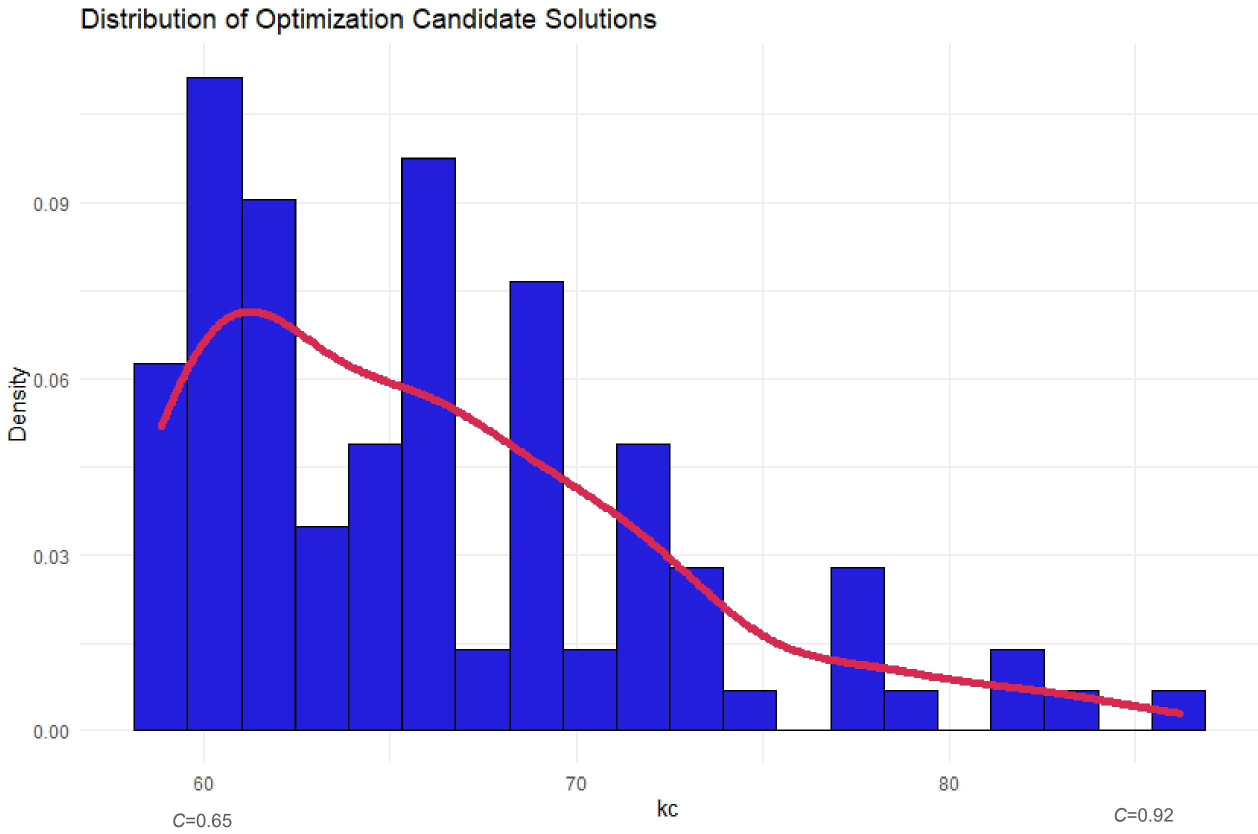


Figure H-10: Parameter sensitivity *kc* for all calibration events (2022, 2011 and 1983).

The results of the 2022, 2011 and 1983 calibration events and 1993 validation event in terms of modelled and observed hydrographs are shown in:

- 2022: Hydrographs in Figure H-11 and hyetographs in Figure H-12.
- 2011: Hydrographs in Figure H-13 and hyetographs in Figure H-14.
- 1983: Hydrographs in Figure H-15 and hyetographs in Figure H-16.
- 1993: Hydrographs in Figure H10-17 and hyetographs in Figure H-18.

A summary of the goodness-of-fit statistics can be seen in Table H-4.

- The 2022 calibration event has the best performance across the statistics presented in Table H-4 and is considered to be good in terms of NSE and according to the guidance Table H-1. This is confirmed by the visual fit Figure H-11 with the resulting total and effective hyetographs in Figure H-12. Given the importance of this event this is considered an excellent outcome.

- The January 2011 calibration event has the poorest statistically performance according to the data in Table H-4, but still achieves a good fit according to NSE. Visually, as seen in Figure H-13, the 2011 hydrograph is the most complex which contributes to the lower statistical score. Further, this event is the only summer event in the calibration and validation events that occurred at the end of the millennium drought, and it is possible these factors have also contributed to the lower scores. Overall, this event had the lowest peak and did not cause any significant flood impacts and is the least influential of the events. The resulting total and effective hyetographs in Figure H-14.
- The 1983 calibration also had a good fit to NSE and event has the best performance across the statistics presented in Table H-4 and is considered to be good in terms of NSE and is confirmed by the visual fit Figure H-15 with the resulting total and effective hyetographs in Figure H-16. There is a strong performance across the statistics with the peak based statistics (NSE, r and R^2) than the volume driven statistics such as PBIAS, Volumetric Efficiency (VE) and (to a lesser extent) the Kling Gupta Efficiency (KGE).
- The 1993 validation event is also considered to have a good fit according to NSE as listed in Table H-4, and performs well across peak difference statistics (NSE, r and R^2) as there is strong agreement between modelled and observed peaks. The volume driven statistics (PBIAS, VE and KGE) do not perform as well as the 2022 and 1983 calibration events, but similarly to 2011. Overall, this is a strong performance for a validation event. This is visually shown in Figure H10-17 with the hyetographs in Figure H-18.

It is noted that across all calibration and validation events, the model did underestimate hydrograph volumes (see PBIAS and VE in Table H-4). Refer to Section 8.1 for discussion on sensitivity. The hydraulic model calibration (Section 6.10) and historic information has demonstrated that peak water levels in the Lower Maribyrnong are driven by peak flows hence the systematic underestimation will not affect flood mapping results (refer Section 8.1). It is also noted that the explicitly incorporating baseflow in the RORB modelling would have improved the volume-based statistics, but not the overall outcomes of the study.

Overall, the statistical evaluation of the model fits to the observed hydrographs as well as the visual fit to these events is good.

Table H-4: Calibrated and validation statistics.

Statistic	2022 Calibration	2011 Calibration	1983 Calibration	1993 Validation
Difference in peaks	1.3 m^3/s	1.5 m^3/s	-1.9 m^3/s	6.5 m^3/s
Difference in time of peak	-1.50 hr	-5.25 hr	-2.25 hr	-1.00 hr
PBIAS*	-14.80%	-30.50%	-20.1%	-30.80%
NSE	0.92	0.80	0.86	0.93
r	0.97	0.91	0.94	0.98
R^2	0.93	0.83	0.88	0.97
KGE	0.85	0.67	0.76	0.69
VE	0.74	0.56	0.64	0.64

* Equivalent to difference in volume

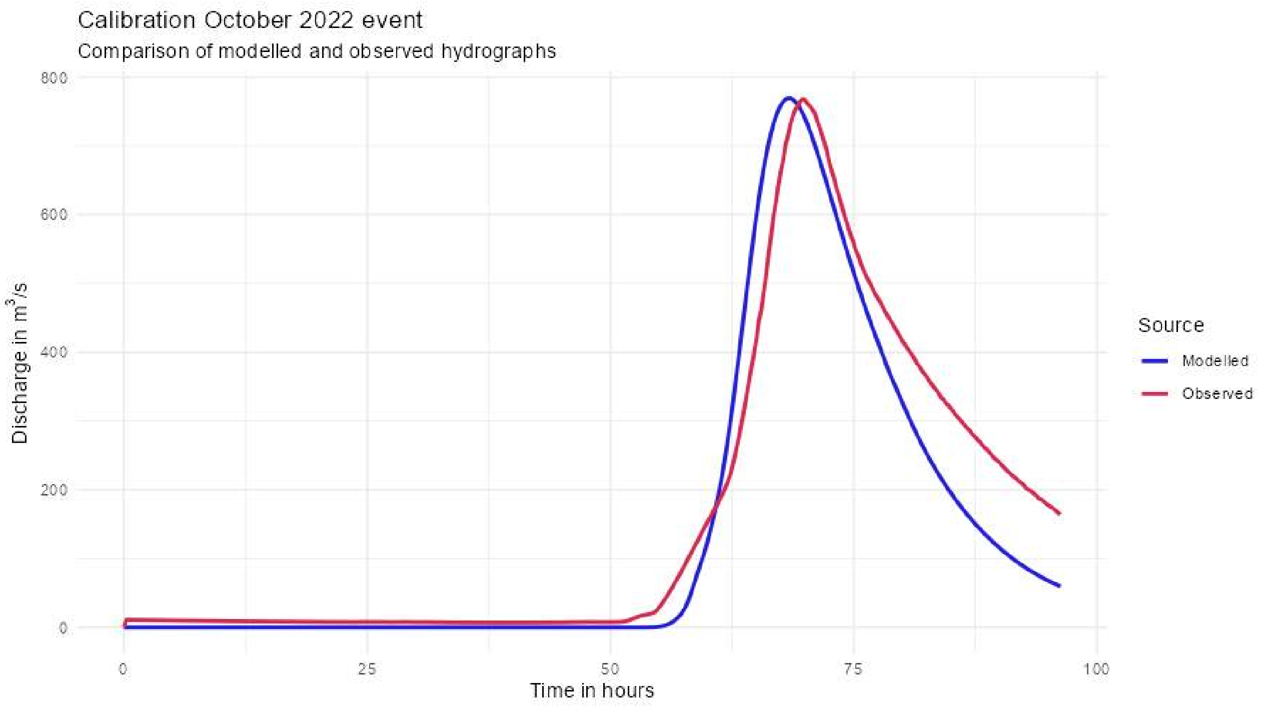


Figure H-11: October 2022 calibration event hydrographs.

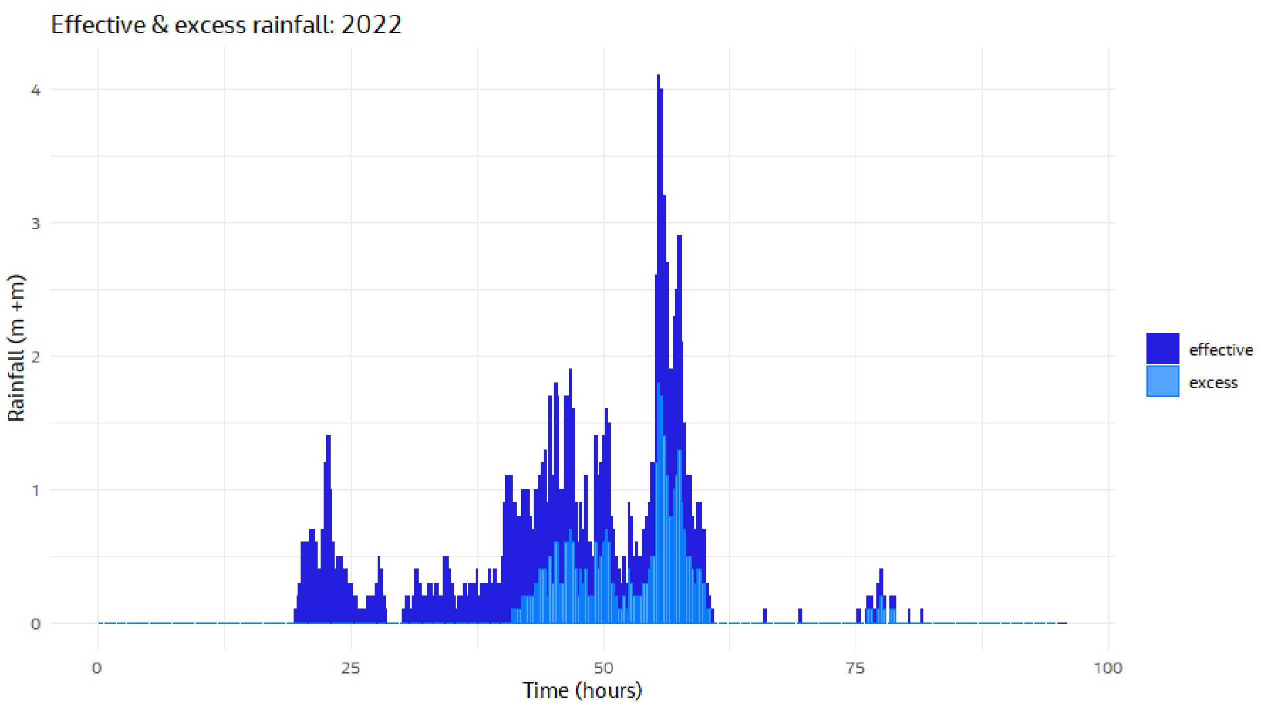


Figure H-12: October 2022 calibration event total and effective hyetographs.

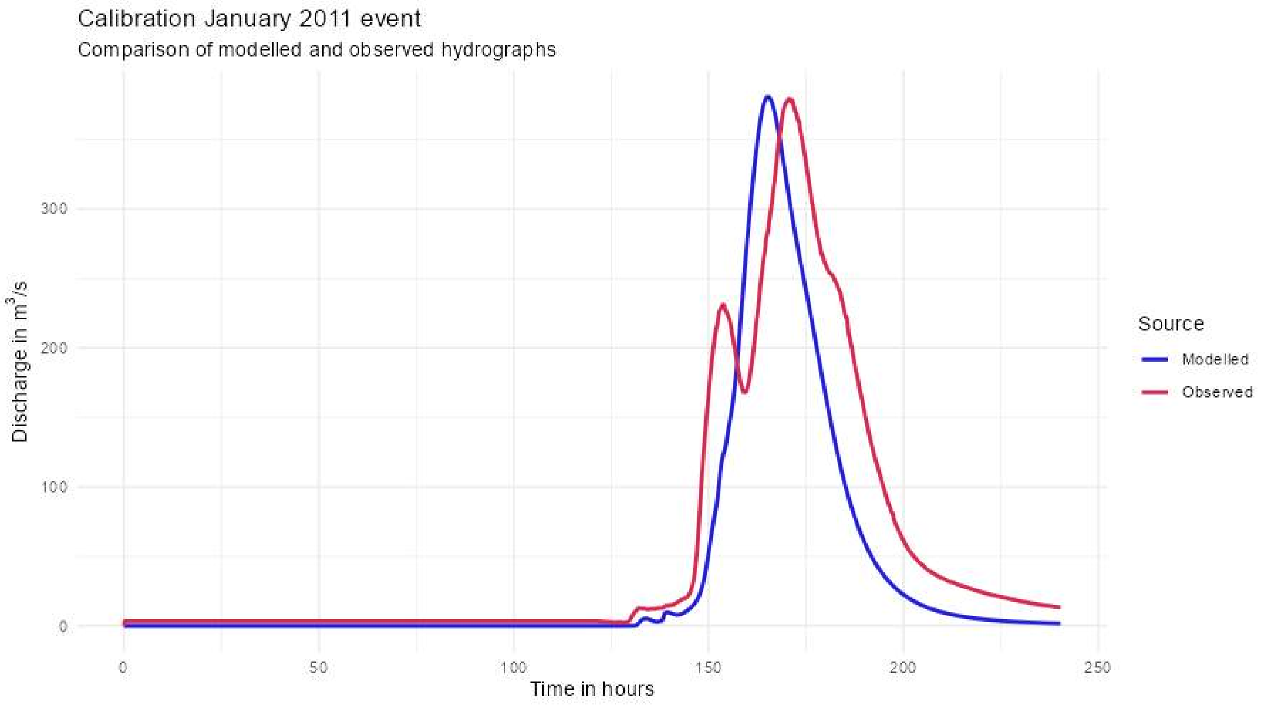


Figure H-13: January 2011 calibration event.

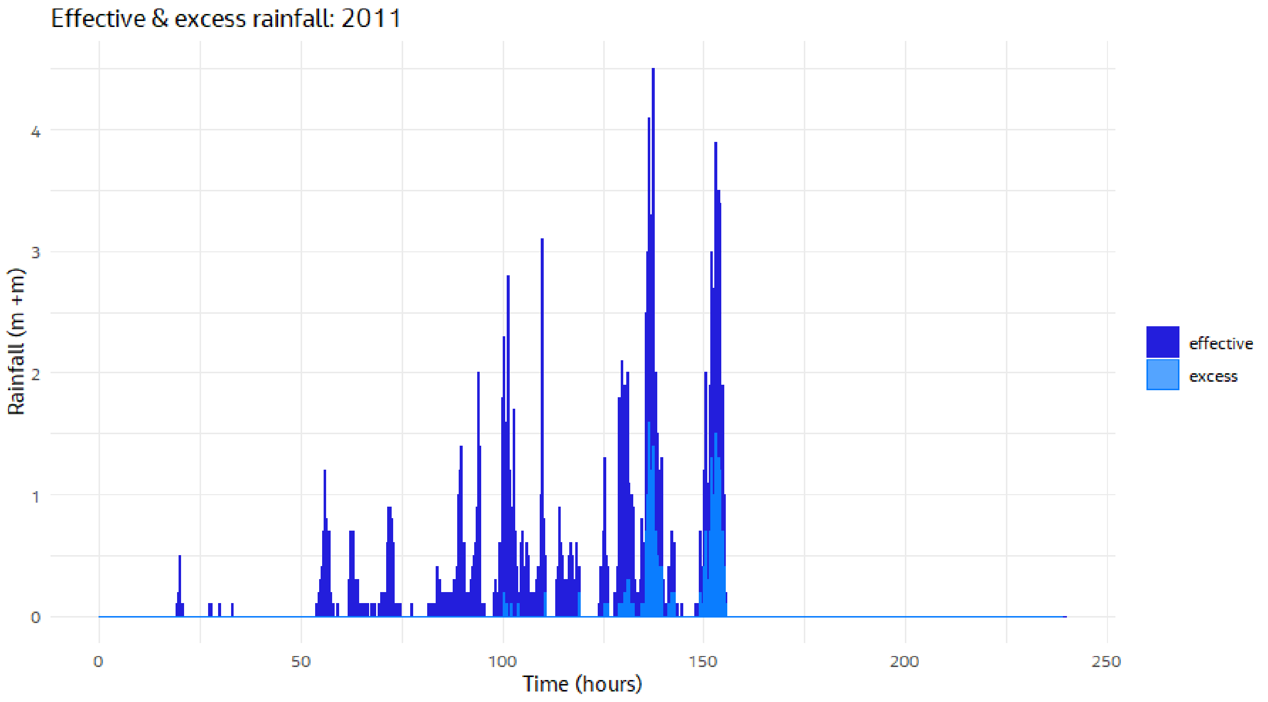


Figure H-14: October 2011 calibration event total and effective hyetographs.

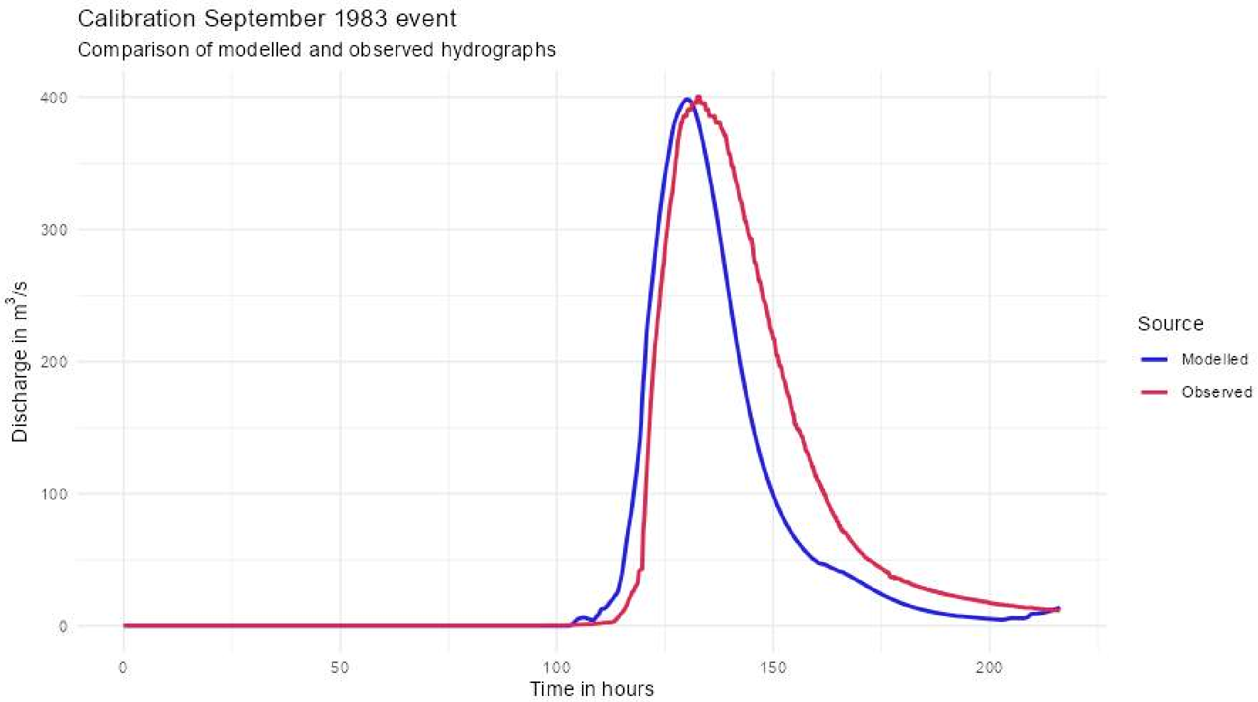


Figure H-15: October 1983 calibration event.

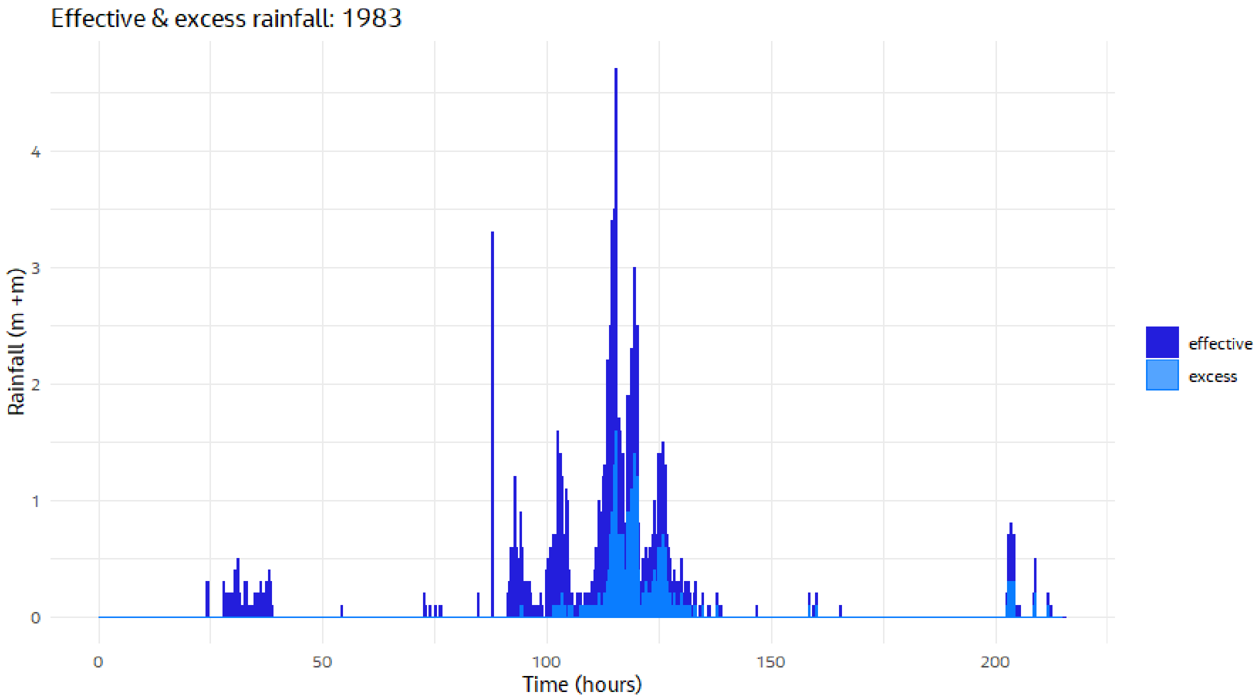


Figure H-16: October 1983 calibration event total and effective hyetographs.

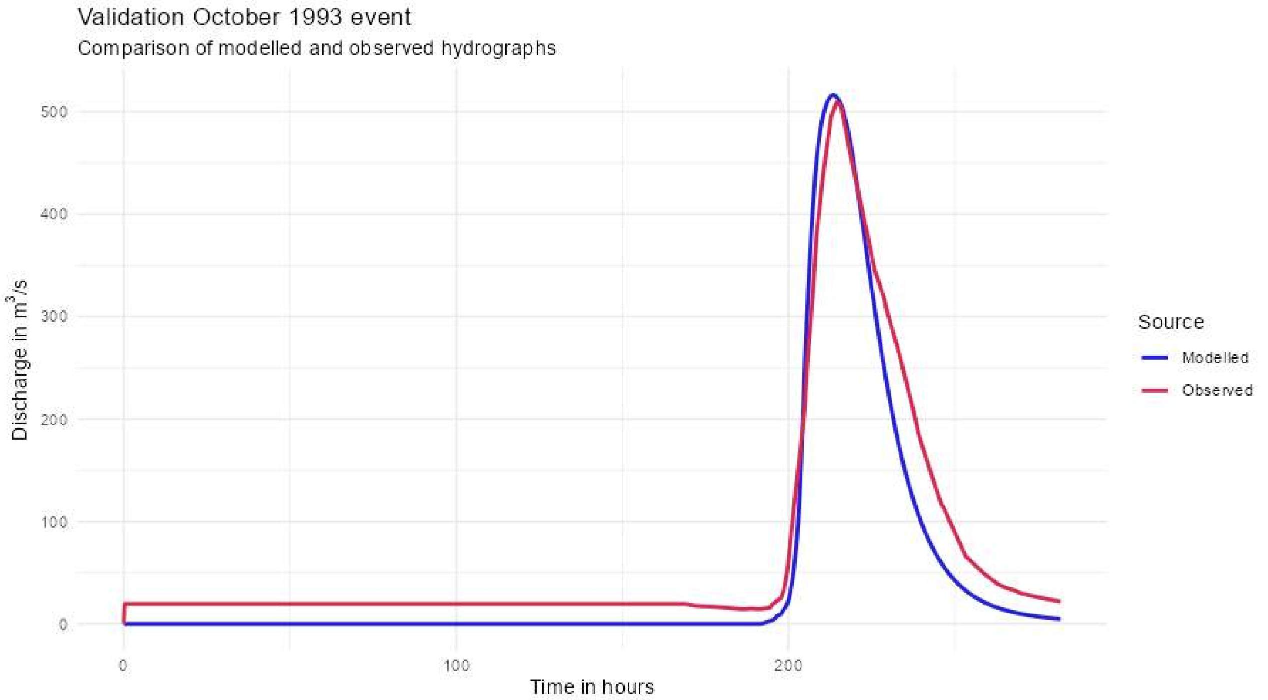


Figure H10-17: October 1993 validation event.

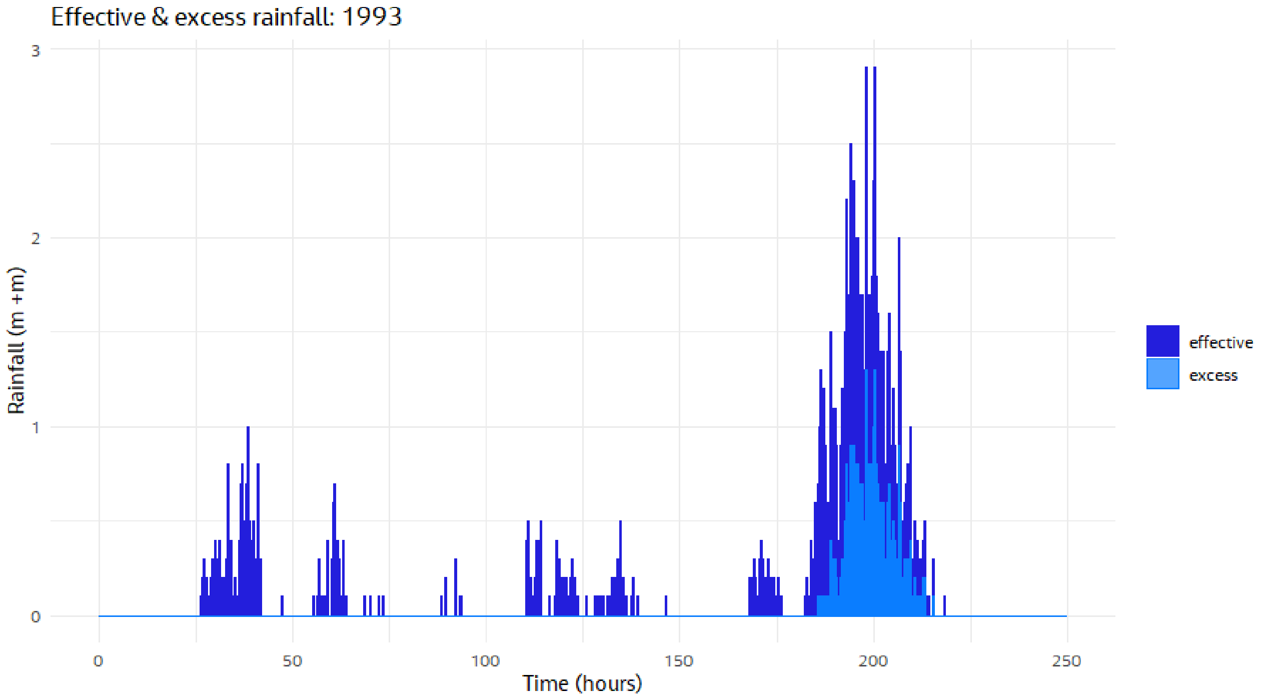
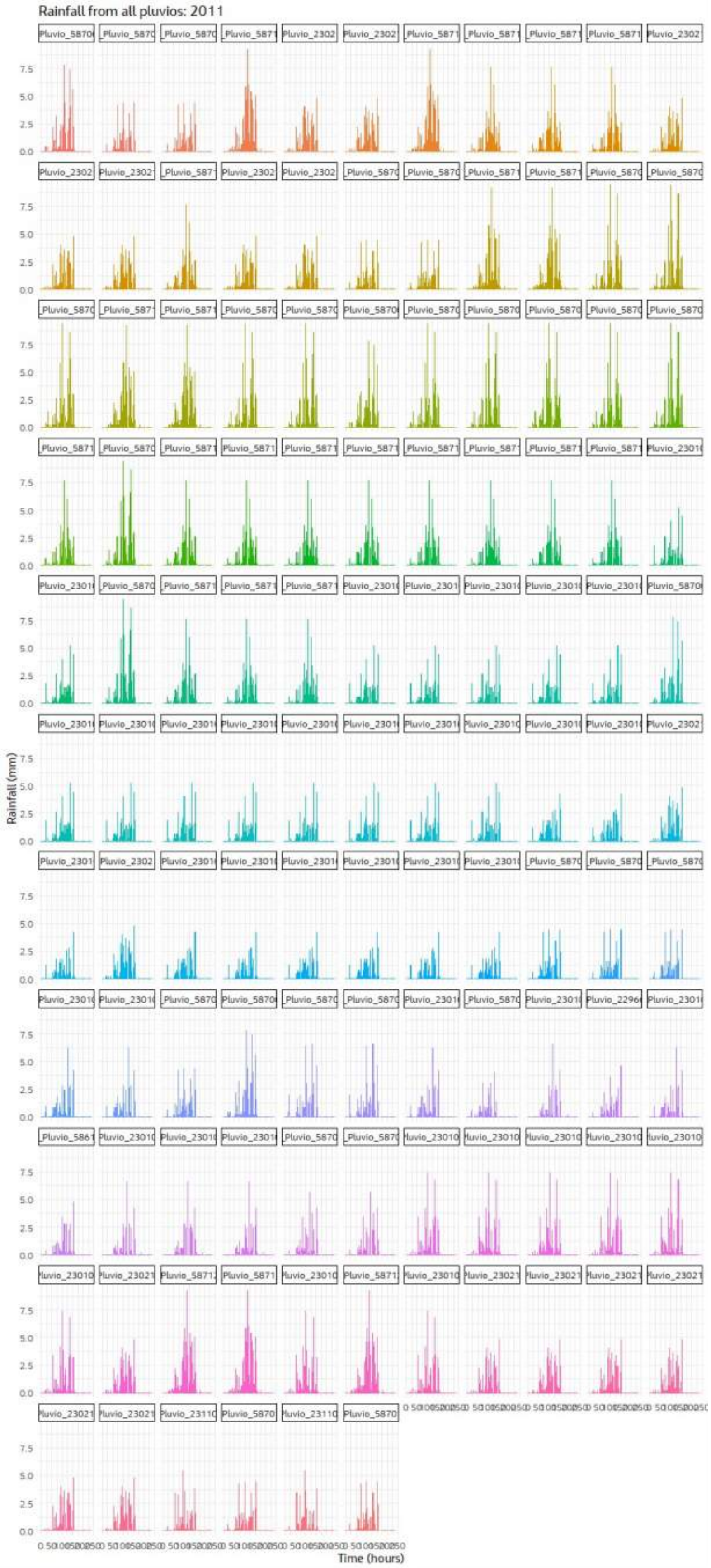


Figure H-18: October 1993 calibration event total and effective hyetographs.

