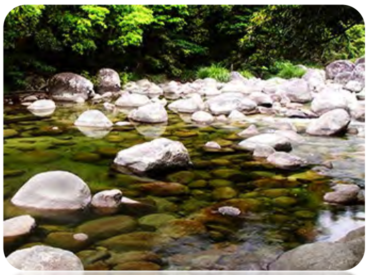
MELBOURNE WATER AND CITY OF MELBOURNE

Arden Macaulay Precinct & Moonee Ponds Creek Flood Modelling

Model Build Report



August 2020

V3000_080-REP-001-1

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1. INTRODUCTION

This report documents the flood modelling undertaken by Engeny Water Management (Engeny) on behalf of the City of Melbourne and Melbourne Water that has been used as the basis for the preparation of planning scheme overlays for Moonee Ponds Creek and contributing local catchments south of Racecourse Road, including the Arden Macaulay Precinct.

The flood modelling is based on a RORB hydrological model and a TUFLOW hydraulic model.

The TUFLOW model that has been adopted by Engeny was originally developed by AECOM in 2013 as part of planning for major developments within the study area. AECOM's model development is documented in the report titled Hydrologic and Hydraulic Modelling of Arden Street and E-Gate (AECOM, September 2013), which is provided in **Appendix A**.

The AECOM model was provided to Engeny by Melbourne Water for use in flood and drainage planning for the Arden Macaulay Precinct. Engeny made numerous refinements to the model so that it reflected the best available data and was fit for purpose for the Arden Macaulay Precinct planning.

The modelling has been undertaken to predict flooding in a 1 % annual exceedance probability (AEP) event, inclusive of an 18.5 % increase in rainfall intensity due to climate change and 0.8 metres of sea level rise. This is a consistent approach across the numerous models used to inform the current planning scheme amendment for the City of Melbourne and Melbourne Water.

This report documents the modelling methodology that has been adopted to prepare the modelling results that have been used as the basis of the planning scheme overlays.

2. BACKGROUND INFORMATION

2.1 Catchment Overview and Study Area

The extent of the flood modelling is located at the downstream end of the Moonee Ponds Creek catchment, extending from the confluence of Moonee Ponds Creek and the Yarra River to Moonee Ponds Creek at Mt Alexander Road. The flood modelling includes the local catchments draining to this section of Moonee Ponds Creek, which covers parts of the suburbs of Kensington, Parkville, Docklands, North Melbourne and West Melbourne.

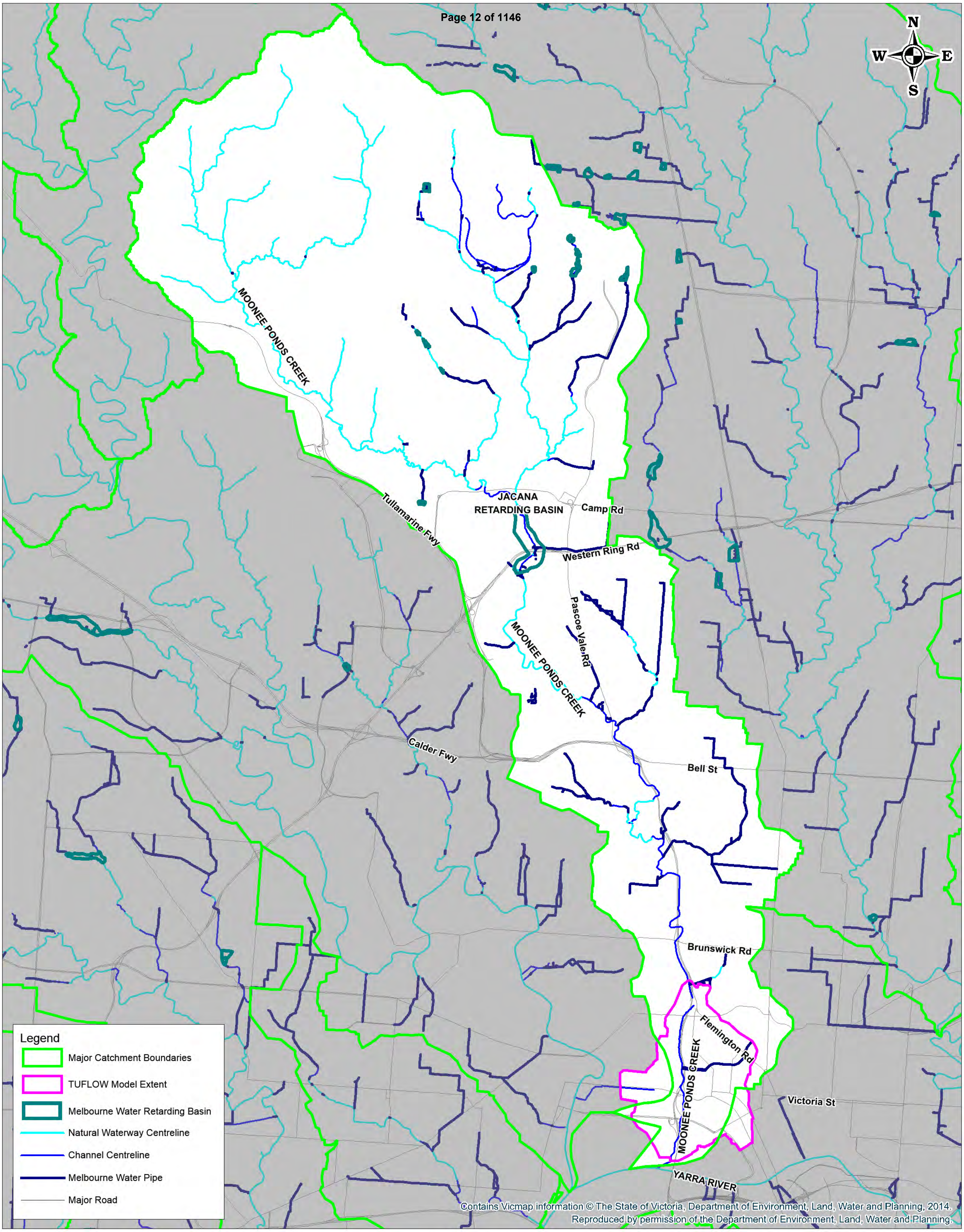
Figure 2.1 provides an overview of the Moonee Ponds Creek catchment the location of the extent of the flood model.

The Moonee Ponds Creek catchment covers an area of approximately 139 square kilometres. The northernmost 89 square kilometres of the catchment drains to the Jacana Retarding Basin (a Melbourne Water asset), located at the Western Ring Road. This retarding basin provides an effective control of runoff from the upper section of the Moonee Ponds Creek catchment.

The section of the Moonee Ponds Creek catchment between the Jacana Retarding Basin and the Yarra River is highly urbanised with no significant formalised flood storage assets. This lack of flood storage assets is typical to some older urban areas of Melbourne and is due to systems being designed in the past to convey runoff efficiently to a receiving waterway, in this case Moonee Ponds Creek, via a piped drainage system and increasing the capacity of the receiving waterway through measures such as re-construction as a concrete lined waterway.

While the flood model covers a small area outside of the City of Melbourne (within the City of Moonee Valley), only results from the section of the model within the City of Melbourne is to be used for the current planning scheme amendment. Within the City of Melbourne section of the flood model, some areas of the model are not to be used to inform the planning scheme amendment due to low reliability in the setup of the model in these areas only.

Figure 2.2 provides an overview of the extent of the flood model and the contributing local catchments draining to Moonee Ponds Creek. This plan also highlights the area of the flood model from which results are to be used to inform the planning scheme amendment (the mapping extent).



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Arden Macaulay Precinct &
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Figure 2.1
Overview of the Moonee Ponds Creek Catchment

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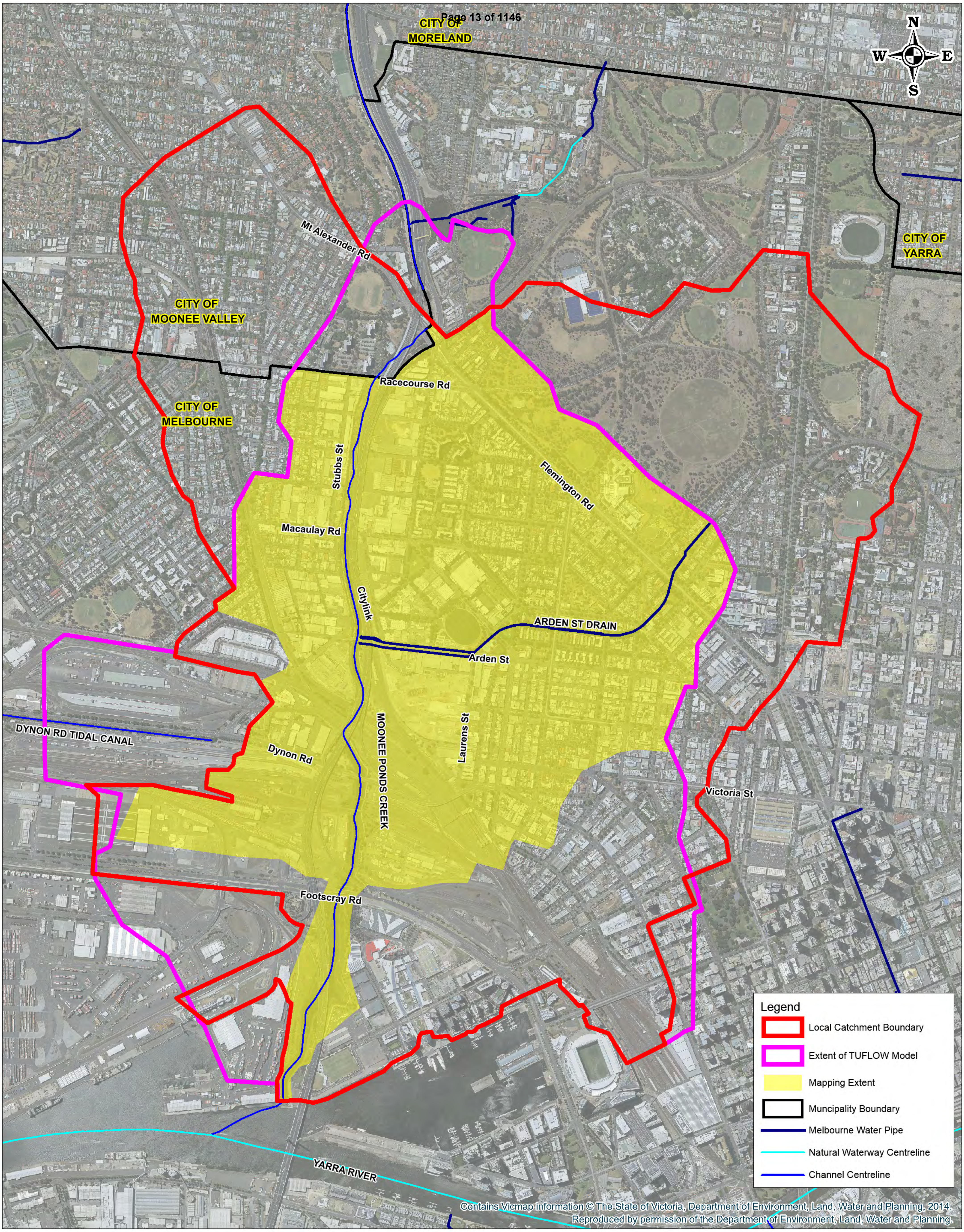

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Figure 2.2
Flood model extent
and the local catchment

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2.2 Flood Modelling Methodology Overview

The flood modelling has been completed in accordance with Australian Rainfall and Runoff 1987 using a combination of hydrologic and hydraulic modelling. The hydrologic modelling converts design rainfall events to flood hydrographs, with the flood hydrographs then applied to the hydraulic model to produce a range of flood related information.

Hydrological modelling has been undertaken using RORB. Two RORB models have been used for the flood modelling, which are:

- An overall Moonee Ponds Creek model, which has been used to apply routed hydrographs for Moonee Ponds Creek at Mt Alexander Road to the hydraulic model.
- A local catchment RORB model for the catchments draining into Moonee Ponds Creek downstream of Mt Alexander Road, which has been used to apply routed hydrographs to the hydraulic model at the boundary of the hydraulic model, as well as rainfall excess hydrographs within the extent of the hydraulic model.

Hydraulic modelling has been undertaken using TUFLOW.

2.3 The Existing Drainage System and Topography

A key component of the drainage system are the levees on both the eastern and western banks of Moonee Ponds Creek. The levees extend from Racecourse Road to Arden Street. As shown in Figure 2.3, the levees are typically an earthen embankment with either a masonry blockwork or precast concrete parapet wall on top of the earthen embankment. The levees aim to prevent creek flows entering the low-lying areas adjacent to this section Moonee Ponds Creek.

Figure 2.3 Existing levee on eastern side of Moonee Ponds Creek between Arden Street and Macaulay Road

Moonee Ponds Creek is a highly modified channel with a reserve width of approximately 50 metres between the levees. Within the model extent, Moonee Ponds Creek is partially covered by the Citylink Freeway, which has numerous piers within the creek corridor. There are several road and rail bridge crossings of Moonee Ponds Creek, some of which impose a significant hydraulic constraint on creek flows due to low bridge decks and hydraulically inefficient pier structures. Figure 2.4 is a photo of the first rail bridge downstream of Arden Street, with the bridge deck relatively low to the creek level. This photo also shows the Citylink Freeway above Moonee Ponds Creek.

Figure 2.4 Rail bridge downstream of Arden Street (looking downstream)

Behind the creek's levees, both Melbourne Water and City of Melbourne manage underground drainage assets to convey local runoff into Moonee Ponds Creek. The catchment of Melbourne Water's Arden Street drain extends as far east as the Melbourne Cemetery. The Arden Street drain starts at Morrah St in North Melbourne as a 900 millimetre diameter pipe, increasing in size as the contributing catchment increases before splitting into two parallel drains along Arden Street, with an 1830 millimetre pipe on the southern side of the road and 2440 millimetre wide by 2260 millimetre high arch drain on the northern side of the road. The Arden Street Drain discharges directly to Moonee Ponds Creek.

In significant storms events the performance of City of Melbourne's drainage system in the parts of the model extent is dependent on six pump stations to lift and discharge flow from low lying areas into Moonee Ponds Creek. The pump stations are required as the flood level of Moonee Pond Creek often exceeds the flood level of the local drainage system, meaning that the drainage system's conventional gravity outlets to Moonee Ponds Creek are not able to discharge local catchment flows into the creek.

Figure 2.5 provides an overview of the existing drainage system within the model extent, which also shows the topography of the area and the locations of the existing pump stations.

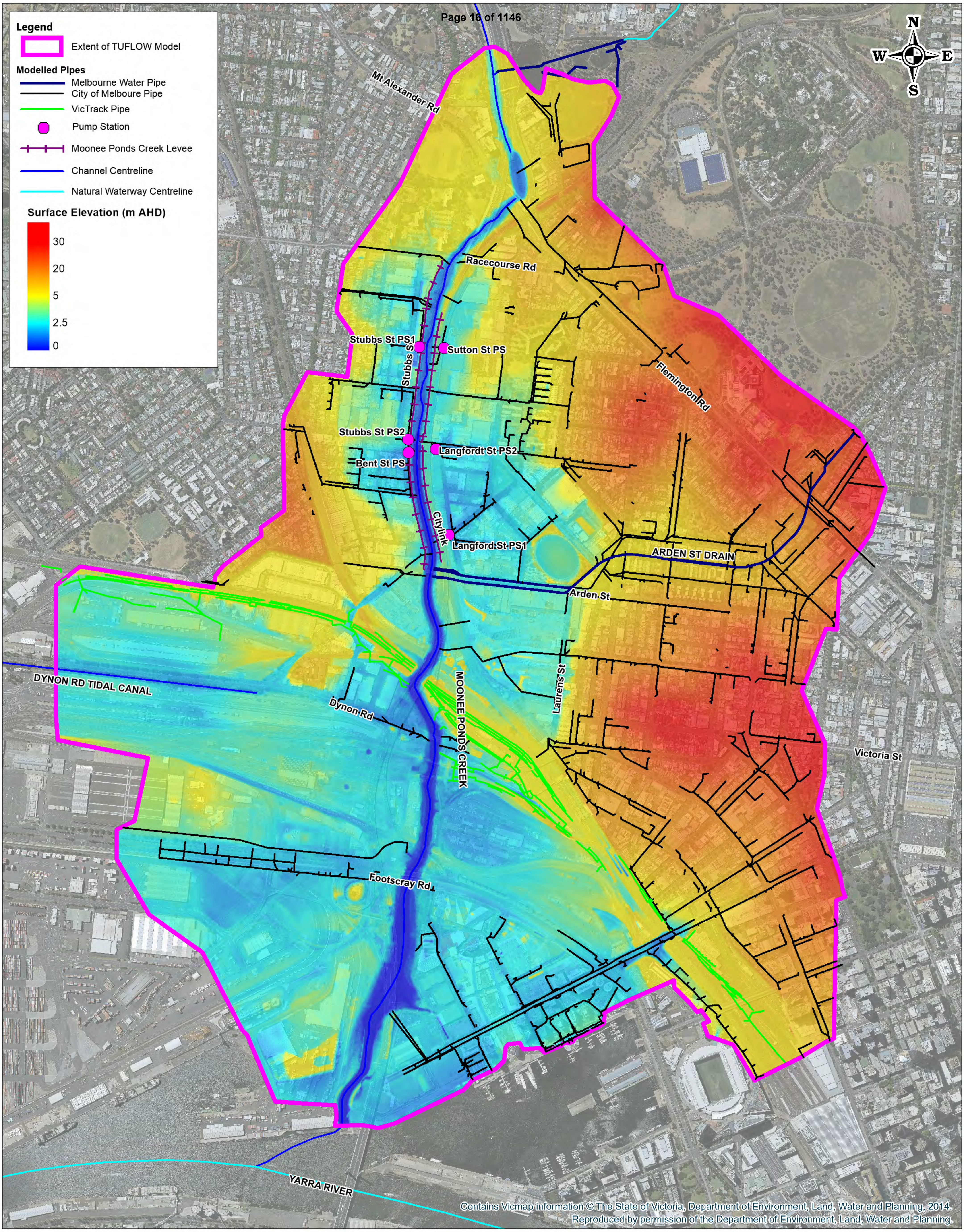

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Figure 2.5
Existing Drainage System
and Topography

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2.4 Available Information

The following data has been used to develop and refine the flood model:

- Aerial photography
- LiDAR terrain data (capture date 2007)
- Moonee Ponds Creek levee survey data
- Moonee Ponds Creek survey
- GIS pipe asset data from Melbourne Water
- As constructed plans for the Arden Street Drain, provided by Melbourne Water
- GIS pit and pipe asset data from the City of Melbourne
- Catchment boundaries
- Contours
- Planning zones
- Cadastre boundaries

3. HYDROLOGY MODELLING

3.1 Overview

The key objective of hydrological modelling in this study is to produce routed hydrographs and rainfall excess hydrographs for use in the TUFLOW hydraulic model. The hydrological modelling has been undertaken in accordance with Australian Rainfall and Runoff 1987.

Hydrological modelling has been undertaken using RORB. Two RORB models have been used for the flood modelling, which are:

- An overall Moonee Ponds Creek model, which has been used to apply routed hydrographs for Moonee Ponds Creek at Mt Alexander Road to the hydraulic model.
- A local catchment RORB model for the catchments draining into Moonee Ponds Creek downstream of Mt Alexander Road, which has been used to apply routed hydrographs to the hydraulic model at the boundary of the hydraulic model, as well as rainfall excess hydrographs within the extent of the hydraulic model.

The following sections of this report provide an overview of both hydrological models.

3.2 Moonee Ponds Creek Catchment RORB Model

3.2.1 Model Delineation

The Moonee Ponds Creek RORB model was provided to Engeny by Melbourne Water. The model includes a total of 17 subareas, 7 of which cover the catchment downstream of the Jacana Retarding Basin.

GIS tables for the Moonee Ponds Creek RORB model's subareas, reaches, nodes and catchment boundary are not available. A catchment layout plan image was provided to Engeny, which is included in Figure 3.1, with annotations to show the location of the hydraulic model extent and some key catchment features.

Reach types in the model are type 3 (lined channel or pipe) downstream of the Jacana Retarding Basin and generally type 1 (natural) upstream of the Jacana Retarding Basin.

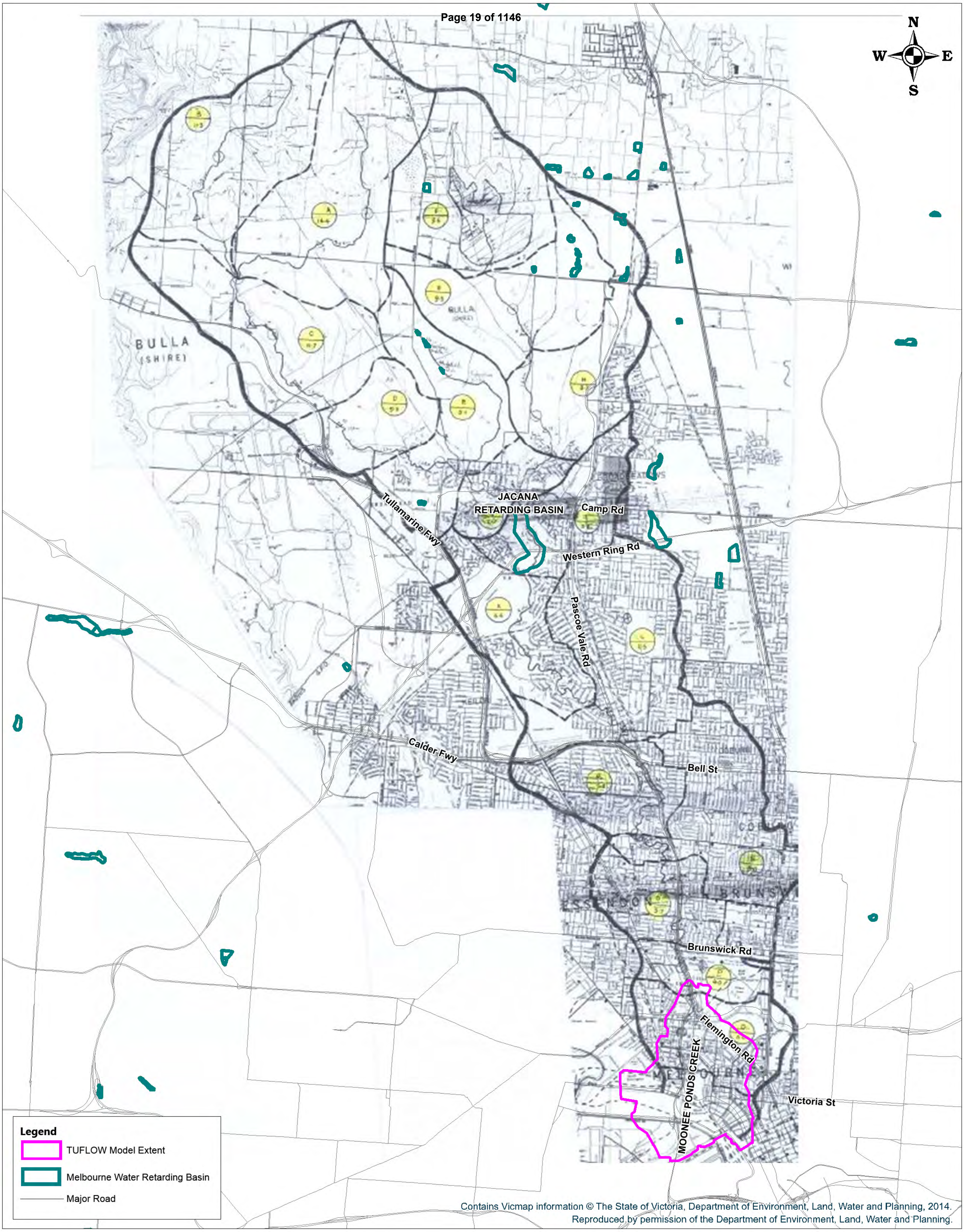

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Figure 3.1
Moonee Ponds Creek RORB Model Layout Plan

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3.2.2 Catchment Imperviousness

The fraction impervious values in the Moonee Ponds Creek are summarised below:

- Downstream of the Jacana Retarding Basin, the fraction impervious values range from 0.5 to 0.55.
- Upstream of Jacana Retarding Basin, the fraction impervious values range from 0 to 0.5, with the more urban areas of this section of the catchment close to Jacana Retarding Basin reflected by the fraction impervious values of 0.5 and the rural upper sections of the catchment having impervious values of 0 to 0.1.

No changes have been made by Engeny to the fraction impervious values in the Moonee Ponds Creek RORB model.

3.2.3 Intensity-Frequency-Duration Data

The Intensity-Frequency-Duration (IFD) data adopted in the Moonee Ponds Creek RORB model is reflective of the centroid of the catchment (co-ordinates 37.70 degrees south and 144.90 degrees east).

Table 3.1 provides the IFD parameters obtained from the Bureau of Meteorology online tool for existing rainfall conditions. Table 3.1 also provides the factored IFD parameters to account for the 18.5 % increase in rainfall intensity. The F2 and F50 parameters have been increased in accordance with the approach in Australian Rainfall and Runoff 1987.

Table 3.1 Moonee Ponds Creek RORB model IFD parameters

Parameter	Existing Conditions	18.5 % Rainfall Intensity Increase
Intensity - 1 hour duration, ARI = 2 years (${}^{2}I_{1}$)	19.22	22.78
Intensity - 12 hour duration, ARI = 2 years (${}^{2}I_{12}$)	3.94	4.67
Intensity - 72 hour duration, ARI = 2 years (${}^{2}I_{72}$)	1.07	1.27
Intensity - 1 hour duration, ARI = 50 years (${}^{50}I_{1}$)	40.16	47.59
Intensity - 12 hour duration, ARI = 50 years (${}^{50}I1_{2}$)	7.13	8.45
Intensity - 72 hour duration, ARI = 50 years (${}^{50}I_{72}$)	2.19	2.60
Skew (G)	0.35	0.35
F_2	4.29	4.36
F_{50}	14.95	16.00

3.2.4 Model Parameters

The adopted Moonee Ponds Creek RORB model simulation parameters are based on the parameter file provided to Engeny by Melbourne Water. The simulation parameters are:

- Initial loss: 15 millimetres
- 1 % AEP runoff coefficient: 0.65
- m = 0.8
- kc = 26.0
- Aerial reduction factors based on ARR87 Bk II, Figs 1.6 and 1.7
- Unfiltered temporal patterns
- Uniform areal patterns

3.2.5 Model Validation and Results

The Moonee Ponds Creek RORB model predicts the following peak 1 % AEP flows at Mt Alexander Road (the inflow location to the TUFLOW model):

- Existing conditions: 217 m^3/s, critical duration 2 hours
- 18.5 % rainfall intensity increase: 263 m^3/s, critical duration 2 hours

A critical duration of 2 hours is relatively short for a catchment with the size of Moonee Ponds Creek (139 square kilometres). The short critical duration reflects that runoff from the developed catchment downstream of Jacana Retarding Basin is controlling peak flows due to the hydraulically efficient drainage system and no formal flood storage in this section of the catchment. Runoff from the catchment upstream of Jacana Retarding Basin has very little influence on the predicted peak flows in Moonee Ponds Creek at Mt Alexander Road.

There is uncertainty regarding how the Moonee Ponds Creek RORB model was validated. To understand whether the peak flows were reasonable, Engeny undertook a flood frequency analysis on flow gauge data provided by Melbourne Water for Moonee Ponds Creek at Mt Alexander Road. The flood frequency analysis identified a 1 % AEP flow of 207 m^3/s. The predicted existing conditions peak flow of 217 m^3/s is well within the confidence limits of the flood frequency analysis.

Engeny's review of the Moonee Ponds Creek RORB model deemed it sufficiently reliable for use in the flood modelling.

3.3 Local Catchment RORB Model

3.3.1 Model Delineation

The local catchment RORB model was developed by AECOM as part of the study documented in the report Hydrologic and Hydraulic Modelling of Arden Street and E-Gate (AECOM, September 2013). The following sections of this report provide an overview of key aspects of the local catchment RORB model and further details can be found in AECOM's 2013 report in **Appendix A**.

Figure 3.2 provides a layout of the local catchment RORB model.

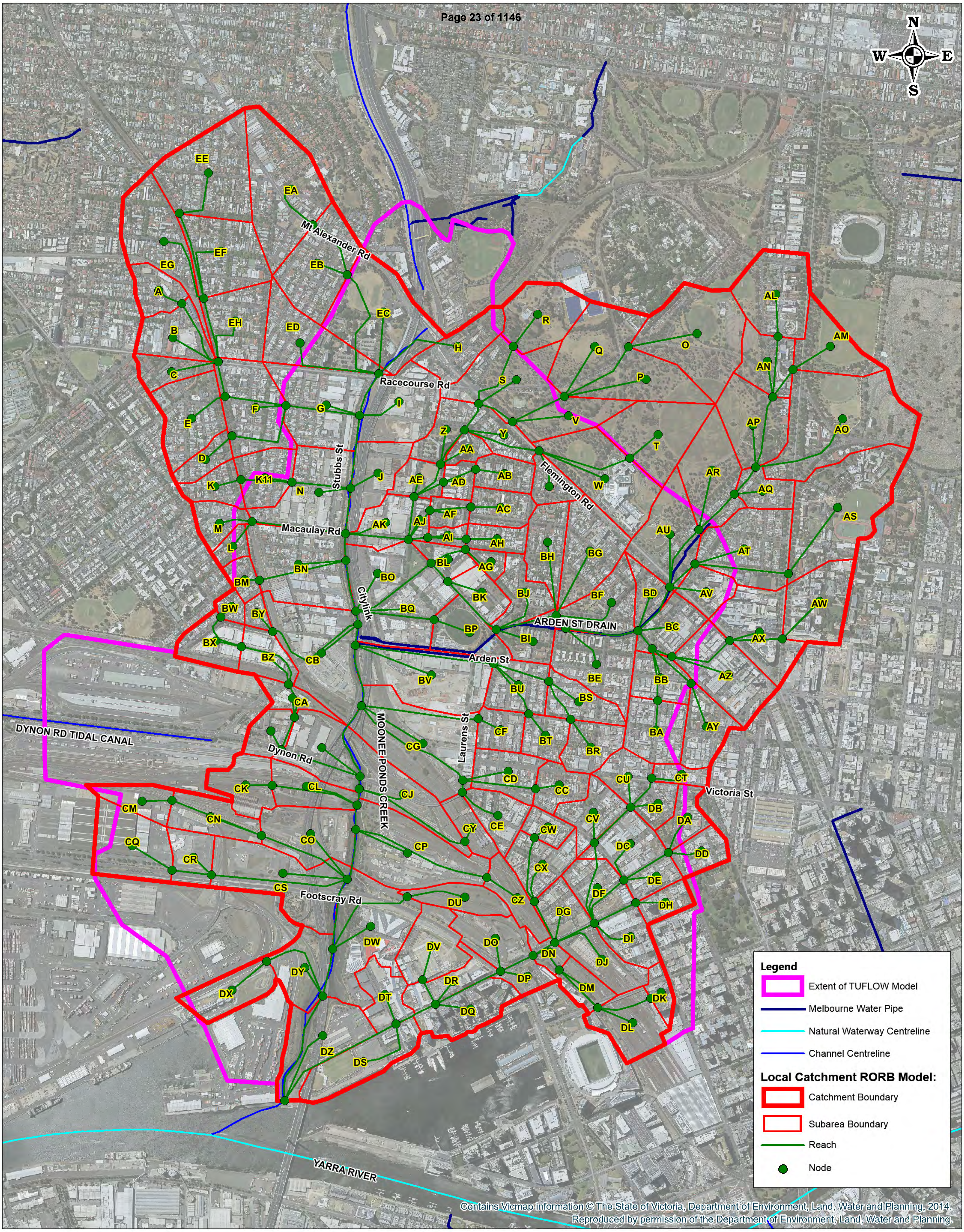

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Figure 3.2
Local catchment RORB
model layout plan

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3.3.2 Catchment Imperviousness

The adopted imperviousness in the local catchment RORB model is reflective of existing site conditions, including the developed urban, commercial and industrial areas along the Moonee Ponds Creek corridor, as well as the large open spaces associated with Royal Park.

Figure 3.3 shows the variation in imperviousness throughout the local catchment RORB model.

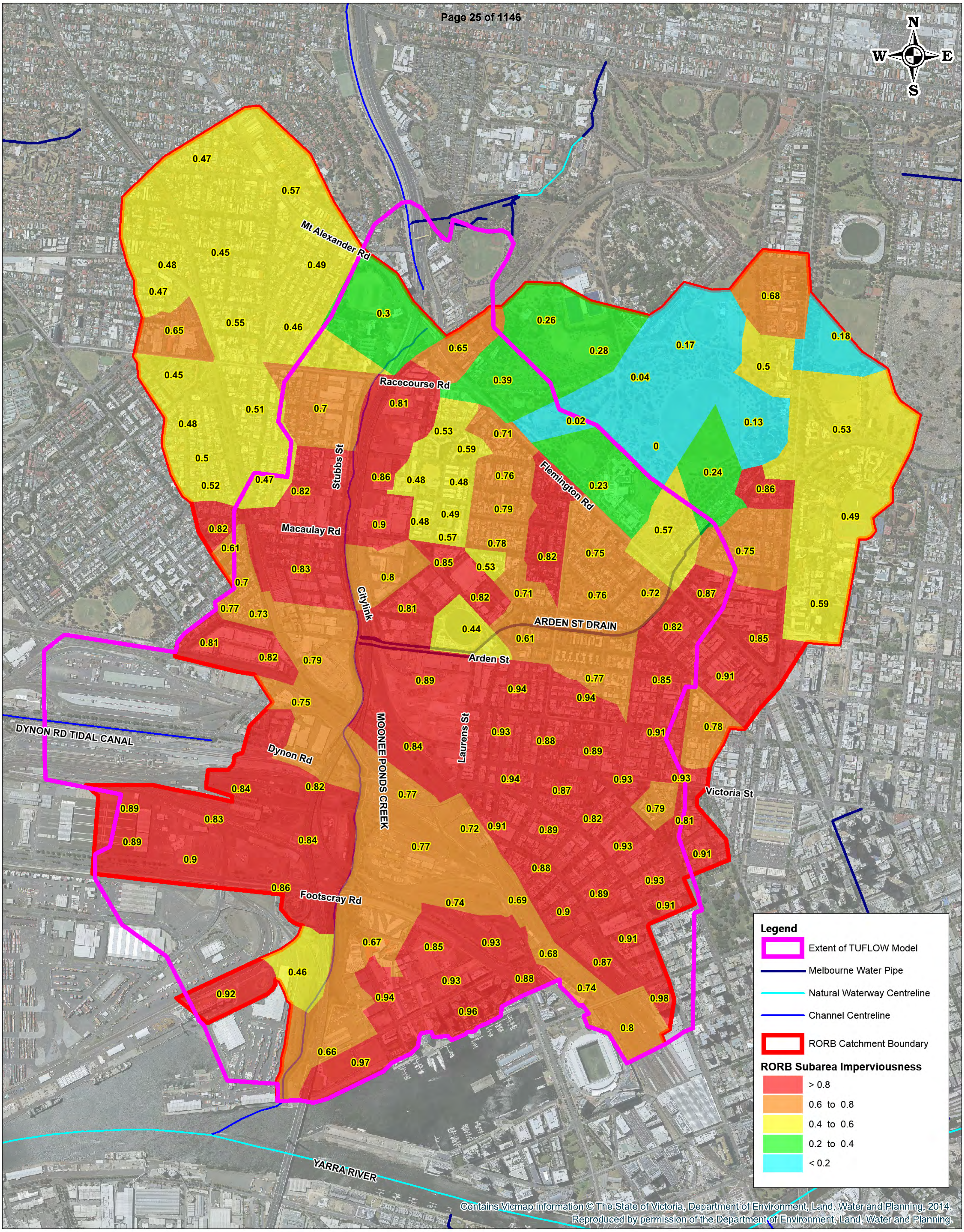

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Figure 3.3
Local catchment RORB Imperviousness

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3.3.3 Intensity-Frequency-Duration Data

The Intensity-Frequency-Duration (IFD) data adopted in the local catchment RORB model is reflective of the centroid of the local catchment (co-ordinates -37.80 degrees south and 144.95 degrees east).

Table 3.2 provides the IFD parameters obtained from the Bureau of Meteorology online tool for existing rainfall conditions (which correlate to the IFD parameters adopted by AECOM). Table 3.2 also provides the factored IFD parameters to account for the 18.5 % increase in rainfall intensity. The F2 and F50 parameters have been increased in accordance with the approach in Australian Rainfall and Runoff 1987.

Table 3.2 Local catchment RORB model IFD parameters

Parameter	Existing Conditions	18.5 % Rainfall Intensity Increase
Intensity - 1 hour duration, ARI = 2 years $(^{2}I_{1})$	18.96	22.47
Intensity - 12 hour duration, ARI = 2 years $(^{2}I_{12})$	3.74	4.43
Intensity - 72 hour duration, ARI = 2 years $(^{2}I_{72})$	1.11	1.32
Intensity - 1 hour duration, ARI = 50 years $(^{50}I_{1})$	39.18	46.43
Intensity - 12 hour duration, ARI = 50 years $(^{50}I1_{2})$	7.10	8.41
Intensity - 72 hour duration, ARI = 50 years $(^{50}I_{72})$	2.21	2.62
Skew (G)	0.36	0.36
F_2	4.29	4.36
F_{50}	14.95	16.00

3.3.4 Model Parameters

The adopted simulation parameters in the local catchment RORB model are based on the AECOM parameter file provided to Engeny by Melbourne Water. The simulation parameters are:

- Initial loss: 10 millimetres
- 1 % AEP runoff coefficient: 0.6
- m = 0.8
- kc = 3.4

- Aerial reduction factors based on ARR87 Bk II, Figs 1.6 and 1.7
- Filtered temporal patterns
- Uniform areal patterns

3.3.5 Model Validation

The local catchment RORB model was validated by AECOM using Rational Method Calculations, which is an approach in accordance with Australian Rainfall and Runoff 1987. Three validation points were adopted and a good match (within +/- 2 %) was achieved at the three validation points.

The adopted kc of 3.4 is within the expected range for an area the size of the local catchment RORB model.

Full details of the local catchment RORB model are provided in the AECOM's report in **Appendix A**.

Engeny's review of the local catchment RORB model deemed it sufficiently reliable for use in the flood modelling.

4. HYDRAULIC MODELLING

4.1 Model Layout

The TUFLOW hydraulic model was developed by AECOM as part of the study documented in the report Hydrologic and Hydraulic Modelling of Arden Street and E-Gate (AECOM, September 2013). Engeny has updated and refined the AECOM TUFLOW model.

Figure 4.1 shows key features of the TUFLOW model and the following sections of this report provide an overview of the model setup.

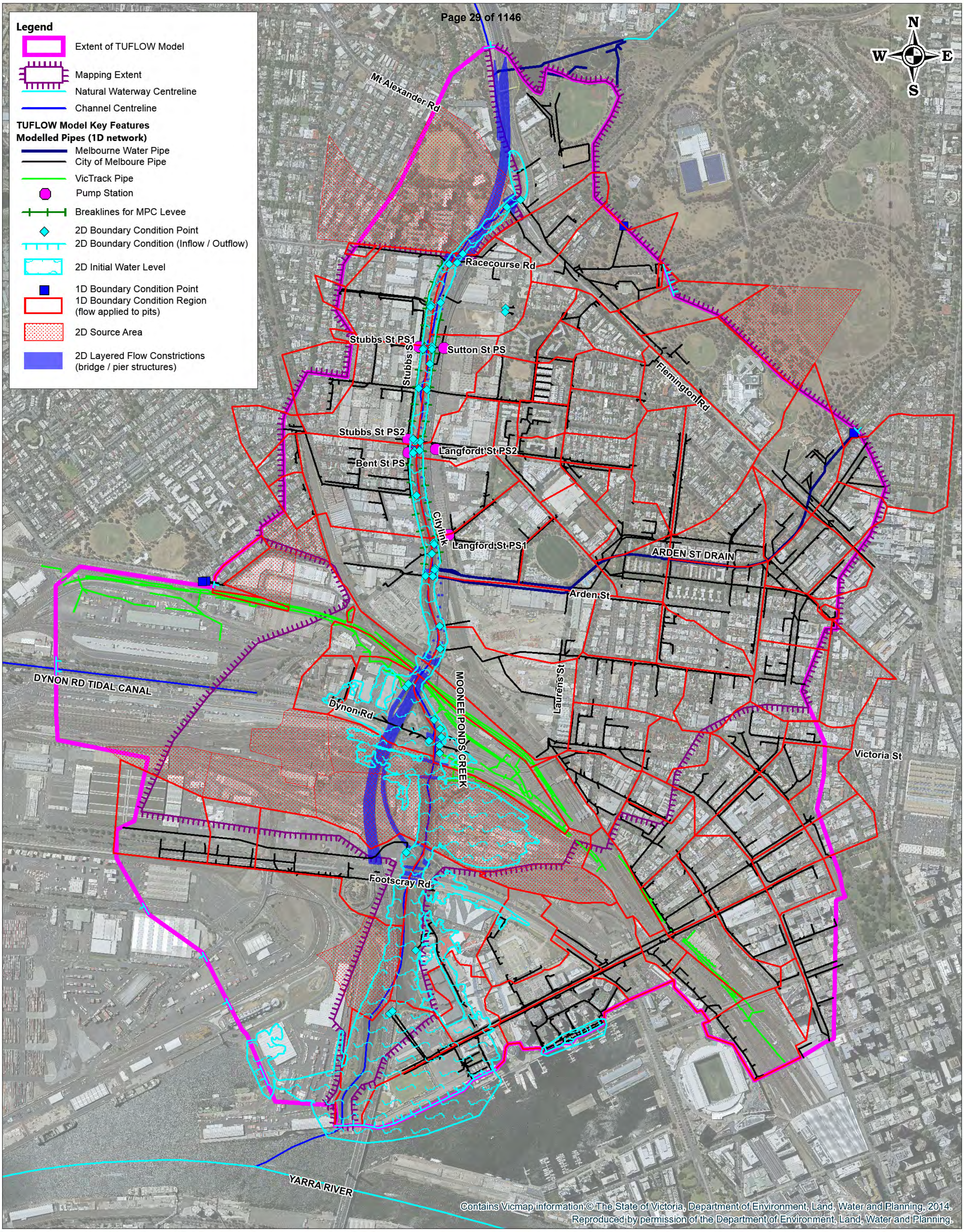

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Figure 4.1
TUFLOW model layout plan

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4.2 Model Cell Size

The AECOM setup of the TUFLOW model included a four metre cell size. Melbourne Water's Flood Mapping Projects Guidelines and Technical Specifications (September, 2018) recommend a cell size of two to three metres for urban flood modelling.

Engeny considered reducing the model cell size in order to satisfy the Melbourne Water recommendation. A four metre cell size was retained, due to the fact that the four metre cell size, in combination with break lines to define some key topographical features based on feature survey, allows for an adequate representation of catchment topography and overland flow paths in in the model.

4.3 Representation of Moonee Ponds Creek

Moonee Ponds Creek has been represented in the 2D domain of the TUFLOW model. The width of Moonee Ponds Creek between the levees is approximately 50 metres. As the model adopts a 4 metre cell size, this allows for approximately 12 cells to represent the creek profile in the 2D domain, which is sufficient.

A survey tin has been read into the model in order to define sections of the creek profile and break lines have been adopted to represent the crest level of the levees, based on feature survey.

4.4 Surface Roughness

Within TUFLOW, a land use (materials) layer is utilised to represent the surface roughness impacting overland flows in the 2D domain of the model.

The model's surface roughness was initially developed by AECOM and was based on:

- Use of the City of Melbourne's 2007 Land Cover data, where available.
- Planning scheme overlays for areas of the model outside of the City of Melbourne.
- Aerial photography to manually digitise large areas of uniform roughness.
- For Moonee Ponds Creek, the adopted Manning's was defined based on achieving a match of the hydraulic grade line with Melbourne Water's HEC-RAS model of the Moonee Ponds Creek.

Engeny reviewed and refined some areas of the model's surface roughness based on aerial photography. In some instances, the City of Melbourne 2007 Land Cover data defined significant areas of trees in road reserves, which may have led to an over estimation of surface roughness. Adjustments were made to reduce roughness in these areas in order to improve the representation of flows path along roads.

4.5 Pit and Pipe Network

The underground drainage system is represented in the 1D domain of the TUFLOW model. Different sections of the underground drainage system within the model extent is managed by:

- Melbourne Water (the Arden Street Drain)
- City of Melbourne
- VicTrack, for the drainage system associated with rail assets

Engeny made a series of refinements to the representation of the pit and pipe network in the model in order to:

- Rectify inconsistent invert levels and asset data.
- Add missing pipe data.
- Use the most current GIS data provided by City of Melbourne in January 2016 and September 2017.

City of Melbourne identified that there are some sections of the drainage asset GIS data with low confidence in the accuracy of the data. This includes the drainage system around Docklands Drive. While these areas are still represented in the TUFLOW model, the model's results in these areas are not to be used to inform the planning scheme amendments and are not influencing results in the areas that are being included. Updates to the model based on field inspections of the drainage system would be required in order to improve the confidence in the model setup in these areas. Previously provided Figure 2.2 shows the model's mapping extent, with the low confidence areas of the model outside of the mapping extent.

4.6 Pit and Pipe Losses

A manhole layer within TUFLOW can be either automatically or manually created and used to apply the losses to the nodes created in the 1-dimensional network layers in a variety of different ways. The TUFLOW model uses an automatically generated manhole layer, applying losses using the Engelund method. This method recalculates losses at each time step using the angle of the entry and exit culverts, water levels and flow distributions. The losses calculated by this automatic approach have been checked to ensure that they appear reasonable.

4.7 Pump Station Operation

Six pump stations are located within the model extent. The intention of the pump stations is to lift and discharge flow from low lying areas over the levees and into Moonee Ponds Creek.

The model's representation of the pump station capacities is based on information provided by City of Melbourne, including a report titled Arden Macaulay Precinct Flood Investigation (Cardno, April 2012). The capacities of the pump stations are:

- Stubbs Street Pump Station 1 (corner of Stubbs St and Smith St): 560 L/s
- Stubbs Street Pump Station 2 (corner of Stubbs St and Macaulay Rd): 1196 L/s
- Bent St Pump Station (corner of Bent St and Little Hardiman St): 700 L/s
- Langford St Pump Station 1 (corner of Langford St and Gracie St): 700 L/s
- Langford St Pump Station 2 (corner of Langford St and Macaulay Rd): 700 L/s
- Sutton St Pump Station (west end of Sutton St): 700 L/s

Pump stations have the potential to be unreliable in storm events if they lose power. A key objective of the flood related planning scheme overlays is to manage the setting of floor levels for future developments in flood prone areas. Due to potential unreliability of the pump stations, Melbourne Water and City of Melbourne intend to set floor levels on the assumption that the pump stations have failed.

Based on this, the modelling used for the basis of delineating the planning scheme overlays reflects that the pumps fail to operate in the 1 % AEP storm event.

There is some uncertainty in the pump station operating levels (i.e. the flood levels that result in the pumps turning on and off) and further investigation of these levels is recommended prior to using the model with the pumps operational.

4.8 Downstream Boundary Condition

The downstream end of the flood model is the confluence of Moonee Ponds Creek and the Yarra River. This section of the Yarra River is heavily influenced by the tide level in Port Phillip Bay and this tidal impact extends up through Moonee Ponds Creek.

The AECOM model was based on a static tail water level to represent the influence of downstream tide levels. The updated model includes a cyclical tide boundary condition in order to represent the dynamic impact of the Port Phillip Bay tide level on flooding within the model extent. The boundary condition is based on a 10 % AEP tide, with an allowance of 0.8 metres of sea level rise. The peak of the cyclical tide is 1.975 m AHD.

The timing of the cyclical tide has been tailored for each duration storm event so that the peak of the tide occurs at the end of the rainfall event. This means that for the 2 hour storm event, the peak tide occurs 2 hours into the model simulations and for the 9 hour event the peak tide occurs 9 hours into the model simulation.

While there is some variance between the different storm durations, the adopted approach results in the peak tide level occurring when flows in Moonee Ponds Creek are close to their peak.

Figure 4.2 shows the RORB hydrograph for flow in Moonee Ponds Creek at Mt Alexander Road, as well as the applied cyclical tide boundary. The graph shows the peak flow at Mt Alexander Road occurring just prior to the peak tide level. As the creek flows move through the hydraulic model extent, the peak creek flow has a closer match to the timing of the peak tide.

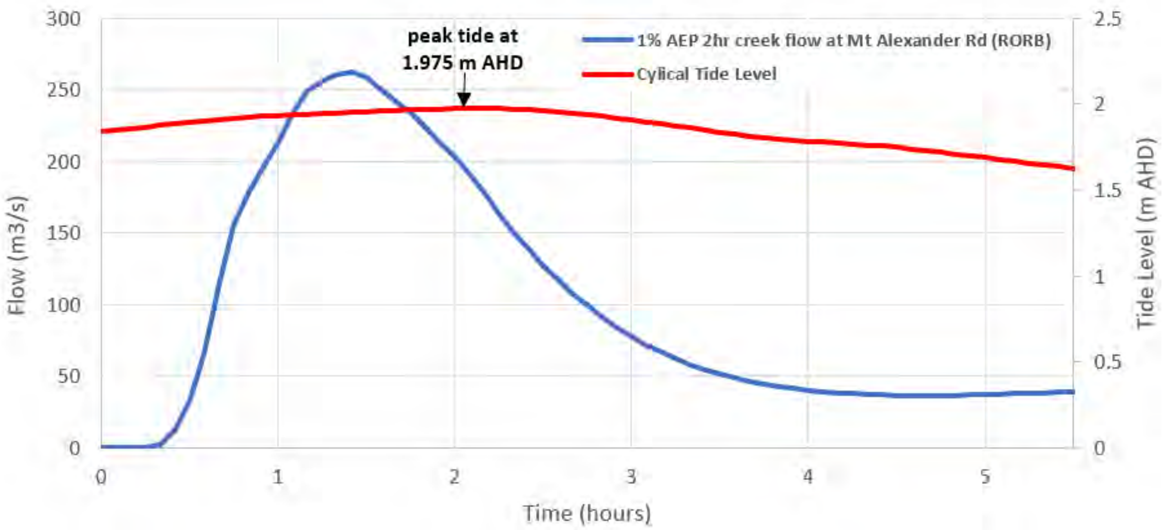


Figure 4.2 1 % AEP 2 hour storm event (including 18.5 % rainfall intensity increase), Moonee Ponds Creek hydrograph and cyclical tide boundary

4.9 Initial Water Levels

Initial water levels have been adopted to prevent a “backflow wave” from the downstream boundary condition. As the downstream boundary condition is a cyclical tide boundary, the water level of the cyclical tide at the start of the model simulation is unique to each duration event. Therefore, individual initial water levels have been adopted for each duration storm event to match the starting water level of the cyclical tide.

4.10 Application of Inflows

The Moonee Ponds Creek RORB model and the local catchment RORB model have been used to apply inflow hydrographs to the TUFLOW model for each duration storm event. The application of inflows consists of:

- From the Moonee Ponds Creek RORB model:
  - Routed hydrographs applied to Moonee Ponds Creek just upstream of Mt Alexander Road. A 2D boundary condition type QT has been used to apply this hydrograph.

- From the local catchment RORB model:
  - Routed hydrographs applied at the boundary of the hydraulic model representing the inflows from the areas of the local catchment beyond the flood model extent. These hydrographs have been applied using a combination of 1D boundary conditions type QT to apply external flows to pipe and 2D boundary conditions type QT to apply external flows to the 2D domain. In some instances, factors have been used in the model's boundary condition database to split the RORB hydrograph to 1D and 2D boundary conditions or to split the RORB hydrograph for application to separate sections of the model's drainage system.
  - Rainfall excess hydrographs within the extent of the hydraulic model. The rainfall excess hydrographs have typically been applied to pits using 1D boundary conditions, with some rainfall excess hydrographs applied as 2D source areas for areas of large open space.

4.11 Bridge Structures

There are numerous bridge crossings of Moonee Ponds Creek that impact the conveyance capacity of the creek.

The bridge structures, including piers, bridge decks and railings have been represented in the TUFLOW model using 2D layered flow constrictions. The bridge structure data is based on:

- Available survey data.
- The representation of the bridges in Melbourne Water's HEC-RAS model.

The form loss coefficients were defined by AECOM so that the head loss across the structures in TUFLOW matched the head loss in the HEC-RAS model. Engeny reviewed the form loss coefficients and head loss across the structures to check that the results were reasonable.

4.12 Version of TUFLOW

The TUFLOW model has been run in TUFLOW version 2013-12-AE-w64 double precision, which was the version of TUFLOW used by AECOM. Engeny did a trial run of the model in a later version of TUFLOW, with changes to the model's results observed, particularly along Moonee Ponds Creek. Upon investigation, it was found that this was due to a different approach to applying form losses in the new versions of TUFLOW. It was therefore decided to continue to run the TUFLOW model in version 2013-12-AE-w64 to avoid impacting the validation of the form loss coefficients.

The 2013-12-AE-w64 version of TUFLOW is sufficiently reliable for the purpose of the flood modelling.

4.13 Model Timesteps

The TUFLOW model adopts the following time steps:

- 2D time step: 1 second
- 1D time step: 0.25 seconds

Melbourne Water's Flood Mapping Guidelines and Technical Specification (September 2019) states that the 2D time step should normally be between 1/5 and 1/2 of the grid size and the 1D time step should be a multiple of the 2D timestep, and generally not less than 0.5 seconds. As the TUFLOW model uses a 4 metres grid size, the 2D timestep is within the recommended range. The 1D timestep is just below the recommendation range, but Engeny believes that the 1D timestep is reasonable and adjusting the timestep would have little impact on the modelling outputs.

4.14 TUFLOW Warning Messages

The TUFLOW model produces 1533 pre-simulation warning messages. These are described below:

- Warning 1262: 1,477 instances. This warning relates to a 1D Manning's roughness below expectations and is due to the Manning's value of 0.009 that has been applied to the Regional Rail Link pipes. A Manning's value of 0.009 is just below the expected range for a concrete pipe and may have been applied by AECOM if the pipes were made of a more hydraulically efficient material than concrete, such as plastic. Results from this section of the model are not being used for the planning scheme overlays and therefore the low Manning's value is of little consequence.
- Warning 2118: 23 instances. This warning is produced by TUFLOW at 2D SX boundaries where adjustments of the cell elevation are made by TUFLOW to match a pipe's inlet / outlet inverts. This does not impact on the accuracy of reliability of the model.
- Warning 1313: 19 instances. This warning is produced by TUFLOW when there is more than 1 outgoing pipe from a pit. All instances of this warning are in sections of the model that are not being used for the planning scheme overlays.
- Warning 2124: 11 instances. This warning is produced by TUFLOW when a pit or node does not have a connection to the 2D domain. This is common for junction pits and therefore the warning is not of concern.
- Warning 1100: 7 instances. This warning is produced by TUFLOW where there is an increase or fall in invert levels through a pit (i.e. the incoming pipe to a pit enters at a higher level than the outgoing pipe, or vice versa). This is not an uncommon feature of a drainage system and this aspect of the model setup does not impact on the accuracy of reliability of the model.

- Warning 2122: 1 instance. This warning is produced by TUFLOW where there is pit that it outside of the active code of the model. The isolated instance of this warning is in an area of the model (Docklands) where the results are not being used for the planning scheme overlays and therefore the warning is not of concern.

4.15 Model Health

No errors were recorded for any simulation to be used as the basis of the planning scheme overlays. There are no instances of 1-D or 2-D negative depths in the TUFLOW model.

Melbourne Water's Flood Mapping Guidelines and Technical Specification (September 2019) states that models should have total, 1D and 2D mass errors within +/- 1 %. All peak mass errors for the TUFLOW model are within +/- 1 %.

There are two sections of the model with high velocities in the pipe network, which can at times be an indicator of potential model insatiability. These areas are:

- A section of pipe along Parsons St in Kensington. This is an existing pressure pipe to convey flow from the higher area of the catchment into Moonee Ponds Creek. The high velocities in the pressure pipe are reasonable. The model's velocities show a steady rise / fall, indicating sound model stability.

- A section of the Arden St Main Drain near Curzon St. This is a large drainage asset with a relatively steep grade (1 in 80) and the high velocities are reasonable. The model's velocities show a steady rise / fall, indicating sound model stability.

Overall, Engeny is confident in the reliability of the model is believes the model's results are appropriate to form the basis of the planning scheme overlays.

5. FLOOD MAPPING

The TUFLOW model has been simulated for standard storm durations ranging from 10 minutes to 12 hours. The critical storm duration in Moonee Ponds Creek is the 2 hour event and the simulation of storm events up to the 12 hour duration event is sufficient to capture critical flood levels across the model.

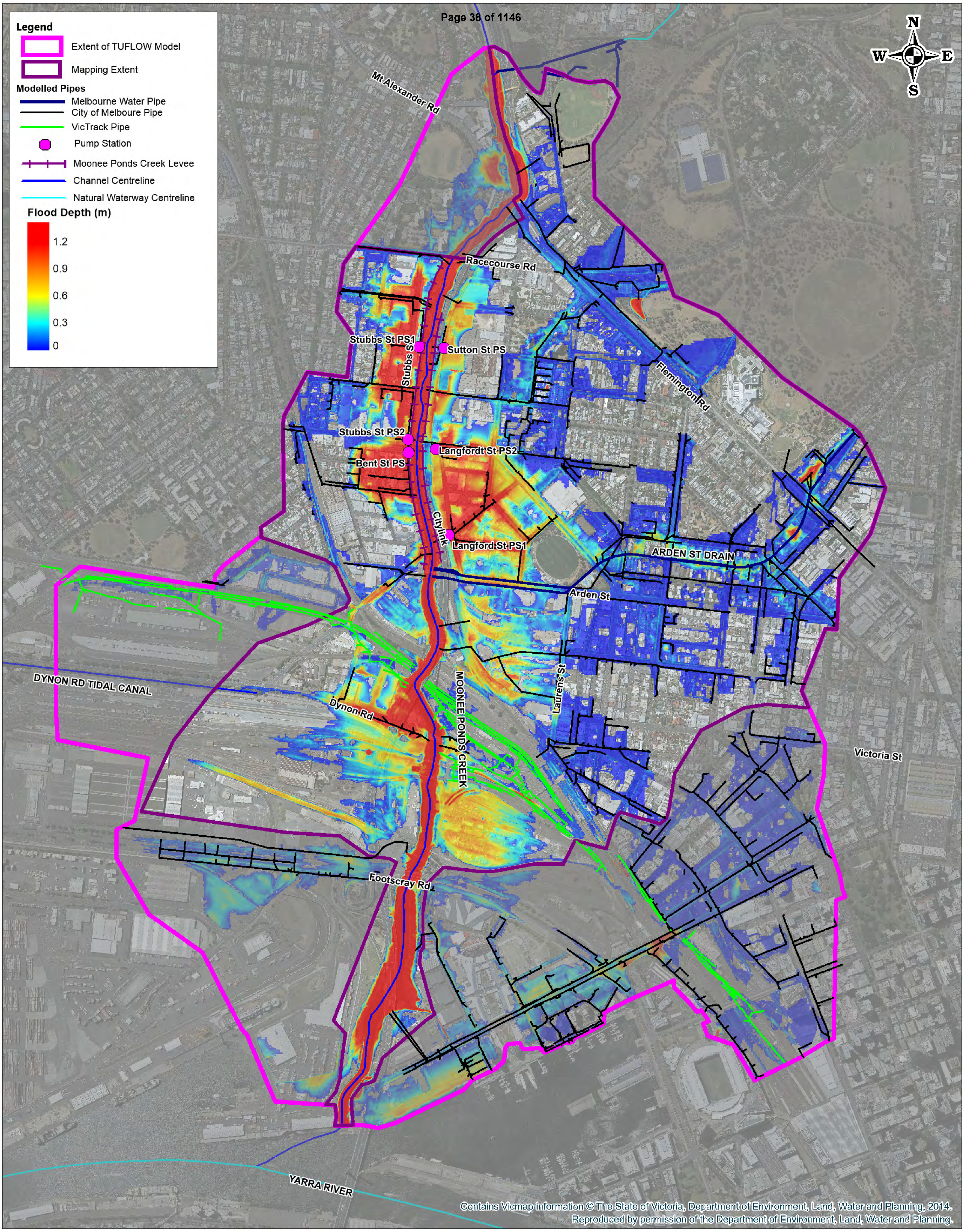
Figure 5.1 provides a 1 % AEP flood map, representing:

- An 18.5 % rainfall intensity increase.
- A 10 % AEP Yarra River cyclical tide, accounting for 0.8 metres of sea level rise.

The results in Figure 5.1 will form the basis of the delineation of planning scheme overlays.

The flood modelling predicts extensive inundation of low-lying areas adjacent to Moonee Ponds Creek. This is attributed to:

- High flows in Moonee Ponds Creek overtopping the creek's levees and inundating the low-lying areas behind the levees.
- Local catchment flows draining to the low-lying areas behind creek's levees, and once runoff is in the low-lying areas the drainage system is unable to convey flow into Moonee Ponds Creek due to a higher water level in the creek than the ground level in the local catchment. This impact is exacerbated by the modelled failure of the pump stations.



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ENGENY WATER MANAGEMENT

CITY OF MELBOURNE

0 250 500

Scale in metres (1:12,500 @ A3)

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994.
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Arden Macaulay Precinct &
Moonee Ponds Creek Flood Modelling

Figure 5.1
1 % AEP flood map, 18.5 % rainfall intensity increase & 0.8 m sea level rise

Job Number: V3000_080
Revision: 0
Drawn: PC
Checked: GO
Date: 3 June 2020

6. SUMMARY

This report documents the flood modelling on behalf of City of Melbourne and Melbourne Water that is to be used as the basis for the preparation of planning scheme overlays for Moonee Ponds Creek and contributing local catchments south of Racecourse Road, including the Arden Macaulay Precinct.

The flood modelling is based on a RORB hydrological model and a TUFLOW hydraulic model. The TUFLOW model that has been adopted by Engeny was originally developed by AECOM in 2013 as part of planning for major developments within the study area.

Engeny has updated and refined the modelling so that it reflects the best available data and is fit for purpose. Some areas of the model are not to be used to inform the planning scheme amendment due to low reliability in the setup of the model in these areas. Previously provided Figure 2.2 shows the model's mapping extent (i.e. the area of the flood model which is sufficiently reliable for use in the planning scheme amendment).

The modelling has been undertaken to predict flooding in a 1 % annual exceedance probability (AEP) event, inclusive of an 18.5 % increase in rainfall intensity due to climate change and 0.8 metres of sea level rise.

Six pump stations are located within the model extent. Pump stations have the potential to be unreliable in storm events if they lose power. A key objective of the flood related planning scheme overlays is to manage the setting of floor levels for future developments in flood prone areas. Due to potential unreliability of the pump stations, Melbourne Water and City of Melbourne intend to set floor levels on the assumption that the pump stations have failed. Based on this, the modelling used for the basis of delineating the planning scheme overlays reflects that the pumps do not operate in the 1 % AEP storm event.

The flood modelling predicts extensive inundation of low-lying areas adjacent to Moonee Ponds Creek. This is attributed to:

- High flows in Moonee Ponds Creek overtopping the creek's levees and inundating the low-lying areas behind the levees.
- Local catchment flows draining to the low-lying areas behind creek's levees, and once runoff is in the low-lying areas the drainage system is unable to convey flow into Moonee Ponds Creek due to a higher water level in the creek than the ground level in the local catchment. This impact is exacerbated by the modelled failure of the pump stations.

Overall, Engeny is confident in the reliability of the model and believes the model's results are appropriate to form the basis of the planning scheme overlays.

7. QUALIFICATIONS

a. In preparing this document, including all relevant calculation and modelling, Engeny Water Management (Engeny) has exercised the degree of skill, care and diligence normally exercised by members of the engineering profession and has acted in accordance with accepted practices of engineering principles.

b. Engeny has used reasonable endeavours to inform itself of the parameters and requirements of the project and has taken reasonable steps to ensure that the works and document is as accurate and comprehensive as possible given the information upon which it has been based including information that may have been provided or obtained by any third party or external sources which has not been independently verified.

c. Engeny reserves the right to review and amend any aspect of the works performed including any opinions and recommendations from the works included or referred to in the works if:

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   (ii) Engeny considers it prudent to revise any aspect of the works in light of any information which becomes known to it after the date of submission.

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g. This report does not provide legal advice.

8. REFERENCES

Melbourne Water's Flood Mapping Projects Guidelines and Technical Specifications (September, 2018)

Hydrologic and Hydraulic Modelling of Arden Street and E-Gate (AECOM, September 2013)

Arden Macaulay Precinct Flood Investigation (Cardno, April 2012)

APPENDIX A

AECOM 2013 Model Build Report

AECOM

Hydrologic and Hydraulic Modelling of Arden Street and E-Gate

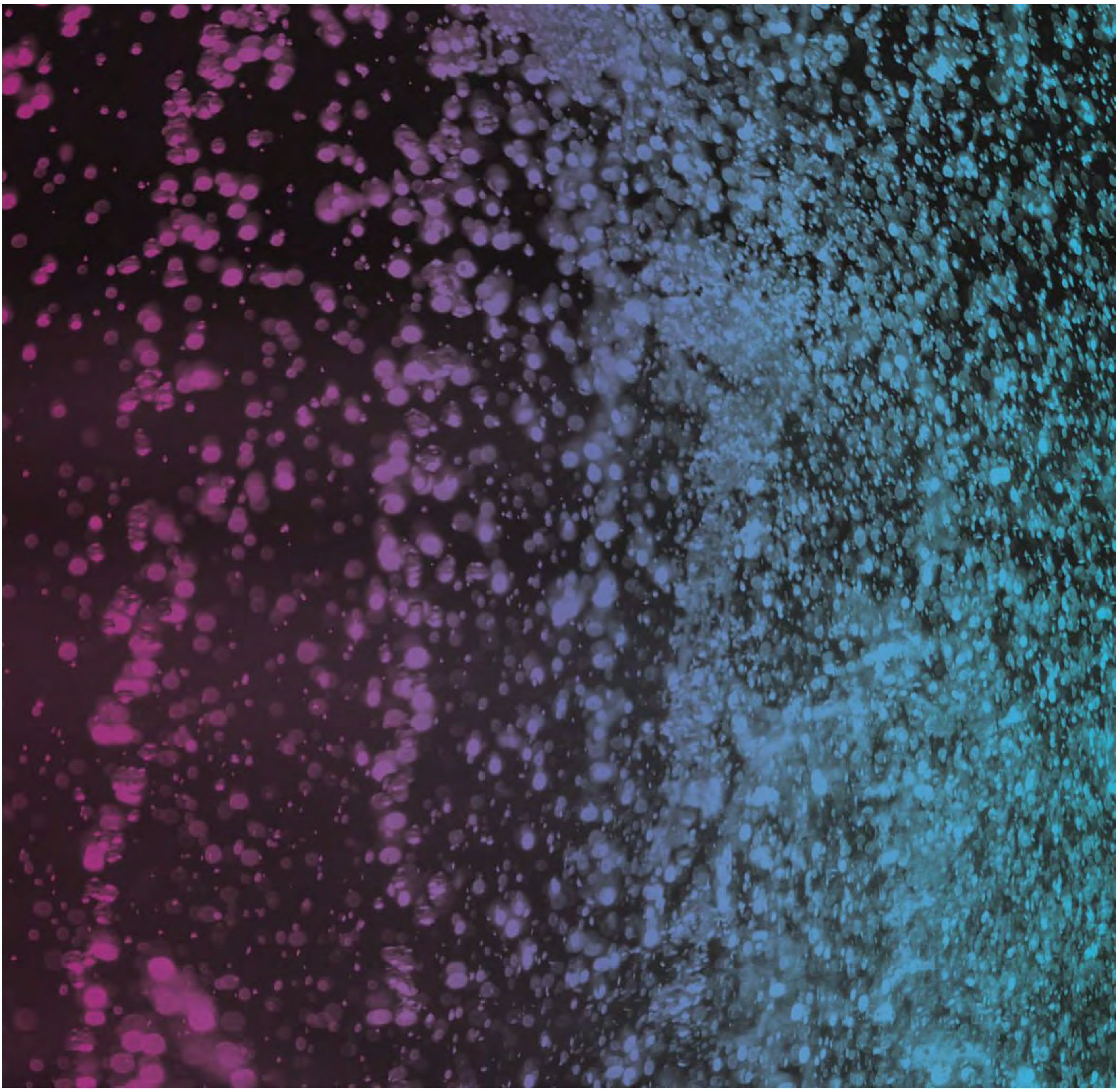
Department of Transport, Planning and Local Infrastructure Victoria

10-Sep-2013

DRAFT

Arden Street and E-Gate

Hydrologic and Hydraulic Modelling



D R A F T

Arden Street and E-Gate

Hydrologic and Hydraulic Modelling

Client: Department of Transport, Planning and Local Infrastructure Victoria

ABN: 90719052204

Prepared by

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10-Sep-2013

Job No.: 60304612

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Quality Information

Document	Arden Street and E-Gate Hydrologic and Hydraulic Modelling
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Date	10-Sep-2013
Prepared by	Sam Marginson and James Baker
Reviewed by	Melanie Collett

Revision History

Revision	Revision Date	Details	Authorised	
			Name/Position	Signature
	10-Sep-2013	DRAFT	Melanie Collett Associate Director - Water Resources	

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Table of Contents

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Executive Summary

To be included in the next revision of this report.

1.0 Introduction

1.1 Objectives and Scope

AECOM has been commissioned to undertake detailed flood modelling of the study area for the Department of Transport, Planning and Local Infrastructure's Arden Street Urban Renewal project, as well as the E-Gate site. Hydrologic modelling was undertaken using RORB, with the intention of providing inflows to the hydraulic model. Hydraulic modelling was undertaken using TUFLOW, with the intention of producing water levels and flood maps for the study area. Please note that the results of these models should not be used for any other purposes.

This study also involved the simulation of the impacts of climate change in 2040, 2070 and 2100. Climate change conditions have been assumed to be as specified in Melbourne Water Corporation's "Flood Mapping Projects Guidelines and Technical Specifications – December 2011". This involves an increase in extreme sea level of 0.8m and an increase in extreme rainfall intensity of 32% by 2100. We have assumed that these changes will occur linearly and consequently linear interpolation has been used to establish sea level rise and rainfall intensity increase for 2040 and 2070 scenarios.

1.2 Information Used

The following data has been used in this study:

- LiDAR data from the City of Melbourne (2007);
- Moonee Ponds Creek levee field survey data (2012) taken by Surfcoast Survey and Drafting Services, provided by the City of Melbourne;
- Proposed final surface (as of August 2013) TIN data from Region Rail Link Package B (RRL);
- GIS pipe data from Melbourne Water (provided June 2013);
- GIS pit and pipe data from the City of Melbourne (provided June 2013);
- GIS pipe data from RRL (as of August 2013);
- Landuse / Land Cover data from the City of Melbourne (2007);
- Building outlines and planning scheme zones for the City of Melbourne (accessed August 2013).

1.3 Limitations

Given that the objective of modelling and mapping this site was to produce flood maps as part of a constraints analysis of the study area, flood levels outside the study area are indicative only. The flow of water out of the study area via the rail tunnels to the south-east of North Melbourne station has not been simulated by assuming the tunnel mouths to be blocked. The result of this is a conservative estimation of flood levels in the vicinity of the mouths of the rail tunnels.

Additionally, discussions with the City of Melbourne led to the agreement that a conservative assumption should be made with regards to the operation of pump stations. Consequently it was assumed that these pumps would not be operational during the flood events modelled. Finally, the simulation of the effectiveness of the City of Melbourne drainage network could be improved if data were to be gathered regarding invert levels and pit dimensions.

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2.0 Site Inspection

On 7 August 2013, two AECOM staff members conducted a site visit to the Arden Street and E-Gate site. The site inspection consisted of walking the length of Moonee Ponds Creek within the study area, where observations were made regarding surrounding vegetation, hydraulic structures and the general interface between the creek, roads and rail. Additionally the study area was drive to observe the broader area where observations of property types and drainage infrastructure were made.

The top row of the picture panel below shows the northern end of Moonee Ponds Creek which has been paved during the development of CityLink. The bottom row shows the more natural sections of the creek and its interactions with various hydraulic structures.

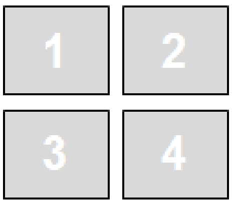

Photo 1: Northern end of Moonee Ponds Creek prior to crossing under CityLink.

Photo 2: Northern end of Moonee Ponds Creek prior to crossing Mt. Alexander Road.

Photo 3: Looking South from Arden Street Bridge.

Photo 4: Southern end of Moonee Ponds Creek passing under the rail line and CityLink.

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3.0 Hydrologic Modelling

A hydrograph for the 1% Annual Exceedance Probability (AEP), 2 hour duration event at Flemington Road was obtained from Melbourne Water's RORB model of Moonee Ponds Creek. This was scaled to produce inflows for events of other AEPs and durations. A RORB model of the local catchments was then developed using MIRORB to generate sub-catchment hydrographs to be used as inflows in the hydraulic model.

3.1 Catchment Delineation

The Arden Street and E-Gate catchment was delineated using LiDAR data (City of Melbourne, 2007) and 1m contours (VicMap, 2009). This resulted in a combined local catchment area of approximately 9.4km^2 as shown in Figure 1. The catchment was then divided into sub-catchments based on topography, the location of structures on Moonee Ponds Creek, the underground drainage network and the need to produce inflows for the hydraulic model near the edge of the study area. These sub-catchments are also shown in Figure 1.

3.2 Fraction Impervious

Within the City of Melbourne, impervious areas were designated using the Land Cover data (City of Melbourne, 2007). Outside the City of Melbourne, fraction impervious was designated according to Planning Scheme Zone as shown in Table 1. Values were assigned based on Melbourne Water's Music Guidelines and a visual inspection of aerial photos.

Table 1 Fraction Impervious Values for Planning Scheme Zones

Zone Type	Adopted Fraction Impervious Value
Business and Industrial	0.9
Mixed Use	0.9
Public Park and Recreation	0.1
Public Use	0.7
Residential	0.45
Road	0.7

Planning Scheme Zone polygons were split according to the sub-catchments then combined to produce sub-catchments with fraction impervious values that were weighted averages of those of the Planning Scheme Zones within them.

3.3 Rational Method Calculations

Due to the absence of historical flood data for this site, the RORB model flows were calibrated to the Rational Method as per the Modified Friend's Equation for the time of concentration detailed in Australia Rainfall and Runoff (Institution of Engineers Australia, 2001). Figure 2 shows the layout of the RORB model and the locations where calibration was undertaken.

Intensity-Frequency-Duration (IFD) factors were generated from the Bureau of Meteorology website and are shown in Table 2. Factors for climate change scenarios were then linearly interpolated based on a 32% increase in extreme rainfall intensity by 2100, as per Melbourne Water's "Flood Mapping Project Guidelines and Technical Specifications – December 2011".

The major source of flooding in the study area is from Moonee Ponds Creek, which has a critical storm duration of two hours. Consequently the F_2 and F_{50} values have not been modified for the climate change scenarios, as these values are only changed for storm durations less than one hour.

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Table 2 IFD Factors for the Arden and E-Gate Study Area (Including Climate Change Adjustments)

Annual Recurrence Interval	Intensity (mm/hour)		
	1 hour	12 hour	72 hour
2 year (current)	18.96	3.74	1.11
50 year (current)	39.18	7.10	2.21
2 year (2040)	20.98	4.14	1.23
50 year (2040)	43.36	7.86	2.45
2 year (2070)	23.00	4.54	1.35
50 year (2070)	47.54	8.61	2.68
2 year (2100)	25.03	4.94	1.47
50 year (2100)	47.54	8.61	2.68
	Skew (G) = 0.36	F_2 value = 4.29	F_{50} value = 14.95

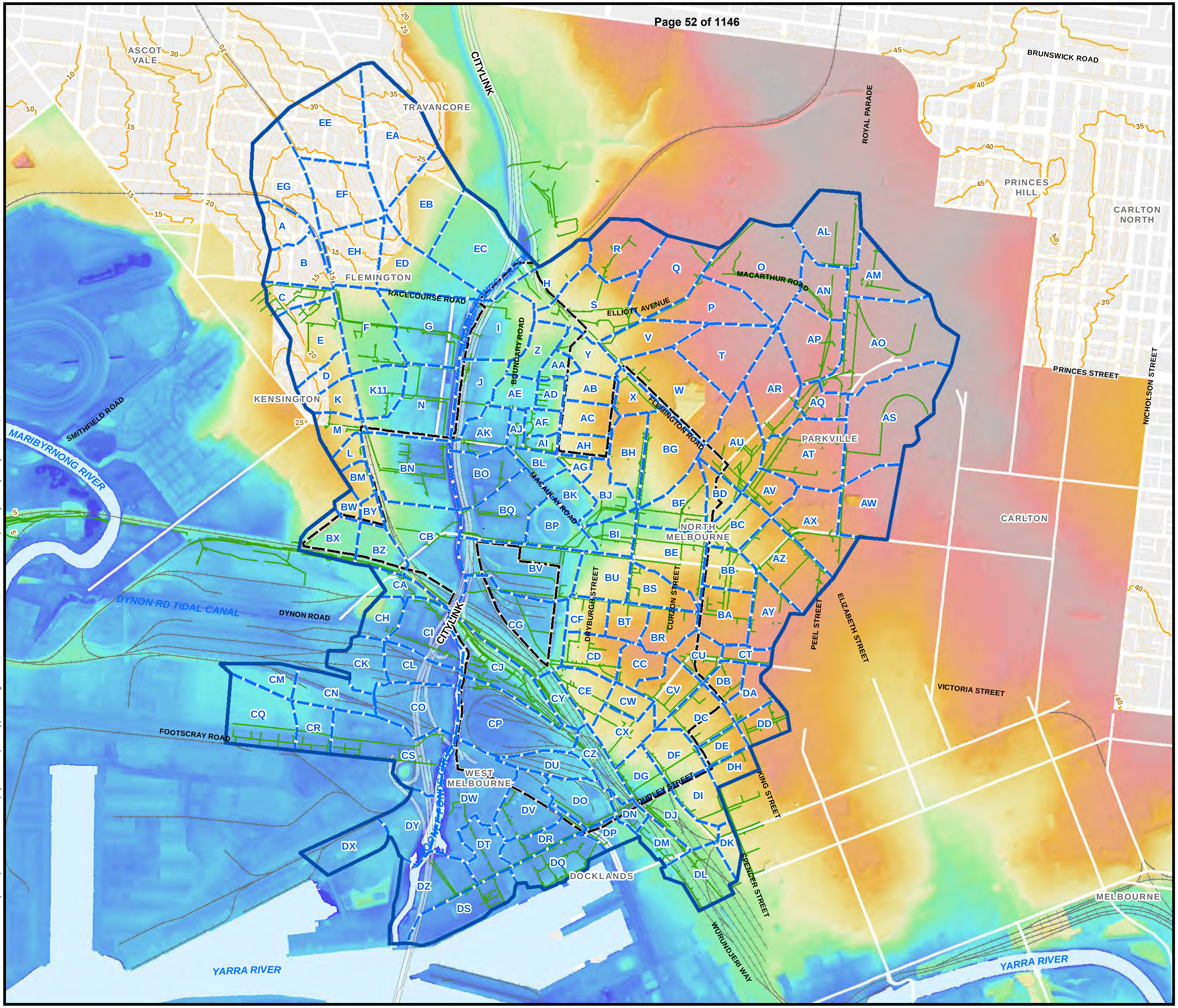
Table 3 shows the details of the Rational Method calculations of the 1% AEP flows at the calibration points.

Table 3 Rational Method Calculations

Calibration Point	Area (km^2)	Fraction Impervious	Adopted t_c (min.)	Runoff Coefficient C_{10}	1% AEP Frequency Factor	Runoff Coefficient C_{100}	1% AEP Intensity for t_c (mm/hr)	Peak 1% AEP Flow (m^3/s)
F1	0.81	0.50	29	0.61	1.2	0.73	77.1	12.7
AR1	0.68	0.44	31	0.57	1.2	0.69	74.0	9.6
AZ1	0.30	0.79	21	0.77	1.2	0.93	92.9	7.1

3.4 RORB Model

The RORB model was created in MiRORB and is shown in Figure 2. Appendix A supplements this figure by providing sub catchment data in tabular form.



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DATUM GDA 1994, PROJECTION MGA ZONE 55

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LEGEND

- Catchment Boundary
- Sub-Catchment
- Study Area
- Pipe network
- Freeway
- Existing Rail
- Major contour
- Minor contour
- Cadastre

Elevation (mAHD)
High : 51.01

Low : 0

Data sources:
Base Data: (c) 2012 DEPI
DEM: (c) 2007 City of Melbourne

CATCHMENT DELINEATION

Department of Transport, Planning and Local Infrastructure

Hydrologic and Hydraulic Modelling of Arden and E-Gate

Figure

F1

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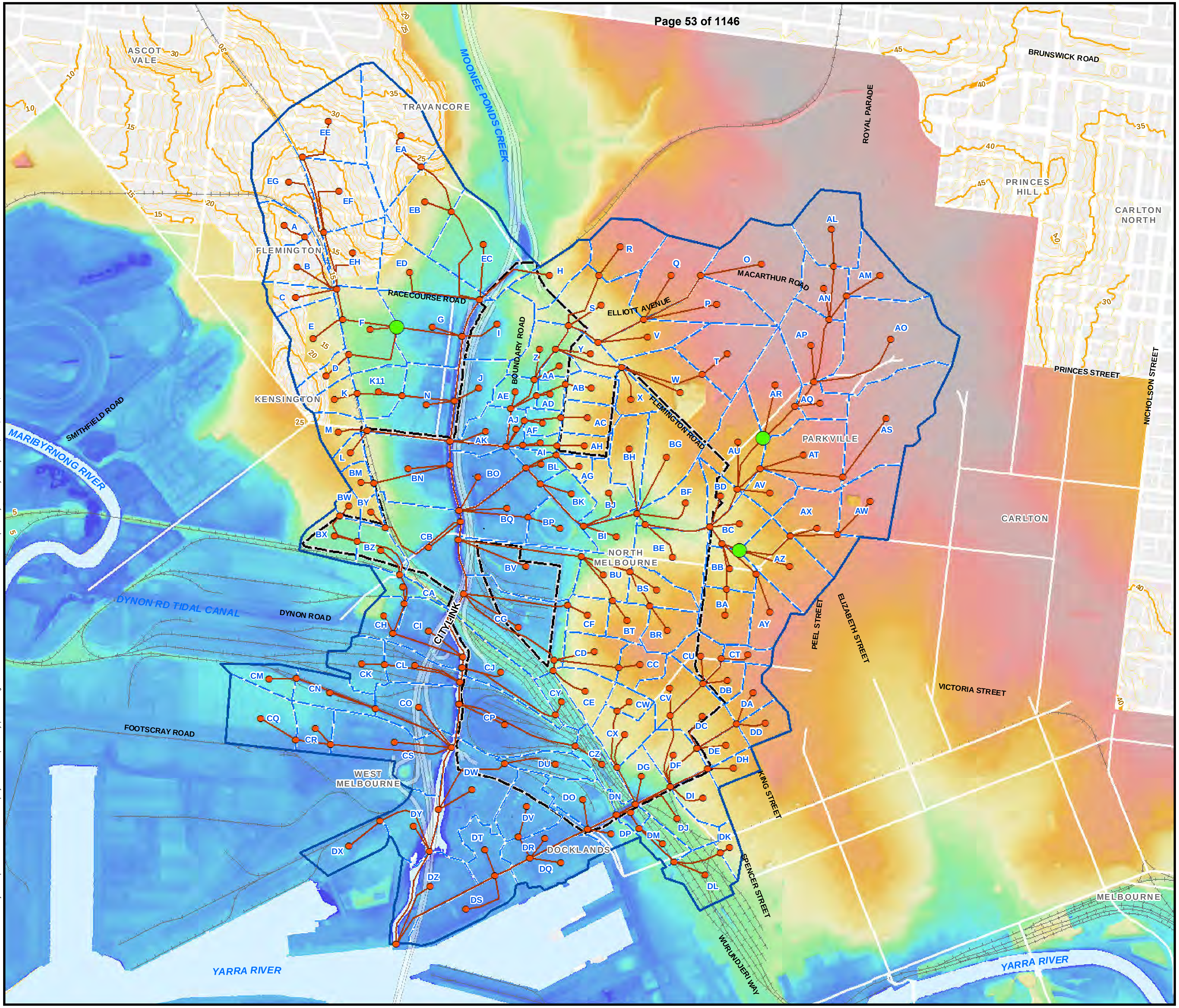

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DATUM GDA 1994, PROJECTION MGA ZONE 55

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LEGEND

- Calibration Point
- Node
- Reach
- Catchment Boundary
- Sub-Catchment
- Study Area
- Freeway
- Existing Rail
- Major contour
- Minor contour
- Cadastre

Elevation (mAHD)
High : 51.01
Low : 0

Data sources:
Base Data: (c) 2012 DEPI
DEM: (c) 2007 City of Melbourne

RORB MODEL WITH CALIBRATION POINTS

Department of Transport, Planning and Local Infrastructure

Hydrologic and Hydraulic Modelling of Arden and E-Gate

Figure

F2

Map Document: (P:\60304612\4. Tech work area\4.99 GIS\02_Maps\M002_RORB_Model_20130905.mxd)

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3.5 Calibration

The purpose of calibrating the RORB model is to gain confidence in the results from the hydrological model that provides input to the hydraulic model. In the absence of historical rainfall-runoff data for the catchment, calibration using the Rational Method flow estimate has been undertaken. The following factors from the Melbourne Water Technical Specifications and Requirements were used in the calibration of the RORB model:

- A value of 0.8 has been used for the exponent m in the reach storage equation, $S = k_c Q^m$;
- k_c was adjusted to match the Rational Method flow estimate;
- The Institution of Engineers' 1987 Australian Rainfall and Runoff (AR&R) method used for the Areal Reduction Factor;
- Initial Loss =10mm (urban catchment);
- Temporal Patterns fully filtered; and,
- Runoff coefficients as per Table 4 below.

Table 4 Runoff Coefficients for Range of AEP Events

AEP	Runoff Coefficient
10%	0.35
1%	0.60
0.5%	0.60
0.2%	0.60

Please note that the value specified for the 1% AEP event has been used for larger events.

Through a process of trial and error, the value for k_c was adjusted until RORB results matched the peak flows estimated using the Rational Method. The k_c recommended using equation 2.4 in the RORB manual is 6.75 and the recommendation using equation 3.22 (for areas of Victoria with mean annual rainfall less than 800mm) in Book 5 of AR&R is 2.11. It was found that the lowest sum of percentage error occurred with a k_c value of 3.4 as highlighted in Table 5. This value is within the range of those recommended and was therefore adopted for this study.

Table 5 Calibration of k_c for RORB Model

k_c	Calibration Point	F1	AR1	AZ1
	Rational Method 1% AEP Flow (m^3/s)	12.7	9.6	7.1
	Rational Method t_c (min)	24	26	16
3.3	RORB 1% AEP Flow	12.7	9.7	7.3
	RORB peak storm duration (min)	60	120	15
	% Error	0	1	3
3.4	**RORB 1% AEP Flow**	**12.5**	**9.5**	**7.2**
	RORB peak storm duration (min)	**90**	**120**	**15**
	% Error	**-2**	**-1**	**1**
3.5	RORB 1% AEP Flow	12.3	9.4	7.1
	RORB peak storm duration (min)	90	120	15
	% Error	-3	-2	0

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The k_c value of 3.4 that was found to produce flows with an acceptable level of accuracy at the calibration points when compared to the Rational Method was then used in conjunction with other values listed in above to generate hydrographs for each sub-catchment for the full range of AEP events.

3.6 Results

The RORB model was used to produce sub-catchment inflows under existing conditions, as well as climate change conditions in 2040, 2070 and 2100, for the following AEPs using the 2 hour storm event to correspond with flooding in the Moonee Ponds Creek:

- 10%;
- 1%;
- 0.5%; and,
- 0.2%.

A comparison between the inflows to the TUFLOW model in the 2 hour duration, 1% AEP event under both existing and climate change conditions can be seen in Appendix B.

4.0 Hydraulic Modelling

The objective of creating a hydraulic model of the study area was to develop flood extents to feed into the Arden Street Urban Renewal project and assist in the planning of the E-Gate development. The extent of flooding has been determined for a range of recurrence intervals for the existing extent of development in both existing and climate change conditions. Hydraulic modelling allows for the following:

- Identification of properties at risk of flooding;
- Identification of inadequacies in the existing stormwater network; and,
- Identification of locations where future works may be implemented in order to reduce the severity of flooding.

The hydraulic modelling software package TUFLOW was used to undertake the hydraulic modelling. The following steps outline the tasks undertaken to develop a TUFLOW model of the study area and to obtain results:

1) Generate a Digital Elevation Model (DEM)
2) Use the RORB model to compile hydrographs for 16 possible combinations of AEP and climate change conditions for existing levels of development:
    - 10%, 1%, 0.5% and 0.2% AEP events; and
    - Climate conditions as they are now as well as in how they are projected to be in 2040, 2070 and 2100. These conditions were modelled based on the assumption that there will be a 32% increase in extreme rainfall intensity in the period from 2010 to 2100, as per Melbourne Water's "Flood Mapping Project Guidelines and Technical Specifications – December 2011" and that increases in extreme rainfall intensity up until 2100 will be linear.
3) Input surface roughness (materials layer)
4) Input and verify data for the one-dimensional network
5) Set boundary conditions for the one and two-dimensional domains
6) Input open channel structure data and calibrate head losses to the results of the existing Melbourne Water HEC-RAS model, as provided by Melbourne Water and is understood to have been developed in 2010/2011.
7) Compile, interpret and validate the results
8) Run TUFLOW for all 16 possible combinations of AEP and climate change conditions for existing levels of development
    - 10%, 1%, 0.5% and 0.2% AEP events; and
    - Climate conditions as they are now as well as in how they are projected to be in 2040, 2070 and 2100. These conditions were modelled based on the assumption that there will be an increase of 0.8m in extreme sea level in the period from 2010 to 2100, as per Melbourne Water's "Flood Mapping Project Guidelines and Technical Specifications – December 2011" and that increases in extreme sea level up until 2100 will be linear.