Appendix I. Calibration and validation event hyetographs

I.1 October 2022 hyetographs

I.2 January 2011 hyetographs



I.3 September 1993 hyetographs

I.4 October 1983 hyetographs

Appendix J. RORB losses calibration

Several different combinations of K_c, m, IL and CL values were tested to determine the probability neutral losses. Multiple Pre-Burst and spatial patterns were also tested. These are presented in this Appendix.

These results show that a K_c of 105, a 'm' of 0.8, an IL of 10mm and a continuing loss of around 0.8mm/hr with a standard pre-burst of 75th percentile and a Design Spatial Pattern produces the closest results.

Table J-1: Summary of process followed to determine the probability neutral losses.

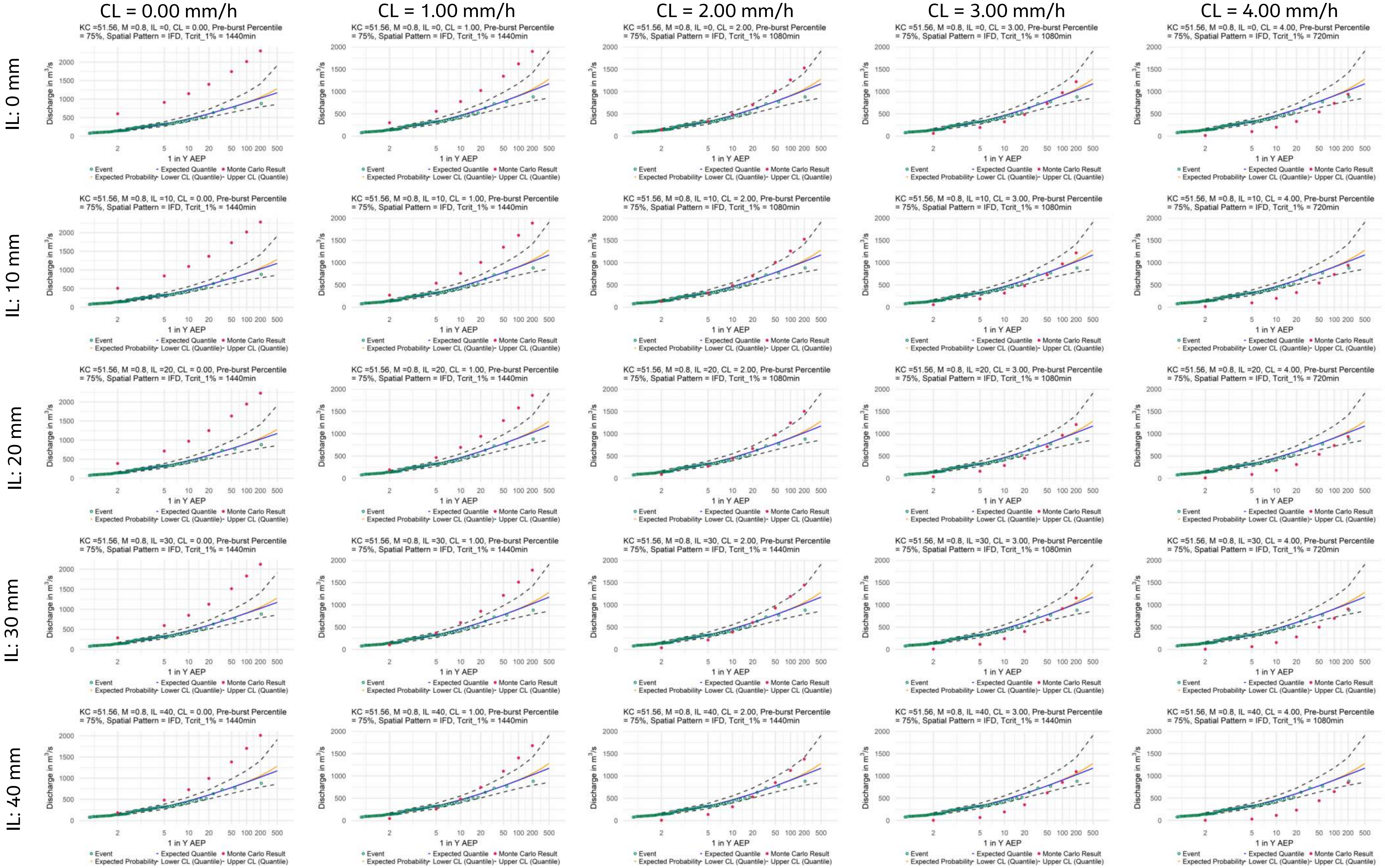
Approach	Parameter and Run Setup Details	Finding
Typical Approach: Initial Attempt	K_c = 51.56 (Fixed from event calibration), m = 0.8 (Fixed), IL = Variable, CL = Variable, Pre-burst = 75th percentile, Design IFD Spatial Pattern	Not an adequate representation of the FFA quantiles given the level of confidence established in the data. The curve of the Monte Carlo results is too steep.
Alternate Approach: Replace Design Spatial Pattern with Event Spatial Pattern	K_c = 51.56 (Fixed from event calibration), m = 0.8 (Fixed), IL = Variable, CL = Variable, Pre-burst = 75th percentile, October 2022 Event Spatial Pattern	No meaningful improvement to steep shape of the Monte Carto results compared with FFA quantiles.
Alternate Approach: Update 'm' Parameter	K_c = 27 (Fixed from updated event calibration with m=0.9), m = 0.9 (Fixed), IL = Variable, CL = Variable, Pre-burst = 75th percentile, Design Spatial Pattern	No meaningful improvement to steep shape of the Monte Carto results compared with FFA quantiles.
Alternate Approach: Increase Pre-Burst	K_c = 51.56 (Fixed from event calibration), m = 0.8 (Fixed), IL = Variable, CL = Variable, Pre-burst = 90th percentile, Design Spatial Pattern	No meaningful improvement to steep shape of the Monte Carto results compared with FFA quantiles.
Alternate Approach: Remove Constraint of Fixed Routing Parameter K_c (set 'm' to 0.8)	K_c = Variable, m = 0.8 (Fixed), IL = Variable, CL = Variable, Pre-burst = 75th percentile, Design Spatial Pattern	Able to closely replicate FFA quantiles with a K_c value of 105 and m of 0.8.
Alternate Approach: Remove Constraint of Fixed Routing Parameter K_c (set 'm' to 0.9)	K_c = Variable, m = 0.9 (Fixed), IL = Variable, CL = Variable, Pre-burst = 75th percentile, Design Spatial Pattern	Able to closely replicate FFA but no improvement to fit achieved with m = 0.8.
Alternate Approach: Remove Constraint of Fixed Routing Parameter K_c (set 'm' to 1.0)	K_c = Variable, m = 1.0 (Fixed), IL = Variable, CL = Variable, Pre-burst = 75th percentile, Design Spatial Pattern	Able to closely replicate FFA but no improvement to fit achieved with m = 0.8.
Final Approach: Fix new routing parameters and calibrate losses	**K_c = 105 (Fixed), m = 0.8 (Fixed), IL = Variable, CL = Variable, Pre-burst = 75th percentile, Design Spatial Pattern**	**The losses that provided the best fit to the FFA quantiles with a K_c value of 105 and m value of 0.8 were IL = 10mm, and CL = 0.8mm/h**

Typical Approach: Initial Attempt

Finding: Not an adequate representation of the FFA quantiles given the level of confidence established in the data. The curve of the Monte Carlo results is too steep.

K_c = 51.56 (Fixed from event calibration), m = 0.8 (Fixed),

IL = Variable, CL = Variable, 75% Pre-burst, Design IFD Spatial Pattern

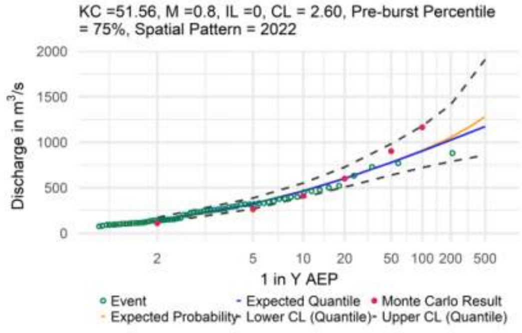


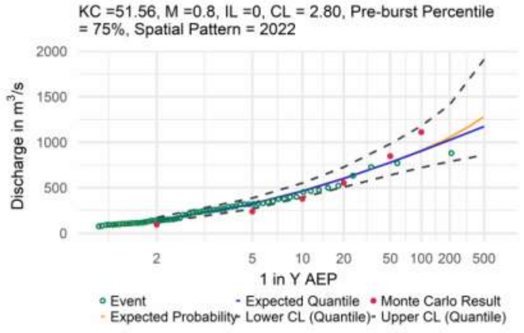
Alternate Approach: Replace Design Spatial Pattern with Event Spatial Pattern

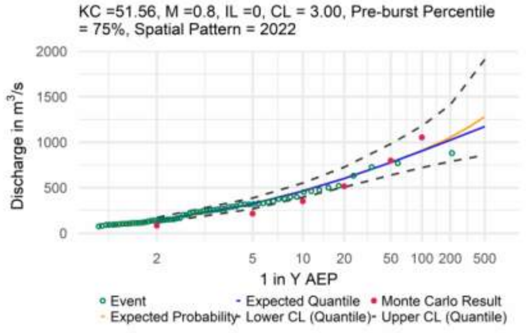
Finding: No meaningful improvement to steep shape of the Monte Carto results compared with FFA quantiles. The 200 Year Monte Carlo results were not produced for this test.

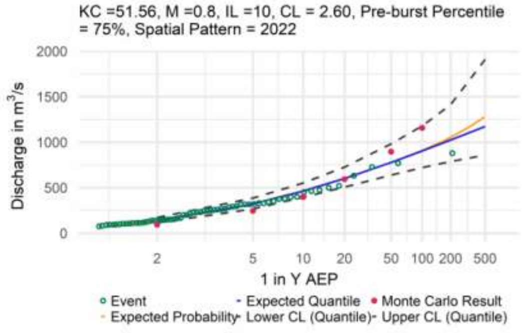
Kc = 51.56 (Fixed from event calibration), m = 0.8 (Fixed),

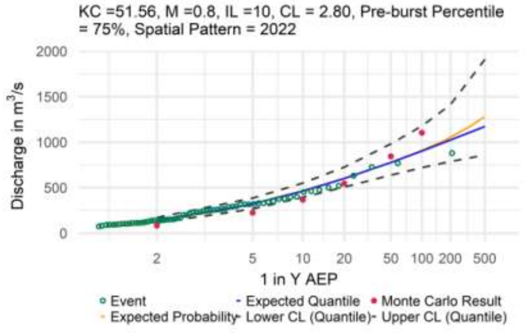
IL = Variable, CL = Variable, 75% Pre-burst, October 2022 Event Spatial Pattern

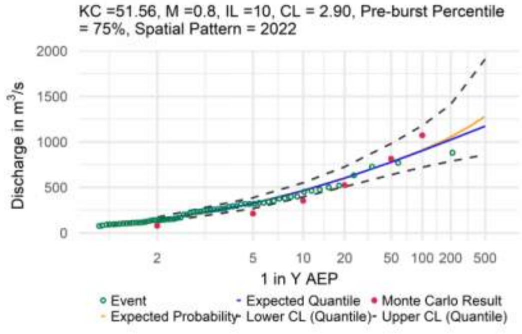


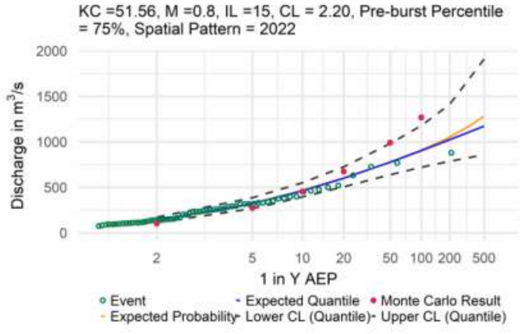


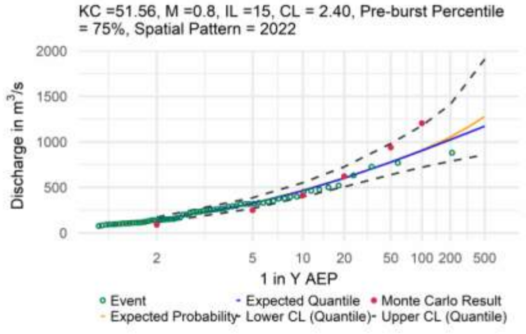


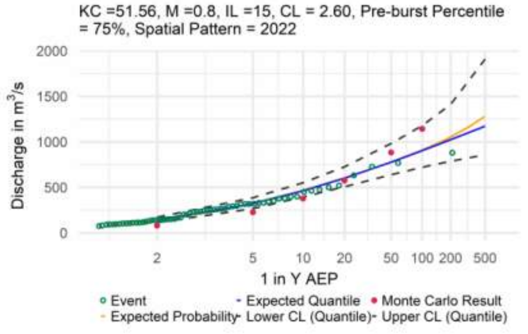


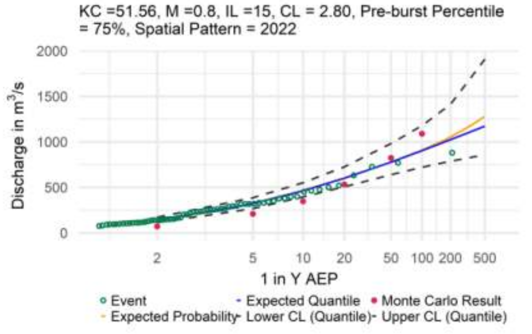


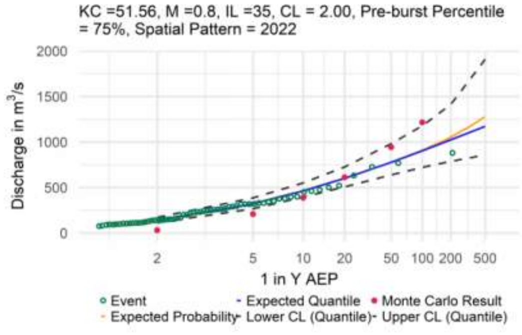










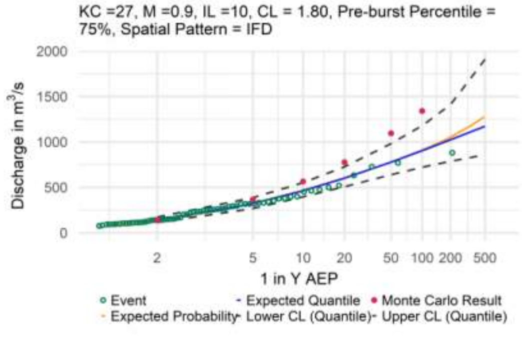


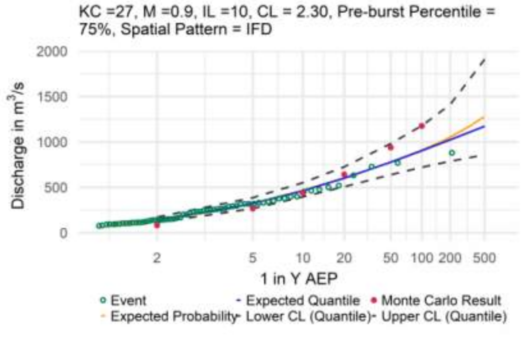
Alternate Approach: Update 'm' Parameter

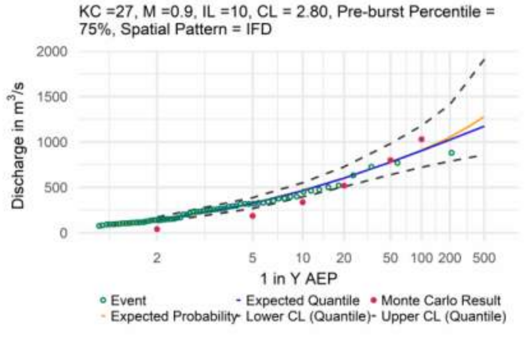
Finding: No meaningful improvement to steep shape of the Monte Carto results compared with FFA quantiles. The 200 Year Monte Carlo results were not produced for this test.

Kc = 27 (Fixed from updated event calibration with m=0.9), m = 0.9 (Fixed),

IL = Variable, CL = Variable, 75% Pre-burst, Design Spatial Pattern





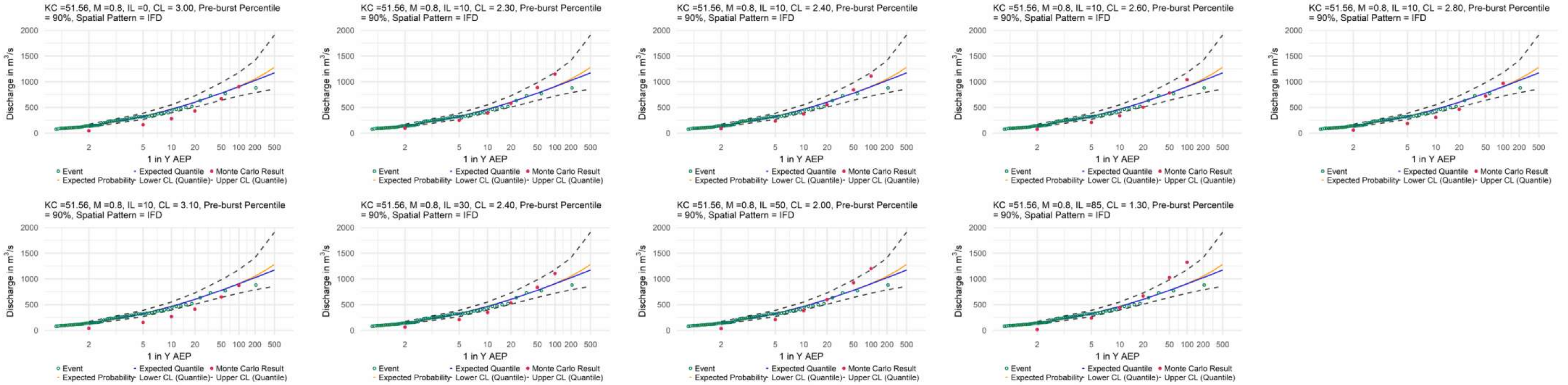


Alternate Approach: Increase Pre-Burst

Finding: No meaningful improvement to steep shape of the Monte Carto results compared with FFA quantiles. The 200 Year Monte Carlo results were not produced for this test.

Kc = 51.56 (Fixed from event calibration), m = 0.8 (Fixed),

IL = Variable, CL = Variable, 90% Pre-burst, Design Spatial Pattern

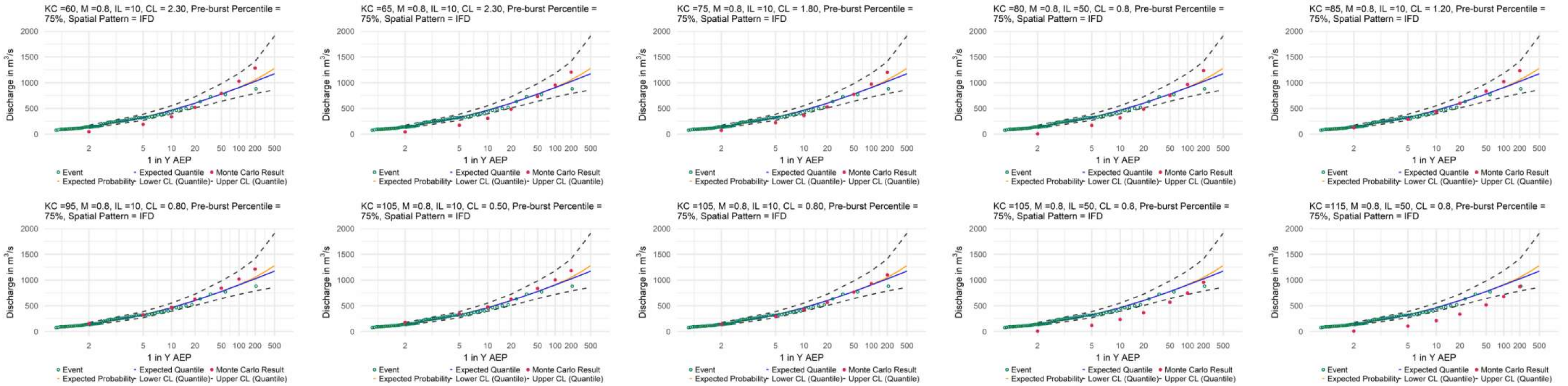


Alternate Approach: Remove Constraint of Fixed Routing Parameter Kc (set 'm' to 0.8)

Finding: Able to closely replicate FFA quantiles with a Kc value of 105 and m of 0.8.

Kc = Variable, m = 0.8 (Fixed), IL = Variable, CL = Variable,

75% Pre-burst, Design IFD Spatial Pattern

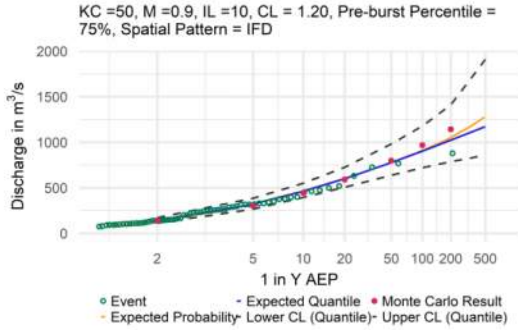


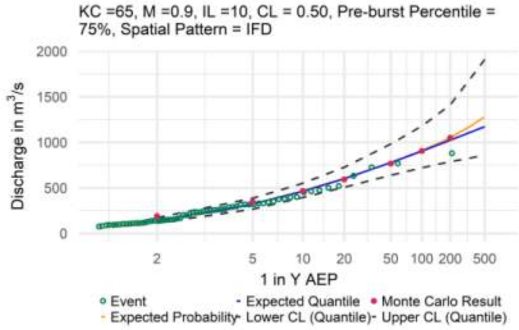
Alternate Approach: Remove Constraint of Fixed Routing Parameter Kc (set 'm' to 0.9)

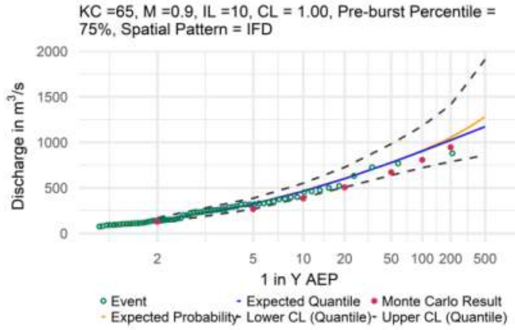
Finding: No improvement compared with kc of 105 and m of 0.8, although good fits were able to be obtained.

Kc = Variable, m = 0.9 (Fixed), IL = Variable, CL = Variable,

75% Pre-burst, Design IFD Spatial Pattern





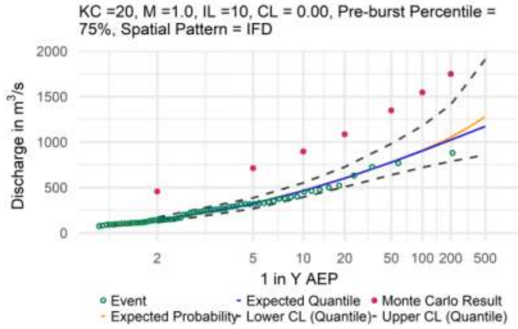


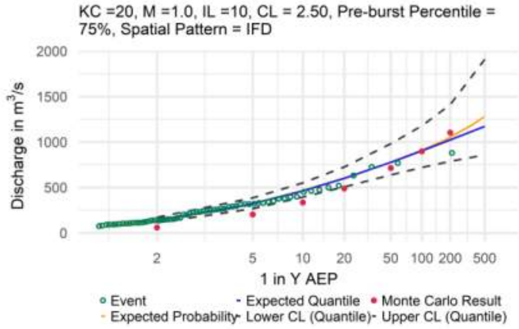
Alternate Approach: Remove Constraint of Fixed Routing Parameter Kc (set 'm' to 1.0)

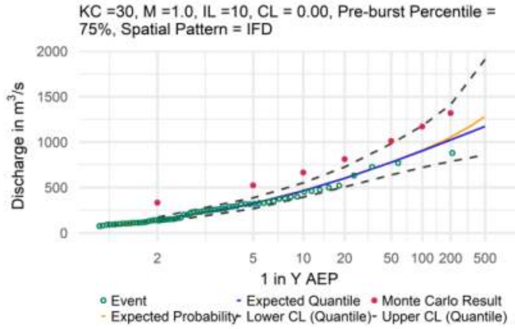
Finding: No improvement compared with kc of 105 and m of 0.8, although good fits were able to be obtained.

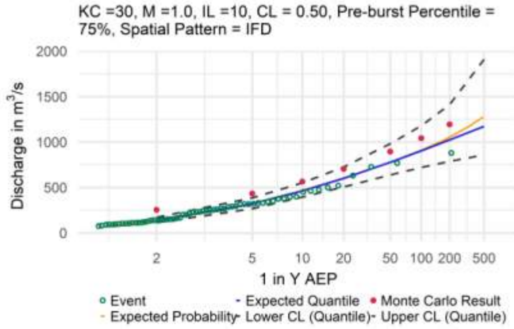
Kc = Variable, m = 1.0 (Fixed), IL = Variable, CL = Variable,

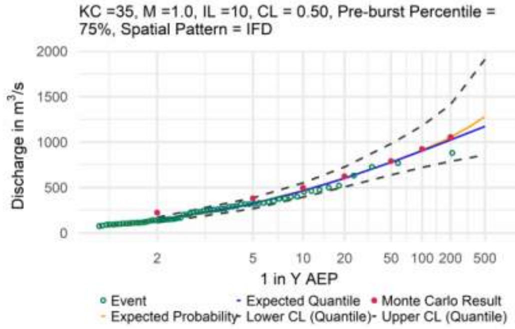
75% Pre-burst, Design IFD Spatial Pattern

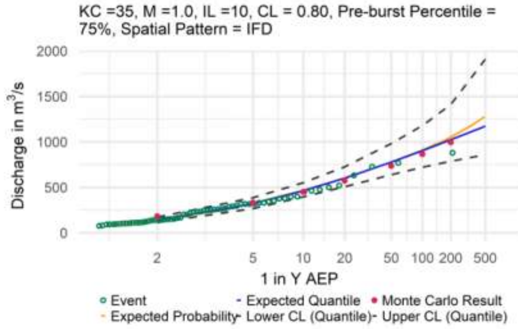


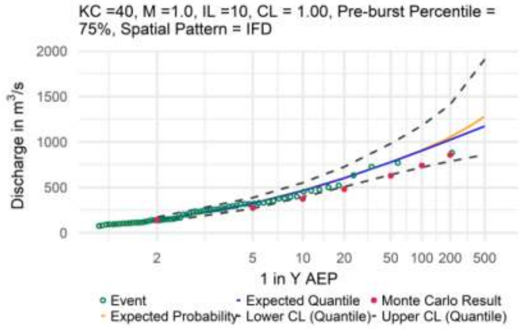


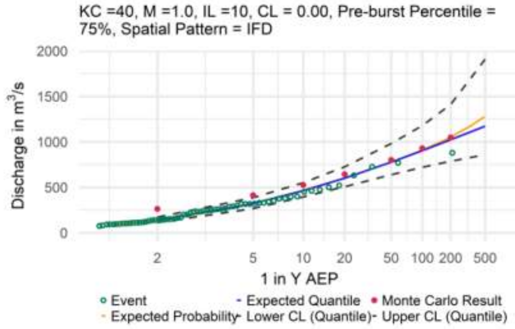


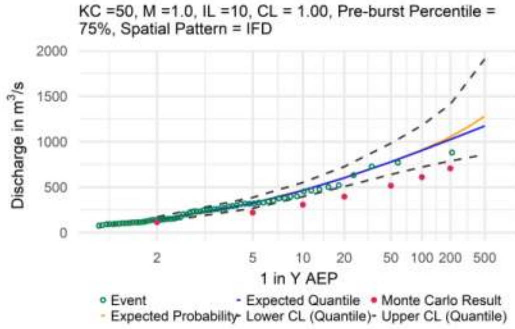


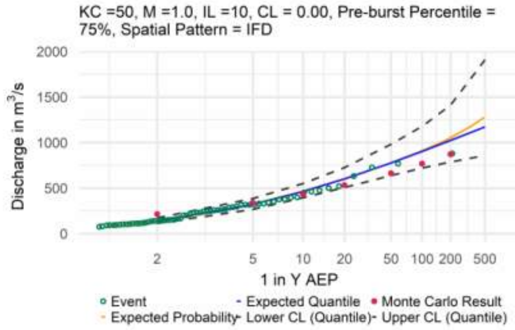


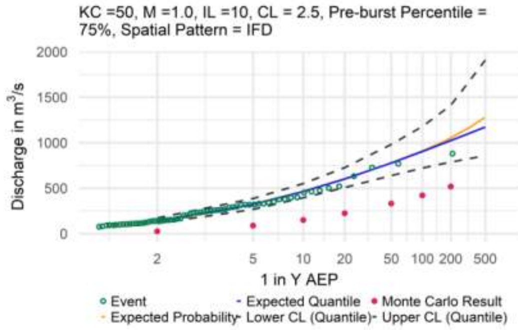


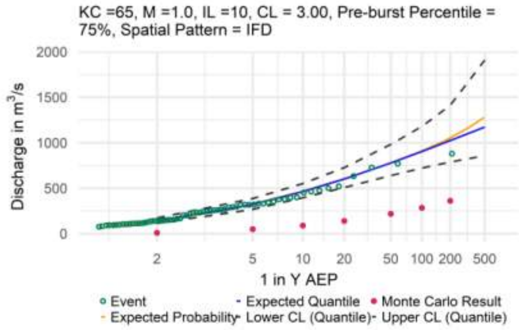










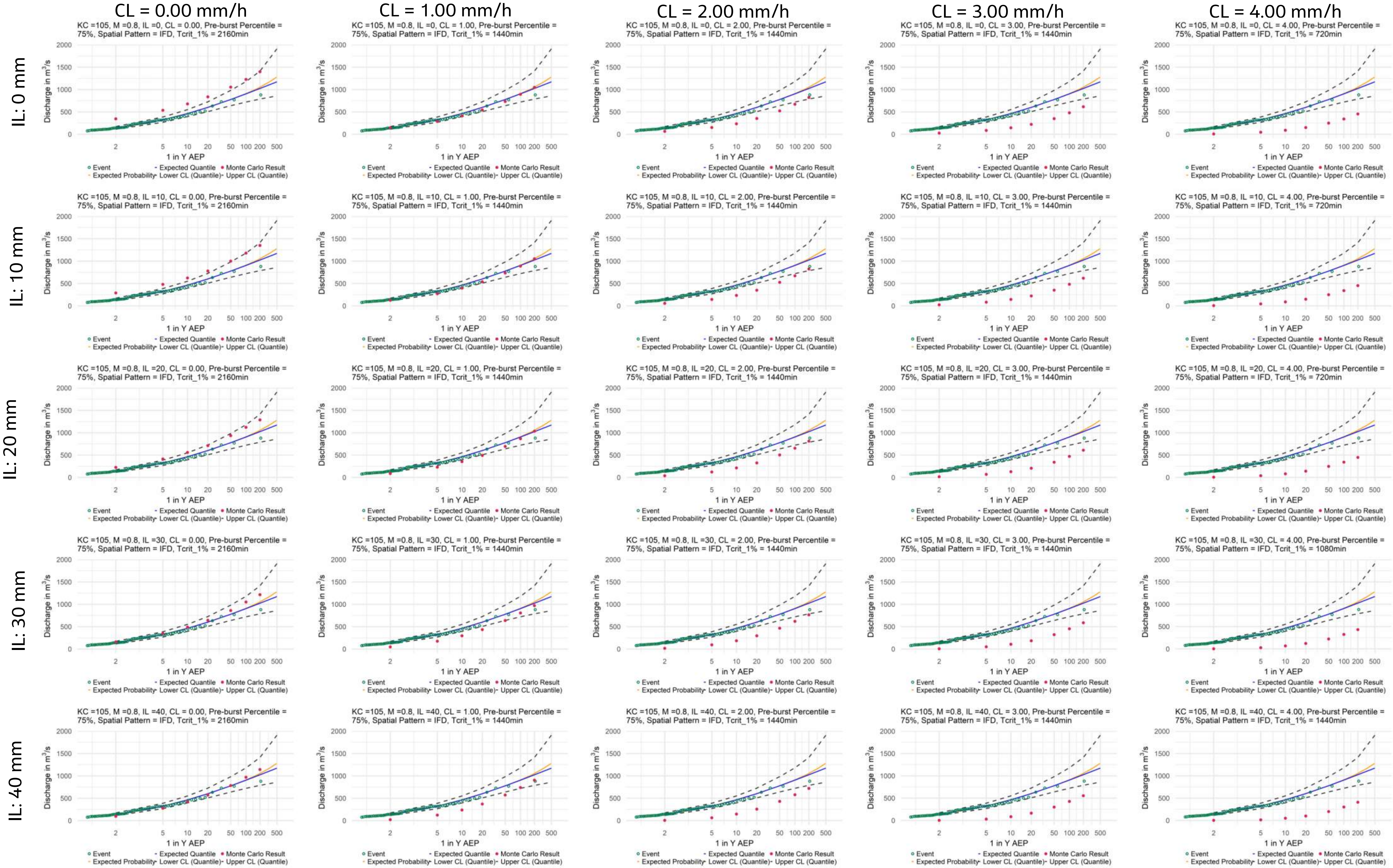


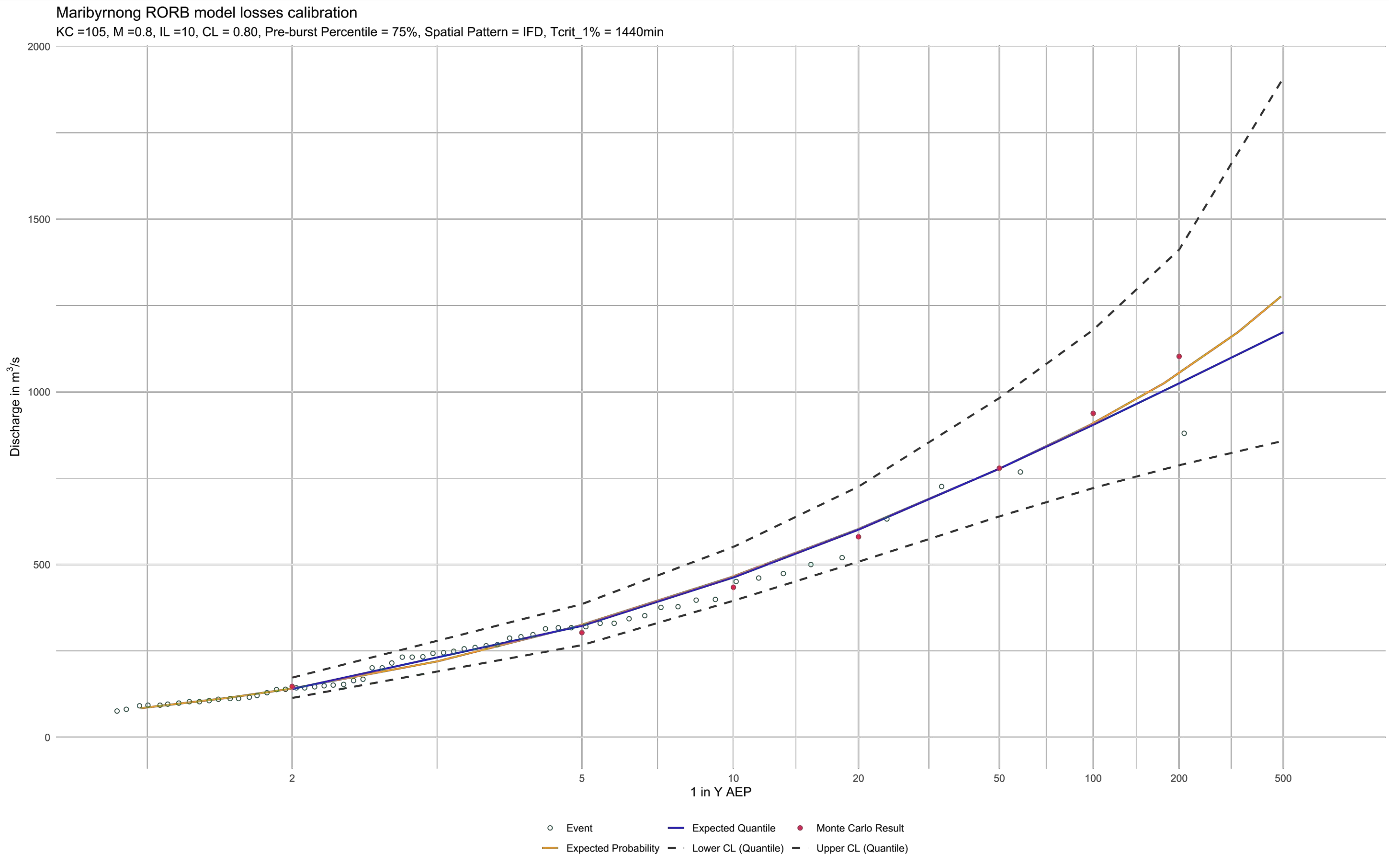
Final Approach: Fix routing parameters which produced a good fit to FFA quantiles and calibrate losses

Finding: The losses that provided the best fit to the FFA quantiles were IL = 10mm, and CL = 0.8mm/h

Kc = 105 (Fixed), m = 0.8 (Fixed), IL = Variable, CL = Variable,

75% Pre-burst, Design IFD Spatial Pattern




Maribyrnong RORB model losses calibration
KC =105, M =0.8, IL =10, CL = 0.80, Pre-burst Percentile = 75%, Spatial Pattern = IFD, Tcrit_1% = 1440min
Discharge in m3/s
2000
1500
1000
500
0
2
5
10
20
50
100
200
500
1 in Y AEP
Event
Expected Quantile
Monte Carlo Result
Expected Probability
Lower CL (Quantile)
Upper CL (Quantile)

Appendix K. Spatial Pattern Details

DESIGN SPATIAL PATTERN

Table K-1: Design spatial pattern as a percentage of catchment average rainfall. (e.g. 120.0 represents a rainfall depth 20% higher than average).

Subarea	Area	5min	10min	15min	20min	25min	30min	45min	60min	90min	120min	180min	270min	360min	540min	720min	1080min	1440min	1800min	2160min	2880min	4320min	5760min	7200min	8640min	10080min
AR	12.92	102.36	102.73	102.6	102.58	102.34	102.08	101.49	100.95	100.01	99.35	98.51	97.74	97.25	96.84	96.56	97.48	97.74	98.14	98.28	99.36	101.04	102.39	103.43	104.16	104.72
AS	10.94	103.72	104.07	103.89	103.73	103.69	103.34	102.71	102.06	101.08	100.24	99.05	97.87	97.14	96.29	95.67	95.95	96.01	96.2	97.05	97.93	99.73	101.13	102.45	103.67	104.24
AT	14.08	101.68	101.6	101.62	101.49	101.39	101.24	100.79	100.21	99.39	98.7	97.7	96.57	95.86	95.03	94.78	94.67	94.51	94.91	95.32	96.22	97.71	99.27	100.39	101.32	101.92
AU	11.13	102.25	102.37	102.45	102.23	102.03	101.75	101.06	100.29	99.2	98.37	97.25	96.25	95.76	95.42	95.66	96.43	96.74	97.83	98.63	100.2	102.53	104.5	105.87	106.63	107.41
AV	10.49	101.04	100.57	100.67	100.61	100.55	100.31	100.11	99.65	98.96	98.32	97.33	96.23	95.52	94.6	94.16	93.98	93.84	93.9	94.18	95.07	96.28	97.62	98.81	99.61	100.24
AW	19.48	100.65	101.49	101.49	101.19	100.84	100.47	99.47	98.84	97.91	97.54	97.14	97.27	97.69	98.76	99.69	102.09	103.29	104.75	105.78	107.47	109.6	110.99	111.83	112.17	112.27
AX	19.31	99.17	99.8	99.65	99.53	99.29	99.09	98.35	97.91	97.31	96.94	96.57	96.53	96.61	97.04	97.46	98.51	99.36	100.07	100.62	101.54	103.32	104.33	105	105.53	105.92
AY	7.18	100.16	99.81	99.93	99.83	99.73	99.5	99.32	98.92	98.43	97.84	97.01	96.09	95.51	94.75	94.53	94.13	94.2	94.11	94.3	95.1	96.28	97.26	98.32	99.11	99.74
AZ	17.22	100.31	100.4	100.39	100.19	100.09	99.93	99.49	99.02	98.29	97.64	96.73	95.87	95.31	94.73	94.78	94.92	95.2	95.77	96.34	97.36	99.29	100.62	101.7	102.3	102.88
BB	8.26	100.65	100.93	100.94	100.79	100.69	100.4	99.78	99.17	98.25	97.32	96.22	95.04	94.37	93.63	93.43	94.03	94.27	94.91	95.52	97.08	99.47	101.38	102.69	103.67	104.48
BA	16.89	99.97	99.35	99.28	99.32	99.49	99.56	99.65	99.62	99.13	98.56	97.52	96.16	95.02	93.58	92.99	92.11	91.5	91.68	91.85	92.24	93.41	94.55	95.53	96.14	96.57
BC	7.06	98.6	98.9	98.73	98.66	98.6	98.29	97.94	97.61	97.08	96.7	96.14	95.76	95.61	95.53	95.67	96.33	96.7	96.85	97.66	98.5	99.99	100.87	101.7	102.21	102.8
BD	13.33	99.29	98.9	98.91	98.99	98.89	99	98.8	98.39	97.77	96.97	95.76	94.38	93.37	92.08	91.2	90.96	90.46	90.71	91.23	92.24	93.68	95.31	96.52	97.36	98.01
BE	13.14	98.88	98.91	98.73	98.73	98.71	98.67	98.5	98.29	97.78	97.4	96.77	96.04	95.57	95	94.66	94.93	94.78	95.18	95.52	96.2	97.38	98.47	99.25	99.91	100.33
BG	22.05	99.63	99.2	99.28	99.32	99.29	99.37	99.25	99.1	98.29	97.7	96.57	95.3	94.33	93.2	92.69	92.62	92.43	92.76	93.28	94.33	96.31	97.92	98.91	99.71	99.85
BF	17.8	99.4	98.9	98.91	98.99	98.99	99.09	99.08	99.02	98.54	98.12	97.24	96.27	95.51	94.57	93.88	93.64	93.81	94.05	94.5	95.28	96.83	97.92	98.74	99.38	99.69
BH	12.76	98.72	98.6	98.66	98.55	98.6	98.53	98.35	98.21	97.9	97.58	97.24	96.75	96.49	96.2	96.27	96.46	96.58	96.85	97.36	97.74	99.11	100.11	100.72	101.32	101.6
BI	11.79	98.92	98.76	98.67	98.61	98.79	98.66	98.71	98.67	98.5	98.3	98.06	97.62	97.35	97.02	97.04	97.16	96.97	97.01	97.51	97.79	98.91	99.76	100.4	100.78	101.03
BJ	10.43	98.6	99.13	99.09	98.83	98.6	98.29	97.82	97.28	96.69	96.52	96.37	96.62	97.02	97.84	98.8	100.17	101.21	102.33	102.56	103.91	105.25	106.18	107.14	107.31	107.84
BK	17.69	98.49	98.45	98.42	98.34	98.4	98.25	98.19	98.21	98.09	98.06	97.95	97.89	97.9	97.9	98.05	98.25	98.43	98.57	98.79	99.26	99.82	100.45	101.05	101.49	101.76
BL	14.29	99.17	98.75	98.91	98.88	98.89	99	99.08	99.1	99.06	99.06	98.92	98.77	98.65	98.47	98.35	98.76	98.66	98.78	98.79	99.45	100.34	100.79	101.38	101.65	101.92
BM	11.85	99.17	98.6	98.66	98.55	98.8	98.9	99.25	99.54	99.84	100.18	100.46	100.48	100.41	99.97	99.84	99.27	98.66	98.35	98.17	97.93	97.54	97.42	97.59	97.93	98.25
BN	20.53	100.77	99.65	99.65	99.75	100.09	100.3	100.96	101.54	102.18	102.42	102.5	102.06	101.35	100.11	98.65	96.97	95.2	94.05	92.87	91.86	90.52	90.17	90.35	90.8	91.38
BO	5.8	99.78	99	98.99	99.13	99.33	99.4	99.74	99.96	100.28	100.44	100.52	100.41	100.2	99.88	99.22	99.07	98.28	98.13	97.79	97.72	97.81	97.78	98.25	98.57	98.78
BP	10.59	100.86	99.72	99.63	99.93	100.19	100.31	100.96	101.4	101.76	101.84	101.66	101.05	100.39	99.17	98.15	96.77	95.63	94.77	94.29	93.68	93.24	93.44	93.76	94.16	94.63
BR	12.58	99.63	99.58	99.46	99.48	99.49	99.42	99.04	98.5	97.77	97.05	96.06	95.17	94.66	94.33	94.33	95.18	96.01	96.52	97.66	99.36	102.1	103.65	104.91	105.61	105.68
BS	17.1	99.63	99.13	99.28	99.15	99.19	99.28	99.16	98.95	98.54	98.2	97.52	96.88	96.43	95.93	95.67	95.95	96.35	96.85	97.36	98.5	100.26	101.38	102.45	102.7	102.8
BT	9.48	100.4	99.42	99.7	99.74	100.06	100.22	100.54	100.81	100.68	100.44	99.71	98.75	97.88	96.65	95.9	95.28	94.66	94.53	94.86	95.16	96.14	97.17	97.75	98.09	98.38
BU	15.6	100.31	99.35	99.46	99.64	99.79	99.98	100.26	100.5	100.49	100.41	100.05	99.45	98.9	98.14	97.46	97.1	96.7	96.85	96.75	97.08	97.62	98.34	98.74	99.06	99.45
BV	7.92	102.02	100.03	100.2	100.46	100.99	101.38	102.22	102.62	102.93	102.71	101.81	100.24	98.78	96.34	94.78	92.49	91.15	90.39	89.7	89.39	89.2	89.75	90.35	90.8	91.06
BY	7.35	102.41	101.5	101.44	101.87	102.15	102.39	102.9	103.06	102.97	102.55	101.6	100.09	98.95	97.27	96.3	94.94	94.58	94.51	94.79	95.32	96.4	97.45	98.14	98.42	98.12
BW	10	101.68	100.25	100.39	100.73	101.09	101.43	102.26	102.51	102.5	102.12	100.97	99.29	97.86	95.7	94.18	92.62	91.73	91.47	91.23	91.67	92.62	93.54	94.13	94.36	94.58
BX	8.89	102.2	100.52	100.61	101.01	101.4	101.85	102.67	103.03	103.08	102.76	101.64	99.88	98.35	96.01	94.24	92.29	91.42	90.97	90.45	90.52	91.29	91.97	92.56	92.89	92.92
BZ	16.19	102.36	100.93	100.76	101.11	101.59	101.94	102.95	103.4	103.8	103.68	102.8	101.22	99.67	97.09	95.22	92.49	90.81	89.42	88.79	87.97	87.36	87.47	87.88	88.38	88.66
CA	20.11	102.87	102.05	101.96	102.26	102.49	102.78	103.38	103.62	103.66	103.46	102.61	101.39	100.25	98.54	97.23	95.95	94.79	94.75	94.3	94.23	94.6	95.44	95.78	96.02	96.21
CB	12.16	101.68	100.25	100.26	100.51	100.89	101.15	101.93	102.51	102.89	102.89	102.45	101.31	100.18	98.2	96.56	94.41	92.66	91.47	90.62	89.96	89.12	88.99	89.36	89.83	90.26
BQ	9.56	103.04	101.38	101.31	101.6	101.89	102.36	103.32	104.06	104.78	104.83	104.34	103.07	101.55	98.64	96.56	92.88	89.77	88.13	86.64	84.55	82.36	81.66	81.96	82.55	83.39
CD	3.53	103.04	101.39	101.32	101.63	101.92	102.38	103.34	104.08	104.79	104.85	104.35	103.08	101.56	98.65	96.56	92.88	89.8	88.15	86.67	84.57	82.38	81.68	81.99	82.59	83.43
CE	11.02	103.72	102.28	102.05	102.42	102.64	103.06	103.81	104.28	104.87	104.92	104.57	103.53	102.37	100.09	98.35	95.95	93.93	92.65	91.85	90.25	89.2	88.99	89.11	89.59	90.1
CF	5.16	103.11	101.51	101.42	101.61	101.9	102.35	103.3	103.89	104.61	104.81	104.53	103.46	102.18	99.59	97.42	94.18	91.64	89.57	88.13	86.24	84.07	83.43	83.45	84.01	84.61
CG	9.06	102.36	101.15	100.94	101.11	101.44	101.8	102.58	103.17	103.9	104.21	104.18	103.4	102.43	100.54	98.35	95.56	93.58	91.68	90.32	88.54	86.57	85.96	85.91	86.43	86.99
CH	4.54	103.53	102.23	102.01	102.3	102.53	102.83	103.72	104.31	105.04	105.25	105.18	104.41	103.35	101.26	99.31	96.53	94.42	92.42	91.16	89.42	87.36	86.83	86.64	87.16	87.7

CI	7.7	101.98	100.98	100.81	100.97	101.23	101.61	102.31	102.9	103.7	104.03	104.18	103.68	102.9	101.4	99.56	97.25	95.09	93.55	92.29	90.43	88.7	87.99	87.8	88.3	89.02
CJ	11.85	103.72	102.5	102.36	102.58	102.89	103.11	103.89	104.58	105.23	105.54	105.61	105.04	104.22	102.48	101.03	98.51	96.12	94.48	93.48	91.67	89.64	88.82	88.7	88.86	89.3
CK	14.29	103.38	102.05	102.05	102.26	102.49	102.64	103.44	103.95	104.78	105.19	105.49	105.3	104.78	103.65	102.38	100.17	98.43	97.17	95.83	94.23	92.1	91.01	90.6	90.56	90.58
CL	17.13	100.31	99.35	99.28	99.32	99.64	99.98	100.63	101.06	101.76	102.18	102.5	102.47	102.14	101.14	100.14	98.63	97.05	95.88	95.21	93.95	92.36	91.77	92.08	92.26	92.74
CM	10.91	100.77	100.1	99.89	99.97	100.19	100.49	101.12	101.69	102.5	103.01	103.42	103.33	103	102.14	100.74	99.02	97.05	95.77	94.91	93.19	91.57	90.68	90.51	90.97	91.7
CN	13.84	100.65	100.03	99.83	99.97	100.24	100.4	101	101.62	102.34	102.89	103.34	103.46	103.25	102.64	101.93	100.17	98.43	97.49	96.13	94.52	92.89	92.02	91.83	91.77	92.26
CO	7.63	101.82	100.81	100.77	100.93	101.19	101.45	102.12	102.72	103.51	103.98	104.31	104.13	103.62	102.44	101.2	99.23	97.25	95.92	94.71	92.87	91.03	90.1	89.88	89.96	90.34
CP	13.86	99.4	98.75	98.66	98.66	98.8	99.09	99.57	99.99	100.75	101.36	102.19	102.85	103.2	103.14	103.12	102.34	101.44	100.72	99.81	98.69	97.19	96.24	95.94	95.82	96.33
CQ	6	102.03	101.04	101.05	101.21	101.53	101.75	102.36	102.93	103.64	104.15	104.46	104.42	104.09	103.35	102.27	100.25	98.82	97.49	96.58	94.93	92.69	91.86	91.3	91.25	91.38
CR	16.46	102.36	101.83	101.68	101.77	101.89	102.15	102.77	103.23	103.95	104.35	104.87	105.07	105.02	104.65	103.94	102.66	101.55	100.56	99.65	97.93	96.18	95.06	94.3	94.08	94.06
CS	10.65	100.51	99.99	99.87	100.08	100.21	100.32	100.85	101.34	102.02	102.63	103.33	103.79	103.96	104.02	103.69	102.71	101.77	100.76	99.95	98.6	96.93	96.06	95.29	95.1	95.31
CT	24.91	101.45	101	101.12	101.17	101.19	101.43	101.85	102.28	102.83	103.24	103.83	104.21	104.37	104.48	104.01	103.37	102.59	102.01	101.44	100.21	98.41	97.25	96.44	95.98	95.53
AF	15.52	99.12	100.43	100.43	100.09	99.7	99.21	98.16	97.45	96.67	96.5	96.67	97.66	98.81	101.14	103.03	106.36	108.82	110.48	112.01	114.25	116.75	117.87	118.15	118.15	117.83
AG	12.21	98.04	98.45	98.3	98.12	98.2	97.97	97.7	97.54	97.51	97.7	98.06	98.72	99.31	100.37	101.03	102.09	102.82	103.09	103.28	104.01	104.38	104.66	104.83	105.05	105.28
AH	10.16	98.26	98.45	98.36	98.17	98	97.87	97.7	97.61	97.47	97.41	97.67	97.93	98.31	98.84	99.25	100.17	100.51	101.04	101.34	101.63	102.36	102.9	102.94	103.43	103.76
AI	7.93	98.23	98.24	98.13	97.97	97.93	97.88	97.76	97.67	97.75	97.9	98.24	98.7	99.11	99.81	100.11	100.87	101.21	101.55	101.58	101.96	102.24	102.49	102.59	102.94	103.09
AJ	8.4	97.64	97.38	97.28	97.22	97.31	97.46	97.81	98.11	98.74	99.22	99.91	100.6	100.95	101.14	101.3	100.85	100.62	99.85	99.59	98.97	97.9	97.43	97.21	97.07	97.25
AC	10.33	98.6	100.03	100.02	99.64	99.27	98.79	97.76	97.11	96.6	96.44	96.91	98.13	99.49	101.89	103.94	107.65	109.87	111.7	113.28	115.3	117.36	118.19	118.37	118.12	117.78
AD	7	97.31	97.57	97.45	97.37	97.22	97.18	97.09	97.21	97.51	97.81	98.56	99.54	100.32	101.17	101.84	103.16	103.48	103.4	103.6	103.44	103.13	102.86	102.89	102.86	103.04
AE	12.67	97.92	98.23	98.17	98.01	97.7	97.59	97.33	97.28	97.28	97.5	97.98	98.85	99.61	100.64	101.48	102.86	103.63	103.63	104.09	104.48	104.73	104.66	104.91	104.89	105.2
AK	10.99	97.03	97.39	97.08	97.05	96.89	96.86	96.8	96.85	97.22	97.69	98.62	99.74	100.7	101.93	102.6	103.92	104.41	104.41	104.59	104.25	103.97	103.42	103.26	103.04	103.13
AM	20.26	98.26	98.01	97.93	97.9	98	98.06	98.27	98.58	99.06	99.47	100	100.48	100.72	101.11	100.74	100.81	100.28	100.07	99.81	99.07	98.59	98.26	98.41	98.41	98.73
AN	13.57	98.6	98.23	97.99	98.01	98.15	98.15	98.68	99.06	99.71	100.15	100.81	101.36	101.55	101.64	101.03	100.94	100.17	99.43	99.19	98.22	97.36	96.83	96.77	96.87	97.29
AL	14.19	98.26	97.78	97.62	97.68	97.7	97.87	98.31	98.73	99.52	100.06	100.74	101.42	101.84	101.64	101.93	101.32	100.51	100.07	99.5	98.5	97.36	96.57	96.27	96.39	96.57
AO	7.06	98.67	98.42	98.35	98.34	98.45	98.58	99.02	99.48	100.15	100.74	101.56	102.33	102.72	102.91	103.13	102.67	101.74	101.05	100.38	99.47	97.95	97.05	96.46	96.33	96.52
AP	20.76	98.67	98.45	98.32	98.4	98.54	98.66	98.97	99.39	99.99	100.48	101.21	101.88	102.25	102.54	102.64	102.39	101.9	101.11	100.79	99.87	98.52	97.59	96.87	96.63	96.52
AQ	13.93	99.63	99.35	99.46	99.48	99.49	99.7	100.14	100.5	101.08	101.56	102.19	102.74	103.02	103.14	103.27	102.47	101.55	101.04	100.42	99.64	97.89	97.08	96.27	95.9	95.61
CU	13.96	101.45	101.45	101.62	101.6	101.79	101.89	102.18	102.51	102.76	103.01	103.37	103.46	103.47	103.48	103.12	102.6	101.9	101.15	100.83	99.83	98.24	97.08	96.11	95.17	94.58
A	16.28	103.38	105.65	105.92	105.52	104.89	104.04	102.34	101.17	99.62	98.73	98.29	98.72	99.55	101.64	103.72	107.08	109.18	111.37	112.97	115.01	117.62	118.82	119.23	119.21	118.86
B	7.15	103.36	105.36	105.56	105.09	104.49	103.88	102.32	101.04	99.67	98.93	98.58	99.02	99.9	101.82	103.86	107.18	109.44	111.38	112.83	115.26	117.52	118.67	119.17	119.15	119.15
C	17.84	99.63	101.6	101.62	101.28	100.79	100.21	99	98.13	97.18	96.82	96.83	97.63	98.61	100.14	102.23	105.16	106.98	108.47	109.6	110.84	112.27	112.59	112.4	112.33	111.83
D	6.3	98.37	100.46	100.37	100.06	99.58	99.07	97.73	96.93	96	95.77	96.05	97.07	98.32	100.6	102.82	106.03	107.92	109.53	110.7	111.86	113.13	113.41	112.96	112.47	111.97
E	16.03	102.02	103.85	104.08	103.56	103.09	102.5	101.12	100.06	99.03	98.47	98.29	98.79	99.61	101.64	103.27	105.93	107.79	109.44	110.52	112.74	114.2	115.03	115.53	115.57	115.5
F	11.67	96.34	97.65	97.6	97.26	96.92	96.59	95.97	95.66	95.47	95.73	96.57	98	99.33	101.55	103.19	105.79	106.94	107.98	108.33	108.92	109.13	108.5	108.03	107.58	107.14
G	17.91	98.78	100.14	100.11	99.81	99.42	99.07	98.25	97.78	97.28	97.28	97.63	98.49	99.46	101.14	102.6	104.58	105.71	106.69	107.31	108.18	108.94	108.96	108.86	108.77	108.67
H	10.69	95.19	96.66	96.51	96.21	95.75	95.49	94.77	94.5	94.46	94.76	95.91	97.74	99.49	102.14	104.16	107.46	108.83	110.08	110.52	111.31	111.31	110.48	109.6	109.01	108.31
I	24.54	94.85	95.98	95.96	95.64	95.22	95	94.52	94.28	94.6	95.2	96.75	98.99	100.9	103.9	105.95	109	110.74	111.53	111.9	112.17	111.83	110.86	109.85	109.13	108.79
J	8.67	94.19	95.38	95.09	94.93	94.57	94.36	94.03	93.94	94.41	95.17	96.86	99.27	101.36	104.21	106.56	109.99	111.44	112.27	112.39	112.56	111.73	110.63	109.82	108.99	108.53
K	17.22	95.08	95.46	95.47	95.29	95.1	95.07	95.18	95.32	95.95	96.64	97.85	99.47	100.76	102.14	103.72	105.16	105.37	105.45	105.32	105.14	103.85	102.98	102.2	101.81	101.6
L	15.3	100.65	102.05	101.86	101.6	101.14	100.82	99.78	99.06	98.25	97.94	97.98	98.66	99.49	100.64	102.82	104.77	106.75	107.82	108.99	110.46	112.1	112.75	113.06	113.14	113.11
M	11.6	99.97	101.6	101.49	101.28	100.69	100.26	98.92	98.17	97.38	97.23	97.52	98.66	100.02	102.64	105.06	108.61	111.26	113.31	115.11	117.58	120.25	121.35	121.45	121.15	120.78
N	13.55	96.56	97.56	97.43	97.19	96.95	96.75	96.23	96.17	96.21	96.52	97.44	98.85	100.14	102.14	103.72	105.54	106.75	107.18	107.46	107.61	107.62	106.94	106.39	106.1	105.92
O	20.15	99.17	100.7	100.63	100.3	99.79	99.37	98.27	97.47	96.79	96.7	97.08	98.33	99.71	102.48	104.61	107.97	110.45	112.56	114.09	116.34	118.41	119.33	119.48	119.29	118.86
P	13.93	96.56	97.11	97.07	96.78	96.57	96.26	95.93	95.84	96.06	96.57	97.71	99.35	100.7	102.64	104.61	106.5	107.44	107.98	108.23	108.47	108.02	107.32	106.77	106.46	106.52
Q	22.45	95.88	96.21	95.96	95.89	95.75	95.77	95.87	96.06	96.69	97.32	98.44	99.84	100.9	102.64	102.82	104.01	104.33	104.27	104.09	103.63	102.62	101.88	101.46	101	100.89
R	10.74	97.17	97.66	97.5	97.39	97.13	97	96.78	96.67	96.9	97.29	98.15	99.41	100.47	102.23	103.24	104.78	105.64	106.11	106.42	106.54	106.52	106.05	105.88	105.65	105.62