Figure 3 shows the main features of the TUFLOW model. Further sections elaborate on elements of the model that are of importance, which are as follows:

- Digital Elevation Model (DEM);
- Two-dimensional grid;
- One-dimensional network data; and,
- Levee banks.

It should be noted that we have not attempted to simulate the flow of water out of the study area via the rail tunnels to the south-east of North Melbourne station, instead simply representing the tunnel mouths as blocked. The result of this is a conservative estimation of flood levels in the vicinity of the mouths of the rail tunnels.

4.1 Digital Elevation Model (DEM)

The 2007 LiDAR data supplied by the City of Melbourne was used for this investigation and a DEM with a resolution of 1m was produced from this data. This was read directly into TUFLOW. Figure 4 shows the DEM generated for the study.

4.2 Two-Dimensional Grid

A 4m grid size was used in order to strike a balance between model accuracy and run times. The extent of the final 417,788 grid cell model is shown in Figure 4. The proposed final design surface (as of August 2013) in Triangular Irregular Network (TIN) format was obtained from RRL package B works and was incorporated into the model. The extent of the design surface is also shown in Figure 4.

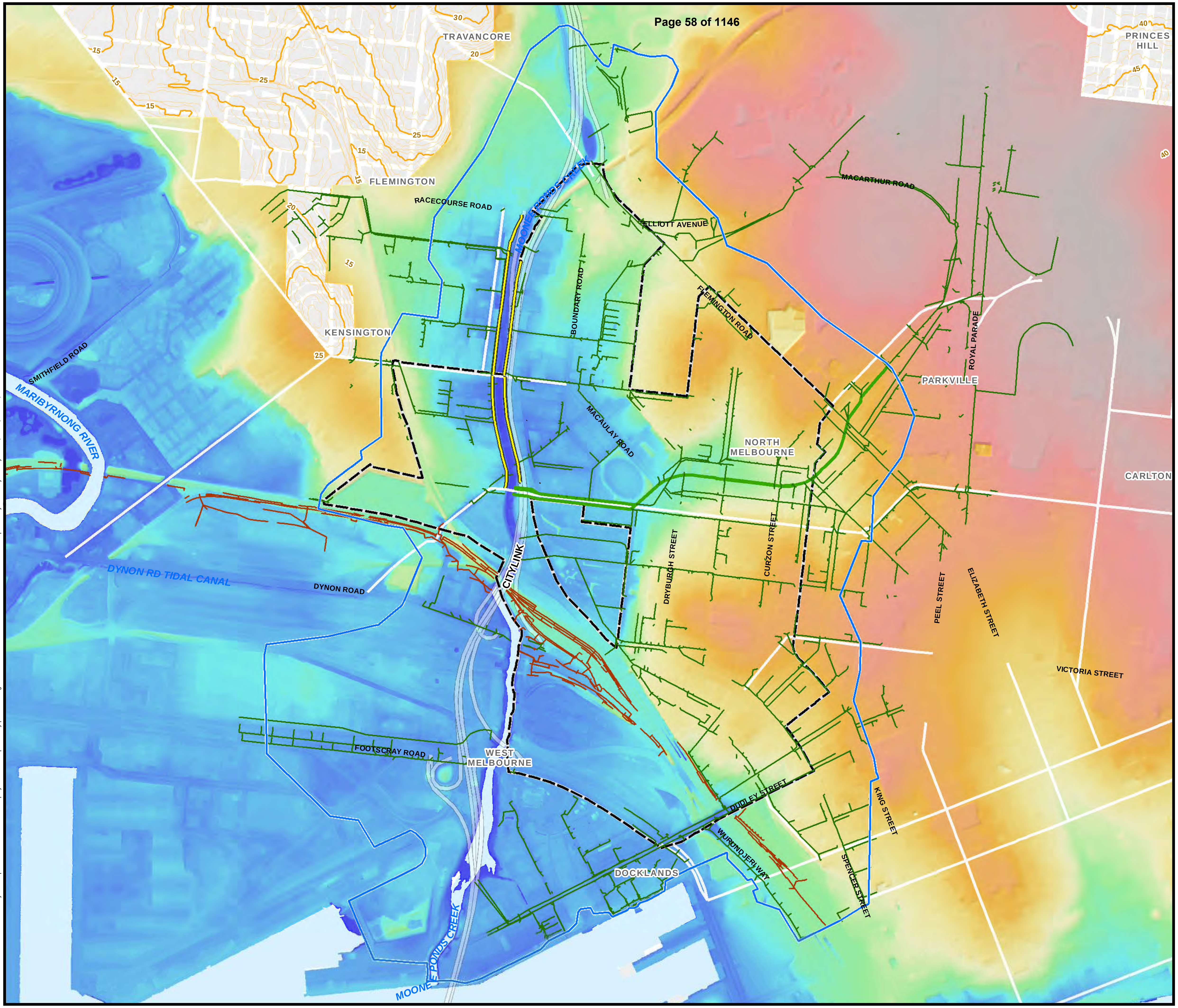
The locations shown as "Interpolated Areas" are where the design surface crosses a flow-path that has necessitated the flow-path being "cut" through the TIN in order to be represented in the model. The exception to this is the Royal Children's Hospital on Flemington Road. As this site was undergoing excavation when the LiDAR data was gathered, there is a false hole in the DEM where the hospital now sits. This has been smoothed over in the TUFLOW model by interpolating between surface levels surrounding the erroneous data, resulting in topography consistent with the adjacent land.

Bathymetric data was obtained from Melbourne Water's HEC-RAS model of Moonee Ponds Creek and used to create a TIN. The Surfcoast Survey and Drafting Services 2012 survey of the Moonee Ponds Creek levees was provided by the City of Melbourne and used to restrict flow to and from the creek below the levee level, as the LiDAR data did not adequately capture the levee. These features are shown in Figure 4.

4.3 Open Channel Structures

Bridges and piers in Moonee Ponds creek have been modelled using TUFLOW's Layered Flow Constriction Shapes, which allow resistance to flow between grid cells to vary depending on the water level. Structure data was obtained from Melbourne Water's HEC-RAS model and Form Loss Coefficients were adjusted such that head loss across structures in TUFLOW replicated those in the HEC-RAS model, with the exception of the Dynon Road bridge, where significant overland flow to the west bypasses the bridge itself.

Where survey data from the City of Melbourne appeared to conflict with the topography within the HEC-RAS model, the survey data was given preference. This is most relevant for the northern-most rail crossing of Moonee Ponds Creek where the incorporation of more detailed survey of this structure into the model would minimise any uncertainty regarding outcomes if this structure were to become the site of any mitigation opportunities.



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DATUM GDA 1994, PROJECTION MGA ZONE 55

0 200 400 800
metres
1:15,000 (when printed at A3)

LEGEND

- TUFLOW Model Extent
- Levee
- Melbourne Water Pipe Network
- City of Melbourne Pipe Network
- RRL Pipe Network
- Study Area
- Freeway
- Major contour
- Minor contour
- Cadastre

Elevation (mAHD)
High : 51.01
Low : 0

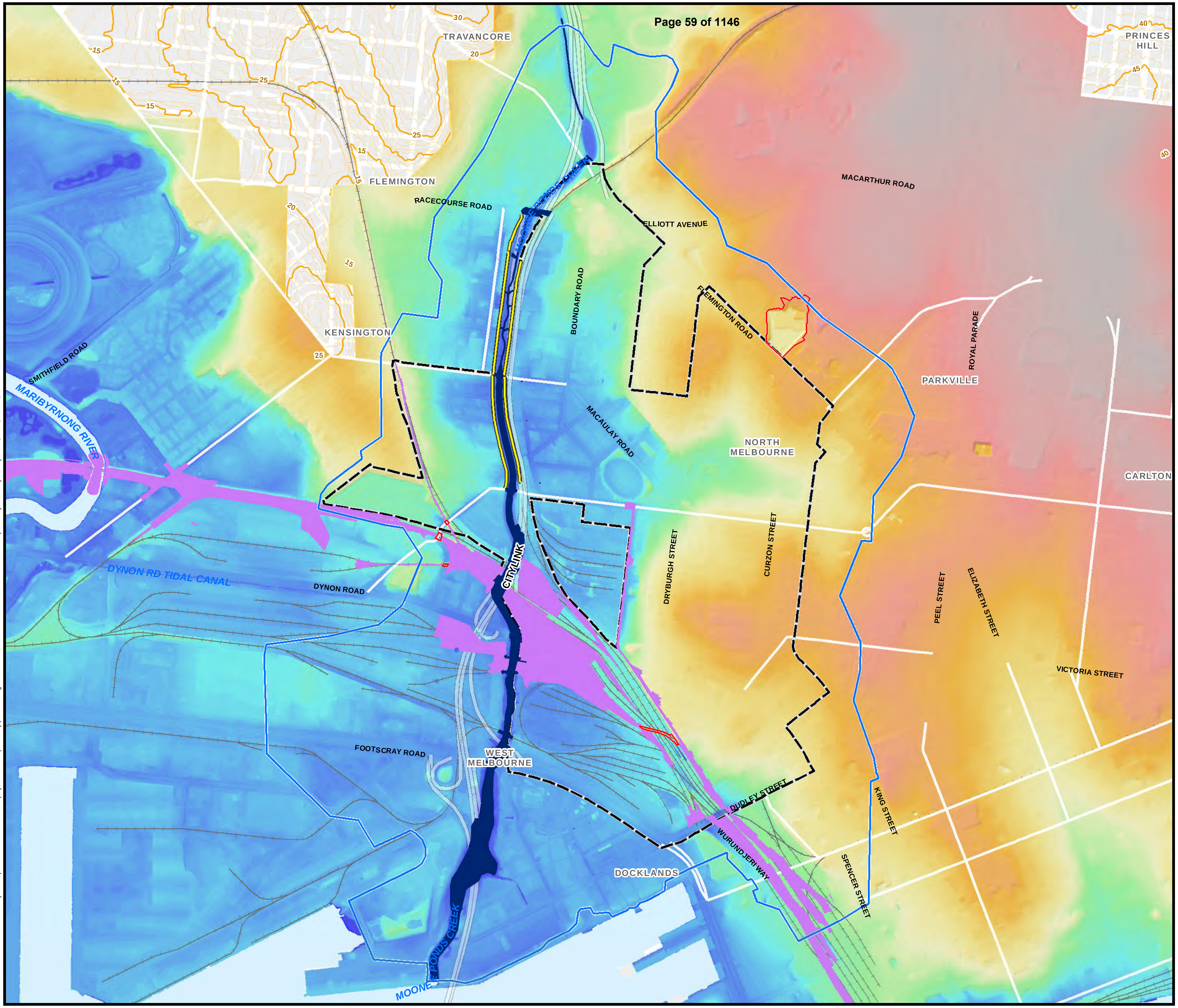
Data sources:
Base Data: (c) 2012 DEPI
DEM: (c) 2007 City of Melbourne

TUFLOW MODEL OVERVIEW

Department of Transport, Planning and Local Infrastructure

Hydrologic and Hydraulic Modelling of Arden and E-Gate

Figure
F3



PROJECT ID 60304612
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DATUM GDA 1994, PROJECTION MGA ZONE 55

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metres
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LEGEND

- TUFLOW Model Extent
- Levee
- Creek TIN
- Interpolated Areas
- Regional Rail Link Design TIN extent
- Study Area
- Freeway
- Existing Rail
- Major contour
- Minor contour
- Cadastre

Elevation (mAHD)
High : 51.01
Low : 0

Data sources:
Base Data: (c) 2012 DEPI
DEM: (c) 2007 City of Melbourne

TUFLOW MODEL TOPOGRAPHY

Department of Transport, Planning and Local Infrastructure

Hydrologic and Hydraulic Modelling of Arden and E-Gate

Figure
F4

Map Document: (P:\60304612\4. Tech work area\4.99 GIS\02_Maps\M004_TUFLOW_Topography_20130905.mxd)

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4.4 One-Dimensional Network Data

GIS data for the existing Melbourne Water, City of Melbourne and RRL drainage infrastructure network was obtained directly from these agencies in 2013. Verification and manipulation of this data in GIS packages was necessary, as detailed below.

4.4.1 Melbourne Water Underground Drainage

Melbourne Water's only underground asset included in the model was the Arden Street Drain. Where objects in Melbourne Water's GIS data for this drain were lacking invert levels, these were interpolated based on the upstream or downstream levels of adjacent pipes.

4.4.2 City of Melbourne Drainage

City of Melbourne GIS asset data supplied in 2013 was utilised to obtain pipe locations and diameters however no invert levels were available. Information regarding pit connections was utilised to obtain surface levels from the level of the DEM at the pit location at the upstream and downstream ends of the pipe network, as well as at junctions.

A cover of 600mm from the natural surface to the top of the pipe was assumed to obtain invert levels using these surface levels. All grated pits were considered to be 1.2 m wide by 0.5 m high and all other pits were considered to be 1.2 m wide by 0.15 m high. Pits labelled "System Node" and "Junction" were not considered to facilitate an exchange of water between the surface and the pipe network, due to conclusions drawn based on visual inspections at a number of these locations.

Discussions with the City of Melbourne led to the agreement that a conservative assumption should be made with regards to the operation of pump stations. Consequently it was assumed that these pumps would not be operated during the flood events modelled.

4.4.3 RRL Drainage

The drainage network from the RRL project in the model area was obtained in 2013. Diameters and inverts were used as supplied, however the pipes were constructed as slotted polyethylene, which cannot be easily incorporated into a TUFLOW model. Consequently 1.2m wide by 0.15m high pits were introduced at the end of each pipe object to facilitate interaction between the surface and pipe drainage.

4.5 Surface Roughness

Within TUFLOW, a land use (materials) layer is utilised to import surface roughness information into the model. A materials layer for the model area was constructed by using the City of Melbourne's 2007 Land Cover data, where available. Use of this data may be conservative in some areas due to the presence of trees in the road reservations.

Outside of the City of Melbourne, Planning Scheme Zones were used to assign roughness values to city blocks and large areas of uniform roughness were digitised by hand. Additionally, Manning's "n" values in Moonee Ponds Creek were initially based on those from Melbourne Water's HEC-RAS model, though these were adjusted to provide a better match to the hydraulic grade between the two models. The Manning's "n" values used are shown in Table 6.

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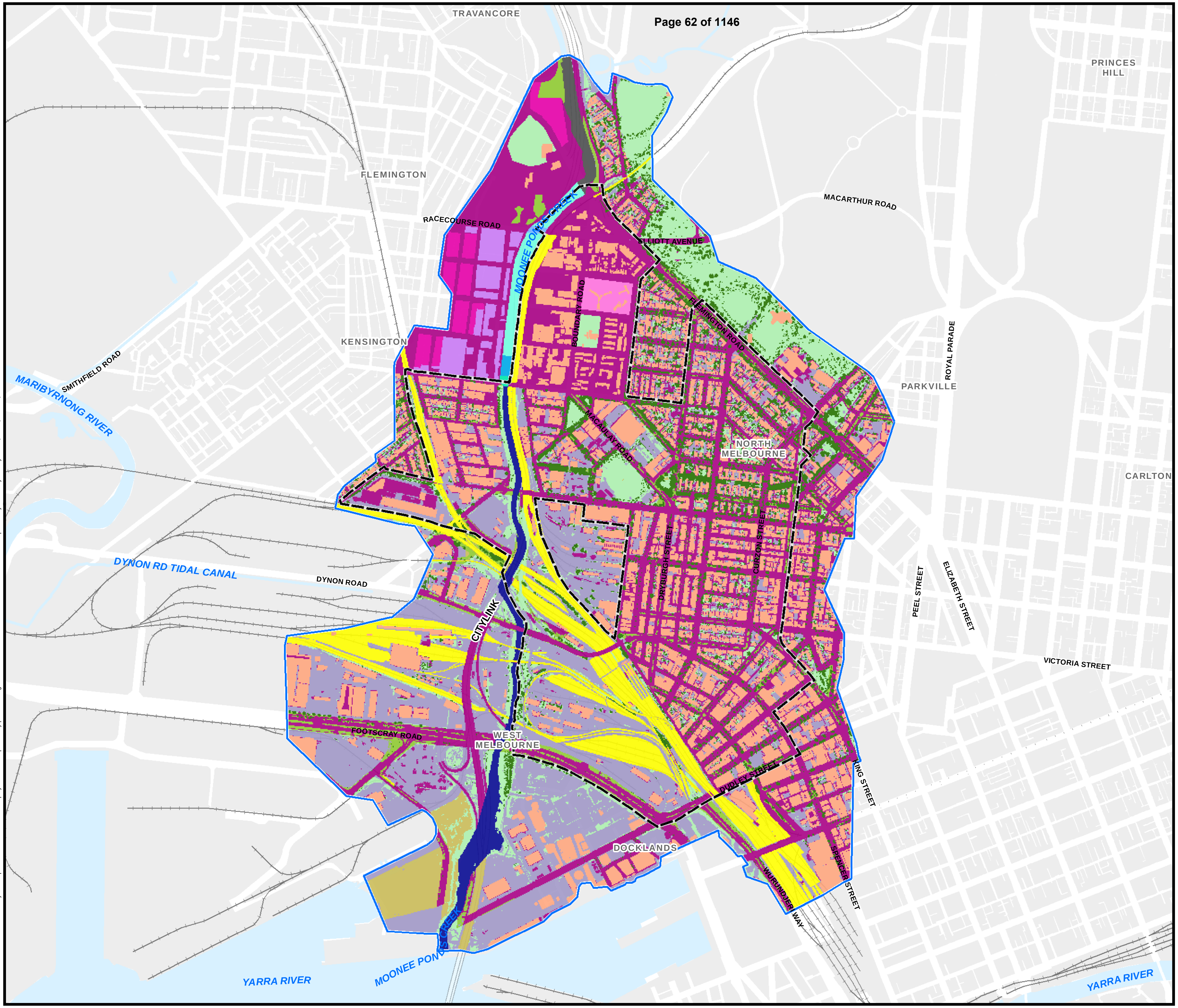
Table 6 Roughness Coefficients

Material	Manning's n
Industrial	0.200
Bare Soil	0.025
Grass Areas	0.035
Hard Surfaces	0.030
Nature Strips	0.050
Railway	0.100
Road	0.020
Trees	0.070
Water Bodies	0.021
Buildings	0.500
Concrete	0.018
Open Channel 1	0.033
Open Channel 2	0.024
Open Channel 3	0.040
Open Channel 4	0.0206
Residential (Buildings Separate)	0.080
High Density Residential (Including Buildings)	0.300



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DATUM GDA 1994, PROJECTION MGA ZONE 55

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LEGEND

- Study Area
- TUFLOW Model Extent

Material

- Bare Soil
- Buildings
- Concrete
- Grass Areas
- Hard Surfaces
- Industrial
- Nature Strips
- Open Channel 1
- Open Channel 2
- Open Channel 3
- Open Channel 4
- Railway
- Road
- Trees
- Water Bodies
- High Density Residential (Including Buildings)
- Residential (Buildings Separate)

Data sources:
Base Data: (c) 2012 DEPI
DEM: (c) 2007 City of Melbourne

TUFLOW MODEL MATERIALS

Department of Transport, Planning and Local Infrastructure

Hydrologic and Hydraulic Modelling of Arden and E-Gate

Figure

F5

Map Document: (P:\60304612\4. Tech work area\4.99 GIS\02_Maps\M005_TUFLOW_Model_Materials_20130905.mxd)

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4.6 Boundary Conditions

4.6.1 Outflows

Two-dimensional boundary conditions were applied at the outlet of Moonee Ponds Creek to the Yarra River and along the edge of the model at Victoria Harbour. This tail water level was set to the 10% AEP extreme sea level in Port Phillip Bay of 1.22 m AHD for current conditions, as per Melbourne Water specifications for models that outlet to the bay. Thus the difference between the Yarra River level and the level in the bay at the outlet of Moonee Ponds Creek was considered negligible.

Sea level rise was then applied on top of this downstream water level for climate change conditions, which was 0.8 m by 2100, with rises by 2040 and 2070 linearly interpolated. The only other location where water was allowed to leave the model was on Childers Street, where two pipes lead to the Maribyrnong River. These were also assumed to have a tail water level of 1.22 m AHD.

4.6.2 Inflows

In the majority of the model, the inflows are the un-routed hydrographs from the RORB model, which were applied to the bottom of the pits in the one-dimensional network. This approach ensures that the pipe network should be at or close to capacity before any water spills into the two-dimensional domain.

The flow from each of the sub-catchments is split evenly over all of the pits within each sub-catchment. In sub-catchments where this resulted in an excessive amount of flow being applied to some pits (such as the RRL drainage network), flow was applied only to the City of Melbourne network.

In some locations, the application of routed hydrographs was appropriate. This was the case where the TUFLOW model extent fell significantly short of the catchment extent, but was also the case for some sub-catchments that only contained an underground drainage network at their most downstream boundary. The Moonee Ponds Creek inflow was applied across the width of the open channel at the upstream extent of the TUFLOW model.

4.6.3 Connections between One- and Two-Dimensional Domains

Boundaries have been assigned to the pits to allow discharge of water from the pipe network to flow to the two-dimensional grid cells representing the ground surface and vice versa. This allows for the simulation of real world processes such as when flow drains from a road into a pit, or when the piped network reaches capacity and flow begins to spill back out of the pits respectively.

4.7 Model Checking

The log files of all simulations were checked to ascertain mass balance errors at the peak and end of the event. Mass balance error in the model is acceptably low (less than 1%) for all TUFLOW simulations.

4.8 Flood Mapping

The maximum depths of inundation for each AEP for each set of climate change conditions were calculated to produce the final results of the study. These depths are presented in the following figures:

- Appendix C shows water depths for 10%, 1%, 0.5% and 0.2% AEP events in existing conditions
- Appendix D shows water depths for 10%, 1%, 0.5% and 0.2% AEP events in 2040 climate change conditions
- Appendix E shows water depths for 10%, 1%, 0.5% and 0.2% AEP events in 2070 climate change conditions
- Appendix F shows water depths for 10%, 1%, 0.5% and 0.2% AEP events in 2100 climate change conditions

5.0 Discussion

Floodplains on both sides of Moonee Ponds Creek experience flooding as a result of run-off from local sub-catchments exceeding the capacity of the underground drainage network and flowing overland towards the creek. Flows are then prevented from entering the creek by the levees resulting in pooling, with flood waters outside of the levee being higher than those in the creek in the existing case, 1% AEP event south of Macauley Road.

It should be noted that the topography of the railway line underneath CityLink has not been accurately captured by the LiDAR data. It is recommended that this be surveyed and incorporated into the model if this area is to become the site of mitigation works.

The most significant constriction on flow in Moonee Ponds Creek is the northern-most rail bridge, which crosses the creek underneath CityLink. The obvert of this bridge is 2.06 m AHD and the existing case, 1% AEP flood level on the upstream side is estimated to be 2.99 m AHD. There is also some uncertainty about the cross-section of the bridge opening, with data obtained from Melbourne Water's HEC-RAS model not being verified by the City of Melbourne's survey of the area. If this is to become the location of any mitigation works, it is recommended that the structure be surveyed and revised in the model.

There is some uncertainty about the Dynon Road Bridge as the dimensions do not appear to be accurately reflected in the structure data in Melbourne Water's HEC-RAS model. As a result almost 50 m^3/s of flow in Moonee Ponds Creek is diverted onto the western floodplain at this location in the 1% AEP event under existing conditions. This means that the flow rate passing under the Dynon Road Bridge differs between this TUFLOW model and the existing HEC-RAS model, thus calibration of the Dynon Road structure could not be undertaken.

Flooding of the Docklands area is extensive and relatively deep at the eastern end of Docklands Drive, with Waterfront Way under almost 2 m of water at the intersection with Docklands Drive in the existing case, 1% AEP event. This is caused by a lack of capacity in the underground drainage network (as well as the absence of a dedicated overland flow-path), though the hydraulic grade along the Dudley Street drain is relatively flat, with head drop in the order of 70 cm between this location and the outlet of the drain in Moonee Ponds Creek. Despite this, the flow through the underpass is approximately 14m^3/s in the existing case, 1% AEP event. It should be noted that invert levels of this drain are not available and the accuracy of results would benefit from survey of these levels.

Flooding in the southern part of E-Gate is predominantly from Moonee Ponds Creek, with run-off from the rail yards to the east peaking at about 0.2 m^3/s in the existing case, 1% AEP event. In the northern section of E-Gate, immediately to the south of Dynon Road, overland flow originating in the rail yards is more significant, peaking at 1.4 m^3/s. However, flooding from the creek is also responsible for some of the inundation towards the western end of this area.

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Appendix A

RORB Sub Catchment Details

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Appendix A RORB Sub Catchment Details

Sub-Area	Area (km^2)	Fraction Impervious	Sub-Area	Area (km^2)	Fraction Impervious	Sub-Area	Area (km^2)	Fraction Impervious
B	0.06	0.65	AV	0.04	0.87	CP	0.15	0.77
C	0.04	0.45	AW	0.09	0.59	CQ	0.10	0.89
D	0.03	0.50	AX	0.10	0.85	CR	0.04	0.90
E	0.09	0.48	AY	0.06	0.78	CS	0.14	0.86
F	0.11	0.51	AZ	0.11	0.91	CT	0.02	0.93
G	0.13	0.70	BA	0.07	0.91	CU	0.04	0.93
H	0.06	0.65	BB	0.05	0.85	CV	0.05	0.82
I	0.10	0.81	BC	0.05	0.82	CW	0.03	0.89
J	0.07	0.86	BD	0.03	0.72	CX	0.06	0.88
K	0.04	0.52	BE	0.10	0.77	CY	0.03	0.72
K11	0.06	0.47	BF	0.07	0.76	CZ	0.04	0.69
L	0.02	0.61	BG	0.10	0.75	DA	0.04	0.81
M	0.04	0.82	BH	0.06	0.82	DB	0.03	0.79
N	0.11	0.82	BI	0.04	0.61	DC	0.06	0.93
O	0.16	0.17	BJ	0.05	0.71	DD	0.04	0.91
P	0.08	0.04	BK	0.04	0.82	DE	0.03	0.93
Q	0.10	0.28	BL	0.03	0.85	DF	0.06	0.89
R	0.08	0.26	BM	0.02	0.70	DG	0.04	0.90
S	0.12	0.39	BN	0.14	0.83	DH	0.03	0.91
T	0.11	0.00	BO	0.07	0.80	DI	0.05	0.91
V	0.06	0.02	BP	0.06	0.44	DJ	0.06	0.87
W	0.13	0.23	BQ	0.10	0.81	DK	0.02	0.98
X	0.03	0.84	BR	0.05	0.89	DL	0.07	0.80
Y	0.04	0.71	BS	0.05	0.94	DM	0.03	0.74
Z	0.05	0.53	BT	0.04	0.88	DN	0.02	0.68
AA	0.02	0.59	BU	0.06	0.94	DO	0.06	0.93
AB	0.04	0.76	BV	0.14	0.89	DP	0.03	0.88
AC	0.04	0.79	BW	0.01	0.77	DQ	0.07	0.96
AD	0.02	0.48	BX	0.05	0.81	DR	0.05	0.93
AE	0.03	0.48	BY	0.01	0.73	DS	0.09	0.97
AF	0.02	0.49	BZ	0.05	0.82	DT	0.05	0.94
AG	0.02	0.53	CA	0.03	0.75	DU	0.04	0.74
AH	0.03	0.78	CB	0.15	0.79	DV	0.08	0.85
AI	0.01	0.57	CC	0.04	0.87	DW	0.15	0.67

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Sub-Area	Area (km^2)	Fraction Impervious	Sub-Area	Area (km^2)	Fraction Impervious	Sub-Area	Area (km^2)	Fraction Impervious
AJ	0.02	0.48	CD	0.06	0.94	DX	0.06	0.92
AK	0.05	0.90	CE	0.05	0.91	DY	0.07	0.46
AL	0.11	0.68	CF	0.04	0.93	DZ	0.11	0.66
AM	0.07	0.18	CG	0.17	0.84	EA	0.17	0.57
AN	0.06	0.50	CH	0.04	0.83	EB	0.11	0.49
AO	0.21	0.53	CI	0.08	0.80	EC	0.16	0.30
AP	0.09	0.13	CJ	0.09	0.77	ED	0.10	0.46
AQ	0.04	0.86	CK	0.06	0.84	EE	0.15	0.47
AR	0.10	0.24	CL	0.05	0.82	EF	0.11	0.45
AS	0.19	0.49	CM	0.04	0.89	EG	0.11	0.48
AT	0.12	0.75	CN	0.06	0.83	EH	0.08	0.55
B	0.06	0.65	AV	0.04	0.87	CP	0.15	0.77

Appendix B

Peak TUFLOW Inflows for 2 Hour, 1% AEP Events

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Appendix B Peak TUFLOW Inflows for 2 Hour, 1% AEP Events

Please note that this table contains some flows from routed and / or lumped hydrographs.

Catchment	Flow (m^3/s)				Catchment	Flow (m^3/s)			
	Existing	2040	2070	2100		Existing	2040	2070	2100
Moonee Ponds Creek	207.4	234.4	263.4	290.4					
F	12.4	13.8	15.3	16.7	BX	1.5	1.7	1.9	2.0
G	3.5	3.9	4.3	4.6	BY	0.3	0.4	0.4	0.4
H	1.7	1.9	2.1	2.3	BZ	1.1	1.2	1.4	1.5
I	2.9	3.2	3.5	3.8	CA	0.7	0.8	0.9	1.0
J	1.9	2.1	2.3	2.5	CB	4.2	4.6	5.1	5.5
K11	1.9	2.2	2.4	2.6	CC	1.0	1.2	1.3	1.4
L	0.5	0.5	0.6	0.6	CD	1.7	1.8	2.0	2.2
M	1.0	1.1	1.2	1.3	CE	1.4	1.6	1.7	1.9
N	3.2	3.6	3.9	4.2	CF	1.1	1.2	1.3	1.4
Q	5.5	6.2	6.8	7.5	CG	5.0	5.5	6.0	6.6
R	1.7	1.9	2.0	2.2	CH	0.9	1.0	1.1	1.2
S	2.9	3.2	3.5	3.8	CI	2.3	2.5	2.8	3.0
T	1.3	1.5	1.7	1.9	CJ	2.6	2.9	3.1	3.4
V	0.6	0.6	0.7	0.8	CK	1.3	1.5	1.6	1.8
W	2.9	3.3	3.6	3.9	CL	1.5	1.7	1.9	2.0
X	0.9	1.0	1.1	1.2	CM	1.0	1.2	1.3	1.4
Y	1.1	1.2	1.4	1.5	CN	1.7	1.9	2.1	2.3
Z	1.1	1.3	1.4	1.5	CO	2.7	3.0	3.3	3.6
AA	0.5	0.5	0.6	0.7	CP	4.2	4.6	5.1	5.5
AB	1.0	1.1	1.2	1.4	CQ	2.9	3.2	3.5	3.8
AC	1.2	1.4	1.5	1.6	CR	1.3	1.4	1.6	1.7
AD	0.5	0.6	0.7	0.7	CS	4.1	4.6	5.0	5.5
AE	0.8	0.9	1.0	1.1	CT	0.6	0.7	0.7	0.8
AF	0.6	0.6	0.7	0.8	CU	1.2	1.3	1.5	1.6
AG	0.4	0.4	0.5	0.5	CV	1.5	1.7	1.8	2.0
AH	0.8	0.9	1.0	1.1	CW	0.7	0.7	0.8	0.9
AI	0.4	0.4	0.4	0.5	CX	1.7	1.9	2.0	2.2
AJ	0.4	0.4	0.5	0.5	CY	0.9	1.0	1.1	1.2
AK	1.4	1.6	1.7	1.9	CZ	1.2	1.3	1.4	1.5
AR	9.5	10.7	11.9	13.1	DA	1.1	1.2	1.3	1.4
AT	5.7	6.4	7.0	7.7	DB	0.8	0.9	1.0	1.0

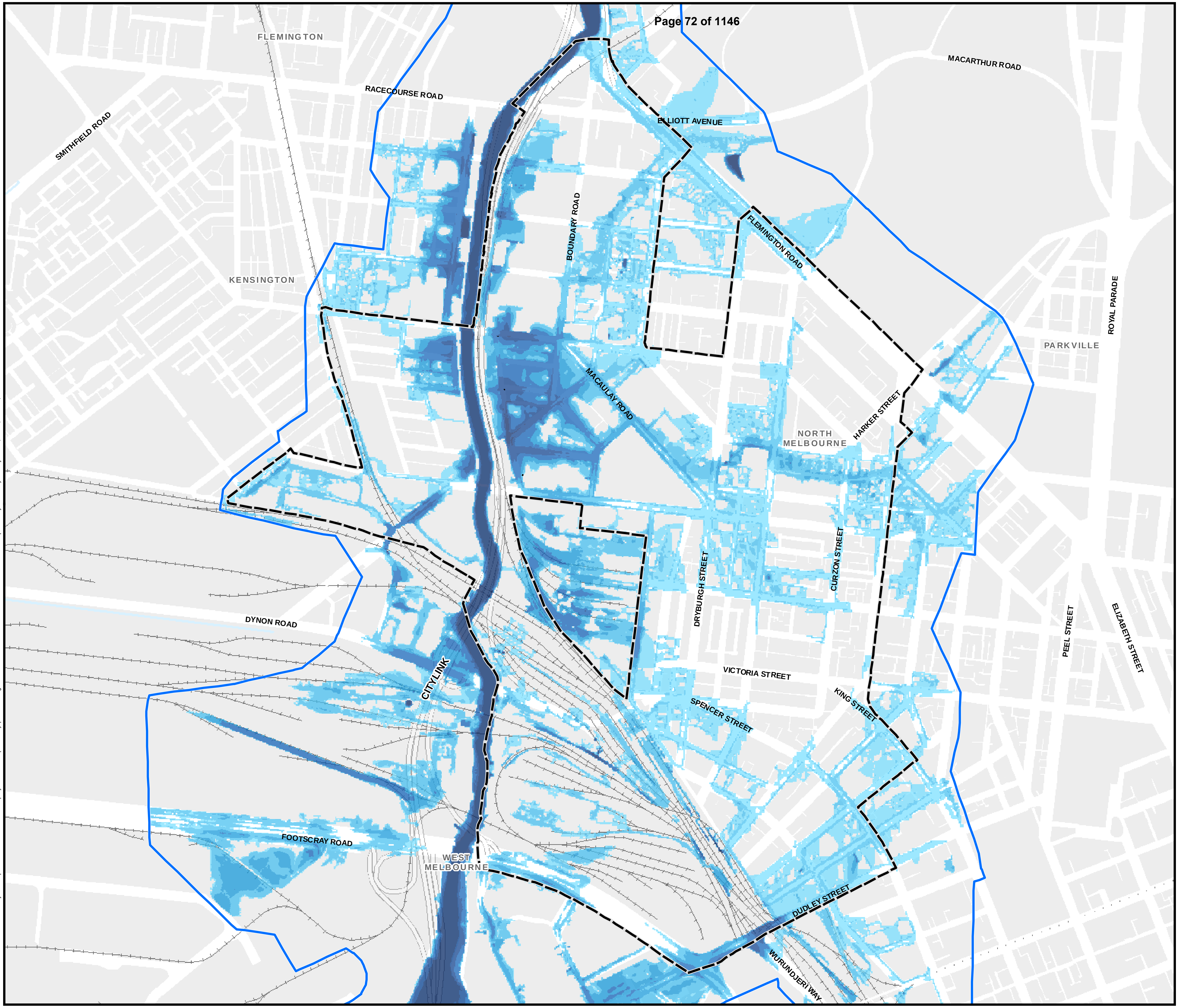
DRAFT

Catchment	Flow (m^3/s)				Catchment	Flow (m^3/s)			
	Existing	2040	2070	2100		Existing	2040	2070	2100
AU	2.5	2.8	3.1	3.3	DC	1.8	2.0	2.2	2.4
AV	1.1	1.2	1.3	1.4	DD	1.1	1.2	1.3	1.4
AY	1.4	1.6	1.7	1.9	DE	0.9	0.9	1.0	1.1
AZ	6.3	7.0	7.7	8.4	DF	1.7	1.8	2.0	2.2
BA	2.0	2.3	2.5	2.7	DG	1.3	1.4	1.5	1.7
BB	1.4	1.6	1.7	1.9	DH	0.8	0.9	1.0	1.1
BC	1.8	1.9	2.1	2.3	DI	1.4	1.6	1.7	1.9
BD	0.9	1.0	1.1	1.2	DJ	1.6	1.8	2.0	2.2
BE	2.6	2.9	3.2	3.5	DK	0.6	0.7	0.8	0.8
BF	2.0	2.2	2.5	2.7	DL	2.0	2.2	2.4	2.6
BG	2.6	2.9	3.2	3.5	DM	0.9	1.0	1.1	1.2
BH	1.8	1.9	2.1	2.3	DN	0.5	0.6	0.6	0.7
BI	1.1	1.2	1.3	1.5	DO	1.3	1.5	1.7	1.8
BJ	1.4	1.6	1.7	1.9	DP	0.8	0.8	0.9	1.0
BK	0.7	0.8	0.9	1.0	DQ	2.1	2.3	2.6	2.8
BL	0.8	0.9	0.9	1.0	DR	1.4	1.5	1.6	1.8
BM	0.5	0.6	0.6	0.7	DS	2.5	2.8	3.1	3.4
BN	4.0	4.5	4.9	5.3	DT	1.4	1.6	1.7	1.9
BO	2.1	2.3	2.5	2.7	DU	0.7	0.8	0.9	1.0
BP	1.4	1.6	1.8	1.9	DV	2.2	2.4	2.6	2.8
BQ	2.8	3.1	3.4	3.7	DW	4.0	4.5	4.9	5.3
BR	1.5	1.6	1.8	1.9	DX	0.8	0.9	1.0	1.1
BS	1.5	1.6	1.8	2.0	DY	1.3	1.4	1.6	1.7
BT	1.1	1.2	1.3	1.4	DZ	2.8	3.1	3.4	3.7
BU	1.8	2.0	2.2	2.3	EB	2.5	2.8	3.1	3.5
BV	4.0	4.5	4.9	5.3	EC	3.6	4.0	4.4	4.8
BW	0.4	0.4	0.4	0.5	ED	1.7	2.0	2.2	2.4

D R A F T

Appendix C

Water Depths for 10%, 1%, 0.5% and 0.2% AEP Events in Existing Conditions



PROJECT ID 60304612
CREATED BY TCH
LAST MODIFIED TCH 06 SEP 2013

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N

DATUM GDA 1994, PROJECTION MGA ZONE 55
0 100 200 400
metres
1:11,000 (when printed at A3)

LEGEND

- TUFLOW Model Extent
- Study Area

Water Depth (metres)

- 0 - 0.05
- 0.06 - 0.25
- 0.26 - 0.5
- 0.51 - 1
- 1.01 - 1.5
- > 1.51

Data sources:
Base Data: (c) 2012 DEPI

EXISTING CONDITIONS 10% AEP WATER DEPTHS

Department of Transport, Planning and Local Infrastructure

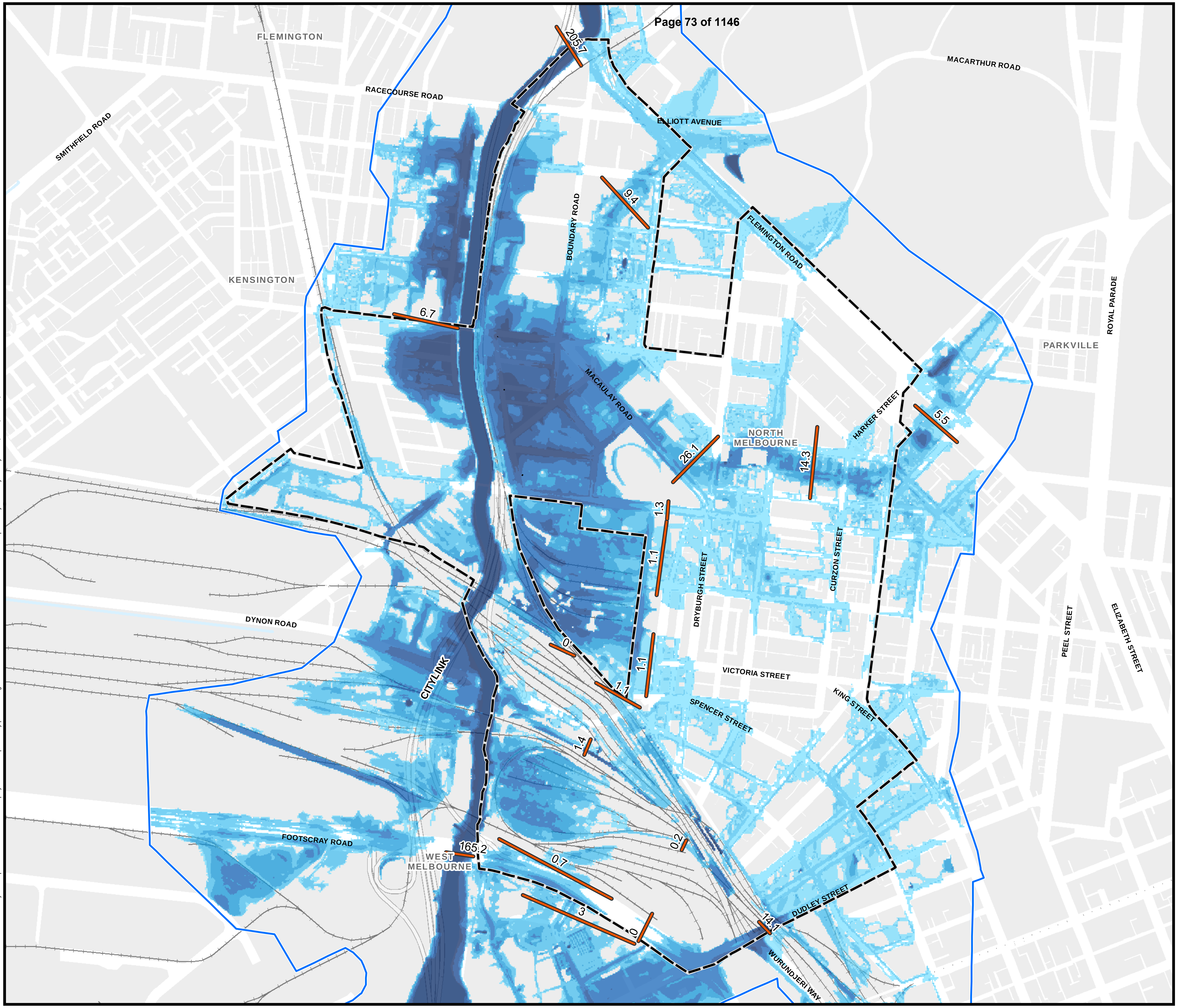
Hydrologic and Hydraulic Modelling of Arden and E-Gate

Figure

F6

Map Document: (P:\60304612\4. Tech work area\4.99 GIS\02_Maps\M006_Depths_20130906.mxd - D_EXG_Q010)

A3 size



PROJECT ID 60304612
CREATED BY TCH
LAST MODIFIED TCH 11 SEP 2013

AECOM
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N

DATUM GDA 1994, PROJECTION MGA ZONE 55
0 100 200 400
metres
1:11,000 (when printed at A3)

LEGEND

- TUFLOW Model Extent
- Study Area
- 1% AEP Existing Flow Rate (m³/s)

Water Depth (metres)

- 0 - 0.05
- 0.06 - 0.25
- 0.26 - 0.5
- 0.51 - 1
- 1.01 - 1.5
- > 1.51

Data sources:
Base Data: (c) 2012 DEPI

EXISTING CONDITIONS 1% AEP WATER DEPTHS

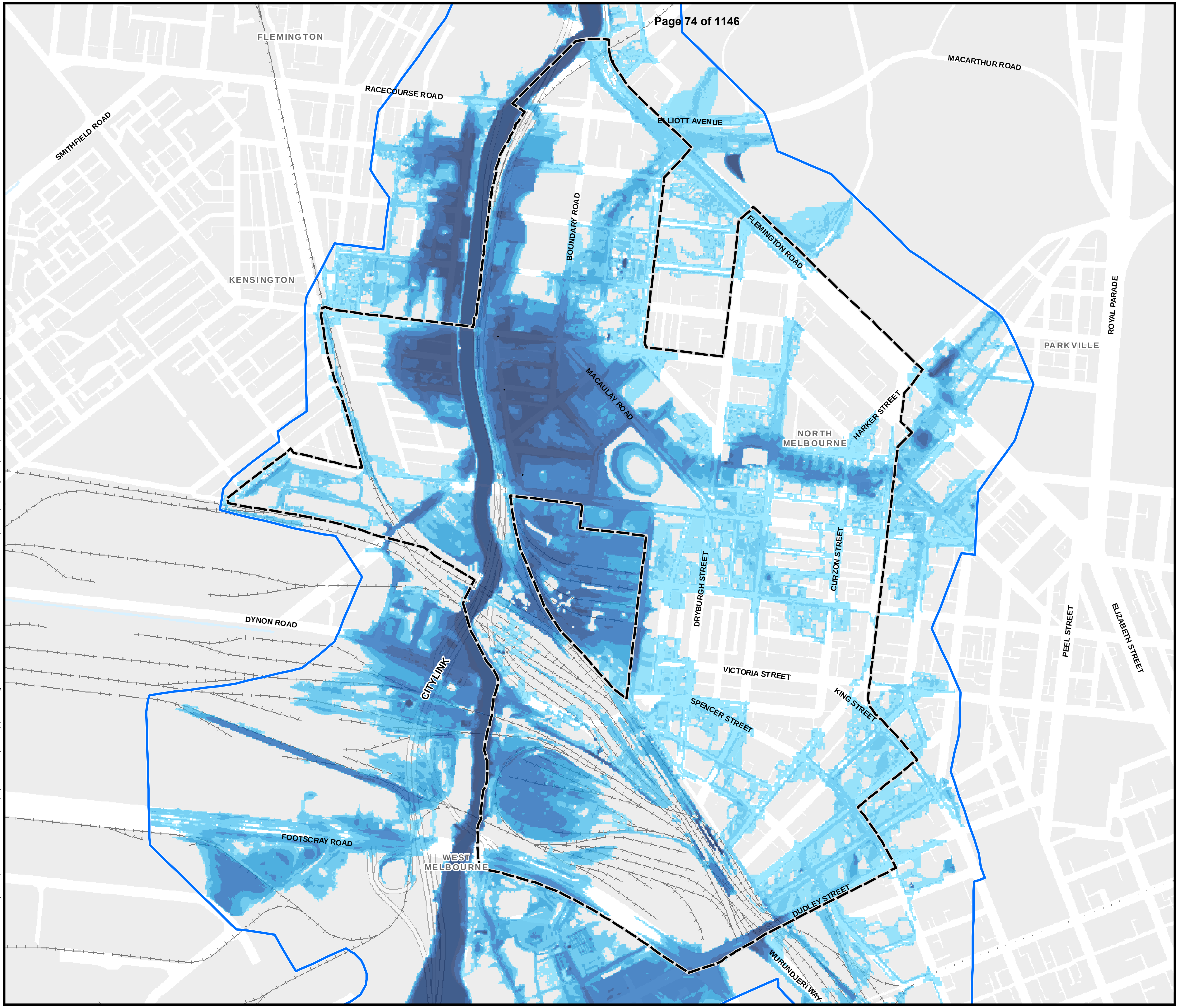
Department of Transport, Planning and Local Infrastructure

Hydrologic and Hydraulic Modelling of Arden and E-Gate

Figure
F7

Map Document: (\\aumel1fp001\projects\60304612\4. Tech work area\4.99 GIS\02_Maps\M007_Depths_ExCond_20130911.mxd - D_EXG_Q100)

A3 size



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LAST MODIFIED TCH 06 SEP 2013

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N

DATUM GDA 1994, PROJECTION MGA ZONE 55

0 100 200 400 metres

1:11,000 (when printed at A3)

LEGEND

- TUFLOW Model Extent
- Study Area

Water Depth (metres)

- 0 - 0.05
- 0.06 - 0.25
- 0.26 - 0.5
- 0.51 - 1
- 1.01 - 1.5
- > 1.51

Data sources:
Base Data: (c) 2012 DEPI

EXISTING CONDITIONS 0.5% AEP WATER DEPTHS

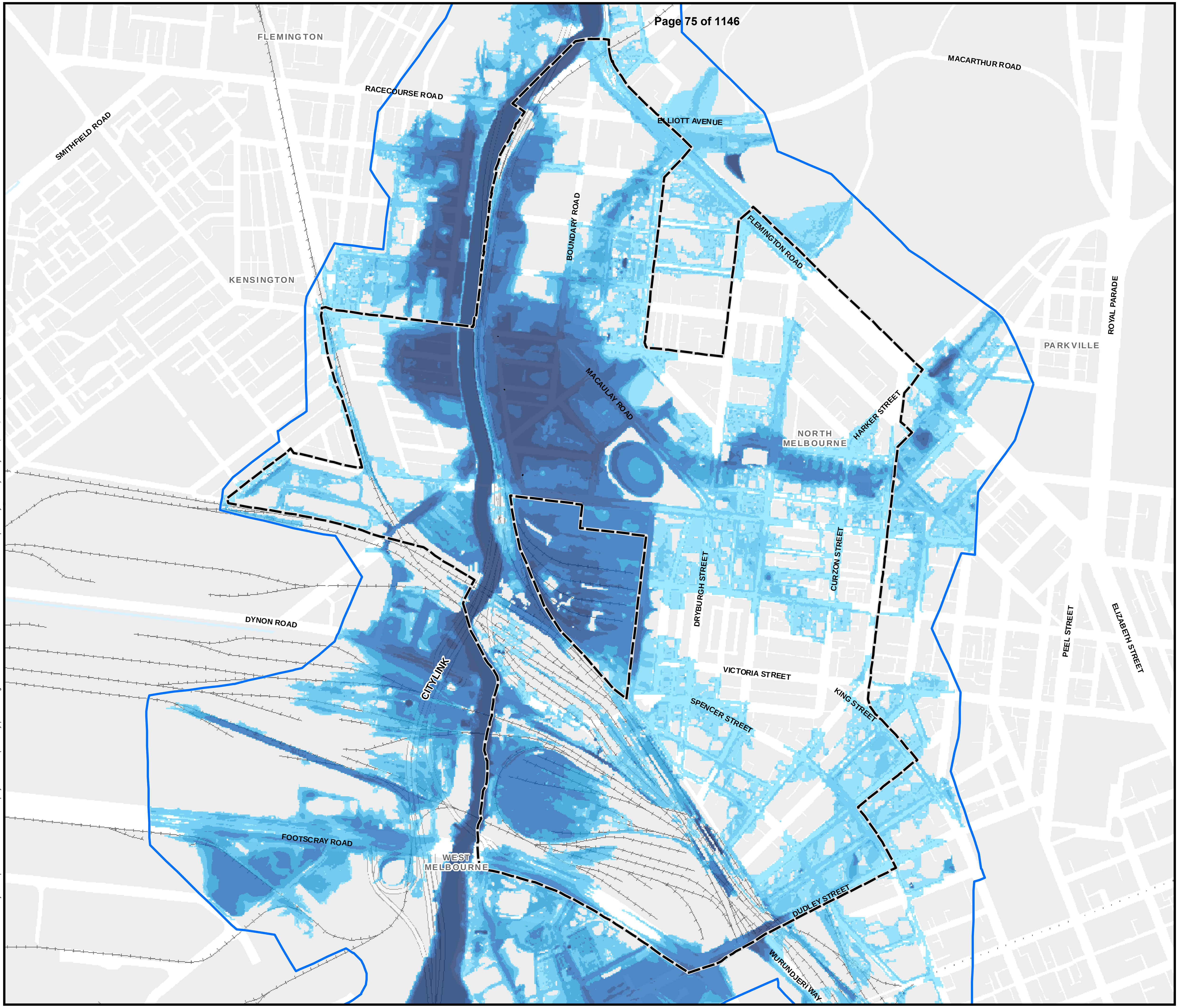
Department of Transport, Planning and Local Infrastructure

Hydrologic and Hydraulic Modelling of Arden and E-Gate

Figure F8

Map Document: (P:\60304612\4. Tech work area\4.99 GIS\02_Maps\M006_Depths_20130906.mxd - D_EXG_Q200)

A3 size



PROJECT ID 60304612
CREATED BY TCH
LAST MODIFIED TCH 06 SEP 2013

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N

DATUM GDA 1994, PROJECTION MGA ZONE 55

0 100 200 400
metres
1:11,000 (when printed at A3)

LEGEND

TUFLOW Model Extent
Study Area
Water Depth (metres)
0 - 0.05
0.06 - 0.25
0.26 - 0.5
0.51 - 1
1.01 - 1.5
> 1.51

Data sources:
Base Data: (c) 2012 DEPI

EXISTING CONDITIONS 0.2% AEP WATER DEPTHS

Department of Transport, Planning and Local Infrastructure

Hydrologic and Hydraulic Modelling of Arden and E-Gate

Figure

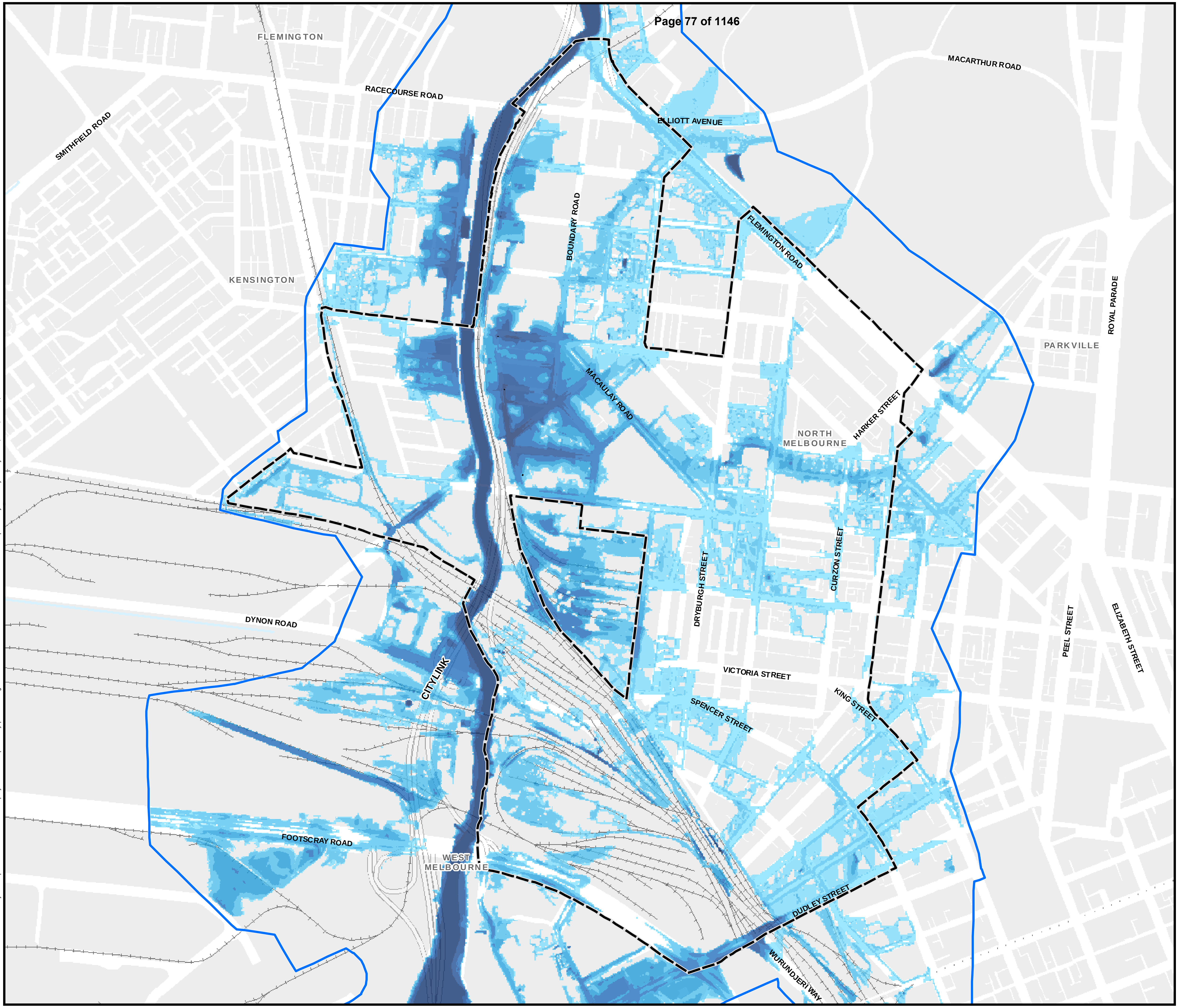
F9

Map Document: (P:\60304612\4. Tech work area\4.99 GIS\02_Maps\M006_Depths_20130906.mxd - D_EXG_Q500)

A3 size

Appendix D

Water Depths for 10%, 1%, 0.5% and 0.2% AEP Events in 2040 Climate Change Conditions



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N

DATUM GDA 1994, PROJECTION MGA ZONE 55
0 100 200 400
metres
1:11,000 (when printed at A3)

LEGEND

- TUFLOW Model Extent
- Study Area

Water Depth (metres)

- 0 - 0.05
- 0.06 - 0.25
- 0.26 - 0.5
- 0.51 - 1
- 1.01 - 1.5
- > 1.51

Data sources:
Base Data: (c) 2012 DEPI

2040 CONDITIONS 10% AEP WATER DEPTHS

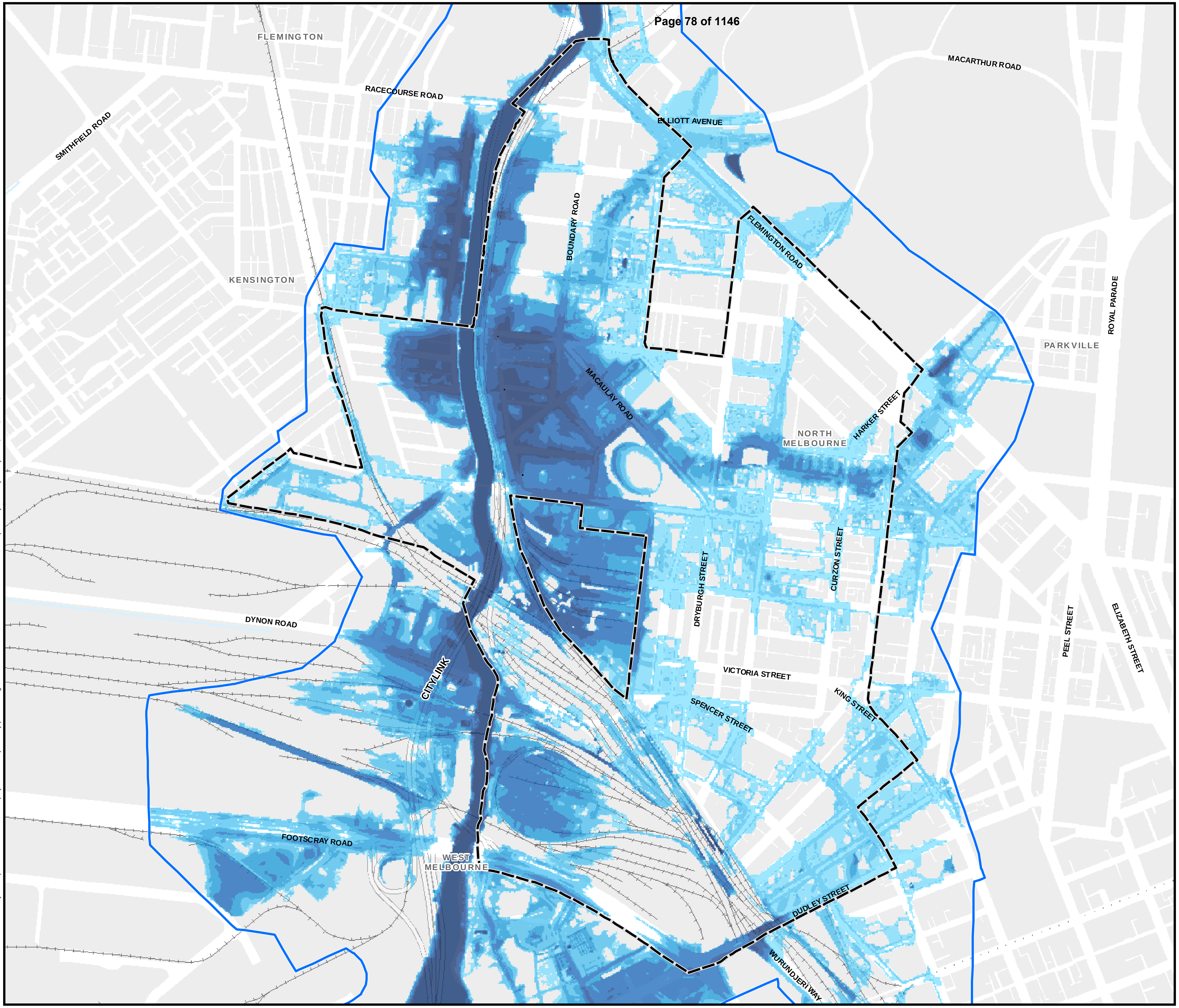
Department of Transport, Planning and Local Infrastructure

Hydrologic and Hydraulic Modelling of Arden and E-Gate

Figure F10

Map Document: (P:\60304612\4. Tech work area\4.99 GIS\02_Maps\M006_Depths_20130906.mxd - D_2040_Q010)

A3 size



PROJECT ID 60304612
CREATED BY TCH
LAST MODIFIED TCH 06 SEP 2013

AECOM
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N

DATUM GDA 1994, PROJECTION MGA ZONE 55
0 100 200 400
metres
1:11,000 (when printed at A3)

LEGEND

- TUFLOW Model Extent
- Study Area

Water Depth (metres)

- 0 - 0.05
- 0.06 - 0.25
- 0.26 - 0.5
- 0.51 - 1
- 1.01 - 1.5
- > 1.51

Data sources:
Base Data: (c) 2012 DEPI

2040 CONDITIONS 1% AEP WATER DEPTHS

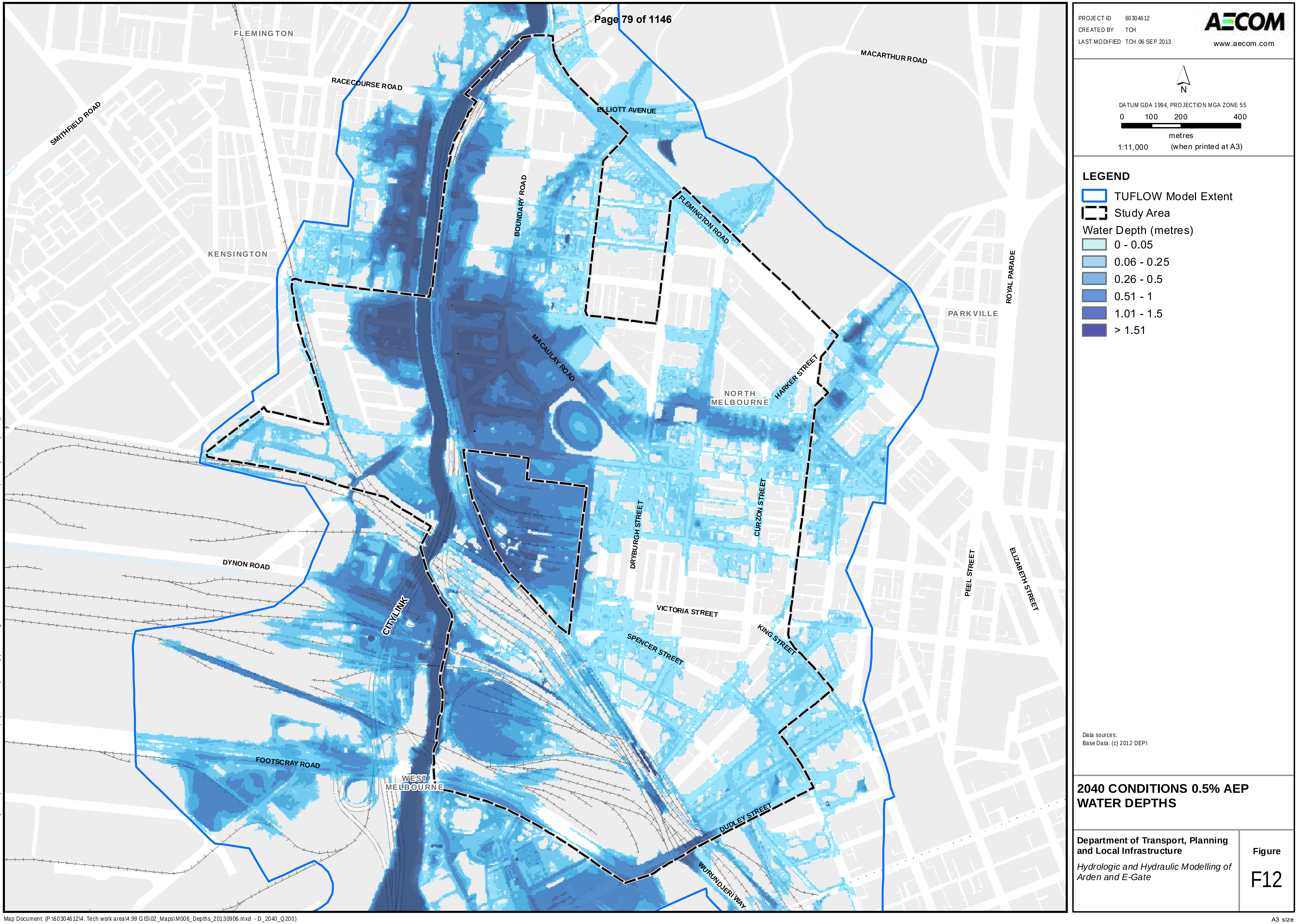
Department of Transport, Planning and Local Infrastructure

Hydrologic and Hydraulic Modelling of Arden and E-Gate

Figure
F11

Map Document: (P:\60304612\4. Tech work area\4.99 GIS\02_Maps\M006_Depths_20130906.mxd - D_2040_Q100)

A3 size


FLEMINGTON
RACECOURSE ROAD
SMITHFIELD ROAD
MACARTHUR ROAD
ELLIOTT AVENUE
BOUNDARY ROAD
FLEMINGTON ROAD
KENSINGTON
ROYAL PARADE
PARKVILLE
MACAULAY ROAD
HARKER STREET
NORTH MELBOURNE
CURZON STREET
DRYBURGH STREET
DYNON ROAD
CITYLINK
VICTORIA STREET
SPENCER STREET
KING STREET
PEEL STREET
ELIZABETH STREET
FOOTSCRAY ROAD
WEST MELBOURNE
DUDLEY STREET
WURUNDJERI WAY
PROJECT ID 60304612
CREATED BY TCH
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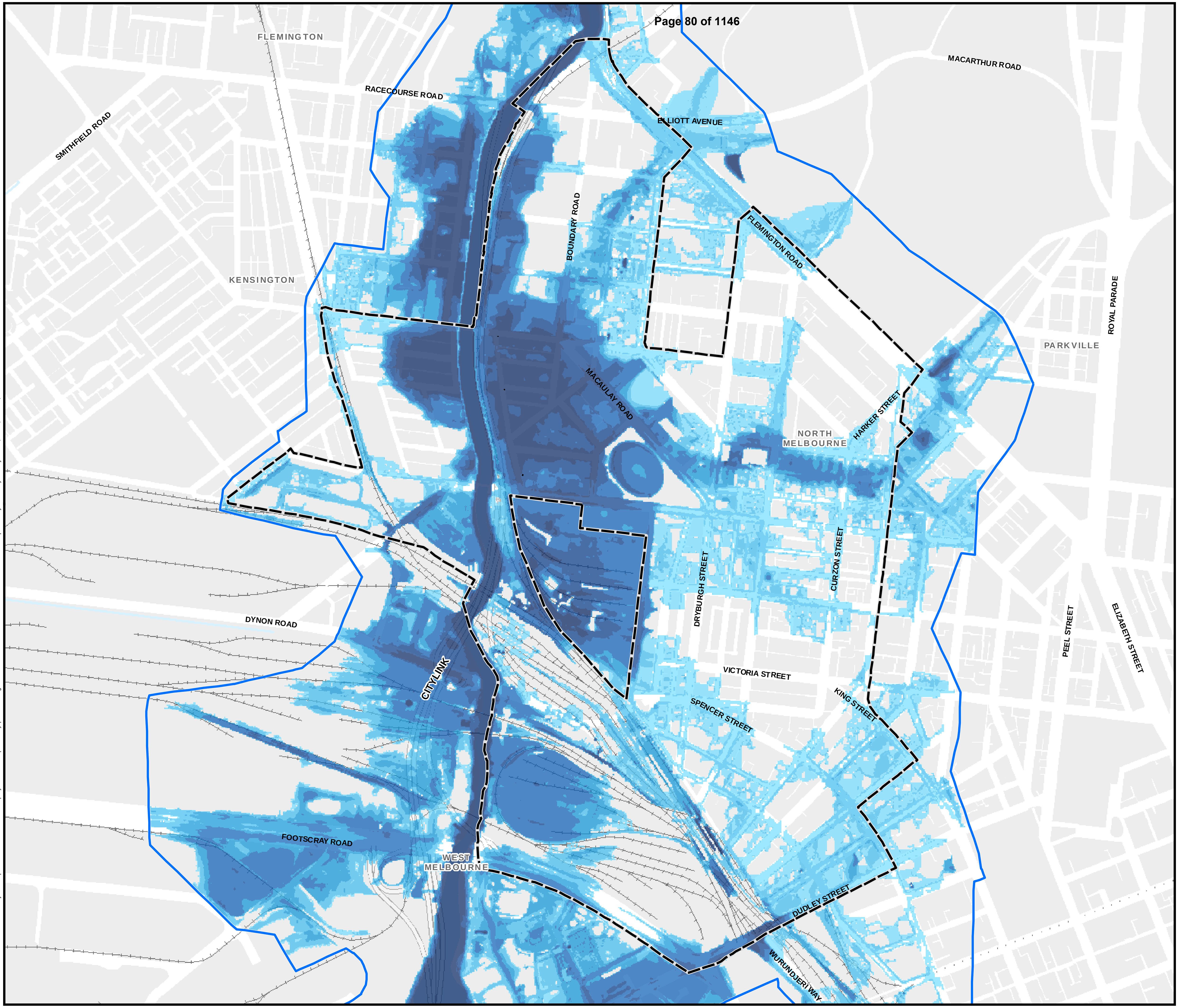
N
DATUM GDA 1994, PROJECTION MGA ZONE 55
0 100 200 400
metres
1:11,000 (when printed at A3)
LEGEND
TUFLOW Model Extent
Study Area
Water Depth (metres)
0 - 0.05
0.06 - 0.25
0.26 - 0.5
0.51 - 1
1.01 - 1.5
> 1.51
Data sources:
Base Data: (c) 2012 DEPI
2040 CONDITIONS 0.5% AEP WATER DEPTHS
Department of Transport, Planning and Local Infrastructure
Hydrologic and Hydraulic Modelling of Arden and E-Gate
Figure
F12
Map Document: (P:\60304612\4. Tech work area\4.99 GIS\02_Maps\M006_Depths_20130906.mxd - D_2040_Q200)
A3 size



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LAST MODIFIED TCH 06 SEP 2013

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N

DATUM GDA 1994, PROJECTION MGA ZONE 55
0 100 200 400
metres
1:11,000 (when printed at A3)

LEGEND

- TUFLOW Model Extent
- Study Area

Water Depth (metres)

- 0 - 0.05
- 0.06 - 0.25
- 0.26 - 0.5
- 0.51 - 1
- 1.01 - 1.5
- > 1.51

Data sources:
Base Data: (c) 2012 DEPI

2040 CONDITIONS 0.2% AEP WATER DEPTHS

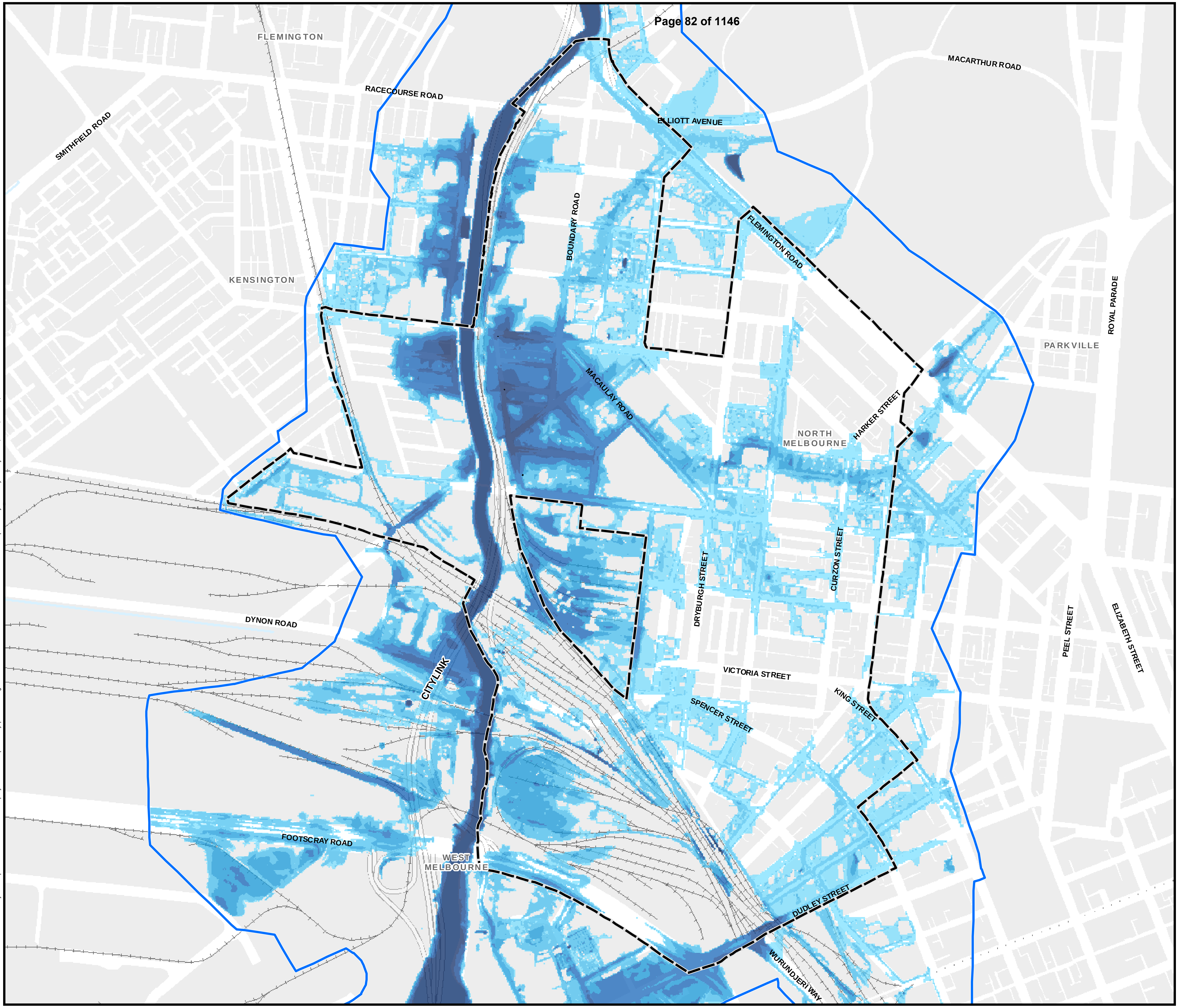
Department of Transport, Planning and Local Infrastructure

Hydrologic and Hydraulic Modelling of Arden and E-Gate

Figure
F13

Appendix E

Water Depths for 10%, 1%, 0.5% and 0.2% AEP Events in 2070 Climate Change Conditions



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LAST MODIFIED TCH 06 SEP 2013

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N

DATUM GDA 1994, PROJECTION MGA ZONE 55
0 100 200 400
metres
1:11,000 (when printed at A3)

LEGEND

TUFLOW Model Extent
Study Area
Water Depth (metres)
- 0 - 0.05
- 0.06 - 0.25
- 0.26 - 0.5
- 0.51 - 1
- 1.01 - 1.5
- > 1.51

Data sources:
Base Data: (c) 2012 DEPI

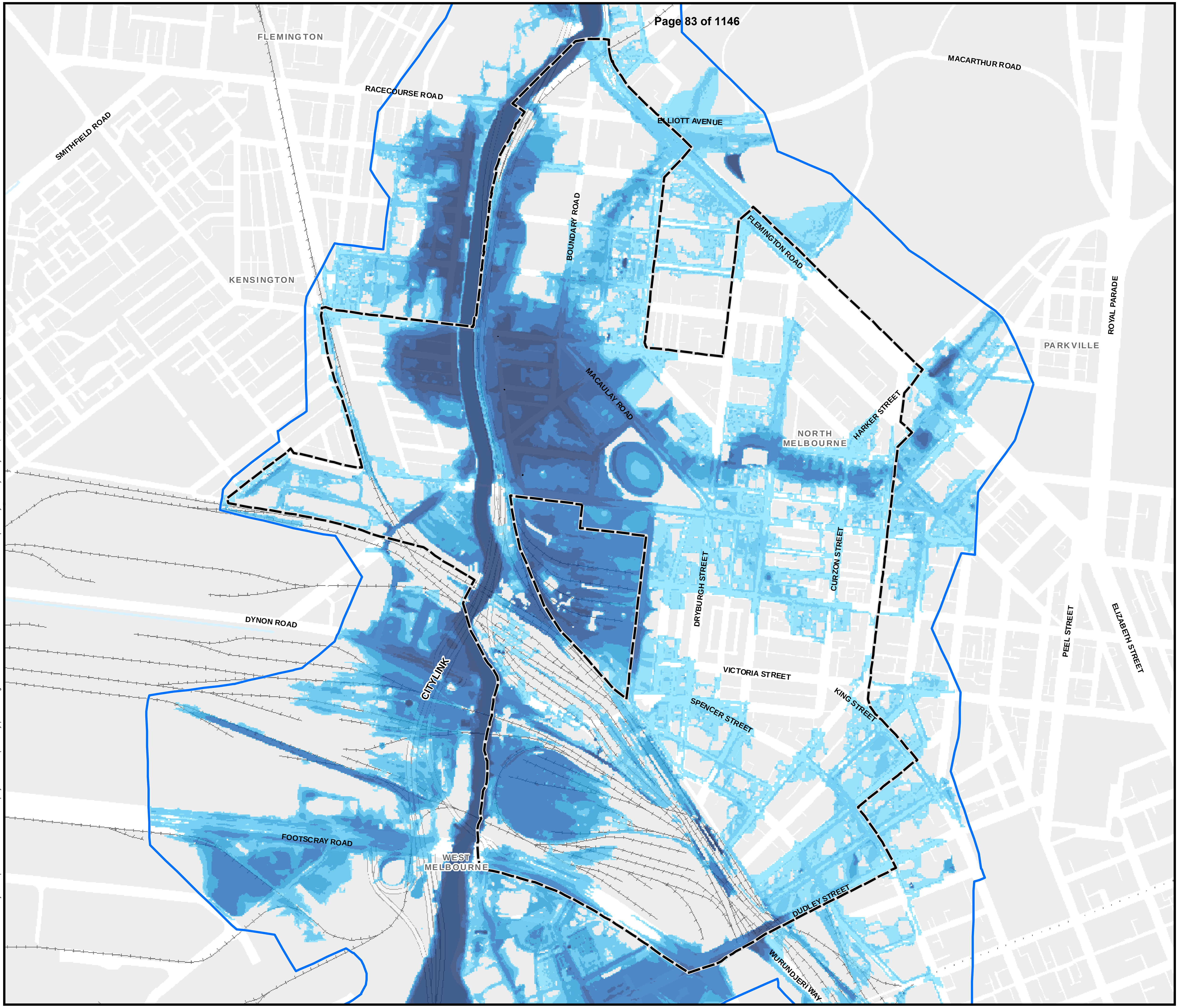
2070 CONDITIONS 10% AEP WATER DEPTHS

Department of Transport, Planning and Local Infrastructure

Hydrologic and Hydraulic Modelling of Arden and E-Gate

Figure

F14



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LAST MODIFIED TCH 06 SEP 2013

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N

DATUM GDA 1994, PROJECTION MGA ZONE 55
0 100 200 400
metres
1:11,000 (when printed at A3)

LEGEND

- TUFLOW Model Extent
- Study Area

Water Depth (metres)

- 0 - 0.05
- 0.06 - 0.25
- 0.26 - 0.5
- 0.51 - 1
- 1.01 - 1.5
- > 1.51

Data sources:
Base Data: (c) 2012 DEPI

2070 CONDITIONS 1% AEP WATER DEPTHS

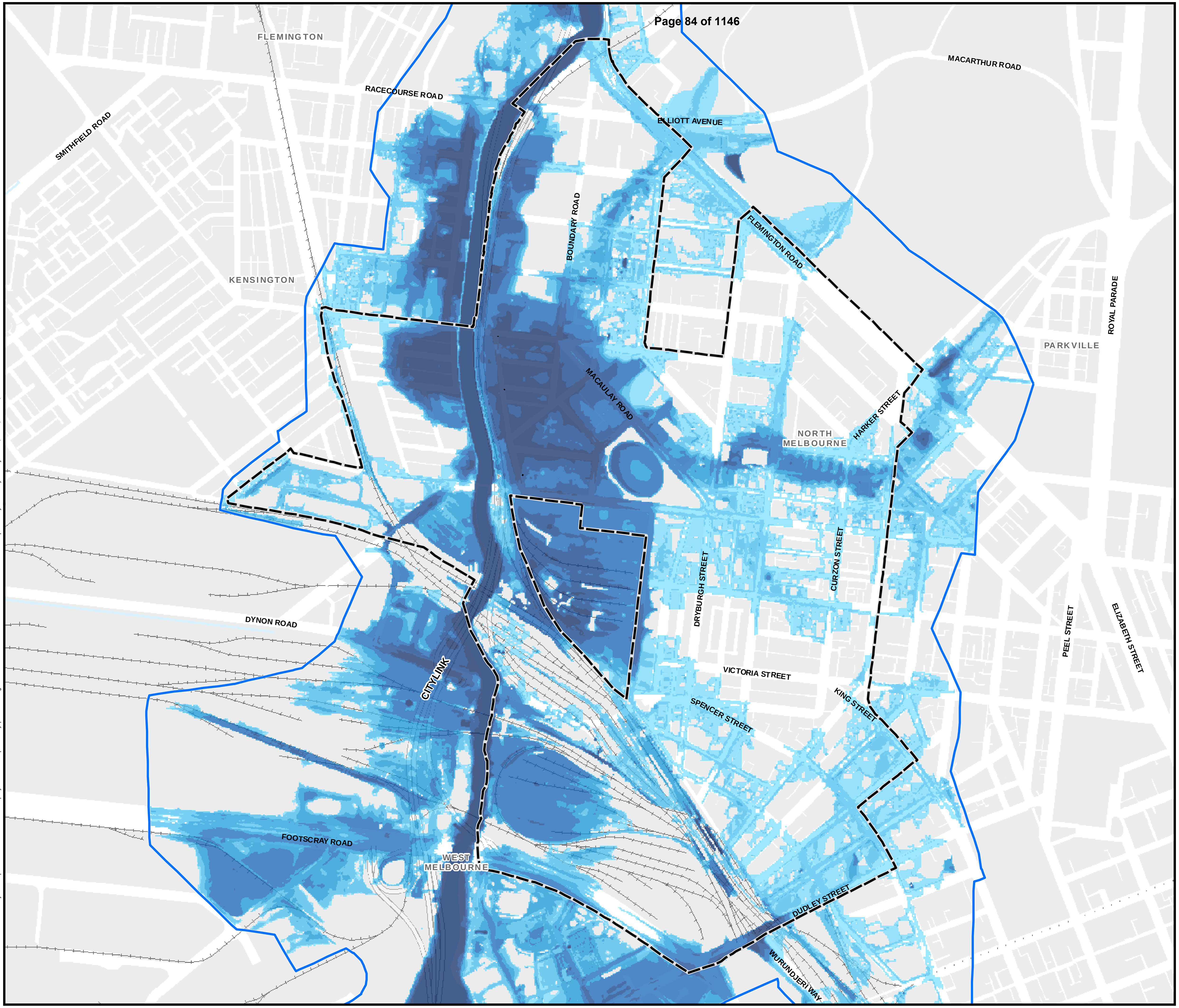
Department of Transport, Planning and Local Infrastructure

Hydrologic and Hydraulic Modelling of Arden and E-Gate

Figure
F15

Map Document: (P:\60304612\4. Tech work area\4.99 GIS\02_Maps\M006_Depths_20130906.mxd - D_2070_Q100)

A3 size



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LAST MODIFIED TCH 06 SEP 2013

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N

DATUM GDA 1994, PROJECTION MGA ZONE 55
0 100 200 400
metres
1:11,000 (when printed at A3)

LEGEND

- TUFLOW Model Extent
- Study Area

Water Depth (metres)

- 0 - 0.05
- 0.06 - 0.25
- 0.26 - 0.5
- 0.51 - 1
- 1.01 - 1.5
- > 1.51

Data sources:
Base Data: (c) 2012 DEPI

2070 CONDITIONS 0.5% AEP WATER DEPTHS

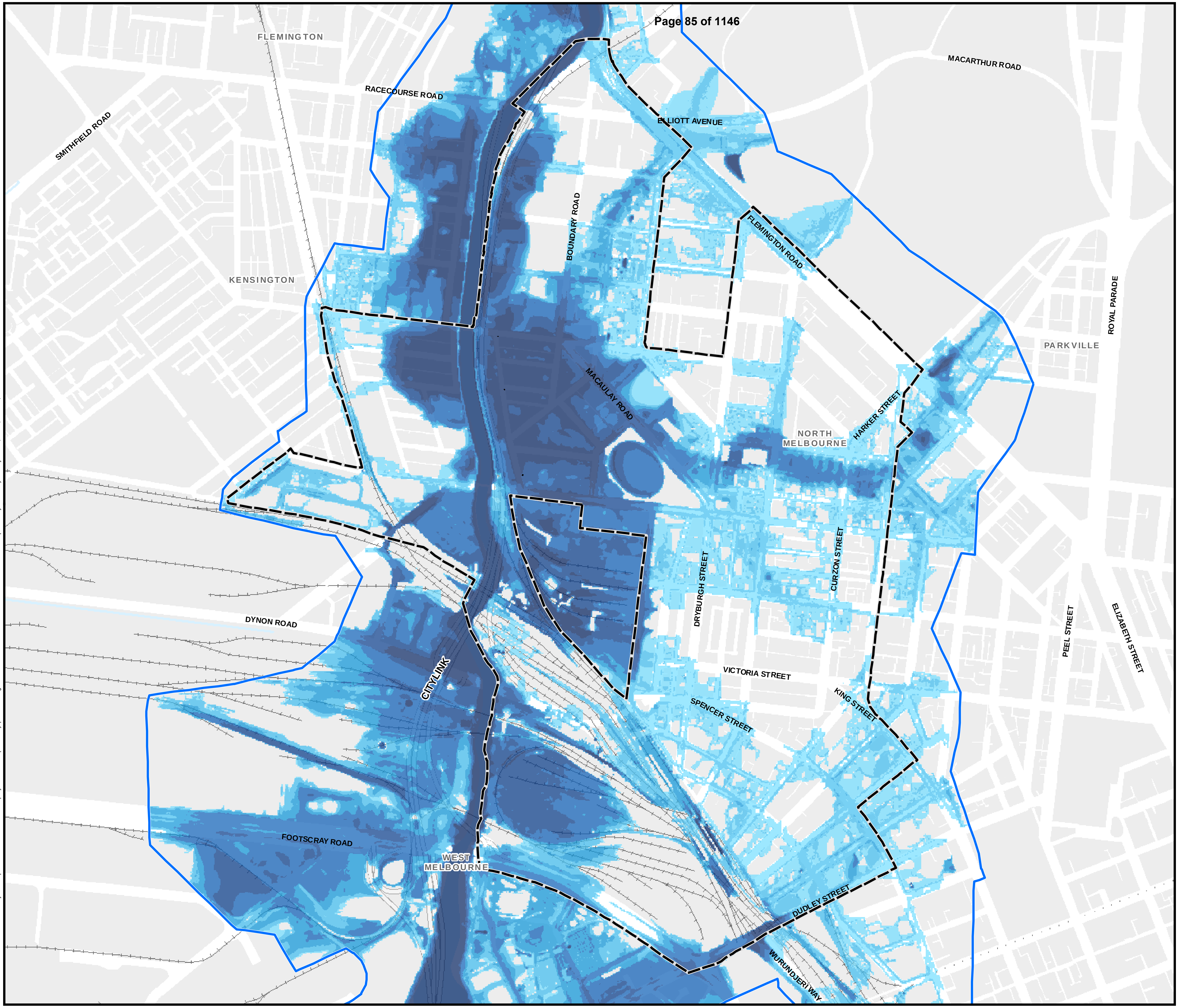
Department of Transport, Planning and Local Infrastructure

Hydrologic and Hydraulic Modelling of Arden and E-Gate

Figure
F16

Map Document: (P:\60304612\4. Tech work area\4.99 GIS\02_Maps\M006_Depths_20130906.mxd - D_2070_Q200)

A3 size



PROJECT ID 60304612
CREATED BY TCH
LAST MODIFIED TCH 06 SEP 2013

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N

DATUM GDA 1994, PROJECTION MGA ZONE 55
0 100 200 400
metres
1:11,000 (when printed at A3)

LEGEND

- TUFLOW Model Extent
- Study Area

Water Depth (metres)