T	14.53	95.53	95.76	95.59	95.5	95.3	95.26	95.34	95.54	96.21	96.88	98.21	99.91	101.16	103.14	104.01	105.67	105.83	106.32	105.93	105.71	104.73	103.65	102.86	102.46	102.4
S	19.94	97.41	97.11	96.97	96.95	97.02	97.17	97.45	97.89	98.59	99.09	99.89	100.66	101.11	101.39	101.48	101.32	100.86	100.24	99.96	98.93	97.62	96.83	96.4	96.27	96.45
U	20.69	96.67	96.81	96.7	96.81	96.8	96.85	97.05	97.39	98.09	98.65	99.43	100.35	101	101.81	101.93	102.34	101.9	101.58	101.44	100.78	99.47	98.6	97.92	97.76	97.61
V	9.57	97.32	97.27	97.15	97.38	97.37	97.45	97.63	97.97	98.5	98.97	99.56	100.28	100.74	101.39	101.4	101.4	101.17	100.82	100.62	99.9	98.71	97.92	97.35	96.97	96.65
W	15.53	95.31	95.61	95.59	95.5	95.4	95.26	95.34	95.46	96.01	96.64	97.8	99.34	100.61	102.81	103.72	105.41	105.83	105.88	106.13	105.71	104.9	103.99	103.19	102.62	102.24
X	8.11	97.17	97.3	97.28	97.44	97.44	97.61	97.69	97.94	98.29	98.67	99.31	99.98	100.47	101	101.15	101.65	101.47	101.54	101.37	100.67	99.84	98.96	98.12	97.84	97.14
Y	10.24	95.53	96.21	96.33	96.38	96.35	96.47	96.48	96.5	96.89	97.23	97.98	98.85	99.55	100.14	101.03	102.09	102.25	102.33	102.26	102.2	101.31	100.37	99.48	99.06	98.49
Z	23.07	99.63	99.71	99.87	99.9	100.09	100.17	100.43	100.59	100.88	101.05	101.3	101.46	101.53	101.34	101.39	101.01	100.51	100.2	99.68	98.84	97.68	96.68	95.78	94.98	94.32
AA	15.31	98.26	98.68	98.91	98.83	98.89	98.86	99.04	99.17	99.32	99.44	99.74	100.1	100.37	100.64	100.59	100.94	100.51	100.72	100.42	99.64	98.68	97.84	97.01	96.39	95.85
AB	8.43	101.67	101.6	101.86	101.94	102.13	102.36	102.54	102.73	102.99	102.99	102.98	102.68	102.42	101.71	101.37	100.64	99.76	99.23	98.56	97.78	96.29	95.42	94.38	93.57	92.57
CV	9.27	103.6	103.07	103.39	103.63	103.8	104.09	104.53	104.73	104.95	104.84	104.53	103.83	103.15	102.25	101.23	99.67	98.42	97.66	97.36	96.33	94.6	93.81	92.68	91.63	90.88
CW	11.93	103.04	103.1	103.34	103.56	103.69	103.86	104.13	104.21	104.52	104.54	104.64	104.47	104.29	103.81	103.42	102.86	101.9	101.37	101.03	99.83	98.41	97.25	96.11	95.17	94.42
CX	5.27	105.22	104.52	104.88	105.34	105.62	105.9	106.46	106.75	106.74	106.45	105.56	104.26	103.05	101	99.96	97.99	96.81	96	95.33	94.74	93.51	92.53	91.81	90.78	89.64
CZ	11.69	100.28	100.54	100.75	100.9	100.93	101.08	101.25	101.44	101.55	101.48	101.5	101.3	101.08	100.65	100.52	99.79	99.27	98.93	98.7	97.96	96.76	95.95	95.04	94.18	93.44
DA	6.77	102.73	102.65	102.79	102.9	103.12	103.41	103.69	103.95	104.1	104.06	103.88	103.29	102.78	102	100.93	100	98.83	98.27	97.73	96.92	95.41	94.63	93.78	92.81	92.09
DB	8.92	104.06	103.62	103.71	104.05	104.44	104.46	105.03	105.29	105.36	105.36	104.87	104.05	103.25	102.14	100.59	99.4	98.43	97.49	97.05	95.94	94.73	93.79	92.82	92.02	91.3
CY	3.99	105.53	105.02	105.05	105.62	105.88	106.36	106.96	107.37	107.28	106.98	106.04	104.5	103.18	100.81	99.84	97.74	96.59	95.77	95.11	94.34	93.49	92.68	91.97	90.95	89.91
DC	4.61	105.77	105.3	105.5	106	106.38	106.81	107.43	107.74	107.68	107.25	106.11	104.39	102.96	100.69	99.34	97.27	96.16	95.45	94.81	94.21	93.51	93.14	92.48	91.5	90.5
DD	4.57	105.77	105.48	105.78	106.37	106.85	107.2	107.85	107.97	107.82	107.1	105.72	103.74	102.06	99.64	98.25	96.13	95.13	94.44	93.85	93.67	93.41	93.25	92.69	92.09	90.9
DE	6.61	105.88	105.79	106.13	106.69	107.05	107.35	107.91	107.91	107.65	106.99	105.6	103.72	102.19	100.05	98.77	96.89	95.81	95.32	94.78	94.49	94.3	93.93	93.48	92.67	91.54
DF	8.05	105.02	105.34	105.71	105.99	106.1	106.29	106.42	106.44	106.41	106.26	105.87	105.32	104.83	104.5	103.85	102.88	102.38	101.9	101.41	100.75	99.62	98.64	97.54	96.67	95.48
DG	7.76	104.8	104.8	105.19	105.5	105.67	105.89	106.24	106.31	106.35	106.14	105.6	104.83	104.14	103.31	102.37	101.08	100.28	99.77	99.11	98.37	97.4	96.27	95.34	94.37	93.19
DH	7.06	106.16	106.19	106.6	106.93	107.27	107.39	107.67	107.62	107.34	106.96	106.05	104.82	103.84	102.47	101.73	100.72	99.63	99.25	98.8	98.39	97.88	97.13	96.48	95.46	94.44
DI	4.66	106.33	106.39	106.84	107.32	107.69	107.84	108.17	108.19	107.69	107.09	105.76	104.05	102.69	100.8	99.68	98.34	97.14	96.81	96.59	96.09	96.08	95.71	95.07	94.34	93.18
DJ	9.27	106.79	107	107.77	108.14	108.48	108.81	108.93	108.73	107.8	106.78	104.72	102.34	100.55	98.04	96.56	94.8	93.93	93.62	93.68	93.38	93.94	93.54	93.31	92.5	91.78
DK	6.33	106.42	106.78	107.51	108.02	108.38	108.62	108.75	108.55	107.54	106.41	104.24	101.74	99.85	97.28	95.94	94.05	93.26	93.01	92.93	93.04	93.66	93.76	93.39	92.74	91.71
DL	5.8	106.32	106.97	107.7	108.39	108.72	108.77	108.85	108.38	107.11	105.69	103.16	100.36	98.33	95.63	94.29	92.5	91.86	91.45	91.62	92.05	93.02	93.41	93.31	92.74	91.54
DM	6.82	105.78	106.05	106.52	107.18	107.54	107.84	108.12	108.02	107.18	106.15	104.02	101.47	99.52	96.89	95.43	93.49	92.75	92.51	92.3	92.66	93.09	93.45	93.1	92.53	91.33

OCTOBER 2022 EVENT SPATIAL PATTERN

Table K-2. October 2022 event spatial pattern as a percentage of catchment average rainfall for the event. (e.g. 120.0 represents a rainfall depth 20% higher than average).

Subarea	Area	5min	10min	15min	20min	25min	30min	45min	60min	90min	120min	180min	270min	360min	540min	720min	1080min	1440min	1800min	2160min	2880min	4320min	5760min	7200min	8640min	10080min
AR	12.92	147.04	147.04	147.04	147.04	147.04	147.04	147.04	147.04	147.04	147.04	147.04	147.04	147.04	147.04	147.04	147.04	147.04	147.04	147.04	147.04	147.04	147.04	147.04	147.04	147.04
AS	10.94	136.31	136.31	136.31	136.31	136.31	136.31	136.31	136.31	136.31	136.31	136.31	136.31	136.31	136.31	136.31	136.31	136.31	136.31	136.31	136.31	136.31	136.31	136.31	136.31	136.31
AT	14.08	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38
AU	11.13	132.38	132.38	132.38	132.38	132.38	132.38	132.38	132.38	132.38	132.38	132.38	132.38	132.38	132.38	132.38	132.38	132.38	132.38	132.38	132.38	132.38	132.38	132.38	132.38	132.38
AV	10.49	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06
AW	19.48	99.52	99.52	99.52	99.52	99.52	99.52	99.52	99.52	99.52	99.52	99.52	99.52	99.52	99.52	99.52	99.52	99.52	99.52	99.52	99.52	99.52	99.52	99.52	99.52	99.52
AX	19.31	107.20	107.20	107.20	107.20	107.20	107.20	107.20	107.20	107.20	107.20	107.20	107.20	107.20	107.20	107.20	107.20	107.20	107.20	107.20	107.20	107.20	107.20	107.20	107.20	107.20
AY	7.18	156.98	156.98	156.98	156.98	156.98	156.98	156.98	156.98	156.98	156.98	156.98	156.98	156.98	156.98	156.98	156.98	156.98	156.98	156.98	156.98	156.98	156.98	156.98	156.98	156.98
AZ	17.22	151.26	151.26	151.26	151.26	151.26	151.26	151.26	151.26	151.26	151.26	151.26	151.26	151.26	151.26	151.26	151.26	151.26	151.26	151.26	151.26	151.26	151.26	151.26	151.26	151.26
BB	8.26	155.07	155.07	155.07	155.07	155.07	155.07	155.07	155.07	155.07	155.07	155.07	155.07	155.07	155.07	155.07	155.07	155.07	155.07	155.07	155.07	155.07	155.07	155.07	155.07	155.07
BA	16.89	148.87	148.87	148.87	148.87	148.87	148.87	148.87	148.87	148.87	148.87	148.87	148.87	148.87	148.87	148.87	148.87	148.87	148.87	148.87	148.87	148.87	148.87	148.87	148.87	148.87
BC	7.06	134.88	134.88	134.88	134.88	134.88	134.88	134.88	134.88	134.88	134.88	134.88	134.88	134.88	134.88	134.88	134.88	134.88	134.88	134.88	134.88	134.88	134.88	134.88	134.88	134.88
BD	13.33	138.33	138.33	138.33	138.33	138.33	138.33	138.33	138.33	138.33	138.33	138.33	138.33	138.33	138.33	138.33	138.33	138.33	138.33	138.33	138.33	138.33	138.33	138.33	138.33	138.33
BE	13.14	149.15	149.15	149.15	149.15	149.15	149.15	149.15	149.15	149.15	149.15	149.15	149.15	149.15	149.15	149.15	149.15	149.15	149.15	149.15	149.15	149.15	149.15	149.15	149.15	149.15
BG	22.05	150.34	150.34	150.34	150.34	150.34	150.34	150.34	150.34	150.34	150.34	150.34	150.34	150.34	150.34	150.34	150.34	150.34	150.34	150.34	150.34	150.34	150.34	150.34	150.34	150.34

BF	17.80	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06	127.06
BH	12.76	128.55	128.55	128.55	128.55	128.55	128.55	128.55	128.55	128.55	128.55	128.55	128.55	128.55	128.55	128.55	128.55	128.55	128.55	128.55	128.55	128.55	128.55	128.55	128.55	128.55
BI	11.79	106.51	106.51	106.51	106.51	106.51	106.51	106.51	106.51	106.51	106.51	106.51	106.51	106.51	106.51	106.51	106.51	106.51	106.51	106.51	106.51	106.51	106.51	106.51	106.51	106.51
BJ	10.43	139.33	139.33	139.33	139.33	139.33	139.33	139.33	139.33	139.33	139.33	139.33	139.33	139.33	139.33	139.33	139.33	139.33	139.33	139.33	139.33	139.33	139.33	139.33	139.33	139.33
BK	17.69	140.34	140.34	140.34	140.34	140.34	140.34	140.34	140.34	140.34	140.34	140.34	140.34	140.34	140.34	140.34	140.34	140.34	140.34	140.34	140.34	140.34	140.34	140.34	140.34	140.34
BL	14.29	121.10	121.10	121.10	121.10	121.10	121.10	121.10	121.10	121.10	121.10	121.10	121.10	121.10	121.10	121.10	121.10	121.10	121.10	121.10	121.10	121.10	121.10	121.10	121.10	121.10
BM	11.85	135.20	135.20	135.20	135.20	135.20	135.20	135.20	135.20	135.20	135.20	135.20	135.20	135.20	135.20	135.20	135.20	135.20	135.20	135.20	135.20	135.20	135.20	135.20	135.20	135.20
BN	20.53	112.49	112.49	112.49	112.49	112.49	112.49	112.49	112.49	112.49	112.49	112.49	112.49	112.49	112.49	112.49	112.49	112.49	112.49	112.49	112.49	112.49	112.49	112.49	112.49	112.49
BO	5.80	94.52	94.52	94.52	94.52	94.52	94.52	94.52	94.52	94.52	94.52	94.52	94.52	94.52	94.52	94.52	94.52	94.52	94.52	94.52	94.52	94.52	94.52	94.52	94.52	94.52
BP	10.59	93.90	93.90	93.90	93.90	93.90	93.90	93.90	93.90	93.90	93.90	93.90	93.90	93.90	93.90	93.90	93.90	93.90	93.90	93.90	93.90	93.90	93.90	93.90	93.90	93.90
BR	12.58	118.85	118.85	118.85	118.85	118.85	118.85	118.85	118.85	118.85	118.85	118.85	118.85	118.85	118.85	118.85	118.85	118.85	118.85	118.85	118.85	118.85	118.85	118.85	118.85	118.85
BS	17.10	98.24	98.24	98.24	98.24	98.24	98.24	98.24	98.24	98.24	98.24	98.24	98.24	98.24	98.24	98.24	98.24	98.24	98.24	98.24	98.24	98.24	98.24	98.24	98.24	98.24
BT	9.48	83.46	83.46	83.46	83.46	83.46	83.46	83.46	83.46	83.46	83.46	83.46	83.46	83.46	83.46	83.46	83.46	83.46	83.46	83.46	83.46	83.46	83.46	83.46	83.46	83.46
BU	15.60	76.64	76.64	76.64	76.64	76.64	76.64	76.64	76.64	76.64	76.64	76.64	76.64	76.64	76.64	76.64	76.64	76.64	76.64	76.64	76.64	76.64	76.64	76.64	76.64	76.64
BV	7.92	73.07	73.07	73.07	73.07	73.07	73.07	73.07	73.07	73.07	73.07	73.07	73.07	73.07	73.07	73.07	73.07	73.07	73.07	73.07	73.07	73.07	73.07	73.07	73.07	73.07
BY	7.35	125.98	125.98	125.98	125.98	125.98	125.98	125.98	125.98	125.98	125.98	125.98	125.98	125.98	125.98	125.98	125.98	125.98	125.98	125.98	125.98	125.98	125.98	125.98	125.98	125.98
BW	10.00	125.36	125.36	125.36	125.36	125.36	125.36	125.36	125.36	125.36	125.36	125.36	125.36	125.36	125.36	125.36	125.36	125.36	125.36	125.36	125.36	125.36	125.36	125.36	125.36	125.36
BX	8.89	107.16	107.16	107.16	107.16	107.16	107.16	107.16	107.16	107.16	107.16	107.16	107.16	107.16	107.16	107.16	107.16	107.16	107.16	107.16	107.16	107.16	107.16	107.16	107.16	107.16
BZ	16.19	120.16	120.16	120.16	120.16	120.16	120.16	120.16	120.16	120.16	120.16	120.16	120.16	120.16	120.16	120.16	120.16	120.16	120.16	120.16	120.16	120.16	120.16	120.16	120.16	120.16
CA	20.11	115.50	115.50	115.50	115.50	115.50	115.50	115.50	115.50	115.50	115.50	115.50	115.50	115.50	115.50	115.50	115.50	115.50	115.50	115.50	115.50	115.50	115.50	115.50	115.50	115.50
CB	12.16	95.62	95.62	95.62	95.62	95.62	95.62	95.62	95.62	95.62	95.62	95.62	95.62	95.62	95.62	95.62	95.62	95.62	95.62	95.62	95.62	95.62	95.62	95.62	95.62	95.62
BQ	9.56	93.96	93.96	93.96	93.96	93.96	93.96	93.96	93.96	93.96	93.96	93.96	93.96	93.96	93.96	93.96	93.96	93.96	93.96	93.96	93.96	93.96	93.96	93.96	93.96	93.96
CD	3.53	109.34	109.34	109.34	109.34	109.34	109.34	109.34	109.34	109.34	109.34	109.34	109.34	109.34	109.34	109.34	109.34	109.34	109.34	109.34	109.34	109.34	109.34	109.34	109.34	109.34
CE	11.02	97.18	97.18	97.18	97.18	97.18	97.18	97.18	97.18	97.18	97.18	97.18	97.18	97.18	97.18	97.18	97.18	97.18	97.18	97.18	97.18	97.18	97.18	97.18	97.18	97.18
CF	5.16	61.87	61.87	61.87	61.87	61.87	61.87	61.87	61.87	61.87	61.87	61.87	61.87	61.87	61.87	61.87	61.87	61.87	61.87	61.87	61.87	61.87	61.87	61.87	61.87	61.87
CG	9.06	107.12	107.12	107.12	107.12	107.12	107.12	107.12	107.12	107.12	107.12	107.12	107.12	107.12	107.12	107.12	107.12	107.12	107.12	107.12	107.12	107.12	107.12	107.12	107.12	107.12
CH	4.54	67.88	67.88	67.88	67.88	67.88	67.88	67.88	67.88	67.88	67.88	67.88	67.88	67.88	67.88	67.88	67.88	67.88	67.88	67.88	67.88	67.88	67.88	67.88	67.88	67.88
CI	7.70	87.66	87.66	87.66	87.66	87.66	87.66	87.66	87.66	87.66	87.66	87.66	87.66	87.66	87.66	87.66	87.66	87.66	87.66	87.66	87.66	87.66	87.66	87.66	87.66	87.66
CJ	11.85	71.35	71.35	71.35	71.35	71.35	71.35	71.35	71.35	71.35	71.35	71.35	71.35	71.35	71.35	71.35	71.35	71.35	71.35	71.35	71.35	71.35	71.35	71.35	71.35	71.35
CK	14.29	75.82	75.82	75.82	75.82	75.82	75.82	75.82	75.82	75.82	75.82	75.82	75.82	75.82	75.82	75.82	75.82	75.82	75.82	75.82	75.82	75.82	75.82	75.82	75.82	75.82
CL	17.13	119.28	119.28	119.28	119.28	119.28	119.28	119.28	119.28	119.28	119.28	119.28	119.28	119.28	119.28	119.28	119.28	119.28	119.28	119.28	119.28	119.28	119.28	119.28	119.28	119.28
CM	10.91	117.71	117.71	117.71	117.71	117.71	117.71	117.71	117.71	117.71	117.71	117.71	117.71	117.71	117.71	117.71	117.71	117.71	117.71	117.71	117.71	117.71	117.71	117.71	117.71	117.71
CN	13.84	104.37	104.37	104.37	104.37	104.37	104.37	104.37	104.37	104.37	104.37	104.37	104.37	104.37	104.37	104.37	104.37	104.37	104.37	104.37	104.37	104.37	104.37	104.37	104.37	104.37
CO	7.63	121.21	121.21	121.21	121.21	121.21	121.21	121.21	121.21	121.21	121.21	121.21	121.21	121.21	121.21	121.21	121.21	121.21	121.21	121.21	121.21	121.21	121.21	121.21	121.21	121.21
CP	13.86	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06
CQ	6.00	100.41	100.41	100.41	100.41	100.41	100.41	100.41	100.41	100.41	100.41	100.41	100.41	100.41	100.41	100.41	100.41	100.41	100.41	100.41	100.41	100.41	100.41	100.41	100.41	100.41
CR	16.46	98.69	98.69	98.69	98.69	98.69	98.69	98.69	98.69	98.69	98.69	98.69	98.69	98.69	98.69	98.69	98.69	98.69	98.69	98.69	98.69	98.69	98.69	98.69	98.69	98.69
CS	10.65	86.63	86.63	86.63	86.63	86.63	86.63	86.63	86.63	86.63	86.63	86.63	86.63	86.63	86.63	86.63	86.63	86.63	86.63	86.63	86.63	86.63	86.63	86.63	86.63	86.63
CT	24.91	77.00	77.00	77.00	77.00	77.00	77.00	77.00	77.00	77.00	77.00	77.00	77.00	77.00	77.00	77.00	77.00	77.00	77.00	77.00	77.00	77.00	77.00	77.00	77.00	77.00
AF	15.52	70.93	70.93	70.93	70.93	70.93	70.93	70.93	70.93	70.93	70.93	70.93	70.93	70.93	70.93	70.93	70.93	70.93	70.93	70.93	70.93	70.93	70.93	70.93	70.93	70.93
AG	12.21	62.41	62.41	62.41	62.41	62.41	62.41	62.41	62.41	62.41	62.41	62.41	62.41	62.41	62.41	62.41	62.41	62.41	62.41	62.41	62.41	62.41	62.41	62.41	62.41	62.41
AH	10.16	72.53	72.53	72.53	72.53	72.53	72.53	72.53	72.53	72.53	72.53	72.53	72.53	72.53	72.53	72.53	72.53	72.53	72.53	72.53	72.53	72.53	72.53	72.53	72.53	72.53
AI	7.93	63.10	63.10	63.10	63.10	63.10	63.10	63.10	63.10	63.10	63.10	63.10	63.10	63.10	63.10	63.10	63.10	63.10	63.10	63.10	63.10	63.10	63.10	63.10	63.10	63.10
AJ	8.40	58.86	58.86	58.86	58.86	58.86	58.86	58.86	58.86	58.86	58.86	58.86	58.86	58.86	58.86	58.86	58.86	58.86	58.86	58.86	58.86	58.86	58.86	58.86	58.86	58.86
AC	10.33	51.46	51.46	51.46	51.46	51.46	51.46	51.46	51.46	51.46	51.46	51.46	51.46	51.46	51.46	51.46	51.46	51.46	51.46	51.46	51.46	51.46	51.46	51.46	51.46	51.46
AD	7.00	55.37	55.37	55.37	55.37	55.37	55.37	55.37	55.37	55.37	55.37	55.37	55.37	55.37	55.37	55.37	55.37	55.37	55.37	55.37	55.37	55.37	55.37	55.37	55.37	55.37

AE	12.67	53.22	53.22	53.22	53.22	53.22	53.22	53.22	53.22	53.22	53.22	53.22	53.22	53.22	53.22	53.22	53.22	53.22	53.22	53.22	53.22	53.22	53.22	53.22	53.22	53.22
AK	10.99	47.79	47.79	47.79	47.79	47.79	47.79	47.79	47.79	47.79	47.79	47.79	47.79	47.79	47.79	47.79	47.79	47.79	47.79	47.79	47.79	47.79	47.79	47.79	47.79	47.79
AM	20.26	47.22	47.22	47.22	47.22	47.22	47.22	47.22	47.22	47.22	47.22	47.22	47.22	47.22	47.22	47.22	47.22	47.22	47.22	47.22	47.22	47.22	47.22	47.22	47.22	47.22
AN	13.57	49.52	49.52	49.52	49.52	49.52	49.52	49.52	49.52	49.52	49.52	49.52	49.52	49.52	49.52	49.52	49.52	49.52	49.52	49.52	49.52	49.52	49.52	49.52	49.52	49.52
AL	14.19	45.58	45.58	45.58	45.58	45.58	45.58	45.58	45.58	45.58	45.58	45.58	45.58	45.58	45.58	45.58	45.58	45.58	45.58	45.58	45.58	45.58	45.58	45.58	45.58	45.58
AO	7.06	51.03	51.03	51.03	51.03	51.03	51.03	51.03	51.03	51.03	51.03	51.03	51.03	51.03	51.03	51.03	51.03	51.03	51.03	51.03	51.03	51.03	51.03	51.03	51.03	51.03
AP	20.76	48.70	48.70	48.70	48.70	48.70	48.70	48.70	48.70	48.70	48.70	48.70	48.70	48.70	48.70	48.70	48.70	48.70	48.70	48.70	48.70	48.70	48.70	48.70	48.70	48.70
AQ	13.93	46.68	46.68	46.68	46.68	46.68	46.68	46.68	46.68	46.68	46.68	46.68	46.68	46.68	46.68	46.68	46.68	46.68	46.68	46.68	46.68	46.68	46.68	46.68	46.68	46.68
CU	13.96	53.21	53.21	53.21	53.21	53.21	53.21	53.21	53.21	53.21	53.21	53.21	53.21	53.21	53.21	53.21	53.21	53.21	53.21	53.21	53.21	53.21	53.21	53.21	53.21	53.21
A	16.28	46.18	46.18	46.18	46.18	46.18	46.18	46.18	46.18	46.18	46.18	46.18	46.18	46.18	46.18	46.18	46.18	46.18	46.18	46.18	46.18	46.18	46.18	46.18	46.18	46.18
B	7.15	63.22	63.22	63.22	63.22	63.22	63.22	63.22	63.22	63.22	63.22	63.22	63.22	63.22	63.22	63.22	63.22	63.22	63.22	63.22	63.22	63.22	63.22	63.22	63.22	63.22
C	17.84	81.62	81.62	81.62	81.62	81.62	81.62	81.62	81.62	81.62	81.62	81.62	81.62	81.62	81.62	81.62	81.62	81.62	81.62	81.62	81.62	81.62	81.62	81.62	81.62	81.62
D	6.30	67.03	67.03	67.03	67.03	67.03	67.03	67.03	67.03	67.03	67.03	67.03	67.03	67.03	67.03	67.03	67.03	67.03	67.03	67.03	67.03	67.03	67.03	67.03	67.03	67.03
E	16.03	59.16	59.16	59.16	59.16	59.16	59.16	59.16	59.16	59.16	59.16	59.16	59.16	59.16	59.16	59.16	59.16	59.16	59.16	59.16	59.16	59.16	59.16	59.16	59.16	59.16
F	11.67	80.85	80.85	80.85	80.85	80.85	80.85	80.85	80.85	80.85	80.85	80.85	80.85	80.85	80.85	80.85	80.85	80.85	80.85	80.85	80.85	80.85	80.85	80.85	80.85	80.85
G	17.91	82.27	82.27	82.27	82.27	82.27	82.27	82.27	82.27	82.27	82.27	82.27	82.27	82.27	82.27	82.27	82.27	82.27	82.27	82.27	82.27	82.27	82.27	82.27	82.27	82.27
H	10.69	102.94	102.94	102.94	102.94	102.94	102.94	102.94	102.94	102.94	102.94	102.94	102.94	102.94	102.94	102.94	102.94	102.94	102.94	102.94	102.94	102.94	102.94	102.94	102.94	102.94
I	24.54	97.86	97.86	97.86	97.86	97.86	97.86	97.86	97.86	97.86	97.86	97.86	97.86	97.86	97.86	97.86	97.86	97.86	97.86	97.86	97.86	97.86	97.86	97.86	97.86	97.86
J	8.67	108.79	108.79	108.79	108.79	108.79	108.79	108.79	108.79	108.79	108.79	108.79	108.79	108.79	108.79	108.79	108.79	108.79	108.79	108.79	108.79	108.79	108.79	108.79	108.79	108.79
K	17.22	118.82	118.82	118.82	118.82	118.82	118.82	118.82	118.82	118.82	118.82	118.82	118.82	118.82	118.82	118.82	118.82	118.82	118.82	118.82	118.82	118.82	118.82	118.82	118.82	118.82
L	15.30	119.57	119.57	119.57	119.57	119.57	119.57	119.57	119.57	119.57	119.57	119.57	119.57	119.57	119.57	119.57	119.57	119.57	119.57	119.57	119.57	119.57	119.57	119.57	119.57	119.57
M	11.60	89.45	89.45	89.45	89.45	89.45	89.45	89.45	89.45	89.45	89.45	89.45	89.45	89.45	89.45	89.45	89.45	89.45	89.45	89.45	89.45	89.45	89.45	89.45	89.45	89.45
N	13.55	79.66	79.66	79.66	79.66	79.66	79.66	79.66	79.66	79.66	79.66	79.66	79.66	79.66	79.66	79.66	79.66	79.66	79.66	79.66	79.66	79.66	79.66	79.66	79.66	79.66
O	20.15	127.82	127.82	127.82	127.82	127.82	127.82	127.82	127.82	127.82	127.82	127.82	127.82	127.82	127.82	127.82	127.82	127.82	127.82	127.82	127.82	127.82	127.82	127.82	127.82	127.82
P	13.93	117.97	117.97	117.97	117.97	117.97	117.97	117.97	117.97	117.97	117.97	117.97	117.97	117.97	117.97	117.97	117.97	117.97	117.97	117.97	117.97	117.97	117.97	117.97	117.97	117.97
Q	22.45	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38	145.38
R	10.74	164.19	164.19	164.19	164.19	164.19	164.19	164.19	164.19	164.19	164.19	164.19	164.19	164.19	164.19	164.19	164.19	164.19	164.19	164.19	164.19	164.19	164.19	164.19	164.19	164.19
T	14.53	135.89	135.89	135.89	135.89	135.89	135.89	135.89	135.89	135.89	135.89	135.89	135.89	135.89	135.89	135.89	135.89	135.89	135.89	135.89	135.89	135.89	135.89	135.89	135.89	135.89
S	19.94	135.41	135.41	135.41	135.41	135.41	135.41	135.41	135.41	135.41	135.41	135.41	135.41	135.41	135.41	135.41	135.41	135.41	135.41	135.41	135.41	135.41	135.41	135.41	135.41	135.41
U	20.69	153.50	153.50	153.50	153.50	153.50	153.50	153.50	153.50	153.50	153.50	153.50	153.50	153.50	153.50	153.50	153.50	153.50	153.50	153.50	153.50	153.50	153.50	153.50	153.50	153.50
V	9.57	49.66	49.66	49.66	49.66	49.66	49.66	49.66	49.66	49.66	49.66	49.66	49.66	49.66	49.66	49.66	49.66	49.66	49.66	49.66	49.66	49.66	49.66	49.66	49.66	49.66
W	15.53	86.83	86.83	86.83	86.83	86.83	86.83	86.83	86.83	86.83	86.83	86.83	86.83	86.83	86.83	86.83	86.83	86.83	86.83	86.83	86.83	86.83	86.83	86.83	86.83	86.83
X	8.11	103.78	103.78	103.78	103.78	103.78	103.78	103.78	103.78	103.78	103.78	103.78	103.78	103.78	103.78	103.78	103.78	103.78	103.78	103.78	103.78	103.78	103.78	103.78	103.78	103.78
Y	10.24	93.08	93.08	93.08	93.08	93.08	93.08	93.08	93.08	93.08	93.08	93.08	93.08	93.08	93.08	93.08	93.08	93.08	93.08	93.08	93.08	93.08	93.08	93.08	93.08	93.08
Z	23.07	88.29	88.29	88.29	88.29	88.29	88.29	88.29	88.29	88.29	88.29	88.29	88.29	88.29	88.29	88.29	88.29	88.29	88.29	88.29	88.29	88.29	88.29	88.29	88.29	88.29
AA	15.31	96.51	96.51	96.51	96.51	96.51	96.51	96.51	96.51	96.51	96.51	96.51	96.51	96.51	96.51	96.51	96.51	96.51	96.51	96.51	96.51	96.51	96.51	96.51	96.51	96.51
AB	8.43	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06	103.06
CV	9.27	101.79	101.79	101.79	101.79	101.79	101.79	101.79	101.79	101.79	101.79	101.79	101.79	101.79	101.79	101.79	101.79	101.79	101.79	101.79	101.79	101.79	101.79	101.79	101.79	101.79
CW	11.93	120.56	120.56	120.56	120.56	120.56	120.56	120.56	120.56	120.56	120.56	120.56	120.56	120.56	120.56	120.56	120.56	120.56	120.56	120.56	120.56	120.56	120.56	120.56	120.56	120.56
CX	5.27	128.73	128.73	128.73	128.73	128.73	128.73	128.73	128.73	128.73	128.73	128.73	128.73	128.73	128.73	128.73	128.73	128.73	128.73	128.73	128.73	128.73	128.73	128.73	128.73	128.73
CZ	11.69	138.52	138.52	138.52	138.52	138.52	138.52	138.52	138.52	138.52	138.52	138.52	138.52	138.52	138.52	138.52	138.52	138.52	138.52	138.52	138.52	138.52	138.52	138.52	138.52	138.52
DA	6.77	129.33	129.33	129.33	129.33	129.33	129.33	129.33	129.33	129.33	129.33	129.33	129.33	129.33	129.33	129.33	129.33	129.33	129.33	129.33	129.33	129.33	129.33	129.33	129.33	129.33
DB	8.92	134.15	134.15	134.15	134.15	134.15	134.15	134.15	134.15	134.15	134.15	134.15	134.15	134.15	134.15	134.15	134.15	134.15	134.15	134.15	134.15	134.15	134.15	134.15	134.15	134.15
CY	3.99	163.18	163.18	163.18	163.18	163.18	163.18	163.18	163.18	163.18	163.18	163.18	163.18	163.18	163.18	163.18	163.18	163.18	163.18	163.18	163.18	163.18	163.18	163.18	163.18	163.18
DC	4.61	45.11	45.11	45.11	45.11	45.11	45.11	45.11	45.11	45.11	45.11	45.11	45.11	45.11	45.11	45.11	45.11	45.11	45.11	45.11	45.11	45.11	45.11	45.11	45.11	45.11
DD	4.57	68.85	68.85	68.85	68.85	68.85	68.85	68.85	68.85	68.85	68.85	68.85	68.85	68.85	68.85	68.85	68.85	68.85	68.85	68.85	68.85	68.85	68.85	68.85	68.85	68.85

DE	6.61	47.16	47.16	47.16	47.16	47.16	47.16	47.16	47.16	47.16	47.16	47.16	47.16	47.16	47.16	47.16	47.16	47.16	47.16	47.16	47.16	47.16	47.16	47.16	47.16	47.16
DF	8.05	49.24	49.24	49.24	49.24	49.24	49.24	49.24	49.24	49.24	49.24	49.24	49.24	49.24	49.24	49.24	49.24	49.24	49.24	49.24	49.24	49.24	49.24	49.24	49.24	49.24
DG	7.76	48.23	48.23	48.23	48.23	48.23	48.23	48.23	48.23	48.23	48.23	48.23	48.23	48.23	48.23	48.23	48.23	48.23	48.23	48.23	48.23	48.23	48.23	48.23	48.23	48.23
DH	7.06	48.77	48.77	48.77	48.77	48.77	48.77	48.77	48.77	48.77	48.77	48.77	48.77	48.77	48.77	48.77	48.77	48.77	48.77	48.77	48.77	48.77	48.77	48.77	48.77	48.77
DI	4.66	50.22	50.22	50.22	50.22	50.22	50.22	50.22	50.22	50.22	50.22	50.22	50.22	50.22	50.22	50.22	50.22	50.22	50.22	50.22	50.22	50.22	50.22	50.22	50.22	50.22
DJ	9.27	47.35	47.35	47.35	47.35	47.35	47.35	47.35	47.35	47.35	47.35	47.35	47.35	47.35	47.35	47.35	47.35	47.35	47.35	47.35	47.35	47.35	47.35	47.35	47.35	47.35
DK	6.33	46.43	46.43	46.43	46.43	46.43	46.43	46.43	46.43	46.43	46.43	46.43	46.43	46.43	46.43	46.43	46.43	46.43	46.43	46.43	46.43	46.43	46.43	46.43	46.43	46.43
DL	5.80	46.60	46.60	46.60	46.60	46.60	46.60	46.60	46.60	46.60	46.60	46.60	46.60	46.60	46.60	46.60	46.60	46.60	46.60	46.60	46.60	46.60	46.60	46.60	46.60	46.60
DM	6.82	46.56	46.56	46.56	46.56	46.56	46.56	46.56	46.56	46.56	46.56	46.56	46.56	46.56	46.56	46.56	46.56	46.56	46.56	46.56	46.56	46.56	46.56	46.56	46.56	46.56

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Appendix L. ARR Data Hub data

Australian Rainfall & Runoff Data Hub - Results

Input Data

Longitude	144.742
Latitude	-37.45
Selected Regions (clear)	
River Region	show
ARF Parameters	show
Storm Losses	show
Temporal Patterns	show
Areal Temporal Patterns	show
BOM IFDs	show
Median Preburst Depths and Ratios	show
10% Preburst Depths	show
25% Preburst Depths	show
75% Preburst Depths	show
90% Preburst Depths	show
Interim Climate Change Factors	show
Baseflow Factors	show

Data

River Region

Division	South East Coast (Victoria)
River Number	6
River Name	Yarra River

Layer Info

Time Accessed	20 November 2023 03:32PM
Version	2016_v1

ARF Parameters

$$ARF = Min\left\{1, \left[1 - a\left(Area^{b} - c\log_{10}Duration\right)Duration^{-d} + eArea^{f}Duration^{g}\left(0.3 + \log_{10}AEP\right) + h10^{iArea\frac{Duration}{1440}}\left(0.3 + \log_{10}AEP\right)\right]\right\}$$

Zone	a	b	c	d	e	f	g	h	i
Southern Temperate	0.158	0.276	0.372	0.315	0.000141	0.41	0.15	0.01	-0.0027

Short Duration ARF

$$ARF = Min\left[1, 1 - 0.287\left(Area^{0.265} - 0.439\log_{10}(Duration)\right).Duration^{-0.36} + 2.26 \text{ x } 10^{-3} \text{ x } Area^{0.226}.Duration^{0.125}\left(0.3 + \log_{10}(AEP)\right) + 0.0141 \text{ x } Area^{0.213} \text{ x } 10^{-0.021\frac{(Duration-180)^2}{1440}}\left(0.3 + \log_{10}(AEP)\right)\right]$$

Layer Info

Time Accessed	20 November 2023 03:32PM
Version	2016_v1

Storm Losses

Note: Burst Loss = Storm Loss - Preburst

Note: These losses are only for rural use and are **NOT FOR DIRECT USE** in urban areas

Note: As this point is in Victoria the advice provided on losses and pre-burst in the VIC specific tab of the ARR Data Hub should be considered.

ID	28583.0
Storm Initial Losses (mm)	25.0
Storm Continuing Losses (mm/h)	2.7

Layer Info

Time Accessed	20 November 2023 03:32PM
Version	2016_v1

Temporal Patterns | Download (.zip) (static/temporal_patterns/TP/SSmainland.zip)

code	SSmainland
Label	Southern Slopes (Vic/NSW)

Layer Info

Time Accessed	20 November 2023 03:32PM
Version	2016_v2

Areal Temporal Patterns | Download (.zip) (./static/temporal_patterns/Areal/Areal_SSmainland.zip)

code	SSmainland
arealabel	Southern Slopes (Vic/NSW)

Layer Info

Time Accessed	20 November 2023 03:32PM
Version	2016_v2

BOM IFDs

Click here (http://www.bom.gov.au/water/designRainfalls/revised-ifd/?year=2016&coordinate_type=dd&latitude=-37.45018&longitude=144.74224&sdmin=true&sdhr=true&sdday=true&user_label=) to obtain the IFD depths for catchment centroid from the BoM website

Layer Info

Time Accessed	20 November 2023 03:32PM

Median Preburst Depths and Ratios

Note: As this point is in Victoria the advice provided on losses and pre-burst in the VIC specific tab of the ARR Data Hub should be considered.

Values are of the format depth (ratio) with depth in mm

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	1.5 (0.095)	1.3 (0.061)	1.2 (0.046)	1.1 (0.036)	1.3 (0.034)	1.4 (0.032)
90 (1.5)	3.6 (0.202)	2.5 (0.101)	1.8 (0.059)	1.1 (0.030)	1.2 (0.027)	1.3 (0.025)
120 (2.0)	2.7 (0.136)	2.1 (0.075)	1.6 (0.049)	1.2 (0.031)	1.2 (0.025)	1.2 (0.021)
180 (3.0)	1.5 (0.064)	2.0 (0.062)	2.3 (0.060)	2.7 (0.058)	5.2 (0.092)	7.0 (0.108)
360 (6.0)	0.7 (0.021)	1.2 (0.029)	1.6 (0.031)	2.0 (0.032)	5.5 (0.074)	8.1 (0.095)
720 (12.0)	0.2 (0.005)	1.8 (0.032)	2.8 (0.042)	3.8 (0.048)	6.9 (0.070)	9.3 (0.081)
1080 (18.0)	0.0 (0.000)	0.8 (0.011)	1.3 (0.016)	1.7 (0.018)	3.1 (0.027)	4.2 (0.032)
1440 (24.0)	0.0 (0.000)	0.4 (0.006)	0.7 (0.008)	0.9 (0.009)	2.9 (0.023)	4.4 (0.030)
2160 (36.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.6 (0.004)	1.1 (0.006)
2880 (48.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
4320 (72.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)

Layer Info

Time Accessed	20 November 2023 03:32PM
Version	2018_v1
Note	Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.

10% Preburst Depths

Values are of the format depth (ratio) with depth in mm

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
90 (1.5)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
120 (2.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
180 (3.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
360 (6.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
720 (12.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
1080 (18.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
1440 (24.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
2160 (36.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
2880 (48.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
4320 (72.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)

Layer Info

Time Accessed	20 November 2023 03:32PM
Version	2018_v1
Note	Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.

25% Preburst Depths

Values are of the format depth (ratio) with depth in mm

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
90 (1.5)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
120 (2.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
180 (3.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
360 (6.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.1 (0.001)	0.2 (0.002)
720 (12.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
1080 (18.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
1440 (24.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
2160 (36.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
2880 (48.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
4320 (72.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)

Layer Info

Time Accessed	20 November 2023 03:32PM
Version	2018_v1
Note	Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.

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75% Preburst Depths

Values are of the format depth (ratio) with depth in mm

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	7.9 (0.504)	8.7 (0.397)	9.2 (0.348)	9.8 (0.311)	11.1 (0.290)	12.2 (0.276)
90 (1.5)	11.3 (0.629)	12.3 (0.490)	12.9 (0.426)	13.6 (0.378)	13.4 (0.306)	13.3 (0.263)
120 (2.0)	12.3 (0.618)	12.3 (0.446)	12.4 (0.369)	12.4 (0.313)	14.4 (0.296)	15.9 (0.284)
180 (3.0)	10.8 (0.464)	13.5 (0.420)	15.3 (0.393)	17.0 (0.370)	19.7 (0.348)	21.7 (0.332)
360 (6.0)	9.9 (0.325)	13.6 (0.323)	16.1 (0.315)	18.4 (0.304)	22.8 (0.307)	26.1 (0.303)
720 (12.0)	4.8 (0.119)	9.7 (0.173)	12.9 (0.190)	16.0 (0.199)	23.5 (0.238)	29.1 (0.255)
1080 (18.0)	5.1 (0.107)	8.8 (0.133)	11.3 (0.141)	13.7 (0.144)	17.1 (0.148)	19.7 (0.149)
1440 (24.0)	1.9 (0.037)	5.5 (0.075)	7.8 (0.088)	10.0 (0.096)	14.8 (0.116)	18.3 (0.126)
2160 (36.0)	0.0 (0.000)	2.2 (0.026)	3.7 (0.036)	5.1 (0.042)	10.3 (0.071)	14.2 (0.087)
2880 (48.0)	0.0 (0.000)	0.6 (0.006)	0.9 (0.008)	1.3 (0.010)	3.7 (0.024)	5.6 (0.032)
4320 (72.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.5 (0.003)	0.9 (0.005)

Layer Info

Time Accessed	20 November 2023 03:32PM
Version	2018_v1
Note	Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.

https://data.arr-software.org 7/9

90% Preburst Depths

Values are of the format depth (ratio) with depth in mm

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	24.7 (1.578)	27.3 (1.247)	29.1 (1.095)	30.8 (0.979)	26.2 (0.682)	22.7 (0.516)
90 (1.5)	22.5 (1.250)	30.3 (1.207)	35.4 (1.167)	40.4 (1.123)	33.2 (0.756)	27.9 (0.550)
120 (2.0)	27.8 (1.395)	26.8 (0.969)	26.2 (0.782)	25.6 (0.645)	41.2 (0.848)	53.0 (0.943)
180 (3.0)	22.7 (0.982)	28.5 (0.889)	32.3 (0.833)	36.0 (0.783)	42.7 (0.757)	47.8 (0.731)
360 (6.0)	29.0 (0.949)	31.7 (0.752)	33.6 (0.658)	35.4 (0.584)	45.6 (0.613)	53.3 (0.619)
720 (12.0)	20.7 (0.510)	27.2 (0.483)	31.5 (0.462)	35.6 (0.441)	52.5 (0.531)	65.1 (0.573)
1080 (18.0)	16.1 (0.340)	20.3 (0.307)	23.1 (0.288)	25.7 (0.272)	33.2 (0.287)	38.7 (0.293)
1440 (24.0)	14.6 (0.278)	19.2 (0.261)	22.2 (0.250)	25.1 (0.239)	31.2 (0.245)	35.8 (0.246)
2160 (36.0)	4.3 (0.071)	12.5 (0.150)	18.0 (0.178)	23.2 (0.194)	31.1 (0.216)	37.0 (0.227)
2880 (48.0)	2.4 (0.037)	7.6 (0.084)	11.1 (0.101)	14.4 (0.112)	23.5 (0.152)	30.3 (0.174)
4320 (72.0)	0.9 (0.013)	9.9 (0.100)	15.8 (0.133)	21.5 (0.154)	21.6 (0.130)	21.7 (0.117)

Layer Info

Time Accessed	20 November 2023 03:32PM
Version	2018_v1
Note	Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.

Interim Climate Change Factors

	RCP 4.5	RCP6	RCP 8.5
2030	**0.648 (3.2%)**	0.687 (3.4%)	**0.811 (4.0%)**
2040	**0.878 (4.4%)**	0.827 (4.1%)	**1.084 (5.4%)**
2050	**1.081 (5.4%)**	1.013 (5.1%)	**1.446 (7.3%)**
2060	**1.251 (6.3%)**	1.229 (6.2%)	**1.862 (9.5%)**
2070	**1.381 (7.0%)**	1.460 (7.4%)	**2.298 (11.9%)**
2080	**1.465 (7.4%)**	1.691 (8.6%)	**2.719 (14.2%)**
2090	**1.496 (7.6%)**	1.906 (9.7%)	**3.090 (16.3%)**

Layer Info

Time Accessed	20 November 2023 03:32PM
Version	2019_v1
Note	ARR recommends the use of RCP4.5 and RCP 8.5 values. These have been updated to the values that can be found on the climate change in Australia website.

Baseflow Factors

Downstream	11203
Area (km2)	1422.01152
Catchment Number	11132
Volume Factor	0.127588
Peak Factor	0.021693

Layer Info

Time Accessed	20 November 2023 03:32PM
Version	2016_v1

Download TXT (downloads/352f841f-6f84-42ca-94f4-8bc79f0897d2.txt)

Download JSON (downloads/d1b65e0e-aba1-4f03-90ad-72990b622be3.json)

Generating PDF... (downloads/6216c7c1-9530-413b-a326-3eaf3e89ac47.pdf)

Appendix M. Melbourne Water Reviewer Comments

Hydrology and Risk Consulting Pty Ltd
PO Box 209
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Blackburn, VIC, 3130

20 April 2024

Wendy Smith
Melbourne Water
PO Box 4342
Melbourne VIC 3001

Re: Draft Lower Maribyrnong River Flood Model Report - Peer Review

Dear Wendy

As requested, I have completed a peer review of the above report, prepared by Jacobs for Melbourne Water. This letter summarises the review scope, outcomes and findings.

Scope of Review

The review was undertaken in two stages. Initially, an advance copy of the draft report, together with a range of hydrologic (RORB) and hydraulic (TUFLOW) modelling files was provided in the week commencing 1 April 2024. HARC provided preliminary comments on this material to Melbourne Water on 5 April 2024, which were focused on identifying several key matters for further clarification. Subsequently, Melbourne Water provided a memorandum on these queries as well as a completed draft report (Jacobs, 2024) in the week beginning 15 April 2024.

I completed the review, with support from Andrew Northfield with detailed review of the TUFLOW model. Carolyn Tsioulos at HARC assisted with data transfer and project management. I have over 20 years of experience in hydrologic and hydraulic modelling for flood estimation, and have acted as project manager or project director and technical reviewer on a large range of flood studies across Victoria, Queensland, New South Wales and Western Australia. Since 2019, I have been a senior member of the HARC team of technical reviewers undertaking flood modelling reviews for Melbourne Water on a range of infrastructure and flood mapping projects. I also regularly provide flood modelling peer review services to a range of other authorities including WaterNSW, Seqwater, HydroTas and BHP. I am not aware of any actual or potential conflicts of interest in relation to my review of this report.

The project was reviewed with reference to the Melbourne Water Flood Mapping Project Specifications (Melbourne Water, August 2023) and Australian Rainfall and Runoff 2019 (Ball et al, 2019).

Hydrologic Modelling

Design flood hydrology for the 1 in 100 AEP and 1 in 100 AEP with climate change has been completed by fitting a RORB model of the catchment to the gauged flood frequency curve at Keilor. Jacobs have noted that flow contributions from tributaries downstream of the Keilor gauge are minor in nature only, which appears reasonable given the ratios of catchment area and significant difference in likely critical storm duration for the catchment to Keilor as compared to the downstream tributary catchments.

It is noteworthy that the Keilor gauge has an extensive period of record of over 100 years, and a reasonably reliable rating curve for the current gauge site location from approximately 1982. This rating curve was further informed by a series of high flow gaugings undertaken by

Melbourne Water hydrographers during the October 2022 flood event. Given this, there appears to be reasonable confidence in the gauged flood frequency estimates up to an AEP of approximately 1 in 200. Considerable effort has been undertaken to research and include estimates of historic flood events prior to the gauge records (particularly the flood of record in 1906), which adds to the level of confidence in the flood frequency analysis.

Further work which could be considered to increase confidence in the gauged flow estimates and hence the flood frequency analysis includes clarification of the rating tables adopted in the period between approximately 1908 and 1982 when the gauge was located at several different sites to the current site. Similarly, I understand that Melbourne Water have commenced a project to review the rating table for the current gauge site using two-dimensional hydraulic modelling. This work may provide further useful confirmation on the current rating table.

For this study, the RORB model was calibrated and validated to several historic flood events as well as reconciled to the gauged flood frequency analysis as Keilor. Whilst a good fit to the historic events was achieved, the report notes that the routing parameter value derived from this fit was not used subsequently. Both the routing parameter and loss parameter values were derived from reconciliation of the RORB model (using design inputs) to the gauged flood frequency analysis. The resulting parameterisation is somewhat unusual, as Jacobs have acknowledged. It appears from the available evidence that the routing parameter value adopted is likely overestimated, but this value was required to ensure a reasonable fit to the gauged flood frequency analysis.

The primary impact of this is that the resulting hydrographs used for the design hydraulic modelling are more attenuated than would otherwise be the case. As such, the adopted critical duration, hydrograph volume and rates of rise and fall are unlikely to be consistent with those derived using the calibrated routing parameter value, although the peak flow quantiles closely match the gauged flood frequency estimates.

Given that the hydraulic modelling is solely used to derive peak flood depth, flood extent and flood hazard data, the adopted hydrograph shape is unlikely to have a significant influence over the majority of the hydraulic model domain. Jacobs have undertaken sensitivity testing on hydrograph volume at the Chifley Drive gauge; the results of this confirm the modelled peak water levels are largely insensitive to hydrograph volume (at that location). The report also clearly states that the modelled results cannot be used to derive flood intelligence outputs such as duration of flooding or rates of rise, due to the uncertainty in the adopted routing parameter value.

I recommend that Melbourne Water consider commissioning additional studies following the completion of this project, in order to reconcile the varying routing parameter values. The advantage of such studies would be;

a) to resolve the apparent inconsistency in parameter values obtained from different method of calibration and,

b) to develop a hydrologic model without significant caveats on hydrograph shape and volume.

Such studies may include:

- Two-dimensional modelling to improve the rating curves at key gauges upstream of Keilor, followed by fitting the RORB model to these gauges. This would assist in confirming routing parameter variability upstream of Keilor.

- Undertaking flood volume frequency analysis at Keilor, in order to reconcile the RORB estimates of flood volume with those at the gauge.
- Investigating the reliability of the 2019 design rainfall IFD estimates upstream of Keilor. It is possible that reconciliation between the modelled and gauged flood frequency curves cannot be achieved due to inaccuracies in the IFD data.
- Investigating the impact of rainfall spatial variability on the modelled design flows at Keilor. The spatial patterns from the historic flood events demonstrate a significant degree of spatial variability, and it is possible that this is driving the modelled runoff response.

Notwithstanding these recommendations, the adopted approach makes reasonable use of the available gauged streamflow data and provides a strong argument as to why the modelled 1 in 100 AEP flood levels downstream of Keilor are reliable.

The RORB model has also been used to derive a 1 in 100 AEP peak flow estimate accounting for climate change, using the approach in the Melbourne Water Flood Mapping Specifications. As noted by Jacobs, it is recommended that this estimate is updated in future once the draft Australian Rainfall and Runoff guidance on climate change in finalised.

Hydraulic Modelling

A detailed TUFLOW two-dimensional hydraulic model of the study area has been developed, and considerable effort has been expended to incorporate features such as channel bathymetry, levees and structures such as bridges, culverts and relevant components of the underground drainage network. The model has been calibrated, validated and verified to a total of six historic flood events, including significant events such as October 2022 and the 1906 flood of record. On the whole, the model calibration results are good. Satisfactory reconciliation between peak flood levels and recorded flood markers has been achieved throughout the study area, and there is significant confidence in the reliability of the hydraulic model. Jacobs note that for certain events (particularly those early in the historic record) there is some uncertainty in the calibration results due to the significant changes in land use and infrastructure in the study area. Whilst further research into these changes could be beneficial to improve aspects of the model fit to some historic events, this appears unlikely to significantly change the modelled design flood levels.

In regards to the downstream tidal levels adopted for the design modelling, the approach used to derive a constrained joint probability analysis of peak flow at Keilor and peak tidal levels at Southbank appears to be reasonable. At a conceptual level, given the relatively long critical duration of the catchment to Keilor, it is not unexpected that there would be minimal correlation between rainfall causative to a flood event and storm surge in the lower reaches of the Yarra River.

The area of the model with the greatest uncertainty in peak flood levels is likely to be around Kensington and West Melbourne. In this region, the impact of the overestimation of hydrograph volume is likely to be most significant, the interaction between riverine and tidal flooding is greatest and there is uncertainty in the nature of the levee and underground drainage infrastructure. Sensitivity checks have been undertaken to test various infrastructure configurations at this location and the adopted approach appears to be reasonable given the limitations of the available information.

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Conclusions

The outcomes of this project have significantly enhanced the current state of knowledge of design peak 1 in 100 AEP flood levels in the lower Maribyrnong River. Jacobs have expended considerable effort to review and make use of the available data to support the project results.

It is my view that the modelled 1 in 100 AEP and 1 in 100 AEP with climate change peak flood depth grid, peak flood extent and peak flood hazard results are reliable given the project context, limitations of the available data and the inherent uncertainties in modelling floods in complex river systems.

There are a number of recommendations for further work raised in the Jacobs report as well as this letter, and I trust that Melbourne Water will consider these when undertaking future studies in this area.

Yours sincerely,

David Stephens
Senior Flood Modeller
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Appendix N. External Reviewers Comment and Response Sheet

5 December 2023

Andrew Little
Project Manager
Melbourne Water
90 La Trobe St
Docklands, VIC 3001

Re: Lower Maribyrnong River Flood Study - Review of Jacob's model calibration

Dear Andrew,

We are writing to provide a review of the calibration results for the hydrology and hydraulic models presented by Jacobs in their report entitled "Draft Hydraulics & Hydrology Model Calibration Report"[1] (referred to herein as the "Report"). Our review is also based on the subsequent discussions with Jacobs and Melbourne Water representatives at an online workshop held on 28 November 2023. Draft minutes of this workshop were issued by Jacobs on 30 November 2023.

This review focusses on the defensibility of the approach as proposed by Jacobs and has not involved the undertaking of any specific checks of data products, calculations, model files or model outputs. In preparing this review, we have relied upon the information (or lack thereof) provided in the reports and presented at the workshop. If the information is incorrect, inaccurate or incomplete, our observations and conclusions contained within this review may change.

Overall Comments

Overall the calibration approach is consistent with best practice as outlined in Australian Rainfall and Runoff (ARR2019). Jacobs has presented the results of a significant amount of investigation, assessment and calibration modelling within the reports. It is particularly noteworthy that the approach adopted to calibrate the hydrology and hydraulic models is supported by detailed information collected on major flood events, which includes streamflow observations collected at the Keilor gauge. It is unusual to have such high quality information available to inform the calibration approach, and this has the potential to provide a high level of confidence in the modelling results. The workshop provided insight into further work that has not been documented but undertaken to inform some of the outcomes described in the reports. Specific comments on key elements of the work are outlined below.

Specific Comments

Hydrology

1. Section 3.3.1. The choice of gridded rainfall product is important and it is agreed that the AWAP data set is to be preferred to that of SILO in this catchment. The main justification for this is that while neither of the AWAP or SILO products used MW gauges in their surface-fitting procedures, the AWAP data set does provide a better estimate of rainfalls at MW gauges. This difference in performance is due to the fact that SILO surfaces are forced to exactly match observed point rainfalls whereas AWAP surfaces are not, and in this catchment it is clear that surface-fitting approach used by AWAP is the more defensible choice.
2. Section 3.4.2. It is expected that the rationale for excluding information from gauges upstream of Keilor will be included in a subsequent version of the report. From the

[1] IA5000NN_RPT_002_Draft_Hydrology_and_Hydraulics_Calibration_002_DRAFT, Version 002 dated 22 November 2023.

information presented in prior discussions it seems reasonable to exclude information from upstream gauges until additional investigation can be undertaken to refine the rating curves. At present the information at the Keilor gauge is sufficient to support lumped parameterisation of the RORB model, and if this is sufficient to provide good validation of the 1% AEP flood estimates at the Keilor gauge (see point 5 below) then this lessens the need to explicitly consider spatial variation in upstream runoff characteristics using information from upstream gauges.

3. The approach used to derive flood frequency quantiles using FLIKE is appropriate. While it is unusual to exclude such a high proportion of low flows, the use of the multiple Grubbs-Beck test does justify this. When comparing results with the earlier Melbourne Metropolitan Board of Works (MMBW) work it is necessary to take account of the differences arising from the partial and annual-maximum series using the Langbein adjustment (noting that this should only affect quantiles more common than 10% AEP).
4. The approach used to calibrate the RORB model to the Keilor gauge is very thorough, and overall the standard of the results achieved when simulating historic events using a common set of routing parameters is very high. This work provides a good level of confidence in the ability of the model to represent floods at the Keilor gauge. It is expected that the simulation of the October 2011 event could be improved by representing the storm as having multiple bursts, but this is of minor significance. Some additional evidence could be presented on the treatment of baseflow, and this might achieve some improvement in the joint representation of flood peaks and volumes, but again the degree of improvement expected from such additional analysis is expected to be minor.
5. The degree of agreement between the frequency curve derived by the RORB model and that based on observations is poor (Figure 4-28), and this needs further investigation. It is essential that the design flood quantiles derived by RORB match the location and shape of the flood frequency analysis, allowing for some differences due to sampling variability (ie it would be expected that the quantiles derived using RORB lie within the 90% confidence bounds and not necessarily on the best estimate of the quantiles derived using gauged observations). Ideally the RORB design quantiles should be obtained using pre-burst rainfalls and fixed loss parameters, where an adequate match is obtained by judicious adjustment of the pre-burst exceedance percentile, the median estimate of initial loss, and the fixed value of continuing loss. The loss values should not be varied by AEP unless absolutely necessary.
6. The spatial pattern of design rainfalls used to derive the 1%AEP quantiles should be based on the duration of the event critical to the location of interest. The labelling of Figure 4-29 needs to be checked and corrected as needed.
7. It needs to be recognised that there is unequivocal evidence that global warming has impacted on extreme rainfalls over the past few decades. The current best estimate of these impacts is summarised in a recent pre-print under public review for an international journal[2] and in the subsequent draft guidance under preparation for Australian Rainfall and Runoff[3]. It is reasonable to assume that the impacts of global warming on observations used to derive current IFD estimates published in 2019 need to be increased to better represent current conditions (for storm burst durations of 24 hours and longer). This adjustment may assist the reconciliation problem discussed in the preceding point, and will need to be considered in some fashion when deriving best estimates of design flood risks for future planning purposes. Rainfall intensities for rainfall events 24 hours and longer should be increased by 8%/°C, where the temperature increase relative the 1961-1990 period has been 1.3°C. The baseline

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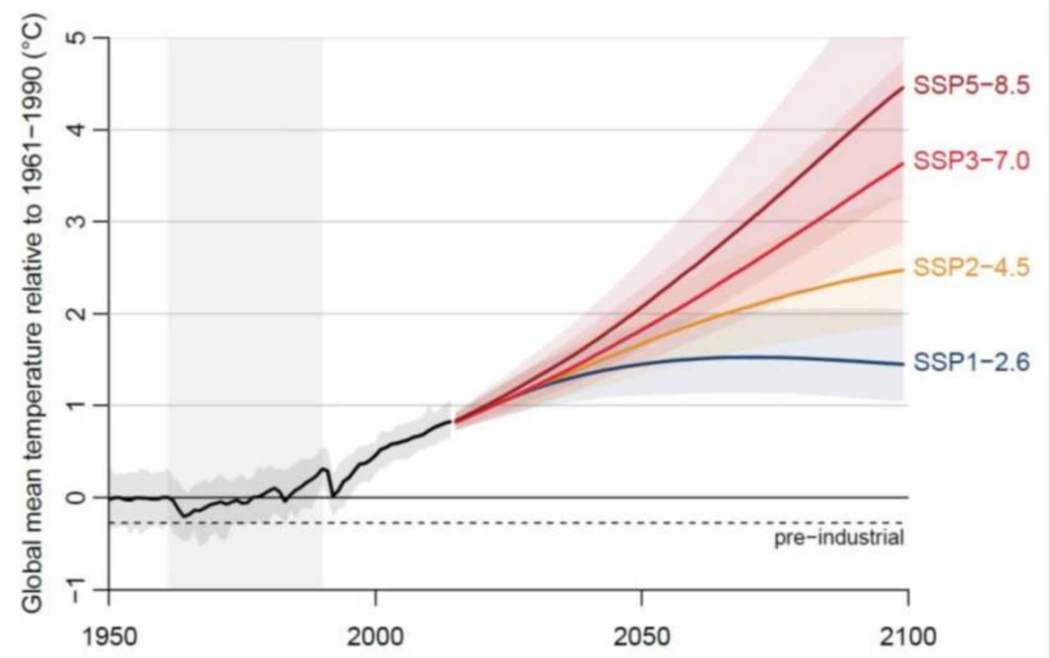
[2] Wasko, C., Westra, S., Nathan, R., Pepler, A., Raupach, T., Dowdy, A., Johnson, F., Ho, M., McInnes, K., Jakob, D., Evans, J., Villarini, G., and Fowler, H.: A systematic review of climate change science relevant to Australian design flood estimation, Hydrol. Earth Syst. Sci. Discuss. [preprint], https://doi.org/10.5194/hess-2023-232, in review, 2023.

[3] https://consult.dcceew.gov.au/update-to-the-cc-considerations-in-the-arrg

most relevant to the analyses being undertaken for reconciliation and future planning periods may not be the same, and this is an issue that would benefit from further discussion and thought. Any adjustments to the IFD design information should based on the historic changes in global temperatures shown in the plot below, as provided in the draft flood guidance[3]:



Hydrology & Hydraulics Interface

8. Data obtained and derived from the Keilor water level gauge is critical to the outcomes of the study. As such, the following is noted and recommended:

   a. The gauge has been moved four times. It appears that there are only consistent level records after 1975 and there is uncertainty in derivation of flows prior to 1975. It is recommended that additional investigations be undertaken to better understand the reliability of historical data, particularly to ensure that the correct rating curves have been used to estimate the different historical flood events.

   b. The gaugings undertaken at the Keilor gauge in 2022 have allowed the rating curve to be adjusted for higher flows. The gaugings were undertaken on the falling limb of the flood peak. If hysteresis exists at this gauge location, it is possible that the adjusted rating curve may underestimate derived flows. Following discussions on this at the workshop, Jacobs developed a H-Q curve at Solomons Ford to demonstrate hysteresis. At this location within the flow range of the 2022 event, minor hysteresis was evident. The difference between rising and falling limb flows was about 5%. In the context of other uncertainties (model, data etc), this is not considered significant and further consideration of hysteresis is not warranted for the range of flows considered in this study. The following is recommended:

      i. Document the additional information on hysteresis in the report;

      ii. Note for future rating curve assessment (understood to be an upcoming investigation by Melbourne Water), a hydraulic model should be used in combination with the gaugings to test and potentially refine the rating curve. The current calibrated hydraulic model would require an upstream extension and recalibration to be fit-for-purpose for this task.

9. The methodology adopted for modelling the calibration events results in the hydrology (RORB) and hydraulics (TUFLOW) model being independently calibrated. That is, the RORB model does not provide calibration inflows to the TUFLOW model, rather inflows are derived

from the recorded Keilor gauge levels. As the models will be used jointly to undertake the design event simulations, evidence is required to provide confidence that they are capable of reproducing historical event behaviour while being used jointly. During the workshop it was agreed that joint simulation of the 2022 event should be undertaken as a verification to demonstrate that the resulting TUFLOW calibration results are similar to those achieved from the independent calibration.

10. In concept, the design efficacy of the joint modelling process would be best assessed by comparing the frequency curve of flood levels derived from observed data with that derived using the combined RORB-TUFLOW modelling chain. That is, rather than merely test the combined ability of the models to simulate a specific historic event, we test the ability of the combined models to reproduce flood levels with a specified annual exceedance probability, which is the design objective of most interest. This is similar to reconciling flood frequency curves (ie Figure 4-28), but extending the process to flood levels with a known exceedance probability. It may be possible to do this at the Chifley gauge (given that the Keilor gauge may be too close to the inflow boundary), but the robustness of the result will be dependent on a number of factors including the availability of suitable historic data. We would be interested in your thoughts on undertaking such a test during the design phase.

Hydraulics

11. It is understood that lateral inflows are not yet included in the hydraulic model but that they will be. This is acceptable. The influence of these inflows on calibration results is expected to be small as lateral inflows will have a far shorter critical duration.