- 0 - 0.05
- 0.06 - 0.25
- 0.26 - 0.5
- 0.51 - 1
- 1.01 - 1.5
- > 1.51

Data sources:
Base Data: (c) 2012 DEPI

2070 CONDITIONS 0.2% AEP WATER DEPTHS

Department of Transport, Planning and Local Infrastructure

Hydrologic and Hydraulic Modelling of Arden and E-Gate

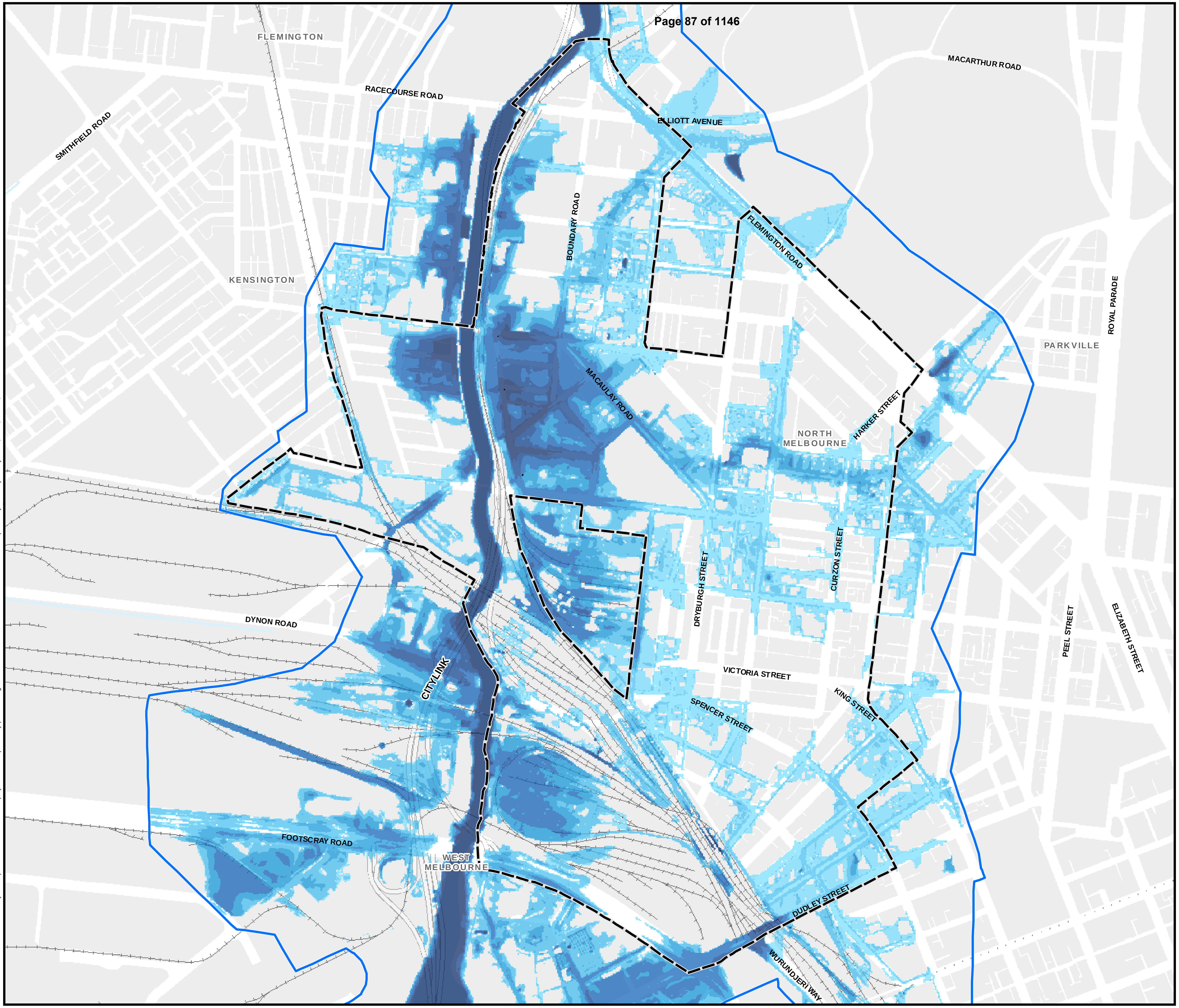
Figure

F17

D R A F T

Appendix F

Water Depths for 10%, 1%, 0.5% and 0.2% AEP Events in 2100 Climate Change Conditions



PROJECT ID 60304612
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Data sources:
Base Data: (c) 2012 DEPI

2100 CONDITIONS 10% AEP WATER DEPTHS

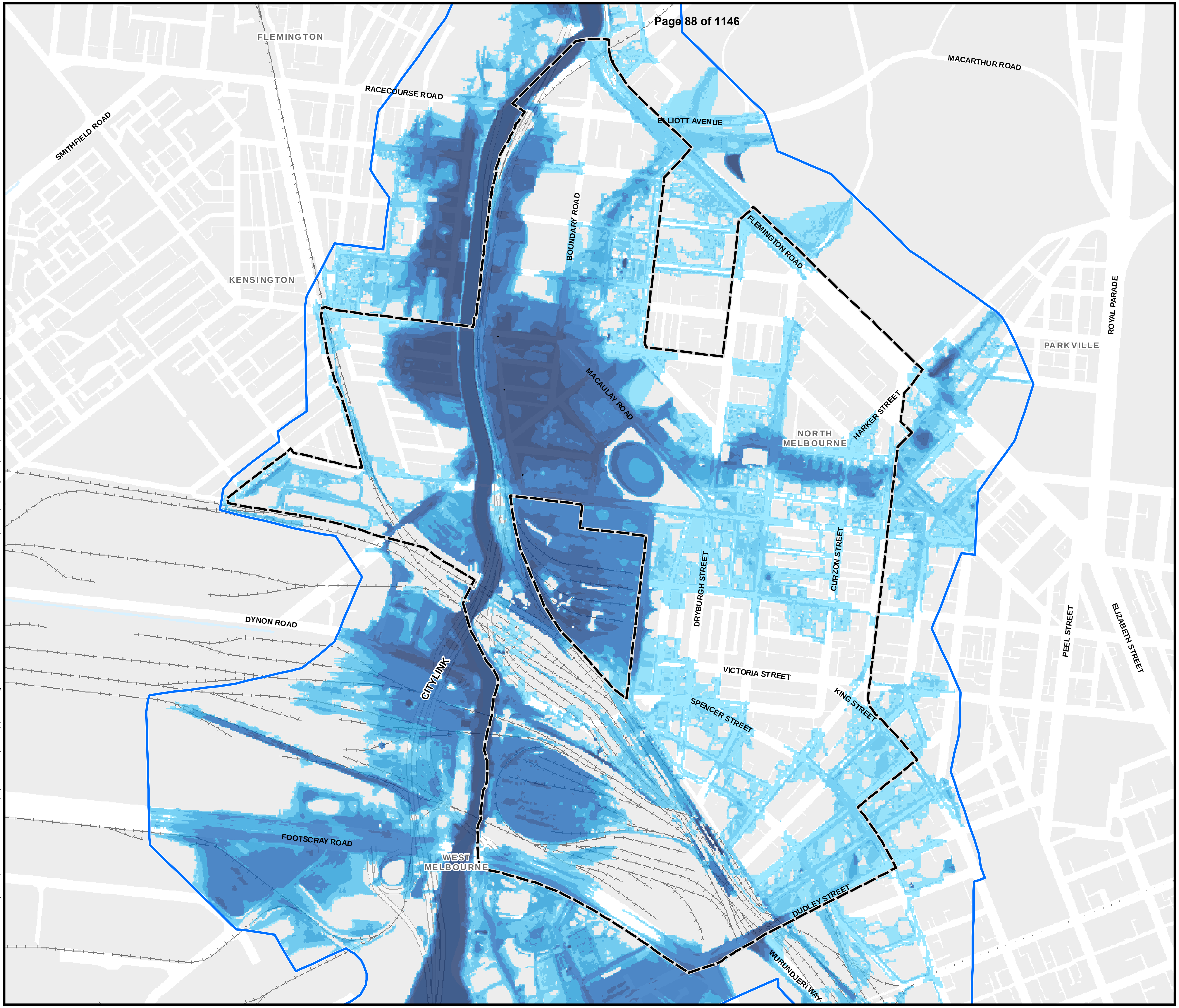
Department of Transport, Planning and Local Infrastructure

Hydrologic and Hydraulic Modelling of Arden and E-Gate

Figure F18

Map Document: (P:\60304612\4. Tech work area\4.99 GIS\02_Maps\M006_Depths_20130906.mxd - D_2100_Q010)

A3 size



PROJECT ID 60304612
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LAST MODIFIED TCH 06 SEP 2013

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N

DATUM GDA 1994, PROJECTION MGA ZONE 55
0 100 200 400
metres
1:11,000 (when printed at A3)

LEGEND

- TUFLOW Model Extent
- Study Area

Water Depth (metres)

- 0 - 0.05
- 0.06 - 0.25
- 0.26 - 0.5
- 0.51 - 1
- 1.01 - 1.5
- > 1.51

Data sources:
Base Data: (c) 2012 DEPI

2100 CONDITIONS 1% AEP WATER DEPTHS

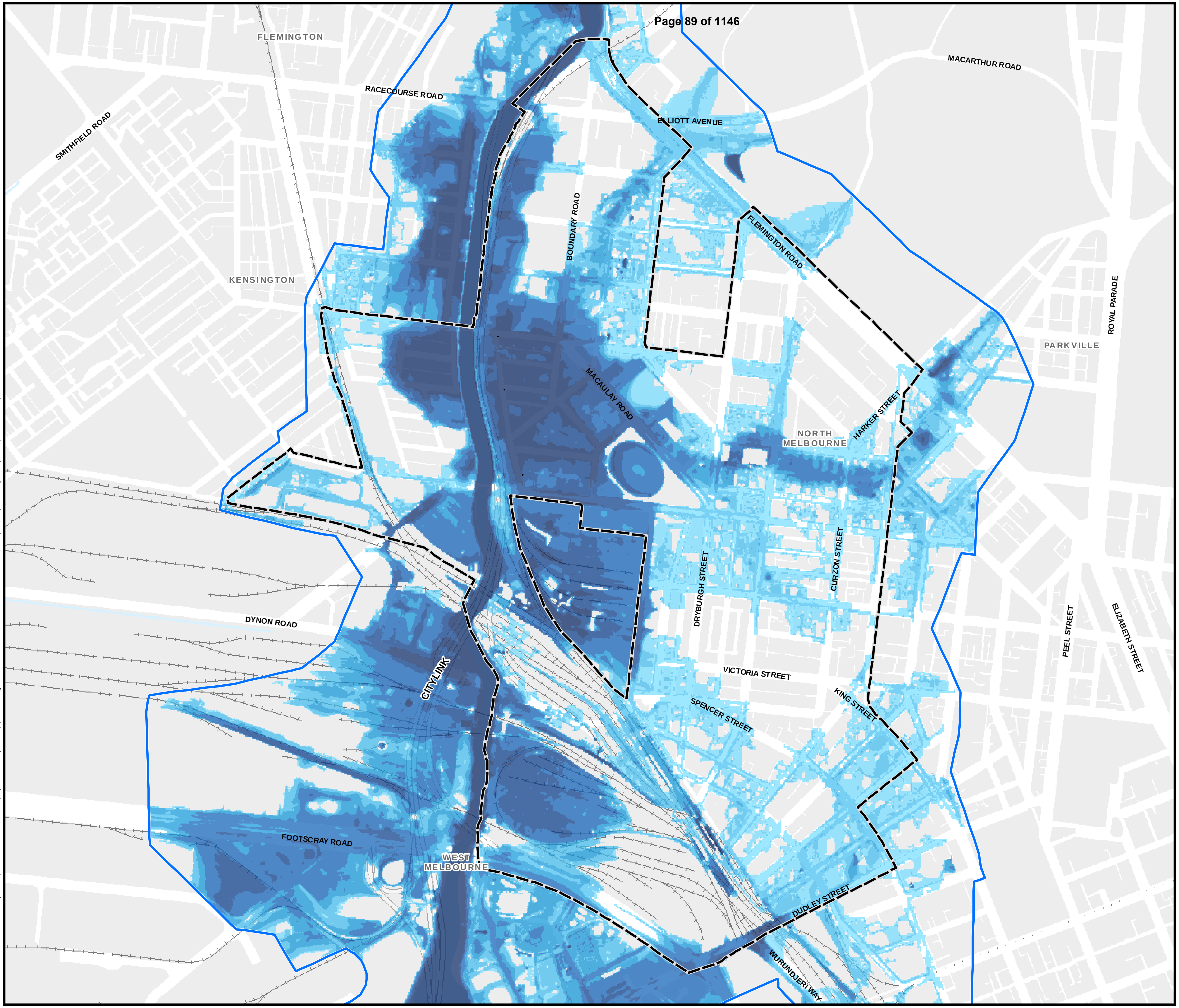
Department of Transport, Planning and Local Infrastructure

Hydrologic and Hydraulic Modelling of Arden and E-Gate

Figure
F19

Map Document: (P:\60304612\4. Tech work area\4.99 GIS\02_Maps\M006_Depths_20130906.mxd - D_2100_Q100)

A3 size



PROJECT ID 60304612
CREATED BY TCH
LAST MODIFIED TCH 06 SEP 2013

AECOM
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N

DATUM GDA 1994, PROJECTION MGA ZONE 55
0 100 200 400
metres
1:11,000 (when printed at A3)

LEGEND

- TUFLOW Model Extent
- Study Area

Water Depth (metres)

- 0 - 0.05
- 0.06 - 0.25
- 0.26 - 0.5
- 0.51 - 1
- 1.01 - 1.5
- > 1.51

Data sources:
Base Data: (c) 2012 DEPI

2100 CONDITIONS 0.5% AEP WATER DEPTHS

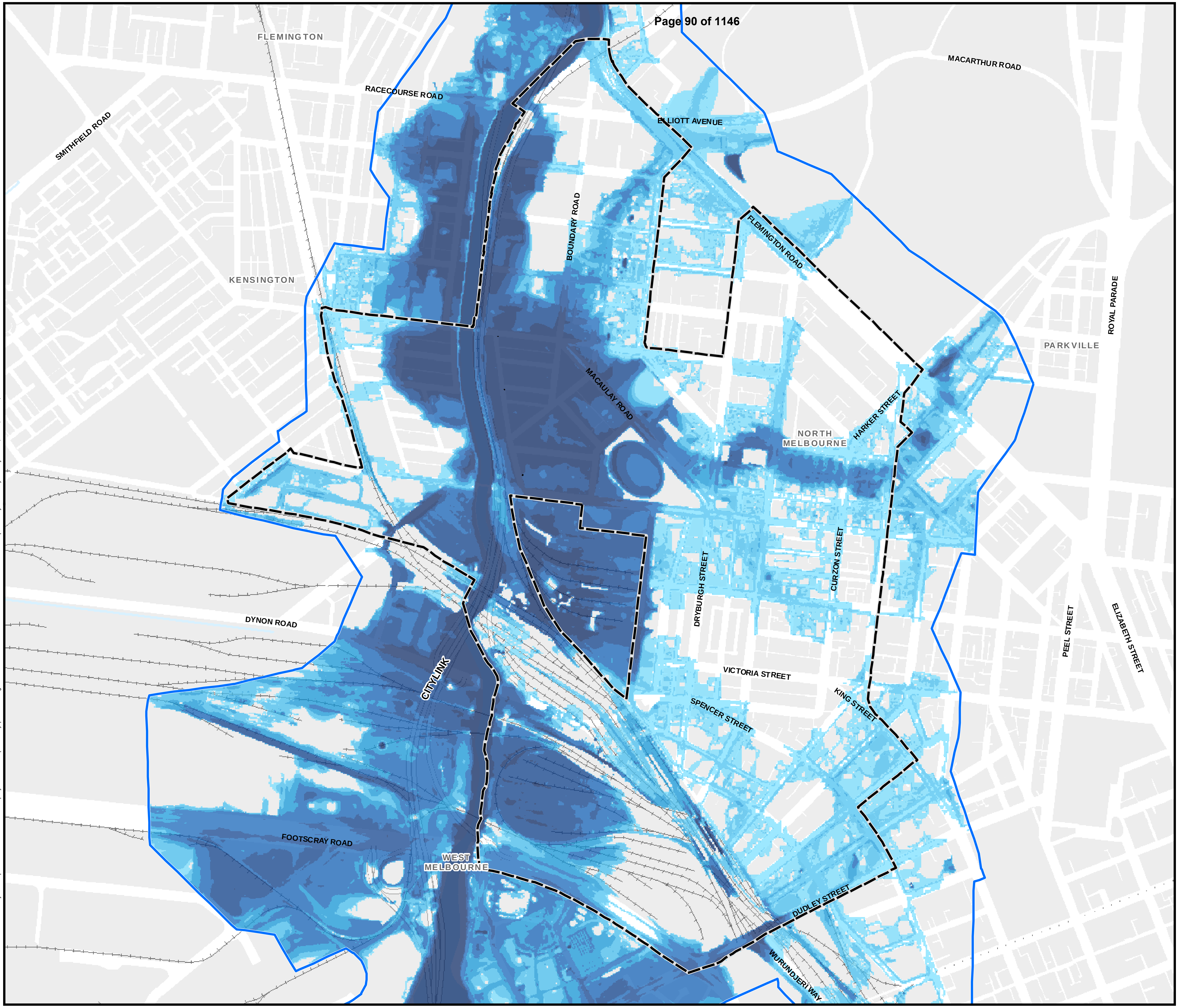
Department of Transport, Planning and Local Infrastructure

Hydrologic and Hydraulic Modelling of Arden and E-Gate

Figure
F20

Map Document: (P:\60304612\4. Tech work area\4.99 GIS\02_Maps\M006_Depths_20130906.mxd - D_2100_Q200)

A3 size



PROJECT ID 60304612
CREATED BY TCH
LAST MODIFIED TCH 06 SEP 2013

AECOM
www.aecom.com

N

DATUM GDA 1994, PROJECTION MGA ZONE 55

0 100 200 400
metres
1:11,000 (when printed at A3)

LEGEND

- TUFLOW Model Extent
- Study Area

Water Depth (metres)

- 0 - 0.05
- 0.06 - 0.25
- 0.26 - 0.5
- 0.51 - 1
- 1.01 - 1.5
- > 1.51

Data sources:
Base Data: (c) 2012 DEPI

2100 CONDITIONS 0.2% AEP WATER DEPTHS

Department of Transport, Planning and Local Infrastructure

Hydrologic and Hydraulic Modelling of Arden and E-Gate

Figure
F21

Melbourne Water Corporation

Lower Yarra River Flood Mapping

September 2020

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Appendices

1. Introduction

1.1 Introduction

Melbourne Water (MW) is the regional drainage and floodplain management authority for the Port Phillip and Westernport Region. In addition to planning, this role involves maintaining and upgrading drainage to convey flood flow through a system made up of underground drains, open waterways and channels, and overland flow paths. Melbourne Water is working towards mapping and assessing catchments across its area of responsibility to identify areas of extreme flooding and reduce flood risk through both structural and non-structural mitigation.

1.2 Background and scope

Mapping of the lower reaches of the Yarra River upstream of Spencer Street has previously been completed with the 1D software package HEC-RAS as part of the "Yarra River Flood Mapping Hydrologic and Hydraulic Study (June 2016)" (SP Goh and Associates, 2016) – referred to herein as the *2016 Yarra River Study*. This was a large scale study that looked at the hydrology and hydraulics of entire Yarra River catchment between Upper Yarra Reservoir and Spencer Street. The 2016 Yarra River Study utilised RORB and HEC-RAS to estimate flood flows and levels for the area.

Given the relatively recent hydrological modelling of the Yarra River catchment and the Maribyrnong River (2016 and circa 2014 respectively), at Melbourne Water's request the current study has excluded updating the hydrology for the catchment (i.e. it was stipulated that inflows be adopted from exiting studies) – as a result the hydrology is based on Australian Rainfall and Runoff 1987 (ARR1987) approaches and data. The scope of the current Study was therefore to establish a detailed 2D hydraulic model using TUFLOW to provide flood levels and characteristics along the Yarra River and associated floodplain from MacRobertson Bridge downstream to near the West Gate Bridge.

The established hydraulic model was then used to run the modelling scenarios in Table 1 for the 48 hour and 72 hour duration storms events as specified by Melbourne Water. These scenarios differ from the standard scenarios defined in Melbourne Water's Guidelines and Technical Specifications for Flood Mapping Projects November 2016 (MWC 2016).

Table 1 Final scenarios modelled and mapped

Scenario	Impervious Fractions	Rainfall Intensities	Sea Level Rise	AEP				
				20%	10%	5%	2%	1%
Base Case	Existing	ARR1987	No	✓	✓	✓	✓	✓
Climate Change 1 (CC_B)	Existing	ARR1987	Yes	✓	×	×	×	×
Climate Change 2 (CC_C)	Existing	ARR1987 increased by 18.5%	Yes	✓	✓	✓	×	✓
Climate Change 3 (CC_D)	Existing	ARR1987 increased by 18.5%	No	✓	✓	✓	×	✓

1.3 Purpose of this report

The purpose of this report is to document the methodology, underlying assumptions used, and results of the modelling and flood mapping of the Lower Yarra River. The outputs of the project are intended to update Melbourne Water's flood mapping information, assisting with planning approvals and flood risk assessment and prioritisation.

1.4 Limitations

This report: has been prepared by GHD for Melbourne Water Corporation and *may only be used and relied on by Melbourne Water Corporation for the purpose agreed between GHD and the Melbourne Water Corporation as set out in Section 1.3 of this report.*

GHD otherwise disclaims responsibility to any person other than Melbourne Water Corporation arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope and limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this Report. GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this report on the basis of information provided by Melbourne Water Corporation and others who provided information to GHD (including Government authorities)], which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

1.5 Available information and limitations

The following information was utilised in undertaking this flood mapping study:

- General cadastral and planning information (e.g. properties boundaries, easements, roads, planning scheme zones and overlays).
- RORB model developed in previous Yarra River Flood Mapping Project (2016)
- RORB model developed in previous study for the Maribyrnong River (circa 2014)
- Aerial ortho-photos (circa 2017)
- General information obtained from Melbourne Water throughout the course of the project:
  – Survey drawings for a majority of the bridges along the Lower Yarra River.
  – Dredged profile information for past dredging schemes, including assumptions to be made where information was not available.
  – First return and processed LiDAR (circa 2008).
  – Tidal data for both existing and climate change scenarios, including related assumptions.
  – Model files from other local or upstream TUFLOW models, namely Southbank, Fisherman's bend and North East Link Project (NELP) "existing conditions" Yarra River model.

2. Catchment and drainage description

2.1 Catchment description

The Yarra River is the longest river under MW's control and this study looks at flooding along the final 15 km of the river before it discharges to Port Philip Bay. The approximate Lower Yarra River Study Area is shown in Figure 1 and covers an area of around 50 km² across six (6) municipalities – the cities of Yarra, Stonington, Melbourne, Port Phillip, Maribyrnong and Hobsons Bay. The contributing hydrologic area extends well beyond even the hydraulic model area shown, with a total contributing catchment area in excess of 4000 km².

Within the Study Area, there is a mix of land use including residential, commercial, industrial, open space and waterways/drainage easements, although the majority of the upper catchment is rural. Key public features of the Study Area include:

- Melbourne's Central Business District (CBD).
- South Bank
- Docklands development
- Sports precinct around Melbourne Cricket Ground (MCG), AAMI Park and Melbourne Park.
- Royal Botanic Gardens.
- Alexandra Gardens.
- Birrarung Marr

2.2 Melbourne Water drainage systems

The focus of this Study was "riverine flooding" along the Yarra River within the Study Area, so there are only three major MW assets that are included in the model, the Yarra River, Moonee Ponds Creek and the Maribyrnong River – these are briefly described in subsequent sections. The underground assets within the Study Area were not represented in the hydraulic model at the request of Melbourne Water. These assets typically respond to smaller local events and would be assessed as part of more localised investigations to inform the Planning Scheme Layers in these areas. Other MW assets exist within the hydraulic model boundary outside the Study Area, but given they are outside the area being mapped they are not documented here.

2.2.1 Yarra River

The Yarra River (MW Asset No. 4400) is a 'natural waterway' asset that passes through the centre of the Study Area. The asset is approximately 15 km long within the Study Area with the following general characteristics:

- Width of 40 m to 350 m
- Depth of 6.5 m to 12.5 m upstream of Spencer Street and up to 19 m downstream of Spencer Street.
- 17 major structures crossing the waterway.

The terrain of this model has been represented using a combination of surveyed cross-sections and bathymetry.

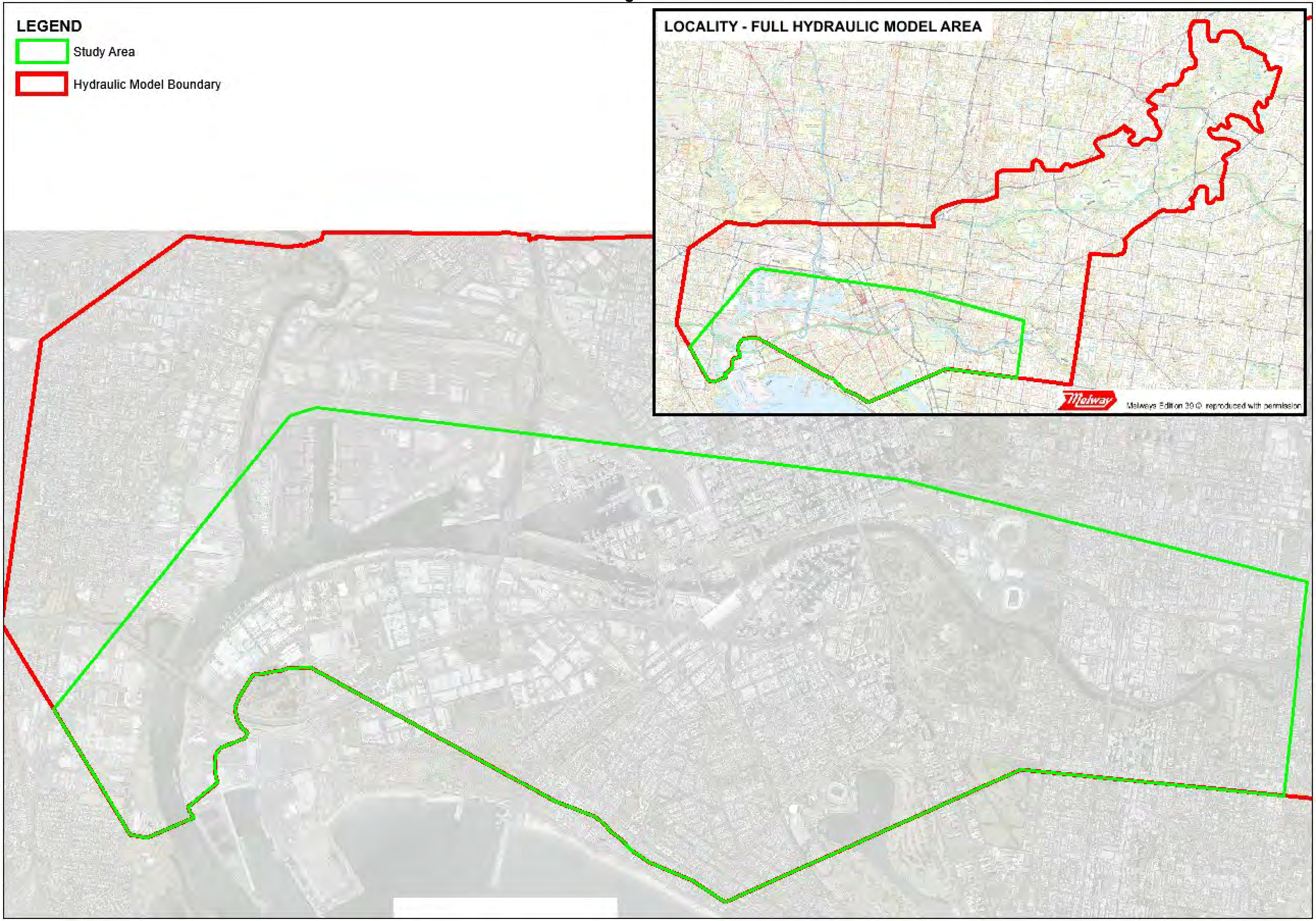

Figure 1 Study Area Location

2.2.2 Moonee Ponds Creek

Moonee Ponds Creek (MW Asset No. 4310) is a 'drainage channel' asset that joins the Yarra River immediately downstream of the Bolte Bridge. This asset has been included in the model from just downstream of Macaulay Road to the confluence with the Yarra River for the purpose of improving flow distribution and allowing the model to access storage within this waterway. In general, the terrain (bathymetry) is simply represented with a 'gully' line and shaping to better define the waterway.

2.2.3 Maribyrnong River

Maribyrnong River (MW Asset No. 4220) is a 'natural waterway' asset that joins the Yarra River approximately 1 km upstream of where the West Gate Bridge crosses. This asset has been included in the model from just downstream of Fisher Parade Road Bridge to the confluence with the Yarra River for the purpose of improving flow distribution and allowing the model to access storage within this waterway. In general, the terrain (bathymetry) is simply represented with a 'gully' line and shaping within the waterway area.

2.3 Known flood issues

No complete flood mapping of the Study Area has previously been completed, but modelling of the Yarra River upstream of Spencer Street (or Clarendon Street) bridge was completed as part of the 2016 Yarra River Study (SP Goh and Associates, 2016). This modelling utilised flows from RORB and the 1D hydraulic modelling package HEC-RAS to estimate flood levels. These results do not appear to have been used to update planning layers or designated levels.

Figure 2 shows the 100 year ARI extent and affected properties derived from previous flood mapping within parts of the Study Area. These results indicate 1247 properties are subject to flooding during a 100 year ARI event from 'waterways' within the Study Area.

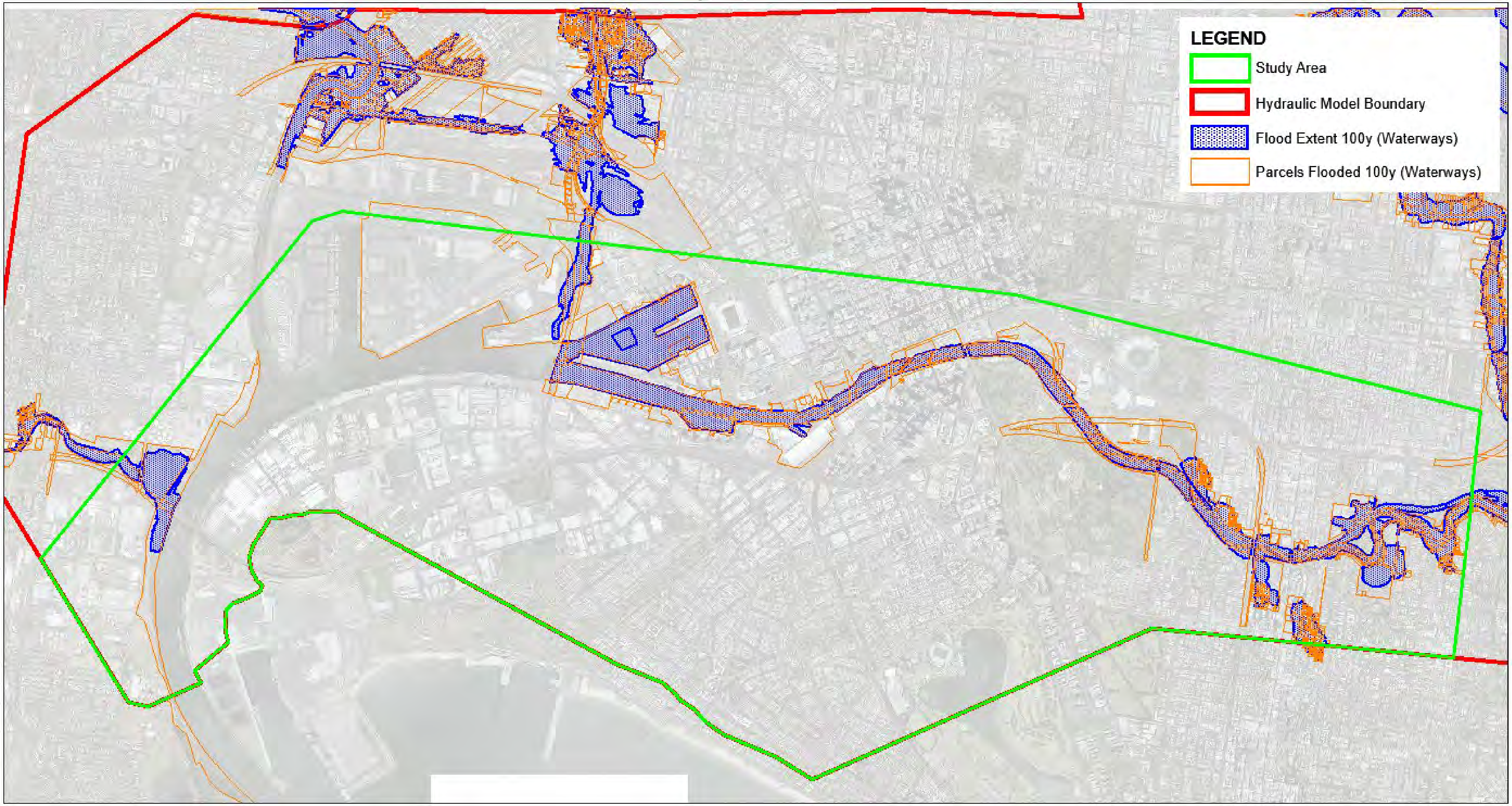

Figure 2 Previous 100 year ARI Flood Extents

3. Modelling approach

3.1 Overview

The general modelling approach utilised in this study is summarised in Figure 3, which includes the following general stages:

1. Preliminary Model – development of model used to determine appropriate grid size, assess representation of channel in 2D and understand run time.
2. Developed Model – initial scenario modelling of existing conditions and subsequent comparison of water level results to MW's designated levels (based on 1934 flood).
3. Quasi-Verification Model - revised scenario modelling based on incorporating terrain changes to quasi represent the channel profile for 1934 flood.
4. Initial Design Run Model – model used to prepare initial design run outputs that were subsequently discounted by MW over concerns in overbank flows around Southbank.
5. Southbank Refinement Model – additional detail added to model in Southbank overflow area to increase confidence in flood levels in area outside of the Yarra River, which was the focus of different local investigations for Southbank and Fisherman's Bend. This process primarily involved incorporating details from local hydraulic models (namely Southbank and Fisherman's Bend) and adding additional terrain detail across this overflow area. Model verification was also revisited.
6. Extended Yarra River Model – refined model above was extended to combine with the "existing" conditions North East Link Project of the Yarra River to increase confidence in the levels within the Study Area by reducing importance of upstream storage assumptions and allowing "verification" to historic levels along a larger length of the Yarra River in less tidally influenced sections of the Yarra River.
7. Revised Design Run Model – model used to compare impact of TUFLOW engine (Classic and HPC) and 'Sub-grid sampling' (SGS) functionality on the consistency of design event results with recorded historic levels.
8. Final Design Run Model – scenario runs used to generate deliverables.

Stage 1 to Stage 7 of this figure are discussed in more detail in Appendix A, whilst the setup for the model in Stage 8 is discussed and documented in this report.

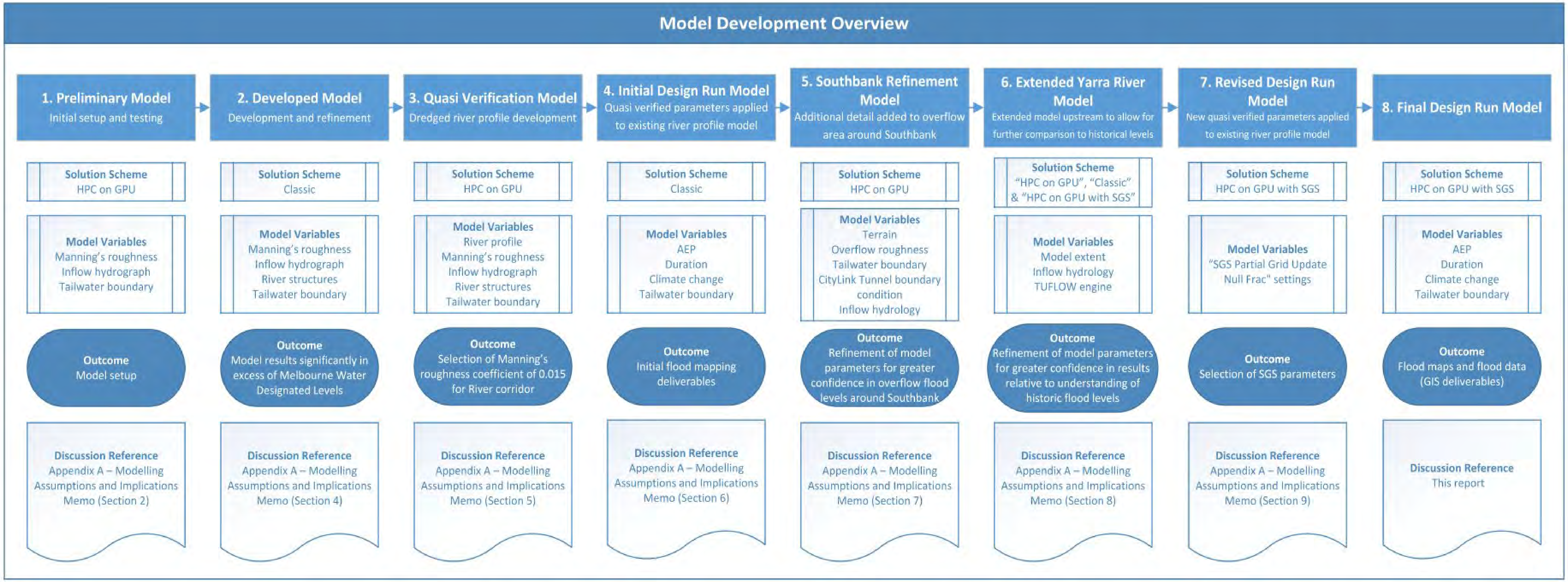

Figure 3 Overview of model development

3.2 Hydrology

The hydraulic model used for this Study required the following inflows along the three major waterways within the Study Area:

- Yarra River – a range of upstream inflows from tributaries or groups of subareas draining to Yarra River and individual subarea inflows along Yarra River corridor.
- Moonee Ponds Creek – one upstream inflow representing all flows entering the Yarra River from Moonee Ponds Creek.
- Maribyrnong River – one upstream inflow representing all flows entering the Yarra River from the Maribyrnong River.

All inflows from the first two waterways were adopted from the Yarra River RORB model established as part of the 2016 Yarra River Study (SP Goh and Associates, 2016) and the latter was adopted from a RORB model provided by Melbourne Water for the Maribyrnong River (dated circa 2014).

Due to the required scenarios and the location of required inflows, the two supplied RORB models were re-run with the agreed modelling parameters described in Table 2 to obtain the necessary inflows. Details of how these parameters were determined or selected are provided in Appendix A.

Table 2 RORB model inputs

Model	Yarra River	Maribyrnong River
RORB Version	6.45	6.45
Rainfall	Stormfiles with variable IFD (adjusted version of those adopted from 2016 Yarra River Study area due to application of ARFs)	ARR1987 IFD @ inbuilt “Keilor” location
ARF	Yarra catchment area (Assumed area = 3,870 km²)	Yarra catchment area (Assumed area = 3,870 km²)
Kc	180 (MW assumed value prior to 2016 Yarra River Study)	70
m	0.8	0.8
IL (mm)	Varies with interstation area: • YarRv@YarGlen-DummyGS = 30 • Catchment outlet = 15	20
Runoff Coefficient	Varies with ARI: • 100y = 0.60 • 50y = 0.55 • 20y = 0.50 • 10y = 0.45 • 5y = 0.40	Varies with ARI: • 100y = 0.6 • 50y = 0.55 • 20y = 0.45 • 10y = 0.35 • 5y = 0.25
Climate Change Scenario	Factored rainfall in stormfiles by 1.185 to represent 18.5% increase as per latest Tech Spec	Adjusted IFD parameters to increase rainfall intensity by 18.5%

3.3 Hydraulic modelling

3.3.1 Introduction

Hydraulic modelling for this Study Area was undertaken using TUFLOW, which is a hydrodynamic model used for simulating one-dimensional (1D) and two-dimensional (2D) flows (*BMTWBM 2016)*. The model is based on the solution to the free-surface shallow water flow equations. The TUFLOW model for this Study consists of a 2D domain (TUFLOW) representing the catchment terrain and roughness together with a set of boundary conditions comprising the calculated RORB hydrograph inflows and the downstream water levels.

The modelling process and assumptions are outlined below:

- The general approach taken to setup the hydraulic model is shown in Figure 4 – with details of the steps shown summarised in the proceeding sections.
- The steps shown in this figure are described in detail in the following sections
- The hydraulic model area is shown in Figure 5.
- A summary of the adopted TUFLOW model parameters is provided in Table 3

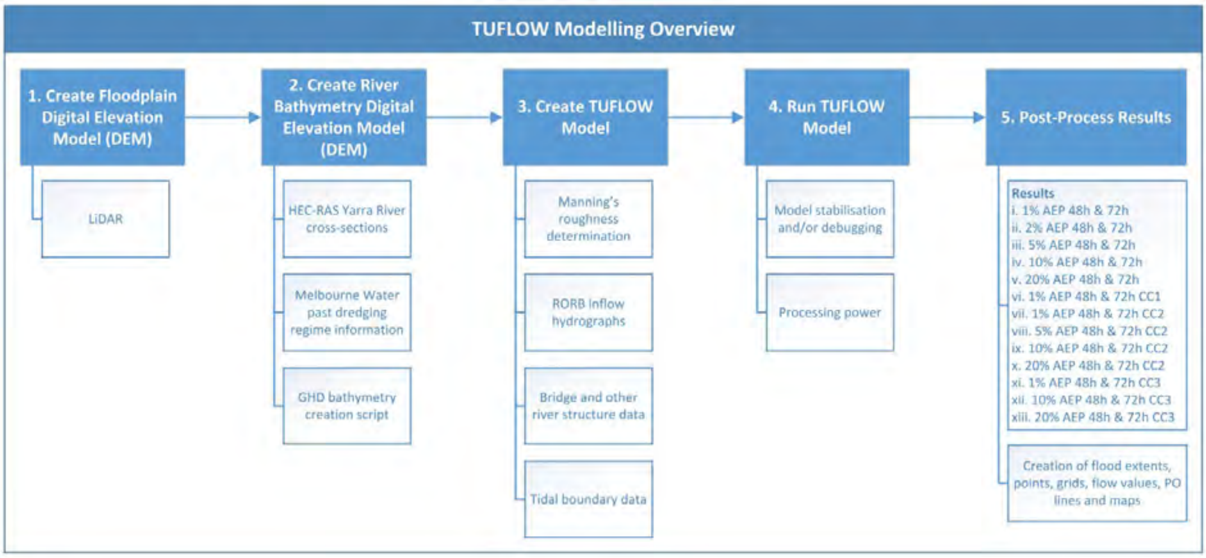

Figure 4 Overview of TUFLOW model setup process

Table 3 TUFLOW model inputs

Variable	Adopted Value/Source	Comment/Source
Model Purpose	Flood mapping outputs and deliverables	-
TUFLOW Version	2020-AB-ISP-w64	Latest available at time of final model runs (July 2020)
TUFLOW Engine	HPC on GPU with 'Sub-grid Sampling' (SGS) enabled	Modified default setting for SGS treatment of partially covered cells to be as follows – "SGS Partial Grid Update Null Frac == 0.6, 0.6" (see discussion in Appendix A).
Cell size (m)	10	Also has SGS enabled with a DEM sampling size of 2 m.
2D Timestep (sec)	2	Adaptive time stepping with maximum of the specified value in *.tcf
1D Timestep (sec)	0.5	Adaptive time stepping with maximum of the specified value in *.tcf
1D Network	Minimal.	Have included some 1d storage at upstream boundaries on Maribyrnong River and Moonee Ponds Creek to represent additional channel storage and to help avoid water sloshing off code boundary. Some minor structures were also adopted from NELP "existing conditions" model of Yarra River.
Inflows	Adopted from MW provided RORB models for the Yarra River catchment and Maribyrnong River catchments	2 upstream inflows on Maribyrnong River and Moonee Ponds Creek and a range of distributed SA inflows along the Yarra River.
Catchment Roughness	See spatial distribution on Figure 6	Default values for land use with manual overrides. Some areas adopted from provided local or upstream models. Manning's roughness along major waterways "quasi-verified".
Tail Water Level (TWL) or downstream (DS) Boundary	HT boundary (tidal curve) at Yarra River and HQ boundary (rating table based on slope) elsewhere.	See locations on Figure 5.

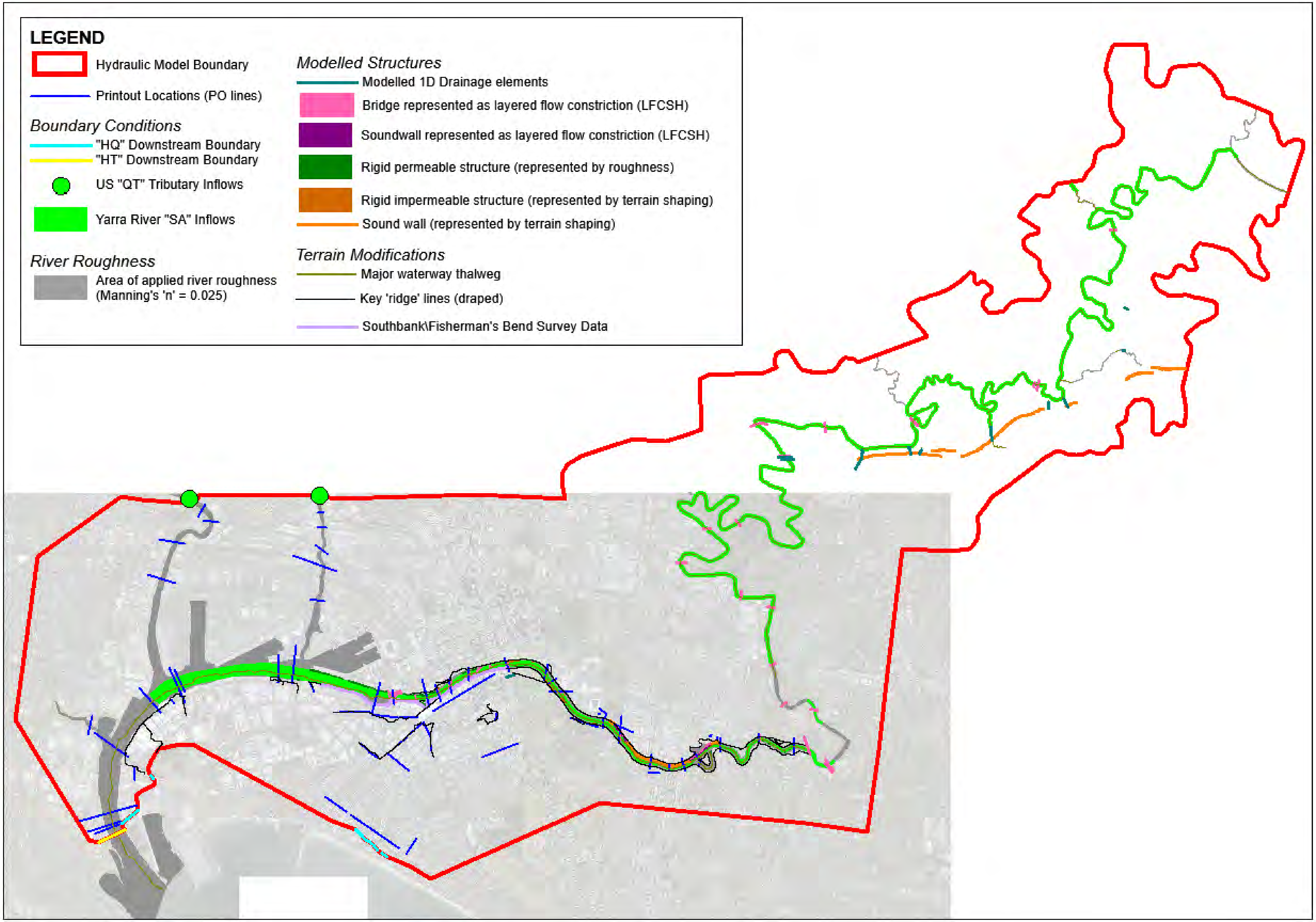

Figure 5 Hydraulic Model General Setup

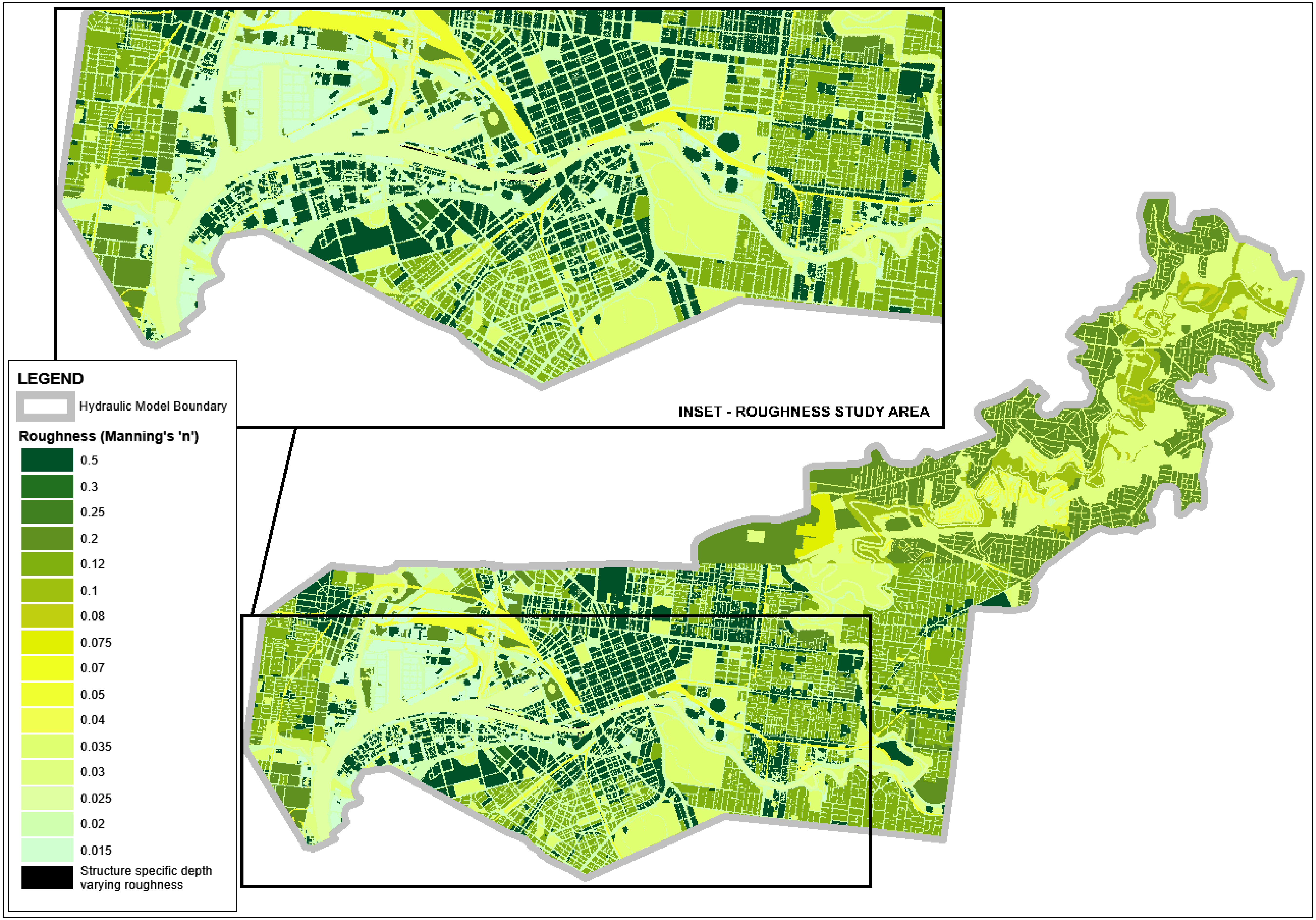

Figure 6 Hydraulic Model Roughness

3.3.2 2D domain

A Digital Terrain Model (DTM) was created to represent the ground features of the catchment both within the channel of the Yarra River (and its major tributaries) and across the floodplain within the Study Area. This DTM was supplemented by other DTMs supplied with the local or upstream models to cover the entire hydraulic model boundary as required. The final DTM created by TUFLOW upon reading in these separated DTMs was used as the basis of the ground surface in the hydraulic model, which when combined with the additional shaping and roughness parameters described in a later section defined the 2D Domain for the Study.

The accuracy of the terrain data was not checked by GHD as this is beyond the scope of this project. The following terrain data was supplied and used in the final DTM together with some breaklines created using engineering judgement to smooth the transition between data sources:

- LiDAR covering the Lower Yarra River project Study Area (circa 2008).
- Two DTMs provided with Southbank hydraulic model that were deemed to be more representative of this area:
  - "DEM_TIN_COASTAL.asc" – understood to be based on LiDAR data.
  - "dem_tin_clipped.asc".
- Three DTMs provided with NELP "existing conditions" model:
  - "clip_dtm10m_e_mga55.asc" – understood to be broader VicMap terrain data covering some of floodplain away from the Yarra River.
  - "dem_1m_mos.asc".
  - "dem_yarra_nela.asc" – understood to be terrain data provided by MW for NELP.
- HEC-RAS cross-section data for the portion of the Yarra River covered by the study area (sourced from the 2016 Yarra River Study) – these were interpolated using an in-house routine that followed the meandering flow path of the Yarra River (required as interpolated cross-sections in HEC-RAS couldn't represent 180 degree bends in river).
- Bathymetry data in the following areas:
  - Surveyed cross-section data for following areas
    - Yarra River upstream of Spencer Street (circa 2005 – adopted from Yarra River HEC-RAS model)
    - Maribyrnong River from upstream of around Footscray Road (circa 2004)
  - Surveyed cross-section and approx. thalweg point data in the following areas (circa 2014)
    - Yarra River roughly between the Bolte Bridge and just downstream of West Gate Bridge.
    - Maribyrnong River from the Yarra River to around Footscray Rd.
  - Detailed bathymetry point data for the following areas
    - Yarra River around Charles Grimes bridge (circa 2004) – extends from just downstream of Spencer Street to around Bolte Bridge
    - Maribyrnong River upstream of around Footscray Road (circa 2004).
  - Thalweg created along Moonee Ponds Creek based on linearly interpolating between inverts at key structures/junctions extracted from an existing HEC-RAS model.
  - Thalweg along Yarra River adopted from the NELP "existing conditions" model.

The final DTM was actually a combination of nine DTMs, six representing the floodplain and three the major waterways within the Study Area. The DTMs needed to be manipulated and/or merged together using terrain modification layers in TUFLOW in the following locations:

- Connection of a branch around Herron Island on the Yarra River
- Transitions between portions of bathymetric DTM created from HEC-RAS and that based on detailed bathymetric soundings
- Burnley Harbour.
- Victoria Harbour and nearby docks.

TUFLOW represented the terrain across the hydraulic model area with 10 m cells, with additional storage and conveyance detail obtained at a 2 m resolution using the 'sub grid sampling' (SGS) functionality in TUFLOW. This new feature essentially provides greater detail in the terrain without the full overhead of a smaller grid size (details of this feature are documented in 2020 TUFLOW Release Notes – BMT, 2020). and was adopted based on comparison of water levels along the Yarra River to historic levels with and without this feature enabled as discussed in Appendix A.

To improve the representation of key catchment characteristics a number of terrain modification layers were also read into the model, including:

- 'ridge' lines to reflect key flow control levels, such as channel banks, road embankments and flood/noise walls;
- 'gully' lines to provide connectivity along the channel thalweg to avoid unnecessary ponding, especially in areas upstream of the Study Area where the profile of the river below the water level at the time of when the terrain data was sourced was used to represent the channel; and
- 'shapes' to represent some permanent structures (see discussion on structures in Section 3.3.4).

3.3.3 Boundary conditions

This model required the following types of boundary conditions, which are summarised below:

- Upstream flows ('inflow boundaries')
- Upstream storages
- Downstream levels ('tailwater boundaries')
- Initial conditions

Inflow boundaries

Inflow hydrographs for the Yarra River, Moonee Ponds Creek and the Maribyrnong River were generated to represent the inflows to the Yarra River from its contributing catchments using RORB models supplied by MWC (see Section 3.2).

The hydrographs were applied as a combination of total hydrographs from groups of subareas upstream of modelled areas and individual subareas along the Yarra River. A summary of the hydrographs used in the modelling can be found in Appendix B.

Upstream Storages

Due to the fact that there is active storage upstream of the Study Area within the three major waterways, there was a need to represent this storage in some form. This was ultimately achieved by the following:

- Extending the hydraulic model upstream along the Yarra River to account for the storage explicitly within the river and on the adjacent floodplain, which is known to be engaged in the less frequent modelled events.
- Given the lack of bathymetry data readily available for the main tributaries within the Study Area, this upstream storage was represented as a 1D node with a "nodal area" based on the approximate surface area of active waterway within the tidally influenced zone.

Tailwater boundaries

A tailwater boundary was created to represent tidal influences on the lower Yarra River. This boundary was applied at the mouth of the Yarra River just before it enters the Port Phillip Bay. The agreed boundary conditions were derived from the following advice and data provided by Melbourne Water:

- Tidal sequences for 10y and 5y ARI events based on modelling by WaterTech. GHD's scope did not include any checking or review of these sequences.
- Advice on the how the peak tidal levels should be varied for other ARI events and climate change scenarios (i.e. sea level rise).
- Advice on extending modelled tidal curve to represent tide over complete modelled event (250 hours)
- Advice on the relative timing of the peak tidal level and the peak hydrograph flow through the Yarra River (refer to Appendix A, Attachment 2)

The modelled tidal data was simplified for reading into TUFLOW (required to avoid model instability issues due to noise in the provided tide curves) and was converted into a smoother curve using the cubic spline interpolation routine ("S" flag on "HT" boundaries) in TUFLOW.. The tidal curves were also shifted such that they achieved the peak tidal level as per Tech Spec requirements. A summary of the tidal curves adopted is shown in Table 4. The final tidal curves (i.e. the smoothed tidal curves as generated by TUFLOW) are shown in Appendix C.

Table 4 Tidal boundaries

ARI	Duration	Sea Level Rise?	Base Tidal Data	Tidal Peak Level (mAHD)	Tidal Peak Time (hours into simulation)
100y	48h & 72h	No	10y WaterTech data supplied by MWC	1.15	30
		Yes		2	
50y	48h & 72h	No		1.15	
20y	48h & 72h	No		1.15	
		Yes		2	
10y	48h & 72h	No		1.15	
		Yes		2	
5y	48h & 72h	No	5y WaterTech data supplied by MWC	1.05	
		Yes		1.9	

Initial water levels

The applied global initial water levels were based on the tidal levels at the beginning of the simulation (refer Appendix C) to avoid water rushing into the model. Each simulation was also run for 36 hours prior to the storm with a typical tide curve to enable the model to establish a dynamic tailwater level along the main waterways within the Study Area (i.e. provide initial conditions for each storm with a hydraulic grade based on tides).

3.3.4 Structures

Structures along the Yarra River have a significant impact on flood levels and therefore the resultant flooding in major storm events. As such, these structures were required to be modelled in some way to allow their impact to be represented appropriately.

Three types of structures were identified along the banks of or crossing the Yarra River – these were bridges, piers and floating structures. These structures and the ways in which they were modelled are discussed below.

Bridge Structures

Given that bridges are a hydraulically significant aspect of this investigation, their representation is important and as such, it was decided that they should be modelled in some detail. This involved modelling bridges in a number of different ways depending on the span direction of the bridge relative to the direction of flow of the river and the bridge characteristics. These approaches were as follows and where they were applied is summarised in Table 5.

- **Bridges perpendicular to the direction of flow** – These bridges were modelled with the use of layered flow constrictions. These objects allow the representation of up to three layers vertically, allowing the representation of bridge piers, deck and railings. These bridge layers all affect the flow of water through the bridge structure differently and so separate representation of these layers to represent this variation is important.

  This representation is made through the application of form loss coefficients and blockage percentages that vary for each layer. The detailed approach developed by GHD and adopted for this project is discussed in Appendix D and is specifically applicable to bridges that cross the Yarra River only.

- **Bridges parallel to the direction of flow** – While the abovementioned approach was adopted for bridges crossing the Yarra River, this same approach could not be used for bridges alongside the river due to TUFLOW applying form losses additively in the direction of flow, which would result in overstating of form losses. These bridges were instead represented using layered flow constrictions with only blockage applied to pier and deck layers to represent the obstruction to flow posed by such structures. The sound walls along CityLink were represented with a combination of thin z lines to completely block the lateral flow of water to a given varying elevation as appropriate or layered flow constrictions along the sides of river-side cells to allow water passage beneath the sound wall but not through at the appropriate elevations.

Table 5 Summary of bridges within hydraulic model

Model Area	Bridge No.	Bridge	Bridge direction relative to flow direction	Bridge representation
Initial Lower Yarra River model area	1	MacRobertsons Bridge	Perpendicular to direction of flow (crosses river)	Layered flow constrictions with form loss and blockage applied (refer Appendix D for details of approach)
	2	Church Street Bridge		
	3	Cremorne Bridge		
	4	Hoddle Street Bridge		
	5	Morell Bridge		
	6	Swan Street Bridge		
	7	Princes Bridge		
	8	Southbank Pedestrian Bridge		
	9	Sandridge Bridge		
	10	Queens Bridge		
	11	Kings Bridge		
	12	Clarendon Street Bridge		
	13	Seafarers Bridge		
	14	Wurundjeri Way		
	15	Webb Bridge		
	16	Citylink	Parallel to direction of flow (runs alongside river)	Layered flow constrictions with only blockage applied
	17	Jim Stynes Bridge		
	18	Bolte Bridge	Perpendicular to direction of flow (crosses river)	Within purely tidally influenced area. Not represented due to model stability issues and fact that impact will be negligible as in area of tidal influence.
	19	West Gate Bridge		
Gap between Lower Yarra River Study Area and NELP Yarra River model	20	Bridge Rd Bridge	Perpendicular to direction of flow (crosses river)	Layered flow constrictions with form loss and blockage applied (refer Appendix D for details of approach)
	21	Hawthorn Rail Bridge		
	22	Wallen Rd Bridge		
	23	Monash Fwy (inbound)		
	24	Monash Fwy (outbound)		
	25	Heyington Rail Bridge		

Model Area	Bridge No.	Bridge	Bridge direction relative to flow direction	Bridge representation
NELP Yarra River Model	26	Banskia St Bridge (including pipe track)	Perpendicular to direction of flow (crosses river)	Layered flow constrictions adopted from NELP model with form loss and blockage applied as provided (refer Appendix D for details of approach)
	27	Burke Rd Bridge		
	28	Chandler Highway		
	29	Eastern Freeway (outbound)		
	30	Eastern Freeway (inbound)		
	31	Main Yarra Trail SUP Bridge		Additional layered flow constrictions added to NELP model area with form loss and blockage applied (refer Appendix D for details of approach)
	32	Darebin Creek Trail Bridge		
	33	Fairfield Pipe Bridge		
	34	Kanes Bridge		
	35	Johnston St Bridge		
	36	Gipps St Main Yarra Trail		
	37	Main Yarra Trail - North of Burnley St		
	38	Barkers Rd Bridge		
	39	Dights Falls		Weir represented as terrain modification, but fishway not modelled due to minimal flow passing and the fact that this areas isn't currently being mapped.

Other Riverside Structures

Piers, jetties, walkways and other structures were identified along the Lower Yarra River within the Study Area. These structures and how they were modelled are described below.

- **Rigid and permeable structures** – These structures formed an obstruction to flow by introducing additional resistance to flow passing through the given structure. These structures included structures such as piers and jetties and were modelled using depth varying Manning's roughness coefficients to represent the increased resistance to flow caused by the given structure.
- **Rigid and impermeable structures** – These structures formed an obstruction to flow by a reduction in the cross-sectional area of the river. These structures included protruding walkways, ramps and similar types of structures, requiring to be modelled in instances where they were not represented by the underlying model terrain and being modelled using z shapes to build up the terrain as necessary.
- **Floating structures** – These structures were initially modelled using "flow constriction" layers in TUFLOW, but after much testing there was a bug identified in the software that required this type of layer not to be used. Alternative ways to represent these structures were investigated (i.e. altered roughness), but ultimately the change in roughness was found to be negligible and so were not explicitly modelled in this Study. This was also considered appropriate as it was agreed that the effect on the flow capacity of the Yarra River during major storm events was likely to be minimal.

Structures of this nature were not identified or modelled in the area upstream of the Study Area.

3.3.5 Manning's roughness

Bed resistance was allocated to each cell as a Manning's n value based on land use type and aerial photography within the Study Area. Outside the Study Area, roughness was adopted from the supplied models with the exception of the major waterways – which is explained further below.

Adopted Manning's n values for various land uses/surface types within the Study Area are tabulated in Table 6 and the spatial distribution of this roughness is shown in Figure 6. This figure also served as a visual check that the correct Manning's n values were being applied in the right locations.

The adopted roughness for major waterways was selected during the "verification" modelling phase of this Study, which is described in Appendix A. The value is within the range commonly used for major waterways and provided a model results acceptable to MW relative to historic levels given the combination of designated levels, design flows and other assumptions in the agreed modelling approach.

Table 6 Bed resistance values for 2D domain

Land Use	Manning's n
Roads (default)	0.020
Residential (outside of building footprints)	0.120
Open space - mostly grass	0.030
Open space - some bush	0.040
Open space - mostly dense bush	0.070
Creek or open space - mostly bush	0.050
Railway	0.050
Low density residential	0.100
Commercial	0.500
"Blocked out" buildings	0.500
Open space - some trees	0.035
Industrial	0.200
Concrete/carparks/bitumen	0.015
En-tout-cas tennis courts/compacted gravel driveway	0.030
Residential/mixed use full properties outside area of interest	0.200
Major waterways (active waterway area)*	0.025
Note: * indicates that this was an agreed value selected during the "verification" modelling phase of this Study, which is described in Appendix A	

3.3.6 Summary of TUFLOW model setup and commands

In addition to the general model setup described in the above sections and previous reports, the following parameters and commands have been adopted for all runs:

- 2D domain size – 24,000 m x 11,500 m.
- Varying end times to allow times of inundation to be adequately determined throughout the 2D domain for each run.
- Maximum Velocity Cutoff Depth == 0.05 (default is 0.1) – this allows maximum velocities to be recorded once depth is above 0.05 m.
- Cell Wet/Dry Depth == 0.0002 (default is 0.002).
- "Zero Z Point == WARNING" – this was required as we had terrain below 0 m AHD.
- "XF Files == OFF" – this turns off the use of "XF files"and requires TUFLOW to process raw input layers each time.
- Commands to activate "HPC on GPU" engine:
  - Solution Scheme == HPC
  - Hardware == GPU
- Commands to activate "SGS" functionality:
  - SGS == ON
  - SGS Sample Distance == 2
  - SGS Partial Grid Update Null Frac == 0.6, 0.6

3.3.7 Qualifications relating to flood mapping output

The hydraulic model and its results extend beyond the region being 'mapped' to achieve a number of objectives, including:

- To improve the distribution of model inflows;
- To reduce the significance of downstream boundary conditions;
- To allow for break away flow both within and upstream of the Study Area; and
- To enable comparison of the adopted modelling approaches with historic flood levels across a broader reach of the Yarra River with less tidal influence.

Therefore, the flood mapping output described in the following sections, and provided to Melbourne Water in accordance with the Guidelines and Technical Specifications for Flood Mapping Projects, November 2016 (*MWC 2006*), have been trimmed to a "Mapping Limit" polygon. This line designates the extent of meaningful results. Outside of the "Mapping Limit" the model results may be misleading for a number of reasons, including:

- Boundary conditions;
- Incomplete representation of drainage assets;
- A number of modelling approximations suitable for the current purposes within the mapping limit but not necessarily suitable for flood mapping requirements outside of the mapping limit.

All modelling results require appropriate interpretation. It should be noted that overland flows for the smaller, more frequent events, such as the 5 and 10 year ARI results, are produced using a hydraulic model established primarily for the purpose of modelling the 100 year ARI event. The implication of this is that, particularly for these smaller events, the modelling results will need to be appropriately interpreted with an understanding of their limitations.

Despite these limitations the results for the smaller, more frequent events are currently believed to be the best available with respect to identifying the effects of riverine flooding. Modelling of local catchments should always be considered particularly in regions adjacent and remote from the Yarra River.

The accuracy of the final results is in part a function of the resolution of the TUFLOW model (which uses a 10 m cell size with SGS at 2m). The higher resolution of results (provided on a 1 m grid) is provided as a partially interpreted data source for the convenience of Melbourne Water. This higher resolution grid of results does not infer a higher accuracy.

4. Mapping

4.1 Introduction

The raw results of the TUFLOW modelling were post-processed to produce the required GIS layers outlined in Melbourne Water's Guidelines and Technical Specifications for Flood Mapping Projects, November 2016 (*MWC 2016)* within the Study Area. Envelopes of maximum values were produced for each AEP and for each of the key output parameters (i.e. flood level, velocity, velocity-depth) using the "ASC to ASC" utility. The maximum flood level envelope from the above process was then further processed using TUFLOW's "remap" functionality in the latest "ASC to ASC" utility, which recalculates flood levels and depths based on a more detailed DEM (this feature is outlined in TUFLOW's latest release notes and/or the TUFLOW Wiki - https://wiki.tuflow.com/index.php?title=TUFLOW_Remapping). The adopted DEM for remapping was the "DEM_Z" file created by running an additional model based on the final "SGS" model on TUFLOW Classic with a 2 m cell size (which was the "SGS" sampling distance). The remaining maximum envelope results were 'filtered' by removing values where there was no depth result and used further to produce the various required output layers. Further details of the mapping output is described in the following sections.

4.2 1 m results grids

MapInfo layers were created containing points on a 1 m orthogonal grid for each of the events listed in Table 1. Each point contains the following information for the specific event:

- Maximum water level (m AHD – based on TUFLOW "h_Max.flt" results remapped to a finer DTM using TUFLOW's "ASC to ASC" utility)
- Maximum depth (m – based on TUFLOW "h_Max.flt" results remapped to a finer DTM using TUFLOW's "ASC to ASC" utility)
- Maximum velocity (m/s – based on TUFLOW "V_Max.flt" results)
- Maximum velocity-depth product (m^2/s – based on TUFLOW "Z0_Max.flt" results)
- Critical storm duration of maximum water level (minutes – based on TUFLOW "h_Max.flt"
- Minimum time to 350 mm depth (hours – based on TUFLOW "TExc_0.35m.flt" results)
- Minimum time to 500 mm depth (hours – based on TUFLOW "TExc_0.5m.flt" results)
- Maximum time of inundation above 350 mm depth (hours – based on TUFLOW "TDur_0.35m.flt" results)
- Maximum time of inundation above 500 mm depth (hours – based on TUFLOW "TDur_0.50m.flt" results)

The 'raw' 1 m points were trimmed back to the respective 'filtered and smoothed' flood extents, and then used in populating the "Parcels Flooded" and "Building Footprints" MapInfo layers (refer to Sections 4.6 and 4.7).

The 1 m point data will not exist where a small island has been removed from the flood extent. So that the data removed by the above processes is not 'lost', 'raw' and 'unfiltered' versions of the 1 m points have also been provided to Melbourne Water.

4.3 Flow values

The flow results at the locations of model ‘printout’ (PO) lines were collated and provided in MapInfo layers for each scenario. The flow values provided in each layer are:

- maximum total flows for each AEP
- maximum overland flows (1% AEP only – from the 2D domain)

The values are maximum from the modelled storms for the each AEP.

A set of “PO Flows” layers were also created to provide additional information not included in the “Flow Values” layers. These “PO Flows” layers were created for each of the events listed in Table 1 and contain the peak total flow and the critical storm in which the maximum “overland” flow occurs.

4.4 Flood extents

Flood extents were created for each of the events listed in Table 1 using a prescribed method provided by Melbourne Water, which is generally as follows:

- Create ‘raw and unsmoothed’ flood extent polygons based on calculated depth results.
- Remove ‘puddles’ or ‘islands’ that are less than 100 m^2 in area.
- Smooth the extents using an FME workspace provided by Melbourne Water, which utilises Densifier, McMaster Weighted Distance and NURBfit algorithms.

All flood extents were then trimmed back to a ‘mapping limit’, thus removing results in areas that were modelled purely for the purposes of establishing appropriate flow distribution and/or boundary conditions.

The remaining Base Case flood extents smaller than the 1% AEP extent were trimmed back to the 1% AEP extent, just to ensure that the “Planning Scheme Ready” process didn’t result in the smaller extents being just outside the 1% AEP extent.

The flood extents created using this method are shown in Appendix E. This appendix also includes maps showing the water surface level and depth results within the Mapping limits of the Study.

There is an implication of removing islands from the flood extents in that this creates areas that look flooded but do not have any underlying flood data such as 1 m grid points or flood contours. No attempt has been made to ‘create’ data where islands have been removed. So that the data removed by the above processes is not ‘lost’, ‘raw’ and ‘unfiltered’ versions of the flood extents have also been provided to Melbourne Water.

4.5 Flood contours

MapInfo layers of flood contours were created for the 1% AEP events only (i.e. Base Case and Climate Change Scenarios). Flood contours were created at 0.5 m intervals from the ‘raw and unfiltered’ maximum water level envelopes and trimmed back to the respective ‘filtered and smoothed’ flood extents.

As per the discussion on the filtered grid data, flood contours will not exist where an island has been removed from the flood extent. So that the data removed by the above processes is not ‘lost’, ‘raw’ and ‘unfiltered’ versions of the flood contours have also been provided to Melbourne Water.

4.6 Parcels (properties) flooded

A MapInfo layer of parcels (properties) flooded was created from the Parcels layer provided by Melbourne Water that were touched by the Base Case 1% AEP flood extent.

The following flood information was assigned to each 'flooded' parcel polygon for the Base Case Scenario:

- Maximum 100, 50, 20, 10 and 5 year ARI flood levels
- Minimum 100 year ARI flood level
- Maximum 100 year ARI velocity
- Maximum 100, 50, 20, 10 and 5 year ARI depths
- Maximum 100, 50, 20, 10 and 5 year ARI velocity-depth product

All values attached were based on the 1 m results grids described in Section 4.2. Where a parcel was not affected by a smaller event, a data value of "-9999" was assigned. The assigned flood levels were checked to ensure that levels were in the right order. This processing identified a small number of parcels at the flood fringe that had values in the incorrect order due to TUFLOW's remapping function and these were manually adjusted.

It is noted that due to the flood extent smoothing process, some parcels that are selected by the Base Case 100 year ARI flood extent may not actually have an attributed 1 m grid point on them and hence have not been assigned 100 year ARI flood data. Where such parcels exist they have been left in the 'parcels flooded' layer.

A similar layer was created for the Climate Change Scenario, based on parcels touched by the Climate Change 1% AEP flood extent.

The total number of parcels flooded in each event for the Base Case and Climate Change Scenarios are summarised in Table 7.

Table 7 Total number of parcels flooded

Event	Total Number of Parcels Flooded in Base Case Scenario	Total Number of Parcels Flooded in Climate Change 1 Scenario	Total Number of Parcels Flooded in Climate Change 2 Scenario	Total Number of Parcels Flooded in Climate Change 3 Scenario
1% AEP	24,677	31,282	34,694	28,152
2% AEP	455	-	-	-
5% AEP	249	-	26,439	-
10% AEP	239	-	7,358	244
20% AEP	235	-	5,688	237

4.7 Building footprints flooded

A MapInfo layer of building footprints flooded was created from the layer of building footprints provided by Melbourne Water that were located within the parcels flooded in the Base Case Scenario. The maximum flood level was assigned to each 'flooded' building footprint polygon for the Base Case Scenario for the 100, 50, 20, 10 and 5 year ARIs.

All values attached were based on the 1 m results grids described in Section 4.2. Where a building footprint was located on an unflooded part of a parcel, or not affected by a smaller event, a data value of "-9999" was assigned. The assigned flood levels were checked to ensure that levels for each event were in the expected order. This checking did not identify the need for any adjustments.

A Flood Risk category was calculated for each building footprint polygon based the criteria provided by Melbourne Water and as shown in Table 8. Each building can only have one risk category assigned and the highest category satisfied governs.

Table 8 Flood Risk Categories

Flood Risk Category	Criteria
1	Building footprint is flooded in the 1% probability flood event but floor level is unknown
2	Floor level is flooded in the 1% probability flood event
3	Floor level is flooded in the 2% probability flood event
4	Floor level is flooded in the 5% probability flood event
0*	Floor level is above the 1% probability flood event
-999*	Building footprint is not flooded in the 1% probability flood event but is within a parcel flooded in the 1% probability flood event
Note: * categories added and defined by GHD.	

The total number of building footprints and floors flooded are shown in Table 9 and Table 12 for the Base Case, Climate Change 1 (CC_B), Climate Change 2 (CC_C), and Climate Change 3 (CC_D) scenarios respectively.

Table 9 Total number of building footprints and floors flooded in the Base Case Scenario

Scenario Event	Number of Building Footprints Flooded	Number of Floors Flooded (where floor level is known)*	Number of Floors NOT Flooded (where floor level is known)*
1% AEP	484	62	30
2% AEP	45	0	92
5% AEP	7	0	92
10% AEP	5	0	92
20% AEP	4	0	92
Note: * indicates that 92 floor levels are known			

Table 10 Total number of building footprints and floors flooded in the Climate Change 1 Scenario

Scenario Event	Number of Building Footprints Flooded	Number of Floors Flooded (where floor level is known)*	Number of Floors NOT Flooded (where floor level is known)*
1% AEP	758	68	17
Note: * indicates that 94 floor levels are known			

Table 11 Total number of building footprints and floors flooded in the Climate Change 2 Scenario

Scenario Event	Number of Building Footprints Flooded	Number of Floors Flooded (where floor level is known)*	Number of Floors NOT Flooded (where floor level is known)*
1% AEP	1118	99	70
5% AEP	422	28	14
10% AEP	153	0	0
20% AEP	99	0	0
Note: * indicates that 182 floor levels are known			

Table 12 Total number of building footprints and floors flooded in the Climate Change 3 Scenario

Scenario Event	Number of Building Footprints Flooded	Number of Floors Flooded (where floor level is known)*	Number of Floors NOT Flooded (where floor level is known)*
1% AEP	784	70	21
10% AEP	6	0	0
20% AEP	4	0	0
Note: * indicates that 97 floor levels are known			

4.8 GIS output

The MapInfo layers listed below were provided to Melbourne Water as a primary output of this flood mapping project. This report describes the methodology and steps taken to arrive at these layers. The primary layers listed in Table 13 conform to Melbourne Water's supplied metadata standards and naming conventions, as outlined in Melbourne Water's Guidelines and Technical Specifications for Flood Mapping Projects, November 2016 (*MWC 2016)*. The projection of all layers is Map Grid of Australia Zone 55 (GDA94) with Bounds (0, 5500000) (1000000, 6500000). The additional "_RAW" layers, also listed in Table 13, while appropriately attributed do not comply with the Tech Spec format since they are raw layers.

Table 13 MapInfo Deliverables

Layer Name (*.TAB)	Description	Deliverable with "_RAW" suffix also provided? (Description)
4400_Points_100YR_1m	Base Case 100 year ARI 1 m results grid – trimmed to smoothed extent	YES (Points from max envelope of raw modelling results across entire model area)
4400_Points_50YR_1m	Base Case 50 year ARI 1 m results grid – trimmed to smoothed extent	YES (Points from max envelope of raw modelling results across entire model area)
4400_Points_20YR_1m	Base Case 20 year ARI 1 m results grid – trimmed to smoothed extent	YES (Points from max envelope of raw modelling results across entire model area)
4400_Points_10YR_1m	Base Case 10 year ARI 1 m results grid – trimmed to smoothed extent	YES (Points from max envelope of raw modelling results across entire model area)
4400_Points_5YR_1m	Base Case 5 year ARI 1 m results grid – trimmed to smoothed extent	YES (Points from max envelope of raw modelling results across entire model area)
4400_CC_B_Points_100YR_1m	Climate Change 1 100 year ARI 1 m results grid – trimmed to smoothed extent	YES (Points from max envelope of raw modelling results across entire model area)
4400_CC_C_Points_100YR_1m	Climate Change 2 100 year ARI 1 m results grid – trimmed to smoothed extent	YES (Points from max envelope of raw modelling results across entire model area)
4400_CC_C_Points_20YR_1m	Climate Change 2 20 year ARI 1 m results grid – trimmed to smoothed extent	YES (Points from max envelope of raw modelling results across entire model area)
4400_CC_C_Points_10YR_1m	Climate Change 2 10 year ARI 1 m results grid – trimmed to smoothed extent	YES (Points from max envelope of raw modelling results across entire model area)

Layer Name (*.TAB)	Description	Deliverable with "_RAW" suffix also provided? (Description)
4400_CC_C_Points_5YR_1m	Climate Change 2 5 year ARI 1 m results grid – trimmed to smoothed extent	YES (Points from max envelope of raw modelling results across entire model area)
4400_CC_D_Points_100YR_1m	Climate Change 3 100 year ARI 1 m results grid – trimmed to smoothed extent	YES (Points from max envelope of raw modelling results across entire model area)
4400_CC_D_Points_10YR_1m	Climate Change 3 10 year ARI 1 m results grid – trimmed to smoothed extent	YES (Points from max envelope of raw modelling results across entire model area)
4400_CC_D_Points_5YR_1m	Climate Change 3 5 year ARI 1 m results grid – trimmed to smoothed extent	YES (Points from max envelope of raw modelling results across entire model area)
4400_Flow_Values	Flow results from Base Case TUFLOW models	NO
4400_Flow_Values_CC1	Flow results from Climate Change 1 TUFLOW models	NO
4400_Flow_Values_CC2	Flow results from Climate Change 2 TUFLOW models	NO
4400_Flow_Values_CC3	Flow results from Climate Change 3 TUFLOW models	NO
4400_PO_Flows_100y	100 year ARI flow results from Base Case TUFLOW models	NO
4400_PO_Flows_50y	50 year ARI flow results from Base Case TUFLOW models	NO
4400_PO_Flows_20y	20 year ARI flow results from Base Case TUFLOW models	NO
4400_PO_Flows_10y	10 year ARI flow results from Base Case TUFLOW models	NO
4400_PO_Flows_5y	5 year ARI flow results from Base Case TUFLOW models	NO
4400_CC_B_PO_Flows_100y	100 year ARI flow results from Climate Change 1 TUFLOW models	NO
4400_CC_C_PO_Flows_100y	100 year ARI flow results from Climate Change 2 TUFLOW models	NO
4400_CC_C_PO_Flows_20y	20 year ARI flow results from Climate Change 2 TUFLOW models	NO
4400_CC_C_PO_Flows_10y	10 year ARI flow results from Climate Change 2 TUFLOW models	NO
4400_CC_C_PO_Flows_5y	5 year ARI flow results from Climate Change 2 TUFLOW models	NO
4400_CC_D_PO_Flows_100y	100 year ARI flow results from Climate Change 3 TUFLOW models	NO
4400_CC_D_PO_Flows_10y	10 year ARI flow results from Climate Change 3 TUFLOW models	NO
4400_CC_D_PO_Flows_5y	5 year ARI flow results from Climate Change 3 TUFLOW models	NO

Layer Name (*.TAB)	Description	Deliverable with "_RAW" suffix also provided? (Description)
4400 Flood Extent 100y Waterways	Base Case 100 year ARI flood extents –smoothed and trimmed to mapping limit (Planning Scheme ready)	YES (Raw extent from max envelope of modelling results - unaltered)
4400_Flood_Extent_50y_ Waterways	Base Case 50 year ARI flood extents – smoothed and trimmed to mapping limit	YES (Raw extent from max envelope of modelling results - unaltered)
4400_Flood_Extent_20y_ Waterways	Base Case 20 year ARI flood extents – smoothed and trimmed to mapping limit	YES (Raw extent from max envelope of modelling results - unaltered)
4400 Flood Extent 10y Waterways	Base Case 10 year ARI flood extents – smoothed and trimmed to mapping limit	YES (Raw extent from max envelope of modelling results - unaltered)
4400 Flood Extent 5y Waterways	Base Case 5 year ARI flood extents – smoothed and trimmed to mapping limit	YES (Raw extent from max envelope of modelling results - unaltered)
4400 CC B Flood Extent 100y Waterways	Climate Change 1 Scenario 100 year ARI flood extents – smoothed and trimmed to mapping limit	YES (Raw extent from max envelope of modelling results - unaltered)
4400 CC C Flood Extent 100y Waterways	Climate Change 2 Scenario 100 year ARI flood extents – smoothed and trimmed to mapping limit	YES (Raw extent from max envelope of modelling results - unaltered)
4400 CC C Flood Extent 20y Waterways	Climate Change 2 Scenario 20 year ARI flood extents – smoothed and trimmed to mapping limit	YES (Raw extent from max envelope of modelling results - unaltered)
4400_CC_C_Flood_Extent_10y_ Waterways	Climate Change 2 Scenario 10 year ARI flood extents – smoothed and trimmed to mapping limit	YES (Raw extent from max envelope of modelling results - unaltered)
4400_CC_C_Flood_Extent_5y_ Waterways	Climate Change 2 Scenario 5 year ARI flood extents – trimmed to smoothed extent	YES (Raw extent from max envelope of modelling results - unaltered)
4400 CC D Flood Extent 100y _Waterways	Climate Change 3 Scenario 100 year ARI flood extents – trimmed to smoothed extent	YES (Raw extent from max envelope of modelling results - unaltered)
4400 CC D Flood Extent 10y Waterways	Climate Change 3 Scenario 10 year ARI flood extents – trimmed to smoothed extent	YES (Raw extent from max envelope of modelling results - unaltered)
4400 CC D Flood Extent 5y Waterways	Climate Change 3 Scenario 5 year ARI flood extents – trimmed to smoothed extent	YES (Raw extent from max envelope of modelling results - unaltered)
4400_Flood_Contour_100y_ Waterways	Base Case 100 year ARI flood contours (0.5 m interval) – trimmed to smoothed extent	YES (Contours from max envelope of raw modelling results)
4400 Flood Contour 50y Waterways	Base Case 50 year ARI flood contours (0.5 m interval) – trimmed to smoothed extent	YES (Contours from max envelope of raw modelling results)
4400 Flood Contour 20y Waterways	Base Case 20 year ARI flood contours (0.5 m interval) – trimmed to smoothed extent	YES (Contours from max envelope of raw modelling results)
4400 Flood Contour 10y Waterways	Base Case 10 year ARI flood contours (0.5 m interval) – trimmed to smoothed extent	YES (Contours from max envelope of raw modelling results)

Layer Name (*.TAB)	Description	Deliverable with "_RAW" suffix also provided? (Description)
4400 Flood Contour 5y Waterways	Base Case 5 year ARI flood contours (0.5 m interval) – trimmed to smoothed extent	YES (Contours from max envelope of raw modelling results)
4400 CC B Flood Contour 100y_Waterways	Climate Change 1 Scenario 100 year ARI flood contours (0.5 m interval) – trimmed to smoothed extent	YES (Contours from max envelope of raw modelling results)
4400_CC_C_Flood_Contour_100y_Waterways	Climate Change 2 Scenario 100 year ARI flood contours (0.5 m interval) – trimmed to smoothed extent	YES (Contours from max envelope of raw modelling results)
4400_CC_C_Flood_Contour_20y_Waterways	Climate Change 2 Scenario 20 year ARI flood contours (0.5 m interval) – trimmed to smoothed extent	YES (Contours from max envelope of raw modelling results)
4400_CC_C_Flood_Contour_10y_Waterways	Climate Change 2 Scenario 10 year ARI flood contours (0.5 m interval) – trimmed to smoothed extent	YES (Contours from max envelope of raw modelling results)
4400 CC C Flood Contour 5y Waterways	Climate Change 2 Scenario 5 year ARI flood contours (0.5 m interval) – trimmed to smoothed extent	YES (Contours from max envelope of raw modelling results)
4400 CC D Flood Contour 100y_Waterways	Climate Change 3 Scenario 100 year ARI flood contours (0.5 m interval) – trimmed to smoothed extent	YES (Contours from max envelope of raw modelling results)
4400 CC D Flood Contour 10y Waterways	Climate Change 3 Scenario 10 year ARI flood contours (0.5 m interval) – trimmed to smoothed extent	YES (Contours from max envelope of raw modelling results)
4400 CC D Flood Contour 5y Waterways	Climate Change 3 Scenario 5 year ARI flood contours (0.5 m interval) – trimmed to smoothed extent	YES (Contours from max envelope of raw modelling results)
4400_Flood_Studies	Study Area	NO
4400_Mapping_Limit	Mapping Limit indicating extent of 'meaningful' results	NO
4400_SRR_LOW	Base Case Low safety risk polygons in roads – trimmed to smoothed extent	NO
4400_SRR_MED	Base Case Medium safety risk polygons in roads – trimmed to smoothed extent	NO
4400_SRR_HIGH	Base Case High safety risk polygons in roads – trimmed to smoothed extent	NO
4400_CC_B_SRR_LOW	Climate Change 1 Low safety risk polygons in roads – trimmed to smoothed extent	NO
4400_CC_B_SRR_MED	Climate Change 1 Medium safety risk polygons in roads – trimmed to smoothed extent	NO
4400_CC_B_SRR_HIGH	Climate Change 1 High safety risk polygons in roads – trimmed to smoothed extent	NO
4400_CC_C_SRR_LOW	Climate Change 2 Low safety risk polygons in roads – trimmed to smoothed extent	NO
4400_CC_C_SRR_MED	Climate Change 2 Medium safety risk polygons in roads – trimmed to smoothed extent	NO

Layer Name (*.TAB)	Description	Deliverable with "_RAW" suffix also provided? (Description)
4400_CC_C_SRR_HIGH	Climate Change 2 High safety risk polygons in roads – trimmed to smoothed extent	NO
4400_CC_D_SRR_LOW	Climate Change 3 Low safety risk polygons in roads – trimmed to smoothed extent	NO
4400_CC_D_SRR_MED	Climate Change 3 Medium safety risk polygons in roads – trimmed to smoothed extent	NO
4400_CC_D_SRR_HIGH	Climate Change 3 High safety risk polygons in roads – trimmed to smoothed extent	NO
4400_Parcels_Flooded_ Waterways	Property parcels flooded in the Base Case 100 year ARI (fully filtered version) with Base Case flood results attached	NO
4400 CC B Parcels Flooded Waterways	Property parcels flooded in the Climate Change 1 100 year ARI event (fully filtered version) with Climate Change 1 flood results attached	NO
4400_CC_C_Parcels_Flooded_ Waterways	Property parcels flooded in the Climate Change 2 100 year ARI event (fully filtered version) with Climate Change 2 flood results attached	NO
4400 CC D Parcels Flooded Waterways	Property parcels flooded in the Climate Change 3 100 year ARI event (fully filtered version) with Climate Change 3 flood results attached	NO
4400_Building_Footprints_ Waterways	Building footprints within the Base Case Parcels Flooded with Base Case flood results attached	NO
4400_CC_B_Building_Footprints_ Waterways	Building footprints within the Climate Change 1 Parcels Flooded with Climate Change 1 flood results attached	NO
4400_CC_C_Building_Footprints_ Waterways	Building footprints within the Climate Change 2 Parcels Flooded with Climate Change 2 flood results attached	NO
4400_CC_D_Building_Footprints_ Waterways	Building footprints within the Climate Change 3 Parcels Flooded with Climate Change 3 flood results attached	NO

5. Recommendations

It is recommended that:

- Melbourne Water consider the outcomes of this investigation to inform future planning decisions. This consideration should comprehend the strengths of the current investigation, which include a significantly improved understanding of flood flows as well as the potential for newer approaches such as ARR2019, additional gauge data and more comprehensive investigations that revise some of the hydrologic approaches to provide revised information in the future.
- Future investigations of the Yarra River consider the merit of updating the base data and/or assumptions used in this Study including:
  - Utilising ARR2019 hydrology approaches
  - Adopt latest LiDAR information and consider updating bathymetry data where assumptions were required (and/or to improve detailed coverage to reduce need for assumptions and interpolation)
  - Obtain data on structures crossing and along waterway, particularly where water is currently shown to break out of the river.
  - Undertake some verification of predicted flood levels against available gauge information where appropriate.
  - Consider generating flood estimates for historic event and comparing them with historic flood level records.

6. References

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Appendices

Appendix A – Modelling Assumptions and Implications Memo

Memorandum

30 July 2020

To	Melbourne Water Corporation		
Copy to			
From	Peter Woodman	Tel	
Subject	Modelling Assumptions & Implications	Job no.	3135474

1 Introduction

This document aims to outline the general model setup and testing that we have completed for the Lower Yarra River Flood Mapping project since Progress Meeting 1. The focus of this document is to explore the implications of key assumptions on results relative to the currently accepted flood level (referred to herein as the 'Designated Levels'). These assumptions include the following key model inputs:

- Downstream tailwater level (TWL);
- Flows for the Yarra River; and
- Surface roughness within Yarra River (as well as other key waterways)

This document also includes an initial test run with all bridge structures crossing the Yarra River represented upstream of Spencer Street.

2 Test Model Setup

The adopted model setup for the completed test runs discussed below is presented in Figure 1. Other key model assumptions were as follows:

- TUFLOW Engine/Solver = HPC – with GPU enabled (various TUFLOW versions – typically latest available at the time of modelling),
- 2D only model with 10 m cell size,
- Terrain based on combination of LiDAR, HEC-RAS cross-sections and river bathymetry data provided by MWC,
- Three (3) upstream inflows (Yarra River, Moonee Ponds Creek & Maribyrnong River) – "SA" inflow polygons to allow for distribution of flow based on depth,
- A single downstream boundary with a fixed or tidal relationship based on levels in Port Phillip Bay.
- No structures (except for one test run).

To test the implication of representing the river with 10 m cells, cross-sections from TUFLOW and HEC-RAS were compared at the four (4) locations presented in Figure 2. The actual comparisons of cross-sections are shown in Figure 3 - Figure 6, which indicate the TUFLOW representation is fairly comparable to HEC-RAS.

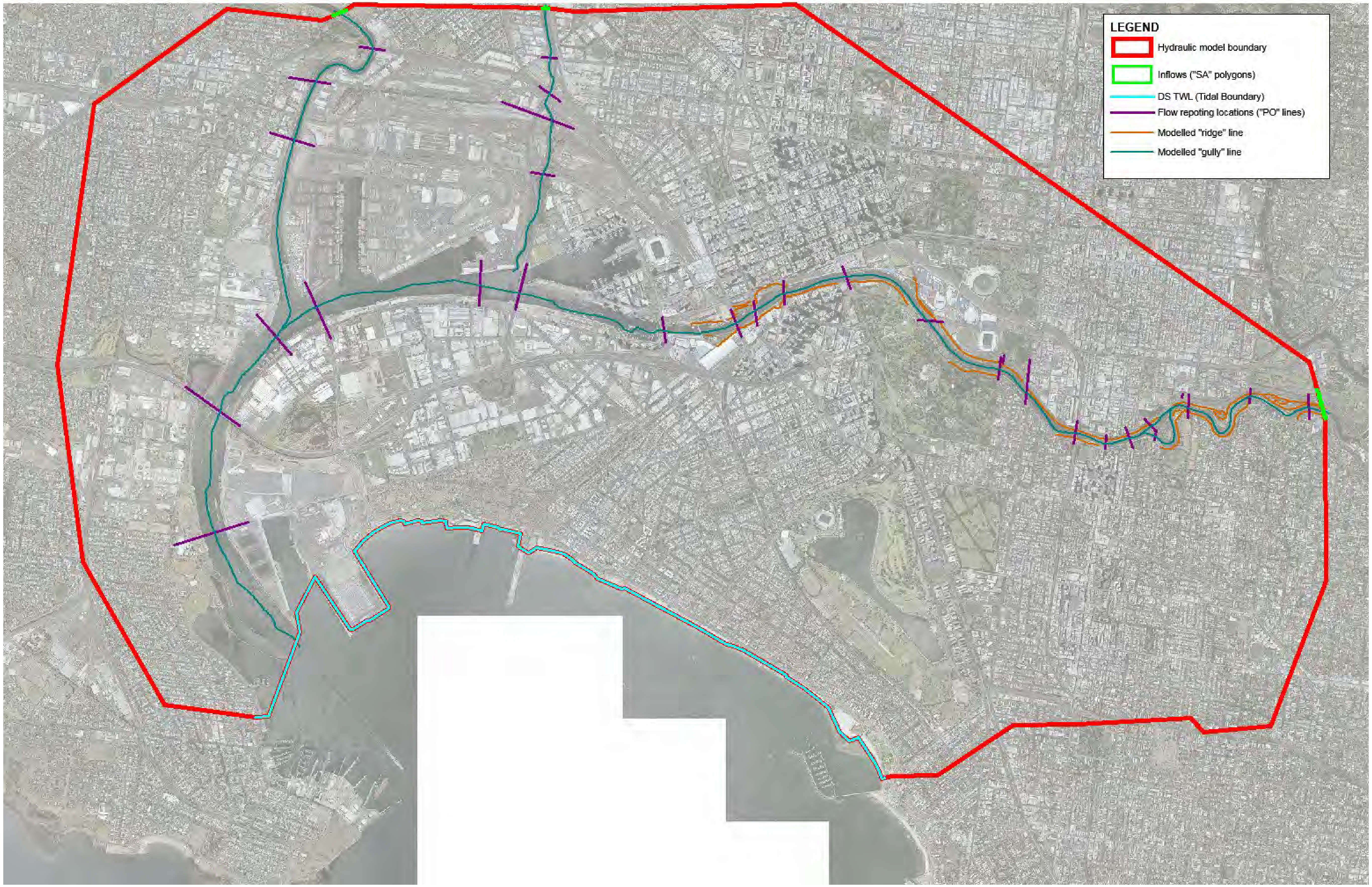


Figure 1 TUFLOW Model Setup for Testing

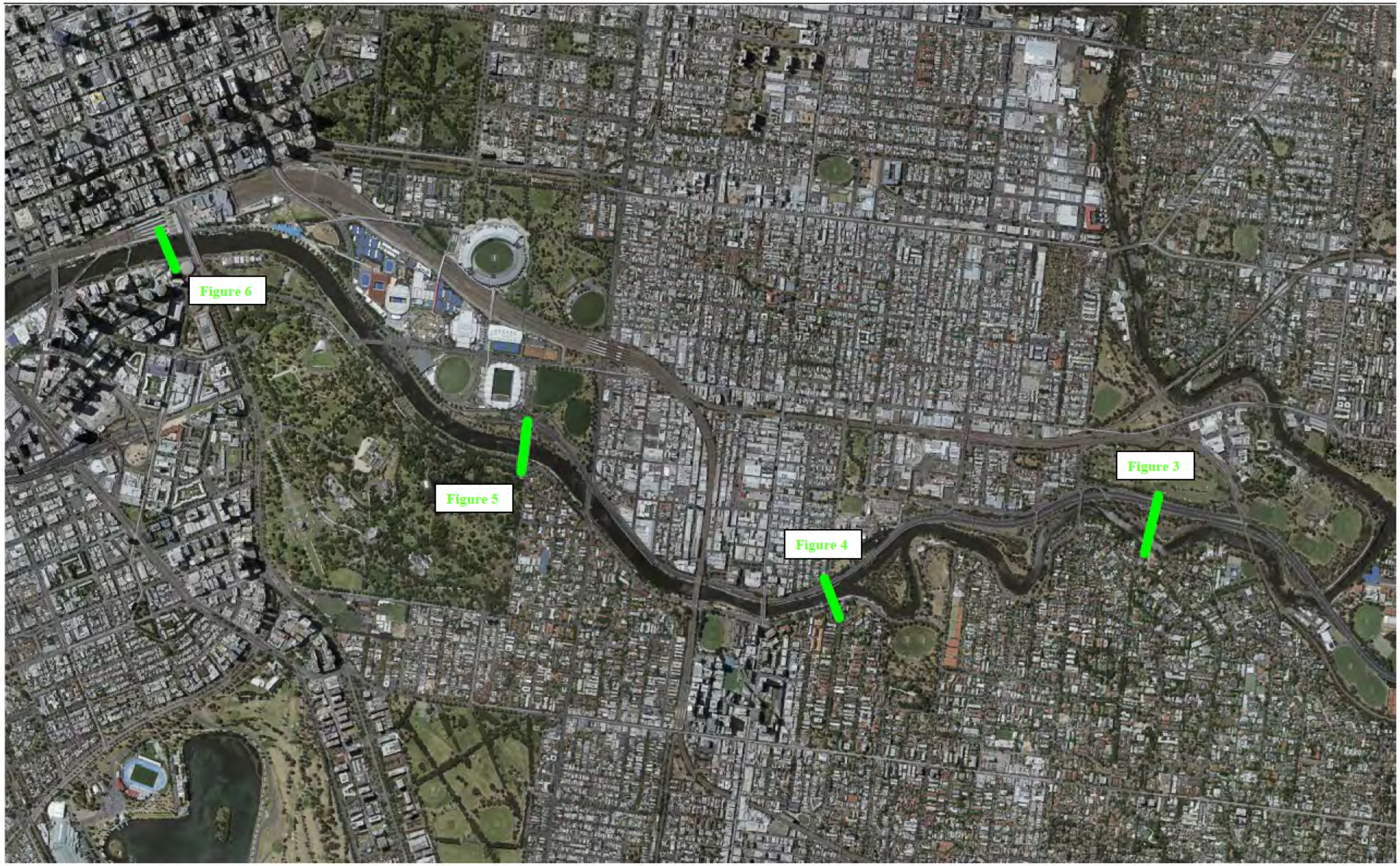


Figure 2 **Location of cross-section comparisons**

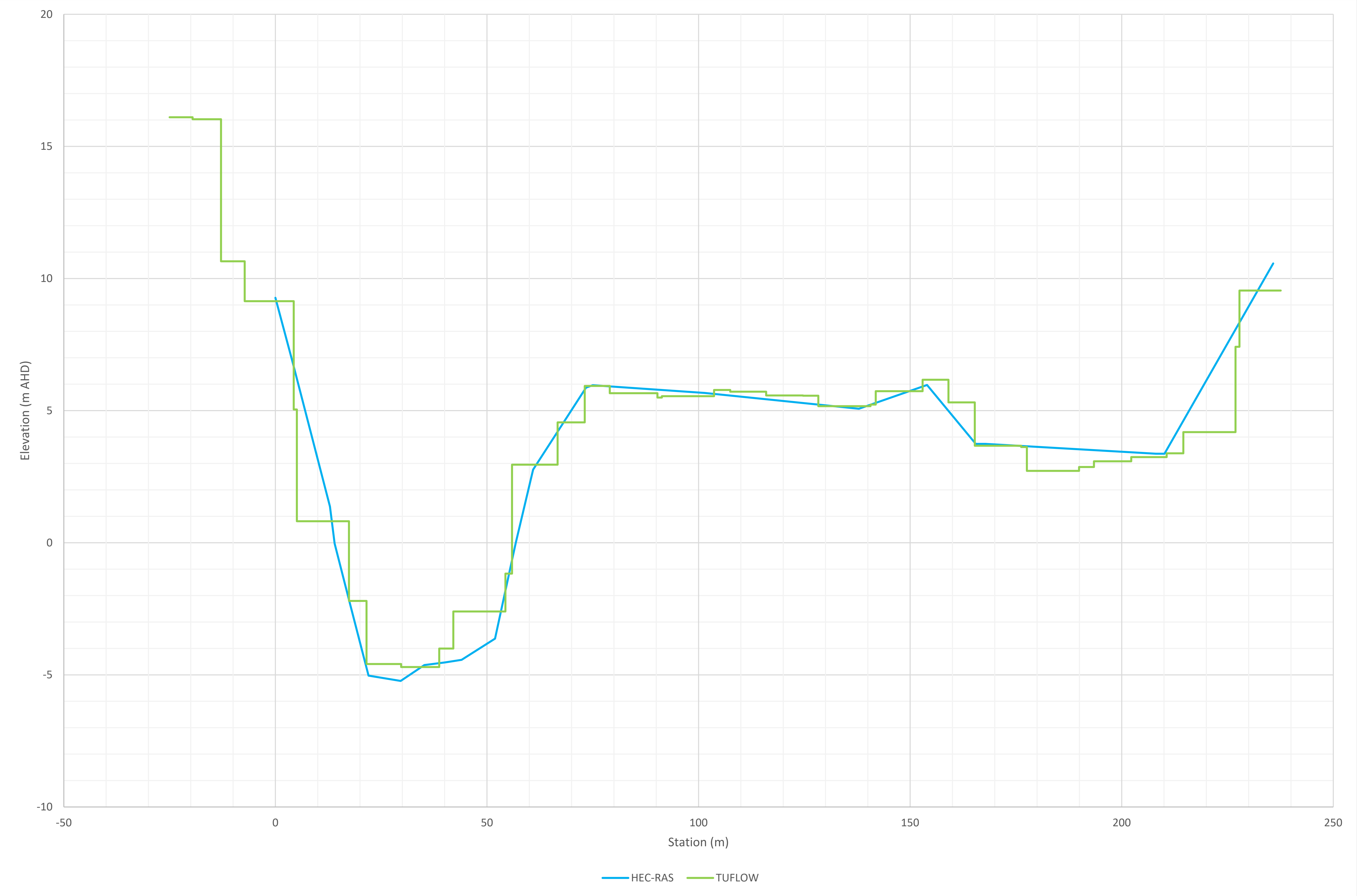


Figure 3 Cross-section comparison at between City Link and MacRobertson Bridge (HEC-RAS Ch 15052, Herr US-Pound DS)

Figure 4 **Cross-section comparison at between Herring Island and Church Street Bridge (HEC-RAS Ch 12877, Spencer-Herr DS)**

Figure 5 Cross-section immediately downstream of Morell Bridge (HEC-RAS Ch 11221, Spencer-Herr DS)

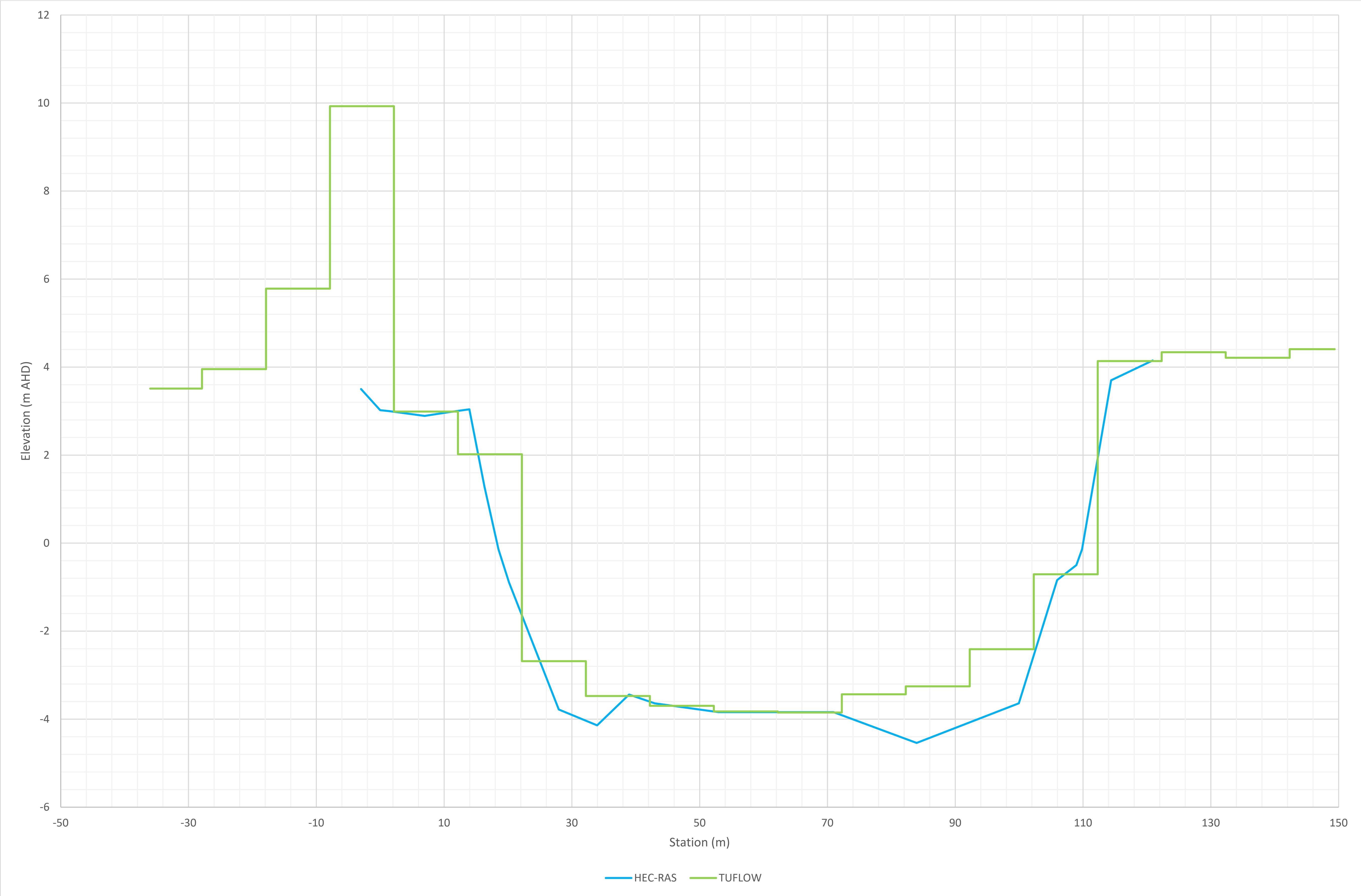


Figure 6 Cross-section between Princes Bridge and Southbank Pedestrian Bridge (HEC-RAS Ch 9249, Spencer-Herr DS)

3 HEC-RAS Modelling

The flows and bathymetry for this project were initially adopted from HEC-RAS modelling undertaken by Melbourne Water. GHD have compared the results of the MW HECRAS model with various tailwater levels (TWLs) to the current 'Designated Levels' within the study area. This is presented in Figure 7, which shows the following:

- Current HEC-RAS modelling provided to MWC (assumed TWL of 1.3 m AHD) doesn't match 'Designated Levels' very well within the study area, with HEC-RAS giving higher results for the entire area except for the top end of the model from just upstream of MacRobertson Bridge;
- Increasing the TWL to 1.6 m AHD (one of the currently requested scenarios) enlarges the differences to the 'Designated levels'; and
- Lowering the TWL to 0.6 m AHD or 0 m AHD reduces the difference to the 'Designated Levels' downstream of Swan Street Bridge and actually causes a slight increase upstream of Swan St Bridge.

Testing of other parameters, such as flow or roughness, within MW's HEC-RAS model was not undertaken.

4 Initial "Existing" TUFLOW Modelling

4.1 Modelling Overview

To test the TUFLOW model setup and determine the implications of the base assumptions regarding flows, TWLs and roughness, numerous TUFLOW model runs have been completed for the 100y ARI 72h storm to compare to both the Designated Levels and those from the previous HEC-RAS modelling (which stops just downstream of Spencer St). The completed model runs and their associated assumptions, summarised in Figure 8, present the modelling results of all these runs on a single plot. This plot includes four distinct colour bands that highlight runs with different TWLs as described below:

- Red – Tidal curve with a peak level of 1.4 m AHD
- Orange – Fixed level of 1.6 m AHD
- Green – Fixed level of 0.6 m AHD
- Blue – Fixed level of 0.0 m AHD

From this plot the following is evident:

- The Designated Levels are significantly lower than the vast majority of TUFLOW model runs,
- The HEC-RAS water surface levels generally lie somewhere in the middle of the TUFLOW model runs,
- Between chainages of 500 m and 7500 m the TWL has a significant effect on water surface levels within the Yarra River,
- Between chainages of 7500 m and 8000 m the TWL begins to have a less significant effect on water surface levels within the Yarra River,
- Above chainages of 8000 m factors other than the TWL (i.e. peak flows and Manning's coefficients applied along the Yarra River) have more significant effects on water surface levels within the Yarra River.

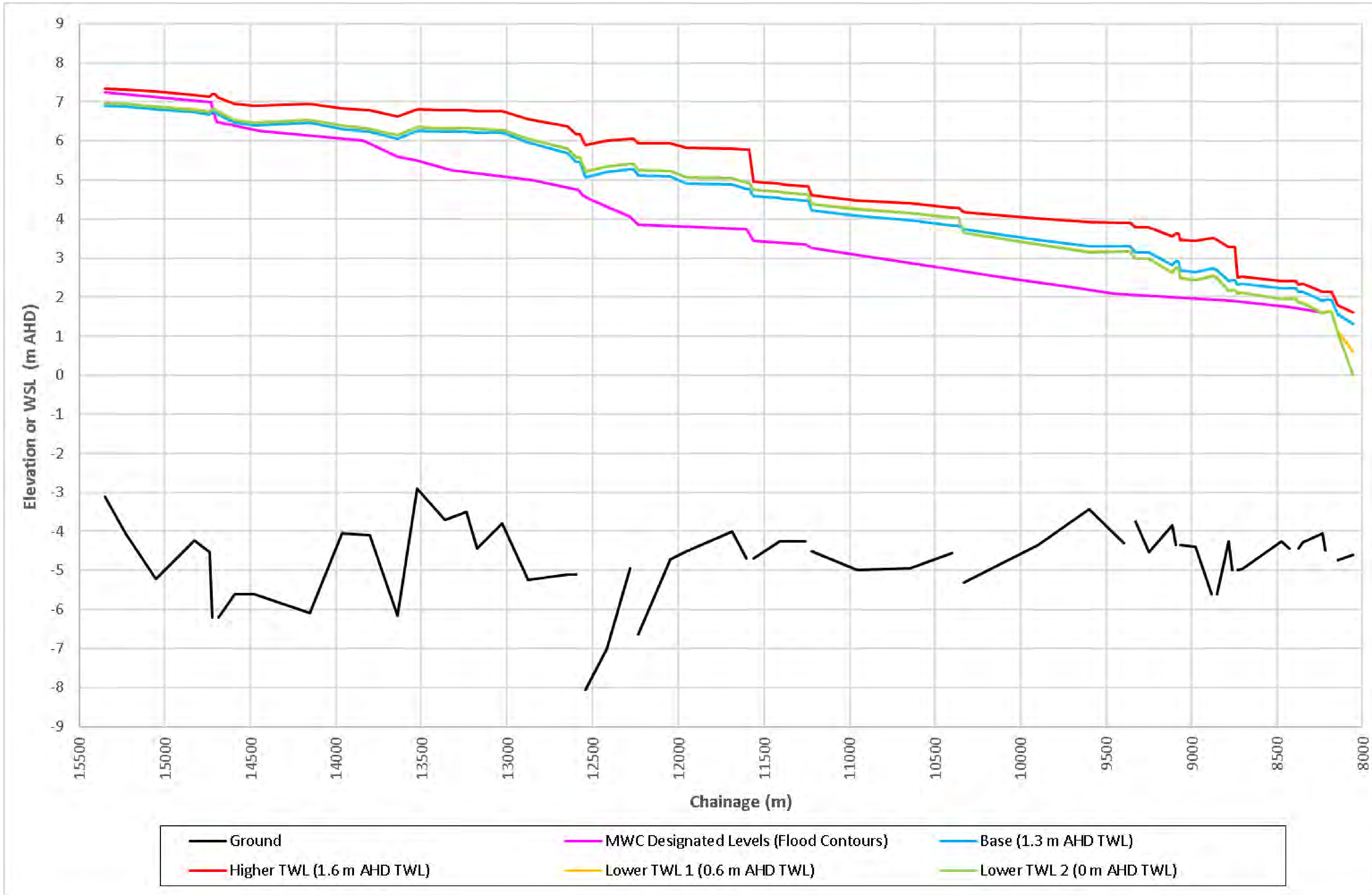


Figure 7 **HEC-RAS WSL Result Comparison to MWC Designated Levels**

Table 1 TUFLOW Model Scenarios

Model Scenario	Yarra River Flow (and Adopted Kc) (m^3/s)	River Roughness (Manning's 'n')	TWL* (m AHD)	Comment
MWC Designated Levels	-	-	-	Comparison levels adopted from MWC's "Flood_Contour_100yr_Waterways" layer
HEC-RAS	1480	0.025	1.3*	Comparison levels adopted from MWC's provided HEC-RAS model for Yarra River called "Yarra River high flow model (Oct 10)"
S1	1475 (145)	0.05	1.6	Initial 'Base Case' Scenario
S2	1475 (145)	0.05	Tidal (1.4 m AHD peak)	Test impact of fixed versus tidal boundary condition
S3	1475 (145)	0.05	0.6	Test impact of lower fixed DS TWL
S4	1475 (145)	0.05	0	Test impact of lower fixed DS TWL
S5	1475 (145)	0.025	1.6	Test impact of lower channel roughness
S6	1475 (145)	0.015	1.6	Test impact of lower channel roughness
S7	1475 (145)	0.025	Tidal (1.4 m AHD peak)	Test combined impact of lower channel roughness and tidal boundary condition
S8	1475 (145)	0.015	Tidal (1.4 m AHD peak)	Test combined impact of lower channel roughness and tidal boundary condition
S9	1475 (145)	0.025	0.6	Test combined impact of lower channel roughness and lower fixed DS TWL
S10	1475 (145)	0.015	0.6	Test combined impact of lower channel roughness and lower fixed DS TWL
S11	1475 (145)	0.025	0	Test combined impact of lower channel roughness and lower fixed DS TWL
S12	1475 (145)	0.015	0	Test combined impact of lower channel roughness and lower fixed DS TWL
S13	1314 (180)	0.05	1.6	Test impact of impact of lower Yarra River flows
S14	1314 (180)	0.025	1.6	Test combined impact of lower Yarra River flows and lower channel roughness
S15	1314 (180)	0.015	1.6	Test combined impact of lower Yarra River flows and lower channel roughness
S16	1314 (180)	0.025	0.6	Test combined impact of lower Yarra River flows, lower channel roughness and lower fixed DS TWL
S17	1314 (180)	0.015	0.6	Test combined impact of lower Yarra River flows, lower channel roughness and lower fixed DS TWL
S18	1314 (180)	0.025	0	Test combined impact of lower Yarra River flows, lower channel roughness and lower fixed DS TWL
S19	1314 (180)	0.015	0	Test combined impact of lower Yarra River flows, lower channel roughness and lower fixed DS TWL

Note:
* indicates that a fixed tailwater level was set at level specified, unless marked as "Tidal" in which case a simplified tide curve shifted to have a peak level at the level specified.

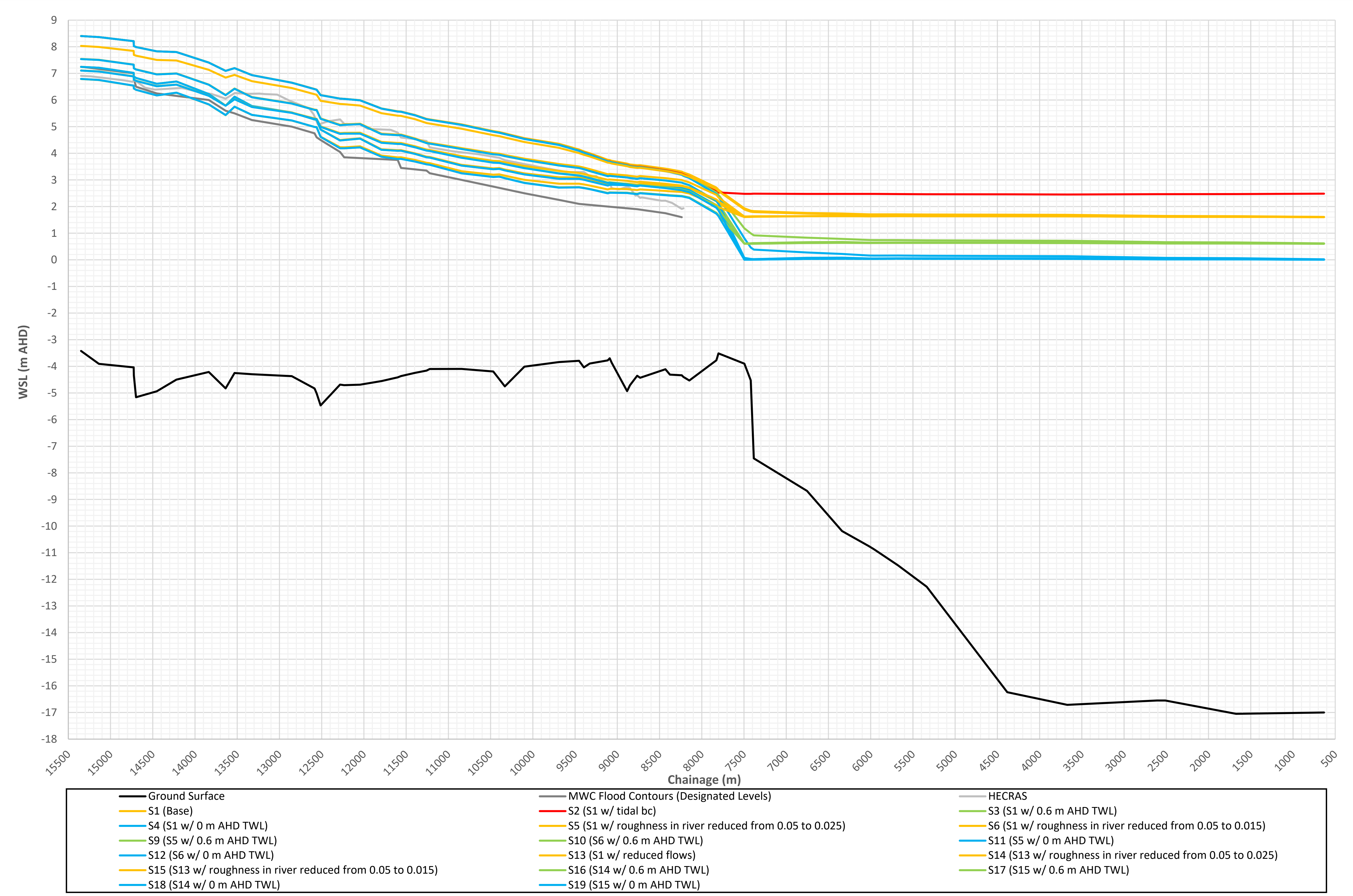


Figure 8 TUFLOW WSL Result Comparison to MWC Designated Levels and Current HEC-RAS results (Long Section 1)

To better assess the impact of other variables, plots showing the change in flow and roughness for each of the four different TWL conditions are presented in Figure 9 - Figure 12. In these plots the darker/lighter lines indicate higher/lower Manning's values (0.05, 0.025 and 0.015) while the triangle markers indicate runs with lower flows applied (peak of 1314 m³/s as opposed to 1475 m³/s). From these plots it can be seen that:

- Higher Manning's values produce higher water surface levels within the river,
- Lower flows produce lower water surface levels within the river,
- Results upwards of a chainage of 10,500 m cover similar ranges of WSLs,
- At a chainage of 10,500 m water surface level ranges are as follows compared to a Designated Level of 2.8 m AHD:
  - Long Section 2a – 4.8 m AHD,
  - Long Section 2b – 3.2 to 4.85 m AHD,
  - Long Section 2c – 3.1 to 4.8 m AHD,
  - Long Section 2d – 3.1 to 4.8 m AHD.
- At a chainage of 14,000 m water surface level ranges are as follows compared to a Designated Level of 6.05 m AHD:
  - Long Section 2a – 7.6 m AHD,
  - Long Section 2b – 6.0 to 7.6 m AHD,
  - Long Section 2c – 6.0 to 7.6 m AHD,
  - Long Section 2d –6.0 to 7.6 m AHD.

Following these base assumption tests, a test model was also run with bridge structure across the Yarra River modelled within the Study Area from Spencer St upstream to gain an appreciation of the likely increase in flood levels from including these. The modelling was for the 100y ARI 72h event with base assumptions from storms based on scenario 'S19' in Table 1 and is presented in Figure 13. From this plot it can be seen that increases in WSL due to structures range between 1 m and 1.7 m in the areas where bridge structures are modelled. Given that some bridges are still to be included in the model and that this model run did not include other riverside structures, this is likely to slightly increase further.

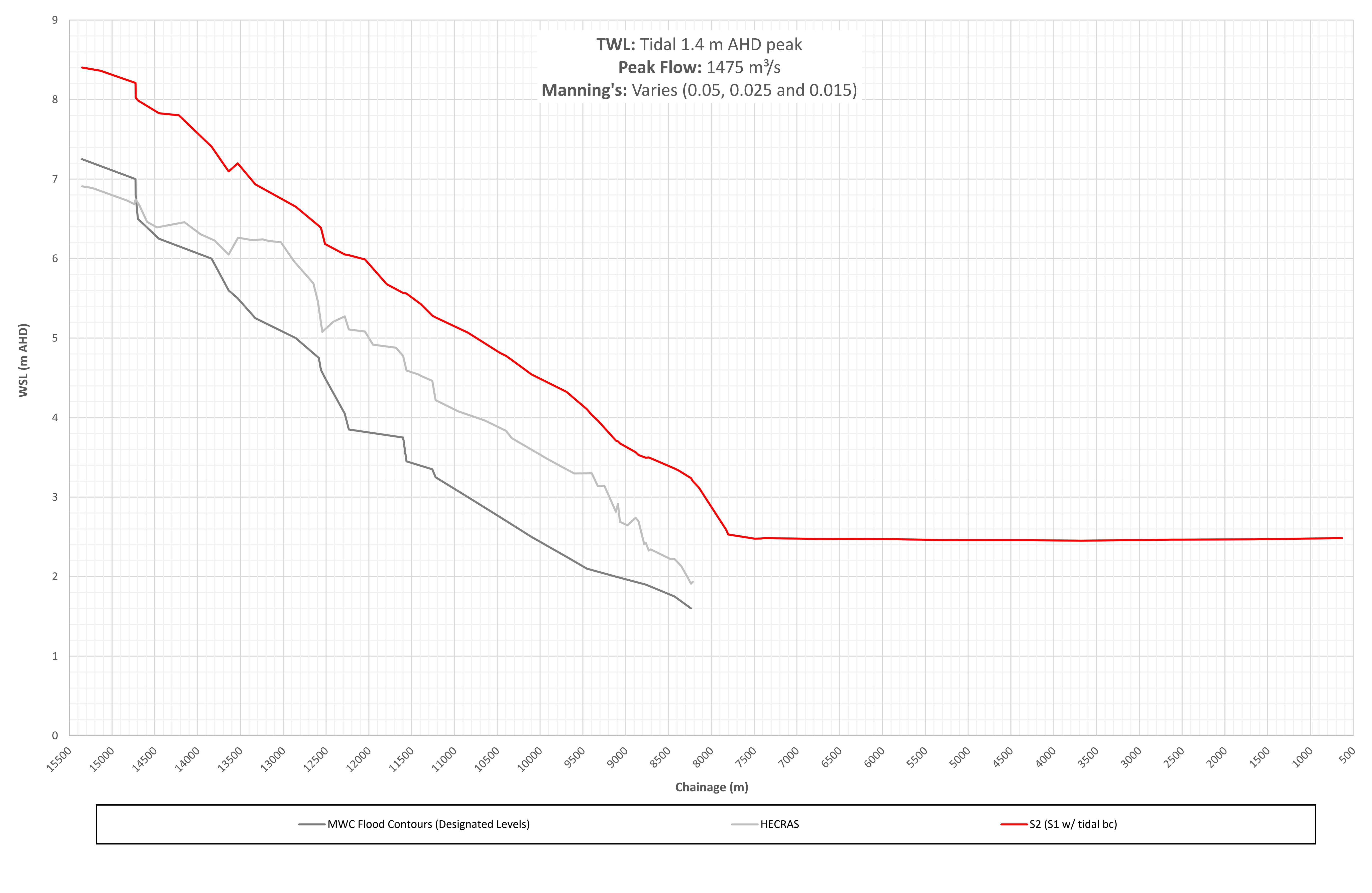


Figure 9 Tidal TWL TUFLOW WSL Result Comparison to MWC Designated Levels (Long Section 2a)

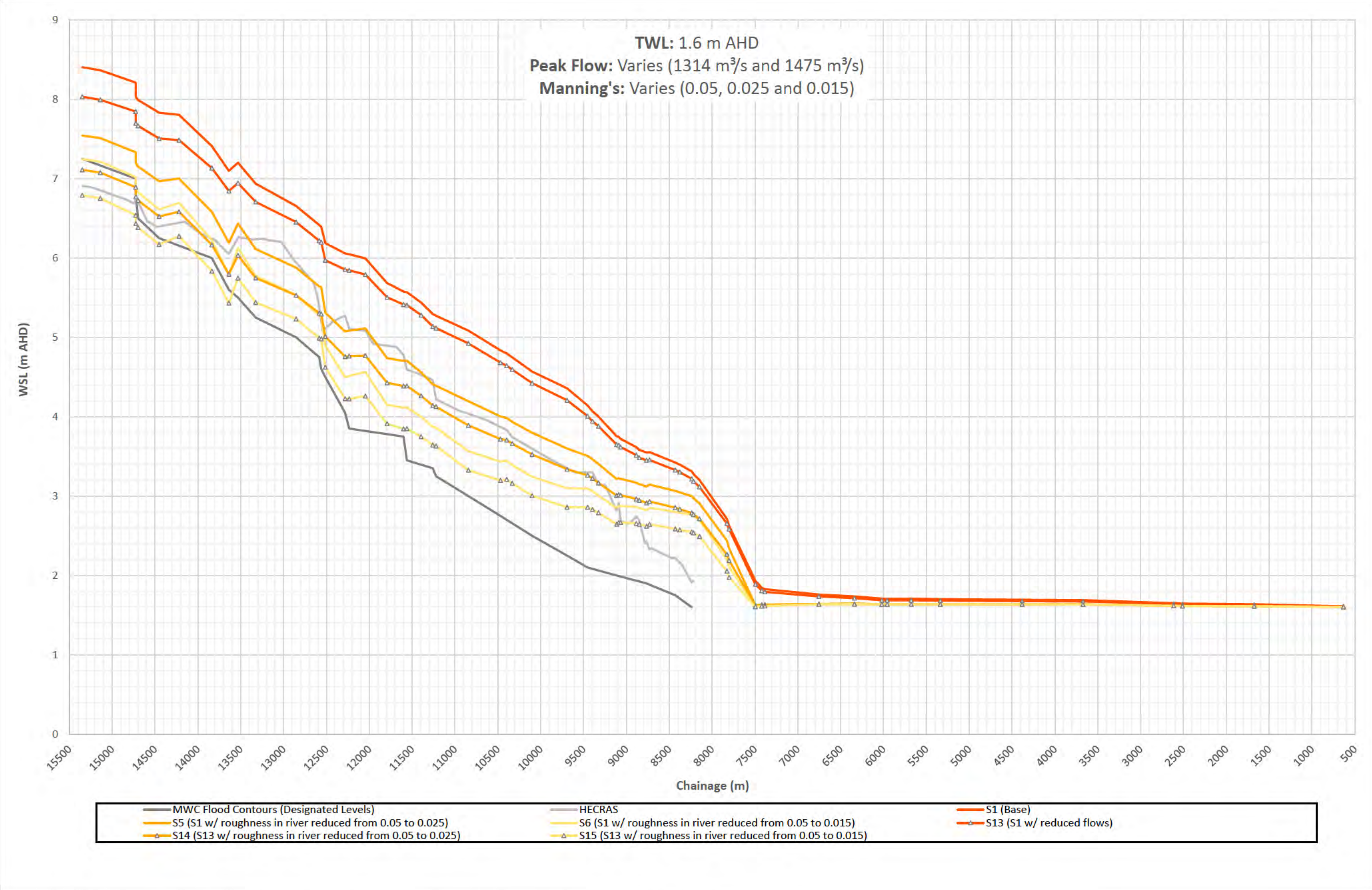


Figure 10 1.6 m AHD Fixed TWL TUFLOW WSL Result Comparison to MWC Designated Levels (Long Section 2b)

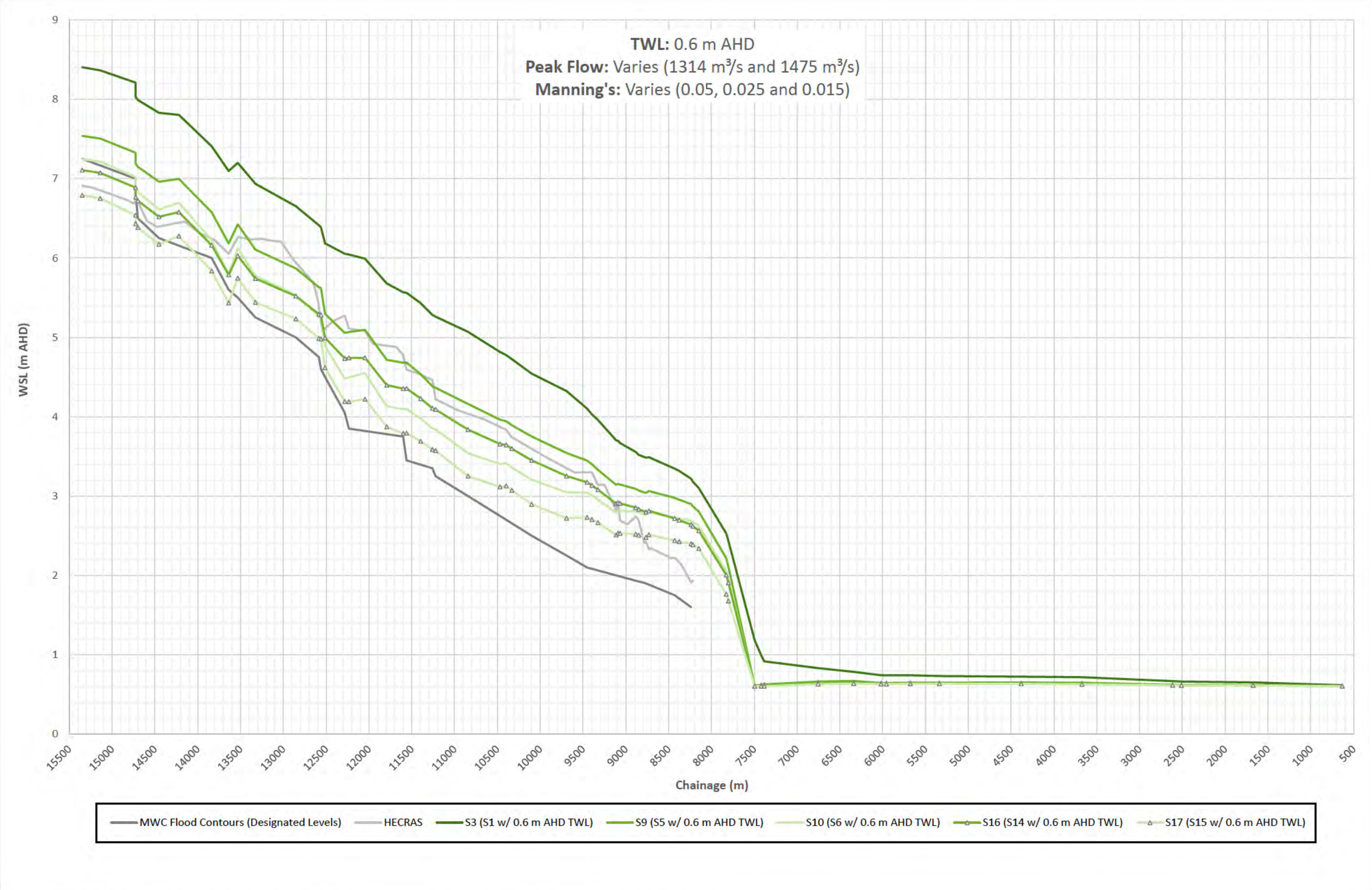


Figure 11 0.6 m AHD Fixed TWL TUFLOW WSL Result Comparison to MWC Designated Levels (Long Section 2c)

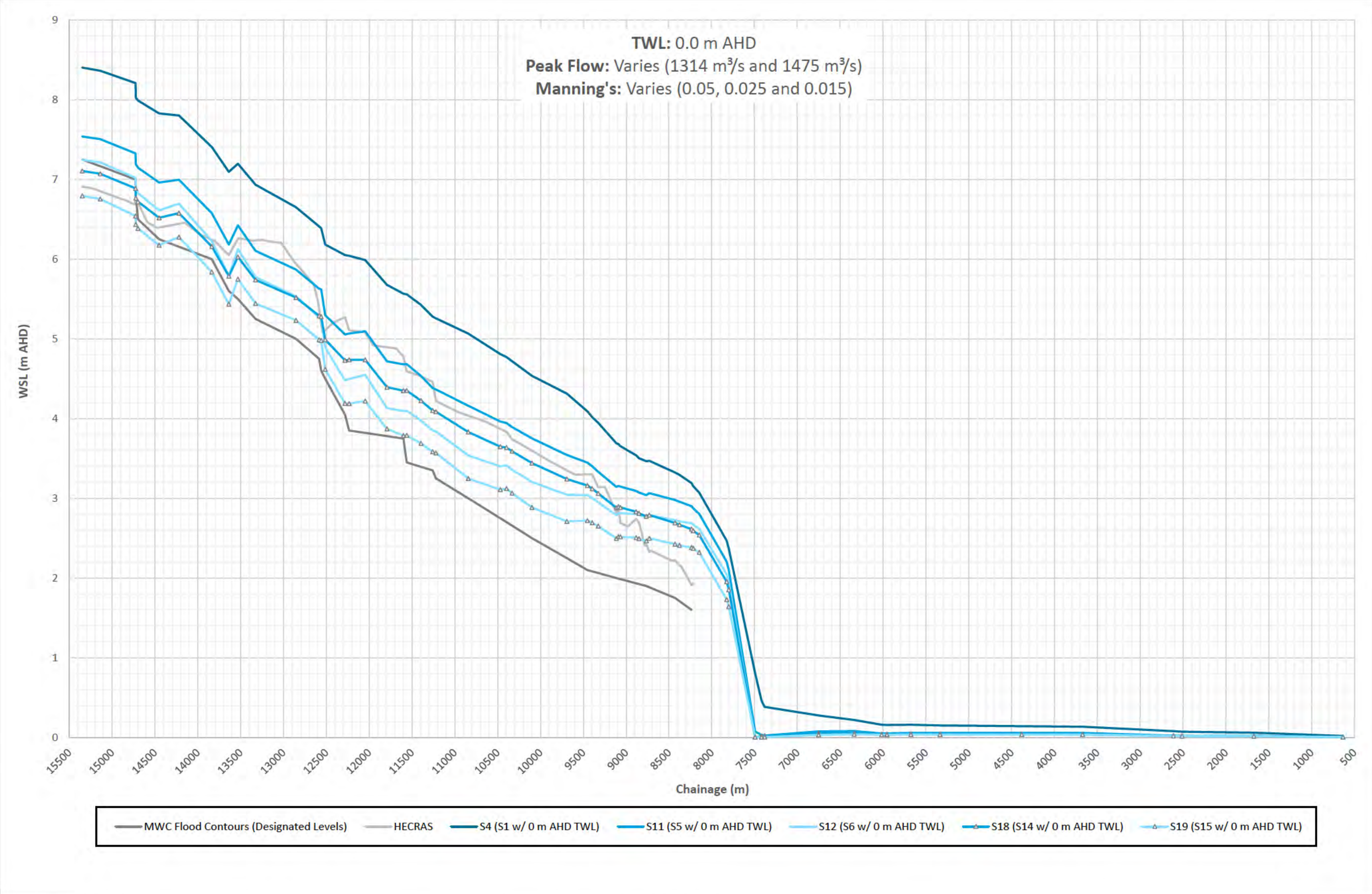


Figure 12 **0.0 m AHD Fixed TWL TUFLOW WSL Result Comparison to MWC Designated Levels (Long Section 2c)**

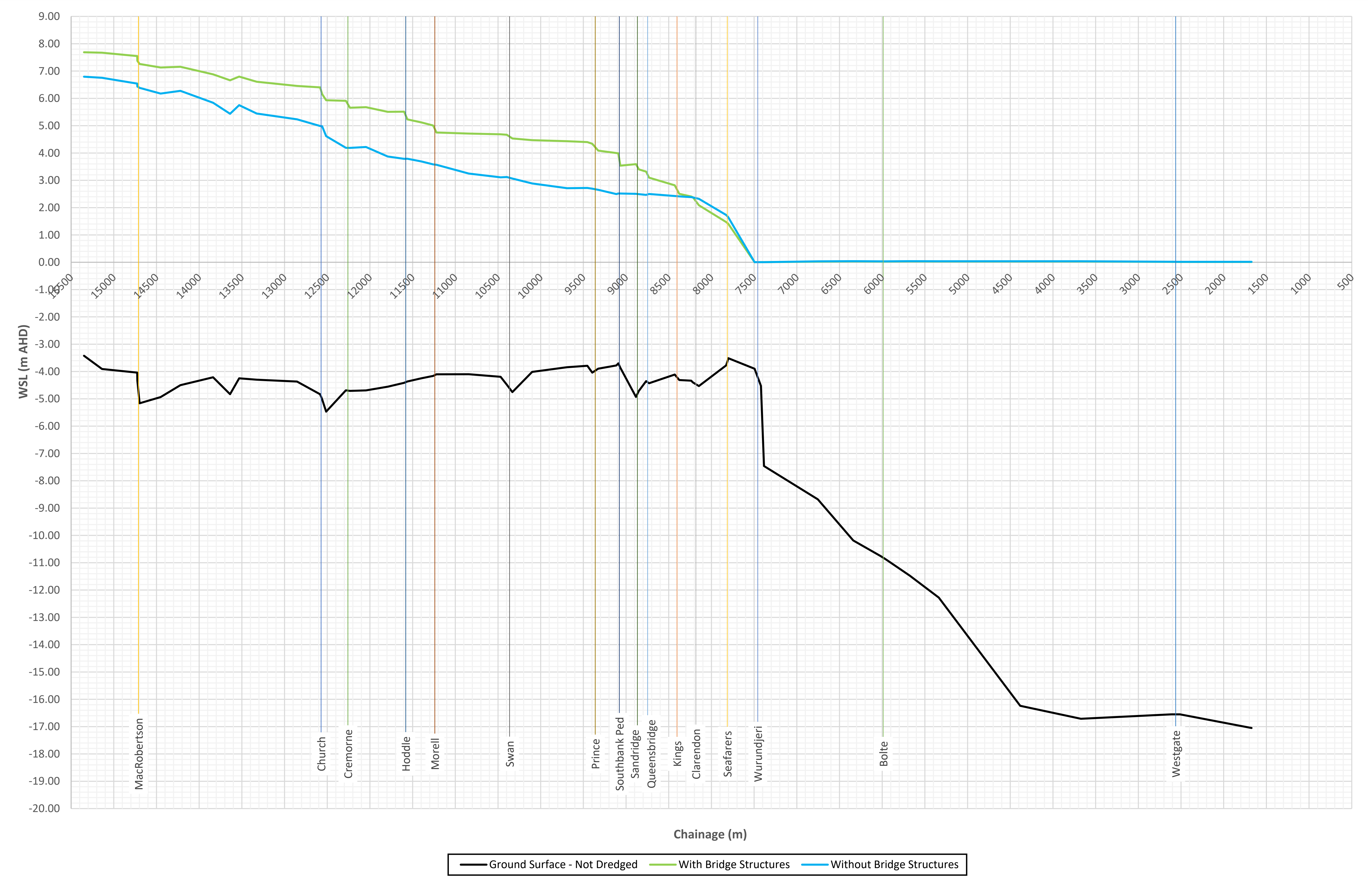


Figure 13 TUFLOW WSL Result Comparison – Impact of Structures (Long Section 3)

4.2 Results Discussion

Some of the differences in results above might be explained by one or a combination of the following factors:

1. Designated Levels are based on observations from the 1934 flood that is generally considered greater than a 100y ARI event (perhaps it was not greater than the 100 year at this location)
2. Designated Levels may be from an event which occurred when MWC was still dredging the Yarra River to a design profile that provides additional flow area (see Attachment 1 for a fax from MWC on a previous job in 1995).
3. The TWL for the event that generated the Designated Levels was much lower than the proposed design levels in the current scope (i.e. fixed TWL of 1.6 m AHD and 1.2 m AHD for the 100y and 5y ARI design events respectively). This raises the question of joint probability of bay levels and floods and perhaps also relates back to point 1.

4.3 Recommendation/Conclusion

As the preliminary results are so different to the current MWC Designated Levels it seemed appropriate that the potential implications of this be considered and that the project scope and assumptions be confirmed before the project proceeded. Following discussion with MWC it was decided that additional investigation should be undertaken to help understand the difference. To do this a quasi-verification of the model was proposed.

MWC Designated Levels represent the best currently available flood information along the Lower Yarra and as such a quasi-verification of the model to this data was deemed appropriate. As MWC Designated Levels were derived from the 1934 event and a dredging regime was maintained at the time, it was decided a dredged profile along the Yarra should be added to the model to represent the additional flow capacity dredging would have provided during the event. Comparing these results to the MWC Designated Levels would then highlight the impact of the dredged profile and facilitate an assessment of whether other factors could be responsible for any remaining difference.

5 Revised "Existing" and "Dredged" TUFLOW Modelling

5.1 Modelling Overview

Following the "initial" modelling discussed in Section 4, Melbourne Water commissioned a further investigation to:

- Better understand the difference between the "design storm" model results and their Designated Levels; and
- Assist in "verifying" some of the modelling assumptions.

MW Designated Levels were derived from the 1934 flood at which time the river is believed to have been actively dredged. Previous modelling represented existing river conditions that did not include dredging and so further investigation has involved the following:

- Applying a dredged river profile representing a likely 1934 dredging regime (available data did not cover full extent of likely works) – see discussion below under "*Dredged Profile*";
- Revising application of downstream tidal conditions to reflect latest information and improving the interpolation of bathymetry data along the thalweg – see discussion under "*Further Model Enhancement*"; and
- Comparing model results to the Designated Levels using a long-section profile along the river.

Dredged Profile

Based on available information (see Attachment 1) a defined dredged profile for the Yarra River was known between Hoddle Street Bridge and Spencer Street Bridge with the properties shown in Table 2 and Figure 14. This generated the simplified long-section profile shown in Figure 15, which shows that without further manipulation there would be barriers to conveyance upstream and downstream of the known dredged profiles. Given that the purpose of the dredging was to provide increased conveyance and the fact that the modelling was only to "verify" model assumptions, it was agreed with Melbourne Water that additional areas should be dredged to remove upstream and downstream humps in the channel invert. The revised extent of dredging is also shown in Figure 15.

Table 2 Dredged Profile Details

Location	Dimensions (m)	
	Depth (D)	Width (W)
Spencer Street Bridge to Princes Bridge	6.2	70
Princes Bridge to Swan Street Bridge	5.8	68
Swan Street Bridge to Hoddle Bridge	5.3	66

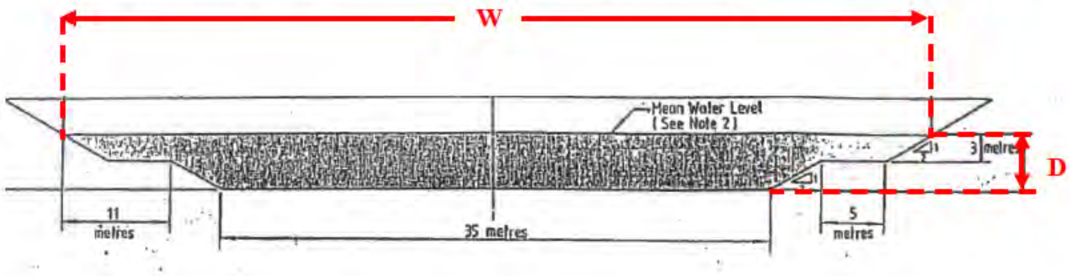


Figure 14 Provided dredged profile cross-section shape (extracted from Attachment 1)

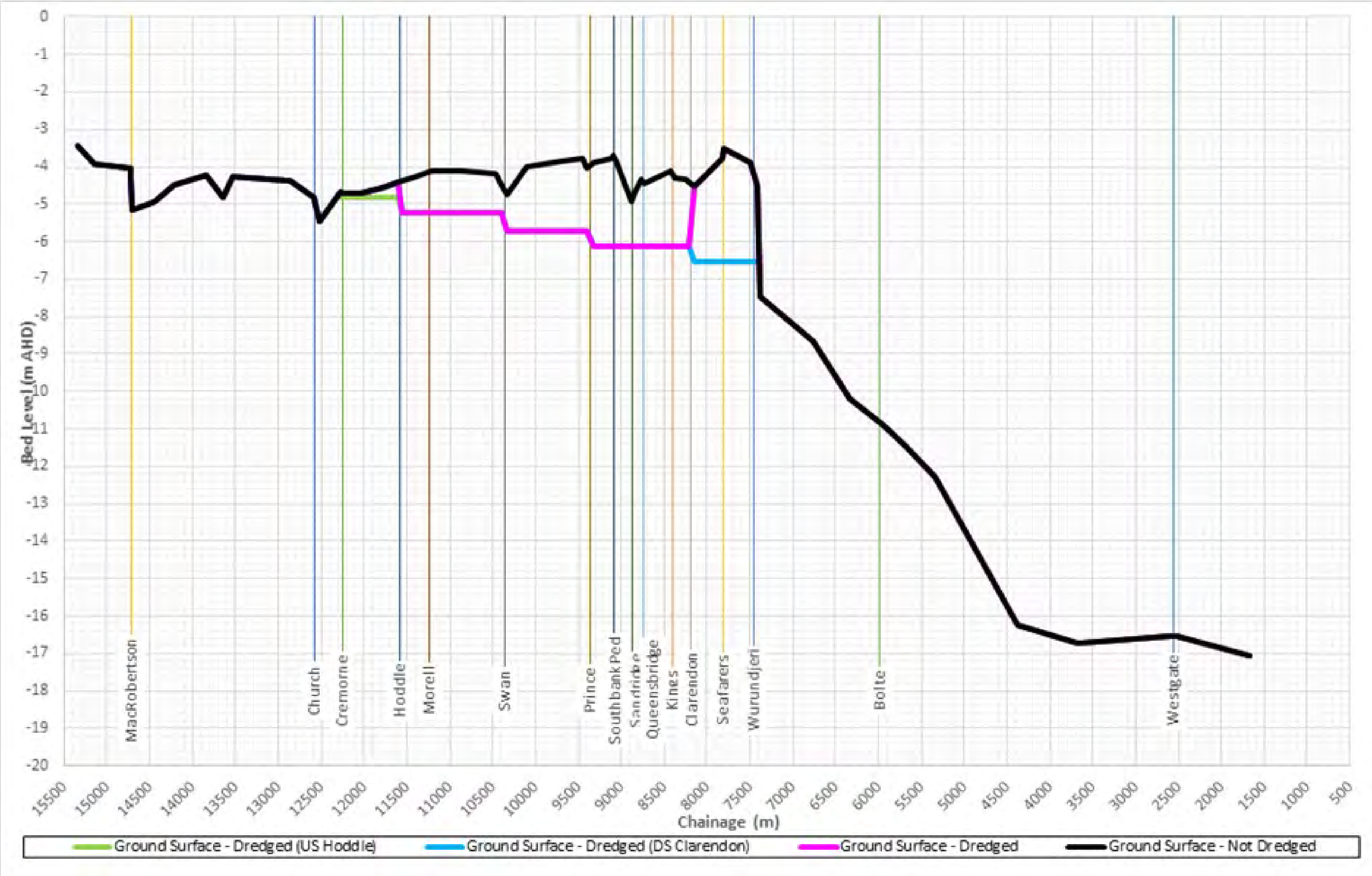


Figure 15 Simplified Long-Section Profile showing implications of dredged profile

Further Model Enhancement

As part of this second round of “exploratory” modelling, the following model enhancements were made:

1. The tidal curve shown in Figure 16 was adopted based on the following data provided by MWC:
    a. Tidal curves produces by Water Technology on another project
    b. Peak water levels to which to adjust peak tides for design event modelling based on the project brief and the MW Tech Spec
    c. Advice on the timing of the tidal curve relative to the peak of the hydrograph from 1934 event (refer to attached email dated 18/04/2019), which was adopted for the design events given the aim to provide confidence in the model results relative to the current Designated Levels.
2. Revised interpolation of bathymetry data based on HEC-RAS cross-sections to improve the representation of the thalweg, including its undulations. This change did alter the cross-sectional area of some of the river, but was confined to the low flow area that was already full due to the assumed initial water conditions and baseflow.

These enhancements require re-running of the “existing” conditions scenario so that the impact of the dredging could be clearly understood – see discussion in Section 5.2 on modelling scenarios.

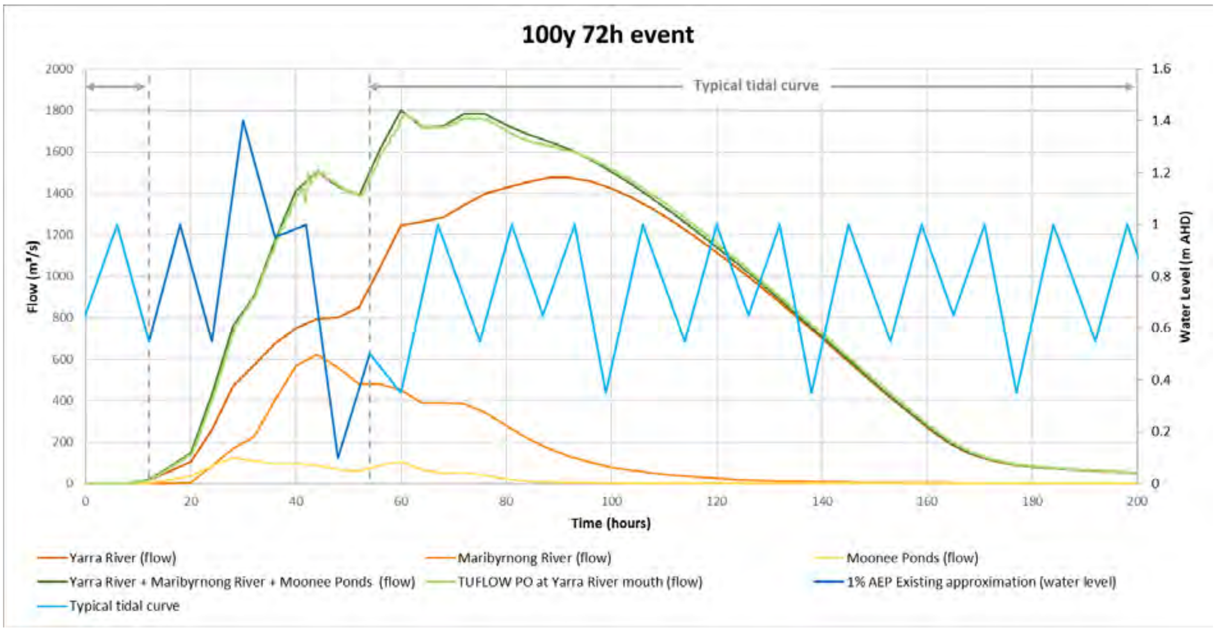


Figure 16 Adopted tidal boundary

5.2 Model Scenarios

Following finalisation of tidal curves and river bathymetry inputs, the 24 model scenarios shown in Table 3 (i.e. all combinations of variables represented) were run in TUFLOW (HPC GPU) for the 1 in 100 year AEP 72 hour storm event. A definition of the variables for each scenario is also provided in Table 4 below. These results were then compared against the MW Designated Levels with the subset of these results marked in Table 3 presented in Figures A-D (see results in Section 5.3).

Table 3 Full suite of scenarios run in TUFLOW and Summary of Plotted Results

River profile	Structures	Flow	Manning's			Number of Scenarios
			0.015	0.020	0.025	
Dredged	Modelled	High	A1/C1			3
		Low		B1/D1		3
	Not modelled	High			A2	3
		Low			B2	3
Existing[1]	Modelled	High	C2			3
		Low		D2		3
	Not modelled	High				3
		Low				3
Total Number of Modelled Scenarios						**24**

Note:
[1] indicates these models were rerun based on model refinements relating to:
- application of bathymetry data along the Yarra River corridor
- representation of tidal boundary based on latest information from MWC

Table 4 Scenario Definitions

Scenario		Definition
River profile	Dredged	Yarra River profile representing a likely 1934 dredging regime, using dredged profiles documented in "Attachment 1" and some agreed assumptions to provide a constant downhill grade along the Yarra River
	Existing	Yarra River profile representing current conditions, using the latest bathymetry and survey data available
Structures	Modelled	Structures modelled including: - Bridges crossing the Yarra River from MacRobertson Bridge to the Westgate Bridge - Piers along the river edge - CityLink bridge following the river edge (including sound walls)
	Not Modelled	No structures modelled
Flow	High	Yarra River flows obtained from the supplied Yarra River RORB model with a peak flow of 1475 m^3/s (k_c of 145). MWC current recommended flow.
	Low	Yarra River flows obtained from an adjusted version of the supplied Yarra River RORB model with a peak flow of 1314 m^3/s (k_c of 180). Sensitivity flow for comparison to MWC Designated Levels.
Manning's	0.015	Estimated lower bounds of Manning's n roughness for main channel areas of Yarra River (this lower bound is based on physical properties of channel from aerial)
	0.020	Intermediate estimate of Yarra River Manning's n roughness for main channel areas of Yarra River
	0.025	Estimated upper bounds of Manning's n roughness for main channel areas of Yarra River (this upper bound is based on physical properties of channel from aerial)

5.3 Results

This section presents the results for the subset of scenarios identified in Table 3 using the following four figures:

- Figures A & B (Figure 17 & Figure 18) show the selection of best-fit Manning's values for a dredged river profile
- Figures C & D (Figure 19 & Figure 20) show the application of these best-fit Manning's values to the existing river profile.

A brief discussion of each of these figures is presented below. A summary of the WSL results presented on each of the long sections is also provided in tabular format in Table 5.

Figure A

Figure A (Figure 17) presents model results along the Yarra River for the dredged river profile with high flows. The purpose of this figure is to identify the Manning's value that produces results closest to the MW Designated Levels for the given combination of scenarios.

Where structures were not modelled a Manning's value of 0.025 provided the best fit, while if structures were modelled a Manning's value of 0.015 provided the best fit.

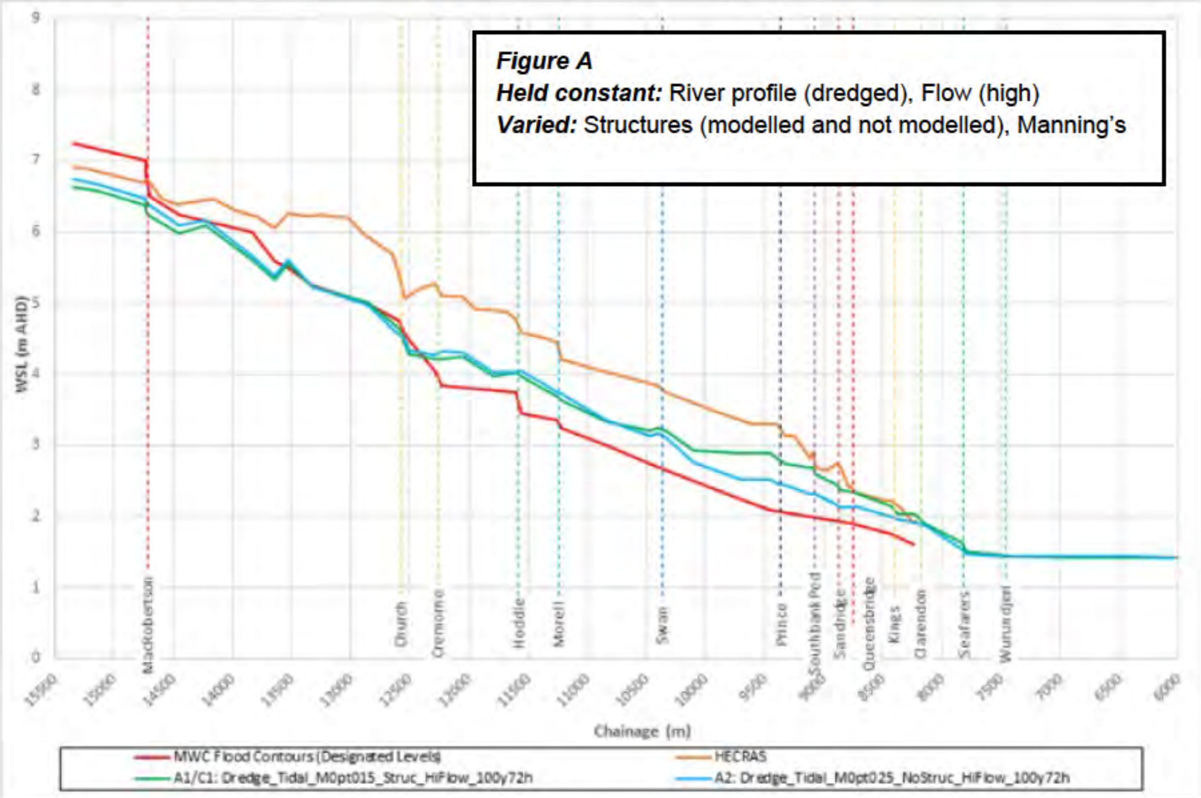


Figure 17 Dredged river profile with high flows (Figure A)

Figure B

Figure B (Figure 18) presents model results along the Yarra River for the <u>dredged</u> river profile with <u>low flows</u>. The purpose of this figure is to identify the Manning's value that produces results closest to the MW Designated Levels for the given combination of scenarios.

Where structures were not modelled a Manning's value of 0.025 provided the best fit, while if structures were modelled a Manning's value of 0.020 provided the best fit.

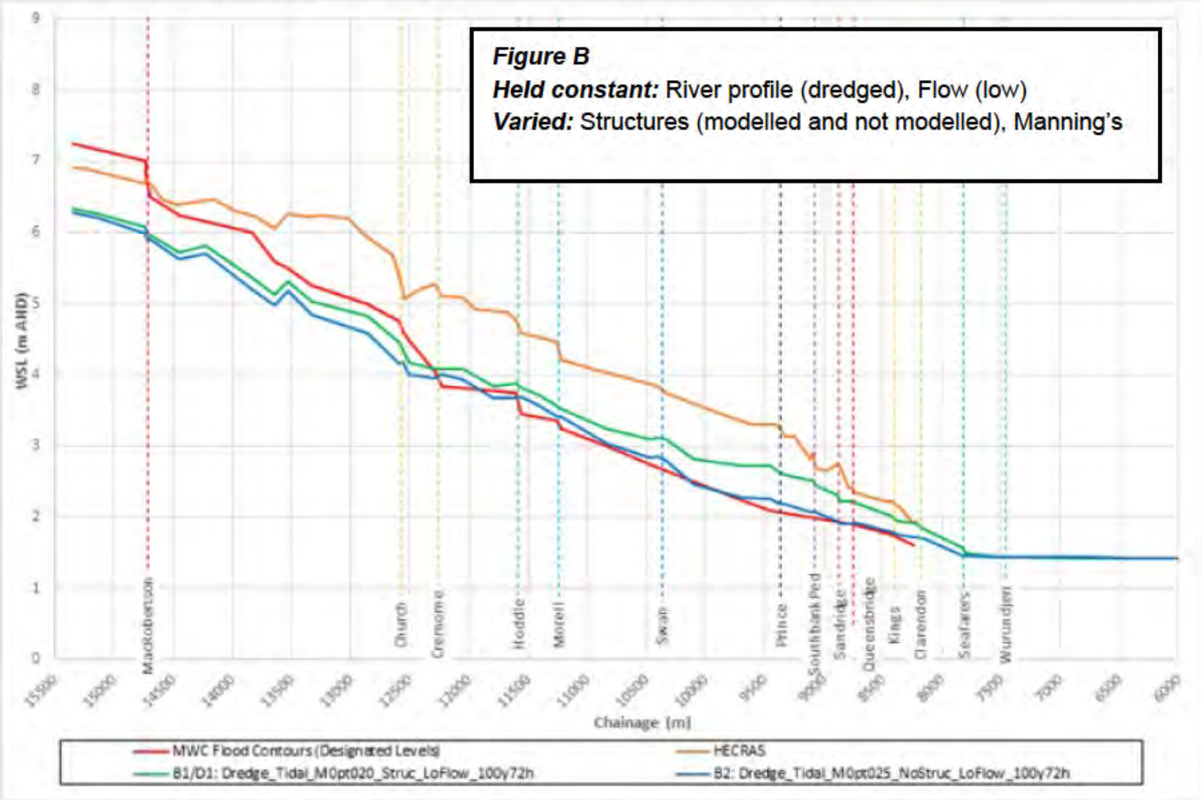


Figure 18 Dredged river profile with low flows (Figure B)

Figure C

Figure C (Figure 19) presents model results along the Yarra River for the same scenarios as in Figure A but with the existing river profile applied rather than the dredged river profile. The purpose of this figure is to observe model results when applying the best-fit Manning's value from Figure A to the existing river profile and to compare model results to the MW Designated Levels.

Model runs utilising the existing river profile can be seen to produce significantly higher levels than those of the dredged profile equivalent shown in Figure A.

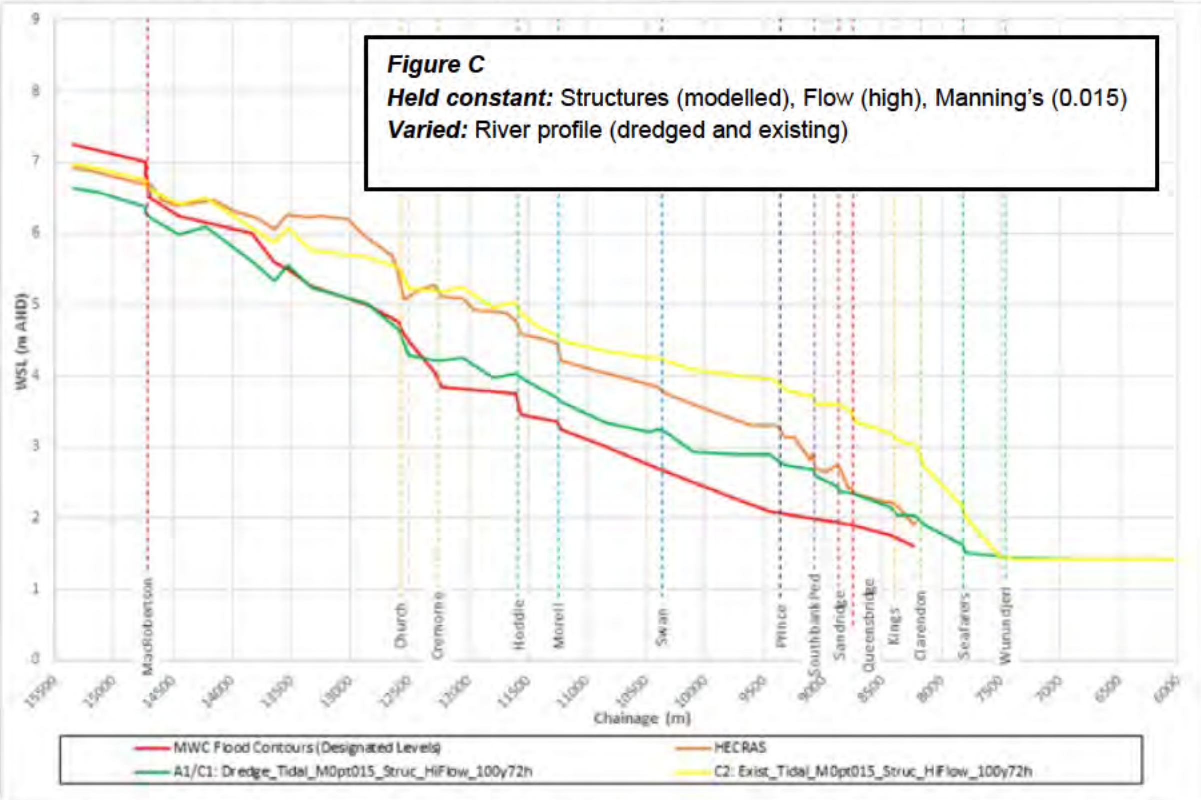


Figure 19 Existing vs dredged river profile with high flows, structures modelled and Manning's of 0.015 (Figure C)

Figure D

Figure D (Figure 20) presents model results along the Yarra River for the same scenarios as in Figure B but with the existing river profile applied rather than the dredged river profile. The purpose of this figure is to observe model results when applying the best-fit Manning's value from Figure B to the existing river profile and to compare model results to the MW Designated Levels.

Model runs utilising the existing river profile can be seen to produce significantly higher levels than those of the dredged profile equivalent shown in Figure B.

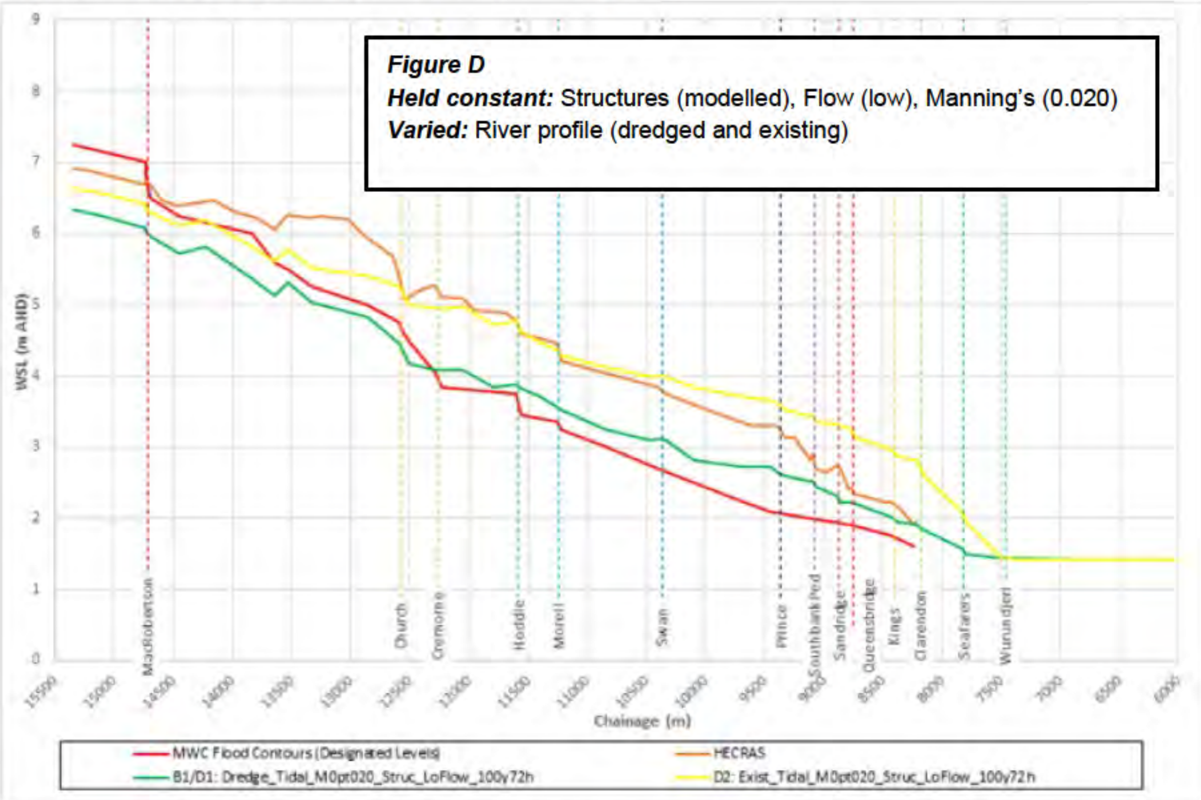


Figure 20 Existing vs dredged river profile with low flows, structures modelled and Manning's of 0.015 (Figure D)

Table 5 Summary of WSL results along Yarra River

		Event:	100 year 72 hour					
		River Profile:	Dredged	Dredged	Dredged	Dredged	Existing	Existing
		Flow:	High	High	Low	Low	High	Low
		Structures:	Yes	No	Yes	No	Yes	Yes
		Manning's:	0.015	0.025	0.02	0.025	0.015	0.02
			PLOT ID FOR FIGURES A – D (Figure 17 - Figure 20) and Table 3					
Description	**Chainage**	**MWC 100y WSL Contour (m AHD)**	**A1/C1**	**A2**	**B1/D1**	**B2**	**C2**	**D2**
	15349	7.25	6.64	6.75	6.34	6.28	6.97	6.63
	15138	-	6.57	6.68	6.26	6.20	6.91	6.57
	14726	7	6.37	6.46	6.08	5.99	6.74	6.41
US MacRobertson	14724	6.8	6.28	6.39	6.01	5.93	6.66	6.34
DS MacRobertson	14698	6.5	6.23	6.37	5.97	5.91	6.61	6.30
	14452	6.25	5.98	6.09	5.72	5.63	6.41	6.10
	14220	-	6.09	6.18	5.81	5.70	6.50	6.18
	13837	6	5.61	5.67	5.36	5.20	6.08	5.81
	13638	5.6	5.34	5.38	5.13	4.97	5.88	5.62
	13532	5.5	5.56	5.61	5.32	5.18	6.07	5.77
	13326	5.25	5.23	5.23	5.03	4.84	5.77	5.51
	12854	5	5.02	4.98	4.82	4.59	5.66	5.41
US Church	12584	4.75	4.64	4.54	4.46	4.17	5.52	5.25
DS Church	12560	4.6	4.49	4.55	4.34	4.18	5.41	5.16
	12513	4.5	4.29	4.34	4.17	4.01	5.23	5.00
US Cremorne	12282	4.05	4.21	4.28	4.08	3.95	5.20	4.96
DS Cremorne	12234	3.85	4.22	4.33	4.08	4.00	5.18	4.94
	12046	-	4.24	4.31	4.09	3.94	5.24	4.97
	11792	-	3.98	4.03	3.85	3.67	4.97	4.71
US Hoddle	11600	3.75	4.03	4.02	3.87	3.67	5.03	4.76
DS Hoddle	11561	3.45	3.97	4.04	3.82	3.69	4.87	4.63
	11395	-	3.83	3.90	3.71	3.57	4.68	4.47
US Morell	11259	3.35	3.69	3.74	3.57	3.42	4.57	4.36
DS Morell	11221	3.25	3.64	3.73	3.53	3.41	4.49	4.30
	10843	3	3.33	3.36	3.25	3.05	4.34	4.12
	10469	2.75	3.21	3.14	3.11	2.83	4.25	4.00
US Swan	10397	-	3.24	3.16	3.12	2.85	4.25	4.00
DS Swan	10332	-	3.21	3.11	3.09	2.80	4.22	3.98
	10100	2.5	2.93	2.75	2.83	2.46	4.09	3.85
	9692	2.25	2.89	2.52	2.73	2.27	4.00	3.72
	9453	2.1	2.89	2.52	2.72	2.25	3.95	3.66
US Prince	9396	-	2.82	2.47	2.66	2.21	3.91	3.63
DS Prince	9326	-	2.75	2.45	2.60	2.19	3.80	3.53
	9114	2	2.68	2.31	2.52	2.08	3.71	3.44
US Southbank Ped	9090	-	2.68	2.31	2.52	2.08	3.73	3.46
DS Southbank Ped	9067	-	2.59	2.31	2.44	2.08	3.61	3.37
US Sandridge	8884	-	2.46	2.16	2.31	1.95	3.59	3.33
DS Sandridge	8850	-	2.36	2.13	2.23	1.92	3.57	3.30
US Queensbridge	8765	1.9	2.34	2.12	2.21	1.91	3.51	3.24
DS Queensbridge	8730	-	2.33	2.14	2.20	1.92	3.36	3.14
US Kings	8430	1.75	2.15	2.00	2.03	1.79	3.20	2.97
DS Kings	8377	-	2.04	1.96	1.94	1.76	3.09	2.88
	8237	1.6	2.05	1.92	1.93	1.73	3.03	2.82
US Clarendon	8217	-	2.01	1.90	1.90	1.71	3.02	2.82
DS Clarendon	8147	-	1.91	1.89	1.83	1.71	2.72	2.59
US Seafarers	7827	-	1.63	1.54	1.58	1.47	2.17	2.08
DS Seafarers	7802	-	1.52	1.48	1.49	1.46	2.03	1.95
US Wurundjeri	7495	-	1.45	1.44	1.45	1.44	1.44	1.44
DS Wurundjeri	7420	-	1.45	1.44	1.44	1.44	1.44	1.44
	7384	-	1.43	1.44	1.43	1.44	1.43	1.43
	6754	-	1.43	1.44	1.43	1.43	1.43	1.43
	6339	-	1.43	1.43	1.43	1.43	1.43	1.43
US Bolte Bridge	6019	-	1.43	1.43	1.43	1.43	1.43	1.43
DS Bolte Bridge	5957	-	1.43	1.43	1.43	1.43	1.43	1.43
Confluence with Moone Ponds Creek	5677	-	1.43	1.43	1.43	1.43	1.43	1.43
	5337	-	1.43	1.43	1.43	1.43	1.42	1.42
	4383	-	1.42	1.43	1.42	1.42	1.42	1.42
Confluence with Maribyrnong River	3673	-	1.42	1.42	1.42	1.42	1.42	1.42
US Westgate Bridge	2613	-	1.41	1.41	1.41	1.41	1.41	1.41
DS Westgate Bridge	2512	-	1.41	1.41	1.41	1.41	1.41	1.41
US Westgate Bridge	1674	-	1.41	1.41	1.41	1.41	1.41	1.41
DS Westgate Bridge	633	-	1.40	1.40	1.40	1.40	1.40	1.40

5.4 Discussion

For the modelled event (100 year ARI, 72 hour storm), looking at the dredged model results with structures and high flows applied (Figure A) a Manning's of 0.015 seems to produce results closest to the MWC Designated Levels. This scenario resulted in the following general model differences to MW Designated Levels:

- Minimal variance around Cremorne Rail Bridge.
- Lower levels upstream of Cremorne Rail Bridge, with a maximum difference of over half a metre just upstream of Cremorne Rail Bridge.
- Higher levels downstream of Cremorne Rail Bridge, with a maximum difference of nearly 1 metre at Princes Bridge.

Utilising the "best fit" Manning's 'n' value from the dredged scenario and applying to the existing scenario with structures modelled and high flows applied (Figure C) resulted in the following general model differences to MW Designated Levels:

- Minimal variance at the upstream end of the model (around MacRobertson Bridge).
- Increasing differences downstream of MacRobertson Bridge (modelled WSLs greater than Designated Levels), exceeding 1 metre at Cremorne Bridge and reaching a maximum of almost 2 metres at Princes Bridge.
- Water levels downstream of Wurundjeri Way (beyond the extent of MWC Designated Levels) are dominated by tidal conditions.

Given that both the existing and dredged "verification" results are so different to the current MWC Designated Levels it seems appropriate that the potential implications of this are considered and that the project scope and assumptions are confirmed before the project proceeds. Reasons for this variance may include the following:

1. Designated Levels are based on observations from the 1934 flood that is generally considered greater than a 100 year ARI event (perhaps it was not greater than the 100 year ARI at this location).
2. Design event hydrology does not simulate real event hydrology.
3. The hydrologic model from which the 100 year ARI hydrographs were extracted may have represented an ARI in excess of the 100 year ARI due to rainfall likely not applying areal reduction factors (ARFs) and thus point storms are being applied throughout the catchment
4. The adopted design hydrology may have been significantly adjusted to improve the fit of the HECRAS hydraulic model across a much larger extent of the Yarra River.
5. While the river profile was altered to represent 'dredged' 1934 conditions, the surrounding terrain and structures have not been modified from those that represent 'existing' conditions to those that would represent conditions during the 1934 event
6. The LiDAR used to define the ground surface around the Yarra River (not including the river bathymetry) may not be completely accurate and reliable.

5.5 Recommendation/Conclusion

In discussions with Melbourne Water, GHD raised concerns that there were potential limitations in the hydrology and/or terrain that may be influencing the “verification” modelling results. Of particular concern were the following items:

- The lack of Areal Reduction Factors (ARFs), which would increase volume and peak flows.
- The adoption of RORB routing parameters to generate design hydrographs for use in TUFLOW (a 2D hydraulic model) based on ‘calibration’ of a HEC-RAS model (1D hydraulic model) – when we could adopt parameters based on ‘calibration’ of hydrologic flows using RORB.
- A comparison of current LiDAR circa 2018 to that used for this Study circa 2009 shows some noticeable differences in levels that may influence results (particularly where overtopping levels are affected).