12. Manning's n:

    a. It is understood from discussions at the workshop, that better calibration results have been achieved by varying the in-channel Manning's n longitudinally along the river with a different value in each of four reaches. Manning's n values start from 0.023 in the downstream reach and rise to 0.042 in the upstream reach. This is considered acceptable given the changing channel roughness demonstrated in each reach, the appropriate range of Manning's n values used, and the calibration results.

    b. Modelled and recorded level hydrographs at the Chifley gauge are presented in the report to demonstrate effectiveness of the model in replicating event behaviour. These include the modelled and recorded tidal signal prior to the commencement of the fluvial event. The model appears to be adequately replicating the tidal signal at the Chifley gauge. This gives confidence that the in-channel Manning's n values in the reaches below the Chifley gauge are appropriate as the conveyance of a tide upstream into a river is strongly influenced by the Manning's n value but not the form (bend) loss. It is recommended that commentary around this is added in the text.

13. Form (Bend) losses:

    a. It is recommended that the bend losses used and presented in Table 5-10 are adjusted to reduce the precision. At present, some of the values are shown with up to 4 decimal points. Such precision implies an accuracy that is unfounded.

    b. The Syme (2015) reference used to guide the selection of the form loss value is outdated and should be replaced with Syme (2021)[4]. The values presented by Syme (2021) are slightly lower than the previous 2015 reference. However, the bend losses presented in Table 5-10 of the report remain within acceptable bounds.

[4] https://awschool.com.au/content/uploads/Webinar-Presentation-Maxmising-the-Accuracy-of-Hydraulic-Models-Bill-Syme.pdf

14. Calibration results are acceptable. Given that the hydraulic model inflow is derived from the gauge record at Keilor rather than the RORB model, a good calibration is expected as uncertainties in inflow are greatly reduced. The following is recommended:

    a. All events are demonstrated to achieve good calibration at the Chifley gauge with the exception of the 2011 event. The 2011 event is the smallest event modelled and the modelled levels at Chifley exceed the recorded. It is recommended that the modelled longitudinal profiles from Keilor to the downstream boundary be plotted together with the gauge levels for the four recent calibration events to investigate the modelled versus recorded longitudinal slopes. It appears, from a rudimentary review of levels, that the recorded longitudinal water slope between Keilor and Chifley is steeper than what would be expected for a relatively minor event. If that comparison produces a noteworthy result, it is recommended that commentary is added to the report.

    b. Some calibration points represent "minimum level possible", rather than peak levels. On the longitudinal plots it would be better to identify these with different markers. In addition, it would be useful to have a zoom of areas of interest on the longitudinal profile to show calibration results at a more readable scale. This would be particularly useful at Maribyrnong town for 2022.

    c. It is understood that some additional information has recently been discovered in relation to historical floods that may influence validation of the hydraulic model. This includes barges being stuck under the Raleigh Rd Bridge in the 1983 flood and additional blockage during the 1974 flood associated with a coffer dam at the Kensington Rail Culverts. It is recommended that this is verified and included in reporting.

Reporting

15. The following would be useful additions/updates to the report:

    a. Section 1.2. The last paragraph refers to "rainfall on land that drains directly to the Maribyrnong River". The meaning of this is not entirely clear, and if this paragraph is intended to differentiate between flooding occurring as a result of stormwater runoff as distinct from a watercourse overtopping its banks, then it might be helpful to use standard terms (perhaps as used by the insurance industry) to make this point clearer.

    b. Section 1.3.1 states that no significant changes have been made to the proposed schematisation approach since the schematisation report. However, it is apparent from the calibration report that there have been some important changes to model schematisation since the schematisation report was presented. As it is our understanding that that schematisation report will not be updated, it is important to acknowledge, in Section 1.3.1, that there have been some key changes.

    c. Section 2.1, second paragraph. The reference to "the last major event recorded in September 1993" is misleading given the information available on the 2022 event. This phrasing should be corrected.

    d. The labelling of dates in Figure 3-3 should be altered to avoid the overlapping.

    e. In Figure 3-5 the symbols used for the (pink) rating curve RT37.01 should be omitted to avoid any possible misinterpretation that these represent spot gaugings. The font size in other annotations should be increased to assist legibility.

    f. Include at least one map showing all water level gauges used in the study. This may require a zoom of the three key gauges relevant to hydraulic modelling (Keilor, Chifley and Southbank) in relation to the hydraulic model extent. In addition, a table summarising key facts about each of the key water level gauges would be useful. As a minimum it should contain name, period of record, peak recorded water levels and peak derived flows for calibration events.

g. The verification of the accuracy of the LiDAR data using 453 surveyed points produces good results. Provide commentary on the location and nature of the 453 comparison points that have been used to verify the LiDAR data.

h. Section 3.6, provide a short explanation of the basis used for removal of spurious flood mark data.

i. The last sentence in the first paragraph of Section 4.1 needs to be deleted or clarified. The statement as currently phrased is not supportable.

j. The heading for the 4th column of Table 4-3 is incorrect and needs to be changed to “Upper CL”.

k. It would be preferable to have consistent colour shading across the rainfall depth distribution figures for each event (Figure 4-12 to Figure 4-15) to enable a visual comparison to be more easily made.

Regards,

Professor Rory Nathan
Director
RJN Hydrology Pty Ltd

Cathie Barton
Senior Principal Engineer
WRM Water & Environment Pty Ltd

Response to External Review (received Dec 2023)

Hydrology

Comment Number	Comment	Jacobs Response	Action
1	Section 3.3.1. The choice of gridded rainfall product is important and it is agreed that the AWAP data set is to be preferred to that of SILO in this catchment. The main justification for this is that while neither of the AWAP or SILO products used MW gauges in their surface-fitting procedures, the AWAP data set does provide a better estimate of rainfalls at MW gauges. This difference in performance is due to the fact that SILO surfaces are forced to exactly match observed point rainfalls whereas AWAP surfaces are not, and in this catchment it is clear that surface-fitting approach used by AWAP is the more defensible choice.	Ok	No action
2	Section 3.4.2. It is expected that the rationale for excluding information from gauges upstream of Keilor will be included in a subsequent version of the report. From the information presented in prior discussions it seems reasonable to exclude	Ok, will include more detailed rationale for excluding information from gauges other than Keilor	Requires additional info in report. Text from reviewer: "It seems reasonable to exclude information from upstream gauges until additional investigation can be undertaken to refine the rating curves. At present the information at the Keilor gauge is sufficient to support lumped parameterisation of the RORB model, and if this is sufficient to provide good validation of the 1% AEP flood estimates at the Keilor gauge, then this lessens the

Comment Number	Comment	Jacobs Response	Action
	information from upstream gauges until additional investigation can be undertaken to refine the rating curves. At present the information at the Keilor gauge is sufficient to support lumped parameterisation of the RORB model, and if this is sufficient to provide good validation of the 1% AEP flood estimates at the Keilor gauge (see point 5 below) then this lessens the need to explicitly consider spatial variation in upstream runoff characteristics using information from upstream gauges.		need to explicitly consider spatial variation in upstream runoff characteristics using information from upstream gauges." Sample text idea: "Multiple gauges within the Maribyrnong Catchment were considered for calibration, however it proved challenging to reconcile observed flows at the Keilor gauge with the modelled events in conjunction with using calibrated interstation areas for gauges upstream." Then add text above from reviewer. This will be included in Section 3.4.2. of the final report
3	The approach used to derive flood frequency quantiles using FLIKE is appropriate. While it is unusual to exclude such a high proportion of low flows, the use of the multiple Grubbs-Beck test does justify this. When comparing results with the earlier Melbourne Metropolitan Board of Works (MMBW) work it is necessary to take account of the differences arising from the partial and annual-maximum series using the Langbein adjustment (noting that this should only affect quantiles more common than 10% AEP).	Ok	Langbein adjustment has been included in Table 4-3

Comment Number	Comment	Jacobs Response	Action
4	The approach used to calibrate the RORB model to the Keilor gauge is very thorough, and overall the standard of the results achieved when simulating historic events using a common set of routing parameters is very high. This work provides a good level of confidence in the ability of the model to represent floods at the Keilor gauge. It is expected that the simulation of the October 2011 event could be improved by representing the storm as having multiple bursts, but this is of minor significance. Some additional evidence could be presented on the treatment of baseflow, and this might achieve some improvement in the joint representation of flood peaks and volumes, but again the degree of improvement expected from such additional analysis is expected to be minor.	Ok. Further evidence was not presented on the treatment of baseflow since this will no longer affect routing parameters which have been chosen through calibration to FFA since different approach was adopted. Given the minor improvements that that these comments would result in preference was given to improving design event modelling.	
5	The degree of agreement between the frequency curve derived by the RORB model and that based on observations is poor (Figure 4-28), and this needs further investigation. It is essential that the design flood quantiles derived by RORB match the	Considerable work has been completed to address this comment as reported in Section 4.4.5.	The report will be updated to include the volume sensitivity analysis in Section 8.1. Initial analysis holding peak flow steady and varying the timebase shows that the levels at Chiefly Drive are relatively insensitive see table below:

Comment Number	Comment	Jacobs Response	Action
	location and shape of the flood frequency analysis, allowing for some differences due to sampling variability (ie it would be expected that the quantiles derived using RORB lie within the 90% confidence bounds and not necessarily on the best estimate of the quantiles derived using gauged observations). Ideally the RORB design quantiles should be obtained using pre-burst rainfalls and fixed loss parameters, where an adequate match is obtained by judicious adjustment of the pre-burst exceedance percentile, the median estimate of initial loss, and the fixed value of continuing loss. The loss values should not be varied by AEP unless absolutely necessary.	Rory Nathan comments on the overall approach [email dated 13/03/2024]: I have read through the extract of the report provided, and as usual I find the reporting to be well-reasoned and clearly documented. With reference to the points of key concern, I agree that: - The "traditional" approach of fitting the routing and loss parameters is not defensible - A suitable range of different approaches has been adopted to explore this problem - The option in which the routing parameter (Kc) is approximately doubled should be adopted for design purposes, noting that:	12-hour timebase 905 70,307,000 4.66 24-hour (base case) 905 140,614,000 4.74 48-hour timebase 905 281,229,000 4.76 72-hour timebase 905 421,843,000 4.77

Comment Number	Comment	Jacobs Response	Action
		o The adopted Kc value is more in line with regional expectations o The corresponding differences between the FFA and RORB quantiles is negligibly small compared to the associated uncertainties - Results from the RORB model should be used with increasing caution for locations further upstream above the Keilor gauge - Caution should also be exercised when relying on estimates of time-to-peak If the volume of the design flood has a material influence on flood levels, then it would be worth undertaking further checks on the RORB model performance. At	

Comment Number	Comment	Jacobs Response	Action
		the least, it would be useful to see how the relationship between flood peak against flood volume (over a time period most relevant to the design question being explored) based on historic flood events compares with those derived for design events. (This might be a little tedious to explore using RORBWin, but it should be possible to derive a notional central tendency and upper/lower limits for a range of AEPs without undertaking an excessive number of manual simulations.)	
6	The spatial pattern of design rainfalls used to derive the 1%AEP quantiles should be based on the duration of the event critical to the location of interest. The labelling of Figure 4-29 needs to be checked and corrected as needed.	Ok, caption has been updated in reporting	Action: Figure 4-29 caption to be amended

Comment Number	Comment	Jacobs Response	Action
7	It needs to be recognised that there is unequivocal evidence that global warming has impacted on extreme rainfalls over the past few decades. The current best estimate of these impacts is summarised in a recent pre-print under public review for an international journal[2] and in the subsequent draft guidance under preparation for Australian Rainfall and Runoff[3]. It is reasonable to assume that the impacts of global warming on observations used to derive current IFD estimates published in 2019 need to be increased to better represent current conditions (for storm burst durations of 24 hours and longer). This adjustment may assist the reconciliation problem discussed in the preceding point, and will need to be considered in some fashion when deriving best estimates of design flood risks for future planning purposes. Rainfall intensities for rainfall events 24 hours and longer should be increased by 8%/°C, where the temperature increase relative the 1961-1990 period has been 1.3°C. The baseline most relevant to the	Ok, will note in the report that global warming continues to impact extreme rainfalls. Methodology for this project will not be updated to reflect upcoming guidance, however a recommendation to update the modelling when practicable will be included.	Action: Add recommendation regarding climate change to report.(Section 9)

Comment Number	Comment	Jacobs Response	Action
	analyses being undertaken for reconciliation and future planning periods may not be the same, and this is an issue that would benefit from further discussion and thought. Any adjustments to the IFD design information should based on the historic changes in global temperatures shown in the plot below, as provided in the draft flood guidance[3]: 2 Wasko, C., Westra, S., Nathan, R., Pepler, A., Raupach, T., Dowdy, A., Johnson, F., Ho, M., McInnes, K., Jakob, D., Evans, J., Villarini, G., and Fowler, H.: A systematic review of climate change science relevant to Australian design flood estimation, Hydrol. Earth Syst. Sci. Discuss. [preprint], https://doi.org/10.5194/hess-2023-232, in review, 2023. 3 https://consult.dcceew.gov.au/update-to-the-cc-considerations-in-the-arrg		

Hydrology and Hydraulics

8	Data obtained and derived from the Keilor water level gauge is critical to the outcomes of the study. As such, the following is noted and recommended:	a. Ok b. Ok	History of gauge to be included in the final report Correspondence with the Independent Reviewers incl Cathie Barton response in green [email 30/11/2023]. Additional comment by Jacobs in blue to reflect updates since last year.

	a. The gauge has been moved four times. It appears that there are only consistent level records after 1975 and there is uncertainty in derivation of flows prior to 1975. It is recommended that additional investigations be undertaken to better understand the reliability of historical data, particularly to ensure that the correct rating curves have been used to estimate the different historical flood events. b. The gaugings undertaken at the Keilor gauge in 2022 have allowed the rating curve to be adjusted for higher flows. The augings were undertaken on the falling limb of the flood peak. If hysteresis exists at this gauge location, it is possible that the adjusted rating curve may underestimate derived flows. Following discussions on this at the workshop, Jacobs developed a H-Q curve at Solomons Ford to demonstrate hysteresis. At this location within the flow range of the 2022 event, minor hysteresis was evident. The difference between rising and falling limb flows was about 5%. In the context of other uncertainties (model, data etc), this is not considered significant and further consideration of hysteresis is not warranted for the range of flows considered in this study. The following is recommended: i. Document the additional information on hysteresis in the report;		I quickly plotted up the H-Q relationship at Solomons Ford for one of the 2022 events to examine the hysteresis – see Figure 1. There is around a 5-10% difference between the rising limb and falling limb, which would mean the peaks calculated from this rating table could be up to 5% under. This part of the model has not had any real attention and we haven't attempted to calibrate to the gauge at this stage. Agree that the peaks could be underestimated by 5-10%. Looking that the plot isn't not a clear "there's nothing to do here" nor does it suggest that "we have to do something". I feel that this is certainly an issue that the Melbourne Water hydrography team will need to address, and they have contacted us about this information i.e. using a hydraulic model in combination with gaugings to inform the Rating Table for the site. They hydraulic modelling in this (the Keilor) area isn't programmed in until after April 2022 so I can't see this occurring within the project timelines. Agree that hydraulic modelling will need to be undertaken to supplement the gaugings to produce a stronger understanding of the rating curve. But I understand that it won't be undertaken as part of the current study. Thinking through the potential consequences of this: • There would be minor changes to the hydrology calibration in terms of the final kc • There might be a minor impact on the hydraulic calibration. In relation to the hydraulic calibration, as we are generally satisfied with the hydraulic model calibration (perhaps except for 2011), it could be argued that the hydraulic model parameters are compensating for the ~5% lower inflows. Thus,

	ii. Note for future rating curve assessment (understood to be an upcoming investigation by Melbourne Water), a hydraulic model should be used in combination with the gaugings to test and potentially refine the rating curve. The current calibrated hydraulic model would require an upstream extension and recalibration to be fit-for-purpose for this task.		the hydraulic model in its current state may produce slightly more conservative (higher) peak design flood levels. Which is not bad. However, this ignores the impact that the lower flows may have on the FFA and RORB model. • The re-rated flows presented in the report for the 2011, 1993, 1987 and 1983 would be low. • The FFA would need to be redone, but I don't think this would have much impact give: o When the re-rated flows were included in the FFA there was only minor changes to the resulting quantiles; the 1% went from 915m^3/s to 905m^3/s. Those changes were much larger than the ~5% suggested here. Good to know that it is not that sensitive Jacobs note: There have been minor changes to the FFA since this] • The validation events would change; o 2011 would be worse; I think this one would be better? Higher flows would produce higher levels at Chifley. o 1993 would also be poorer; o there would be an improvement in 1983 particularly the 'long-section' as flows slightly increased. Poorer at the gauge but better at the flood marks. [Jacobs note: There have been improvements to the 1983 calibration since this] Let me know if I've missed anything. I didn't mention this at the meeting yesterday, but there was a significant improvement at the Chiefly Drive gauge across all events when the re-rated were applied. See Figure 2 for prior to the re-rating and Figure 3 for post re-rating. It was the same pattern for 1983 and 2011 with 2011 having the least improvement. To me this provided

			strong evidence that re-rating was correct thing to do and also that the re-rating was fairly close to the mark. OK Looking at the rising and falling limb from figure 1 at around the 7.89m AHD mark is difference is around 3.8% and this % difference is a slight overestimate as the levels don't perfectly match. I'm leaning towards accepting the rating table as it is as this won't materially change the results and recommend that the hydraulic model is used to develop the next rating table. On reflection, if our high flow gaugings are within 5% at more than 10 other gauges in Australia I'd be staggered! Agree. Given that we have confidence in the gaugings and the hysteresis is not significant, the overall confidence is on the high side of the spectrum when it comes to rating curves in general.

	Rising	Falling	Diff / 2	% diff from falling
Discharge (m3/s)	528	490	18.8	3.8%
Level (m AHD)	7.89	7.88	0.013	

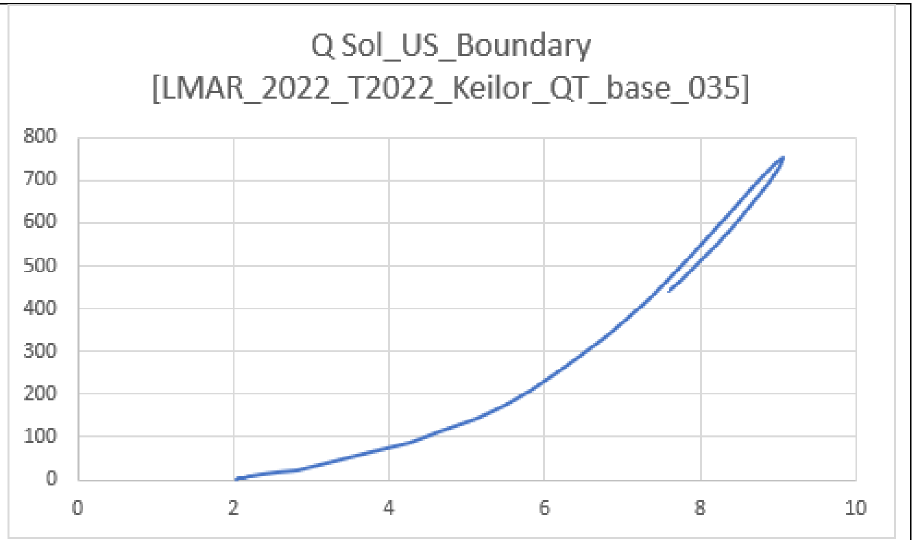


Figure 1 – Hydraulic model results flow verses discharge at Keilor

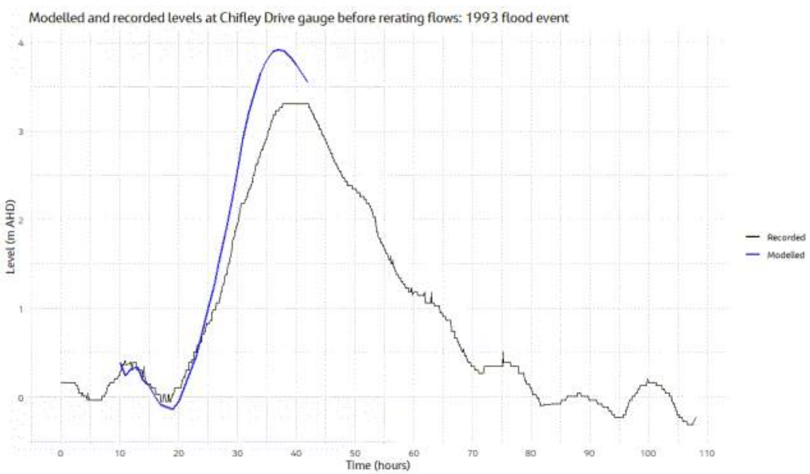
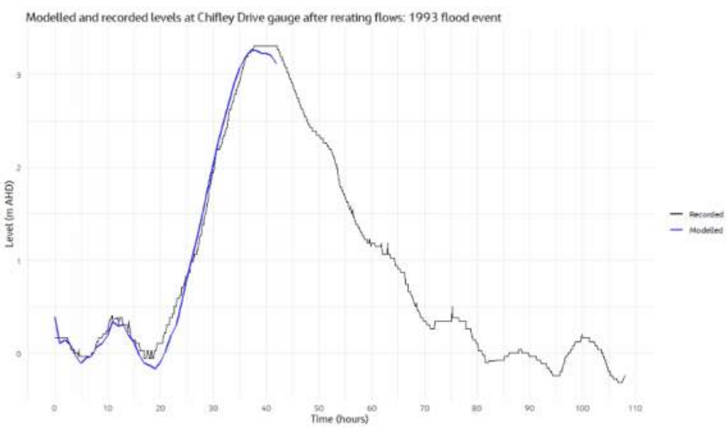


			Figure 2 – 1993 validation results at Chiefley Drive prior to re-rating Keilor flows to RT37.02  Figure 3 – 1993 validation results at Chiefley Drive after to re-rating Keilor flows to RT37.02
9	The methodology adopted for modelling the calibration events results in the hydrology (RORB) and hydraulics (TUFLOW) model being independently calibrated. That is, the RORB model does not provide calibration inflows to the TUFLOW model, rather inflows are derived from the recorded Keilor gauge levels. As the models will be used jointly to undertake the design event simulations, evidence is required to provide confidence that they are capable of reproducing historical event behaviour while being used jointly. During the workshop it was agreed that joint	Noting that the model is recommended to be used for planning and design event modelling.	To be completed in Section 8.

	simulation of the 2022 event should be undertaken as a verification to demonstrate that the resulting TUFLOW calibration results are similar to those achieved from the independent calibration.		
10	In concept, the design efficacy of the joint modelling process would be best assessed by comparing the frequency curve of flood levels derived from observed data with that derived using the combined RORB-TUFLOW modelling chain. That is, rather than merely test the combined ability of the models to simulate a specific historic event, we test the ability of the combined models to reproduce flood levels with a specified annual exceedance probability, which is the design objective of most interest. This is similar to reconciling flood frequency curves (ie Figure 4-28), but extending the process to flood levels with a known exceedance probability. It may be possible to do this at the Chifley gauge (given that the Keilor gauge may be too close to the inflow boundary), but the robustness of the result will be dependent on a number of factors including the availability of suitable historic data. We would be interested in your thoughts on undertaking such a test during the design phase.	Ok, we will provide comment	Section 8.1 has been included which identifies that peak flood levels at Chifley are primarily influenced by peak flow rates at Keilor.

Hydraulics

11	It is understood that lateral inflows are not yet included in the hydraulic model but that they will be. This is acceptable. The	Ok	Lateral flows have now been included in the model (Section 6.5)

	influence of these inflows on calibration results is expected to be small as lateral inflows will have a far shorter critical duration.		
12	Manning's n: a. It is understood from discussions at the workshop, that better calibration results have been achieved by varying the in-channel Manning's n longitudinally along the river with a different value in each of four reaches. Manning's n values start from 0.023 in the downstream reach and rise to 0.042 in the upstream reach. This is considered acceptable given the changing channel roughness demonstrated in each reach, the appropriate range of Manning's n values used, and the calibration results. b. Modelled and recorded level hydrographs at the Chifley gauge are presented in the report to demonstrate effectiveness of the model in replicating event behaviour. These include the modelled and recorded tidal signal prior to the commencement of the fluvial event. The model appears to be adequately replicating the tidal signal at the Chifley gauge. This gives confidence that the in-channel Manning's n values in the reaches below the Chifley gauge are appropriate as the conveyance of a tide upstream into a river is strongly influenced by the Manning's n value but not the form (bend) loss. It is recommended that commentary around this is added in the text.	Ok, will provide additional commentary	Action: Add commentary as per review suggestion "The model appears to be adequately replicating the tidal signal at the Chifley gauge. This gives confidence that the in-channel Manning's n values in the reaches below the Chifley gauge are appropriate as the conveyance of a tide upstream into a river is strongly influenced by the Manning's n value but not the form (bend) loss."
13	Form (Bend) losses: a. It is recommended that the bend losses used and presented in Table 5-10 are adjusted to reduce the precision. At present,	Ok	Action: Reduce precision of bend losses in table 6-10 (table number may have changed)

	some of the values are shown with up to 4 decimal points. Such precision implies an accuracy that is unfounded. b. The Syme (2015) reference used to guide the selection of the form loss value is outdated and should be replaced with Syme (2021)4. The values presented by Syme (2021) are slightly lower than the previous 2015 reference. However, the bend losses presented in Table 5-10 of the report remain within acceptable bounds.		
14	Calibration results are acceptable. Given that the hydraulic model inflow is derived from the gauge record at Keilor rather than the RORB model, a good calibration is expected as uncertainties in inflow are greatly reduced. The following is recommended: a. All events are demonstrated to achieve good calibration at the Chifley gauge with the exception of the 2011 event. The 2011 event is the smallest event modelled and the modelled levels at Chifley exceed the recorded. It is recommended that the modelled longitudinal profiles from Keilor to the downstream boundary be plotted together with the gauge levels for the four recent calibration events to investigate the modelled versus recorded longitudinal slopes. It appears, from a rudimentary review of levels, that the recorded longitudinal water slope between Keilor and Chifley is steeper than what would be expected for a relatively minor event. If that comparison produces a noteworthy result, it is recommended that commentary is added to the report. b. Some calibration points represent "minimum level possible", rather than peak levels. On the longitudinal plots it would be better to identify these with different markers. In addition, it	Ok	a. Comparison has been completed, but nothing noteworthy was found i.e. the slope of the smaller event was slightly steeper, as expected. b. This has been addressed in report figures c. Updated modelling and report has addressed this in Section 6.10.8 and Section 6.10.9

	would be useful to have a zoom of areas of interest on the longitudinal profile to show calibration results at a more readable scale. This would be particularly useful at Maribyrnong town for 2022. c. It is understood that some additional information has recently been discovered in relation to historical floods that may influence validation of the hydraulic model. This includes barges being stuck under the Raleigh Rd Bridge in the 1983 flood and additional blockage during the 1974 flood associated with a coffer dam at the Kensington Rail Culverts. It is recommended that this is verified and included in reporting.		

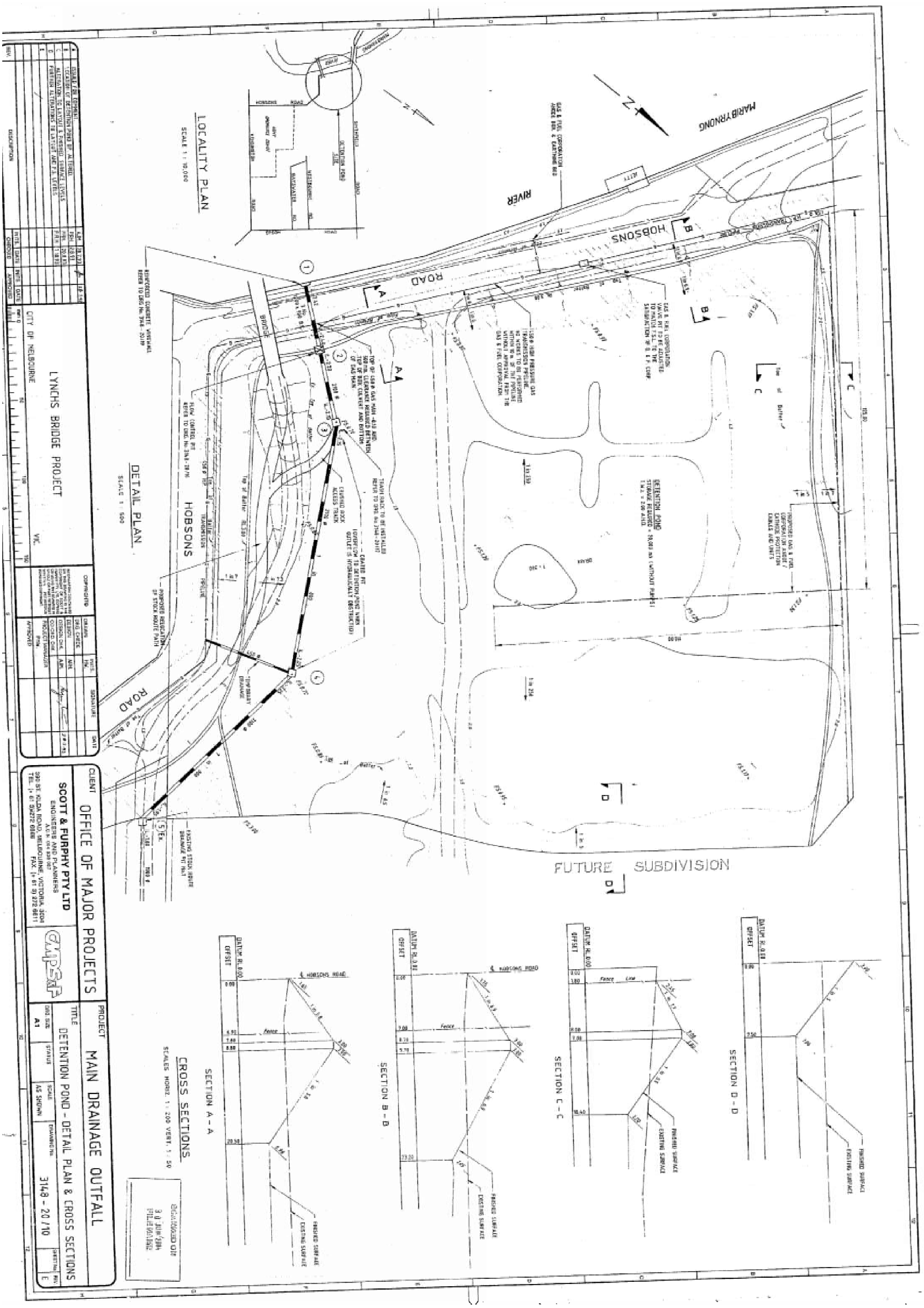
Reporting

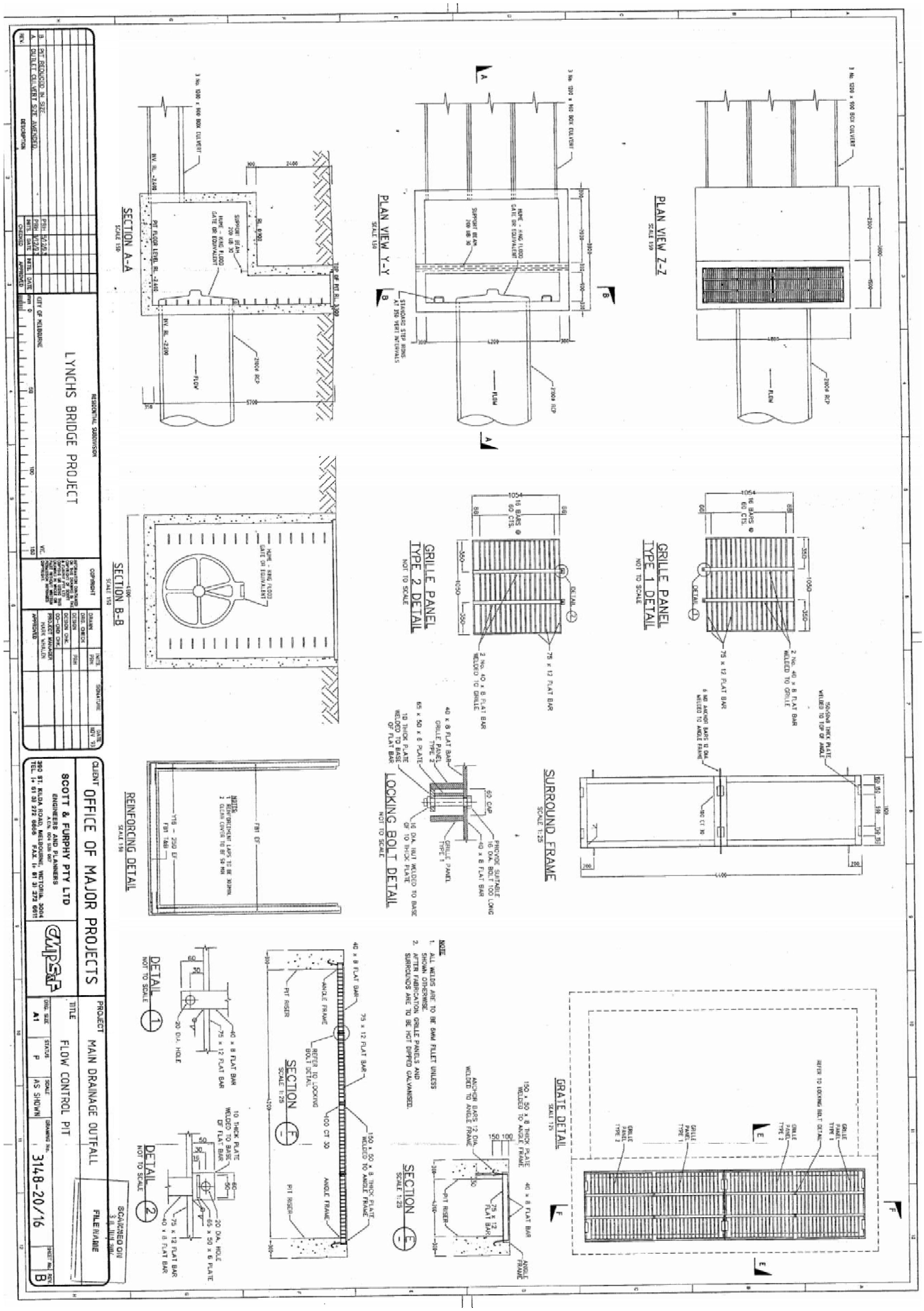
15	The following would be useful additions/updates to the report: a. Section 1.2. The last paragraph refers to "rainfall on land that drains directly to the Maribyrnong River". The meaning of this is not entirely clear, and if this paragraph is intended to differentiate between flooding occurring as a result of stormwater runoff as distinct from a watercourse overtopping its banks, then it might be helpful to use standard terms (perhaps as used by the insurance industry) to make this point clearer. b. Section 1.3.1 states that no significant changes have been made to the proposed schematisation approach since the schematisation report. However, it is apparent from the calibration report that there have been some important changes to model schematisation since the schematisation report was presented. As it is our understanding that that schematisation	Ok	Actions: Update sentence in Section 1.2, 1.3.1 (to indicate changes since schematisation report), Section 2.1 adjust wording of last major event to something clearer Amend labelling in Figure 3-3, Amend Figure 3-5 Note Figure 3-5 was provided by an external supplier to MW i.e. Jacobs did not create this figure. Include figure with gauge locations (Figure 2-2 and 3-7)