However, MWC advised that they were comfortable with the current assumptions in the hydrology/hydraulics used for the “verification” modelling (refer to attached email train dated 6/9/2019) and that GHD should proceed with the required “design runs” with the main channel roughness that achieves results closest to the current MW designated levels.

6 Initial Design Run Assumptions and Developments

6.1 Model Setup and Assumption

Based on outcomes of modelling discussed in Section 5, GHD commenced design run modelling with the general agreed setup shown in Figure 21 and the following parameters/assumptions:

- Adopt provided MWC hydrologic models with assumptions as per Table 10
- Adopt final model setup as per Section 6, with a Manning’s ‘n’ roughness of 0.015 for the major waterway areas.

Table 6 Hydrologic Assumptions

Model Parameter	**Yarra River**	**Maribyrnong River**
RORB Version	6.15	6.15
Rainfall	Stormfiles with variable IFD (adopted from 2016 Yarra River Study)	ARR1987 IFD @ inbuilt "Keilor" location
ARF	None (adopted from 2016 Yarra River Study)	None (for consistency with 2016 Yarra River Study)
Kc	145 (adopted from 2016 Yarra River Study)	70
m	0.8	0.8
IL (mm)	Varies with interstation area: • YarRv@YarGlen-DummyGS = 30 • Catchment outlet = 15	20
Runoff Coefficient	Varies with ARI: • 100y = 0.60 • 50y = 0.55 • 20y = 0.50 • 10y = 0.45 • 5y = 0.40	Varies with ARI: • 100y = 0.6 • 50y = 0.55 • 20y = 0.45 • 10y = 0.35 • 5y = 0.25
Climate Change	Factored rainfall in stormfiles by 1.16 to represent 16% increase as per latest Tech Spec	Adjusted IFD parameters to increase rainfall intensity by 16%

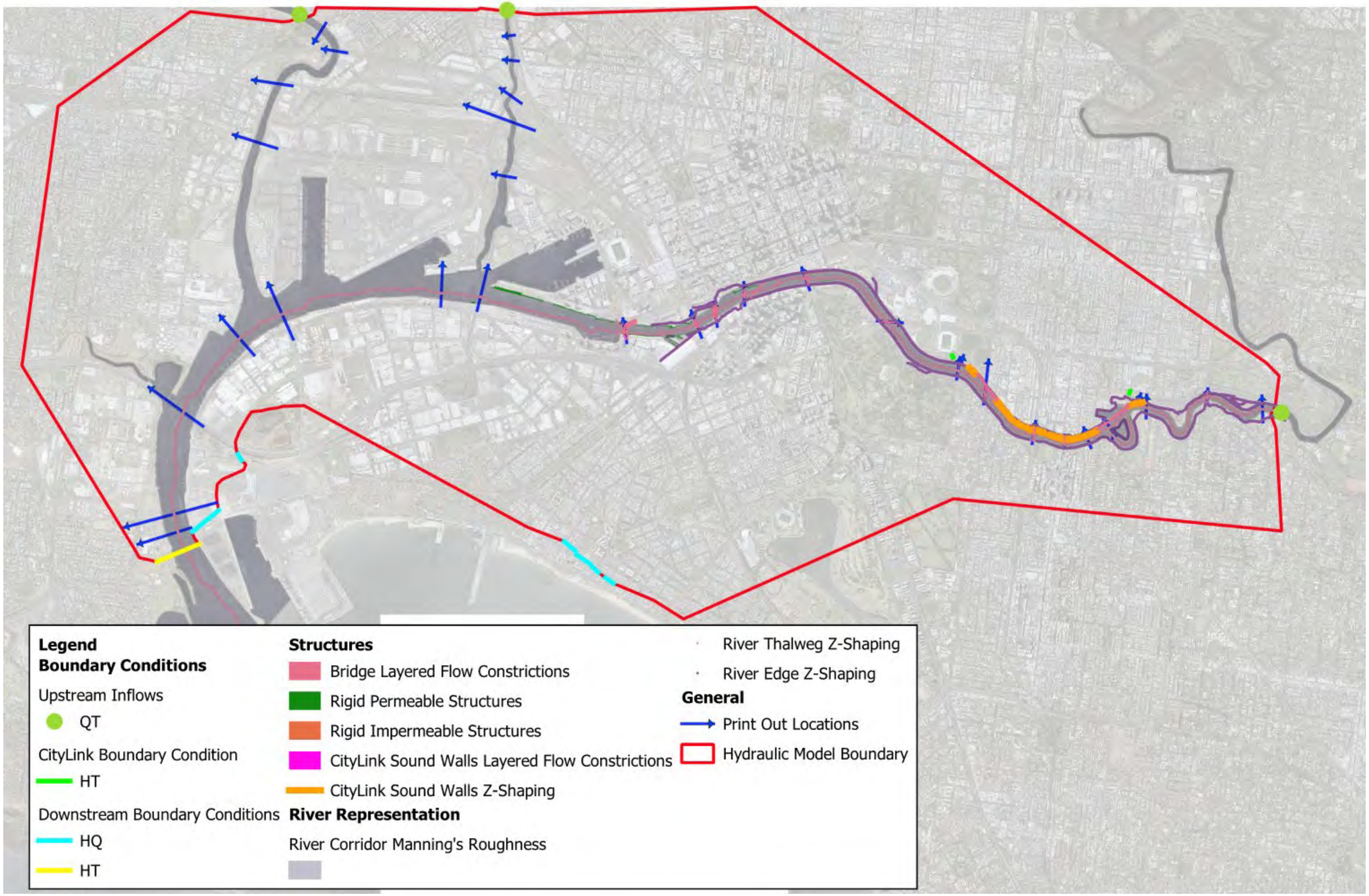


Figure 21 **Final TUFLOW Model Setup (after "verification" and initial "design run" modelling)**

6.2 Additional model changes required

During the process of undertaking the “design runs”, GHD discovered a number of issues with the coding in the TUFLOW software that required changes or simplifications to the modelling approach to achieve a stable model result. The following changes were required after much testing and discussion with TUFLOW Support:

- Remove “SMS Triangles” output format as this was not compatible with traditional flow constrictions;
- Adjust model setup to allow for modelling of tidally influenced areas upstream of Study Area (see revised model setup in **Figure 21**):
  - Add “HX” lines and 1d_nodes to upstream end of three tributaries with inflows to represent storage upstream of the Study Area and reduce potential sloshing off code boundary
  - Alter downstream code boundary to avoid undulating terrain and converted non-Yarra River boundary conditions to “HQ” – i.e. only tidal boundary is on Yarra River
  - Run model for a period (choose 36 h) prior to event starting to set up initial conditions based on a typical tidal cycle (i.e. enables the model to establish an appropriate initial water surface profile along the Yarra River)
- Removed traditional “flow constriction” and “cell width reduction” layers from models as these layers couldn’t handle the range of depths present in the model and were generating corrupt or erroneous results.

6.3 MW review of “Design Run” results

Following delivery of the “design run” results, MW reviewed the results in more detail and became concerned with the level of overtopping around Southbank (which were outside the current assigned mapping limit) and the difference in the modelled levels with both the current designated and historic 1934 flood levels. This review was undertaken by a new project manager at MW who observing that the modelled levels were considerably higher than expected recommended undertaking some model refinements to gain greater confidence in levels outside the tidally influenced confines of the lower Yarra River,. There was also concern over the current directive to model a 100 year ARI with a 100 year bay level given the joint probabilities of these events.

7 Southbank Overflow Refinement Modelling

7.1 Modelling Overview

After discussion regarding the initial design runs, it was decided that additional effort should be made to refine the models representation of the overflow area along Southbank. This refinement focussed on adopting details from the following existing local models, which were adjusted as required for the different grid size and alignment:

- Fisherman’s Bend;
- Southbank.

The key changes to the model used for the ‘design runs’ were as follows:

1. The use of a different terrain model in the Southbank model area;
2. The introduction of additional terrain modifications from local models, in particular the:
   - The surveyed level along the southern Yarra River bank (stretching from St Kilda Road to just east of the Bolte Bridge);
   - The level defining the spill elevation into the Southbank City Link tunnel portal.
3. The review and refinement of the catchment roughness (materials layer).

4. The adoption of an alternate boundary condition arrangement with the 100 year ARI flood event being matched with a 10 year tidal bay level to match assumptions of local modelling and simplistically considers the joint probability concerns.

Considering that we are trying to understand impact of flooding emanating from the Yarra River spilling, it was agreed that the local drainage should not be added as this is likely to be heavily influenced by the presence of non-return mechanisms and/or pump stations that may restrict or alter the magnitude and timing of back flow.

After some initial runs, the concerns with the current hydrology outlined in Section 5.5 were revisited and some models with alternate hydrology were run as discussed further below.

7.2 Model Scenarios

Based on all the previous discussions and validation modelling the scenarios defined in Table 7 were ultimately run for this model configuration using “HPC on GPU” engine in TUFLOW to facilitate a more efficient comparison of scenarios. A comparison of the modelled inflows and the change in downstream boundary conditions for these models are also presented in Figure 22 and Figure 23 respectively. These scenarios were run in three phases as highlighted in Table 7, with the scope of the next phase being defined based on discussion of results of the previous phase

7.3 Results and Discussion

The results of the three phases of modelling undertaken at this stage are presented in detail as Attachments 4 – 6, but can be summarised as follows:

- Phase 1
  - Results showed that model refinements did reduce the flood extent in the Southbank area, but there was still some substantial differences in results between the local models and significant inflow to the City Link tunnel portal in this area which was of concern as this was not previously thought to occur (see Figure 24). Refer to Attachment 4 for all presented results.
  - After discussing the results in detail, it was jointly agreed that the concerns over the hydrology should be revisited with some new model runs and that the output of these runs should also be compared to 1934 historic level points.
- Phase 2
  - Results showed that the alternate hydrology brought the modelled flood levels along the Yarra River more in line with historic levels (see Figure 25) and reduced, but didn’t eliminate inflows to City Link tunnel portal in Southbank. Refer to Attachment 5 for all presented results.
  - After discussing the results in detail, it was jointly agreed that the river roughness should be re-considerred against historic levels using the alternate hydrology that uses the Kc parameter from MW work prior to “2010 - SP Goh & Associates Study” and applies Areal Reduction Factors (ARFs). This would reduce concern that current river roughness was at the extreme smooth end of values that could be justified based on literature.
- Phase 3
  - Results showed that a number of roughness could provide results that are fairly consistent with MW’s understanding of the relative magnitude of the 1934 flood (see Figure 26). There was however discussion over a change in the fit at around Chainage 12,500 and why this might be occurring (such as limitations of the current upstream simplification of inflow application and the representation of available storage upstream.

Table 7 Overflow Refinement Model - Modelled Scenario Definitions

Phase	Runs	Hydrology	Yarra River Inflow (m^3/s)	Yarra River Inflow Volume (m^3)	Downstream Tailwater Level (TWL)	River Roughness (Manning's 'n')
1	1	Base 1% AEP (Kc=145 w/o ARFs)[1] [Solid blue line on Figure 22]	1475	517,000,000	1% AEP Tide	0.015
1	2	Base 1% AEP (Kc=145 w/o ARFs)[1] [Solid blue line on Figure 22]	1475	517,000,000	10% AEP Tide	0.015
2	3	Base 1% (Kc=237 w/o ARFs)[2] [Solid orange line on Figure 22]	1115	517,000,000	10% AEP Tide	0.015
2	4	Base 1% AEP (Kc=180 w/ ARFs)[3] [Solid green line on Figure 22]	1091	432,000,000	10% AEP Tide	0.015
2	5	CC 18.5% 1% AEP (Kc=145 w/o ARFs) [1] [Dashed blue line on Figure 22]	1792	621,000,000	10% AEP SLR Tide	0.015
2	6	CC 18.5% 1% AEP (Kc=237 w/o ARFs) [2] [Dashed green line on Figure 22]	1352	621,000,000	10% AEP SLR Tide	0.015
2	7	CC 18.5% 1% AEP (Kc=180 w ARFs) [3] [Dashed green line on Figure 22]	1293	509,000,000	10% AEP SLR Tide	0.015
3	8	Base 1% AEP (Kc=180 w/ ARFs) [3]	1091	432,000,000	10% AEP Tide	0.020
3	9	Base 1% AEP (Kc=180 w/ ARFs) [3]	1091	432,000,000	10% AEP Tide	0.025
3	10	Base 1% AEP (Kc=180 w/ ARFs) [3]	1091	432,000,000	10% AEP Tide	0.030
3	11	CC 18.5% 1% AEP (Kc=180 w ARFs) [3]	1293	246,000,000	10% AEP SLR Tide	0.020
3	12	CC 18.5% 1% AEP (Kc=180 w ARFs) [3]	1293	246,000,000	10% AEP SLR Tide	0.025
3	13	CC 18.5% 1% AEP (Kc=180 w ARFs) [3]	1293	246,000,000	10% AEP SLR Tide	0.030
3	14	CC 18.5% 10% AEP (Kc=145 w/o ARFs)[1]	831	291,000,000	10% AEP SLR Tide	0.015
3	15	CC 18.5% 10% AEP (Kc=180 w ARFs) [3]	616	246,000,000	10% AEP SLR Tide	0.020
3	16	CC 18.5% 10% AEP (Kc=180 w ARFs) [3]	616	246,000,000	10% AEP SLR Tide	0.030

Note:
[1] indicates that the Kc parameter is based on calibration to flood levels using HEC-RAS from "2010 - SP Goh & Associates Study", which didn't use ARFs.
[2] indicates that the Kc parameter is based on calibration to gauge flows from "2010 - SP Goh & Associates Study" , which didn't use ARFs
[3] indicates that the Kc parameter is based on MW work prior to "2010 - SP Goh & Associates Study", but with the application of ARFs

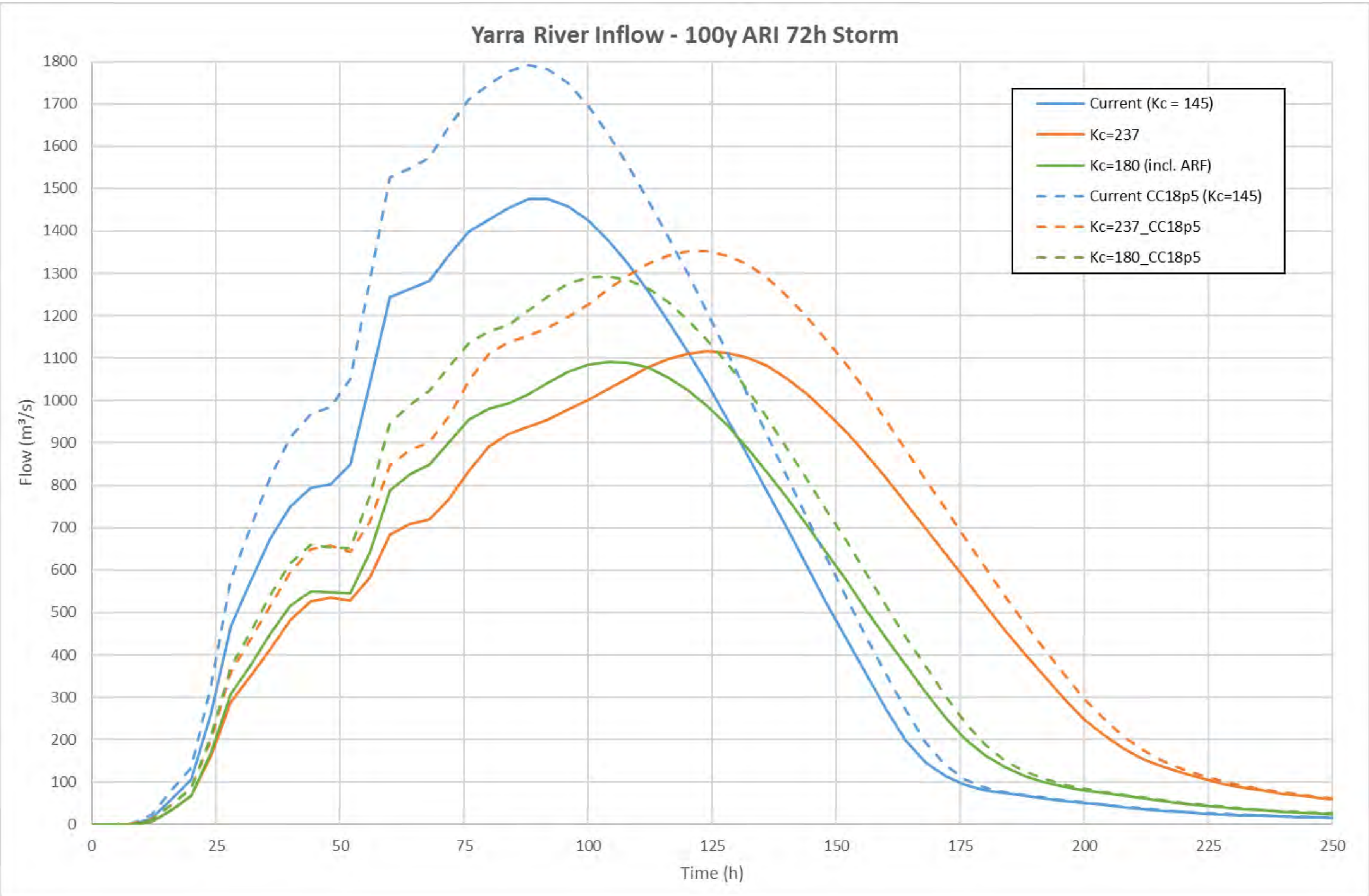


Figure 22 **Comparison of modelled Yarra River inflows**

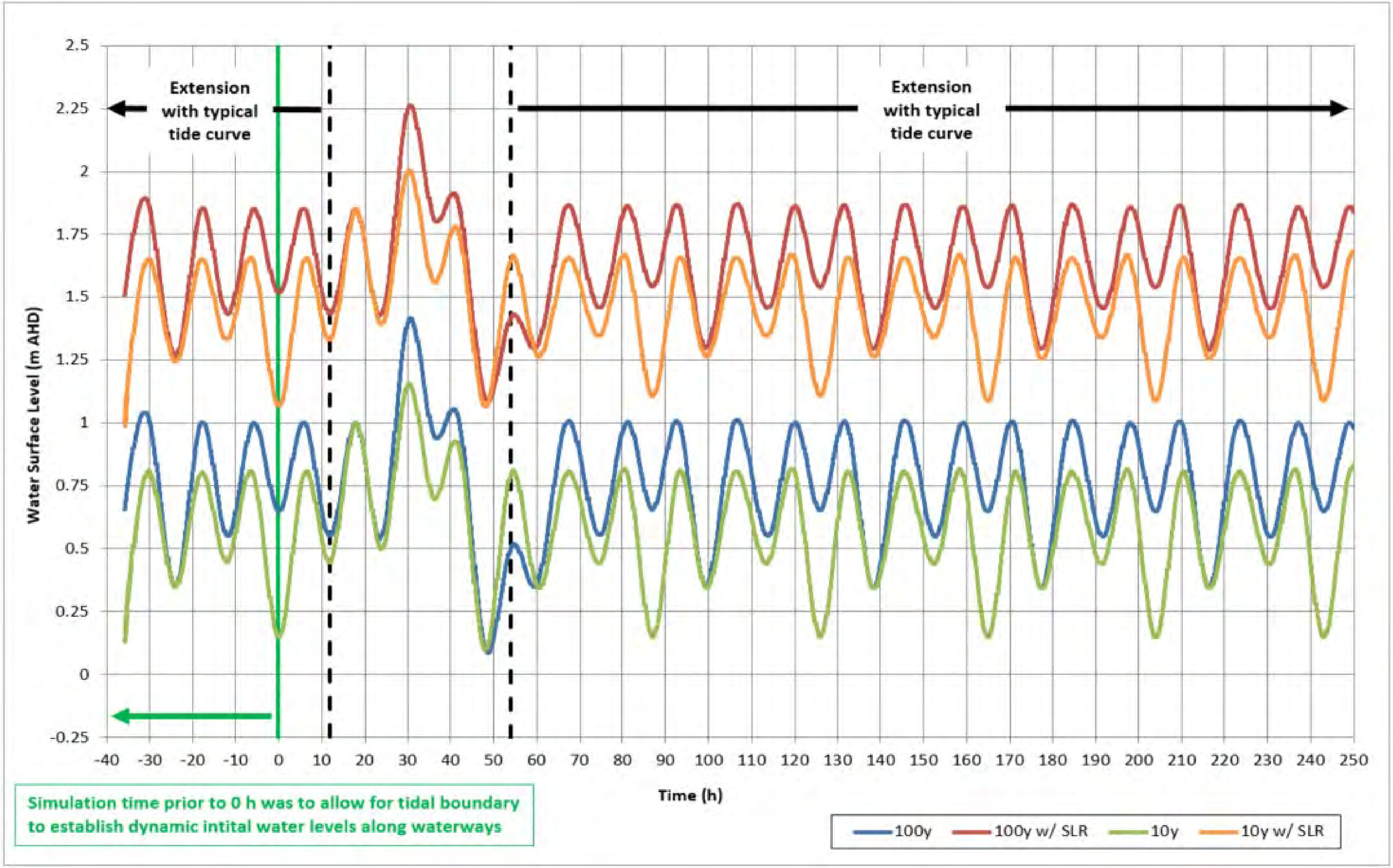


Figure 23 **Comparison of modelled downstream boundary condition or TWL**

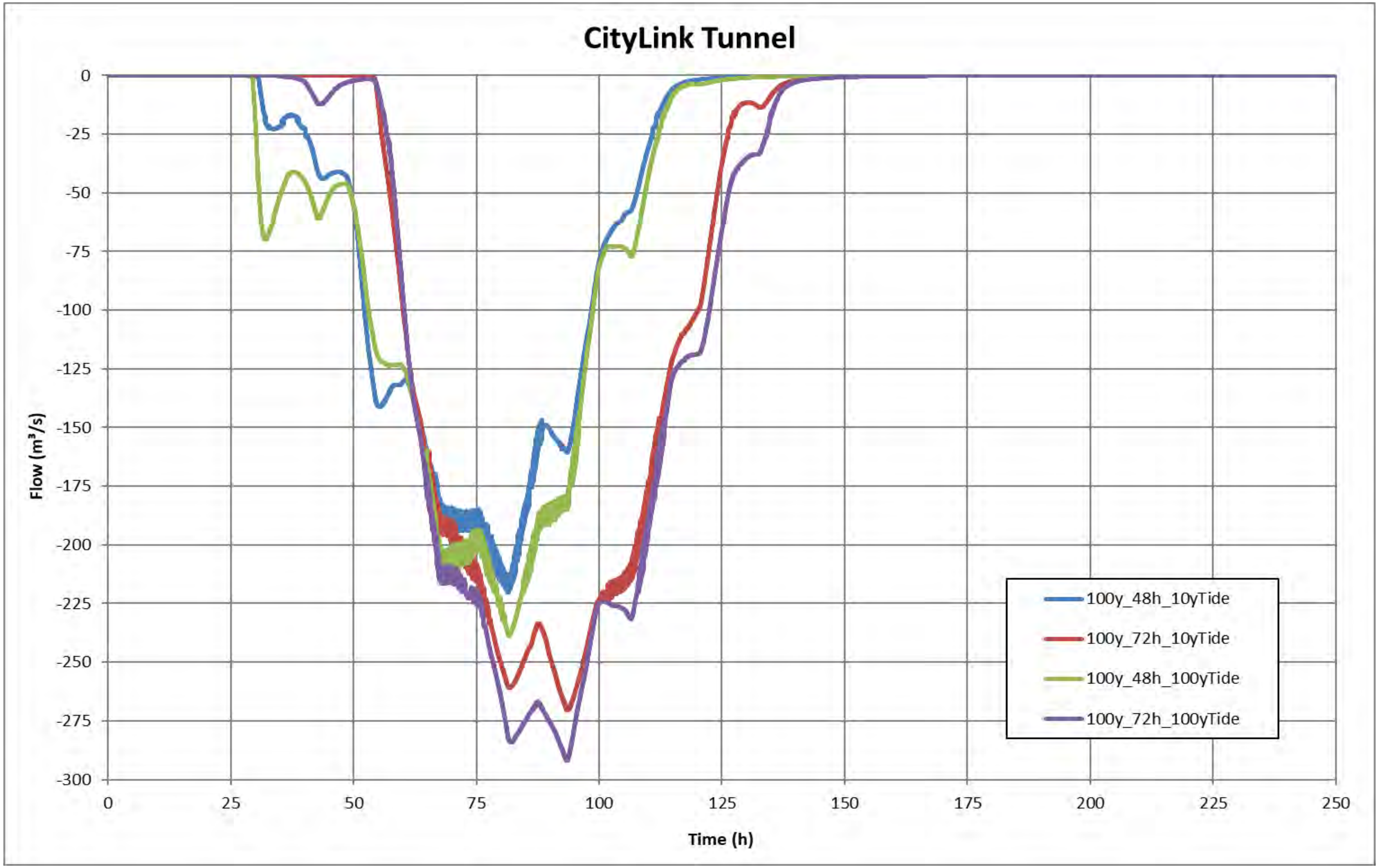


Figure 24 Phase 1 Model Refinement – City Link Tunnels Southbank Portal flows

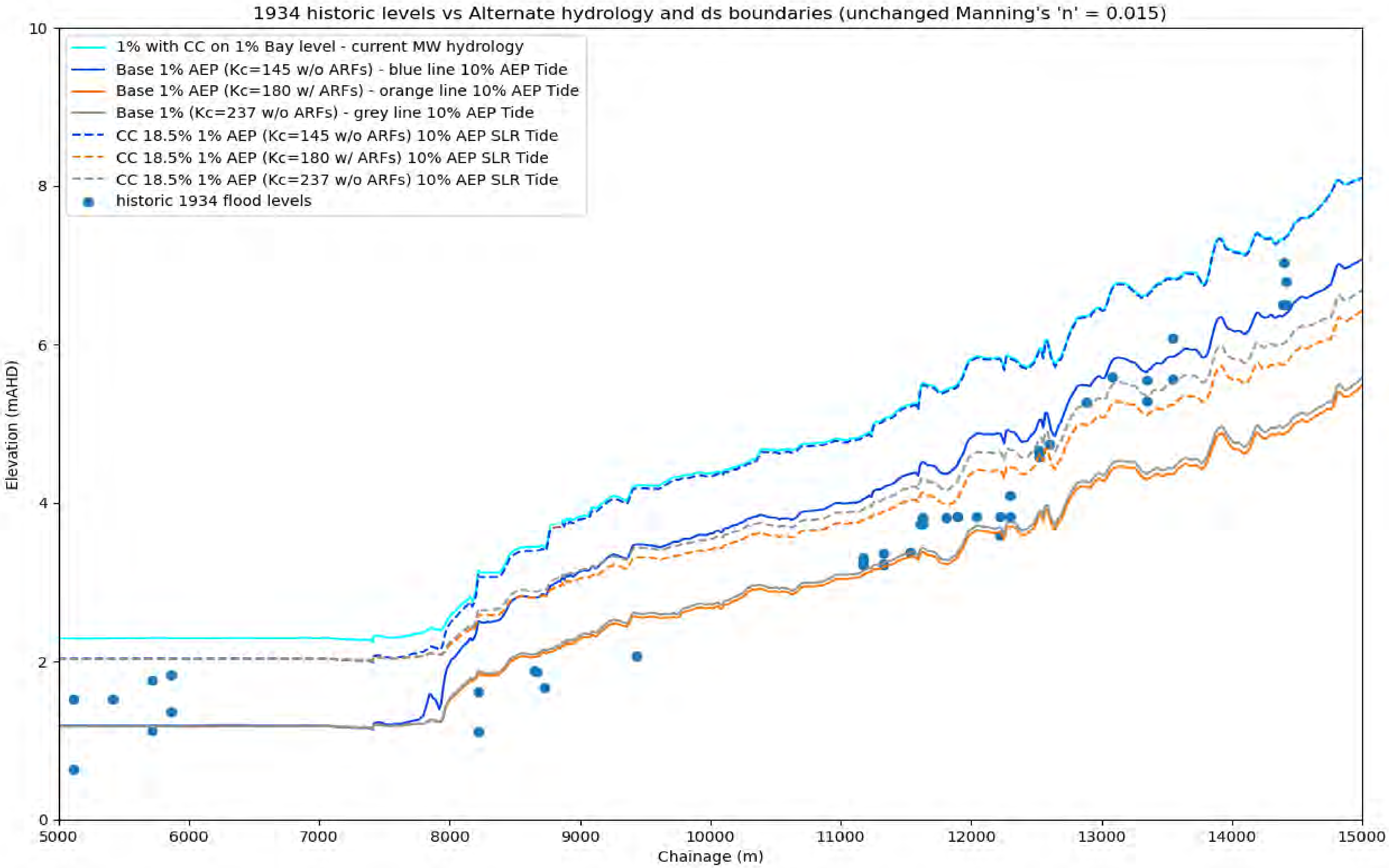


Figure 25 Phase 2 Model Refinement – Yarra River Long-Section comparison to historic levels

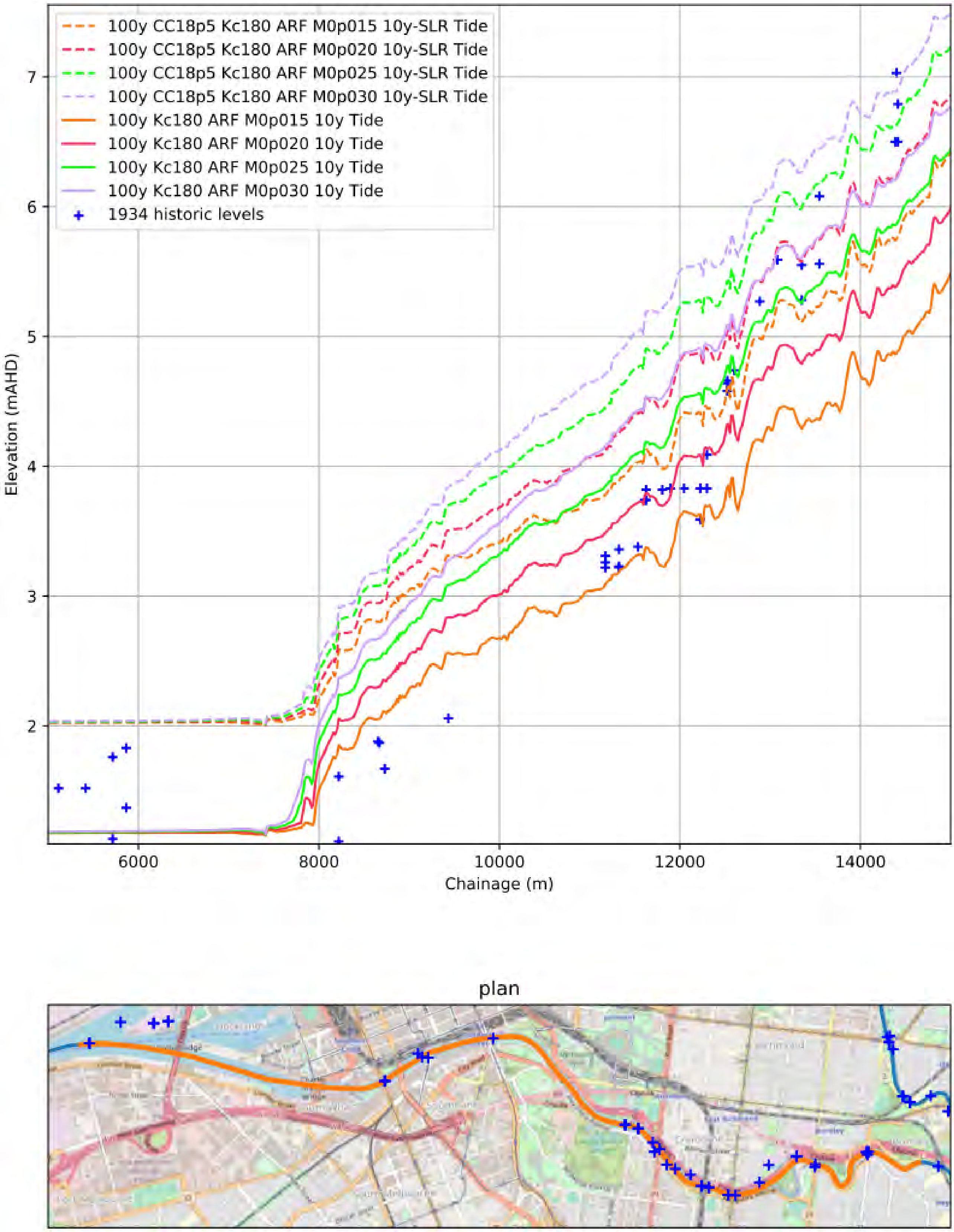


Figure 26 Phase 3 Model Refinement – Yarra River Long-Section comparison to historic levels

7.4 Recommendation/Conclusion

Based on the results of this phase of model refinements, it was jointly agreed that the model should be extended upstream along the Yarra River using data from an existing TUFLOW model developed for the North East Link Project (NELP) and then filling in the gap between the models. This extension of the model will remove or at the very least reduce the magnitude of potential boundary condition effects on results and facilitate a greater understanding of the impact of assumptions like the assumed roughness of the waterway over a greater distance of the Yarra River and the associated “Validation against 1934 flood levels.

For this work to take place MW would need to get approval from NELP team to utilise the ‘existing conditions’ model and provide GHD with details of the missing structures between the upstream limit of the Lower Yarra River model and the downstream limit of the NELP model.

8 Extension of model further up Yarra River

8.1 Modelling Overview

Based on outcomes of the Southbank Overflow model refinements, the model was extended to include the Yarra River all the way to the upstream limit of the NELP “existing conditions” model near the confluence with Plenty River. Following agreement from NELP, this process involved the following key changes:

- Extended code boundary and adding terrain sources from both models adopting grid orientation from Lower Yarra River model;
- Merge materials layers from models and create one river materials layer that allows for consistent modification of river roughness;
- Adjusting terrain modifications and any 1d elements from ‘existing” conditions NELP model to suit new grid orientation;
- Modifying inflow application so that tributary inflows and subarea inflows for the Yarra River are applied incrementally with the agreed revised parameters (i.e. Kc of 180- with ARFs); and
- Adding terrain, initial conditions and structure details for the following features within the “existing conditions” NELP model or between it and Lower Yarra River models:
  - Yarra River thalweg.
  - Dights Falls (including upstream initial water level pond).
  - A preliminary representation of additional bridges and structures across the river, including:
    - Monash Freeway.
    - Chandler Highway.
    - Eastern Freeway.
    - Bridge Road.
    - Hawthorn Rail Bridge.
    - Wallen Road.
    - Heyington Rail Bridge.
    - Banksia Street
    - Main Yarra Trail (x3) and Darebin Creek Trail shared user path (SUP) bridges.
    - Fairfield Pipe Bridge.
    - Kanes Bridge
    - Johnston Street.
    - Barkers Road.

The setup of the extended model is also summarised in Figure 27, which highlights the new extent of the model and the key features/inputs of this new model.

After some initial runs, the extended model setup was tested with TUFLOW Classic and then with TUFLOW’s new ‘Sub-Grid Sampling’ (SGS) functionality due to the apparent differences with the previous “HPC on GPU” results, as well as the historical 1934 flood levels and current MW designated levels.

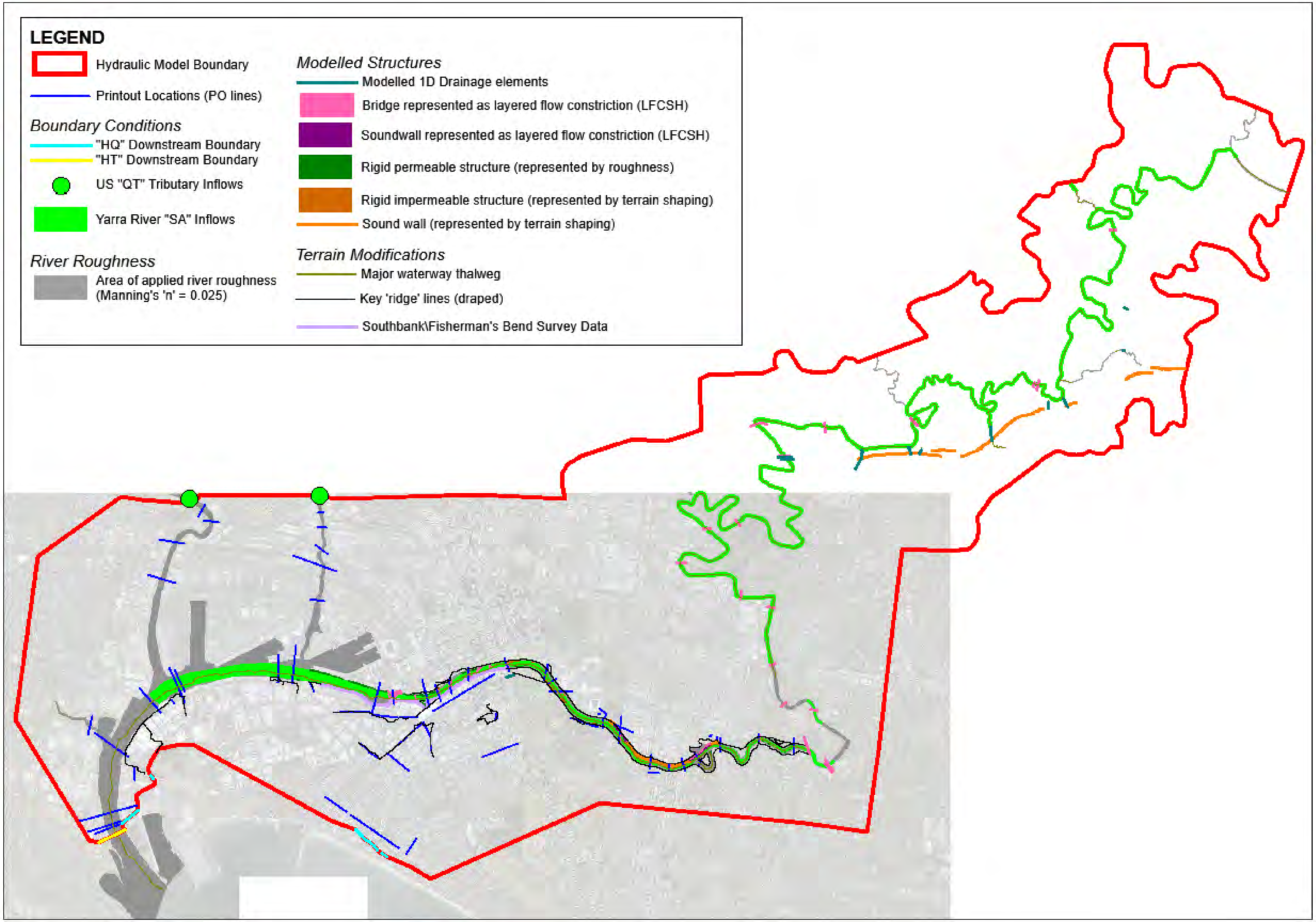


Figure 27 Extended TUFLOW Model Setup

8.2 Model Scenarios

Based on all the previous discussions and validation modelling the scenarios defined in Table 8 were ultimately run for this model configuration. A comparison of the modelled inflows and the change in downstream boundary conditions for these models are also presented in Figure 22 and Figure 23 respectively in Section 7.2. These scenarios were run in several phases as summarised in Table 8, with the scope of subsequent phases being defined based on discussion of results of the previous phase(s)

Table 8 Extended Model - Modelled Scenario Definitions

Phase	Run	*Hydrology* [1]	Yarra River Inflow (m^3/s)	Yarra River Inflow Volume (m^3)	Downstream Tailwater Level (TWL)	River Roughness (Manning's 'n')	TUFLOW Engine
1	1	*Base 1% AEP*	1091	432,000,000	10% AEP Tide	0.020	HPC (DP)
1	2	*Base 1% AEP*	1091	432,000,000	10% AEP Tide	0.025	HPC (DP)
1	3	*CC 1% AEP (18.5% increased intensity)*	1293	246,000,000	10% AEP SLR Tide	0.020	HPC (DP)
1	4	*CC 1% AEP (18.5% increased intensity)*	1293	246,000,000	10% AEP SLR Tide	0.025	HPC (DP)
2	5	*Base 1% AEP*	1091	432,000,000	10% AEP Tide	0.025	Classic
2	6	*Base 1% AEP*	1091	432,000,000	10% AEP Tide	0.025	HPC (SP)
2	7	*Base 1% AEP*	1091	432,000,000	10% AEP Tide	0.025	SGS (Default - SGS Partial Grid Update Null Frac == 0.1, 0.9)
3	8	*Base 1% AEP*	1091	432,000,000	10% AEP Tide	0.025	SGS (SGS Partial Grid Update Null Frac == 0.6, 0.6)
3	9	*Base 1% AEP*	1091	432,000,000	10% AEP Tide	0.025	SGS (SGS Partial Grid Update Null Frac == 0.1, 0.1)

Note:
[1] indicates that the Kc parameter is based on MW work prior to "2010 - SP Goh & Associates Study", but with the application of ARFs

8.3 Results and Discussion

The results of the three phases of modelling are summarised as follows:

- Phase 1
  - Results showed that model extension generally brought flood levels down relative to the smaller model, which allows for more characteristic roughness values to be utilised to see reasonable correlation with the historic levels along the full length of the model. The results also showed that the hydrology based on Kc of 180 with ARFs were generally more realistic in the TUFLOW model than the parameters adopted by MW from their recent work on the Yarra River using HECRAS as documented in Section 5. The full results are presented in Attachment 5, with the key output summarised by the long-section plot presented in Figure 28.
  - After discussing the results in detail, it was jointly agreed that the model adopting a river roughness of 0.025 should be used for a test of TUFLOW Classic engine and that the output of these runs should also be compared to those from the “HPC on GPU” run.
- Phase 2
  - Afflux results for a test model of the 1% AEP run with TUFLOW’s “Classic” engine compared to the “HPC on GPU” run are presented in Figure 29. This plot shows that the TUFLOW “Classic” results are substantially different to the “HPC on GPU” results, which raises questions over the validity of this engine for production (or design) runs given the now poor fit with historic levels.
  - After discussing the results in detail, it was jointly agreed that the model should be re-run with the new ‘Sub-grid Sampling’ (SGS) functionality – which has been shown for deeper flows relative to grid size, through benchmarking and calibration on Brisbane River, to provide greater correlation with TUFLOW Classic results than HPC alone, and more importantly, greater correlation with real world examples (flume tests and flood events). It was agreed that the “SGS” test model should adopt default settings and a sampling size of 2 m (or 1/5 of the cell size).
- Phase 3
  - The results of the “SGS” modelling is presented in Figure 30, which shows that the results with SGS enabled provide a better fit than the TUFLOW “Classic” engine results compared to the historic levels. The “SGS” levels were lower than the “HPC on GPU” runs that were used to test the hydrology, model extent and roughness – but through discussions with MW were deemed the most appropriate because it is anecdotally believed that the 1934 historic levels are higher than the 1% AEP in this area.

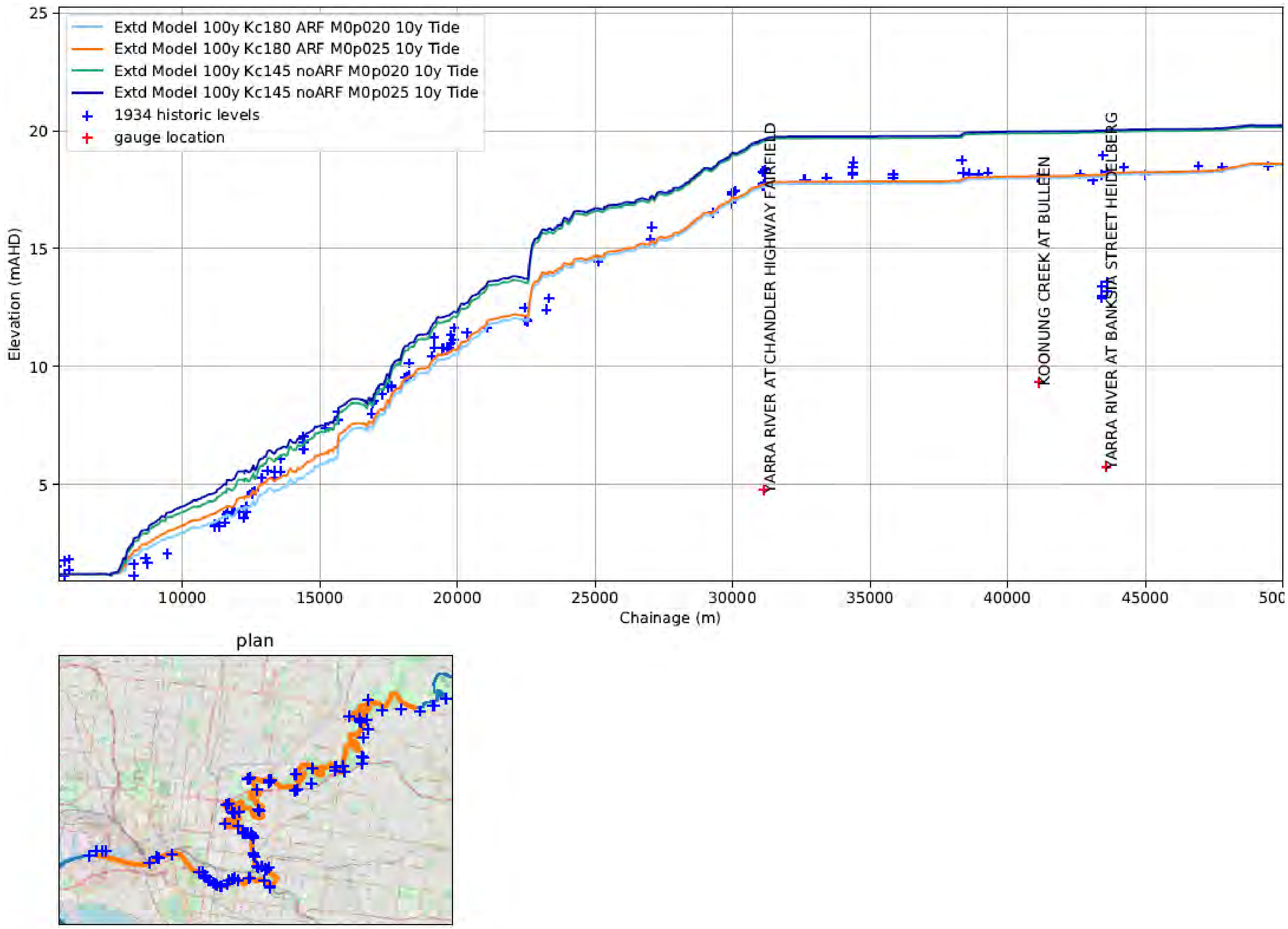


Figure 28 Phase 1 Model Extension – Yarra River Long-Section comparison of water level from various hydrologic assumptions to historic levels

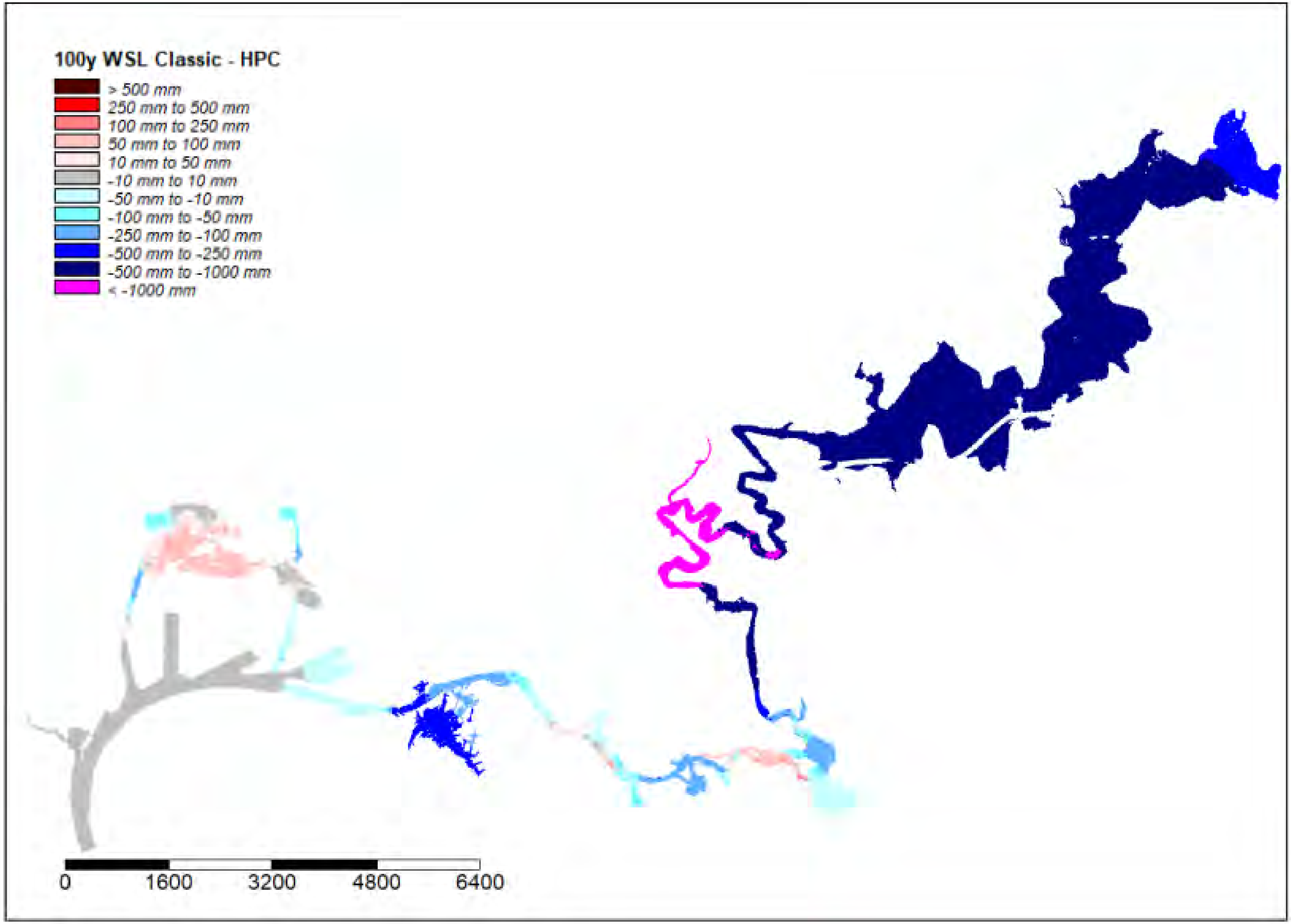


Figure 29 Phase 2 Model Extension – Afflux between TUFLOW Classic and TUFLOW “HPC on GPU”

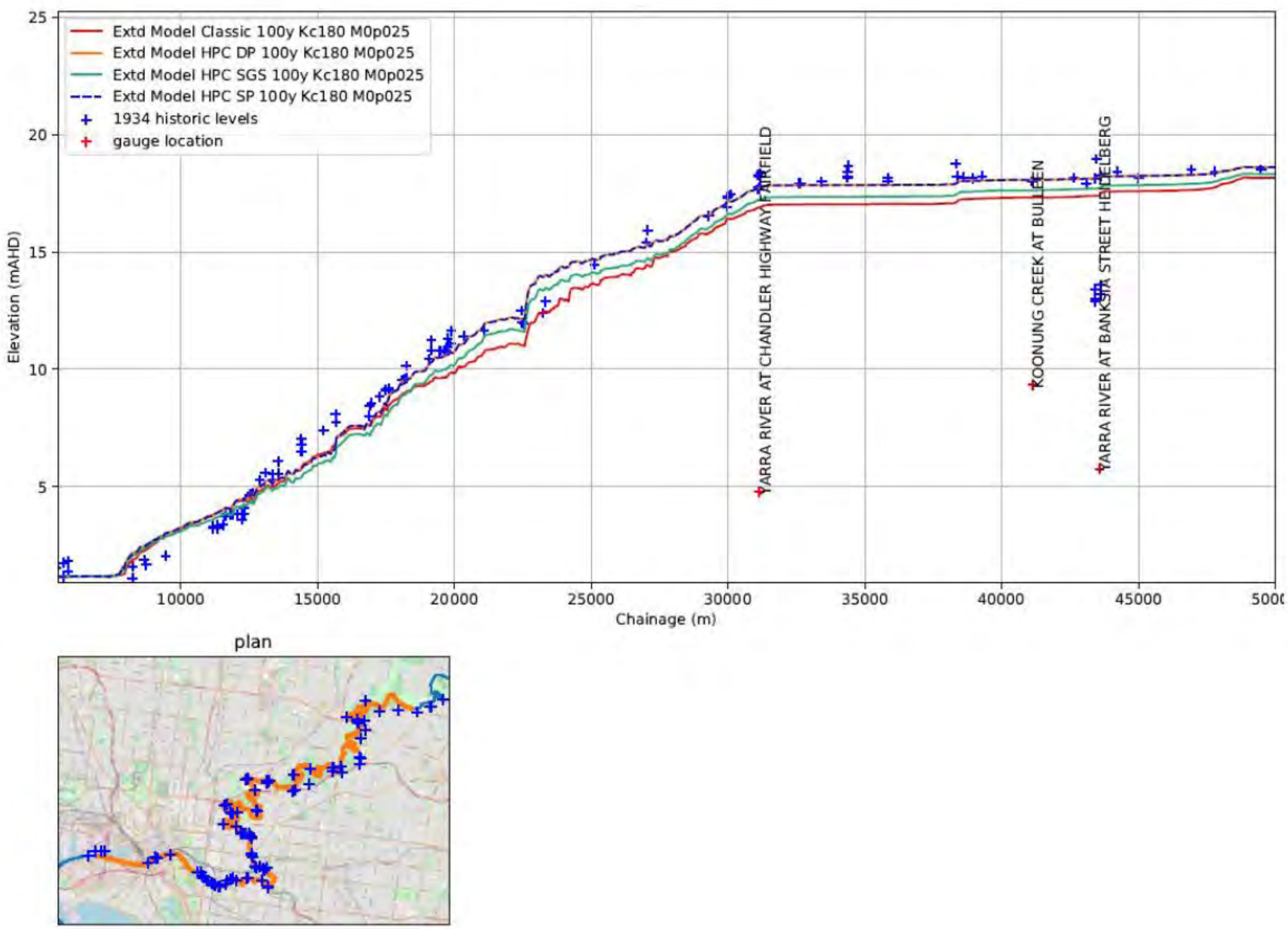


Figure 30 Phase 3 Model Extension – Yarra River Long-Section comparison of modelled flood levels with various TUFLOW engines to historic levels

8.4 Recommendation/Conclusion

Based on the results of this phase of model refinements, it was jointly agreed that following model assumptions should be used for the "design runs" for flood mapping purposes:

- Extended TUFLOW model.
- TUFLOW "HPC on GPU" engine with the SGS functionality enabled (default settings with sampling size of 2 m).
- Hydrology based on MW's previously adopted Kc value of 180 and the application of ARFs (assuming area upstream of mapping limit).
- Adopting a Manning's 'n' value of 0.025 for major waterways.
- Revised "design run" model scenarios as per Table 9, which includes altered downstream boundary conditions.

Table 9 Revised "Design Run" Definitions

Run ID	Scenario	Hydrology	TWL
1	Base Case (A)	1% AEP	10% AEP Tide
2	Base Case (A)	2% AEP	10% AEP Tide
3	Base Case (A)	5% AEP	10% AEP Tide
4	Base Case (A)	10% AEP	10% AEP Tide
5	Base Case (A)	20% AEP	20% AEP Tide
6	Climate Change 1 (CC_B)	1% AEP	10% AEP SLR Tide
7	Climate Change 2 (CC_C)	1% AEP Climate Change (18.5% increase intensity)	10% AEP SLR Tide
8	Climate Change 2 (CC_C)	5% AEP Climate Change (18.5% increase intensity)	10% AEP SLR Tide
9	Climate Change 2 (CC_C)	10% AEP Climate Change (18.5% increase intensity)	10% AEP SLR Tide
10	Climate Change 2 (CC_C)	20% AEP Climate Change (18.5% increase intensity)	20% AEP SLR Tide
11	Climate Change 3 (CC_D)	1% AEP Climate Change (18.5% increase intensity)	10% AEP Tide
12	Climate Change 3 (CC_D)	10% AEP Climate Change (18.5% increase intensity)	10% AEP Tide
13	Climate Change 3 (CC_D)	20% AEP Climate Change (18.5% increase intensity)	20% AEP Tide

9 Final Design Run Developments

Based on outcomes of modelling discussed in Section 8, GHD commenced design run modelling with the agreed setup and upon processing results found that the default ‘SGS’ settings resulted in the ‘2DM’ having some holes in it that prevented results being recorded at a number of locations across the model. With agreement from MW, the model files were sent to TUFLOW Support who agreed there was an issue and recommended that we adjust the default settings of how the ‘SGS’ functionality treats partially covered cells using the “SGS Partial Grid Update Null Frac” command in the *.tgc file. This command is explained in 2020 TUFLOW Release Notes, but in essence tells TUFLOW what to do with cells only partially covered by the terrain model (or DEM) being processed, with the two numbers representing a lower and upper bound for the null fraction (i.e. the fraction of cell not covered by the DEM currently being processed). The ‘SGS’ function does the following based on these numbers (extracted from 2020 TUFLOW Release Notes – BMT**,** 2020):

- *“If the null fraction is below the lower limit, TUFLOW applies the values from the new DEM”;*
- *“If the null fraction is between the lower and upper limits, update the null value from current ZC ZU ZV and ZH values. “the cell are interpolated from current Zpts (ZU, ZV, ZH & ZC)”;* and
- *“If the null fraction is higher than the upper limit, do not update the Zpt.”*

As part of their investigation into the issue TUFLOW Support indicated that the default values of “0.1,0.9” for the “SGS Partial Grid Update Null Frac” command should be altered to either of the following depending on what terrain source we wanted to take priority:

- “0.6,0.6” – this would give preference to elevations from earlier read in terrain sources; or
- “0.1,0.1” – this would give preference to elevations from the terrain source currently being processed.

The following is a summary of our approach and initial thoughts on the most appropriate approach to adjusting the default settings for the “SGS Partial Grid Update Null Frac” command as described above:

- Our initial thoughts were to adopt the “0.6, 0.6” on the basis that it favoured the last read in terrain, which reflects the inherent confidence in that terrain selected during the model build. This showed the afflux in Figure 31 and Figure 32 for the terrain and WSL respectively.
- Given the afflux from above models and the fact that this is a new and untried functionality - we then tested the other approach (values of “0.1, 0.1”) to understand the implications on the results. This showed the afflux in Figure 33 and Figure 34 for the terrain and WSL respectively.
- Upon reviewing the results and some reflection we then favoured the “0.1, 0.1” approach because the differences stem from changes in terrain at the interfaces of the terrain sources and the biggest area of change is that between the LiDAR and bathymetry. The interface between the LiDAR and bathymetry is typically high on the river bank, which is generally well covered by LiDAR and actually likely to be more representative when you consider the bathymetry terrain was largely formed from cross section data that has outer banks represented by a sparse set of points relative to LiDAR data points in this area.
- It was also noted that both changes to default settings increase the water level within the Yarra River and hence improve correlation with our understanding of the 1% AEP levels compared to the historic 1934 flood levels, but the “0.1,0.1” set seemed to provide the best fit.

After discussing the results with MW, it was decided that the design runs should adopt the “0.1,0.1” setting for the “SGS Partial Grid Update Null Frac” command.

Unfortunately, some of the other design runs not used in the sensitivity testing phase described above went unstable with this parameter set at various points within the model run – sometimes in the initial tidal wetting phase and others part way into the modelled storm event. Given that this wasn't occurring in all runs and a quick review of TUFLOW's interpretation of the terrain didn't identify any major concerns, it was agreed with Melbourne Water that the "0.6,0.6" setting for the "SGS Partial Grid Update Null Frac" command could be used instead. This was tested with the problematic design runs and these runs ran through to completion with no problematic errors to report – and was hence adopted for the final design runs.

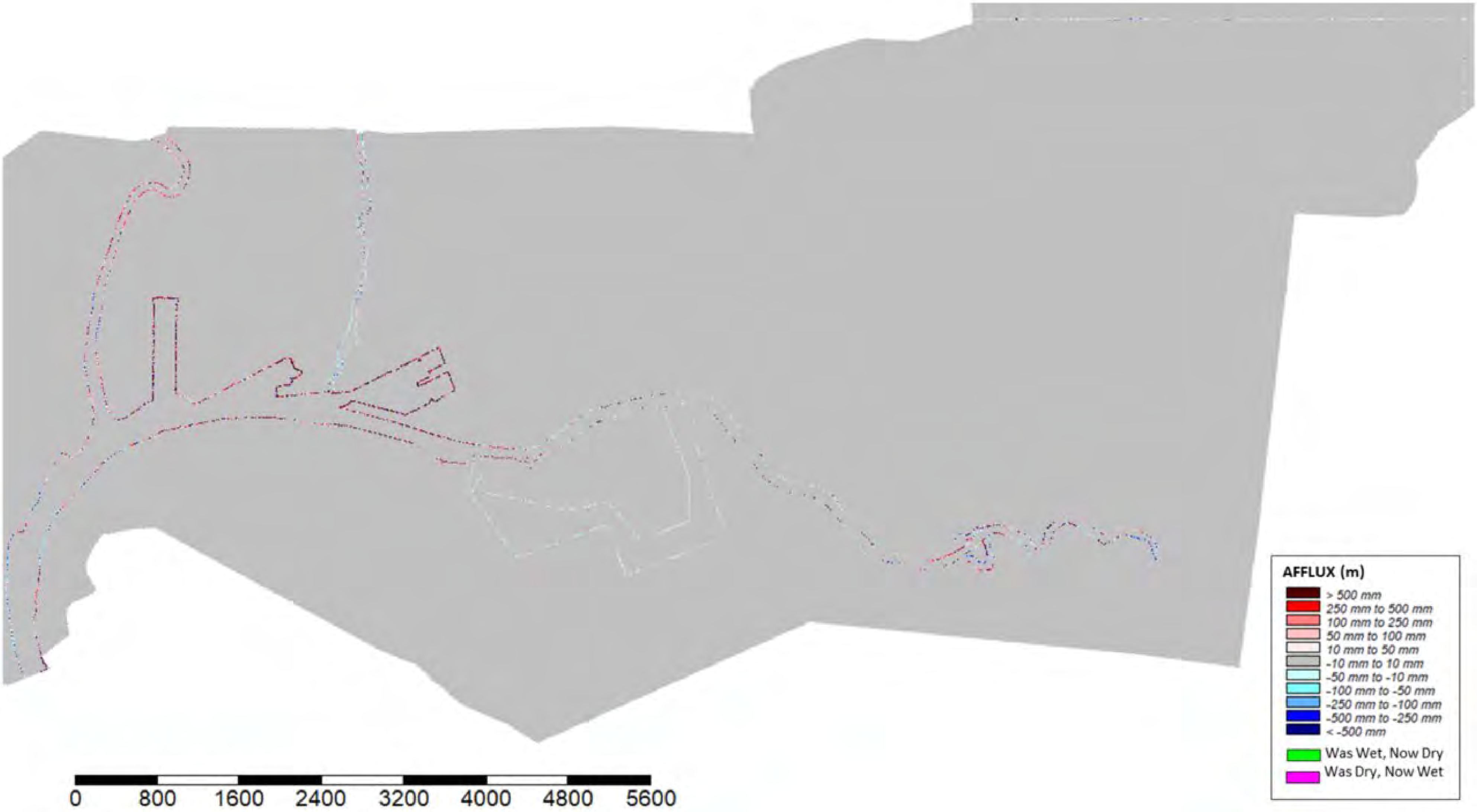


Figure 31 Terrain Difference: 'SGS w/ last read in terrain preferenced on partially covered cells (SGS Partial Grid Update Null Frac = 0.6,0.6)' minus 'SGS w/ default settings on partially covered cells (SGS Partial Grid Update Null Frac = 0.1,0.9)'

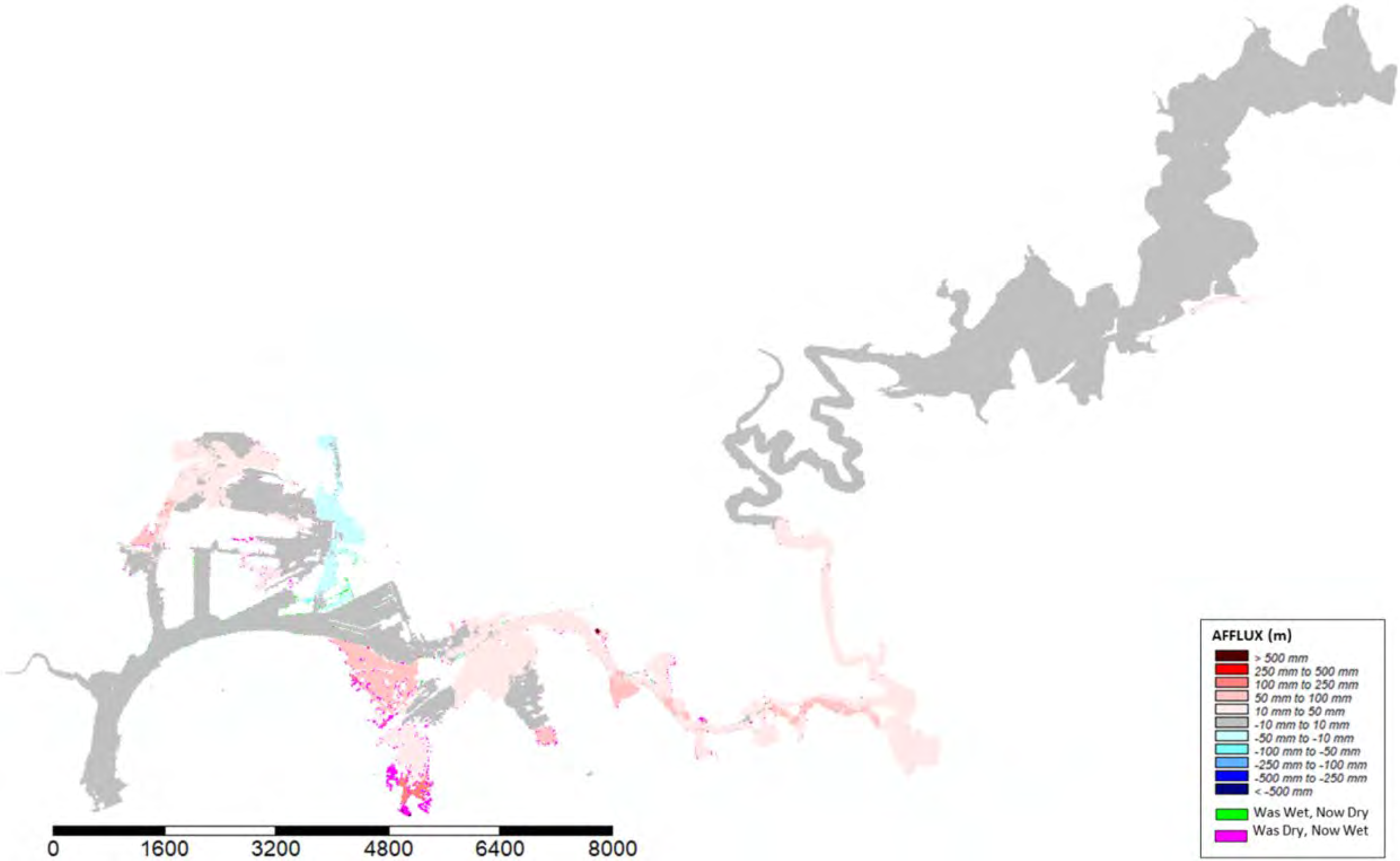


Figure 32 WSL Afflux: 'SGS w/ last read in terrain preferenced on partially covered cells' minus 'SGS w/ default settings on partially covered cells'

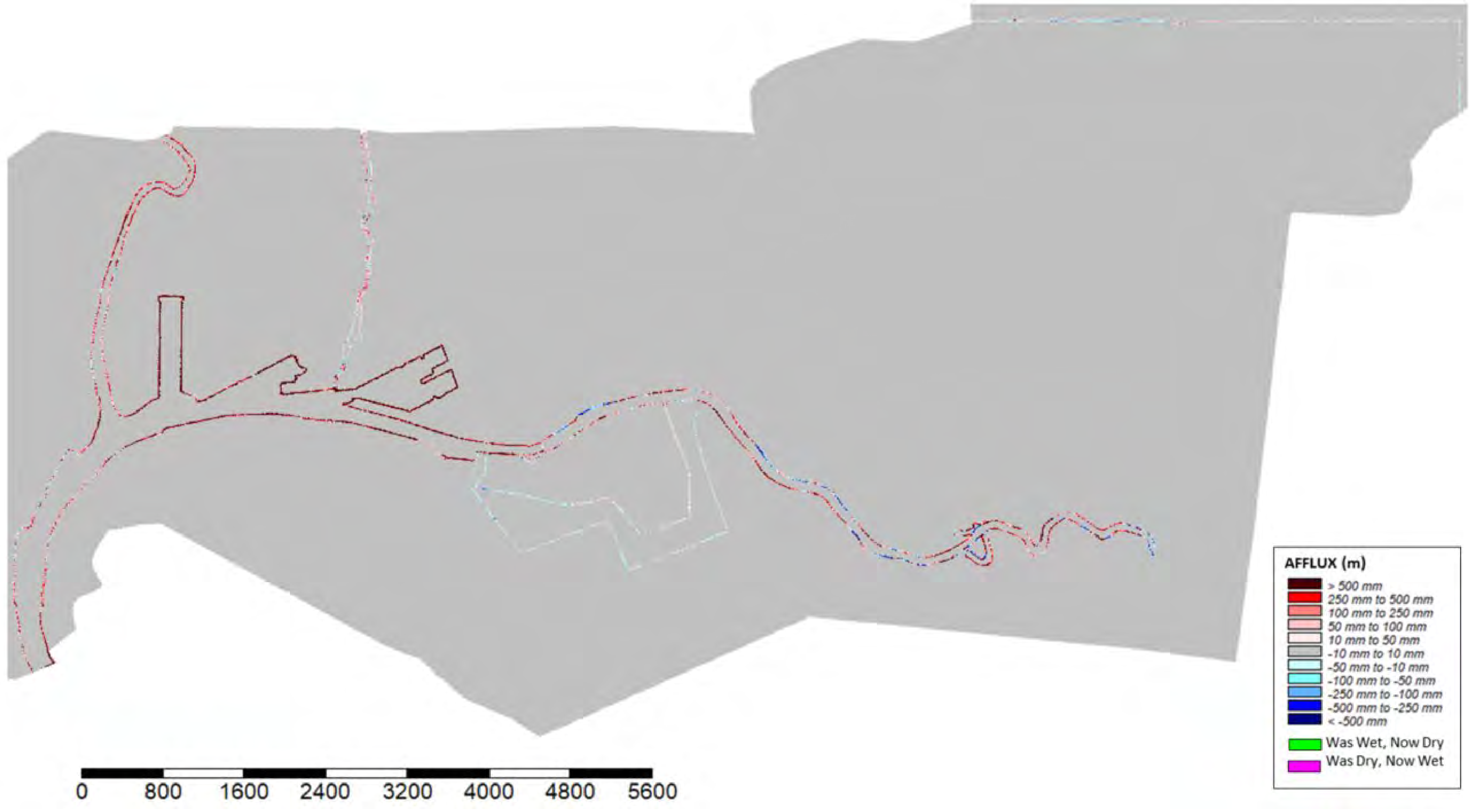


Figure 33 **Terrain Difference: 'SGS w/ earlier read in terrain preferenced on partially covered cells (SGS Partial Grid Update Null Frac = 0.1,0.1)' minus 'SGS w/ default settings on partially covered cells (SGS Partial Grid Update Null Frac = 0.1,0.9)'**

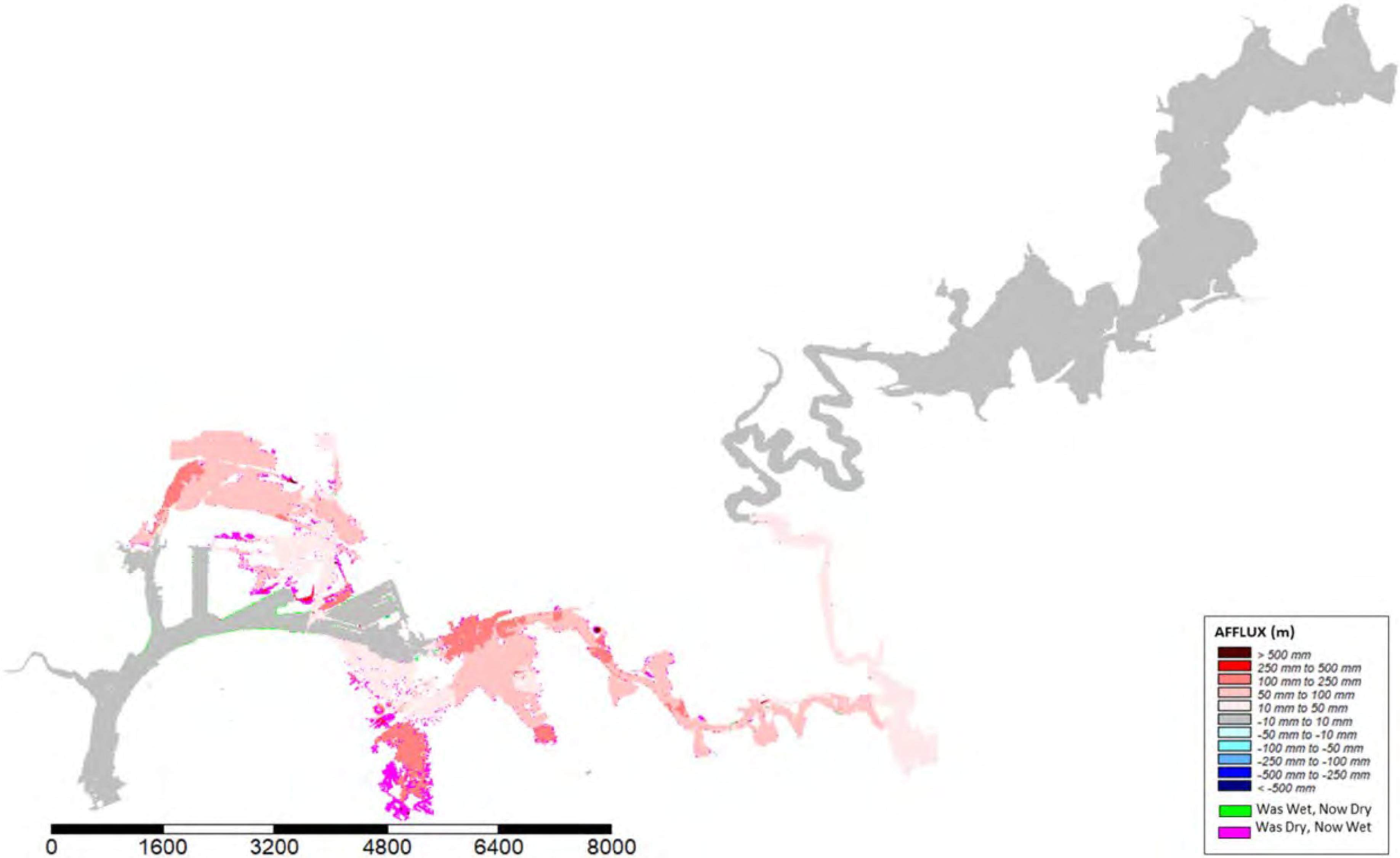


Figure 34 WSL Afflux: 'SGS w/ earlier read in terrain preferenced on partially covered cell' minus 'SGS w/ default settings on partially covered cells'

10 Conclusion

Based on the outcomes of this modelling, it was agreed that the following parameters should be used for the final “design run” models:

- Adopt provided MWC hydrologic models with assumptions as per Table 10
- Adopt final model setup as per Figure 27 in Section 8, with a Manning’s ‘n’ roughness of 0.025 for the major waterway areas.
- Adopted TUFLOW “HPC on GPU” engine with sub-grid sampling (SGS) functionality enabled with the following settings as confirmed in Section 9:
  - “SGS Sample Distance == 2” – a command that sets the sub-grid sampling to a size of 2 m.
  - “SGS Partial Grid Update Null Frac == 0.6, 0.6” – a command that stipulates how terrain is to be treated for partially covered cells. These parameters are reduced from defaults of “0.1, 0.9” to remove holes from DEM and give preference to terrain from the later terrain sources as indicated by TUFLOW Support. This was required as prioritising earlier data sources (our original preferred approach) resulted in some model runs becoming unstable.

Table 10 Hydrologic Assumptions

Model	**Yarra River**	**Maribyrnong River**
RORB Version	6.45	6.45
Rainfall	Stormfiles with variable IFD (adjusted version of those adopted from 2016 Yarra River Study area due to application of ARFs)	ARR1987 IFD @ inbuilt “Keilor” location
ARF	Yarra catchment area (Assumed area = 3,870 km²)	Yarra catchment area (Assumed area = 3,870 km²)
Kc	180 (MW assumed value prior to 2016 Yarra River Study)	70
m	0.8	0.8
IL (mm)	Varies with interstation area: • YarRv@YarGlen-DummyGS = 30 • Catchment outlet = 15	20
Runoff Coefficient	Varies with ARI: • 100y = 0.60 • 50y = 0.55 • 20y = 0.50 • 10y = 0.45 • 5y = 0.40	Varies with ARI: • 100y = 0.6 • 50y = 0.55 • 20y = 0.45 • 10y = 0.35 • 5y = 0.25
Climate Change	Factored rainfall in stormfiles by 1.185 to represent 18.5% increase as per latest Tech Spec	Adjusted IFD parameters to increase rainfall intensity by 18.5%

Regards

Peter Woodman
Senior Environmental Engineer
61 3 8687 8351

References

BMT (2020). TUFLOW Classic & HPC 2020-01 Release Notes. BMT, May 2020.

Attachments:

- *Attachment 1* Fax from MWC regarding Yarra River dredging profile from City Link crossing work in 1996.
- *Attachment 2* Advice from MWC regarding timing of tide relative to timing of Yarra River flows
- *Attachment 3* Email train regarding initial design run assumptions (final email dated 6/9/2019).
- *Attachment 4* Phase 1 Southbank Overflow Refinement Results Memo
- *Attachment 5* Phase 2 Southbank Overflow Refinement Results Memo
- *Attachment 6* Phase 3 Southbank Overflow Refinement Results Memo
- *Attachment 7* Phase 1 Model Extension Results Memo

Attachment 1

Fax from MWC regarding Yarra River dredging profile from City Link crossing work in 1996.

ACER/CMP JV - MCL Project			
Date 17/10/95		Recorded	
File		Doc IS-1233	
M. Brown CO	Action	Initial	Date 17/10/95
RW	AI	RW	17/10
AM	A		
A – Action I – Information		Entered	

FAX DATE: October 17, 1995 **TIME:** 11:25 AM

TO: Tony Schapendonk
Angus Mitchell
Acer/CMP Joint Venture
PHONE: 9272 6666
FAX: 9272 0300

FROM: Michael Brown
Waterways & Drainage
PHONE: 9615 4014
FAX: 9615 4003

copy to M.A. TQ

RE: Yarra Crossing, Cut and Cover Tunnel

With regard to your request for details of Melbourne Water's requirements for Yarra River cross sections in the reach of the tunnel crossings, I advise as follows:

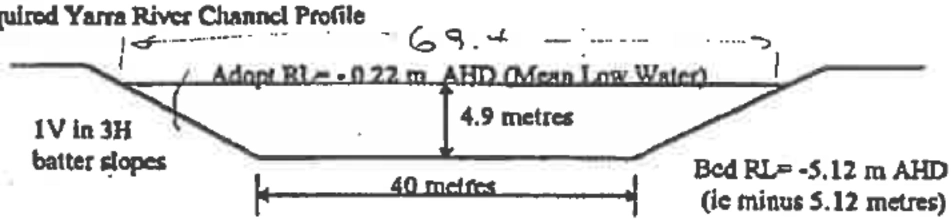
- the requirements provided in Melbourne Parks and Waterways letter of 6 January 1995 are supported as the dredging profile provides a depth and waterway profile that will ensure the river can pass a 1 in 100 year flood event below the adopted 1% AEP Flood Levels in this area. It also provides a channel form that meets operational requirements and provides for better riverbank stability.

- Flood levels for this reach of the river are based on the actual flood event resulting from the storm of November/December 1934. At the time of this flood, the subject reach of river had been modified to the channel form known as the "botanical gardens cut" as recommended by the "Yarra Floods Board" in 1892. The realignment, widening and deepening of the river was carried out in the late 1890's. When the MMBW became responsible for Metropolitan drainage in 1924, it undertook further improvement works to improve the flood carrying capacity of the Yarra River. MMBW survey and design cross section dated 1929/30 indicate the design channel and siltation that had occured at that time. The design cross sections represent Melbourne Water's minimum requirements for hydraulic performance and consists of a trapezoidal shape with a depth of 16 feet (4.9 metres) below the low water mark. *current*

- The Flood levels for the 1934 flood between Morell Bridge (downstream side) and Swan Street *Anderson Street* Bridge (upstream side) are 3.26 and 2.75 metres AHD respectively.

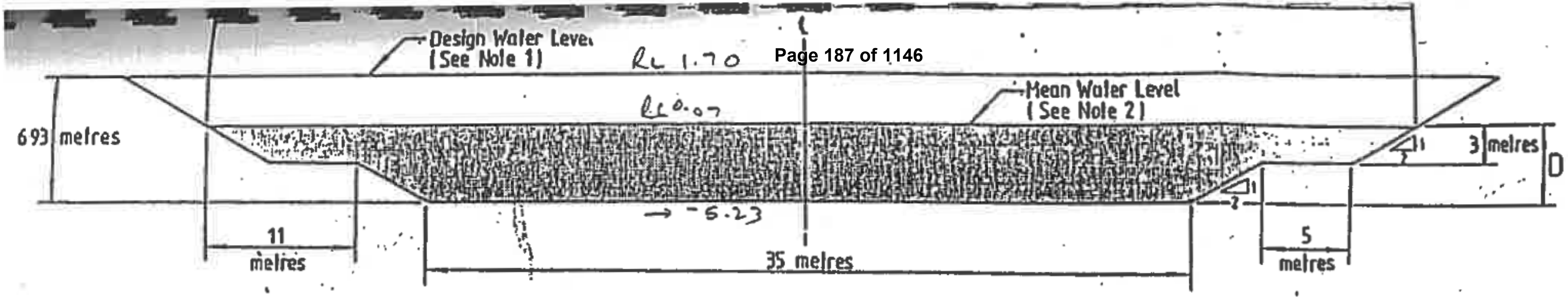
- Hydraulic modelling for the tidal reaches of the Maribyrnong River, by Consultants associated with Monash University, has indicated that scouring of the bed occur during high flows. River bed survey, at that time, confirmed these findings. A Value Management Study of "Dredging in the Yarra and Maribyrnong Rivers" in 1989 supported the view that scouring during flood events creates adequate flow capacity, and consequently the dredging operation was suspended, in the short term, pending hard data concerning sediment deposition and scour rates. Dredging currently occurs for navigational purposes and the aesthetic amenity of the river. Monitoring of the river silt levels is being undertaken by Melbourne Parks and Waterways. Maintaining the design cross section will ensure the capability of the river channel passing a 1% flood event with no increase in the designated flood levels.

- Required Yarra River Channel Profile



I advise that the channel profile shown above is Melbourne Water's minimum requirement. The river will silt up from time to time but during a major flood, the river will scour this silt away down to at least our minimum profile.

M Brown
17/10/95



REACH OF RIVER	DIMENSIONS (Metres)		DWL (20yr)
	D	W	
Spencer St. Bridge to Princes Bridge	6·2	70	
Princes Bridge to Swan St. Bridge	5·8	68	
Swan St. Bridge to Hoddle Bridge	5·3	66 ✓	1.70

NOTE:

1. The <u>Design Water Level</u> is the level reached by a flow of 710 cumecs (This flow is based on the 1923 flood and is estimated to have a 1 in 20 year frequency of recurrence.)

2. The <u>Mean Water Level</u> is R.L. 0·07 metres A.H.D. (This level is derived from records of M.M.B.W. tidal gauges at Hanna St. M.D. outlet and at Burnley Depot.)

APPENDIX 3

TRACED	PLANS	MELBOURNE AND METROPOLITAN BOARD OF WORKS	SCALE NOT TO SCALE
CHECKED	F.D. / L.D.	ENGINEERING BRANCH — DRAINAGE DIVISION	DRAWING NO.
GROUP LEADER	FILE NO.	YARRA RIVER (LOWER)	4400/YRD
SECTION ENGINEER	DESIGNED / DRAWN	PROFILE FOR DREDGING	1

Attachment 2

Advice from MWC regarding timing of tide relative to timing of Yarra River flows

Peter Woodman

From: [redacted]
Sent: Thursday, 18 April 2019 4:22 PM
To: Nathan Lindner
Cc: [redacted]
Subject: RE: Lower Yarra Tidal Curves

Hi Nathan

With regards to your email. If the approach suggested gives the right outcome then happy for you to adopt it.

For the extended time series of tide data, the extended time series used in the Skye Karingal flood mapping project can be adopted for this project.

Regards

[redacted]

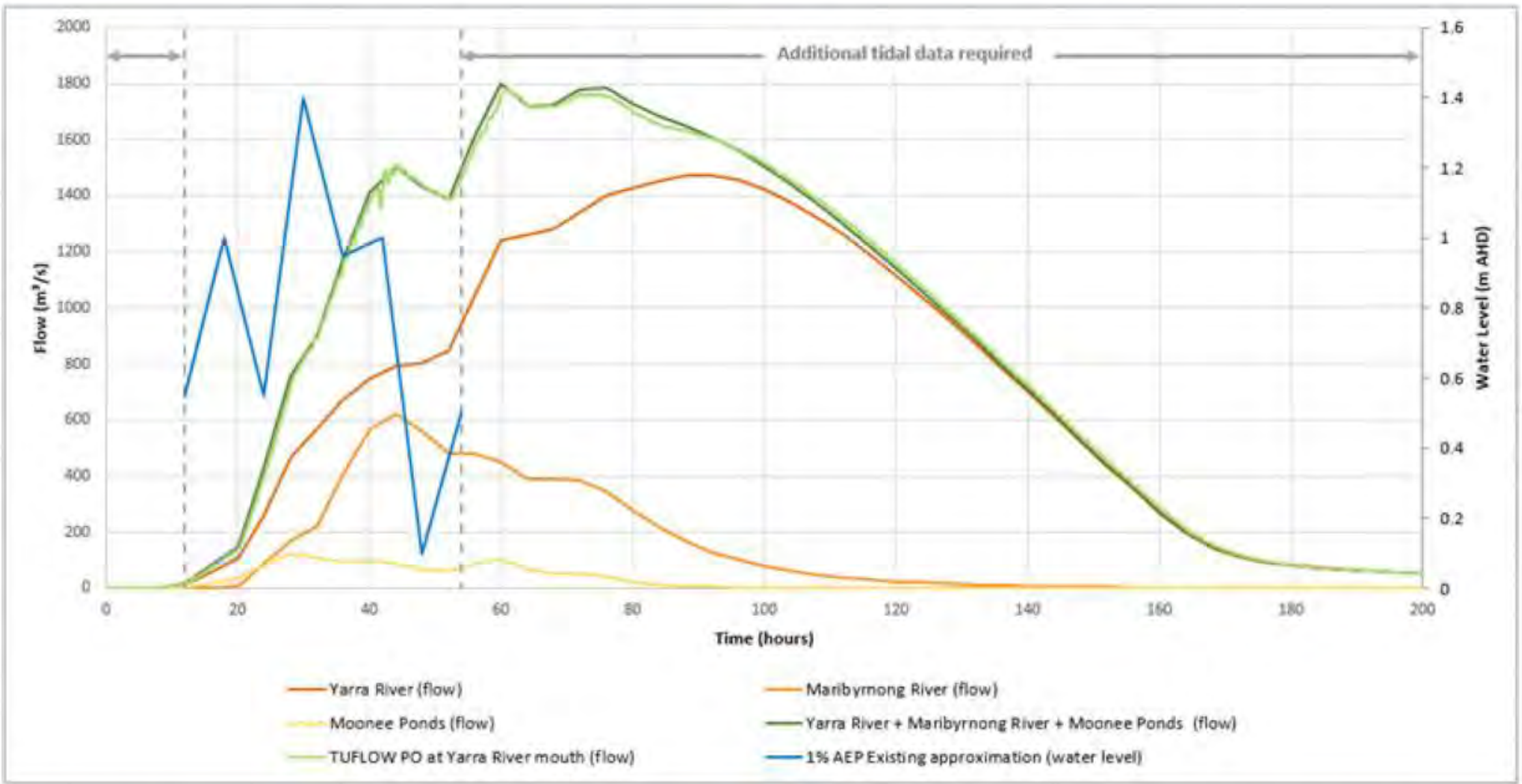
[redacted]
Asset Practitioner - Mapping and Modelling Engineer, Flood Information, Asset Management Services, Service Delivery Group | **Melbourne Water**
T: [redacted] | e: [redacted]
990 Latrobe St, Docklands 3008 | PO Box 4342 Melbourne VIC 3001 | melbournewater.com.au

Enhancing Life and Liveability.

From: Nathan Lindner [mailto:Nathan.Lindner@ghd.com]
Sent: Thursday, 18 April 2019 1:13 PM
To: [redacted]
Cc: [redacted]
Subject: RE: Lower Yarra Tidal Curves

Hi [redacted],

From [redacted] email below it appears he is suggesting that we shift our tide curve (the one developed by Water Tech and simplified by us) so that the peak occurs 30 hours into the simulation, and either side of this tide curve adopt some 'typical' tidal curve. I've produced a figure below to show what this would look like compared to flow hydrographs.



Would you be happy for us to proceed with this approach? If so, could you please provide an extended time series of tide data for us to derive a 'typical' tide curve to be adopted either side of the peak tide curve?

As mentioned in the previous email, derivation of a typical tidal curve is outside the current scope based on previous discussion (see extract from Progress Meeting 1 minutes below). In the variation to complete the dredged profile modelling we allowed $784 to determine the peak tidal boundary and will likely spend this amount again to derive the typical tidal curve. Due to the small magnitude of the cost we won't request a variation for this at this stage but may include it in a future variation should one be required.