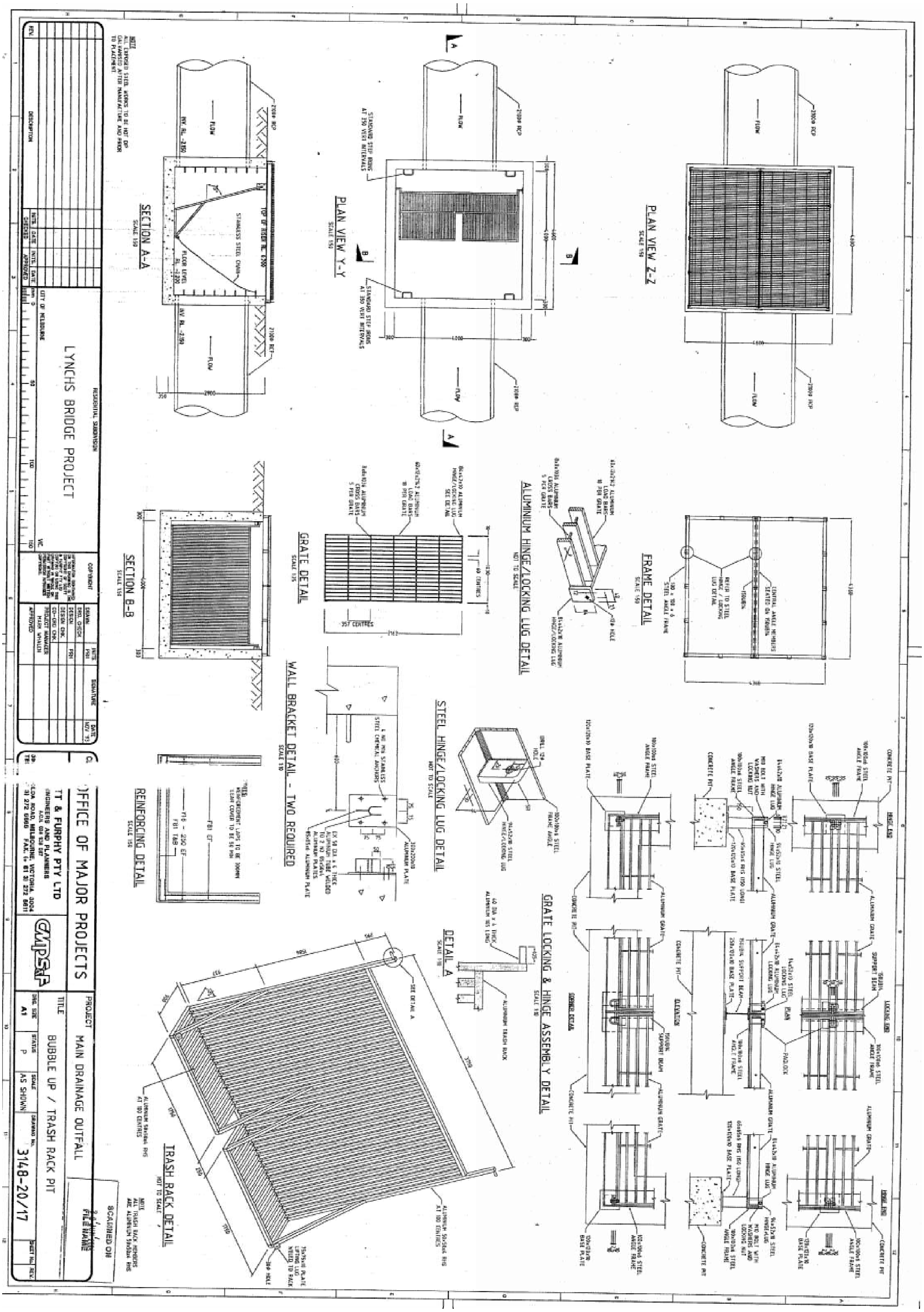
	report will not be updated, it is important to acknowledge, in Section 1.3.1, that there have been some key changes. c. Section 2.1, second paragraph. The reference to "the last major event recorded in September 1993" is misleading given the information available on the 2022 event. This phrasing should be corrected. d. The labelling of dates in Figure 3-3 should be altered to avoid the overlapping. e. In Figure 3-5 the symbols used for the (pink) rating curve RT37.01 should be omitted to avoid any possible misinterpretation that these represent spot gaugings. The font size in other annotations should be increased to assist legibility. f. Include at least one map showing all water level gauges used in the study. This may require a zoom of the three key gauges relevant to hydraulic modelling (Keilor, Chifley and Southbank) in relation to the hydraulic model extent. In addition, a table summarising key facts about each of the key water level gauges would be useful. As a minimum it should contain name, period of record, peak recorded water levels and peak derived flows for calibration events. g. The verification of the accuracy of the LiDAR data using 453 surveyed points produces good results. Provide commentary on the location and nature of the 453 comparison points that have been used to verify the LiDAR data. h. Section 3.6, provide a short explanation of the basis used for removal of spurious flood mark data.		Add figure and survey report regarding survey verification. (Appendix C & D) Add discussion about removal of spurious flood marks. (Appendix A) Amend reporting in Section 4. Add consistent shading to rainfall depth figures where possible.

	i. The last sentence in the first paragraph of Section 4.1 needs to be deleted or clarified. The statement as currently phrased is not supportable. j. The heading for the 4th column of Table 4-3 is incorrect and needs to be changed to "Upper CL". k. It would be preferable to have consistent colour shading across the rainfall depth distribution figures for each event (Figure 4-12 to Figure 4-15) to enable a visual comparison to be more easily made.		

Appendix O. Riverside Park Underground Drainage Plans




SECTION A-A
PLAN VIEW Y-Y
PLAN VIEW Z-Z
SECTION B-B
GRILLE PANEL TYPE 1 DETAIL
GRILLE PANEL TYPE 2 DETAIL
SURROUND FRAME
REINFORCING DETAIL
LOCKING BOLT DETAIL
GRATE DETAIL
LYNCHS BRIDGE PROJECT
OFFICE OF MAJOR PROJECTS
SCOTT & FURPHY PTY LTD
MAIN DRAINAGE OUTFALL
FLOW CONTROL PIT
3148-20/16


SECTION A-A
PLAN VIEW Y-Y
PLAN VIEW Z-Z
SECTION B-B
GRATE DETAIL
ALUMINIUM HINGE/LOCKING LUG DETAIL
FRAME DETAIL
WALL BRACKET DETAIL - TWO REQUIRED
REINFORCING DETAIL
STEEL HINGE/LOCKING LUG DETAIL
DETAIL A
GRATE LOCKING & HINGE ASSEMBLY DETAIL
TRASH RACK DETAIL
CITY OF MELBOURNE
LYNCHS BRIDGE PROJECT
OFFICE OF MAJOR PROJECTS
TT & FURPHY PTY LTD
MAIN DRAINAGE OUTFALL
BUBBLE UP / TRASH RACK PIT
AS SHOWN
3148-20/17
SCANNED ON

Asset Number 1126514

Hobson Road Trash Rack

Location:	Hobsons Road, Kensington Banks adjacent to Maribyrnong River (Lynches Bridge Main Outfall Drain), Melways 42G3
Model:	On-line trash rack – vertical steel bars on outfall drain
Contractor:	Designed by CMPS&F/Egis
Date Installed:	1993
Catchment Area:	New housing developments in Kensington Banks
Pipe Diameter:	1750 mm dia. outfall drain
Other Design Details:	50 mm vertical grate Flood gates between litter trap and the river
Maintenance Regime:	• Cleaned by dewatering & grab bucket removal of material when tide level is low • Full clean out/dewatering in conjunction with tide gate seal maintenance check every 2 years • Inspection and educt floatables including Tide Gate pit every 6 months, Audit by checking depth of material before and after cleanout • Included in CIS contract, vehicle access is a key issue
References:	Location map under "KB Westbourne Rd" file Diagram of trash rack under "Kensington Banks" in large flat drawer Drawing 3148-20/17

Location of Hobsons Road Trash Rack Pit

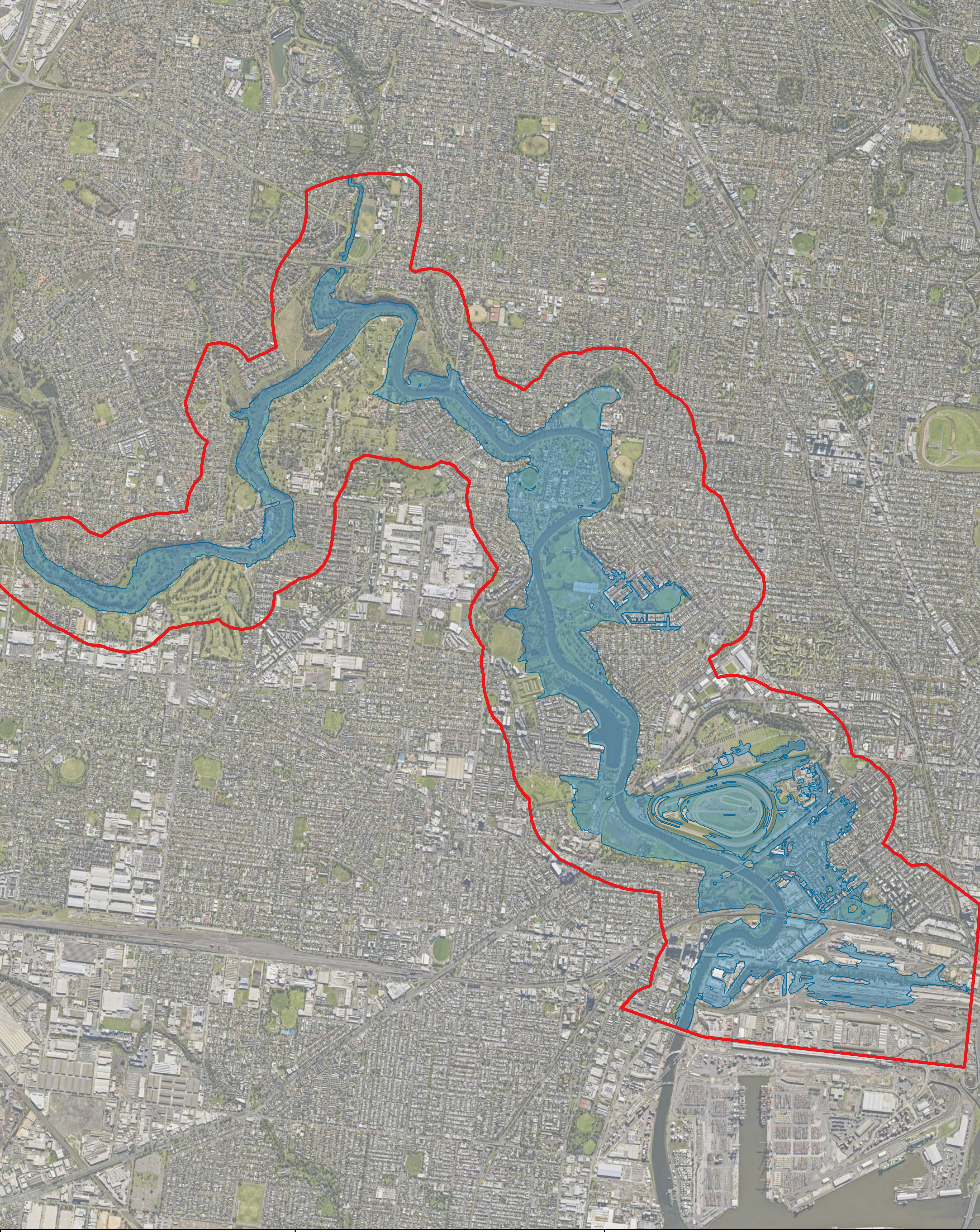
Edge of rack out of its housing

Asset Number 1126514

Floatable Litter in Tide Gate Pit

Flood Gates Pit

Appendix P. Flood Extents for simulated AEP events



Legend
Mapping extent
Flood extent

MGA Zone 55

Jacobs

0 0.5 1 km

1% AEP event modelled flood extent

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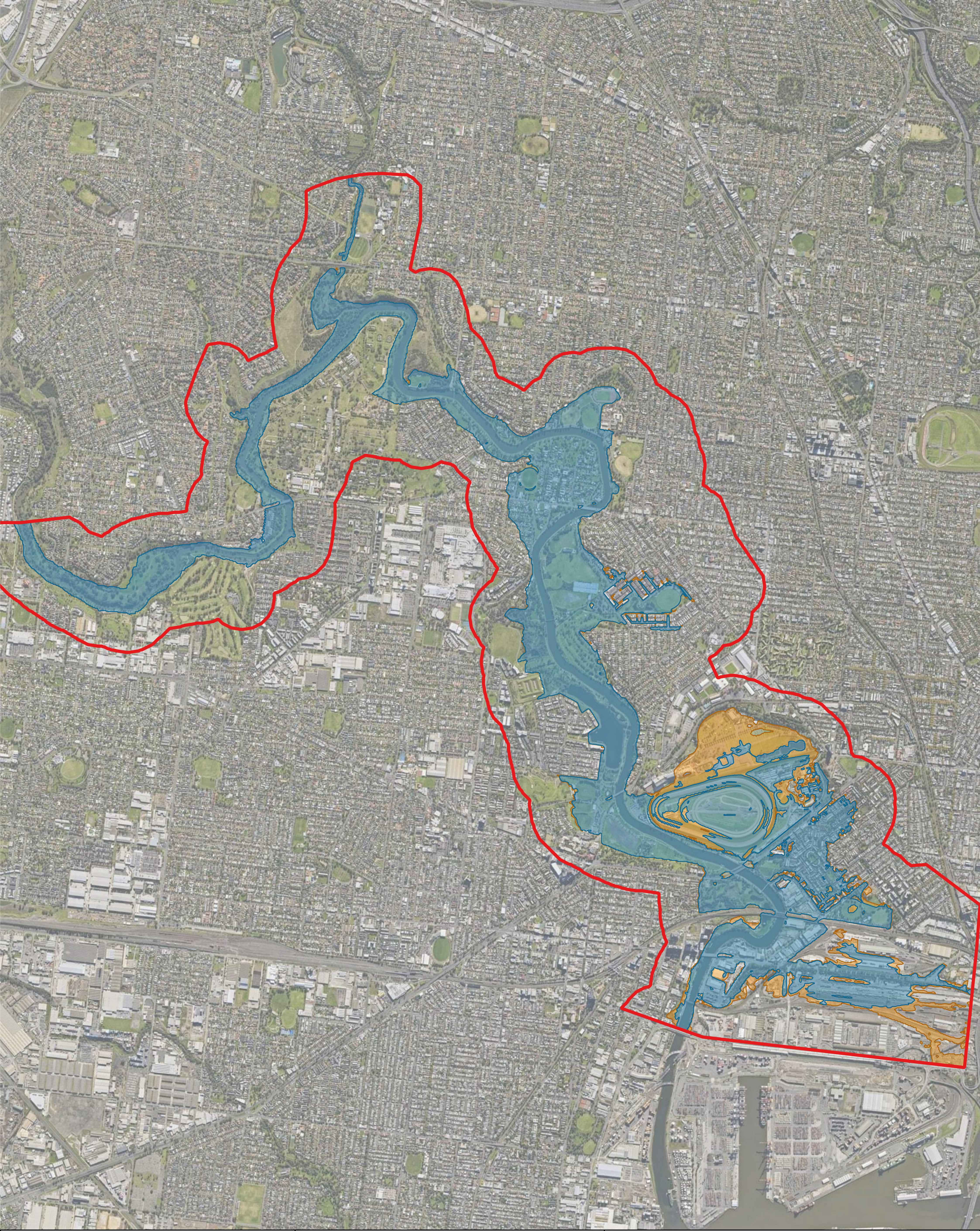
Project Number: IA5000NN

FINAL



Legend

- Mapping extent
- 1% AEP flood extent
- 1% AEP flood extent with climate change (Scenario B)

MGA Zone 55

Jacobs

0 0.5 1 km

1% AEP and 1% AEP with climate change (Scenario B) modelled flood extents

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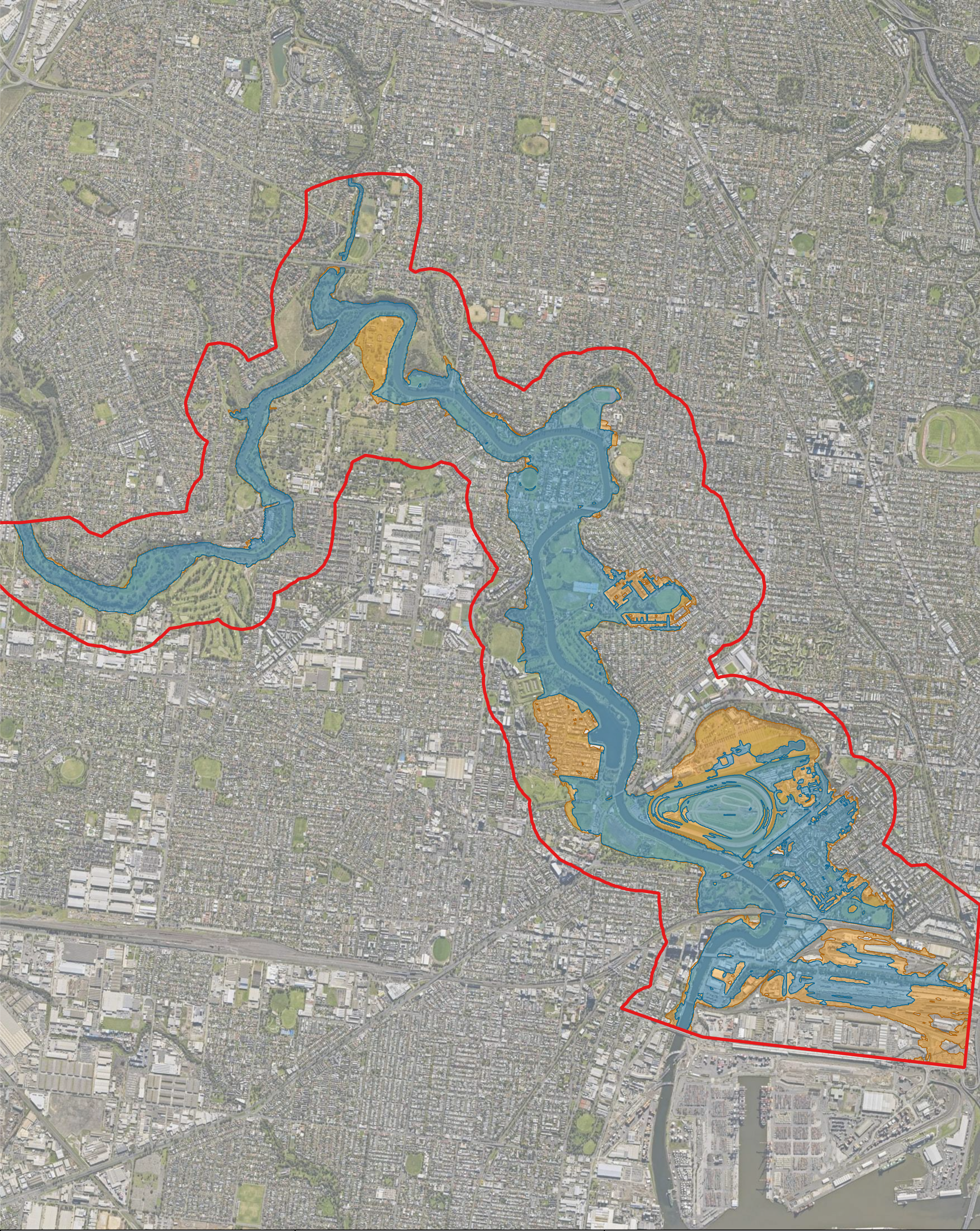
Project Number: IA5000NN	FINAL



Legend

- Mapping extent
- 1% AEP flood extent
- 1% AEP flood extent with climate change (Scenario C)

MGA Zone 55

Jacobs

0 0.5 1 km

1% AEP and 1% AEP with climate change (Scenario C) modelled flood extents

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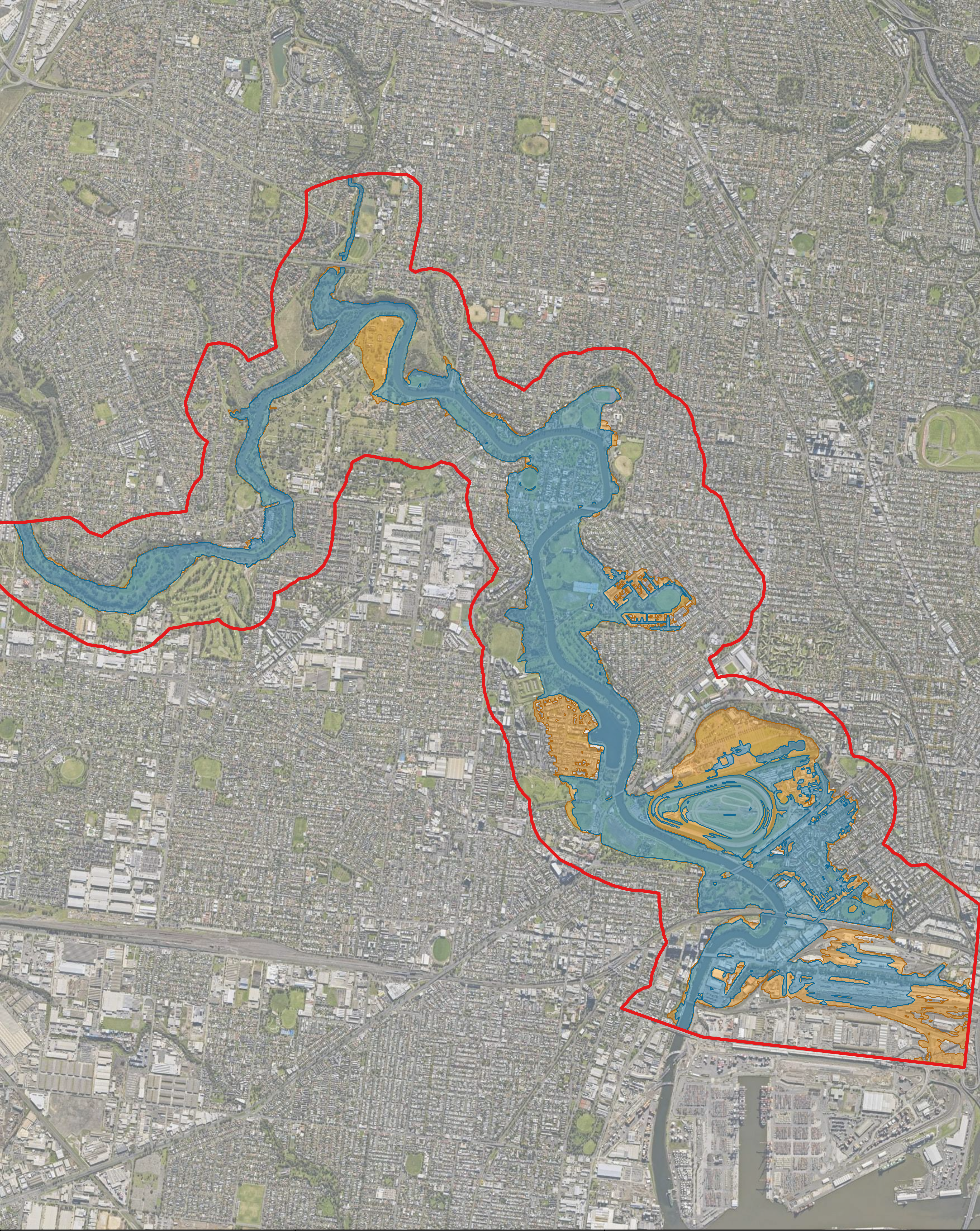
Project Number: IA5000NN

FINAL



Legend

- Mapping extent
- 1% AEP flood extent
- 1% AEP flood extent with climate change (Scenario D)

MGA Zone 55

Jacobs

0 0.5 1 km

1% AEP and 1% AEP with climate change (Scenario D) modelled flood extents

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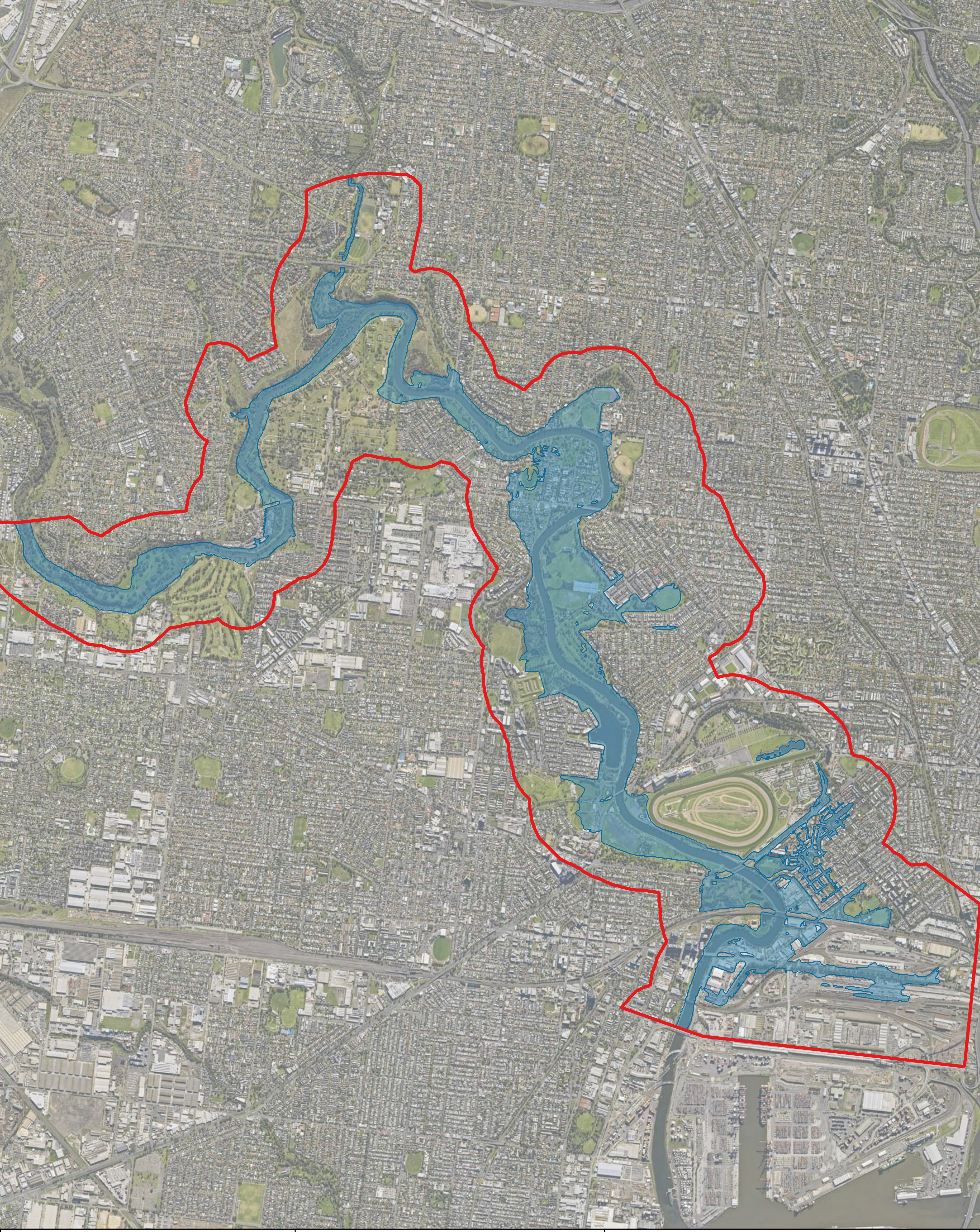
Project Number: IA5000NN	FINAL