Minutes	Outcome/Action
Downstream boundary conditions and location • GHD reiterated that approach was to have single downstream boundary along bay with matching IWL. Boundary will be either fixed TWL or tide curve as supplied by MWC	MWC agreed with approach

If you would like to discuss please call either Pete Woodman or myself.

Regards

Nathan Lindner
Civil Engineer – Water Resources

GHD
T: +61 3 8687 8205 | V: 318205 | E: nathan.lindner@ghd.com
180 Lonsdale Street, Melbourne VIC Australia 3000 | http://www.ghd.com/
WATER | ENERGY & RESOURCES | ENVIRONMENT | PROPERTY & BUILDINGS | TRANSPORTATION

From: [redacted]
Sent: Monday, 25 March 2019 11:28 AM
To: [redacted]
Cc: Gavin Hay <Gavin.Hay@ghd.com>; Peter Woodman <Peter.Woodman@ghd.com>; Nathan Lindner <Nathan.Lindner@ghd.com>
Subject: RE: Lower Yarra Tidal Curves

[redacted]
For discussion.

What GHD have proposed in Figure 2 is also in line with the tide cycle from 2014 at Williamstown. (With timing about the same as in the word document above.)

Extending the tide cycles as was done for Skye Karingal in Figure 3 would be perfectly acceptable.

However, there could be some discussion on starting time for the rainfall event and tide cycle.

Reportedly from Adams Report "Tide Levels During the November 1934 Flood Event and High Tide Frequency Analysis for Williamstown" (1987), peak tide level occurred at 9pm on 30th November.

If we look at the 1934 hydrograph at Johnson Street for the Yarra, 30% flow would have been about 33 hours into the rainfall event.

Without getting too precise about travel times, given the difficulty anyway of the probability of events lining up, it might be prudent to add some tide cycles to the start of what GHD propose, more in line with their figures 1a and 1b below.

The rise time for the combined GHD hydrographs is quicker than the 1934 hydrograph, and 30% flow occurs after about 26 hours. Maybe, say peak tide at about 30 hours after rainfall starts.

Have a think and we can all decide between us.

[redacted]

[redacted] Technical Lead, Catchment Strategies and Services, Waterways & Land Service Delivery Group| **Melbourne Water**
990 Latrobe Street, Docklands, VIC 3008 | PO Box 4342 Melbourne VIC 3001 | www.melbournewater.com.au
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From: Nathan Lindner [mailto:Nathan.Lindner@ghd.com]
Sent: Friday, 22 March 2019 5:36 PM
To: [redacted]
Cc: [redacted] Gavin Hay; Peter Woodman
Subject: Lower Yarra Tidal Curves

Hi [redacted]

In regards to the tidal curve to be applied at the downstream end of the Lower Yarra model, we have received Water Tech modelled tidal data for 1% and 10% AEPs for both existing and 'sea level rise' (SLR) conditions. Given we are running 1%, 5% and 20% AEP events, we need to manipulate this data to approximate 1%, 5% and 20% AEP tidal curves for the length of our model runs (approximately 250 hours). Our proposed approach is as follows:

1. Simplify this data for input into TUFLOW by creating triangular curves approximating the Water Tech modelled data (refer **Figure 1a** and **Figure 1b**)
2. Set the above simplified curve to start this tidal curve at the beginning of the TUFLOW simulation to avoid the peak tide level coinciding with the peak of the hydrograph and the associated joint probabilities of this occurring (refer **Figure 2**)
3. Shift the simplified tidal curve vertically (in elevation) by an amount to make the peak level equal to that specified in Table B2 in the Tech Spec (Nov 2016) for a given AEP and scenario (i.e. existing conditions or some climate change scenario) - the base tidal curve and relevant levels to shift peak levels to are shown in **Table 1**. Alternatively, should we adopt advice regarding tidal curves in Appendix R of current Tech Spec (Nov 2018) – this indicates that we should adopt curves as is and shift by different amounts?
4. Extend the adopted curve from step 3 with a 'typical' tidal relationship for times outside the bands of the Water Tech modelled data (the Water Tech modelled data covers ~40 hours only, while the TUFLOW model runs for up to 250 hours) (refer to **Figure 2** and example in **Figure 3**)

Currently the above data manipulations are out of scope but given the lack of a ready-to-go tidal curve to apply in TUFLOW, these manipulations are likely necessary. Would Melbourne Water like to internally develop tidal curves for use or shall GHD provide a fee estimate for this?

If Melbourne Water would like to us proceed with this approach, then with reference to the numbered items above:

1. Are Melbourne Water happy for us to proceed with the approximation of the Water Tech modelled tidal data shown in **Figure 1a** and **Figure 1b** (this assumes 6 hours between high and low tide)?
2. Are Melbourne Water happy with starting the approximated Water Tech curves at the start of the TUFLOW model run?
3. Are Melbourne Water happy with the previously agreed tidal vertical shifts (in elevation) in Table 1 or should we adopt new guidance in Tech Spec from Nov 2018?
4. Are Melbourne Water able to provide tidal data for an extended period so that a typical tidal curve can be developed and adopted?

If you would like to discuss please feel free to call either Peter, Gavin or myself.

Figure 1a. Approximation of 1% AEP Water Tech modelled tidal curves

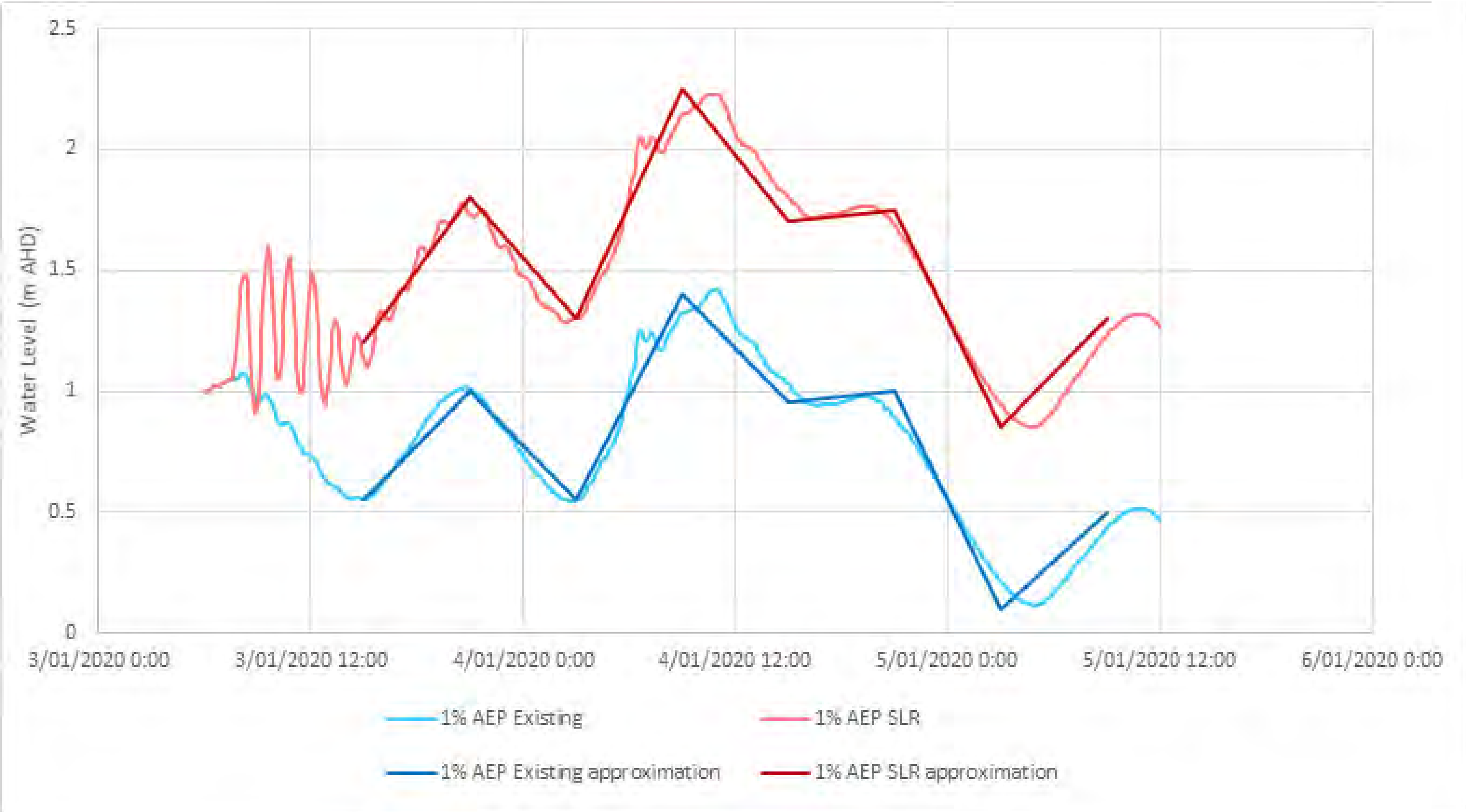


Figure 1b. Approximation of 10% AEP Water Tech modelled tidal curves

Figure 2. Tidal curve and hydrograph timing

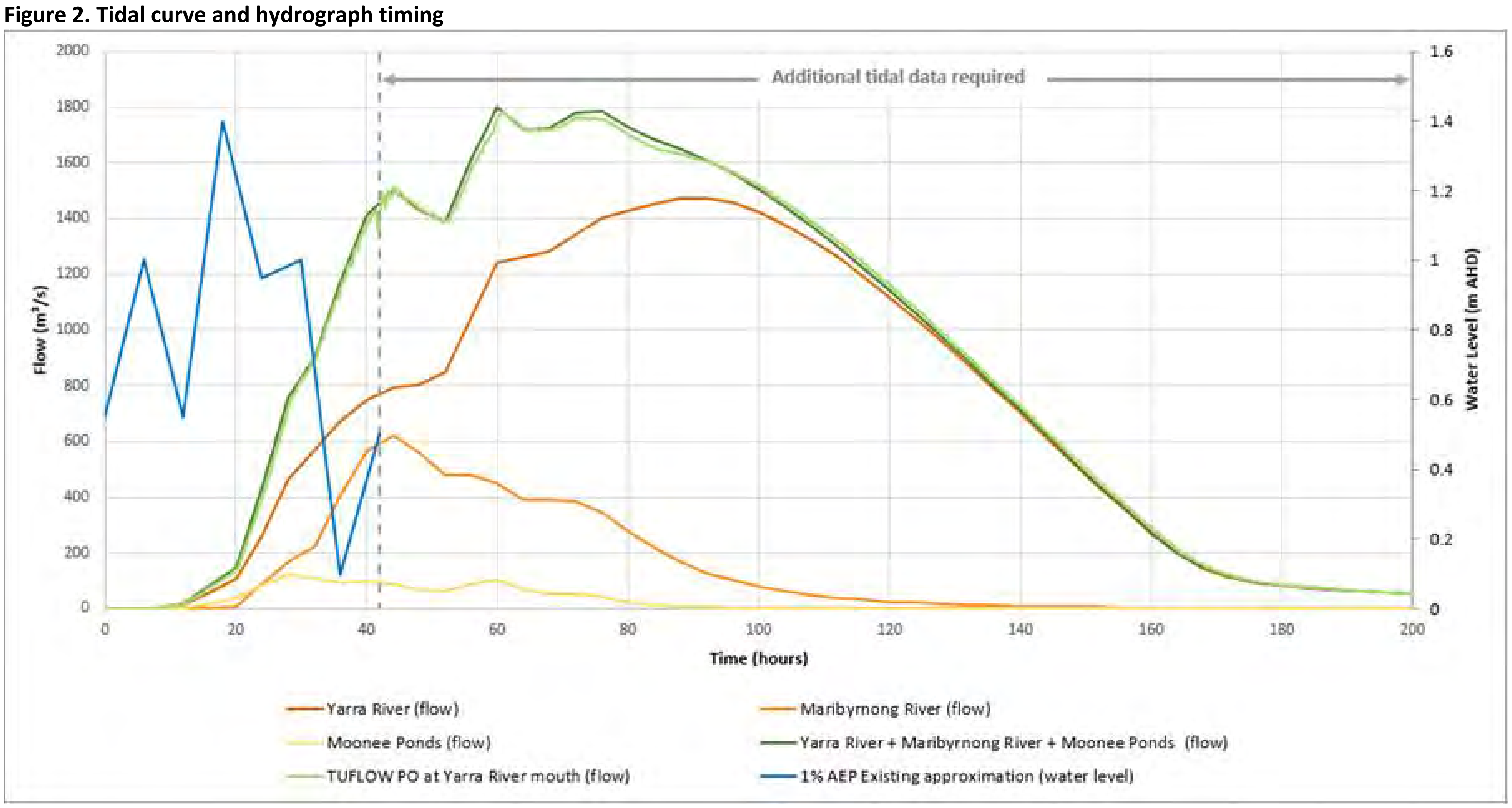
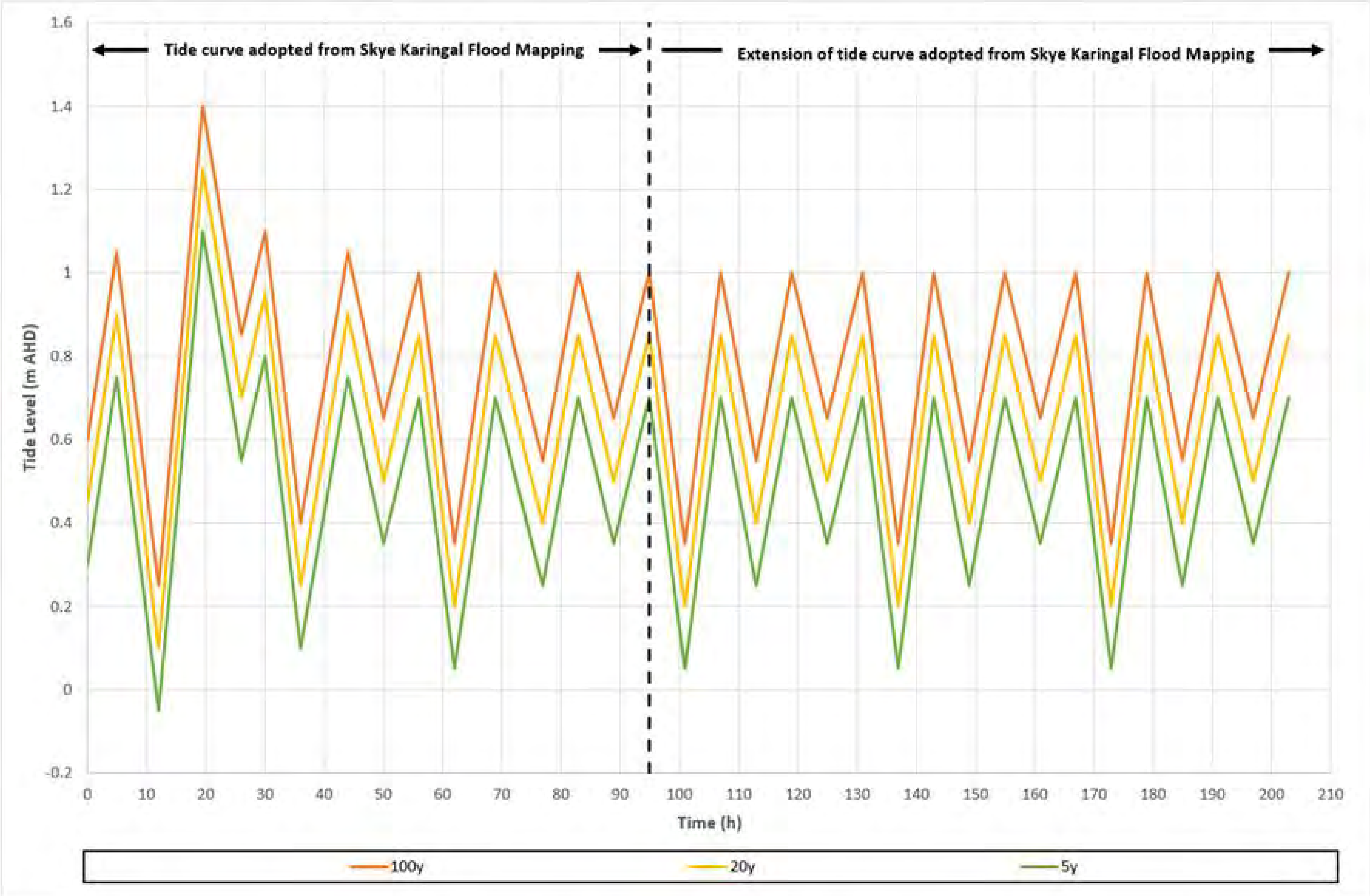


Table 1.

AEP	Base Tidal Curve (AEP)	Peak TWL (existing conditions)	Peak TWL (climate change – sea level rise)
1%	1%	1.6	2.4
5%	1%	1.25	2.05
20%	10%	1.1	1.9

Figure 3. Example of extended tide curve from Skye Karingal Flood Mapping project



Regards

Nathan Lindner
Civil Engineer – Water Resources

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Attachment 3

Email train regarding initial design run assumptions (final email dated 6/9/2019)

From: Peter Woodman
To: [redacted]
Cc: [redacted]
[redacted] RE F als g outsta d g ite to st t desig u s fo Lowe a a Rive Flood Mapp g
Date: F iday 6 September 2019 5:55:49 PM
Attachments: image001.png
image002.png
image003.png
image004.png
image005.png
image006.png

Merran

Thanks for confirming the approach mo ing forward - we will get cracking on setting off the final model runs in the agreed priority order.

We ha e not been able to pro ide a re ised timeline for he project un il now as there was no agreed scope due to some concerns o er the appropriateness of some of the underlying assumptions. In terms of timeframes going forward as noted in our pre ous email GHD are doing e eryth ng we can o try and meet MWC's recently pro ided project timeframe of the end of this month (September). We will howe er keep you posted on progress as the models run and he results are being post-processed.

I ha e also now looked at the scope of the ariation ou lined in our email from 15th August 2019 in light of your comments and can confirm that the additional fee for work outside the current scope is $##### excl GST.

If you would like to discuss please feel free o gi e Ga in (8687 87) or mself a call (please note I am not in the office on Monday).

Regards

Peter Woodman
Senior En ironmen al Engineer – Water Resources
On lea e e ery second Monday
GHD
T 61 3 8687 8351 | V 318351 | peter.woodman@ghd.com
Le el 8 180 Lonsdale Street Melbourne VIC 3000 Australia | http://www.ghd.com/
Wa er | Energy & Resources | En ironment | Property & Buildings | Transportation

Please consider the en ironment before printing this email

From: [redacted]
To: Peter Woodman
Cc: [redacted] Gavin Hay; Nathan Lindner; Nathan C ements
Subject: RE F als g outsta d g ite to sta t desig u s fo Lowe a a Rive Flood Mapping
Date: Fr day 6 September 2019 1:10:50 PM
Attachments: image001.png
image002 ng
image003.png
image004.png
image005 ng
image006.png

Hi Peter

Thankyou for the information on the Lidar difference review.

Melbourne Water agrees with GHDs' proposal to commence the required design runs using the hydrology and Lidar provided for this project.

Melbourne Water urgently requires a timeline for this project by COB today, 6 September 2016.

###.

###.

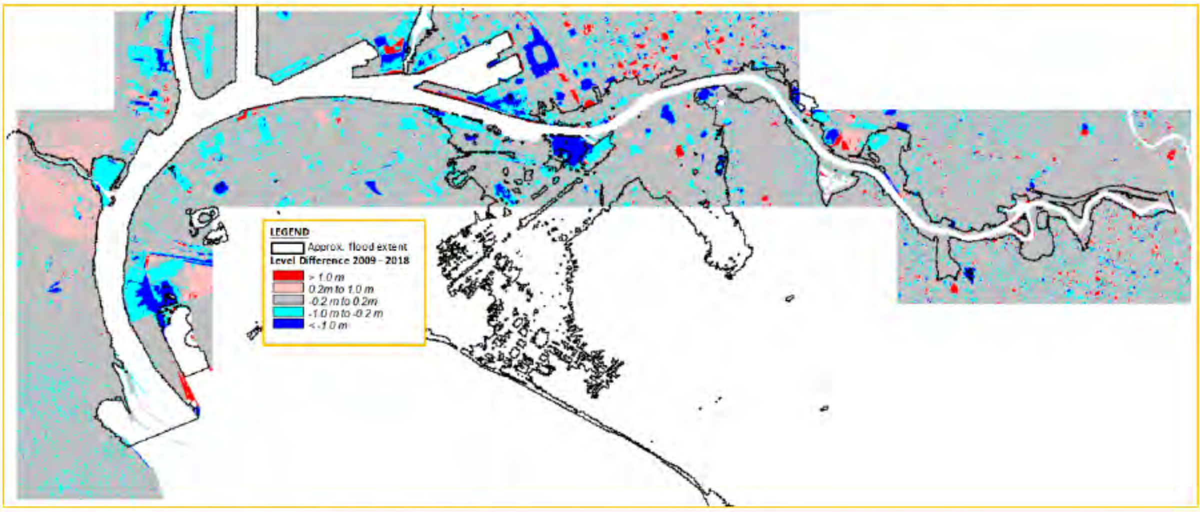
Regards
[redacted]
Asset Practitioner – Mapping and Modelling Engineer, Flood Information, Asset Management Services, Service Delivery Group | **Melbourne Water**
[redacted]
990 Latrobe St, Docklands 3008 | PO Box 4342 Melbourne VIC 3001 | melbournewater.com.au
Enhancing Life and Liveability.

From: Peter Woodman [mailto:Peter.Woodman@ghd.com]
Sent: Thursday, 5 September 2019 10:14 AM
To: [redacted]
Cc: [redacted] Gav n Hay; Nathan Lindner; Nathan Clements
Subject: [redacted]" for Lower Yarra River Flood Mapping

[redacted]

Thank you for arranging for the provision of the LiDAR difference plot earlier in the week.

As requested we have reviewed this information and have prepared the plot below that highlights the differences between the 2009 and 2018 LiDAR. On this plot the shades of red represent a decrease in elevation between 2009 and 2018 (of >0.2m) and shades of blue represent an increase in elevation between 2009 and 2018 (of >0.2m). The grey areas are is considered to have no change outside of the tolerance of the vertical LiDAR accuracy.
From this we note that there are a number of level differences (both increases and decreases) which may be significant to the final results particularly where overtopping thresholds are affected.



Confidence in the results from this project could be improved by undertaking additional investigations such as

- A thorough review (and as appropriate extension) of previous investigations to improve the hydrologic modelling for this part of the Yarra River
- An update of the terrain model to include the new LiDAR.

Our understanding from several conversations with Melbourne Water is that completion of this project is urgent and that additional investigations as noted above are not compatible with the current project time frames – which we now understand are by the end of September. Consequently these additional investigations and refinements will not be possible within the project timeline but should be strongly considered at a later time perhaps as part of a future update to ARR2019 methodologies. On this basis unless advised otherwise we intend to ignore the current limitations with respect to hydrology and survey as part of this current engagement and proceed to commence the required design runs to complete this project as quickly as possible using the hydrologic parameters and original LiDAR (circa 2009) both provided by Melbourne Water. Please advise by the end of this week (COB 06/09/2019) if you disagree with the proposed approach. If we don t hear otherwise we will commence with the model finalisation and will keep you updated as to expected delivery dates.

If you would like to discuss please feel free to give Gavin (8687 8744) or mself a call.

Regards

Peter Woodman
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From: Peter Woodman
Sent: Wednesday 28 August 2019 3 57 PM
To: [redacted]
Cc: [redacted] Gavin Hay <Gavin.Hay@ghd.com>; Nathan Lindner <Nathan.Lindner@ghd.com>
Subject: RE DRAFT Modelling Assumptions and Implications Memo

[redacted]

Based on Melbourne Water s need to complete this project in a timely fashion GHD will summarise the "hydrology and model verification" discussion and proceed with the "design event" modelling based on Melbourne Water s recommendation of a flow of 1 425 m³/s (RORB model with Kc 145 and m 0.8).

Given this the only outstanding item to close out before we can start the "design runs" is to check the difference in circa 2008 to circa 2018 LiDAR. Pending this comparison we can either start models if there are not many differences or provide a variation to update the model based on new terrain if there are key differences. From previous correspondence below to complete this comparison we are waiting on MWC to provide a difference plot that was expected at the end of last week. Can you please provide this at your earliest convenience?

If you would like to discuss the above please feel free to give me a call.

Regards

Peter Woodman
Senior Environmental Engineer – Water Resources

On leave every second Monday

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From: [redacted]
Sent: Thursday 22 August 2019 6 45 PM
To: Peter Woodman <Peter.Woodman@ghd.com>
Cc: [redacted] Gavin Hay <Gavin.Hay@ghd.com>; Nathan Lindner <Nathan.Lindner@ghd.com>
Subject: RE DRAFT Modelling Assumptions and Implications Memo

Hi Peter

With regards to your email dated the 19 August 2019 on the hydrology to be used for the Lower Yarra River project.

Melbourne Water has further discussed and has concluded that Scenario 2 in Table 1 below is to be used for the Lower Yarra River project. So kc = 145, m = 0.8 with flow of 1,425 cumecs is to be adopted.

The higher flow is from a model calibrated to recorded flood levels and the lower flow to a flood frequency analysis of gauged flow based on a rating curve. The gauge flow is quite accurate for more frequent flood event, the flow is within the waterway profile. For rare flood event, the flow is over the top of banks, the rating curve is not very accurate because the curve is extrapolated.

As previously advised on the 22 July 2019, Melbourne Water is satisfied with the process that was used to determine the design rainfall depths.

Regard

[redacted]
Asset Practitioner - Mapping and Modelling Engineer, Flood Information, Asset Management Services, Service Delivery Group | Melbourne Water
[redacted]
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From: Peter Woodman [mailto:Peter.Woodman@ghd.com]
Sent: Monday, 19 August 2019 1:32 PM
To: [redacted]
Cc [redacted] ; Gavin Hay; Nathan Lindner
Subject: RE: DRAFT Modelling Assumptions and Implications Memo

[redacted]

GHD agree with MW in that we should be adopting flows from a "calibrated" model but believe this can be achieved using different parameters as explained below.

Based on our understanding of the SP Goh and Associates study the Yarra River RORB model was calibrated using the following two approaches as summarised in Section 4.8 of the report

1. Hydrologically based on recorded hydrograph and storm data.
2. Hydraulically based on recorded flood levels and a HEC-RAS model.

The recommended parameters and a corresponding peak flow for the upstream inflow on Yarra River for this project for each of these scenarios are shown in Table 1.

The current MWC recommendation is to adopt flows based on the hydraulic calibration (Scenario 2 in Table 1 below) which required the flows to be increased to allow 'realistic roughness to be adopted in HEC-RAS to achieve an "acceptable" match to the recorded levels. As this project is using TUFLOW rather than HEC-RAS to determine flood levels GHD feel that the better approach would be to adopt flows based on a hydrologic calibration (Scenario 1 or 3 in Table 1 below). As the SP Goh and Associates study didn t apply Areal Reduction Factors (ARFs) the only way to achieve an "acceptable" match to recorded flows was to increase the previous Kc to reduce the flows. Given the size of the catchment GHD believe that the better approach to reduce flows is to apply appropriate ARFs. As can be seen in Table 1 by applying Siriwardna & Weinmann ARFs based on the total catchment area upstream of the inflow (Scenario 3) GHD was able to achieve a fairly good match to the flow from Scenario 1 (i.e. the recommended RORB model parameters from the SP Goh and Associates study when "calibrating" to flows).

Table 1 – 1% AEP 72h Yarra River Inflow at confluence with Gardiners Creek

Scenario	Kc	m	Initial Loss (mm)	Runoff Coefficient	Scenario Description	Flow (m³/s)
1	237				SP Goh and Associates study calibration to recorded hydrograph and storm data (no ARFs)	1115
2	145	0.8	30	0.6	SP Goh and Associates study calibration to flood levels using HEC-RAS (no ARFs)	1475
3	180				Previous MWC parameters with ARFs applied*	1091
Note: * indicates that this ARF was based on Siriwardna & Weinmann method using total catchment area upstream of RORB inflow (or 3870 km²)						

As such for this project GHD recommend adopting flows from a RORB model run with Scenario 3 parameters in Table 1 (i.e. Kc 180 & ARFs). This matches the hydraulic calibration as well as being compatible with previous flows and kc values from the Melbourne Water RORB model of the Yarra River (i.e. versions of the RORB model which were not adjusted to increase flows in order to improve the calibration of the HECRAS model which is not really relevant for the current TUFLOW model of the Yarra River).

If MWC accept this the next step in the project would be to run the "verification" models with the new inflow and confirm selected roughness parameters before commencing "design" runs.

Please feel free to give Gavin (8687 8744) or myself a call to discuss.

Regards

Peter Woodman
Senior Environmental Engineer – Water Resources
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From: [redacted]
Sent: Friday 16 August 2019 5 46 PM
To: Peter Woodman <Peter.Woodman@ghd.com>
Cc: [redacted] Hay <Gavin.Hay@ghd.com>; Nathan Lindner <Nathan.Lindner@ghd.com>
Subject: RE DRAFT Modelling Assumptions and Implications Memo

Hi Peter

Thanks for your email.

Regards

[redacted]

Asset Practitioner - Mapping and Modelling Engineer, Flood Information, Asset Management Services, Service Delivery Group | Melbourne Water

[redacted]

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From: Peter Woodman [mailto Peter Woodman@ghd com]
Sent: Friday, 16 August 2019 4:46 PM
To: [redacted]
Cc: [redacted] Gav n Hay; Nathan Lindner
Subject: RE: DRAF Modelling Assumpt ons and Impl cations Memo

[redacted]

Thanks for your responses most of which I understand and agree with – unfortunately Gavin is out of the office this afternoon and I would like to discuss your comments regarding the hydrology with him before making further comment as I think we aren t quite on the same page regarding interpretation of the previous Melbourne Water modelling (I think Gavin and I were of the opinion that there is a set of parameters which are consistent with MW's 1991 2004 and 2010 calibrated models). On this basis I think it is best if we get back to you early next week with a formal response and a revised program.

Hope you have a great weekend

Regards

Peter Woodman
Senior Environmental Engineer – Water Resources
On leave every second Monday

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From [redacted]
Sent: Friday 16 August 2019 12 39 PM
To: Peter Woodman <Peter.Woodman@ghd.com>
Cc: [redacted]; Gavin Hay <Gavin.Hay@ghd.com>; Nathan Lindner <Nathan.Lindner@ghd.com>
Subject: RE DRAFT Modelling Assumptions and Implications Memo

Hi Peter

Thanks for your email detailing the items to progress this project. Our comments have been included in your email below in red font.

Regards

[redacted]

Asset Practitioner - Mapping and Modelling Engineer, Flood Information, Asset Management Services, Service Delivery Group | Melbourne Water

[redacted]

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From: Peter Woodman [mailto Peter Woodman@ghd com]
Sent: Thursday, 15 August 2019 4:41 PM
To: [redacted]
Cc: [redacted] Gavin Hay; Nathan Lindner
Subject: RE: DRAF Modelling Assumptions and Implications Memo

[redacted]

Thanks for sending those priorities through – we are in the process of scoping next steps and determining a program delivery – initially of priority results and later for remainder of scenarios.

We have been looking into the LiDAR and have realised that the issue we had identified with the gantry was not as big an issue as previously thought as the jump in terrain is actually on the crest of one of the abutment for City Link before it drops down into the Burnley Tunnel. As such this issue will not really influence the current modelling results. During this time we did however realise that the "first return LiDAR" used to check the deck levels of the bridges without drawings was from 2018 and the base terrain is from 2008. This raises the question of whether the modelling should utilise the 2008 or 2018 LiDAR. Given the tight timeframe we feel that adopting the 2008 is probably the best approach at this time as altering this will require a number of model features to need to be updated with new data (i.e. ridge lines and layered flow constrictions for bridges) which would add a week or two to the program and require a variation to complete. Can you please advise if MWC would like to proceed with modelling based on 2008 LiDAR (recommended based on our understanding of the project urgency) or would like to update to 2018 lidar (this would delay the project)? The Lidar data provided for the project was 2008 which was the current data at the time of the inception of the project. Melbourne Water was waiting on the 2018 Lidar and from our discussion this could be used if the project wasn t going to be delayed. Melbourne Water is in the process of obtaining a DTM of the difference between the 2008 and 2018 Lidar sets. We are expecting to receive this DTM by the end of next week. When we have obtained this DTM we will forward it to GHD to assess whether the differences is significant to use the 2018 Lidar.

In terms of modelling going forward based on our discussion yesterday and subsequent checks we believe the next steps are to undertake the following assuming we are not altering the base terrain data

- Re-run hydrology with ARFs applied by factoring rainfall for each subarea with a calculated ARF based on the following
  1. Yarra River inflow – Yarra River RORB with kc of 180 and ARF based on total catchment area to Gardiners Creek confluence
  2. Moonee Ponds Creek inflow – Yarra River RORB with Kc of 180 and ARF based on total catchment area to Moonee Ponds Creek confluence (area including both Yarra River and Moonee Ponds Creek catchments)
  3. Maribyrnong River inflow – Maribynong River RORB model with ARF based on approx. total Yarra River catchment area to Maribyrnong River confluence (area including both Yarra and Maribyrnong River catchments)

  The above (larger kc and application of ARFs) will reduce design flows and produce lower flood levels hopefully closer to the designated levels. On reflection early in the meeting we discussed leaving the hydrology without subsequent application of ARFs. During the meeting it was recalled that the S P Goh and Associates study had artificially increased flows so that the HECRAS model could produce high enough flood levels with more realistic roughness values. We now have a hydraulic model (TUFLOW) which in this reach is producing higher flood levels and hence the argument for using higher flows is no longer appropriate. In Gavin s summary we discussed adopting MW s traditional kc of 180 and applying ARFs there is a chance that not all of us in the meeting made this complete journey from ignoring ARFs to applying them. Please let me know if you would like to discuss this further. Melbourne Water had carried out further research regarding the adoption of ARF and kc of 180. From this research we have come to a conclusion that adopting those two parameters will result in uncalibrated RORB model. From our observation SP Goh and Associates RORB model has been calibrated to historical events in deriving these two parameters. In order to maintain a good fit to the recorded flood level if ARF is introduced then the kc value will need to be reduced to maintain the calibrated flow. Therefore it is recommended that SP Goh and Associates RORB model hydrographs to be adopted for this project.
- Re-running the above hydrology models with the rainfall also factored by 1.16 (i.e. increased by 16%) for the climate change scenarios. For the re-run of the hydrology model for climate change scenarios adopt our recommended in the previous dot point.
- Run "verification" models for new scenarios to identify roughness that correlates closest to designated levels. This is now not required.
- Run design events in following priority order in TUFLOW Classic for 48h and 72h storm durations (with tide timing based on MWC advice)
  1. 1% AEP Base Case Scenario with 1% AEP Water Tech tidal curve Agree
  2. 10% AEP Base Case Scenario with 10% AEP with Water Tech tidal curve Agree
  3. 1% AEP Climate Change 2 Scenario with 1% AEP Water Tech Sea Level Rise tidal curve Agree
  4. 10% AEP Climate Change 2 Scenario with 10% AEP Water Tech Sea Level Rise tidal curve Agree
  5. 2% AEP Base Case Scenario with 1% AEP with Water Tech tidal curve adjusted to have a peak level as per Table 1 below Agree
  6. 5% AEP Base Case Scenario with 1% AEP with Water Tech tidal curve adjusted to have a peak level as per Table 1 below Agree
  7. 20% AEP Base Case Scenario with 10% AEP Water Tech tidal curve adjusted to have a peak level as per Table 1 below Agree
  8. 0.2% AEP Base Case Scenario with 1% AEP Water Tech tidal curve Agree
  9. 1% AEP Climate Change 2 Scenario with 1% AEP Water Tech Sea Level Rise tidal curve adjusted to have a peak level as per Table 1 below Could you please advised if this is the same as Priority order 3.
  10. 1% AEP Climate Change 1 Scenario with 1% AEP Water Tech Sea Level Rise tidal curve Agree
  11. 10% AEP Climate Change 1 Scenario with 10% AEP Water Tech Sea Level Rise tidal curve Agree
  12. 1% AEP Climate Change 3 Scenario with 1% AEP Water Tech tidal curve The Tech Specs describe Climate change 3 scenario for Catchments draining to waterways above the tidal influence zone. Therefore this is not required.
  13. 5% AEP Climate Change 3 Scenario with 1% AEP Water Tech tidal curve adjusted to have a peak level as per Table 1 below The Tech Specs describe Climate change 3 scenario for Catchments draining to waterways above the tidal influence zone. Therefore this is not required.
  14. 20% AEP Climate Change 3 Scenario with 10% AEP Water Tech tidal curve adjusted to have a peak level as per Table 1 below The Tech Specs describe Climate change 3 scenario for Catchments draining to waterways above the tidal influence zone. Therefore this is not required.
  15. 10% AEP St Kilda Marina sensitivity scenario with St Kilda Marina tidal curve (have some data from [redacted] that would need to be extended and will need to agree on timing – see attached email) This is no longer required as the Water Tech tidal curves are now being adopted.
  16. 10% AEP Williamstown sensitivity scenario with Williamstown tidal curve (have some data from [redacted] that would need to be extended and will need to agree on timing – see attached email) This is no longer required as the Water Tech tidal curves are now being adopted.

Table 1 – Tailwater Level Basis

AEP	Nov 2016 Tech Spec TWL (m AHD)		Water Tech Tide Curves TWL (m AHD)		Adopted TWL (m AHD)	
	Base Case	Sea Level Rise (Difference to Base Case)	Base Case (Difference to Tech Spec)	Sea Level Rise (Difference to Base Case) / (Difference to Tech Spec)	Base Case	Sea Level Rise
0.2%	-	-	-	-	1.4*	-
1%	1.6	2.4 (0.8 m)	1.4 (-0.2 m)	2.25 (0.85 m) / (-0.15 m)	1.4	2.25
2%	1.35	-	-	-	1.35*	-
5%	1.25	2.05 (0.8 m)	-	-	1.25*	-
10%	1.2	-	1.15 (-0.05 m)	2 (0.85 m) / (n/a)	1.15	2
20%	1.1	1.9 (0.8 m)	-	-	1.05*	1.9*

Note: * indicates that these numbers have been derived based on advice in the latest Nov 2018 Tech Spec

Based on the above approach there are a number of items that have not currently been allowed for in the project scope – these include re-running hydrology with ARFs producing hydrographs for Moonee Ponds Creek and Maribyrnong River and climate changes variations of re-doing verification runs and setting up tide curves for St Kilda and Williamstown. These additional tasks could be undertaken for a fee of **$##### excl GST**. Please review the variation amount based on the comments provided above by Melbourne Water.

If you can confirm that you are happy with our approach outlined above before lunch tomorrow I should be able to provide a program for the top 4 priority runs tomorrow. For the updated timeline, could you please assume the Lidar requires work, the DTM is provided by the end of next week and at this stage only concentrate on delivering priorities 1 to 4 listed above. We would like the timeline to show enough detail to determine the impact of the Lidar work.

Happy to discuss further if you d like.

Regards

Peter Woodman
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On leave every second Monday

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From:[redacted]
Sent: Thursday 15 August 2019 10 26 AM
To: Peter Woodman <Peter.Woodman@ghd.com>
Cc[redacted] Gavin Hay <Gavin.Hay@ghd.com>; Nathan Lindner <Nathan.Lindner@ghd.com>
Subject: RE DRAFT Modelling Assumptions and Implications Memo

Hi Peter

From our meeting yesterday, Wednesday 14 August 2019, the priority of the modelling is listed in the table below.

Also, as agreed GHD will be providing today a timeline for the completion of the project.

	Modelling Scenario	Event	Tailwater Level (m AHD)	Priority
A	Base Case	0.2% AEP	Appropriate level to be discussed and jointly agreed	3
		1% AEP	*1.6*	*Not required*
		1% AEP	1.4 (requested sensitivity test)	1
		2% AEP	1.35	2
		5% AEP	1.25	2
		10% AEP	1.2 / MWC Tidal Curve*	1
		20% AEP	1.1	2
B	Climate Change 1 – Sea level rise	1% AEP	2.4	3
		10% AEP	MWC Tidal Curve*	3
C	Climate Change 2 – Sea level rise and increased rainfall intensity	1% AEP	2.4	1
		5% AEP	2.05	2
		10% AEP	MWC	1
		20% AEP	1.9	2
D	Climate change 3 – Increased rainfall intensity	1% AEP	1.6	3
		5% AEP	1.25	3
		20% AEP	1.1	3

Regards
[redacted]
Asset Practitioner - Mapping and Modelling Engineer, Flood Information, Asset Management Services, Service Delivery Group | Melbourne Water
[redacted]
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From: Peter Woodman [mailto:Peter.Woodman@ghd.com]
Sent: Wednesday, 14 August 2019 12:16 AM
To:[redacted]
Cc:[redacted] Gavin Hay; Nathan Lindner
Subject: DRAFT Modelling Assumptions and Implications Memo

[redacted]

Please find attached a "draft" version of the revised "Modelling Assumptions and Implications" memorandum which summarises all the verification modelling undertaken to date. Since the previous issue we have updated the structure revised conclusion from previous modelling (Section 4) and added the last section on the dredged modelling (Section 5).

We thought we d send this through prior to the meeting as Section 5 summarises the current modelling which we have presented in a series of previous emails and plan to discuss later today.

Regards

Peter Woodman
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On leave every second Monday

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Attachment 4

Phase 1 Southbank Overflow Refinement Results Memo

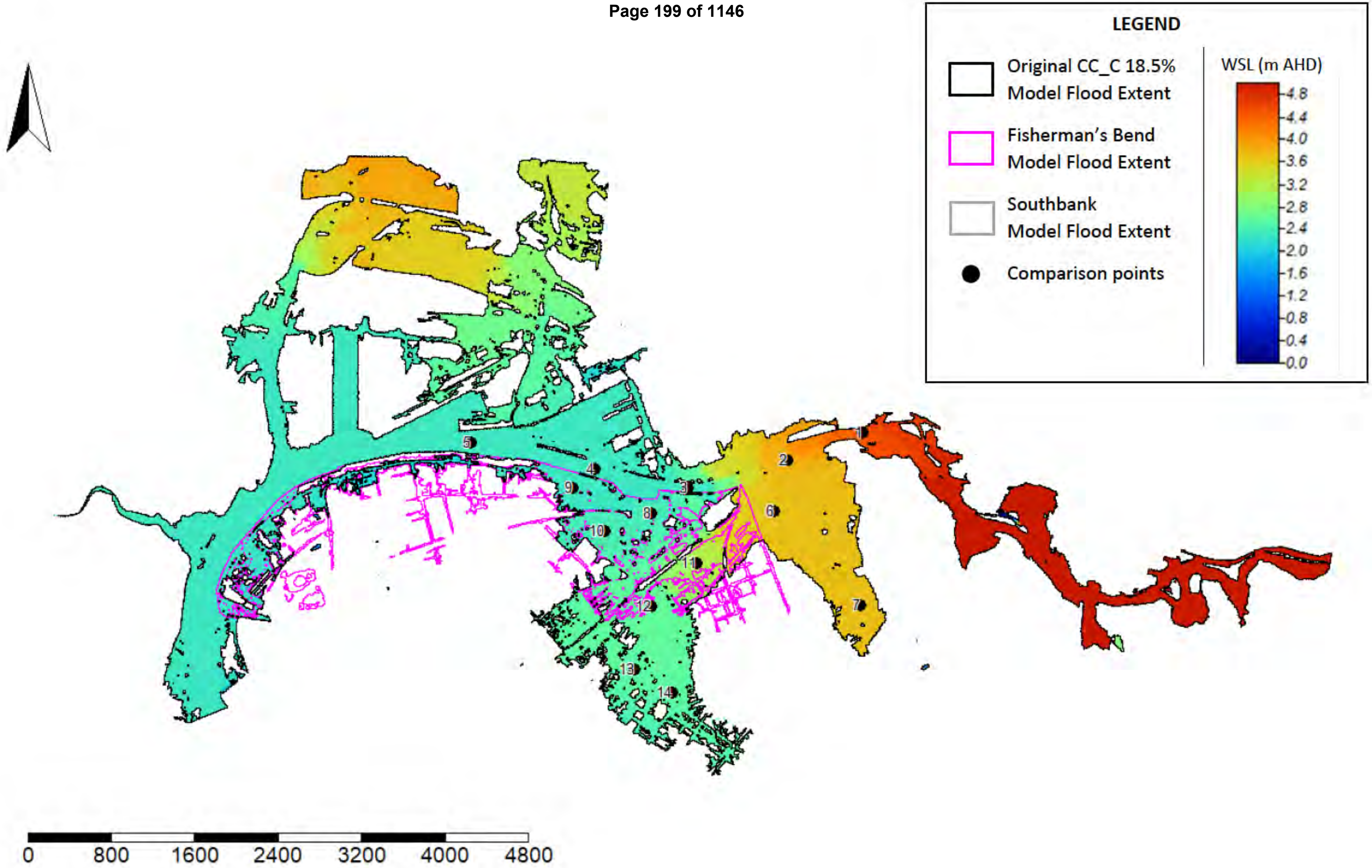

Figure 1 Original Yarra River Model Peak 100y WSL (100y Tide)

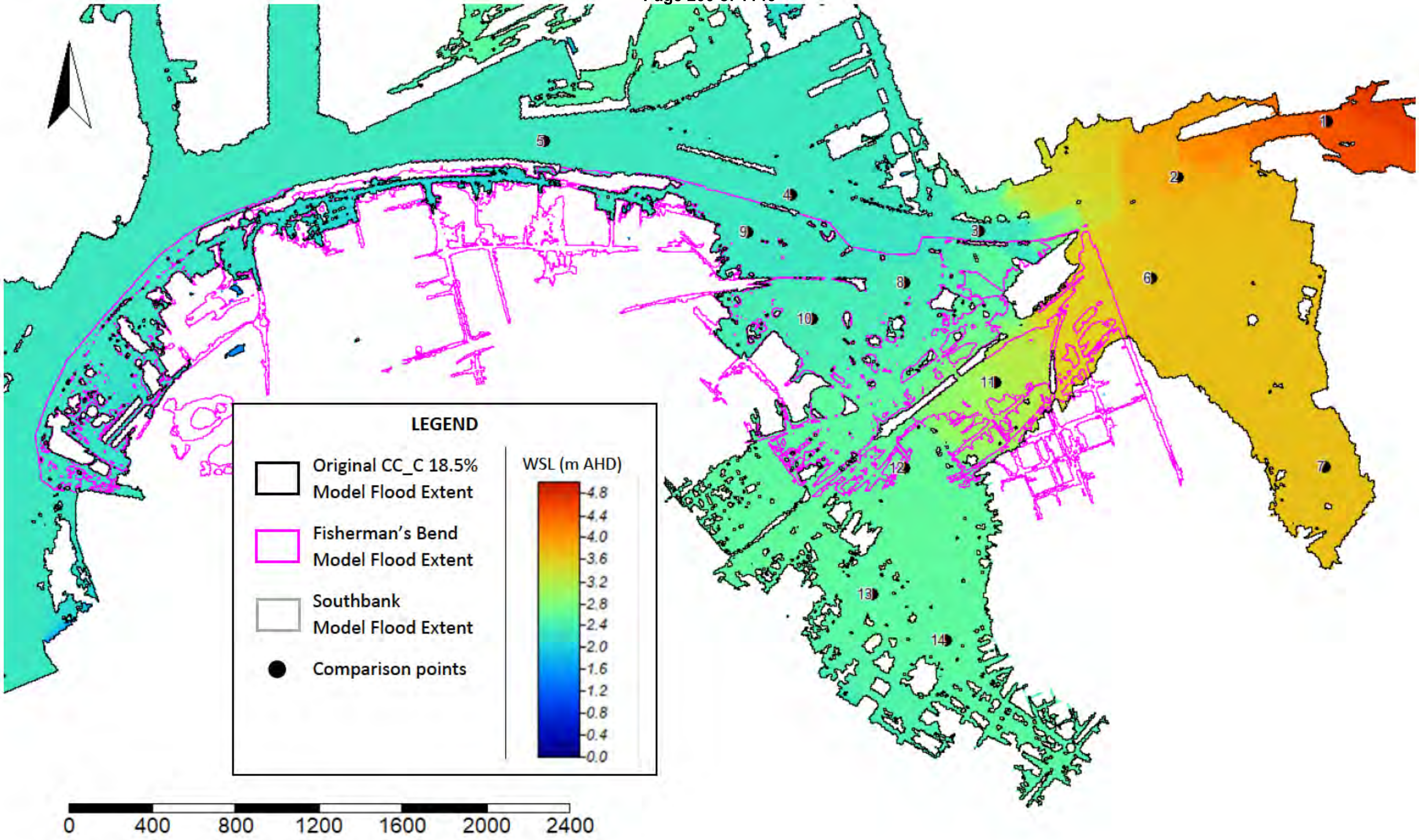

Figure 1B **Original Yarra River Model Peak 100y WSL (100y Tide) – Zoomed to overflow refinement area**

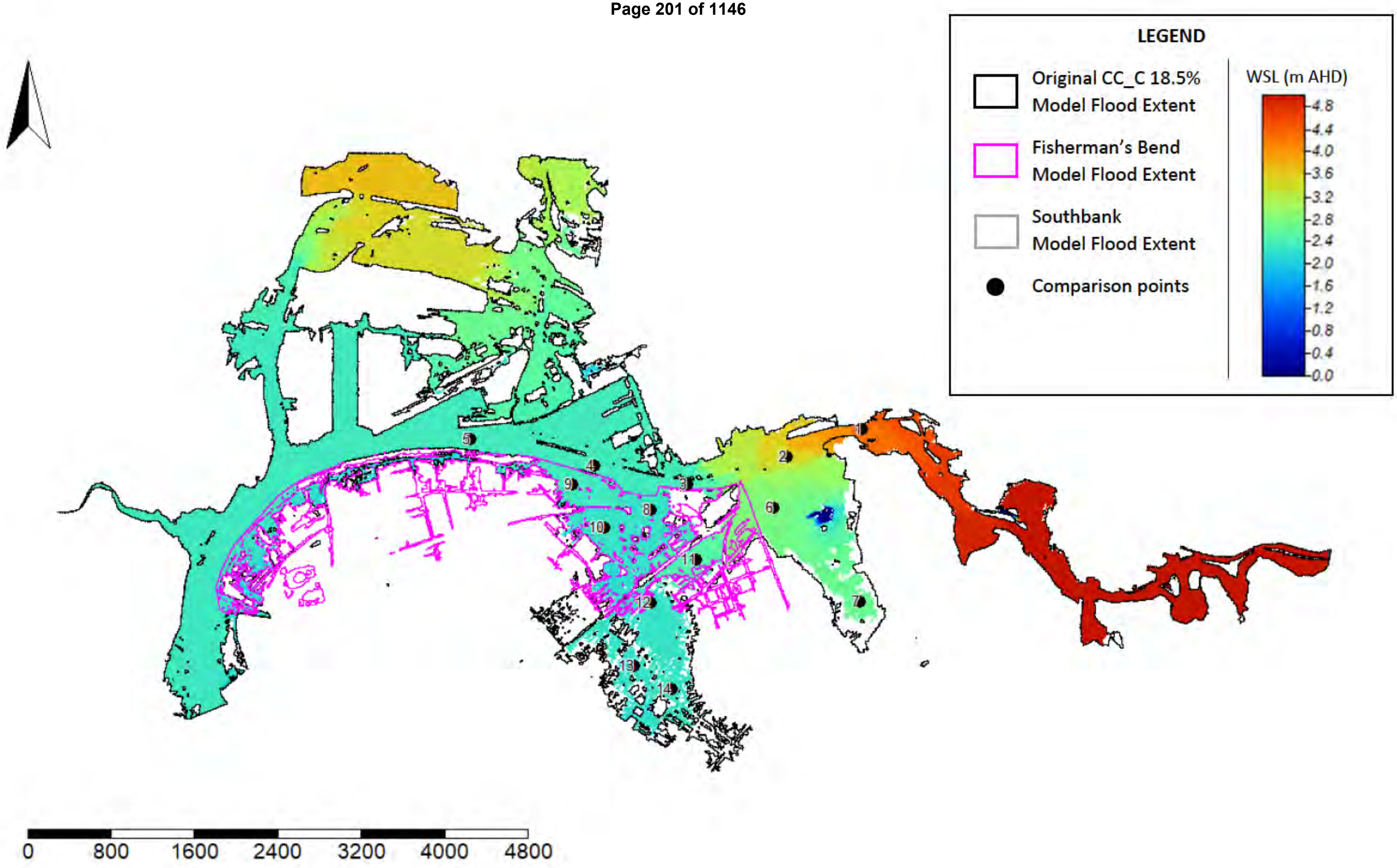

Figure 2 **Overflow Refinement Yarra River Model Peak 100y WSL (100y Tide)**

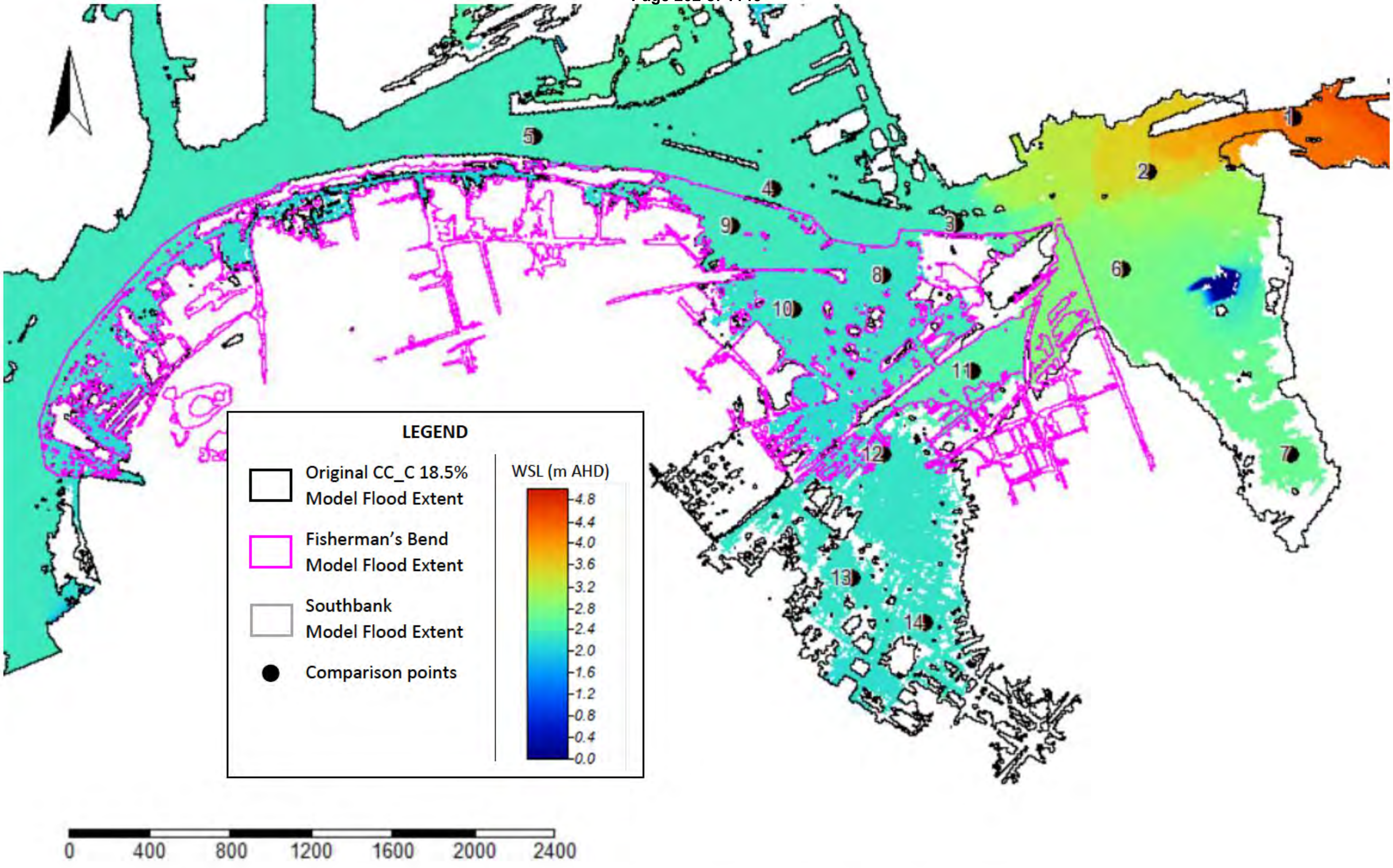

Figure 2B **Overflow Refinement Yarra River Model Peak 100y WSL (100y Tide) – Zoomed to overflow refinement area**

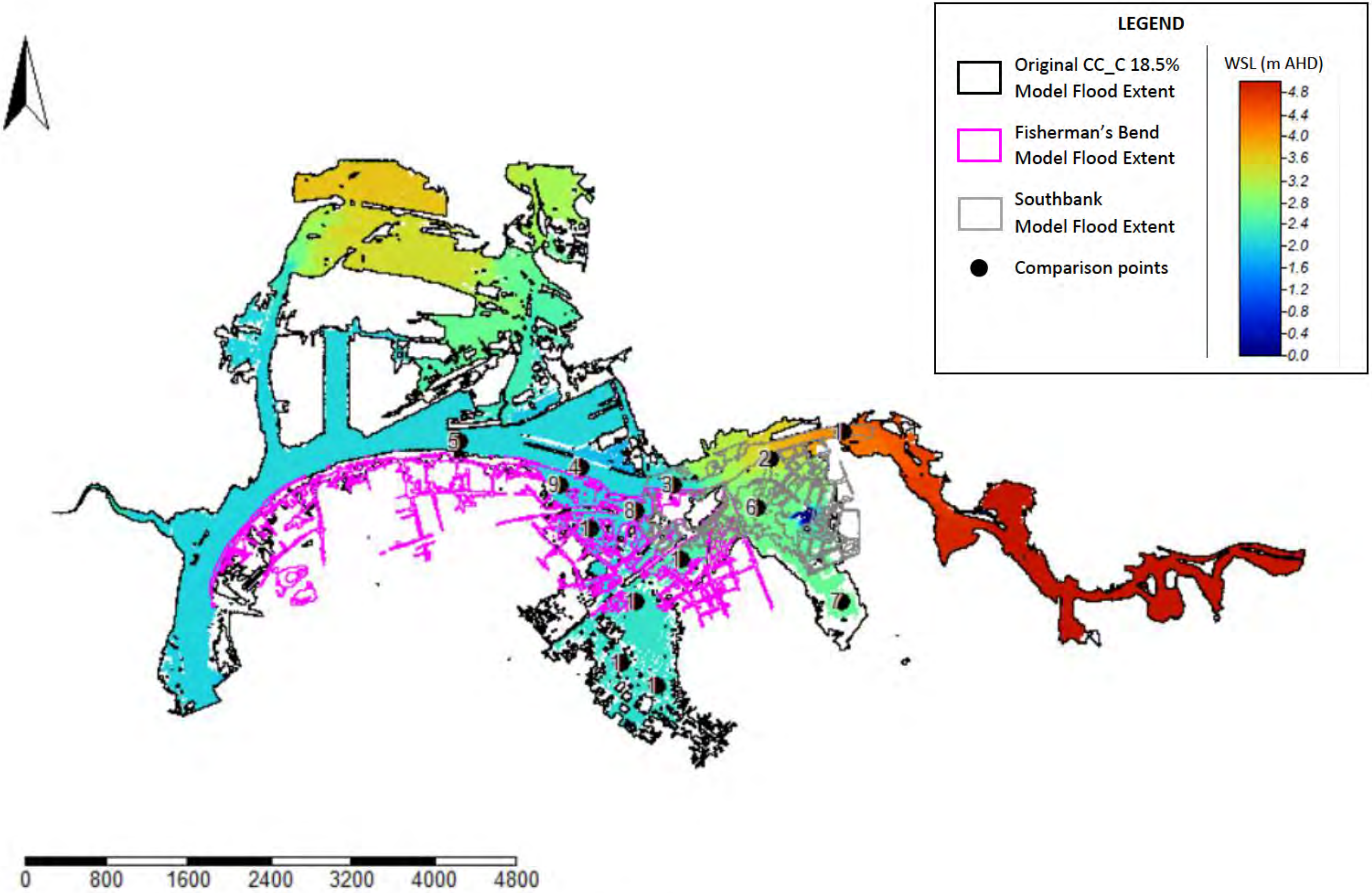

Figure 3 Overflow Refinement Yarra River Model Peak 100y WSL (10y Tide)

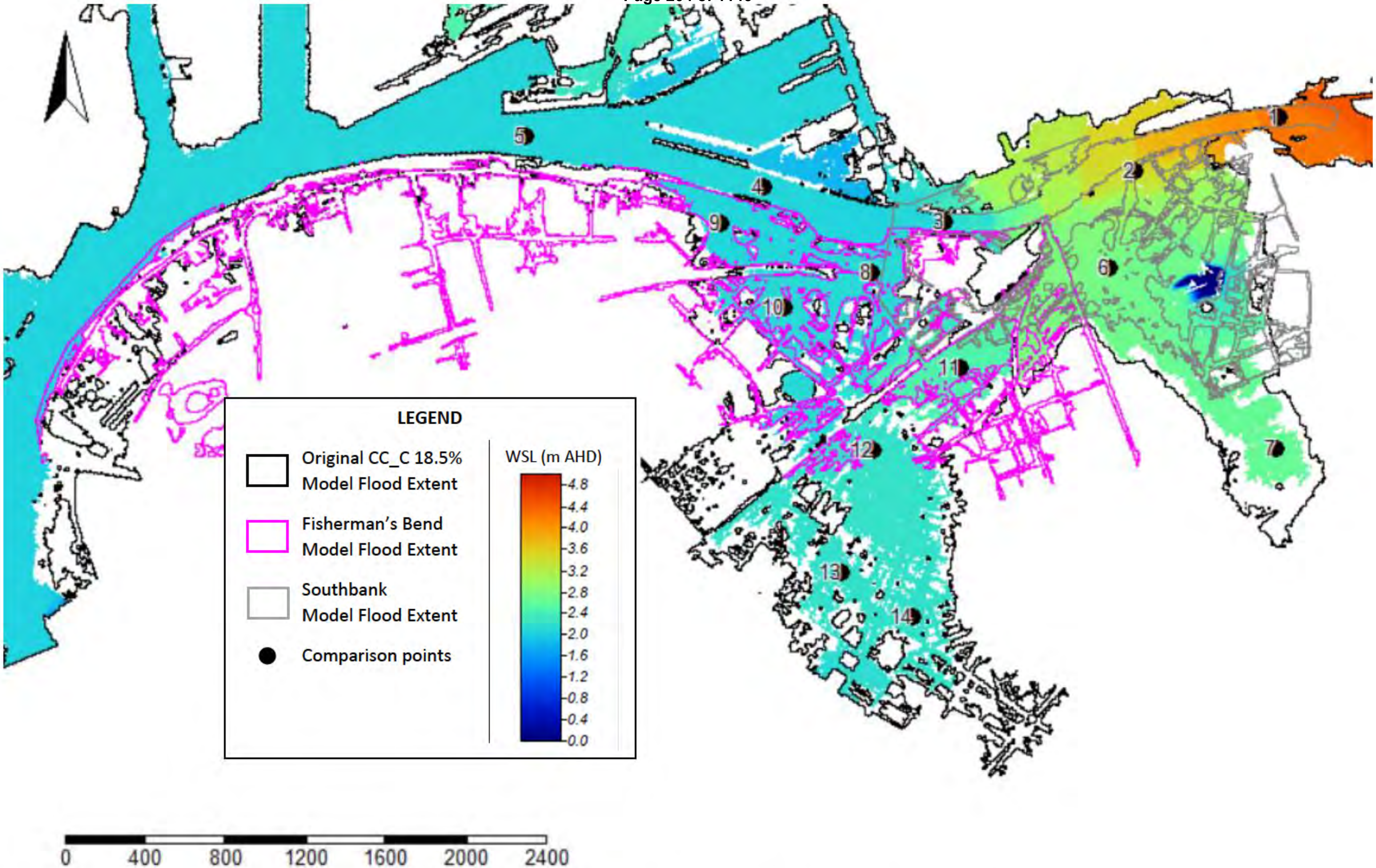

Figure 3B Overflow Refinement Yarra River Model Peak 100y WSL (10y Tide) – Zoomed to overflow refinement area

Table 1 Comparison Point Locations

ID	Description	Peak 100y ARI WSL w/ 100y Tide			Peak 100y ARI WSL w/ 10y Tide		
		Original Lower Yarra River Model	Overflow Refinement Lower Yarra River Model	Fishbend Model	Overflow Refinement Lower Yarra River Model	Southbank Model	Fishbend Model
1	Yarra River 1 (US)	4.48	4.22	-	4.19	2.14	-
2	Yarra River 2	3.84	3.31	-	3.25	1.74	-
3	Yarra River 3	2.29	2.34	-	2.09	2.14	-
4	Yarra River 4	2.27	2.29	-	2.04	-	-
5	Yarra River 5 (DS)	2.29	2.29	-	2.04	-	-
6	South Bank Pond	3.67	2.72	-	2.69	1.28	-
7	Sth Park St	3.68	2.61	-	2.58	-	-
8	Fwy\Montague St	2.36	2.20	2.25	2.08	-	1.82
9	Lorimer St \ Boundary St	2.27	2.28	2.25	2.03	-	1.82
10	Approx. Boundary St \ Gittus St	2.37	2.20	2.25	2.08	-	1.82
11	Approx. Buckhurst St \ George St	3.10	2.44	2.13	2.41	-	1.89
12	Approx. Heath St \ Raglan St	2.58	2.21	-	2.19	-	-
13	Edwards Park	2.53	2.20	-	2.18	-	-
14	Approx. St Vincent St \ Iffla St	2.53	2.20	-	2.18	-	-

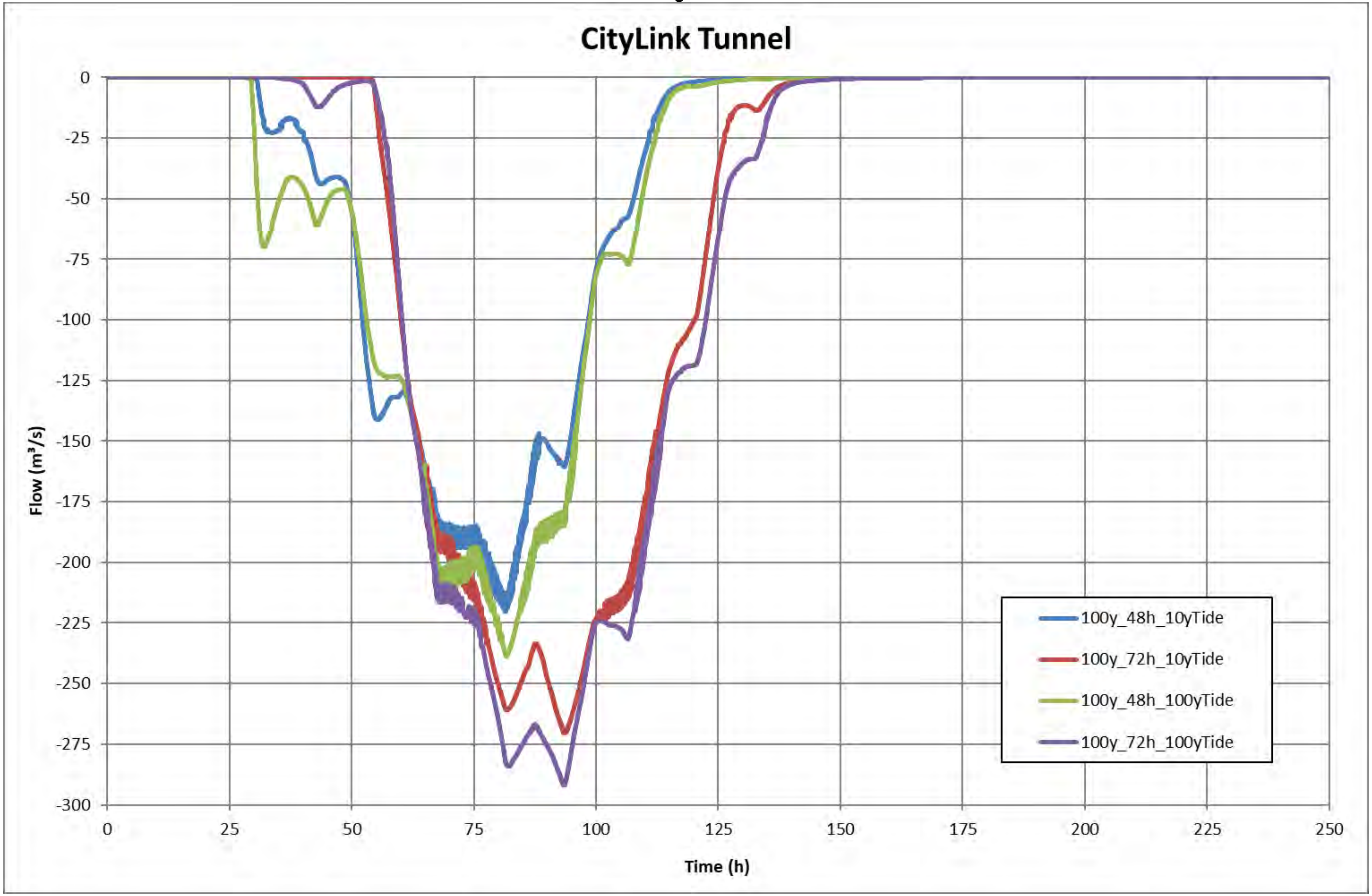

Figure 4 **Flow leaving model via City Link Tunnel portal near Southbank**

Attachment 5

Phase 2 Southbank Overflow Refinement Results Memo

Table 1 Modelled Scenarios

Runs	Flows	DS TWL	Plot Legend
1	Base 1% AEP (Kc=145 w/o ARFs) - blue line	10% AEP Tide	Current (Kc145)
2	Base 1% AEP (Kc=180 w/ ARFs) - orange line	10% AEP Tide	Kc180
3	Base 1% (Kc=237 w/o ARFs) - grey line	10% AEP Tide	Kc237
4	CC 18.5% 1% AEP (Kc=145 w/o ARFs)	10% AEP SLR Tide	Current CC18p5 (Kc145)
5	CC 18.5% 1% AEP (Kc=180 w/ ARFs)	10% AEP SLR Tide	Kc180_CC18p5
6	CC 18.5% 1% AEP (Kc=237 w/o ARFs)	10% AEP SLR Tide	Kc237_CC18p5

Results Presented

- Figure 1 -> Compartison of Yarra River inflow
- Figure 2 - Figure 7 -> WSL Plots
- Figure 8 -> Long-section along Yarra River
- Table 2 & Figure 9 -> Model Comparison Points
- Table 3 & Figure 10 -> 1934 Historic Level Comparison Points
- Figure 11 & 12 and Table 4 -> City Link Tunnel flows and volumes
- Figure 13 -> River roughness sensitivity results (previous modelling)

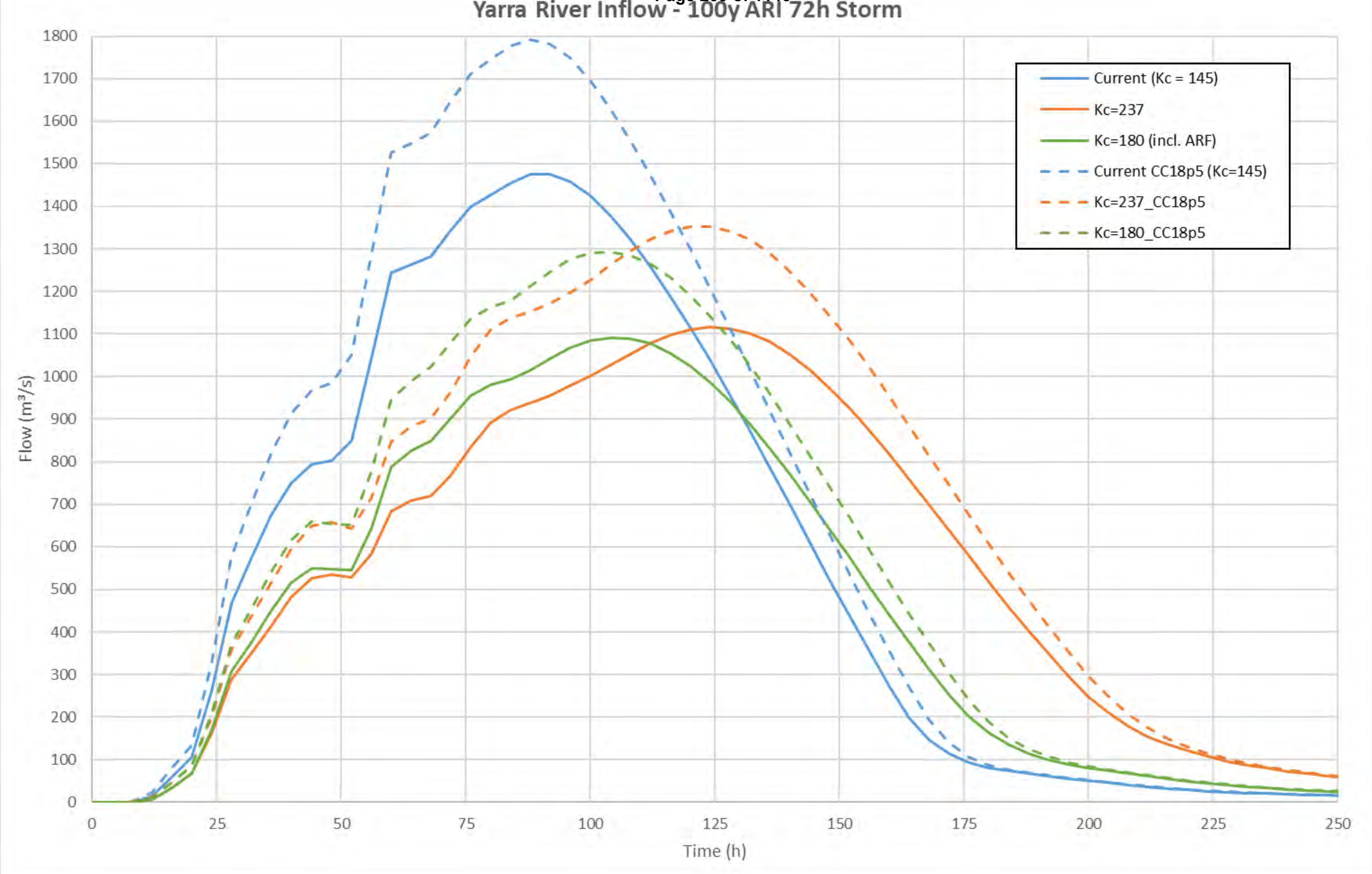

Figure 1 Comparison of Yarra River Inflows

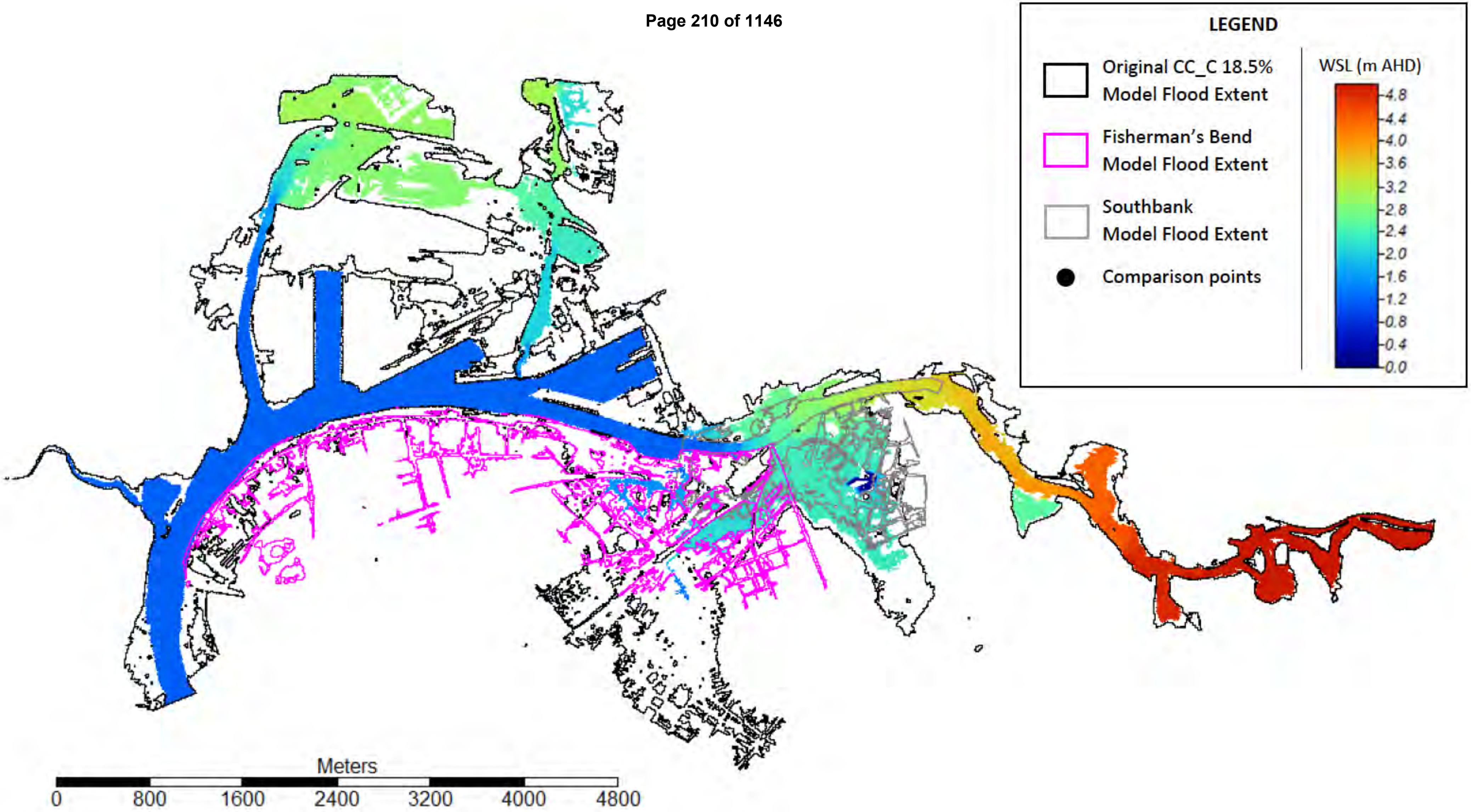

Figure 2 **Current (Kc=145) Yarra River Model Peak 100y WSL (10y Tide)**

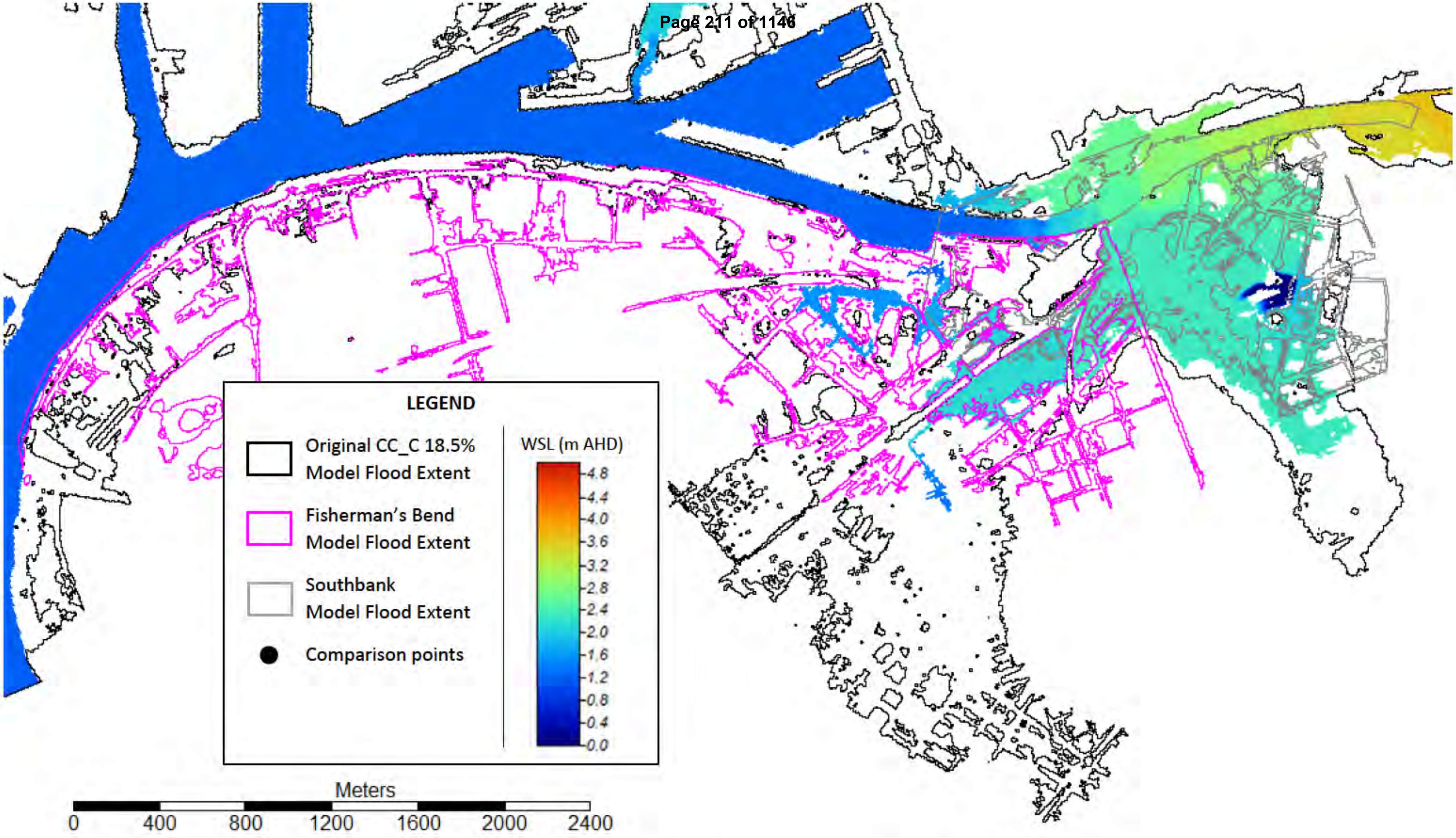

Figure 2B **Current (Kc=145) Yarra River Model Peak 100y WSL (10y Tide) – Zoomed to overflow refinement area**

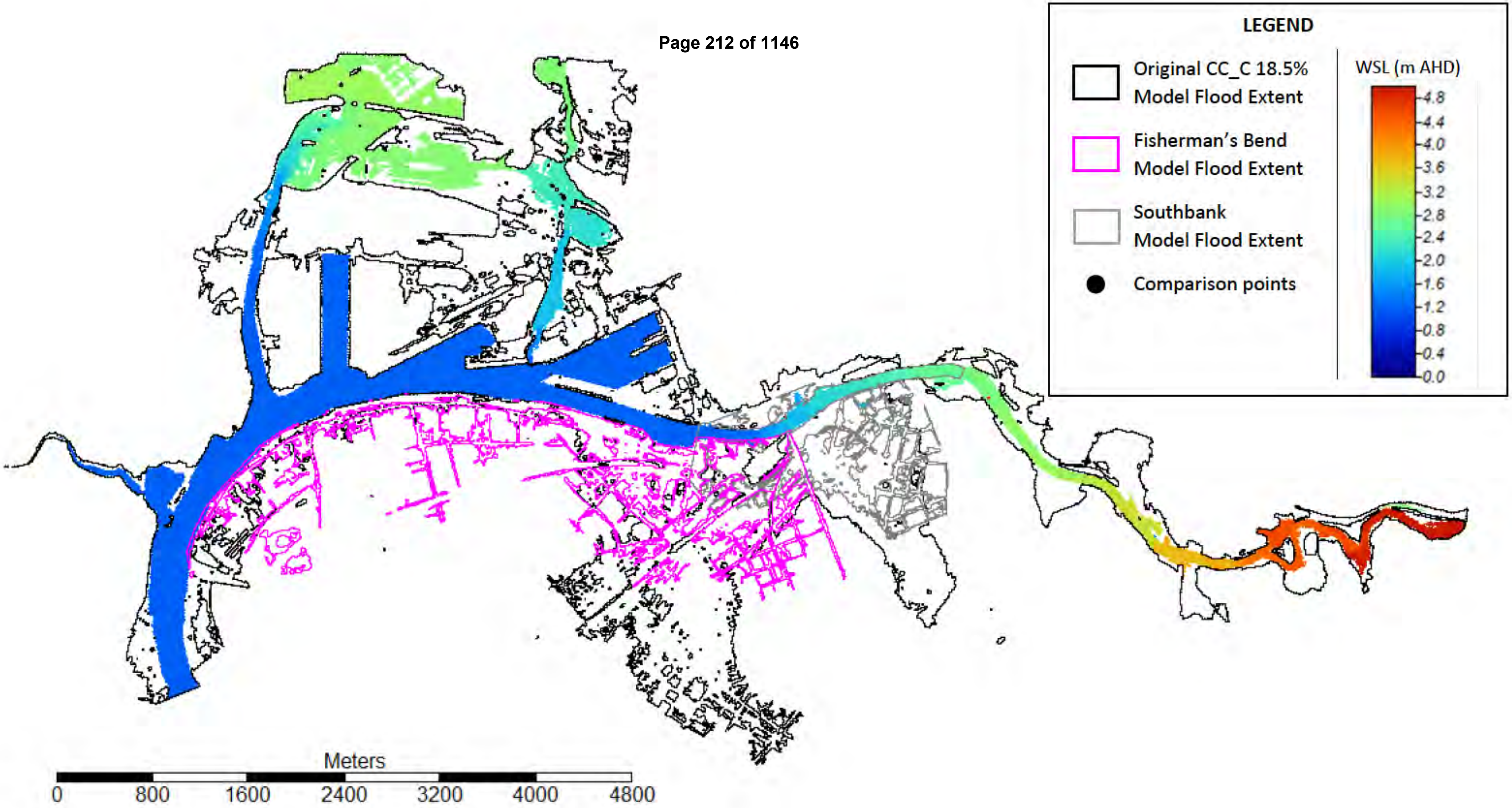

Figure 3 **Kc=237 Yarra River Model Peak 100y WSL (10y Tide)**

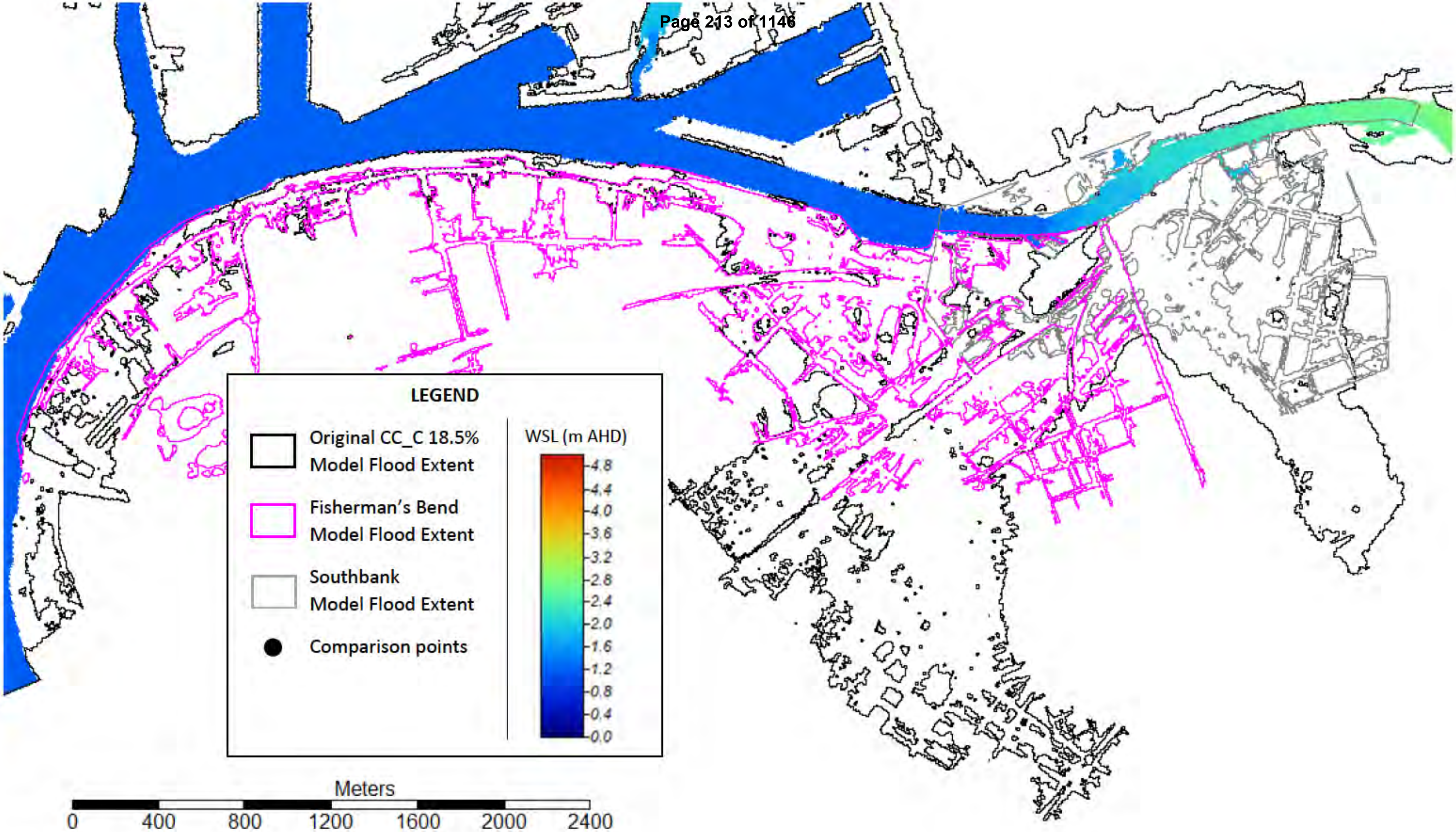

Figure 3B Kc=237 Yarra River Model Peak 100y WSL (10y Tide) – Zoomed to overflow refinement area