Legend

- Mapping extent
- Flood extent

MGA Zone 55

Jacobs

0 0.5 1 km

2% AEP event modelled flood extent

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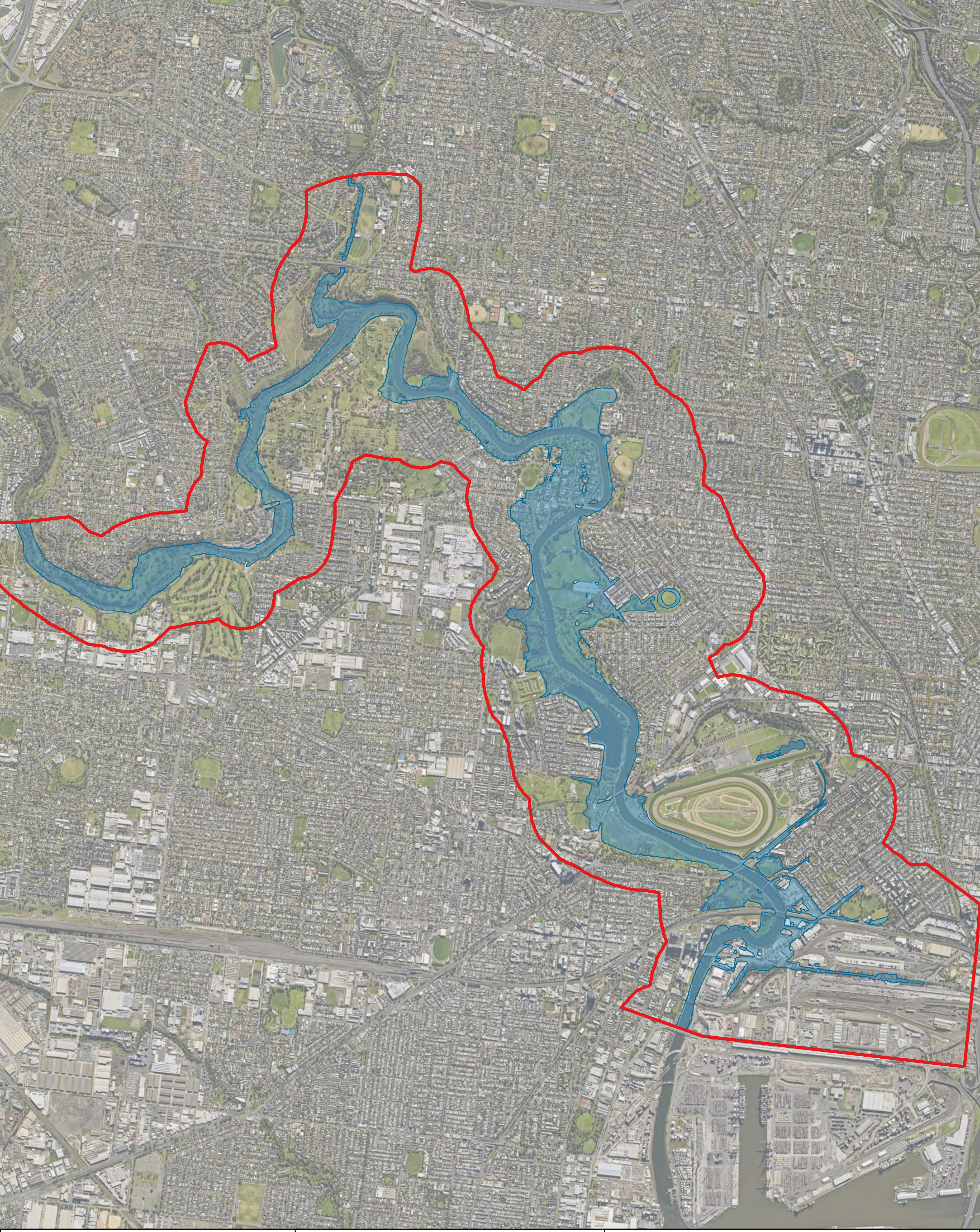
Background imagery from Metromap

Project Number: IA5000NN	FINAL



Legend

Mapping extent

Flood extent

MGA Zone 55

Jacobs

0 0.5 1 km

5% AEP event modelled flood extent

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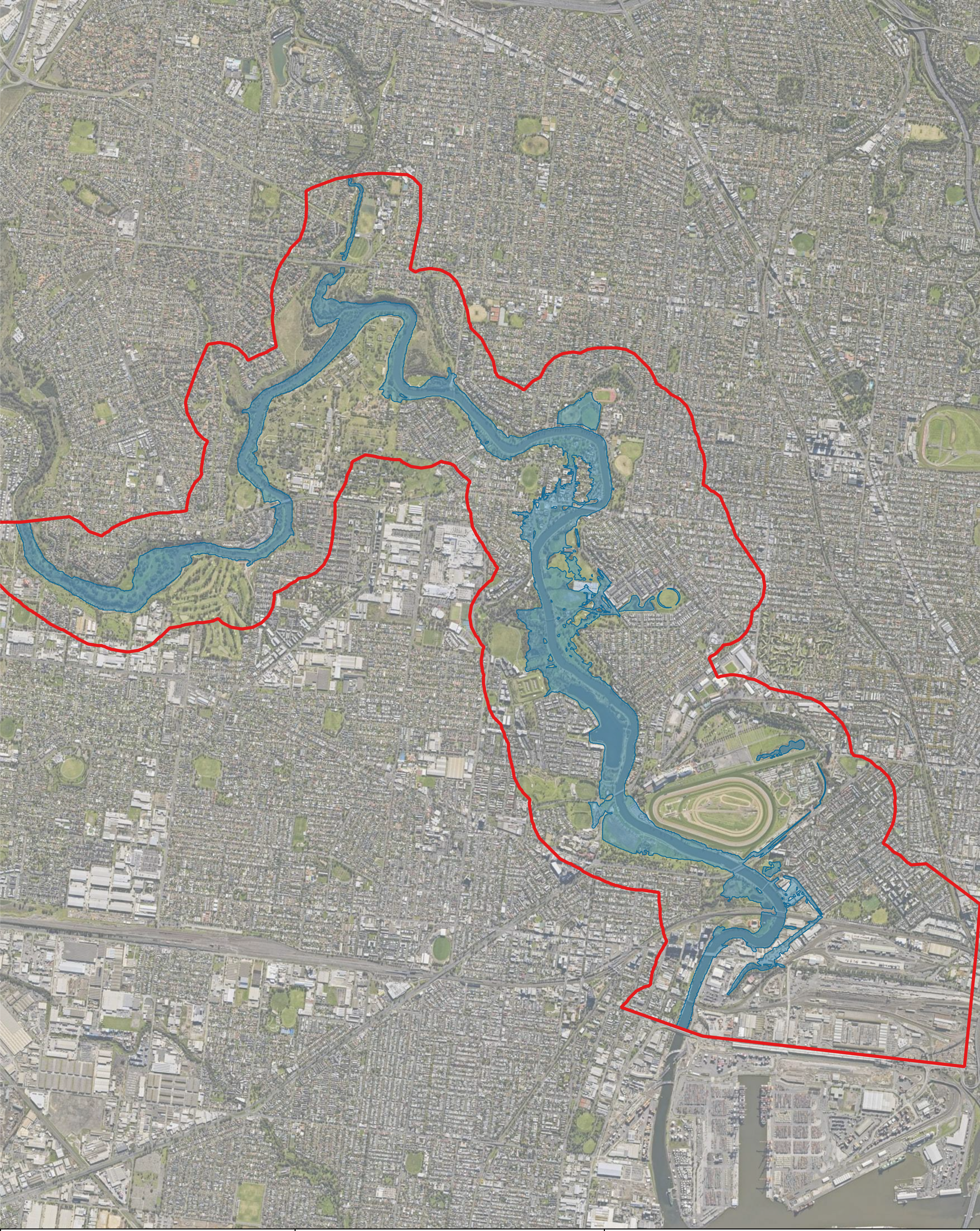
Project Number: IA5000NN	FINAL



Legend
Mapping extent
Flood extent

MGA Zone 55

Jacobs

0 0.5 1 km

10% AEP event modelled flood extent

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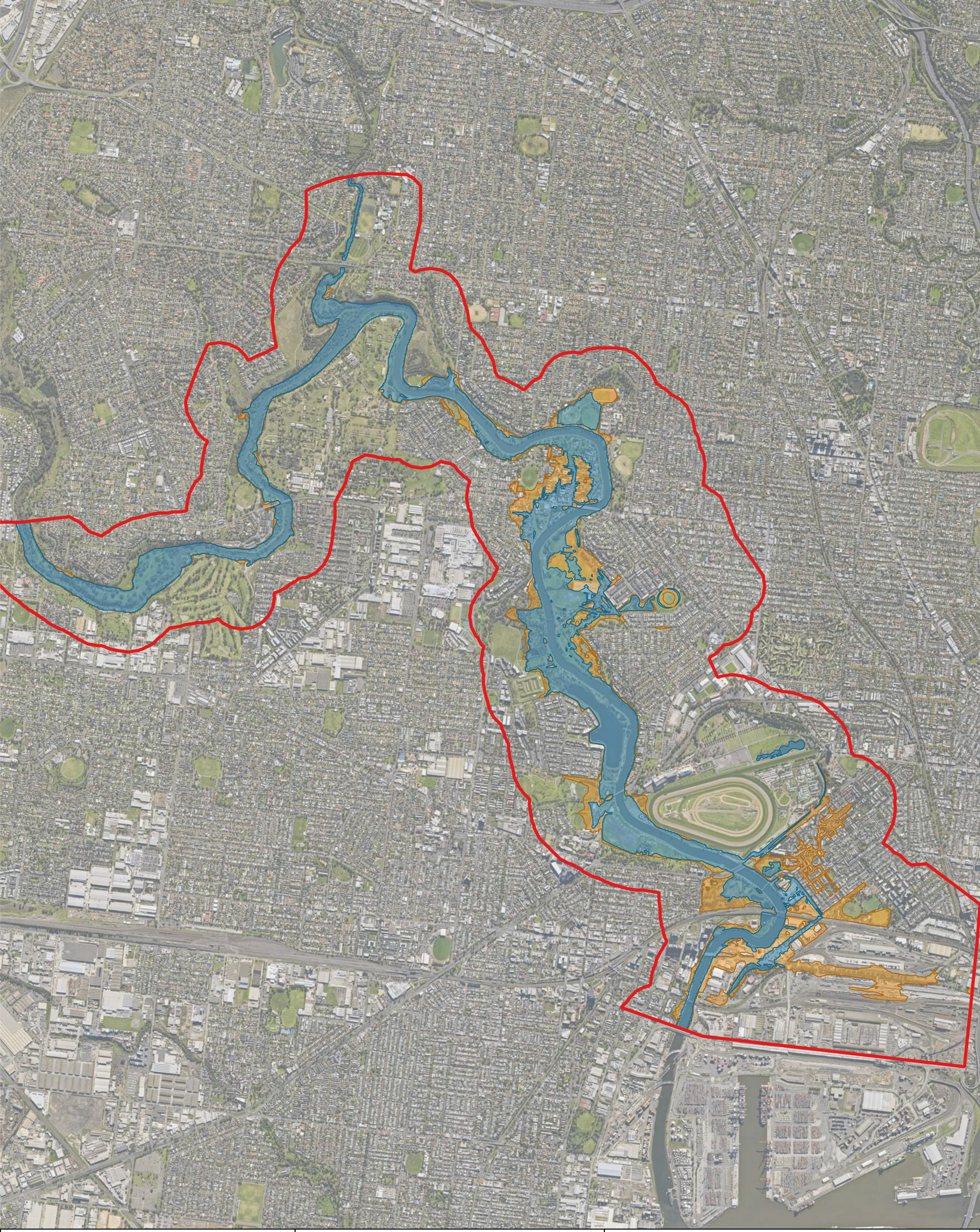
Project Number: IA5000NN

FINAL



Legend

- Mapping extent
- 10% AEP flood extent
- 10% AEP flood extent with climate change (Scenario C)

MGA Zone 55

Jacobs

0 0.5 1 km

10% AEP and 10% AEP with climate change (Scenario C) modelled flood extents

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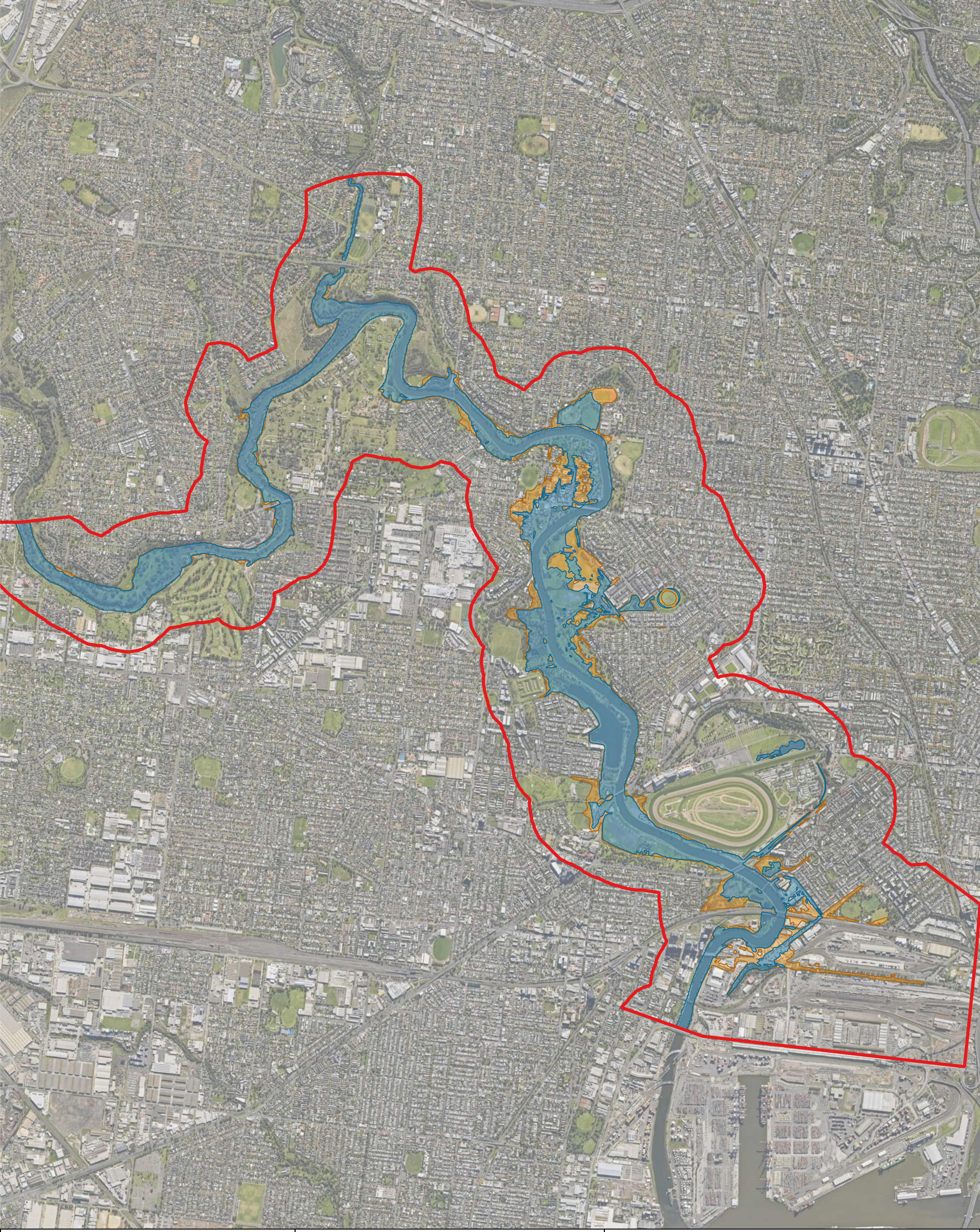
Project Number: IA5000NN	FINAL



Legend

- Mapping extent
- 10% AEP flood extent
- 10% AEP flood extent with climate change (Scenario D)

MGA Zone 55

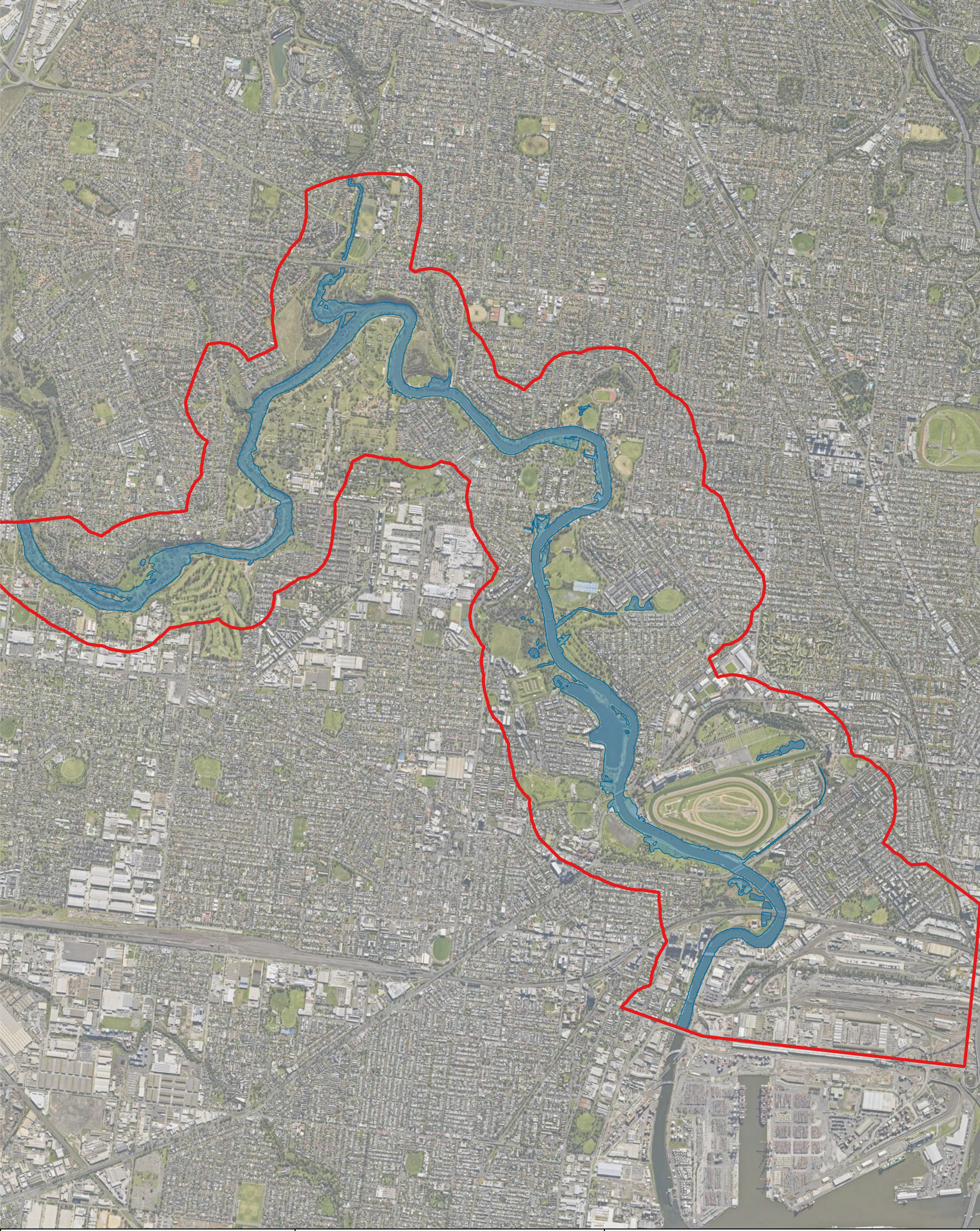
Jacobs

0 0.5 1 km

10% AEP and 10% AEP with climate change (Scenario D) modelled flood extents

Project Number: IA5000NN

FINAL



Legend
- Mapping extent
- Flood extent

MGA Zone 55

Jacobs

0 0.5 1 km

20% AEP event modelled flood extent

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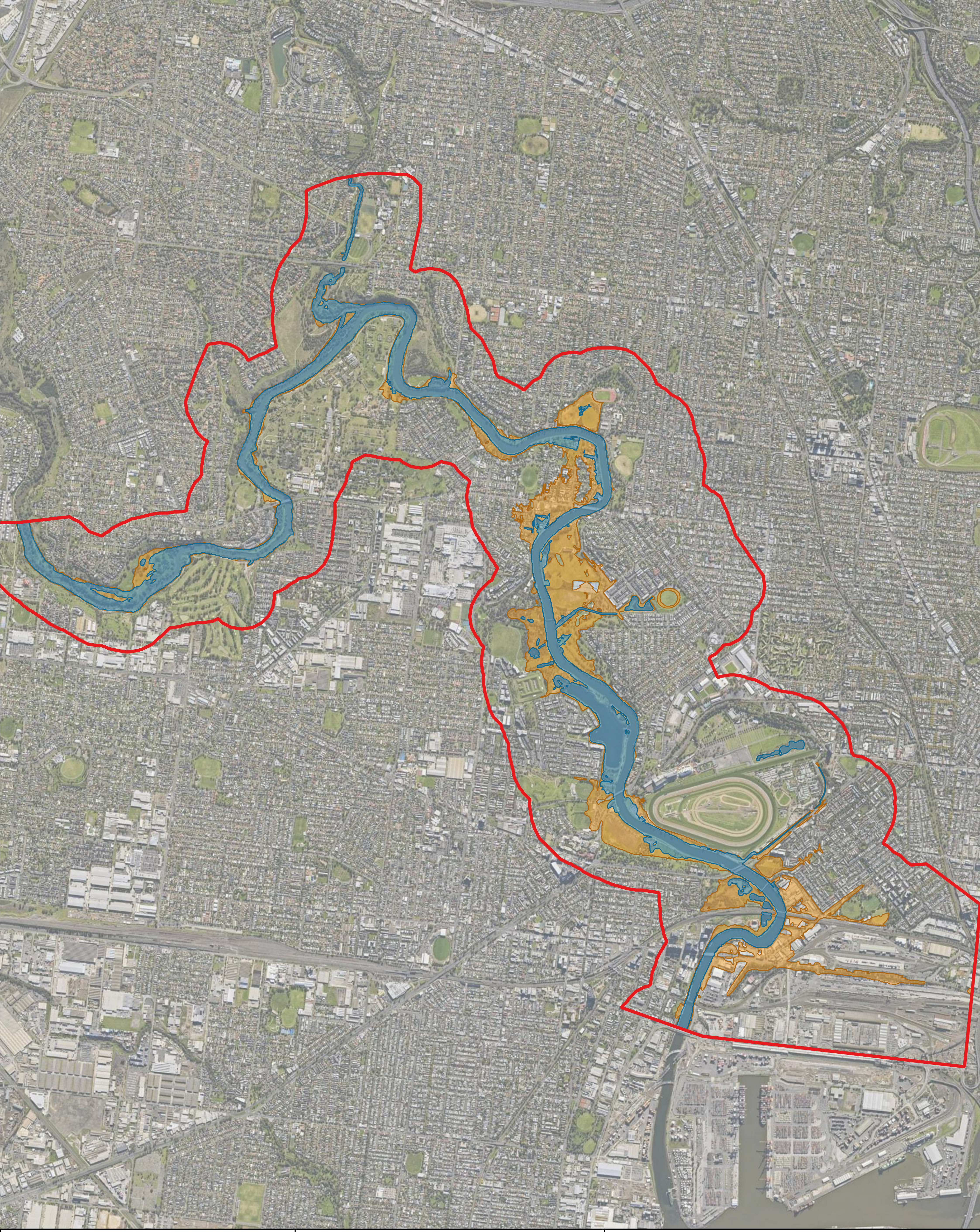
Project Number: IA5000NN

FINAL



Legend

- Mapping extent
- 20% AEP flood extent
- 20% AEP flood extent with climate change (Scenario C)

MGA Zone 55

Jacobs

0 0.5 1 km

20% AEP and 20% AEP with climate change (Scenario C) modelled flood extents

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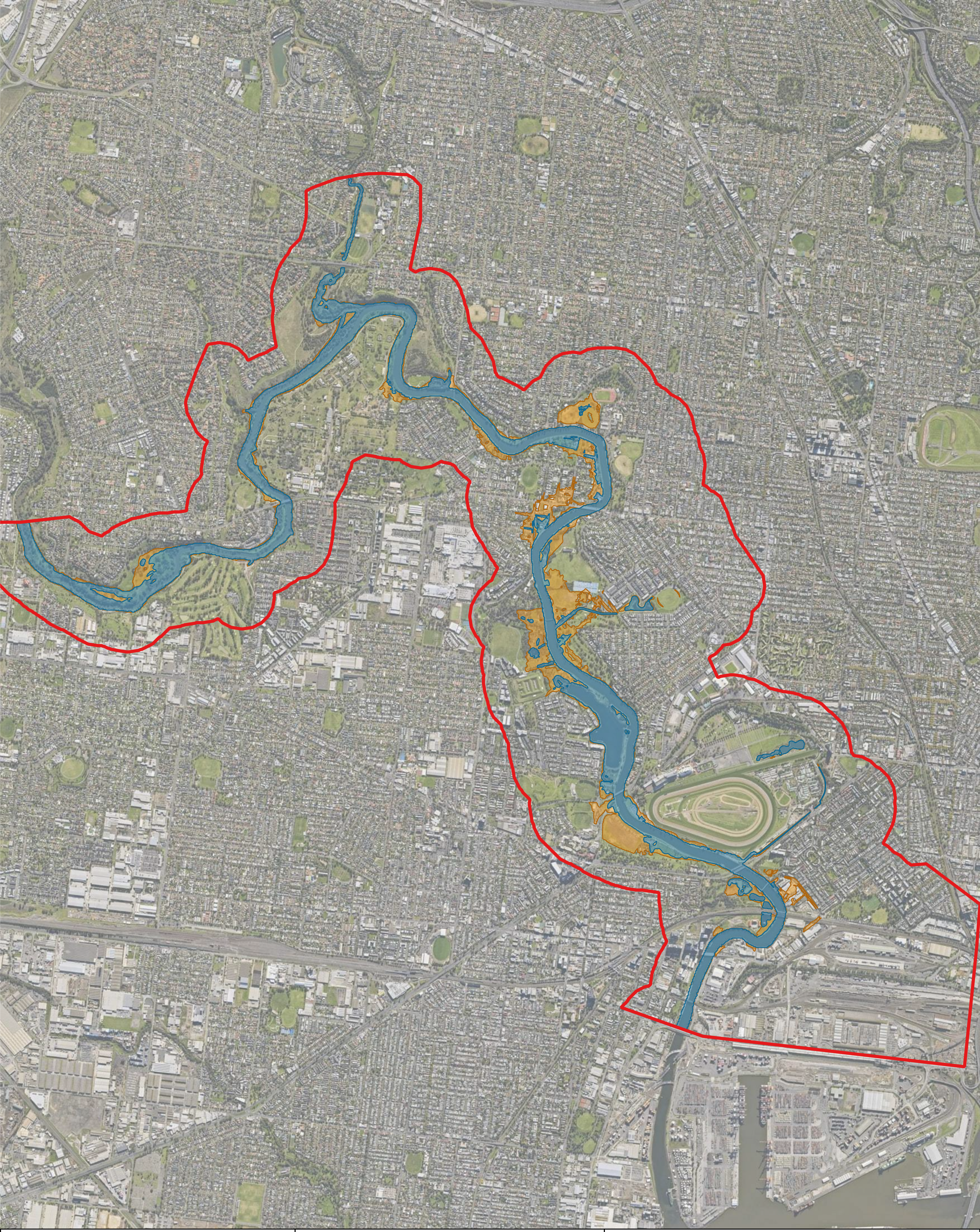
Project Number: IA5000NN	FINAL



Legend

- Mapping extent
- 20% AEP flood extent
- 20% AEP flood extent with climate change (Scenario D)

MGA Zone 55

Jacobs

0 0.5 1 km

20% AEP and 20% AEP with climate change (Scenario D) modelled flood extents

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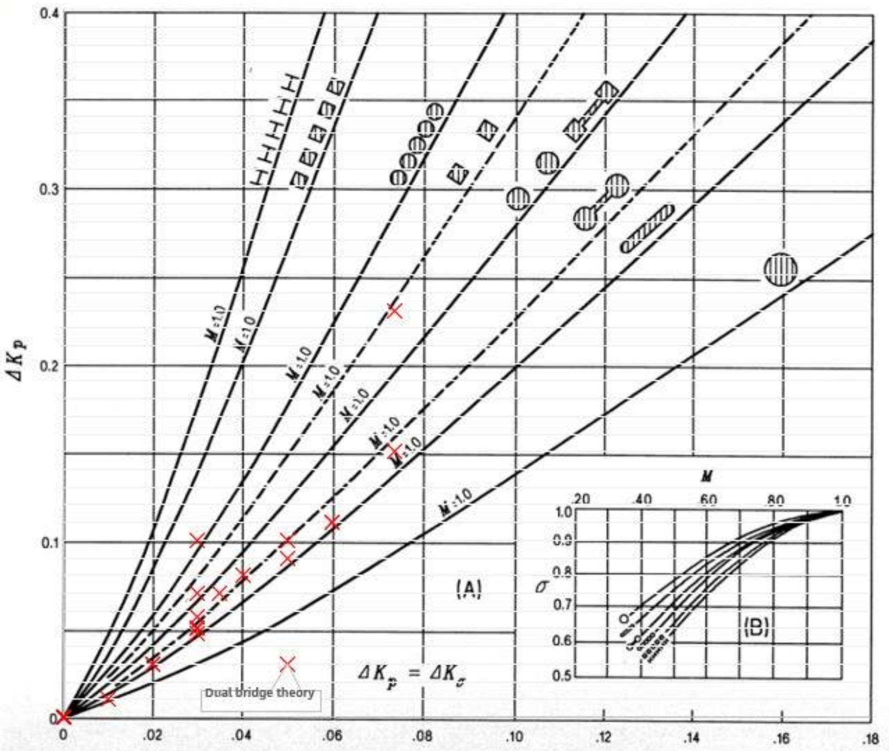
Project Number: IA5000NN	FINAL

Appendix Q. Bridge Loss Calculations

2D_BG LAYER PARAMETERS

ID	Options	Pier_pBloc	Pier_FLC	Deck_Soffi	Deck_Depth	Deck_width	Deck_pBloc	Rail_Depth	Rail_pBloc	SuperS_FLC	SuperS_IPf	Notes
2d_bg_LMAR_076_R		(%)		(m AHD)	(m)	(m)	(%)	(m)	(%)			
CanningSt		4	0.08			18.2	100	0	35	**0.2**	1.6	
Pipemakers_1		0	0			2.4	100	0	25	**0.27**	1.6	end-span
Pipemakers_2		3	0.05			2.4	100	0	25	**0.3**	1.6	support
Pipemakers_3		0	0			2.4	100	0	25	**0.2**	1.6	mid-span
Pipemakers_6		0	0	Varying levels defined by 2g_bg_pts layer		2.4	100	0	25	**0.27**	1.6	symmetrical with 1
Pipemakers_5		3	0.05			2.4	100	0	25	**0.3**	1.6	symmetrical with 2
Pipemakers_4		0	0			2.4	100	0	25	**0.2**	1.6	symmetrical with 3
Lynchs_2nd		3	0.047			16.2	100	0	35	**0.28**	1.6	D/S of the 2
Angliss		3	0.07			4.6	100	0	25	**0.2**	1.6	
Dynon		7.4	0.23			23.5	100	0	25	**0.2**	1.6	
BunburyRail		6	0.11	6.6	0.6	9.8	100	9.2	15	**0.2**	1.6	
FootscrayRd_4th		2	0.03			5.8	100	0	100	**0.2**	1.6	West Bank D/S
FootscrayRd_3rd		0	0	Varying levels		5.8	100	0	100	**0.2**	1.6	Mid D/S Bridge
FootscrayRd_2nd		2	0.03			5.8	100	0	100	**0.2**	1.6	East Bank D/S
Pipebridge		3	0.05	6.9	0.35	4.1	20	1	100	**0.2**	1.6	
KensingtonRd1		5	0.09	6.1	1.4	7.7	100	0.8	10	**0.3**	1.6	U/S of the 2
KensingtonRd2		5	0.03	6.1	1.4	7.7	100	0.8	10	**0.3**	1.6	D/S of the 2
2d_bg_LMAR_FootscrayRd_064_R												
FootscrayRd_1st		6	0.11	Varying levels		22	100	0	10	**0.2**	1.6	U/S of the 2
2d_bg_LMAR_FootscrayRail3rd_045_R												
RailBridge_3rd		3	0.1	5.8	2.9	9.7	100	1	10	**0.28**	1.6	D/S 3rd Bridge
RailBridge_4th		0	0	5.8	2.9	9.7	100	1	10	**0.42**	1.6	between the 2
RailBridge_5th		3.5	0.07	5.8	2.9	9.7	100	1	10	**0.42**	1.6	D/S Culvs
2d_bg_LMAR_FootscrayRail2nd_045_R												
RailBridge_2nd		0	0	6.7	1	10	100	1.05	50	**0.2**	1.6	Middle 2nd Br
2d_bg_LMAR_FootscrayRail1st_045_R												
RailBridge_1st		5	0.1	4.7	3.9	7.3	100	1	15	**0.35**	1.6	Most U/S 1st Br
2d_bg_LMAR_Lynchs1stPostMitigation_045_R												
Lynchs_1st		3	0.0563	Varying levels		10.6	100	0	20	**0.21**	1.6	U/S of the 2
2d_bg_LMAR_FisherBridge_045_R												
Fishers		7.4	0.15	Varying levels		13.1	100	0	25	**0.2**	1.6	
2d_bg_LMAR_EdgewaterBridges_045_R												
Marina_1st		0	0	1.5	0.6	3.3	100	1.2	25	**0.34**	1.6	U/S of the 2
Marina_2nd		0	0	3.7	0.6	3.3	100	1.2	25	**0.2**	1.6	D/S of the 2
2d_bg_LMAR_RaleighBridge_045_R												
RaleighRd		18	0.54	Varying levels		20.4	100	0	35	**0.2**	1.6	
2d_bg_LMAR_AftonBridge_045_R												
Afton		1	0.01	Varying levels		3.3	100	0	20	**0.2**	1.6	



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