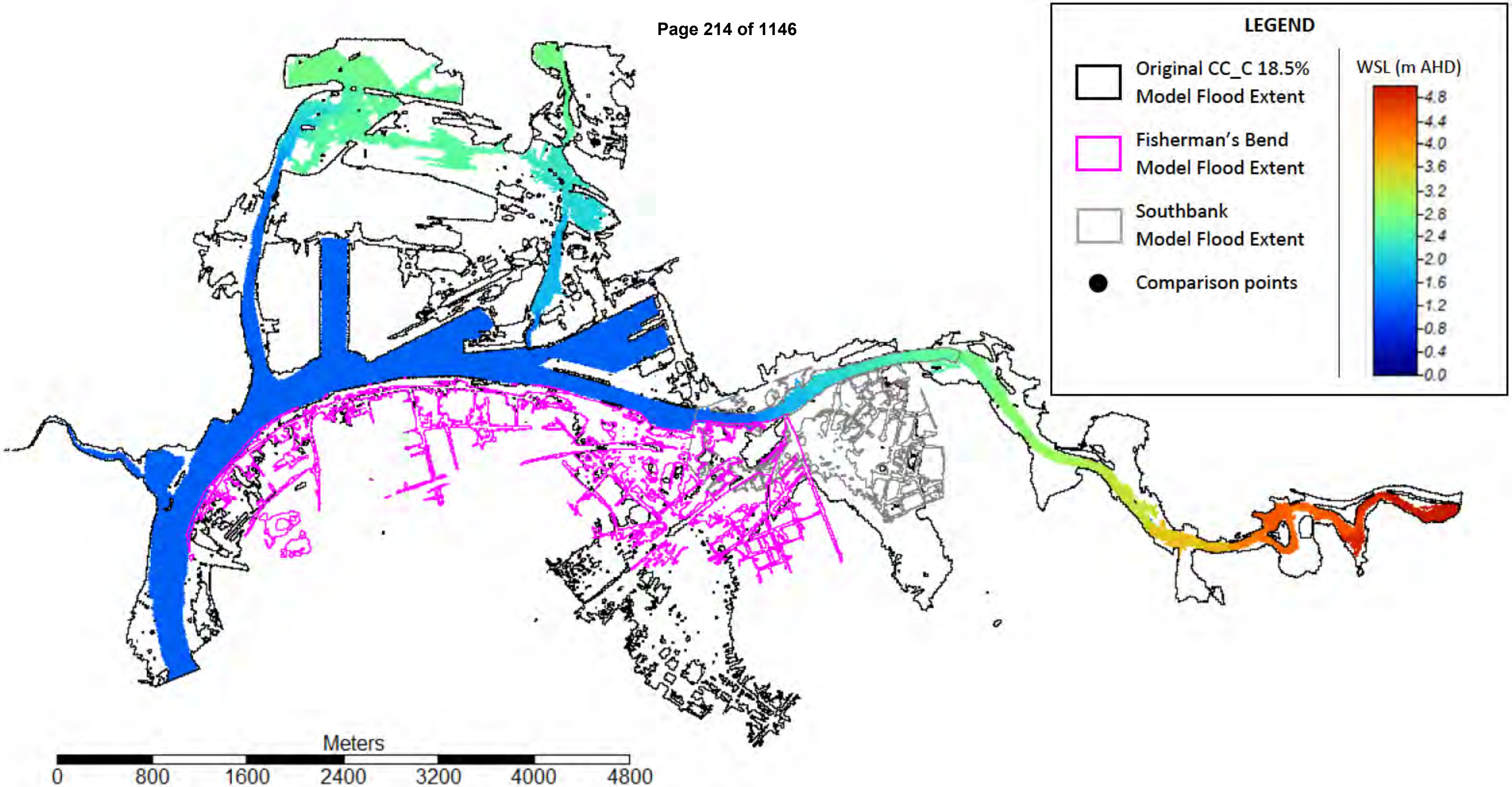

Figure 4 Kc=180 (incl. ARF) Yarra River Model Peak 100y WSL (10y Tide)

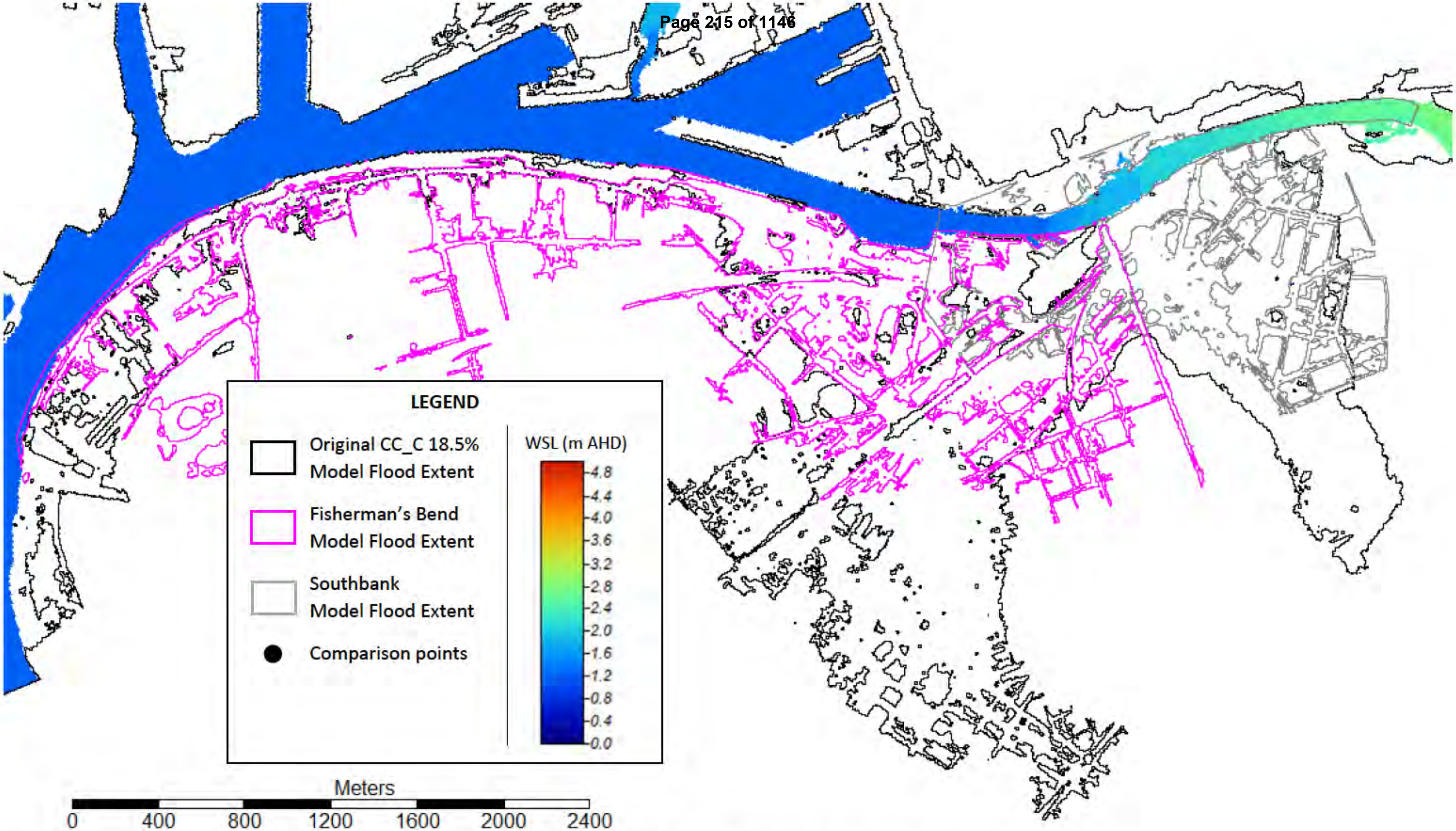

Figure 4B **Kc=180 (incl. ARF) Yarra River Model Peak 100y WSL (10y Tide) – Zoomed to overflow refinement area**

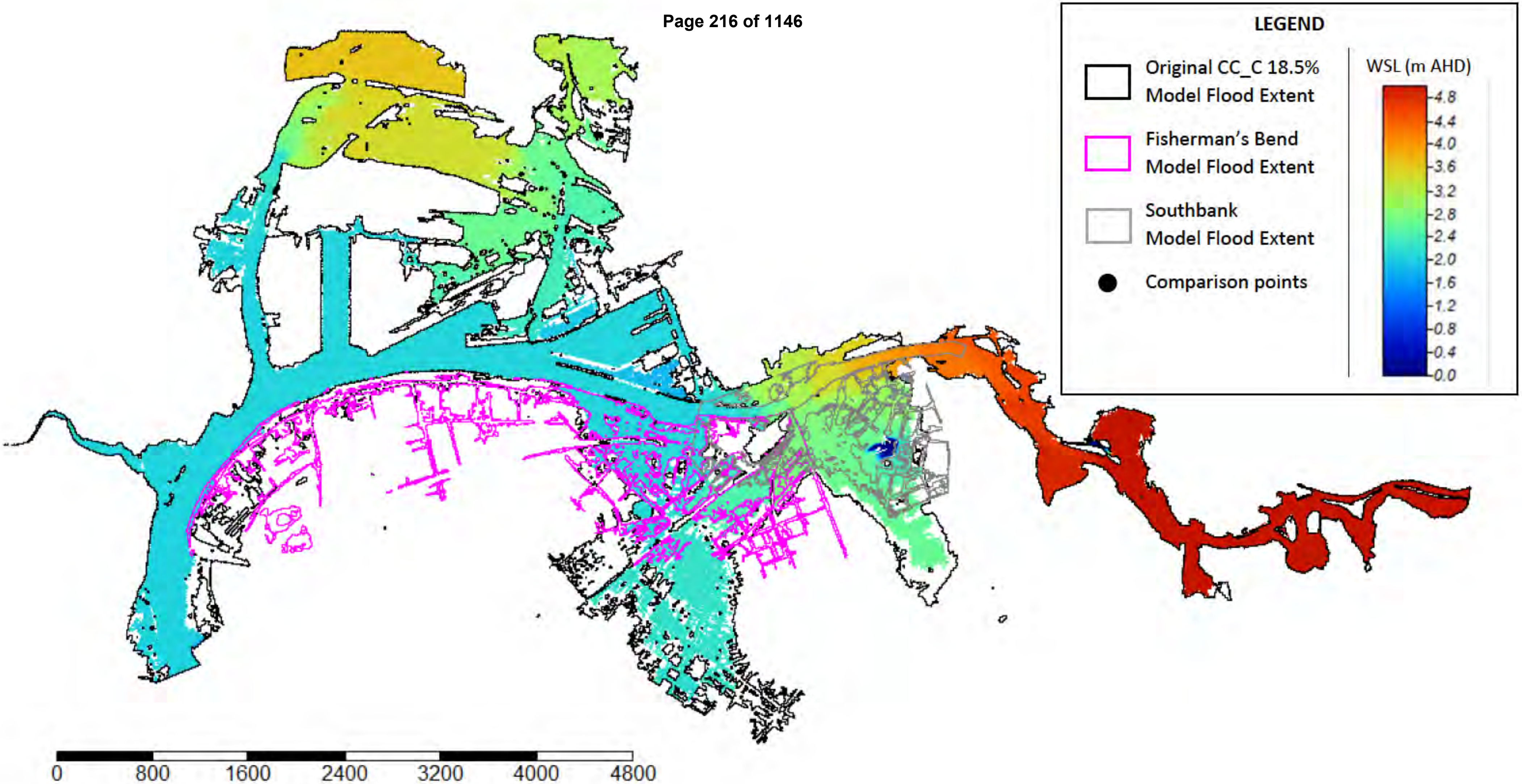

Figure 5 **Current CC18p5 (Kc=145) Yarra River Model Peak 100y WSL (10y SLR Tide)**

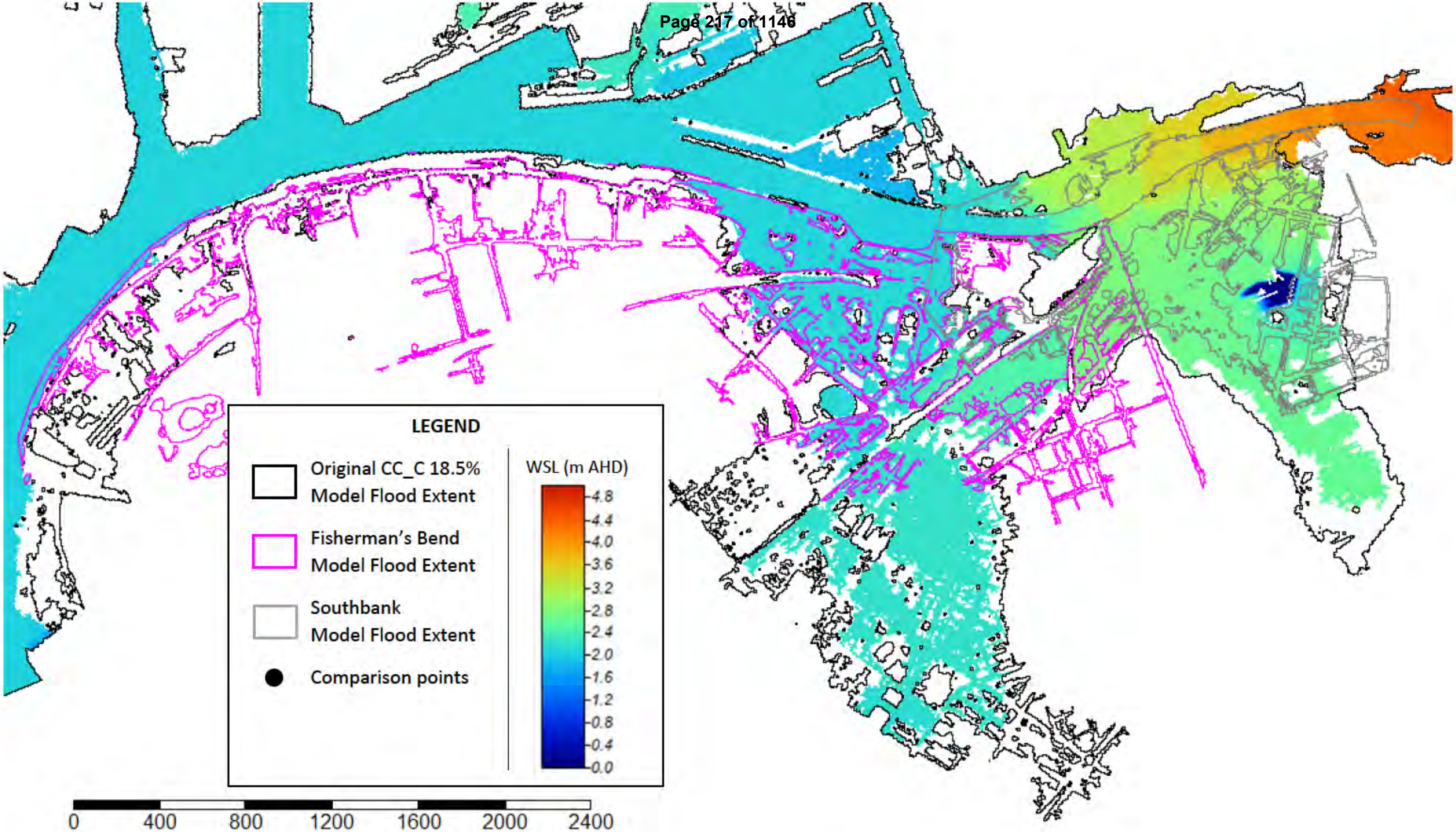

Figure 5B **Current CC18p5 (Kc=145) Yarra River Model Peak 100y WSL (10y SLR Tide) – Zoomed to overflow refinement area**

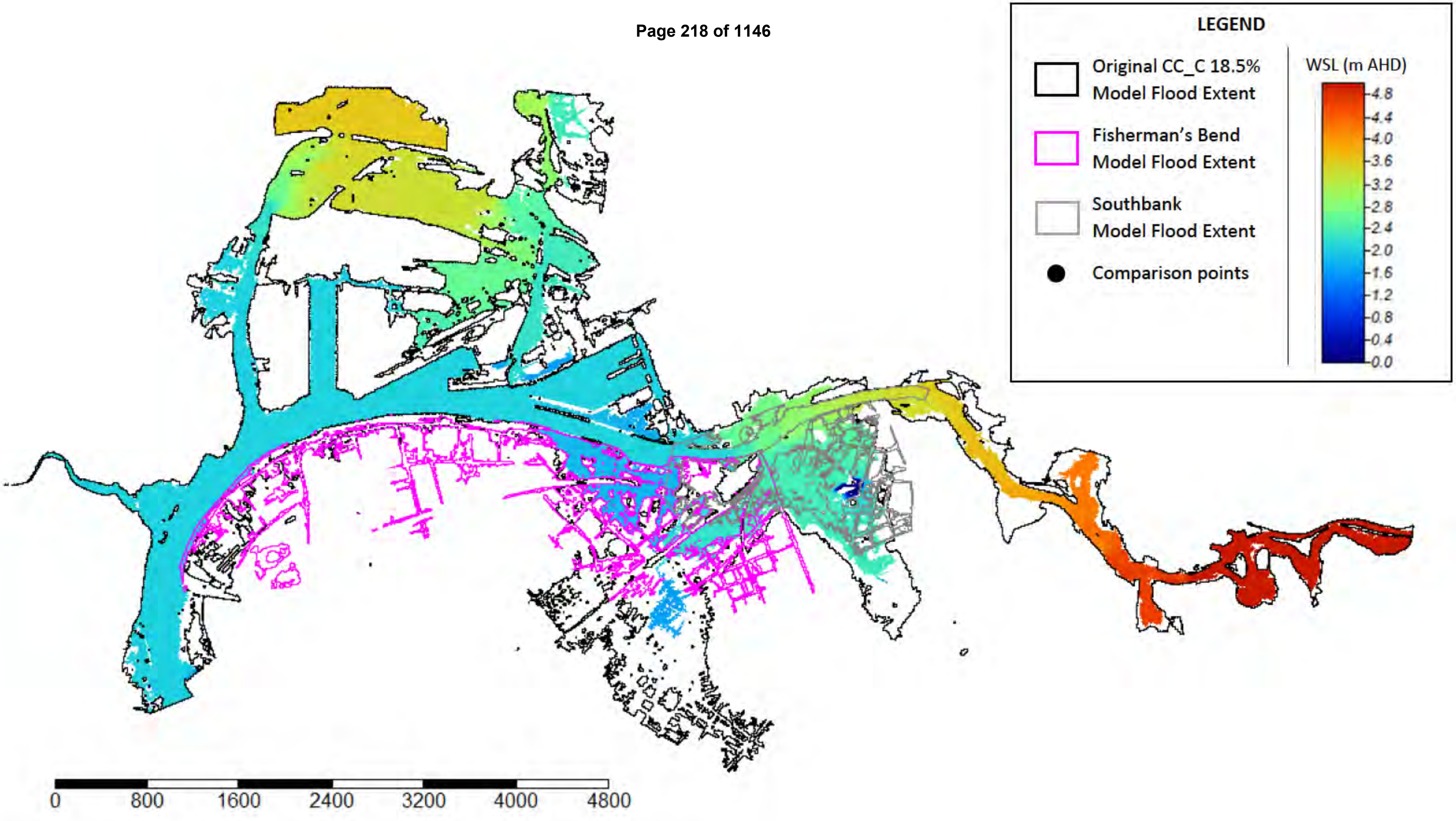

Figure 6 Kc=237 CC18p5 Yarra River Model Peak 100y WSL (10y SLR Tide)

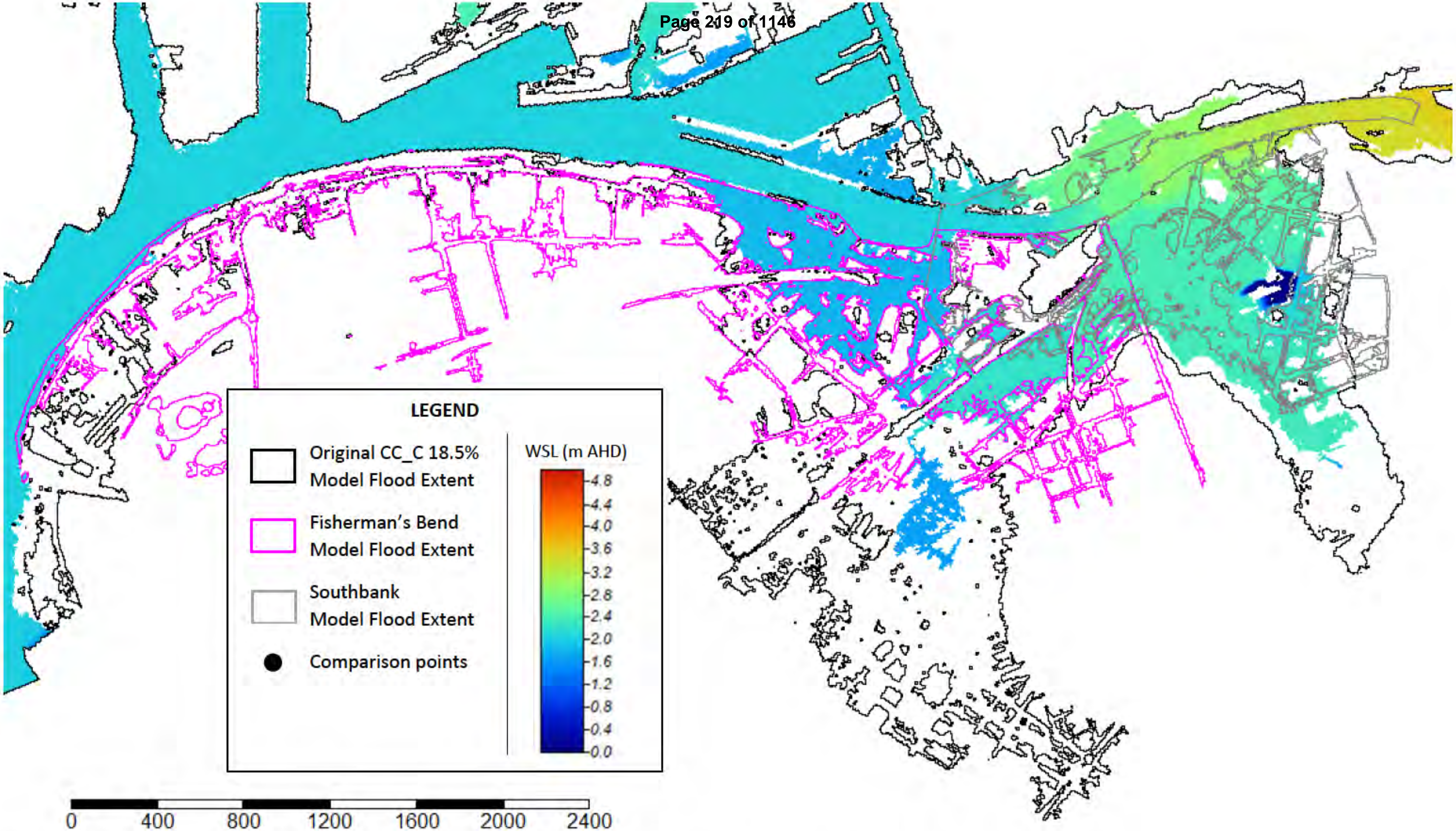

Figure 6B **Kc=237 CC18p5 Yarra River Model Peak 100y WSL (10y SLR Tide) – Zoomed to overflow refinement area**

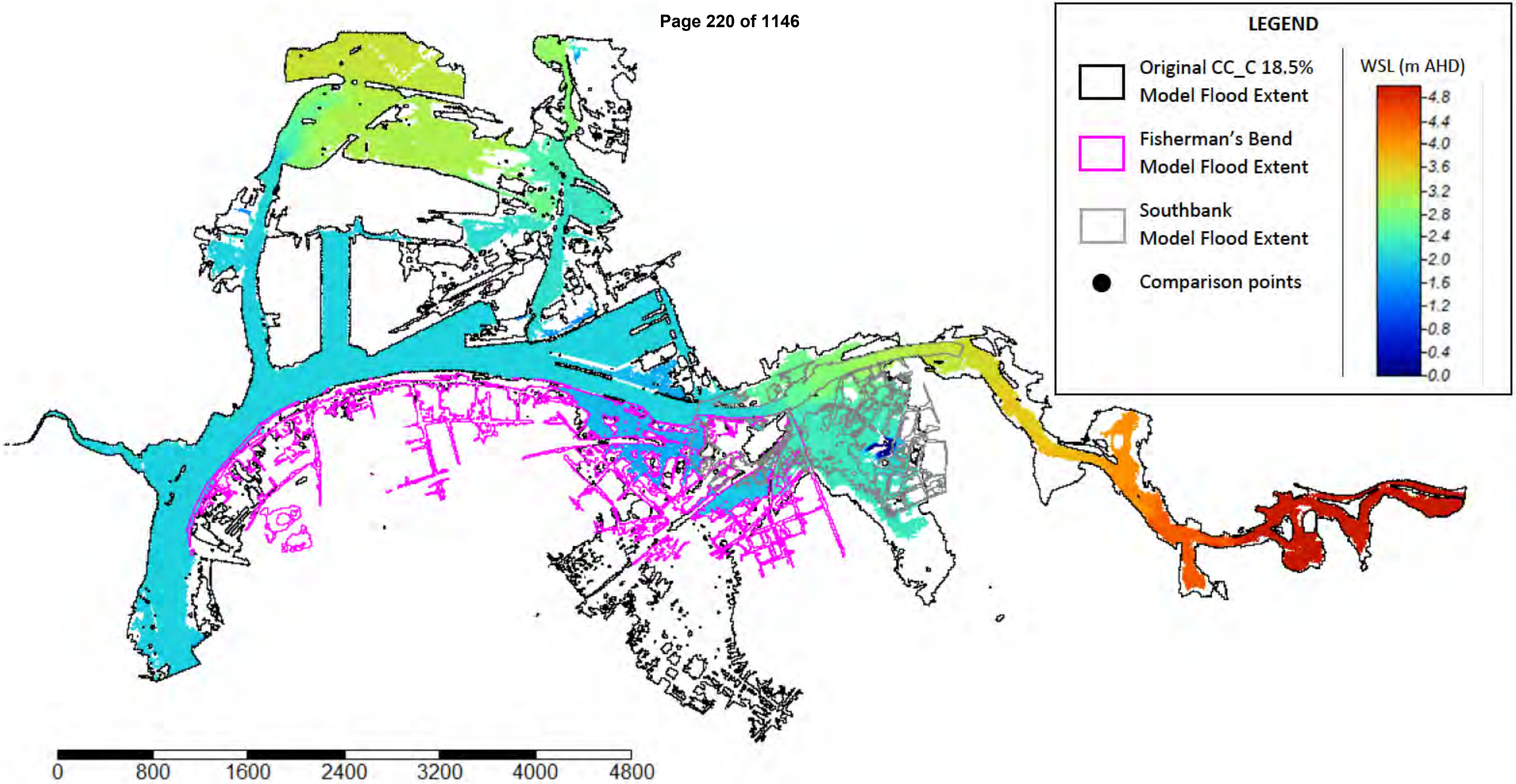

Figure 7 Kc=180 CC18p5 (incl. ARF) Yarra River Model Peak 100y WSL (10y SLR Tide)

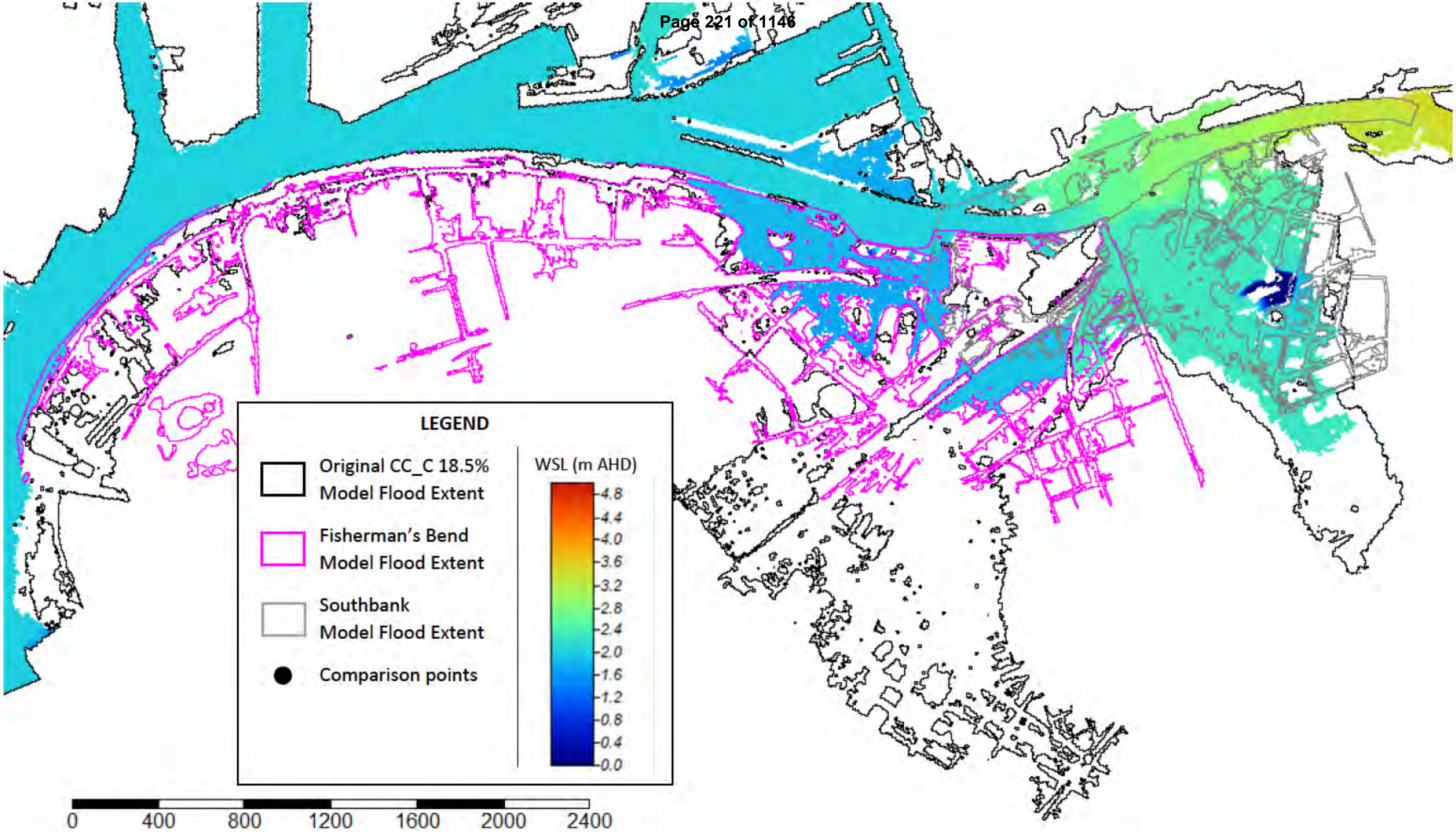

Figure 7B **Kc=180 CC18p5 (incl. ARF) Yarra River Model Peak 100y WSL (10y SLR Tide) – Zoomed to overflow refinement area**

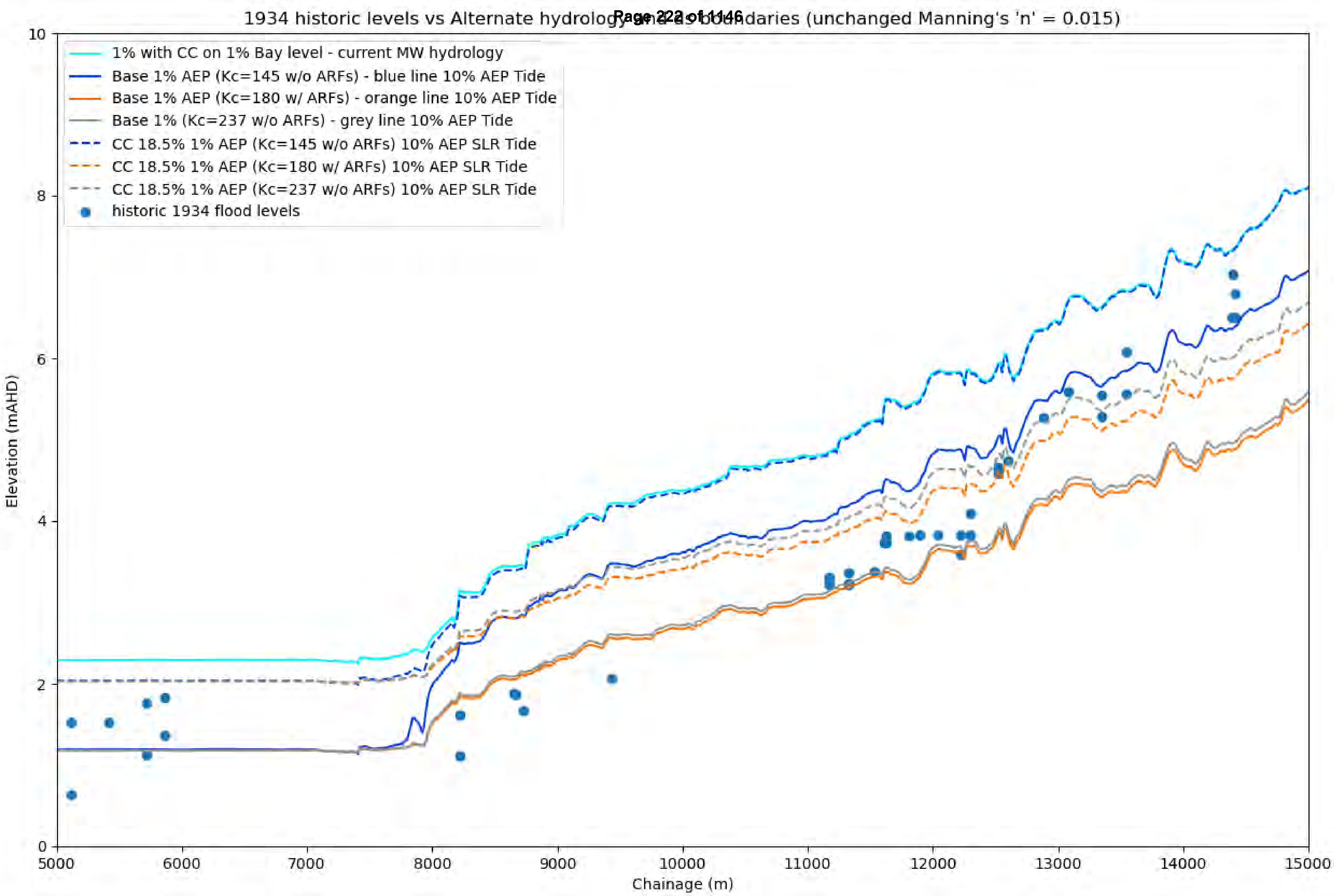

Figure 8 **Comparison of WSL Long-Section along Yarra River**

Table 2 Comparison Point Locations – Base 100y Flows with 10y Tide

ID	Description	1% AEP w/ 1% AEP SLR Tide	1% AEP w/ 10% AEP Tide			1% AEP w/ 10% AEP SLR Tide				
		Current (Kc=145)	Current (Kc=145)	Kc=237	Kc=180 (incl. ARF)	Current (Kc=145)	Kc=237	Kc=180 (incl. ARF)	Fishbend	Southbank
1	Yarra River 1 (US)	4.22	3.48	2.60	2.55	4.19	3.43	3.31	-	2.14
2	Yarra River 2	3.45	2.81	2.10	2.06	3.40	2.89	2.81	-	2.14
3	Yarra River 3	2.34	1.24	1.20	1.20	2.09	2.06	2.05	-	2.14
4	Yarra River 4	2.29	1.19	1.18	1.18	2.04	2.03	2.03	-	-
5	Yarra River 5 (DS)	2.29	1.19	1.18	1.18	2.04	2.03	2.03	-	-
6	South Bank Pond	2.72	2.31	-	-	2.69	2.36	2.30	-	1.28
7	Sth Park St	2.61	-	-	-	2.58	-	-	-	-
8	Fwy\Montague St	2.20	-	-	-	2.08	1.80	1.79	1.82	-
9	Lorimer St \ Boundary St	2.28	-	-	-	2.03	1.83	1.83	1.82	-
10	Approx. Boundary St \ Gittus St	2.20	1.53	-	-	2.08	1.80	1.70	1.82	-
11	Approx. Buckhurst St \ George St	2.44	2.13	-	-	2.41	2.21	1.91	1.89	-
12	Approx. Heath St \ Raglan St	2.21	-	-	-	2.19	-	-	-	-
13	Edwards Park	2.20	-	-	-	2.18	-	-	-	-
14	Approx. St Vincent St \ Iffla St	2.20	-	-	-	2.18	-	-	-	-

Figure 9 Location of Comparison Points

Table 3 **Comparison Point Locations – Climate Change (18.5% increased intensity) 100y Flows with 10y SLR Tide**

ID	1934 Flood Level	1% AEP w/ 1% AEP SLR Tide	1% AEP w/ 10% AEP Tide			1% AEP w/ 10% AEP SLR Tide		
		Current (Kc=145)	Current (Kc=145)	Kc=237	Kc=180 (incl. ARF)	Current (Kc=145)	Kc=237	Kc=180 (incl. ARF)
HL1	3.59	5.80	4.85	3.67	3.61	5.78	4.62	4.39
HL2	3.83	5.83	4.89	3.75	3.69	5.81	4.66	4.45
HL3	4.58	5.93	5.03	3.88	3.83	5.90	4.80	4.59
HL4	4.74	5.97	5.04	3.90	3.84	5.95	4.82	4.61
HL5	1.52	2.29	1.19	1.18	1.18	2.04	2.03	2.03
HL6	0.64	2.29	1.19	1.18	1.18	2.04	2.03	2.03
HL7	1.76	2.46	-	-	-	-	-	-
HL8	1.13	2.46	-	-	-	-	-	-
HL9	1.83	2.46	-	-	-	2.24	-	-
HL10	1.37	2.46	-	-	-	2.24	-	-
HL11	1.11	3.15	2.50	1.88	1.85	3.08	2.66	2.59
HL12	1.88	3.47	2.84	2.11	2.07	3.42	2.91	2.83
HL13	3.26	4.86	4.05	3.15	3.10	4.83	3.92	3.79
HL14	3.23	5.05	4.19	3.24	3.18	5.02	4.04	3.89
HL15	3.22	5.05	4.19	3.24	3.18	5.02	4.04	3.89
HL16	3.38	5.23	4.36	3.36	3.31	5.21	4.19	4.03
HL17	3.74	5.51	4.52	3.43	3.38	5.49	4.31	4.13
HL18	6.5	7.31	6.34	4.93	4.85	7.29	5.98	5.72
HL19	5.28	-	-	-	-	-	-	-
HL20	5.56	6.83	5.84	4.43	4.36	6.81	5.50	5.23
HL21	6.5	7.36	6.38	4.97	4.88	7.34	6.02	5.76
HL22	1.87	3.44	2.80	2.09	2.06	3.39	2.88	2.80
HL23	3.83	5.80	4.85	3.67	3.61	5.78	4.62	4.39
HL24	4.09	5.83	4.89	3.75	3.69	5.81	4.66	4.45
HL25	4.64	5.93	5.03	3.88	3.83	5.90	4.80	4.59
HL26	6.08	6.84	5.85	4.40	4.32	6.82	5.51	5.23
HL27	7.03	7.03	6.07	4.68	4.60	7.02	5.72	5.46
HL28	1.61	3.15	2.50	1.88	1.85	3.08	2.66	2.59
HL29	6.79	7.36	6.38	4.97	4.88	7.34	6.02	5.76
HL30	4.66	5.93	5.03	3.88	3.83	5.90	4.80	4.59
HL31	5.27	5.96	-	-	-	5.96	-	-
HL32	3.22	4.86	4.05	3.15	3.10	4.83	3.92	3.79
HL33	2.06	4.22	3.48	2.61	2.56	4.18	3.43	3.31
HL34	3.82	5.43	4.40	3.33	3.28	5.41	4.21	4.01
HL35	3.83	5.48	4.46	3.35	3.30	5.46	4.26	4.03
HL36	3.74	5.33	4.46	3.42	3.36	5.31	4.27	4.10
HL37	3.83	5.72	4.81	3.79	3.74	5.70	4.65	4.49
HL38	1.52	2.29	1.19	1.18	1.18	2.04	2.03	2.03
HL39	3.31	4.86	4.05	3.15	3.10	4.83	3.92	3.79
HL40	3.82	5.51	4.52	3.43	3.38	5.49	4.31	4.13
HL41	3.36	5.05	4.19	3.24	3.18	5.02	4.04	3.89
HL42	5.55	-	-	-	-	-	-	-
HL43	1.67	3.45	2.83	2.15	2.12	3.40	2.90	2.82
HL44	5.59	6.84	5.88	4.58	4.50	6.82	5.57	5.32

Figure 10 Location of 1934 Historic Flood Levels

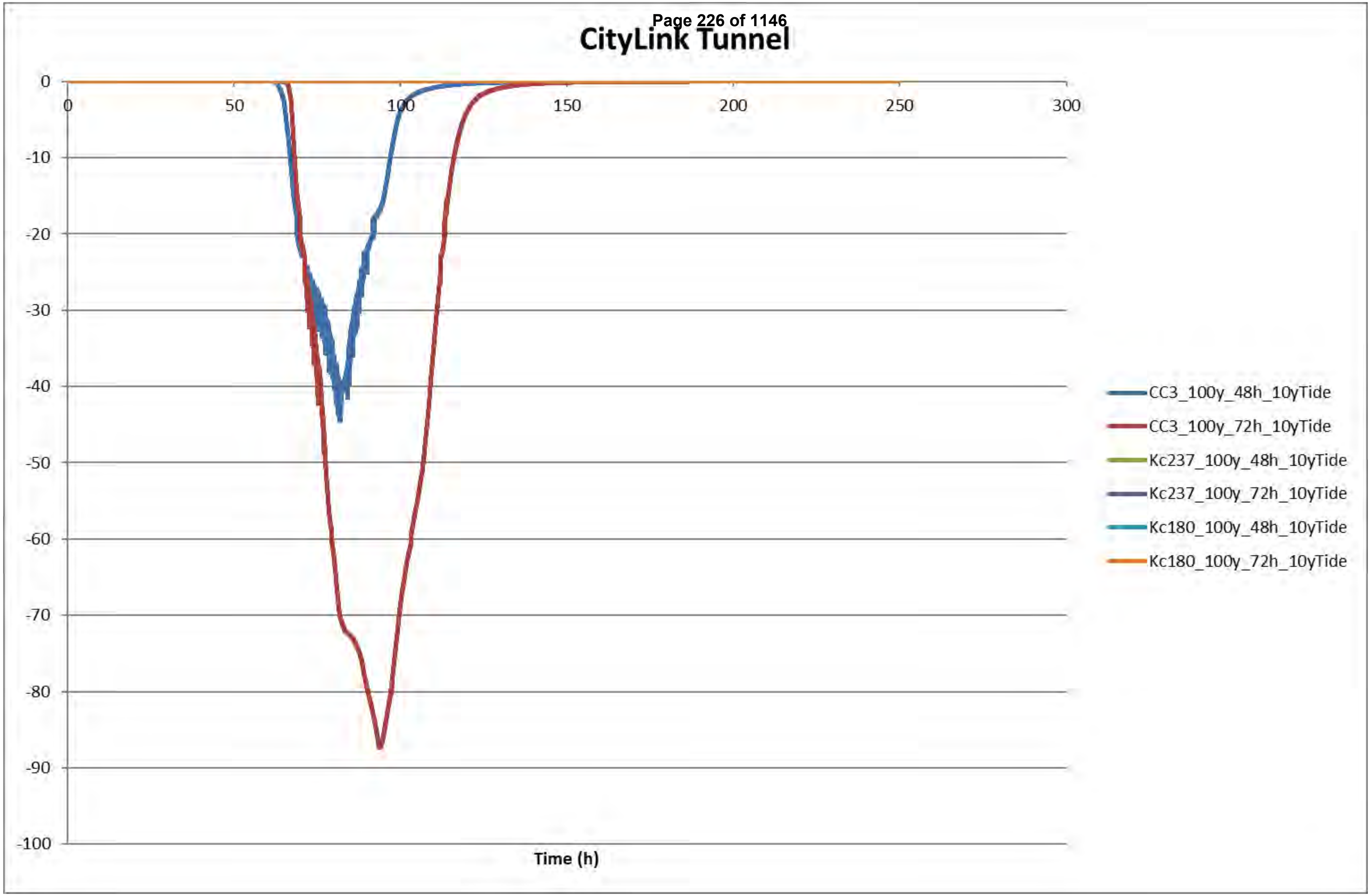

Figure 11 Flow leaving model via City Link Tunnel portal near Southbank with Base Case hydrology

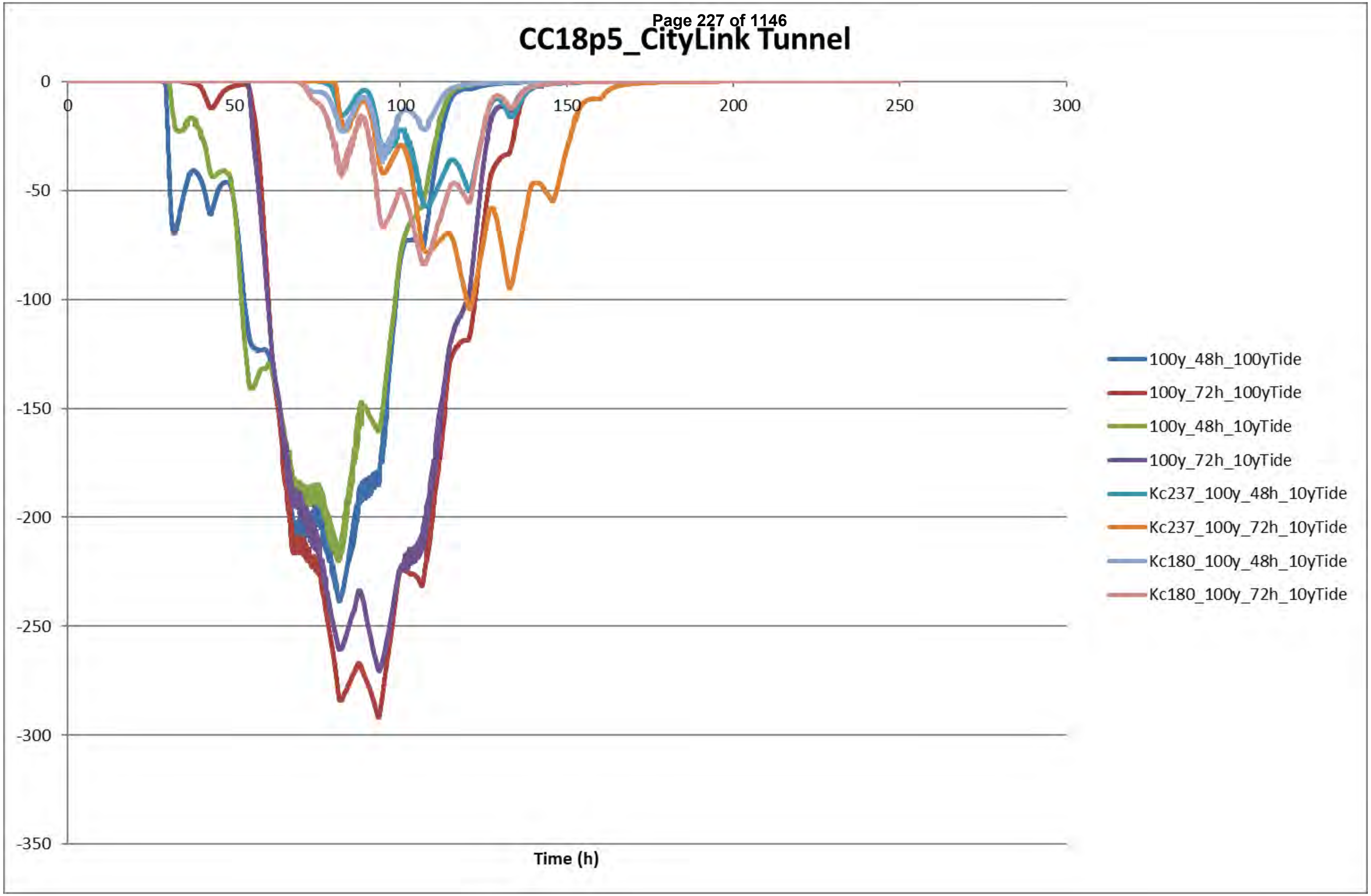

Figure 12 **Flow leaving model via City Link Tunnel portal near Southbank with Climate Change (18.5%) hydrology**

Table 4 **Southbank City Link Tunnel Portal Flows & Volumes**

Scenario	Peak Flow (m^3/s)	Peak Volume (m^3)
Current CC18p5 (Kc=145) - 1% AEP SLR Tide	-292.03	-51,296,280
Current CC18p5 (Kc=145) - 10% AEP SLR Tide	-270.58	-46,754,266
Kc=237 CC18p5 - 10% AEP SLR Tide	-104.48	-14,283,613
Kc=180 CC18p5 (incl. ARF) - 10% AEP SLR Tide	-83.89	-9,027,424
Current (Kc=145) - 10% SLR Tide	-87.37	-9,669,632
Kc=237 - 10% AEP Tide	0	0
Kc=180 (incl. ARF) - 10% AEP Tide	0	0

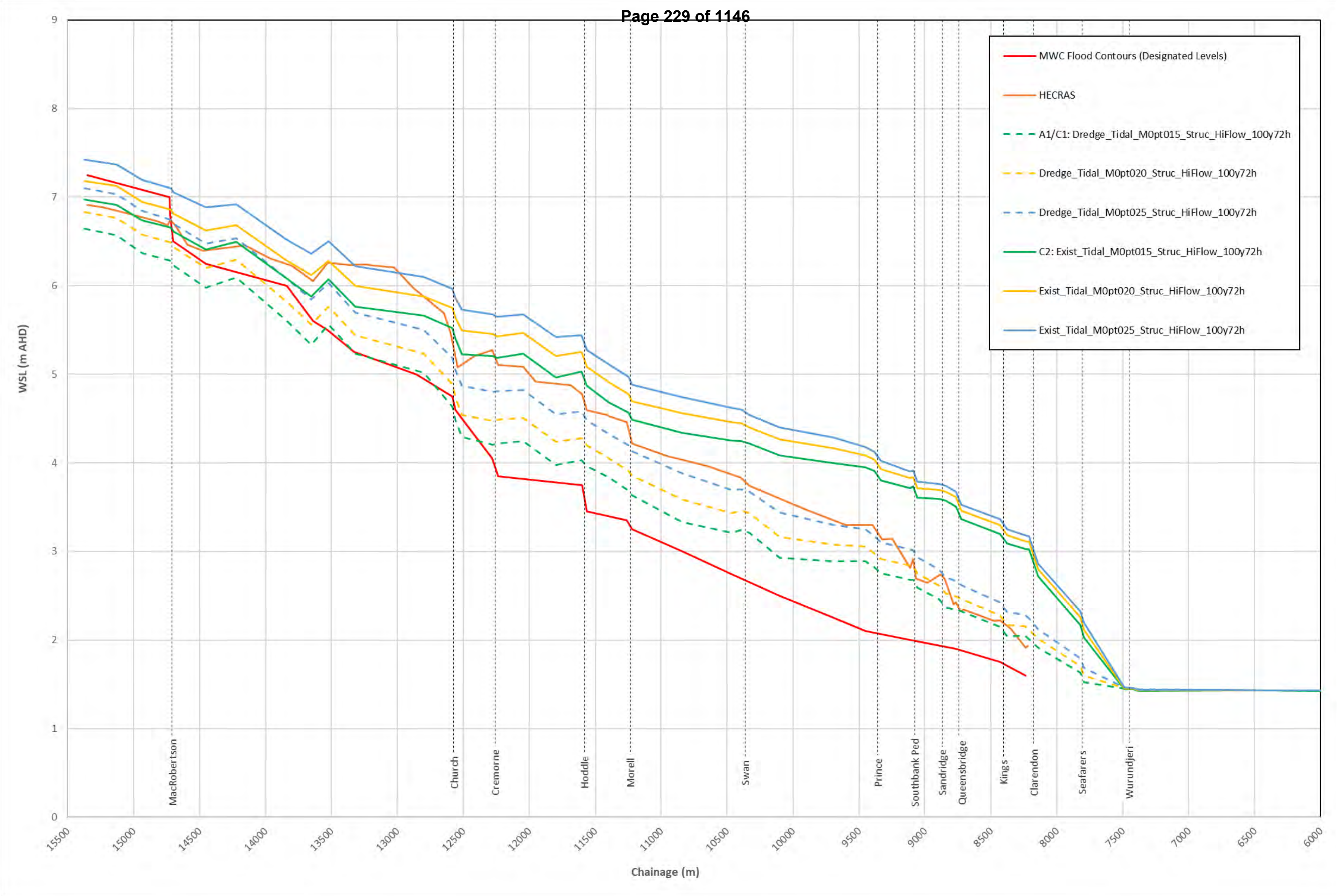

Figure 13 **Waterway Manning's 'n' roughness Sensitivity Modelling (results from modelling undertaken for "Modelling Assumption and Implications Memo")**

Attachment 6
Phase 3 Southbank Overflow Refinement
Results Memo

Stage 1A –
Summary of Results Post-Overflow Refinements

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1. Project Diary

Table 1 summarises of the agreed model refinements carried out on the Lower Yarra River Flood Mapping TUFLOW model since the delivery of the 'Draft Deliverables' in February 2020.

Table 1 Progression of Model Refinement

Date	Time	Description\Outcome
23-04-2020	9:00 am	Skype meeting to discuss the Lower Yarra mapping limit
28-04-2020	5:29 pm	Emailed proposal $#####
29-04-2020	8:30 am	Meeting to discuss scope for Lower Yarra
29-04-2020	12:58 pm	Revised proposal $#####
29-04-2020	3:24 pm	MW accepted revised proposal
06-05-2020	10:19 pm	GHD provide Stage 1A results
07-05-2020	10:00 am	Discussion of stage 1A results
07-05-2020	3:30 pm	Meeting to discuss next steps
08-05-2020	10:07 am	Email to MW clarifying scope, fees and discussions with NELP
08-05-2020	2:50 pm	Emails back and forth, MW emailed NELP with formal request
08-05-2020	3:12 pm	MW confirm request for all 6 runs.
12-05-2020	2:57 pm	GHD provide results for the additional 6 runs
13-05-2020	8:30 am	Meeting to discuss results
13-05-2020	3:11 pm	GHD provided email to summarise revised scope
14-05-2020	3:21 pm	MW request information of the 10year tidal boundary time series
14-05-2020	3:45 pm	GHD referred MW to Appendix C of the report
15-05-2020	7:17 am	MW requested GHD to proceed in accordance with revised scope (13/5)
15-05-2020	3:58 pm	MW provide additional info on 1934 event
15-05-2020	4:10 pm	GHD advised that we had responded to NELP and expected that NELP would advise MW of their decision
18-05-2020	6:00 pm	NELP approve use of existing conditions TUFLOW and RORB models for MW

2. Preliminary Results for Discussion

2.1 Modelled Scenarios

Table 2 summarises the modelled scenarios completed since the initial overflow refinement modelling, which added terrain details from the Southbank and Fisherman's Bend TUFLOW models, a new boundary condition at the City Link portal in Southbank area, and a DS tidal boundary based on 10% AEP.

Table 2 Modelled Scenarios

Runs	Hydrology	Yarra River Inflow (m^3/s)	Yarra River Inflow Volume (m^3)	DS TWL	River Roughness (Manning's 'n')	Plot Legend
1	Base 1% AEP (Kc=145 w/o ARFs)[1] [Solid blue line on Figure 1]	1475	517,000,000	10% AEP Tide	0.015	100y Kc145 NoARF M0p015 (Current)
2	Base 1% (Kc=237 w/o ARFs)[2] [Solid orange line on Figure 1]	1115	517,000,000	10% AEP Tide	0.015	100y Kc237 NoARF M0p015
3	Base 1% AEP (Kc=180 w/ ARFs)[3] [Solid green line on Figure 1]	1091	432,000,000	10% AEP Tide	0.015	100y Kc180 ARF M0p015
4	CC 18.5% 1% AEP (Kc=145 w/o ARFs)[1] [Dashed blue line on Figure 1]	1792	621,000,000	10% AEP SLR Tide	0.015	100y CC18p5 Kc145 NoARF M0p015 (Current)
5	CC 18.5% 1% AEP (Kc=237 w/o ARFs)[2] [Dashed green line on Figure 1]	1352	621,000,000	10% AEP SLR Tide	0.015	100y CC18p5 Kc237 NoARF M0p015
6	CC 18.5% 1% AEP (Kc=180 w ARFs)[3] [Dashed green line on Figure 1]	1293	509,000,000	10% AEP SLR Tide	0.015	100y CC18p5 Kc180 ARF M0p015
7	Base 1% AEP (Kc=180 w/ ARFs)[3]	-	-	10% AEP Tide	0.020	100y Kc180 ARF M0p020
8	Base 1% AEP (Kc=180 w/ ARFs)[3]	-	-	10% AEP Tide	0.025	100y Kc180 ARF M0p025
9	Base 1% AEP (Kc=180 w/ ARFs)[3]	-	-	10% AEP Tide	0.030	100y Kc180 ARF M0p030
10	CC 18.5% 1% AEP (Kc=180 w ARFs)[3]	-	-	10% AEP SLR Tide	0.020	100y CC18p5 Kc180 ARF M0p020
11	CC 18.5% 1% AEP (Kc=180 w ARFs)[3]	-	-	10% AEP SLR Tide	0.025	100y CC18p5 Kc180 ARF M0p025
12	CC 18.5% 1% AEP (Kc=180 w ARFs)[3]	-	-	10% AEP SLR Tide	0.030	100y CC18p5 Kc180 ARF M0p030
13	CC 18.5% 10% AEP (Kc=145 w/o ARFs)[1]	831	291,000,000	10% AEP SLR Tide	0.015	10y Kc145 NoARF M0p015 (Current)
14	CC 18.5% 10% AEP (Kc=180 w ARFs)[3]	616	246,000,000	10% AEP SLR Tide	0.020	10y CC18p5 Kc180 ARF M0p020
15	CC 18.5% 10% AEP (Kc=180 w ARFs)[3]	616	246,000,000	10% AEP SLR Tide	0.030	10y CC18p5 Kc180 ARF M0p030

Note:

[1] indicates that the Kc parameter is based on calibration to flood levels using HEC-RAS from "2010 - SP Goh & Associates Study", which didn't use ARFs.

[2] indicates that the Kc parameter is based on calibration to gauge flows from "2010 - SP Goh & Associates Study" , which didn't use ARFs

[3] indicates that the Kc parameter is based on MW work prior to "2010 - SP Goh & Associates Study", but with the application of ARFs

2.2 Yarra River Boundary Conditions

Figure 1 and Figure 2 summarise the key boundary condition assumptions for the modelling presented in Section 2.1.

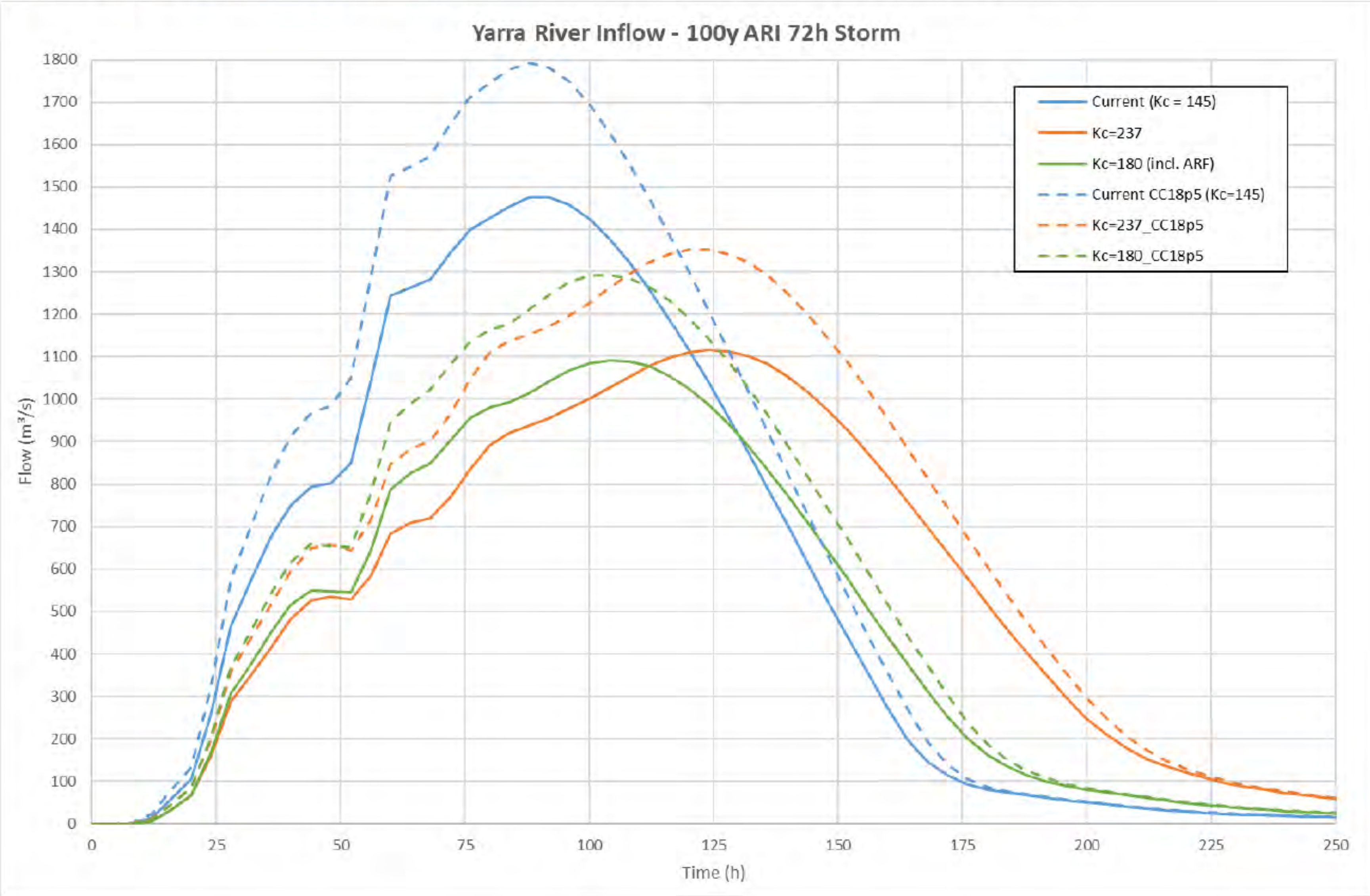

Figure 1 Comparison of Yarra Inflows

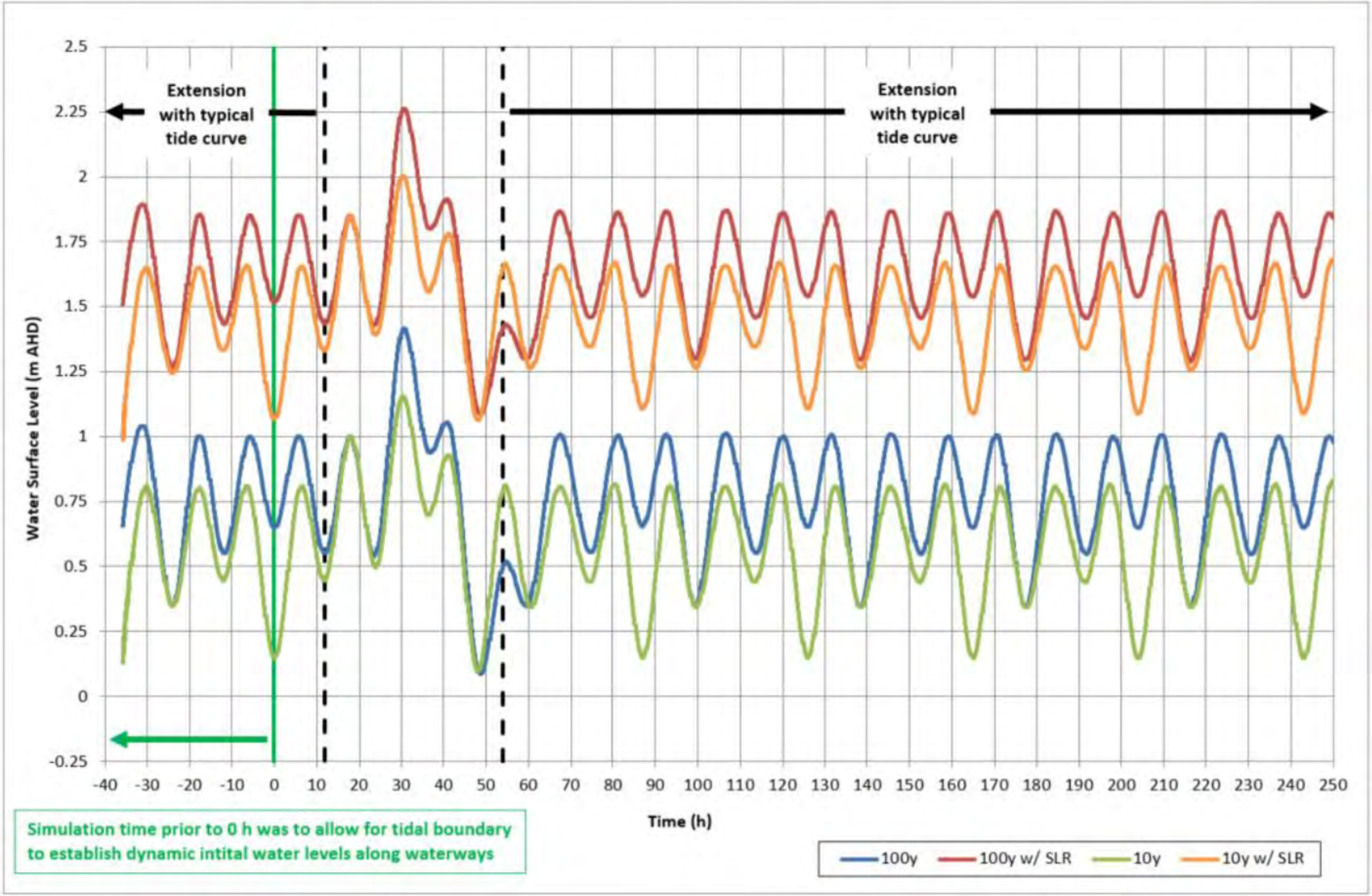

Figure 2 Adopted Yarra River DS Tidal Boundary Curves

2.3 Flood Extents

2.3.1 Run 1

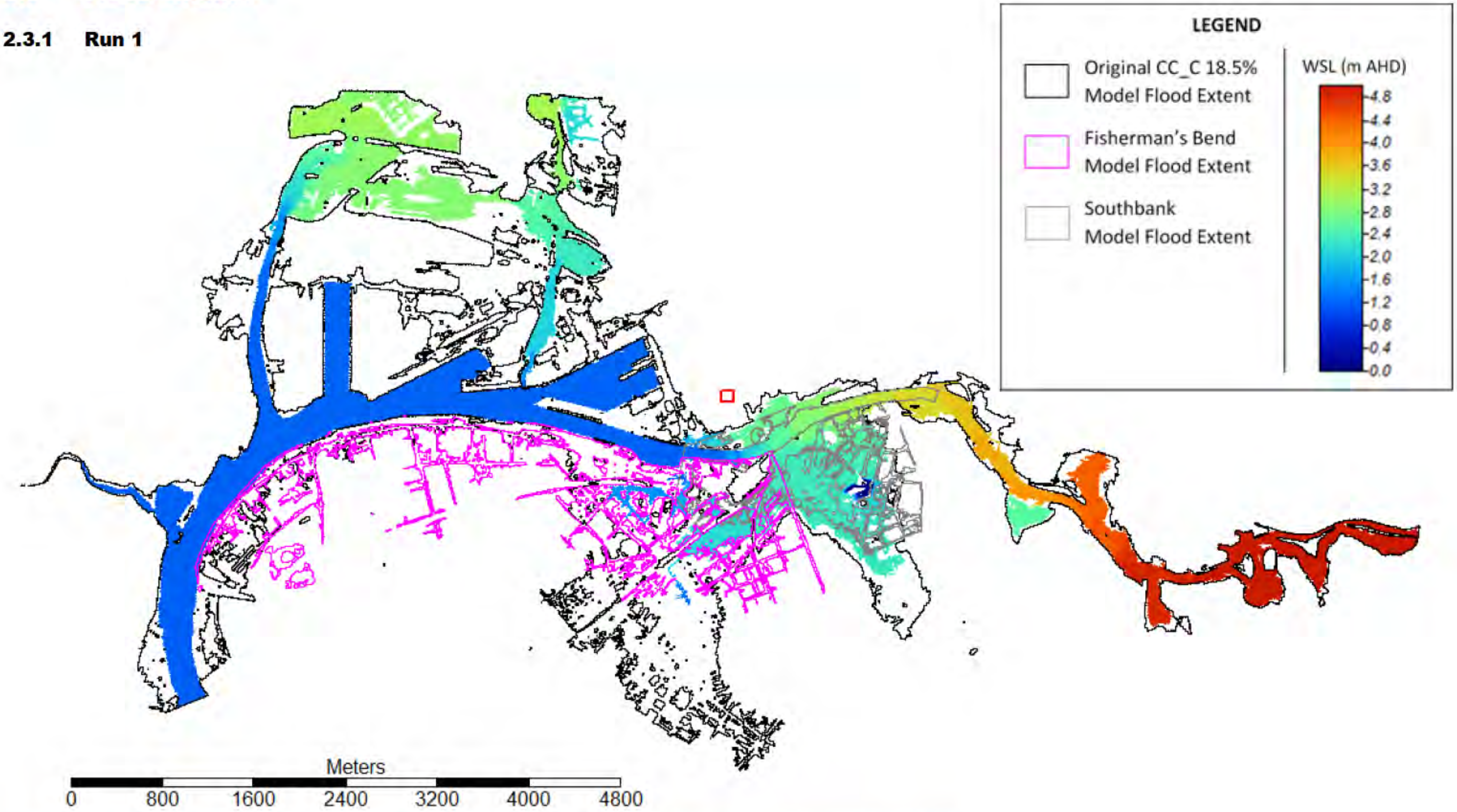

Figure 3 Peak 100y WSL Current (Kc=145 w/o ARFs, 10y Tide & River Manning's 'n' of 0.015)

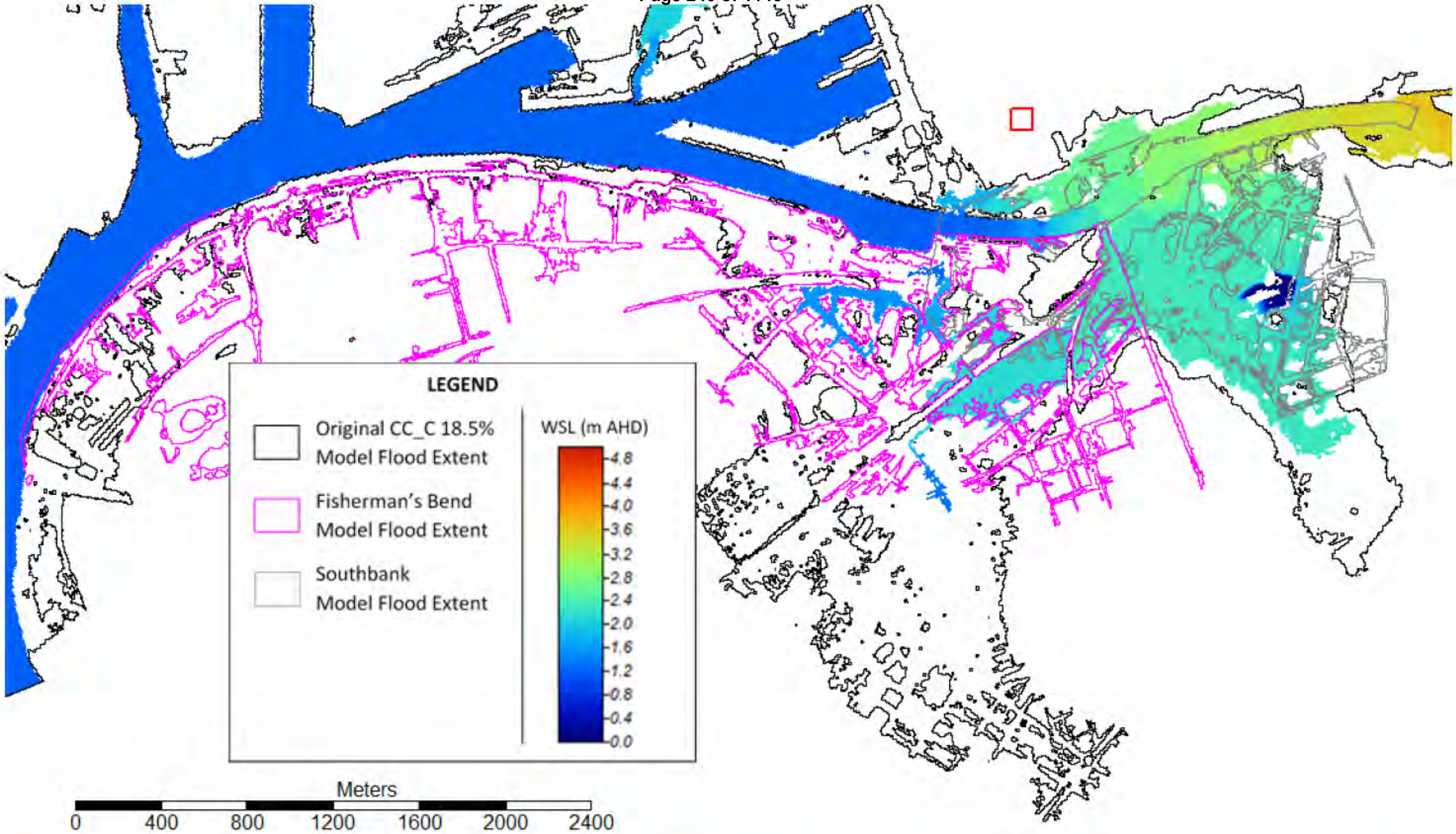

Figure 4 **Peak 100y WSL Current (Kc=145 w/o ARFs, 10y Tide & River Manning's 'n' of 0.015) – Zoomed to refinement area**

2.3.2 Run 2

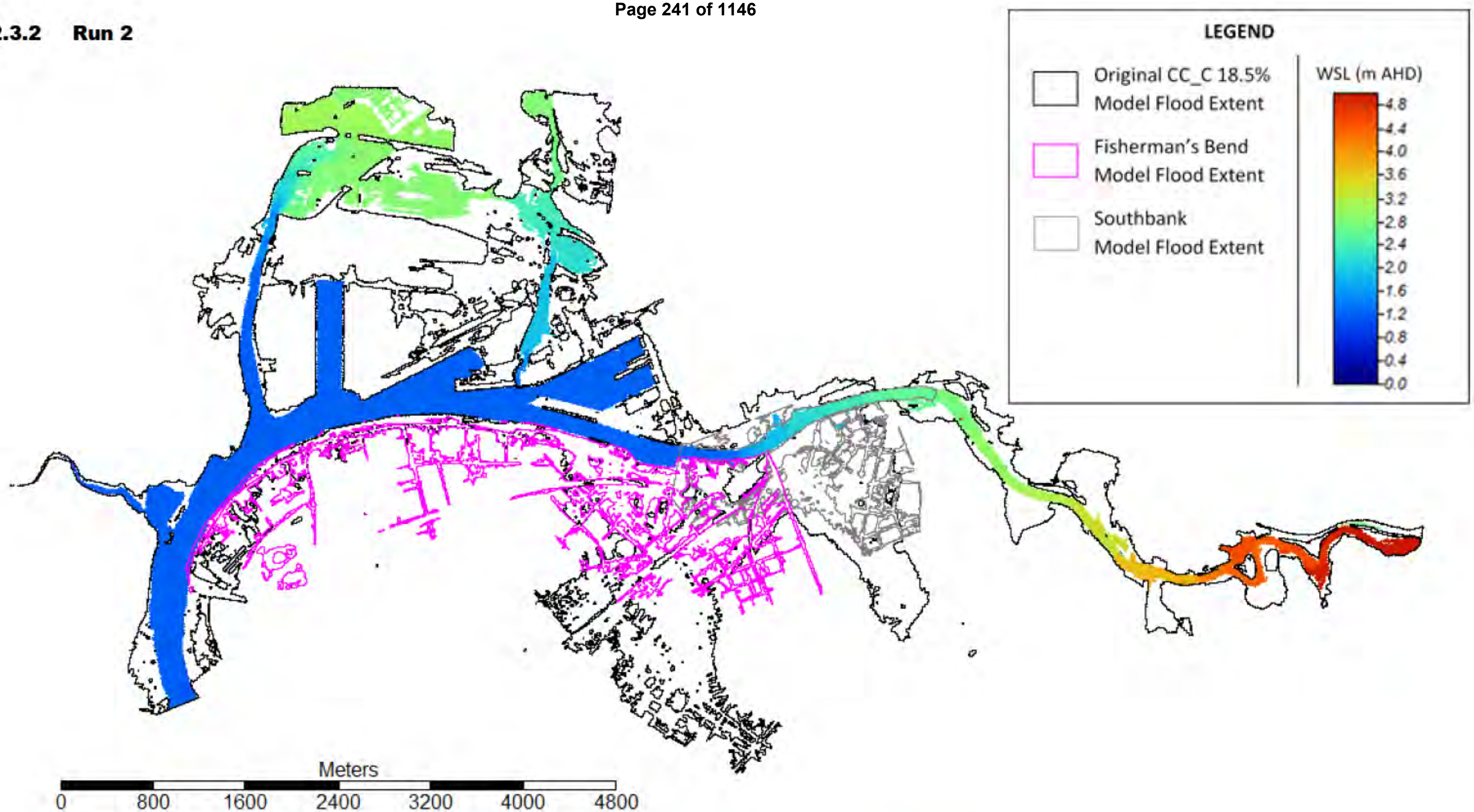

Figure 5 Peak 100y WSL Current (Kc=237 w/o ARFs, 10y Tide & River Manning's 'n' of 0.015)

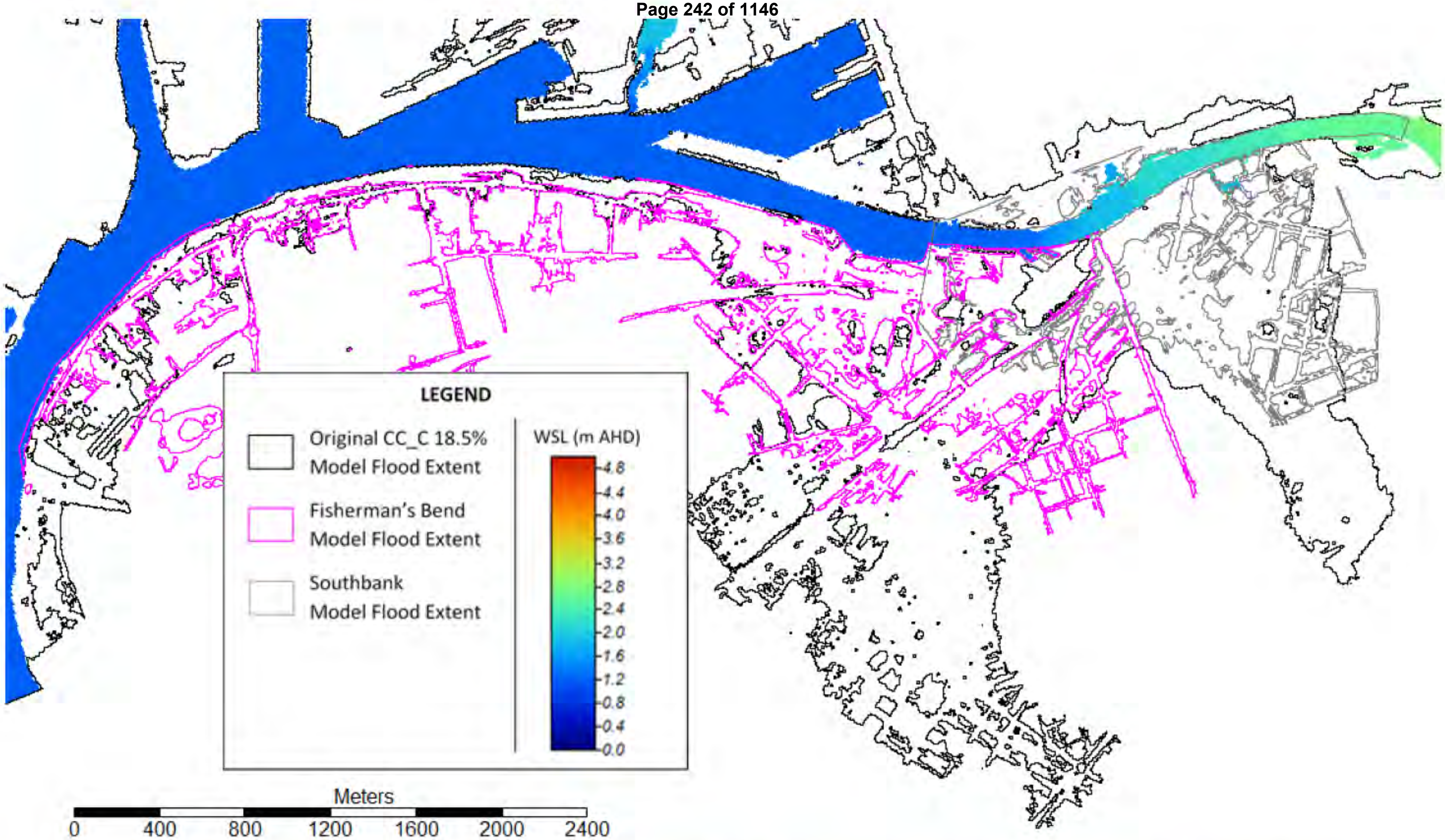

Figure 6 Peak 100y WSL Current (Kc=237 w/o ARFs, 10y Tide & River Manning's 'n' of 0.015) – Zoomed to refinement area

2.3.3 Run 3

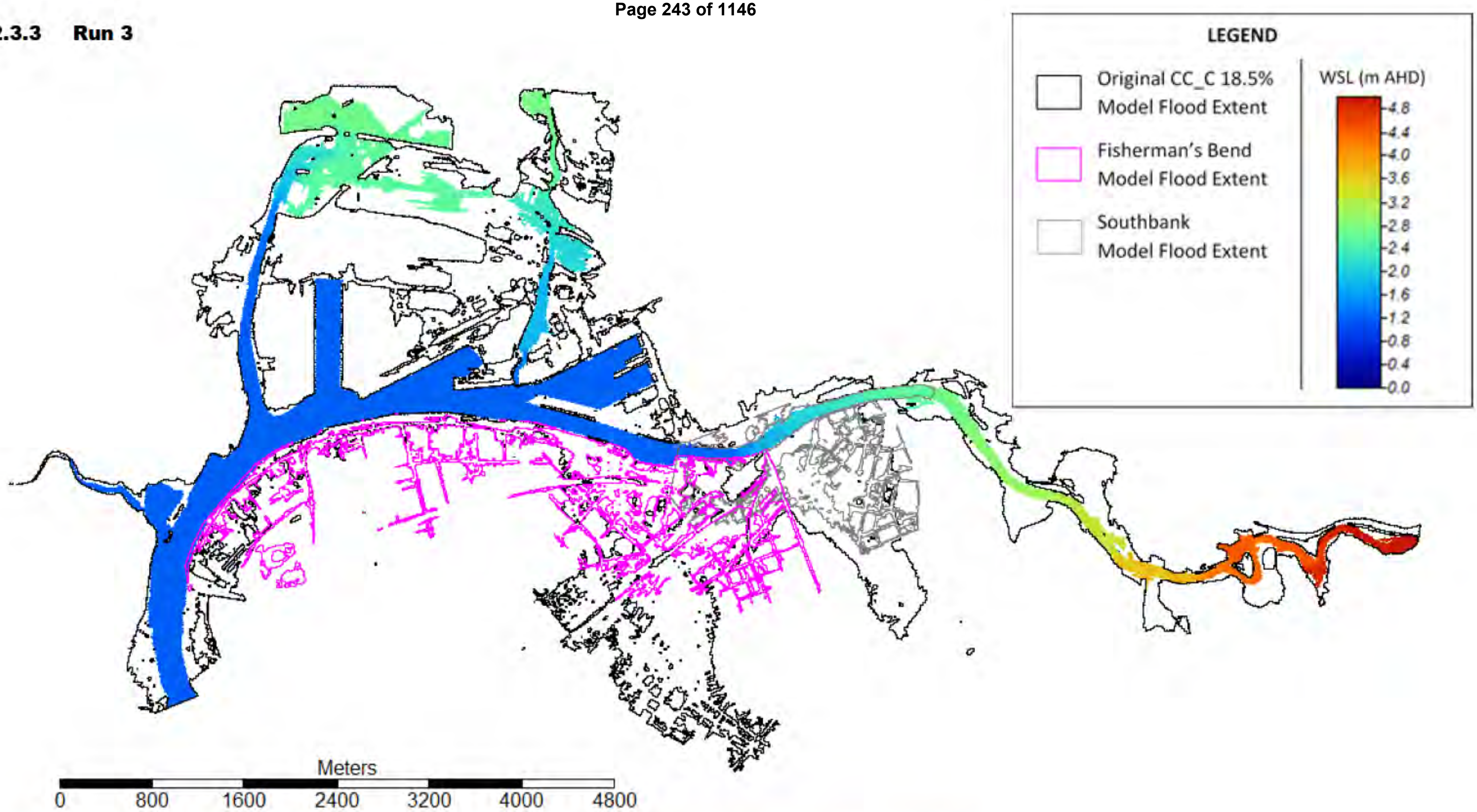

Figure 7 Peak 100y WSL Current (Kc=180 w/ ARFs, 10y Tide & River Manning's 'n' of 0.015)

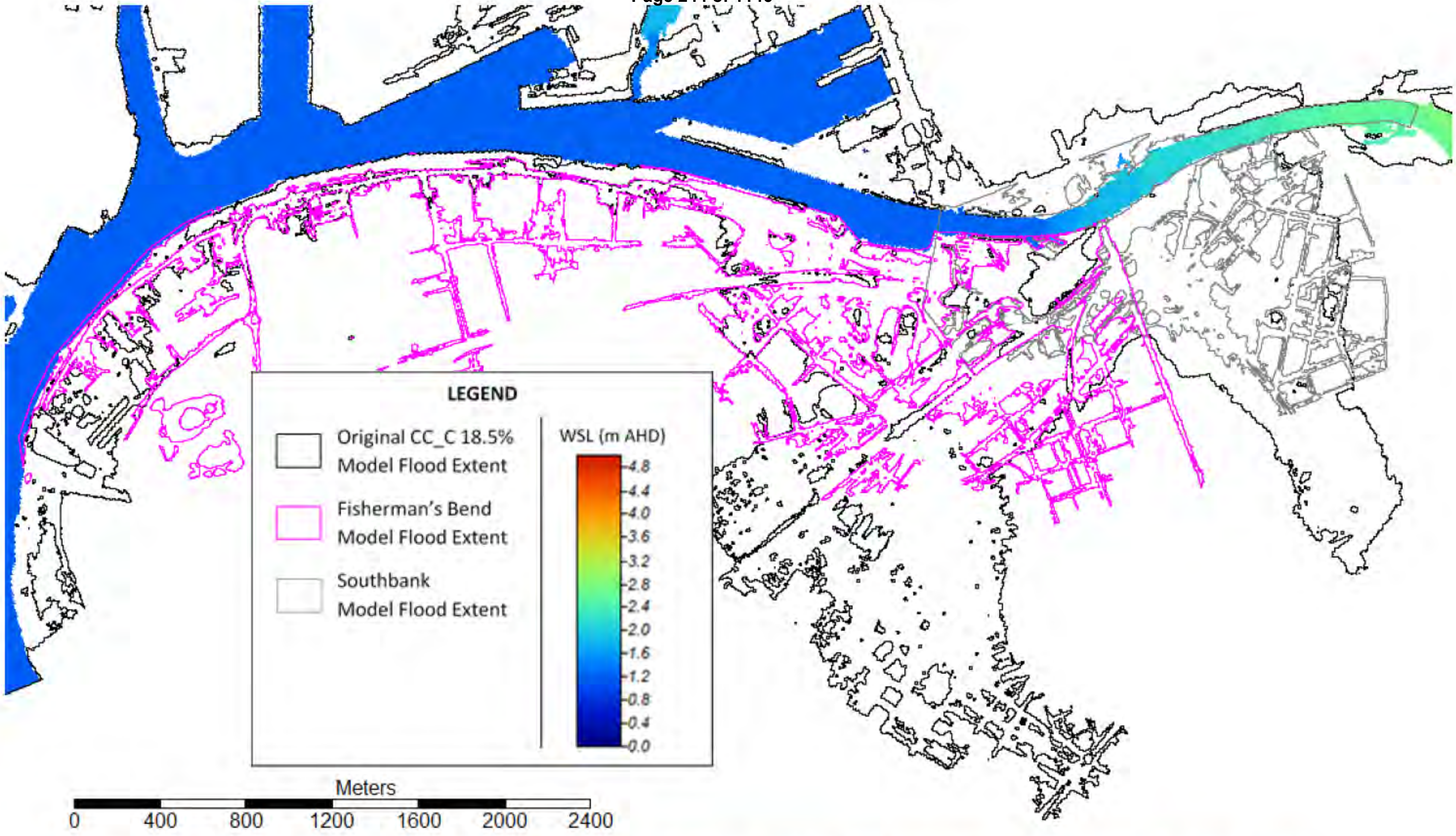

Figure 8 Peak 100y WSL Current (Kc=180 w/ ARFs, 10y Tide & River Manning's 'n' of 0.015) – Zoomed to refinement area

2.3.4 Run 4

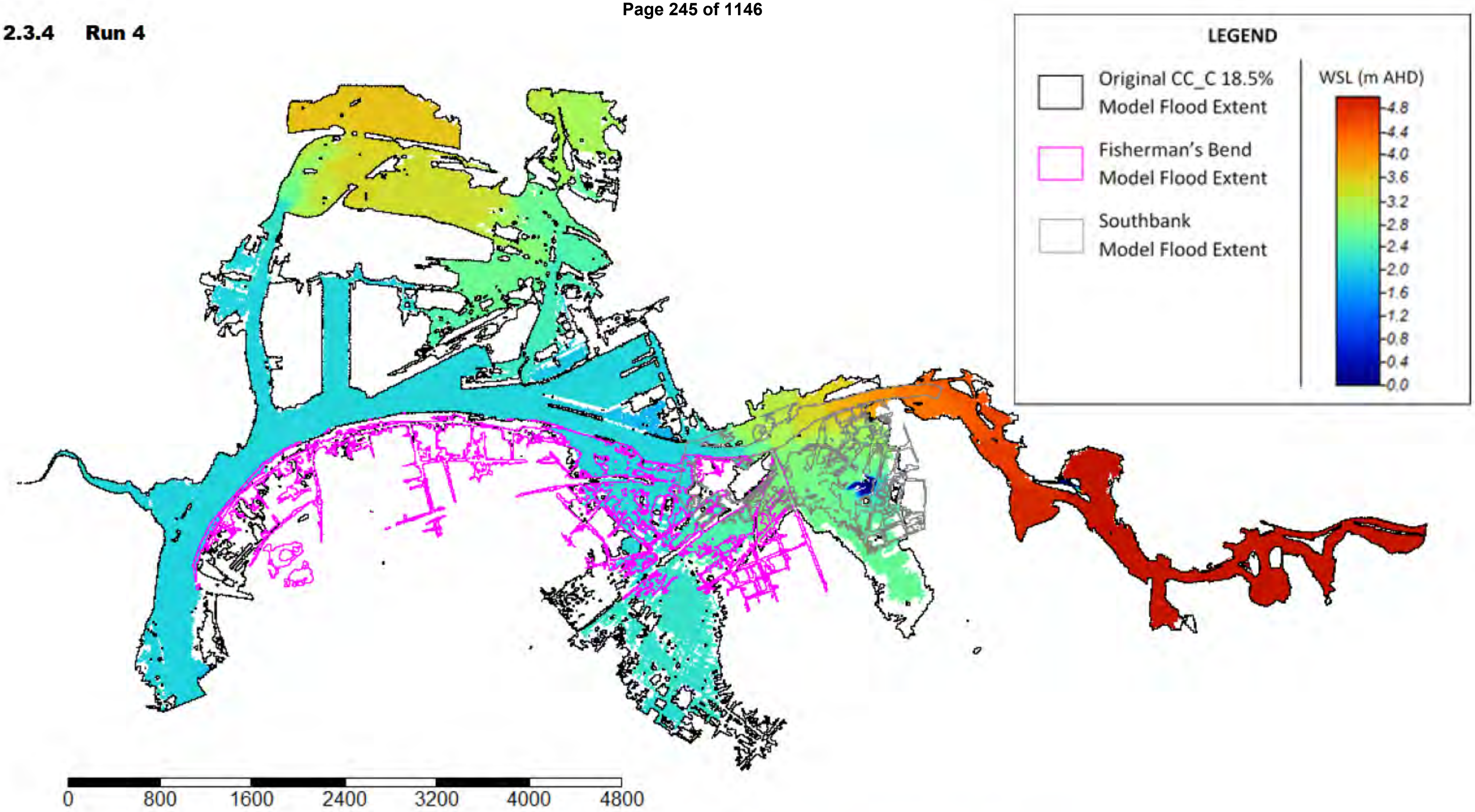

Figure 9 Peak 100y WSL Current CC18p5 (Kc=145 w/o ARFs, 10y Tide & River Manning's 'n' of 0.015)

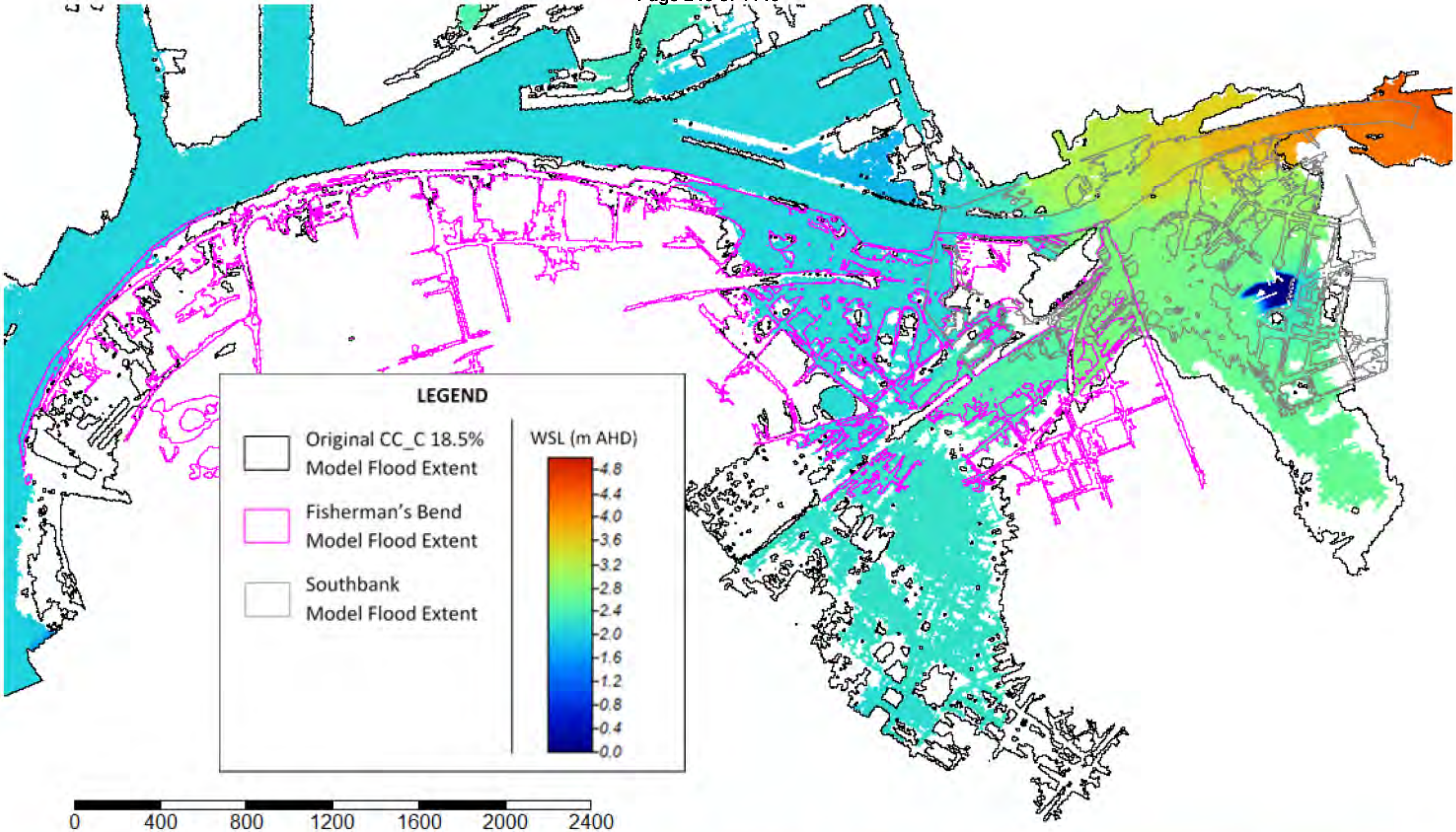

Figure 10 Peak 100y WSL Current CC18p5 (Kc=145 w/o ARFs, 10y Tide & River Manning's 'n' of 0.015) – Zoomed to refinement area

2.3.5 Run 5

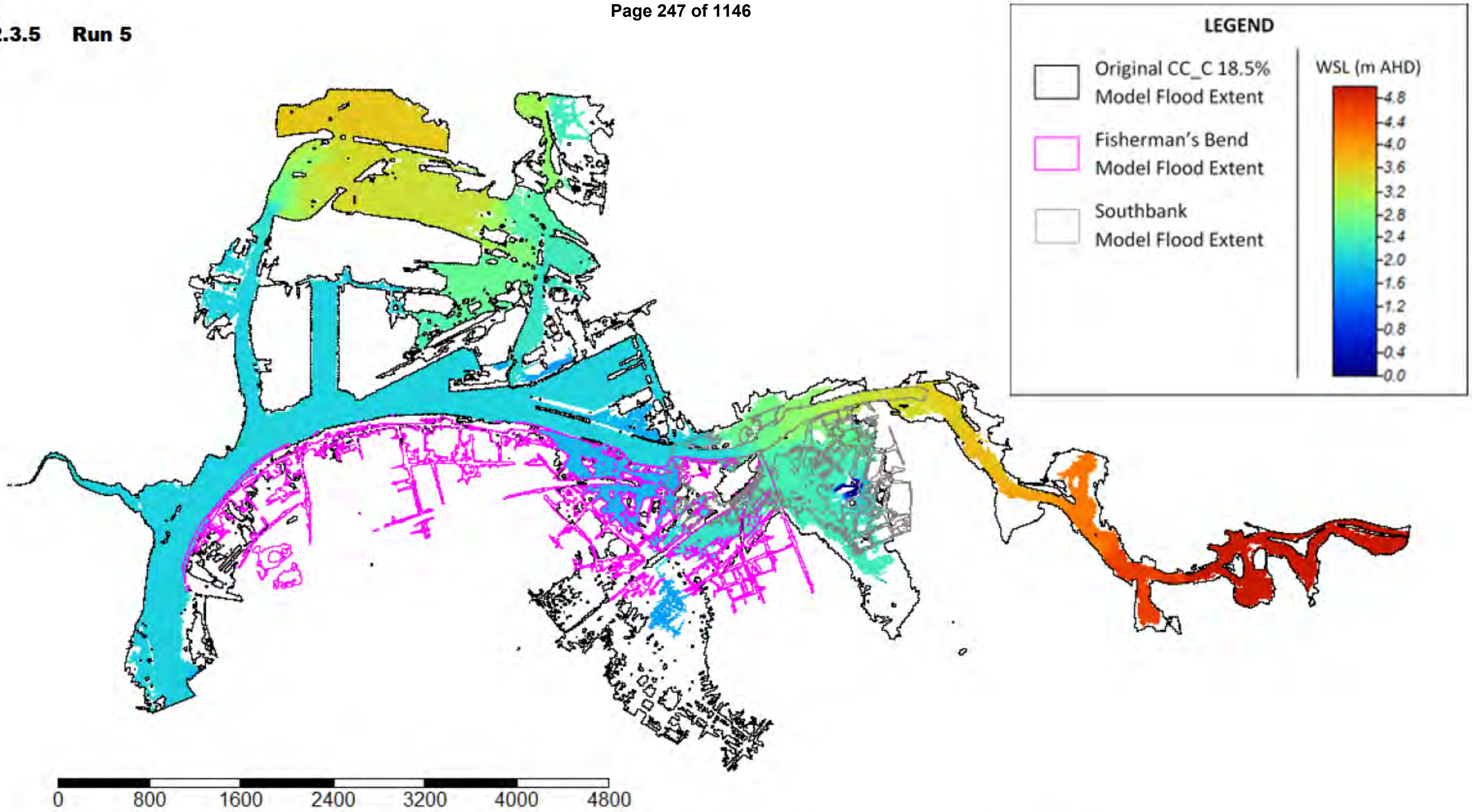

Figure 11 Peak 100y WSL Current CC18p5 (Kc=237 w/o ARFs, 10y Tide & River Manning's 'n' of 0.015)

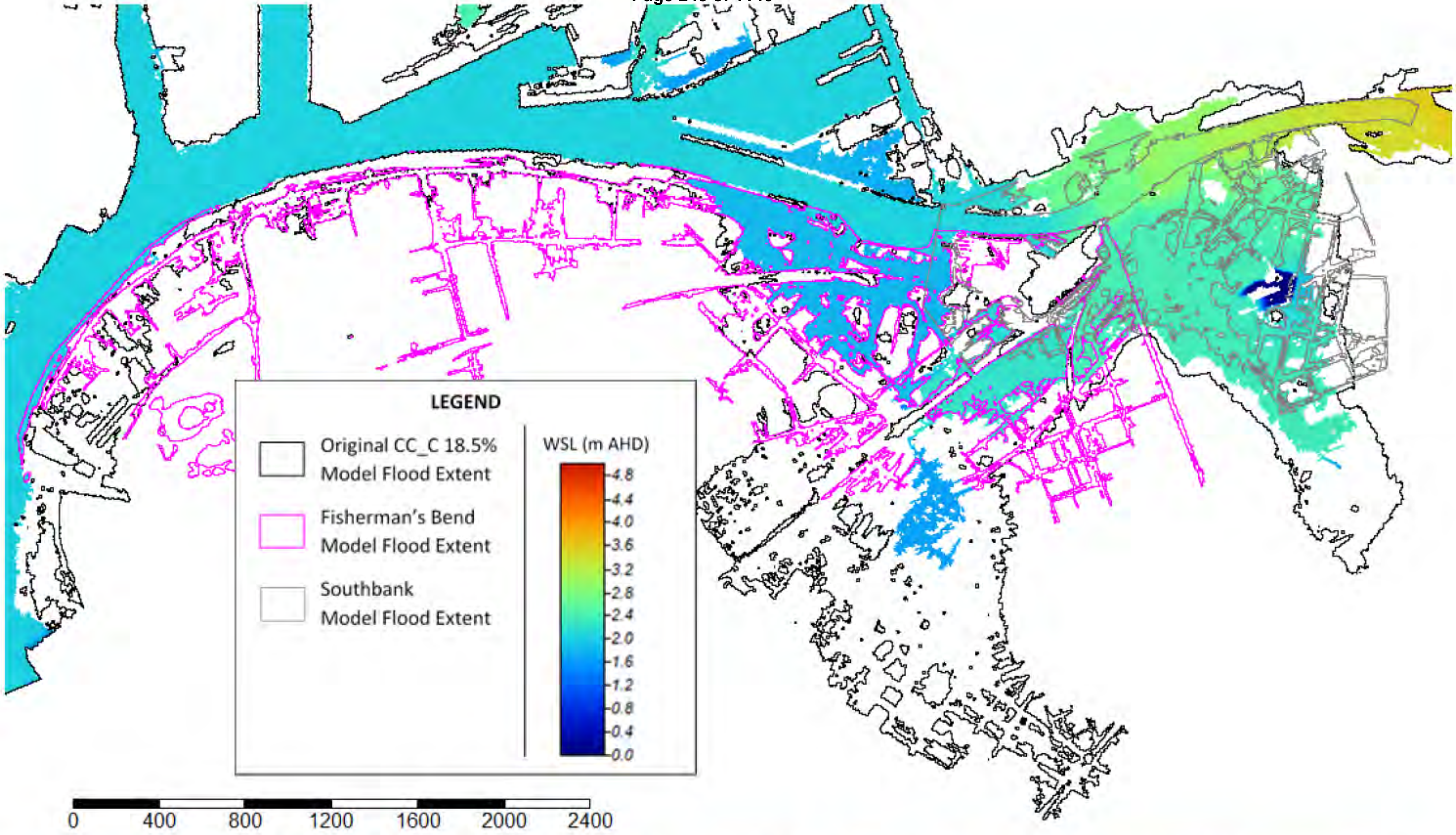

Figure 12 Peak 100y WSL Current CC18p5 (Kc=237 w/o ARFs, 10y Tide & River Manning's 'n' of 0.015) – Zoomed to refinement area

2.3.6 Run 6

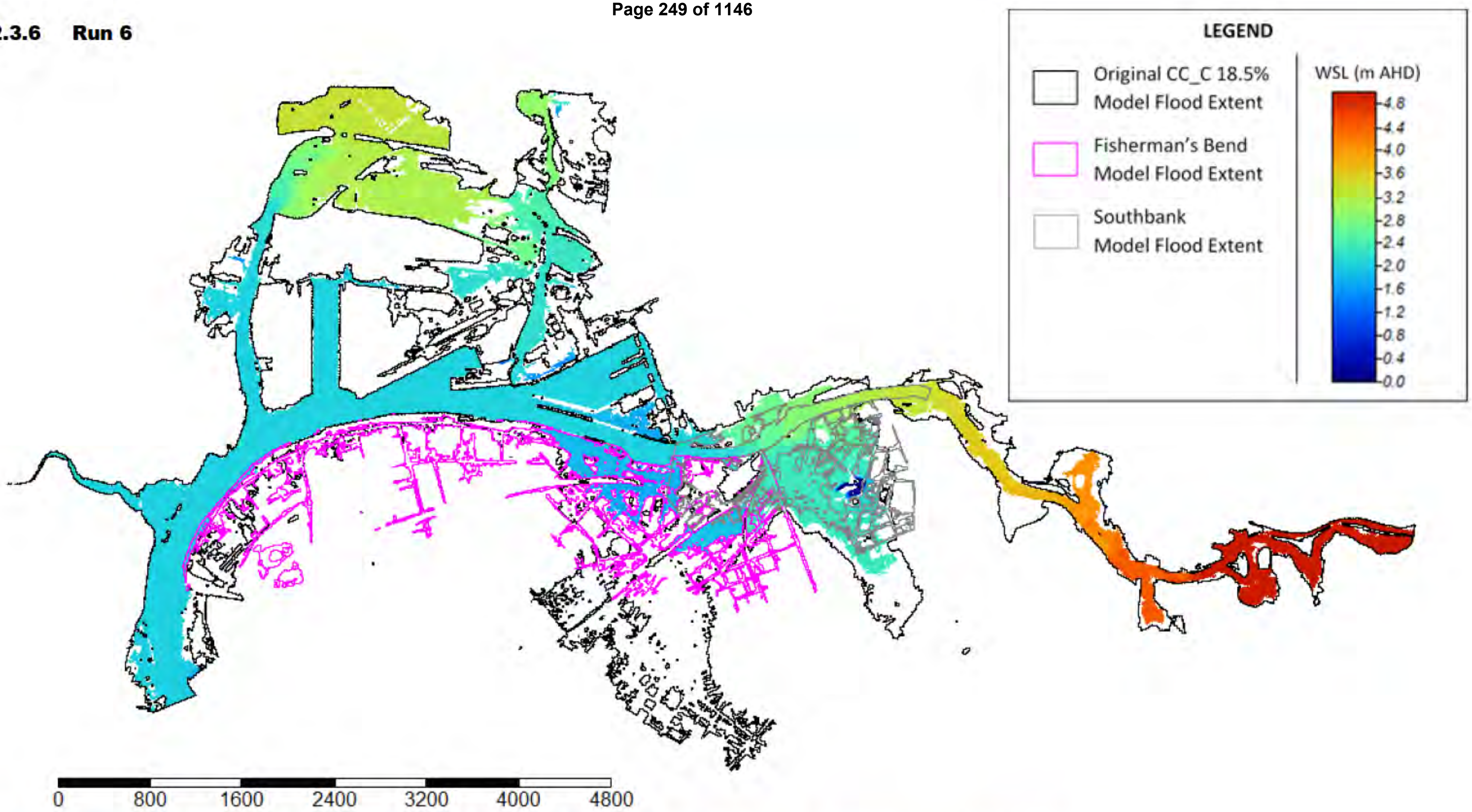

Figure 13 Peak 100y WSL Current CC18p5 (Kc=180 w/ ARFs, 10y Tide & River Manning's 'n' of 0.015)

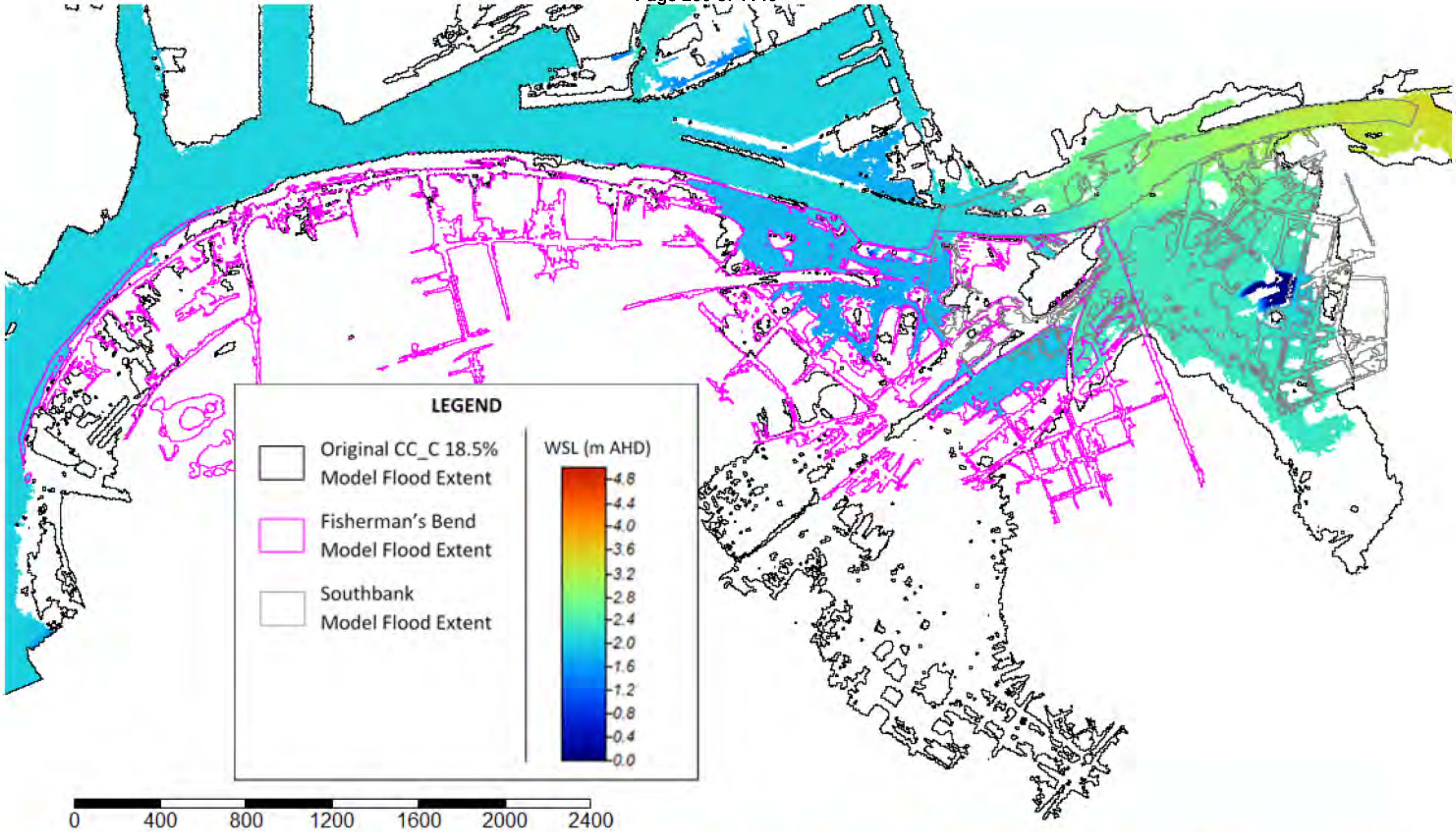

Figure 14 Peak 100y WSL Current CC18p5 (Kc=180 w/ ARFs, 10y Tide & River Manning's 'n' of 0.015) – Zoomed to refinement area

2.3.7 Run 7

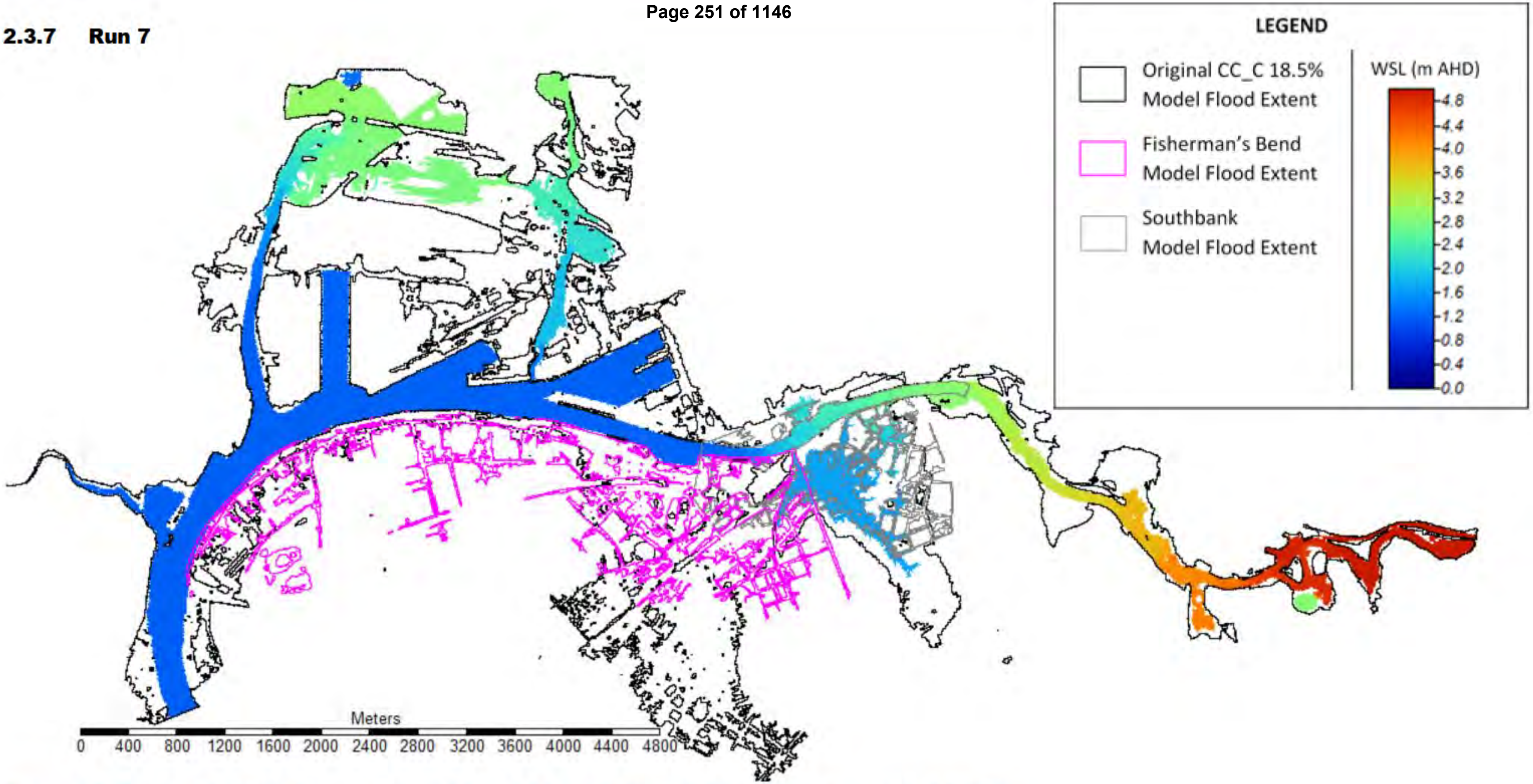

Figure 15 Peak 100y WSL Current (Kc=180 w/ ARFs, 10y Tide & River Manning's 'n' of 0.020)

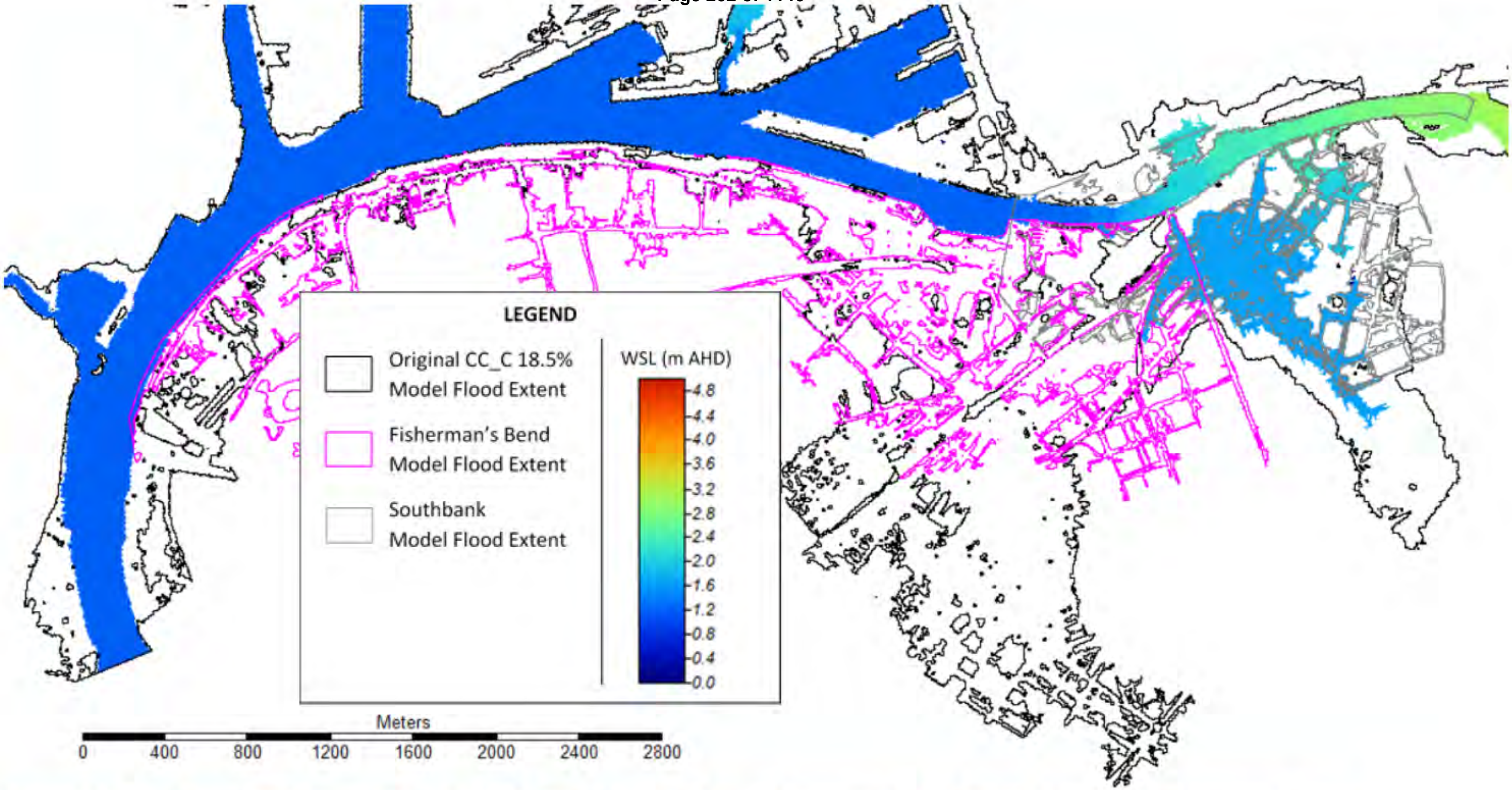

Figure 16 Peak 100y WSL Current (Kc=180 w/ ARFs, 10y Tide & River Manning's 'n' of 0.020– Zoomed to refinement area

2.3.8 Run 8

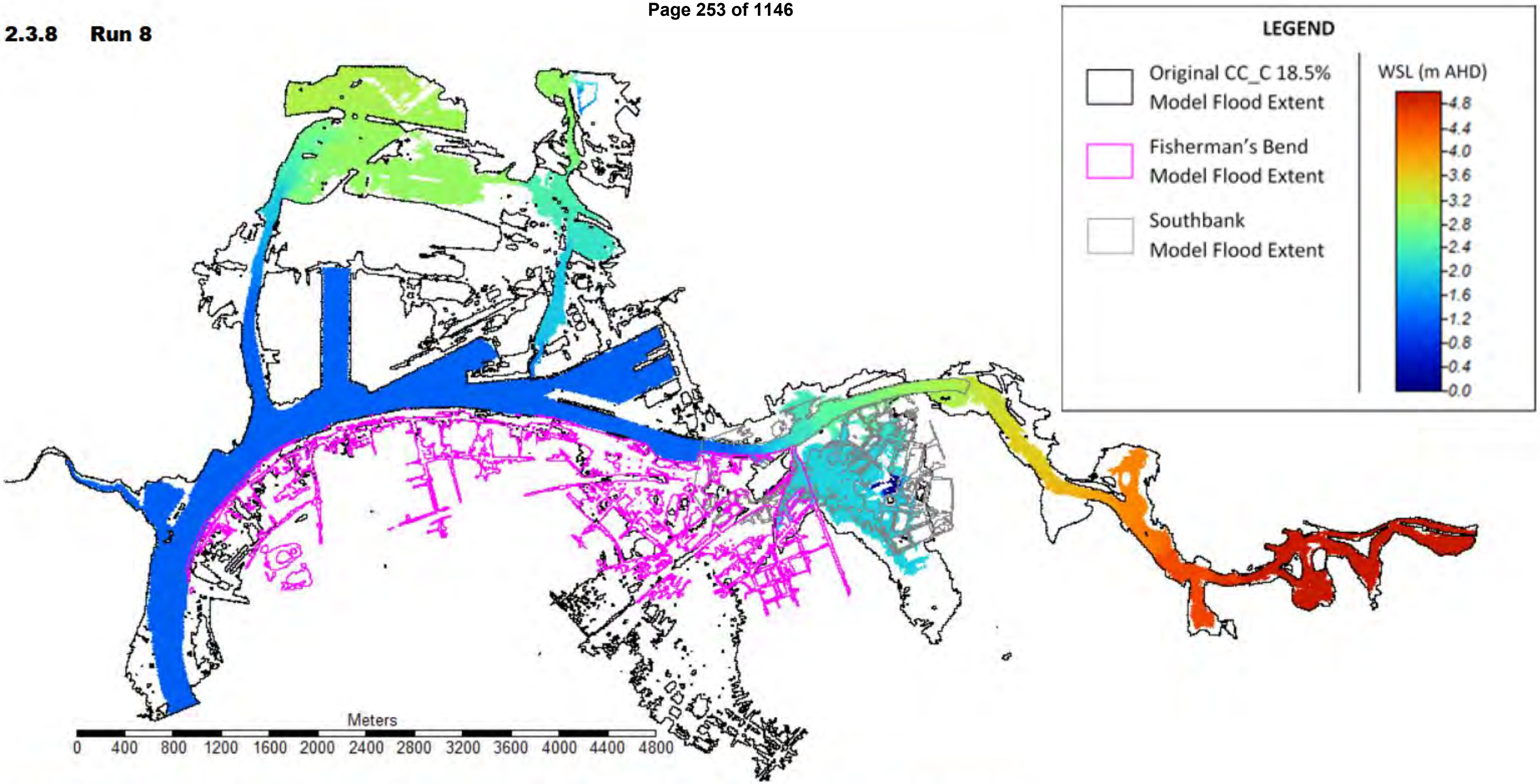

Figure 17 Peak 100y WSL Current (Kc=180 w/ ARFs, 10y Tide & River Manning's 'n' of 0.025)

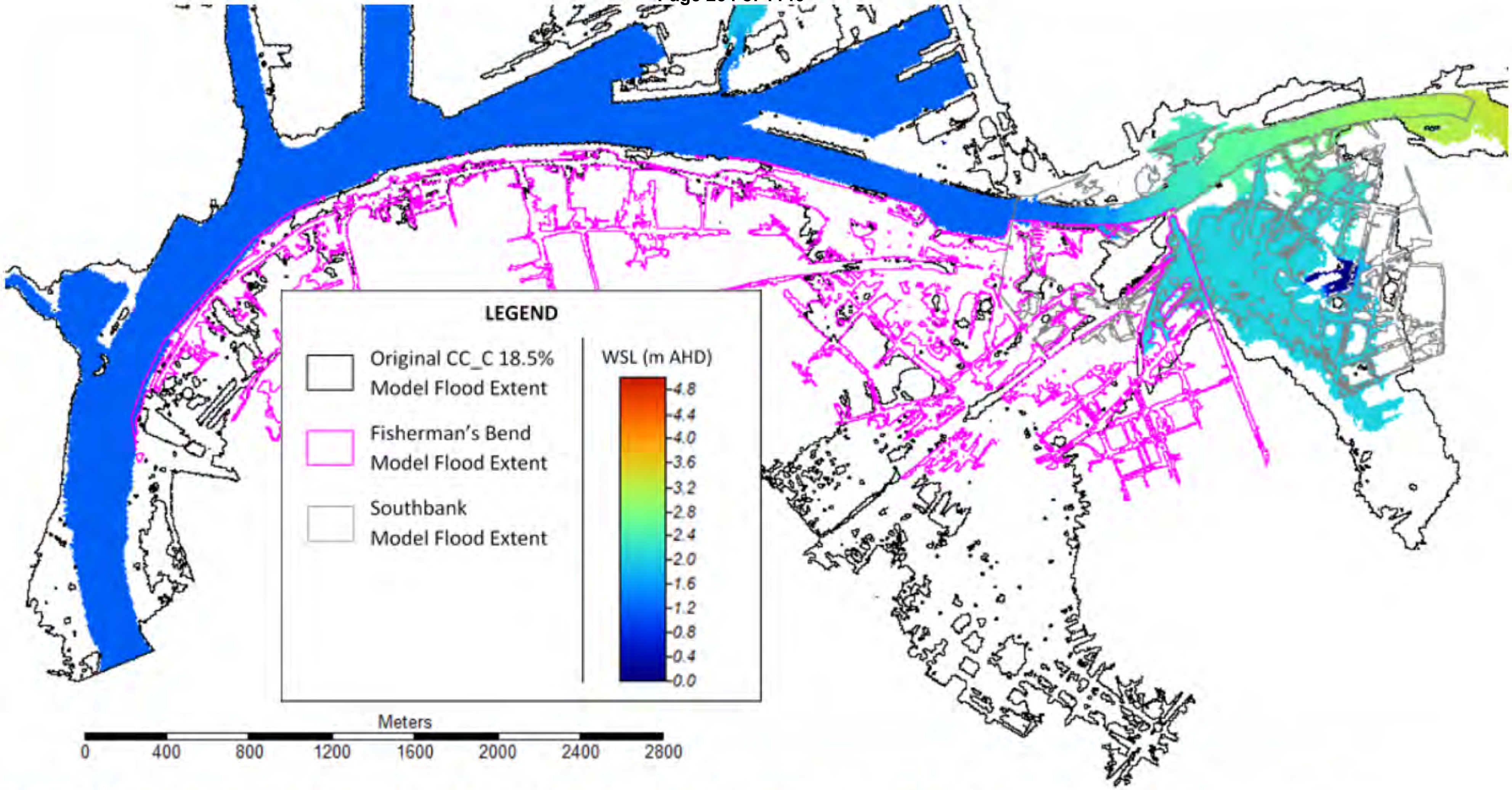

Figure 18 Peak 100y WSL Current (Kc=180 w/ ARFs, 10y Tide & River Manning's 'n' of 0.025) – Zoomed to refinement area

2.3.9 Run 9

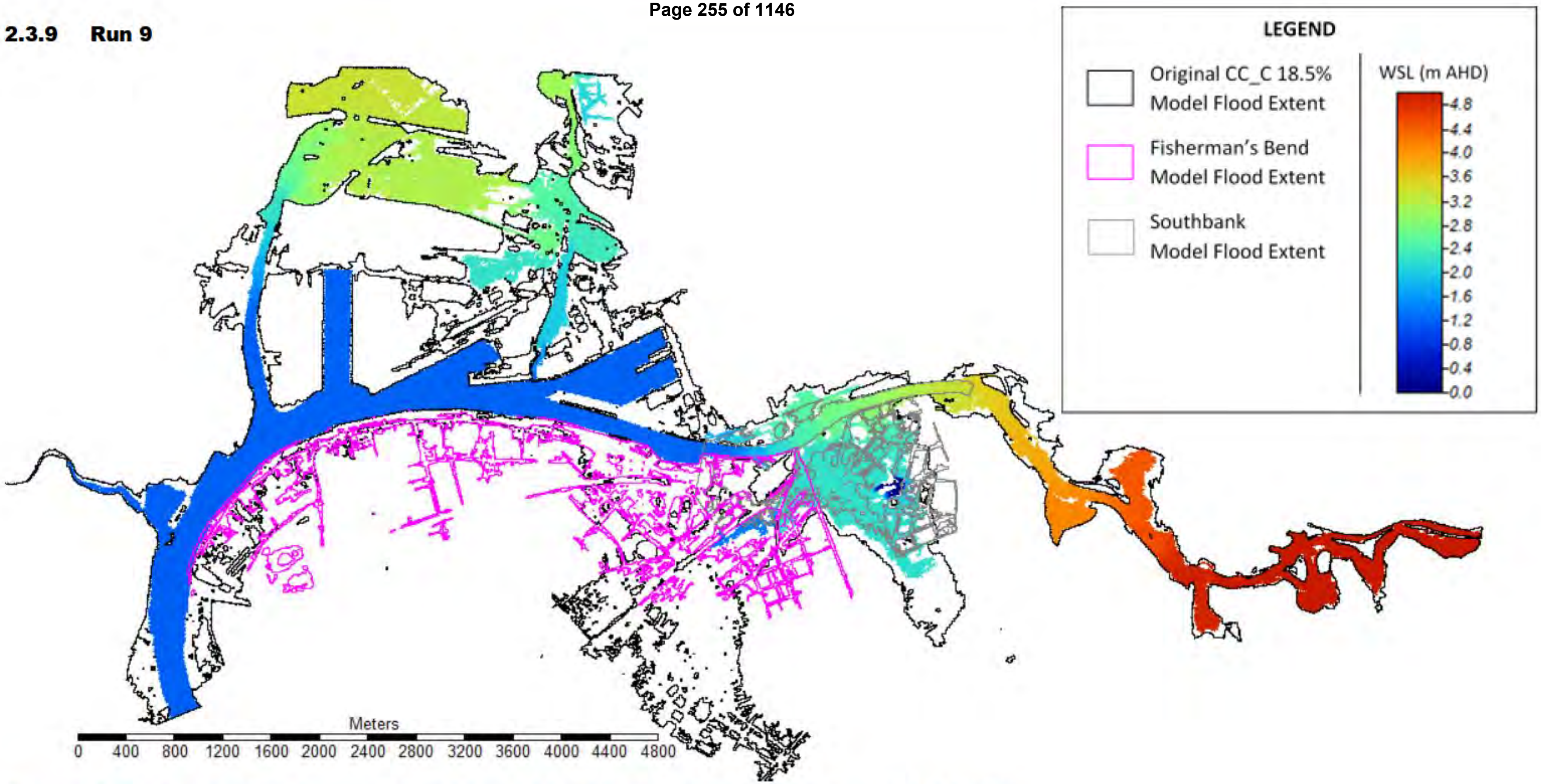

Figure 19 Peak 100y WSL Current (Kc=180 w/ ARFs, 10y Tide & River Manning's 'n' of 0.030)

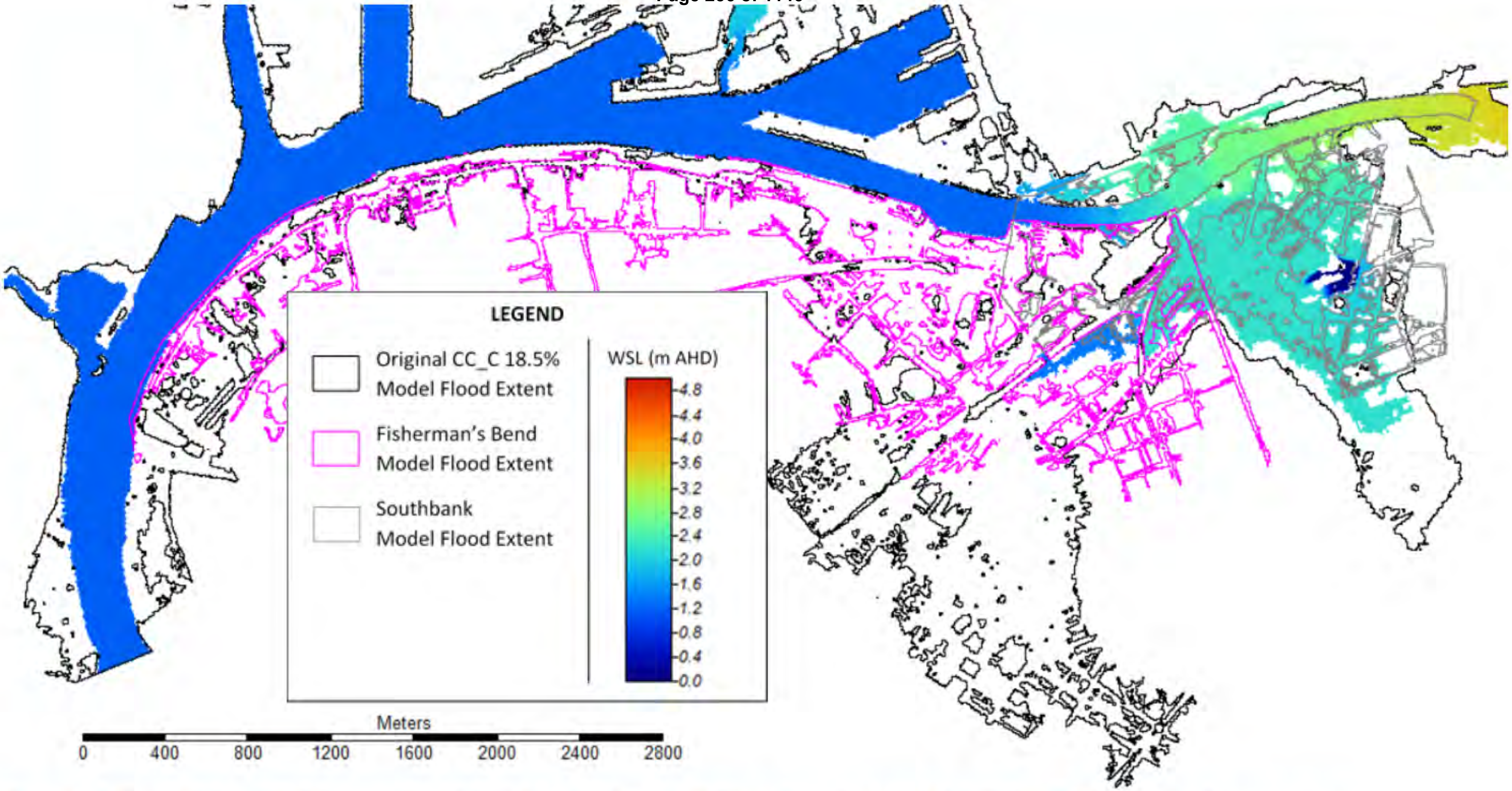

Figure 20 Peak 100y WSL Current (Kc=180 w/ ARFs, 10y Tide & River Manning's 'n' of 0.030) – Zoomed to refinement area

2.3.10 Run 10

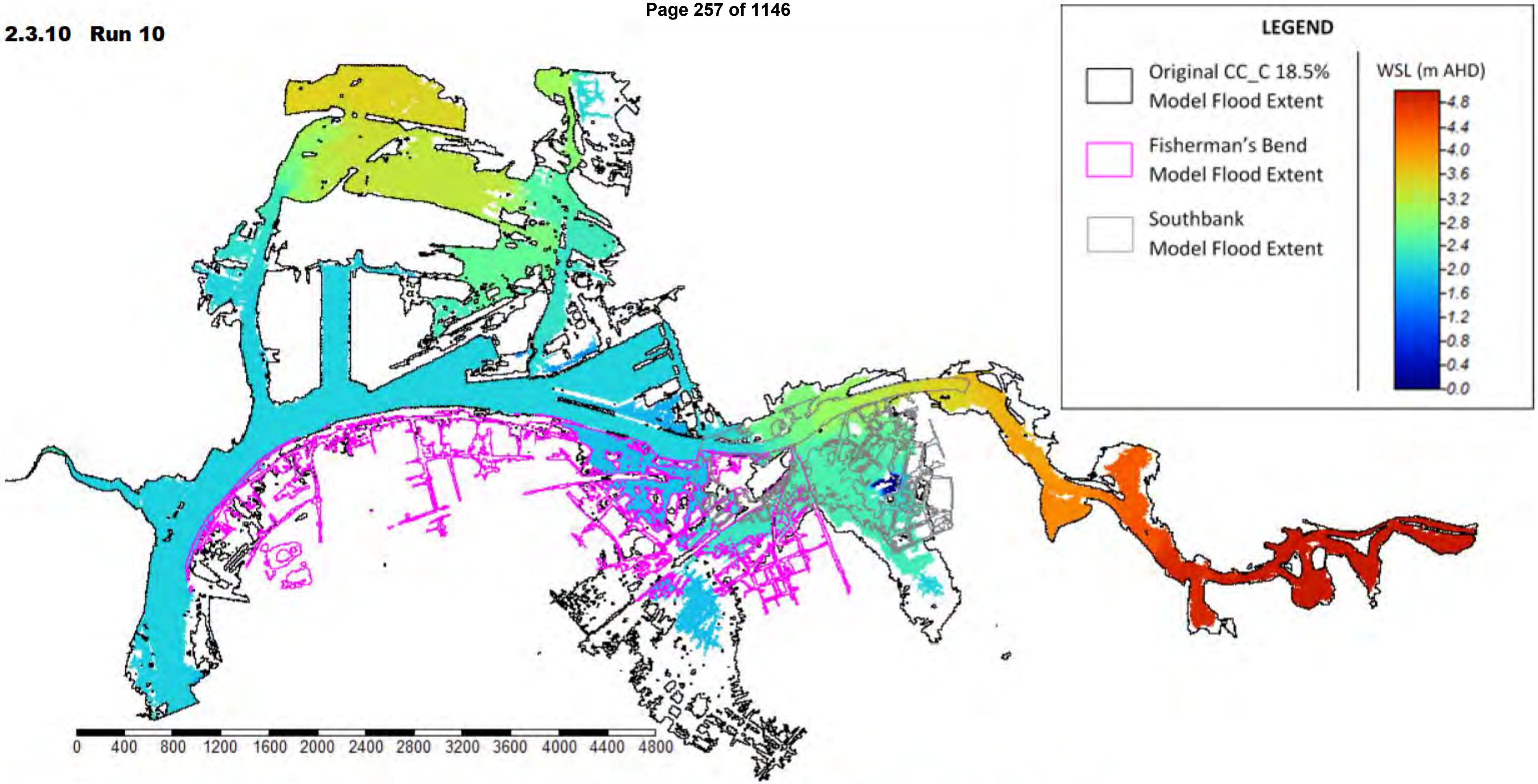

Figure 21 Peak 100y WSL Current CC18p5 (Kc=180 w/ ARFs, 10y Tide & River Manning's 'n' of 0.020)

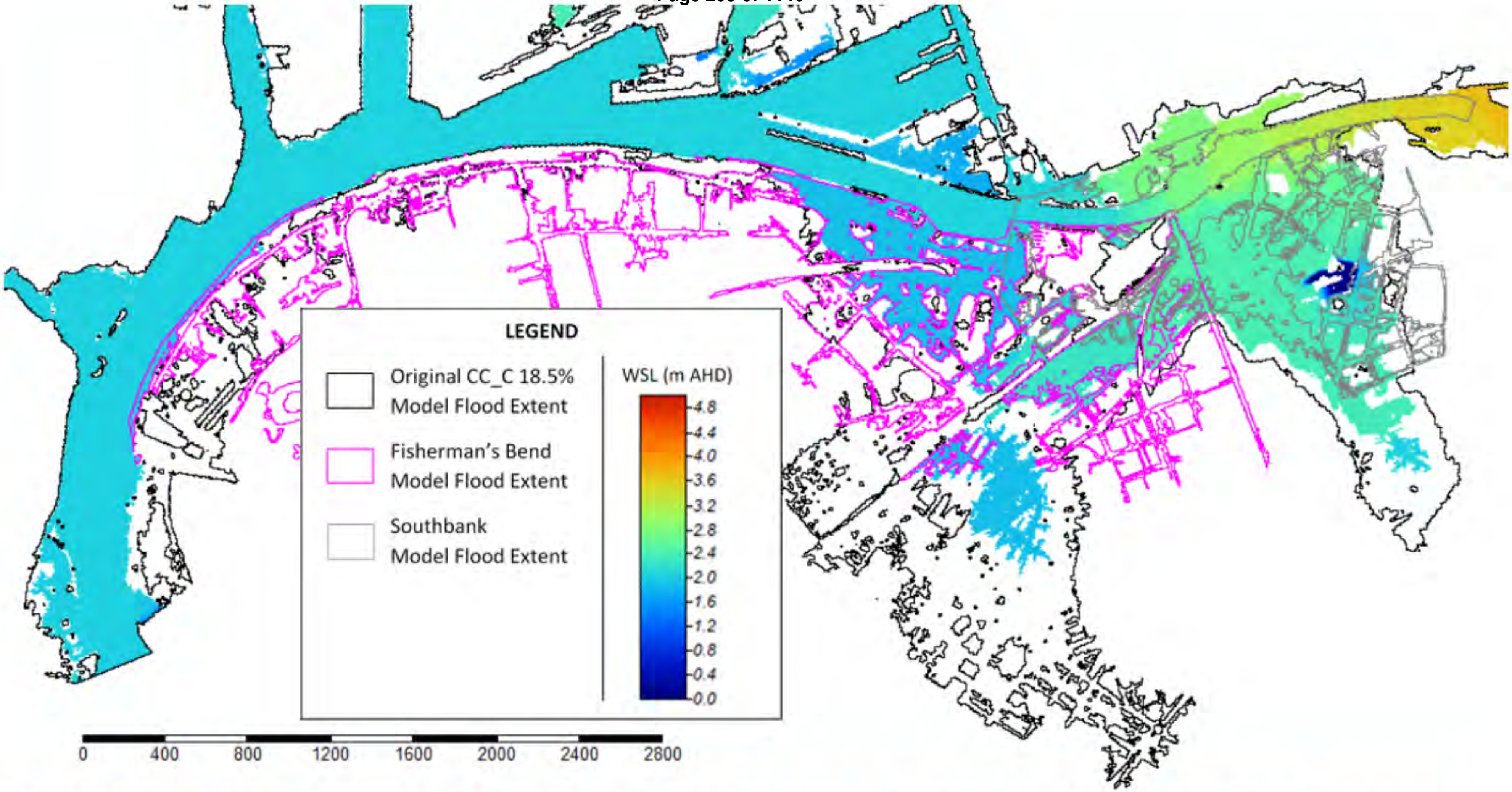

Figure 22 Peak 100y WSL Current CC18p5 (Kc=180 w/ ARFs, 10y Tide & River Manning's 'n' of 0.020) – Zoomed to refinement area

2.3.11 Run 11

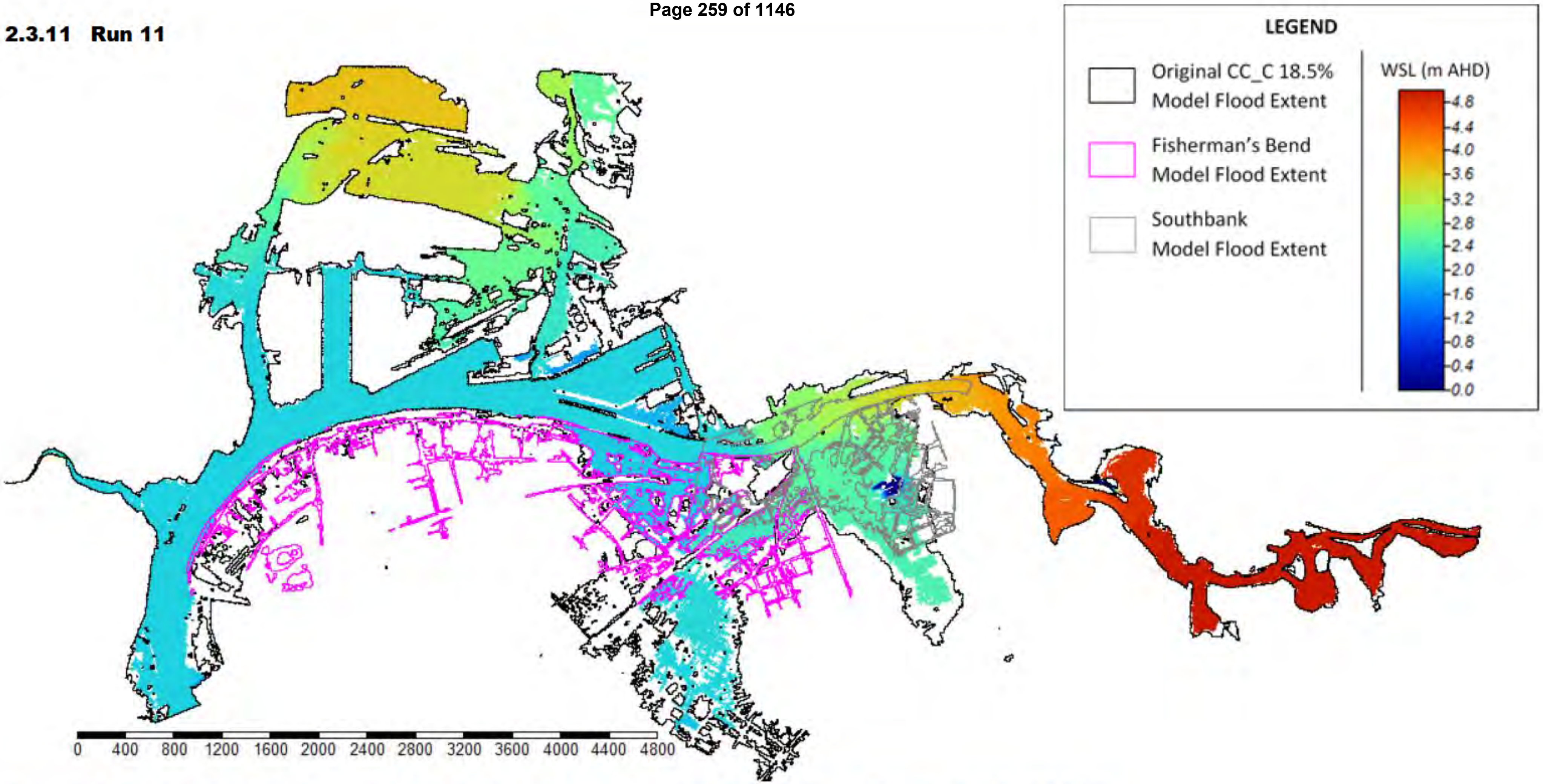

Figure 23 Peak 100y WSL Current CC18p5 (Kc=180 w/ ARFs, 10y Tide & River Manning's 'n' of 0.025)

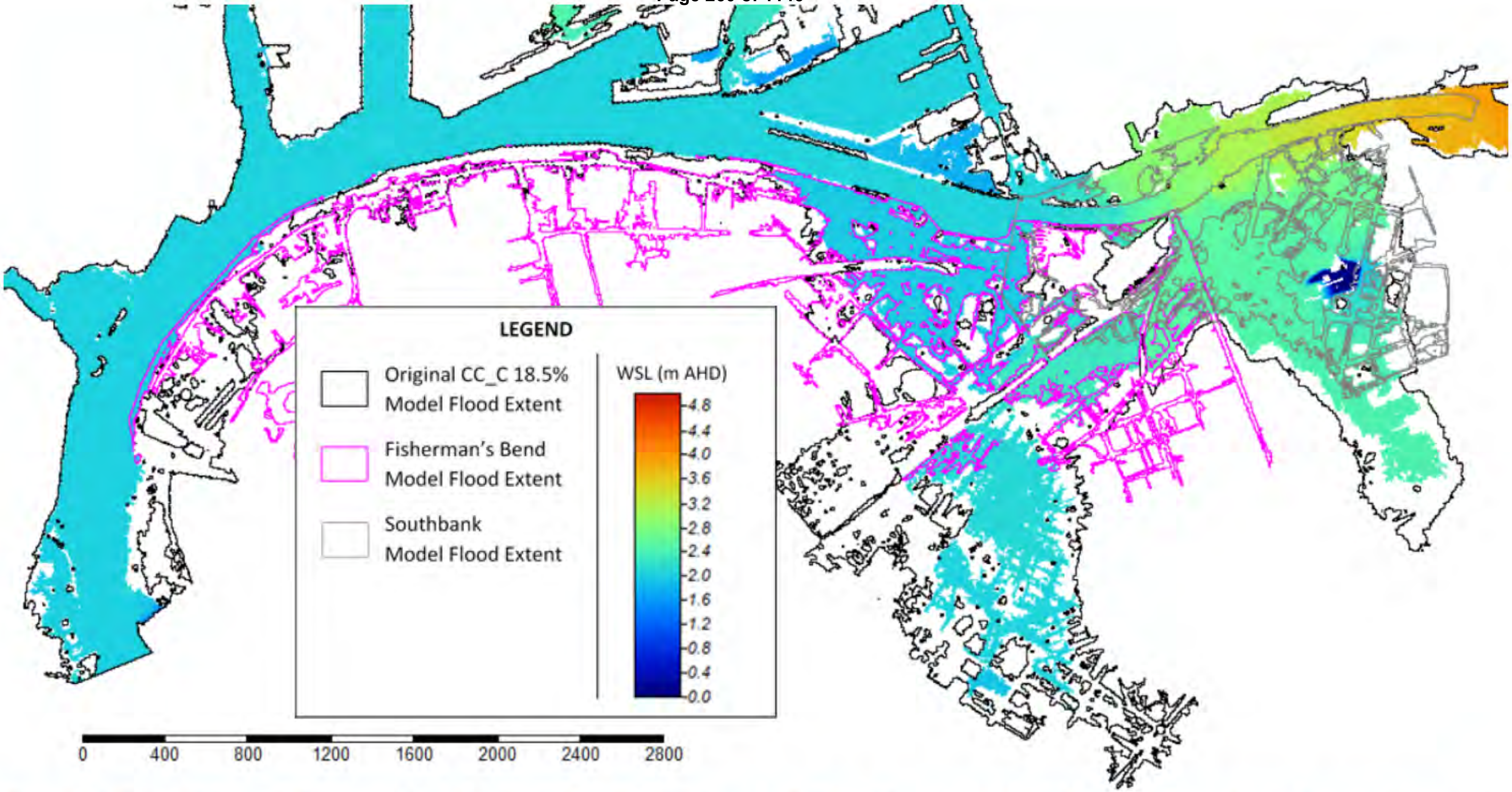

Figure 24 Peak 100y WSL Current CC18p5 (Kc=180 w/ ARFs, 10y Tide & River Manning's 'n' of 0.025) – Zoomed to refinement area

2.3.12 Run 12

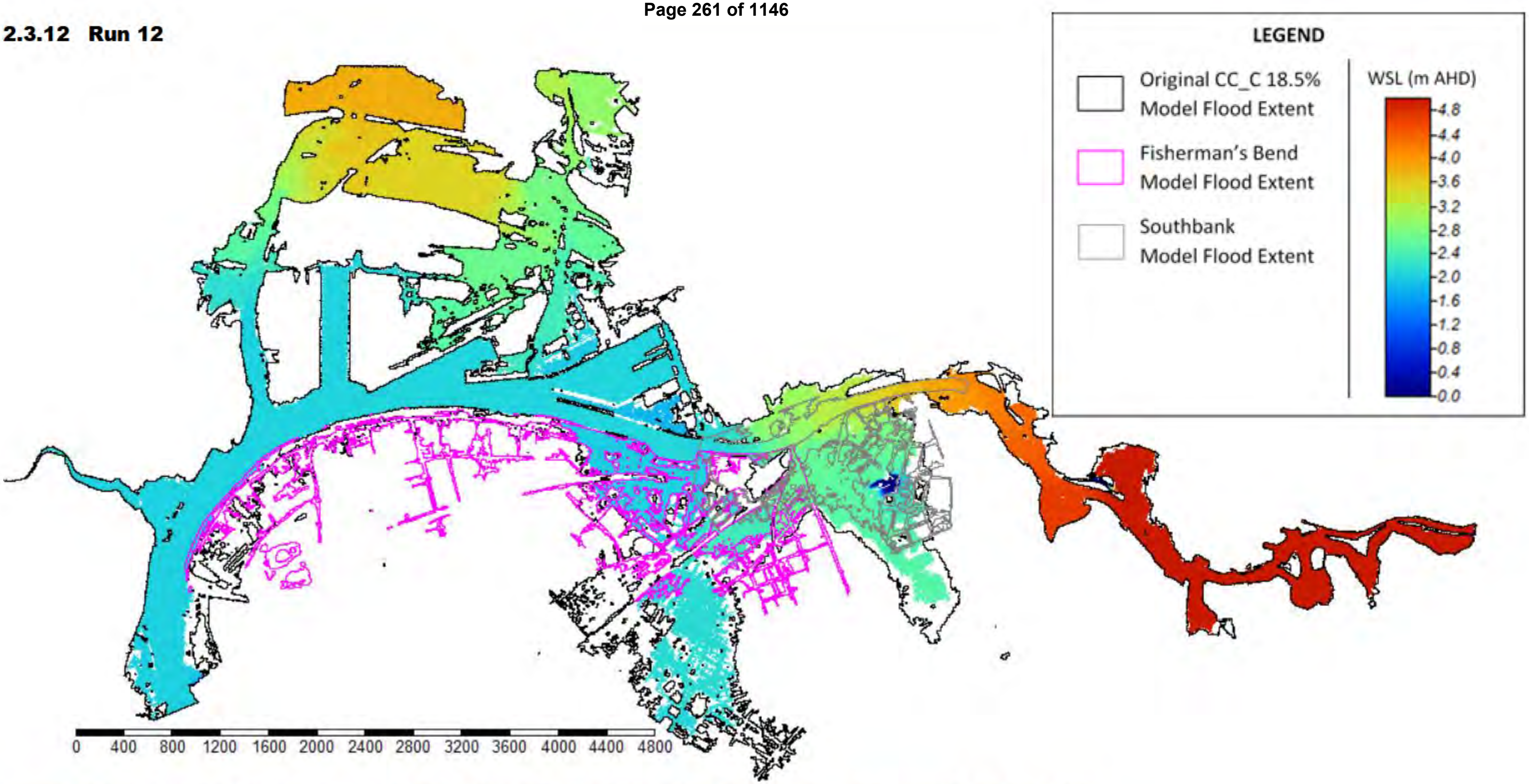

Figure 25 Peak 100y WSL Current CC18p5 (Kc=180 w/ ARFs, 10y Tide & River Manning's 'n' of 0.030)

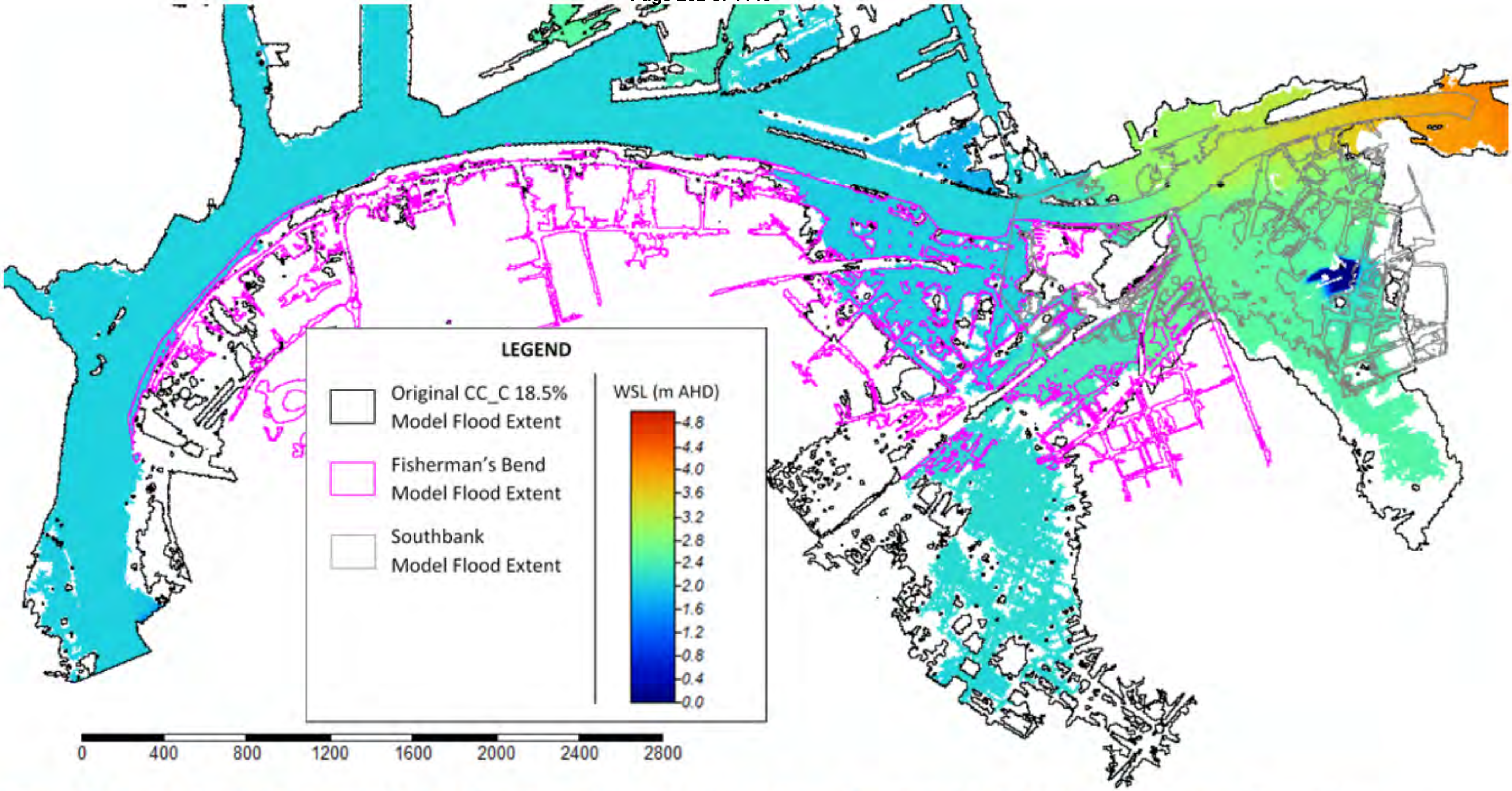

Figure 26 Peak 100y WSL Current CC18p5 (Kc=180 w/ ARFs, 10y Tide & River Manning's 'n' of 0.030) – Zoomed to refinement area

2.4 Long Sections

2.4.1 Runs 1 to 6 - Varying flow (kc and ARF) and d/s boundaries

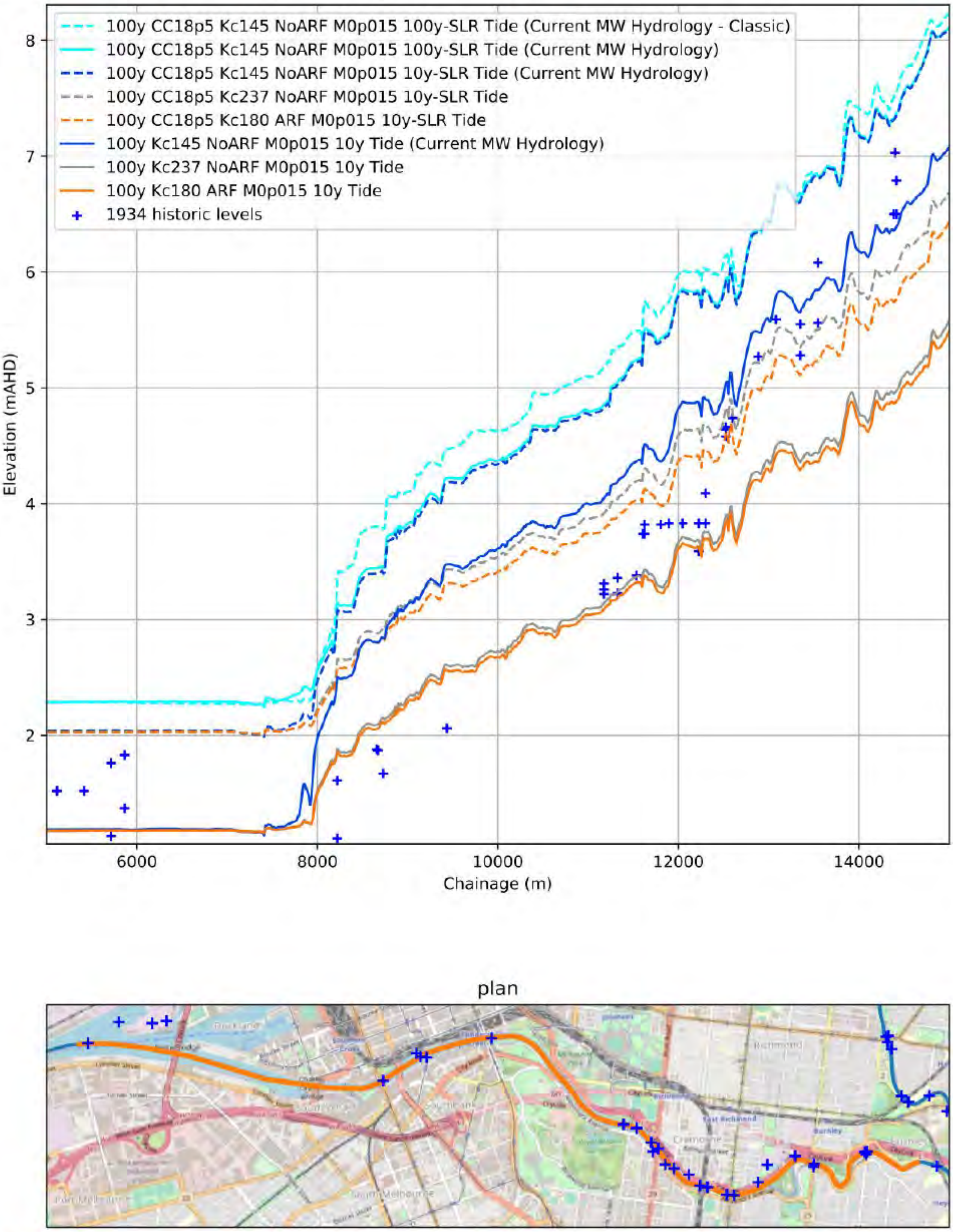

Figure 27 1% AEP Long-section along Yarra River comparing WSL along Yarra to historic levels - Impact of Kc & ARFs

2.4.2 Runs 7 to 12 - Varying Manning's 'n'

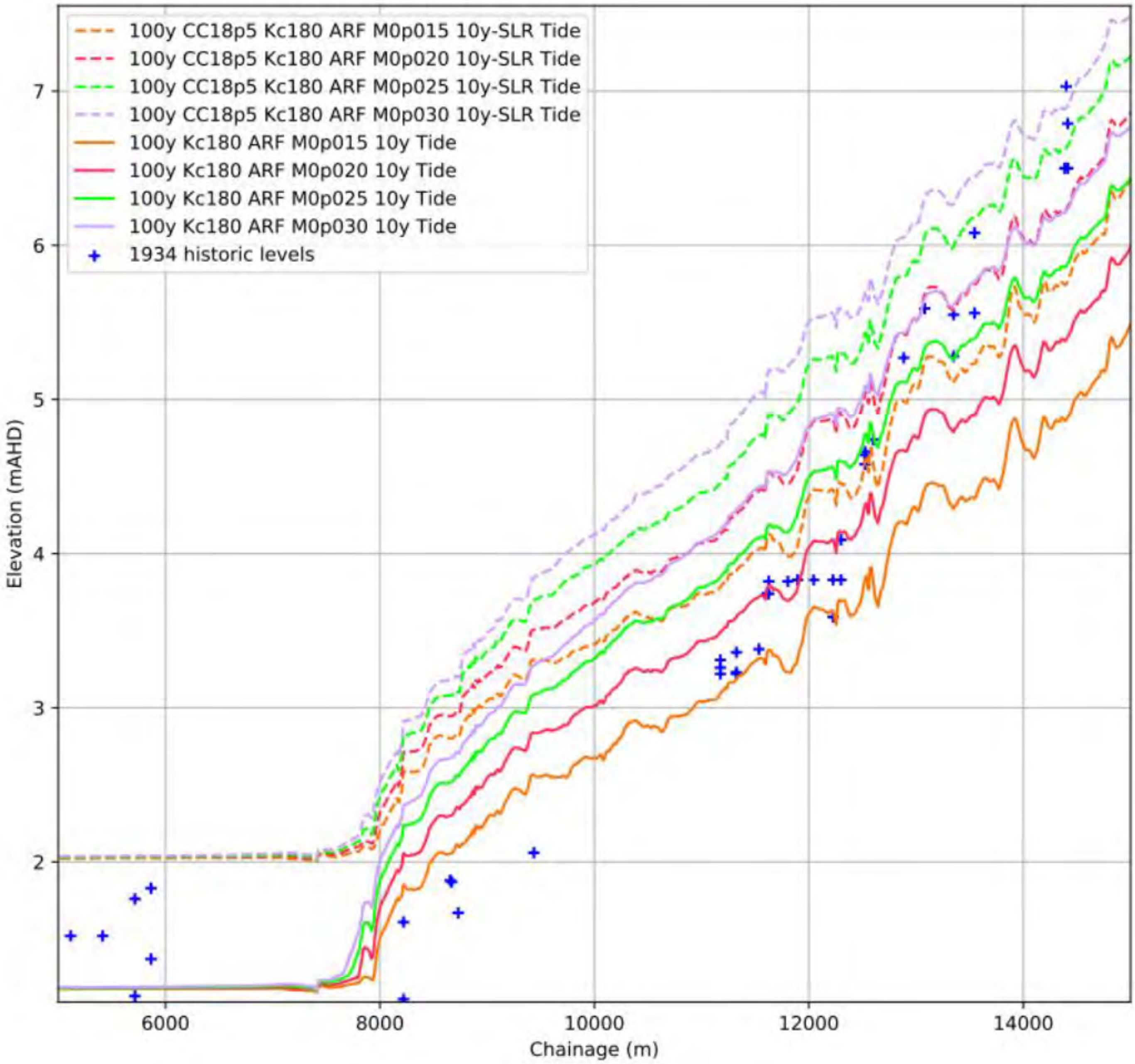

Figure 28 1% AEP Long-section along Yarra River comparing WSL along Yarra to historic levels - Impact of River Roughness

2.4.3 Runs 13 to 15 – Sensitivity of changes to 10 year ARI results provided to City of Melbourne

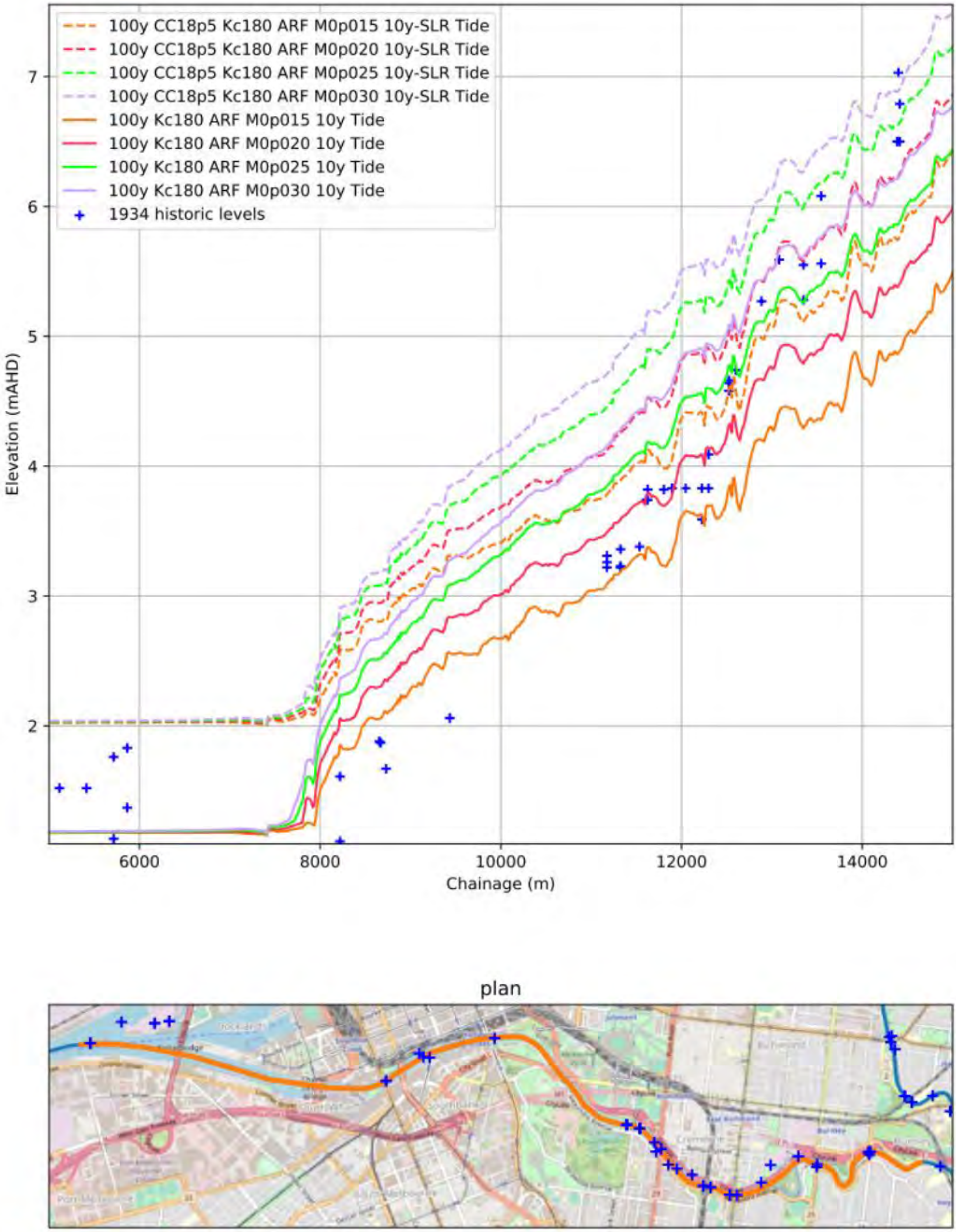

Figure 29 10% AEP Long-section along Yarra River comparing WSL along Yarra to historic levels – Impact of assumptions on TWL for City of Melbourne

2.5 Comparison Point Results – Overflow Refinement Area

Figure 30 Location of Comparison Points

2.5.1 Boundary Conditions Sensitivity (comparison of runs 1 to 6)

Table 3 Comparison Point Locations – Impact of Kc and ARFs

ID	Description	1% AEP w/ 1% AEP SLR Tide	1% AEP w/ 10% AEP Tide			1% AEP CC 18.5% w/ 10% AEP SLR Tide				
		Current [Classic] (Kc = 145 w/o ARFs & n = 0.015)	Current - Kc=145 w/o ARFs & n = 0.015	Kc=237 w/o ARFs & n = 0.015	Kc=180 w/ ARFs & n = 0.015	Current - Kc=145 w/o ARFs & n = 0.015	Kc=237 w/o ARFs & n = 0.015	Kc=180 w/ ARFs & n = 0.015	Fishbend	Southbank
1	Yarra River 1 (US)	4.48	3.48	2.60	2.55	4.19	3.43	3.31	-	2.14
2	Yarra River 2	3.80	2.81	2.10	2.06	3.40	2.89	2.81	-	2.14
3	Yarra River 3	2.29	1.24	1.20	1.20	2.09	2.06	2.05	-	2.14
4	Yarra River 4	2.27	1.19	1.18	1.18	2.04	2.03	2.03	-	-
5	Yarra River 5 (DS)	2.29	1.19	1.18	1.18	2.04	2.03	2.03	-	-
6	South Bank Pond	3.67	2.31	-	-	2.69	2.36	2.30	-	1.28
7	Sth Park St	3.68	-	-	-	2.58	-	-	-	-
8	Fwy\Montague St	2.36	-	-	-	2.08	1.80	1.79	1.82	-
9	Lorimer St \ Boundary St	2.27	-	-	-	2.03	1.83	1.83	1.82	-
10	Approx. Boundary St \ Gittus St	2.37	1.53	-	-	2.08	1.80	1.70	1.82	-
11	Approx. Buckhurst St \ George St	3.10	2.13	-	-	2.41	2.21	1.91	1.89	-
12	Approx. Heath St \ Raglan St	2.58	-	-	-	2.19	-	-	-	-
13	Edwards Park	2.53	-	-	-	2.18	-	-	-	-
14	Approx. St Vincent St \ Iffla St	2.53	-	-	-	2.18	-	-	-	-

2.5.2 Roughness Sensitivity (comparison of runs 7 to 12)

Table 4 Comparison Point Locations – Impact of Roughness

ID	Description	1% AEP w/ 10% AEP Tide					1% AEP CC 18.5% w/ 10% AEP SLR Tide				
		Current [HPC] (Kc = 145 w/o ARFs & n = 0.015)	Kc = 180 w/ ARF River Roughness n = 0.015	Kc = 180 w/ ARF River Roughness n = 0.020	Kc = 180 w/ ARF River Roughness n = 0.025	Kc = 180 w/ ARF River Roughness n = 0.030	Current [HPC] (Kc = 145 w/o ARFs & n = 0.015)	Kc = 180 w/ ARF River Roughness n = 0.015	Kc = 180 w/ ARF River Roughness n = 0.020	Kc = 180 w/ ARF River Roughness n = 0.025	Kc = 180 w/ ARF River Roughness n = 0.030
1	Yarra River 1 (US)	3.48	2.55	2.84	3.10	3.30	4.19	3.31	3.52	3.72	3.87
2	Yarra River 2	2.81	2.06	2.31	2.53	2.68	3.40	2.81	2.95	3.09	3.19
3	Yarra River 3	1.24	1.20	1.23	1.26	1.37	2.09	2.05	2.08	2.11	2.13
4	Yarra River 4	1.19	1.18	1.18	1.19	1.20	2.04	2.03	2.03	2.04	2.05
5	Yarra River 5 (DS)	1.19	1.18	1.18	1.18	1.19	2.04	2.03	2.03	2.03	2.04
6	South Bank Pond	2.31	-	1.65	2.03	2.20	2.69	2.30	2.40	2.48	2.55
7	Sth Park St	-	-	-	-	-	2.58	-	2.04	2.42	2.47
8	Fwy\Montague St	-	-	-	-	-	2.08	1.79	1.88	1.97	2.01
9	Lorimer St \ Boundary St	-	-	-	-	-	2.03	1.83	1.88	1.95	1.98
10	Approx. Boundary St \ Gittus St	1.53	-	-	-	-	2.08	1.70	1.88	1.97	2.01
11	Approx. Buckhurst St \ George St	2.13	-	-	-	-	2.41	1.91	2.25	2.29	2.33
12	Approx. Heath St \ Raglan St	-	-	-	-	-	2.19	-	-	2.09	2.13
13	Edwards Park	-	-	-	-	-	2.18	-	-	2.04	2.12
14	Approx. St Vincent St \ Iffla St	-	-	-	-	-	2.18	-	-	2.04	2.12

2.5.3 Effect on 10 year ARI levels (comparison of runs 13 to 15)

Table 5 Comparison Point Locations – Impact on TWL for City of Melbourne

ID	Description	10% AEP CC 18.5% w/ 10% AEP SLR Tide			
		Current [Classic] (Kc = 145 w/o ARFs & n = 0.015)	Current [HPC OR] (Kc = 145 w/o ARF & n = 0.015)	Kc = 180 w/ ARF & n = 0.020	Kc = 180 w/ ARF & n = 0.030
1	Yarra River 1 (US)	2.37	2.46	2.22	2.48
2	Yarra River 2	2.14	2.19	2.10	2.21
3	Yarra River 3	2.01	2.03	2.03	2.04
4	Yarra River 4	2.01	2.02	2.02	2.02
5	Yarra River 5 (DS)	2.01	2.02	2.01	2.01

2.6 Comparison with 1934 historic points

Figure 31 Location of 1934 Historic Flood Levels

Table 6 1934 Flood Level Comparison Points

ID	1934 Flood Level	1% AEP w/ 1% AEP SLR Tide	1% AEP w/ 10% AEP Tide						1% AEP w/ 10% AEP SLR Tide					
		Current (Kc=145) River Roughness n = 0.015	Current (Kc=145) River Roughness n = 0.015	Kc=237 River Roughness n = 0.015	Kc = 180 w/ ARF River Roughness n = 0.015	Kc = 180 w/ ARF River Roughness n = 0.020	Kc = 180 w/ ARF River Roughness n = 0.025	Kc = 180 w/ ARF River Roughness n = 0.030	Current (Kc=145) River Roughness n = 0.015	Kc=237 River Roughness n = 0.015	Kc = 180 w/ ARF River Roughness n = 0.015	Kc = 180 w/ ARF River Roughness n = 0.020	Kc = 180 w/ ARF River Roughness n = 0.025	Kc = 180 w/ ARF River Roughness n = 0.030
HL1	3.59	5.80	4.85	3.67	3.61	4.07	4.54	4.89	5.78	4.62	4.39	4.85	5.26	5.54
HL2	3.83	5.83	4.89	3.75	3.69	4.14	4.60	4.93	5.81	4.66	4.45	4.90	5.30	5.58
HL3	4.58	5.93	5.03	3.88	3.83	4.31	4.76	5.08	5.90	4.80	4.59	5.03	5.42	5.68
HL4	4.74	5.97	5.04	3.90	3.84	4.33	4.79	5.11	5.95	4.82	4.61	5.05	5.44	5.73
HL5	1.52	2.29	1.19	1.18	1.18	1.18	1.18	1.19	2.04	2.03	2.03	2.03	2.03	2.04
HL6	0.64	2.29	1.19	1.18	1.18	1.18	1.18	1.19	2.04	2.03	2.03	2.03	2.03	2.04
HL7	1.76	2.46	-	-	-	-	-	-	-	-	-	-	-	-
HL8	1.13	2.46	-	-	-	-	-	-	-	-	-	-	-	-
HL9	1.83	2.46	-	-	-	-	-	-	2.24	-	-	-	-	2.28
HL10	1.37	2.46	-	-	-	-	-	-	2.24	-	-	-	-	2.28
HL11	1.11	3.15	2.50	1.88	1.85	2.06	2.24	2.37	3.08	2.66	2.59	2.71	2.82	2.91
HL12	1.88	3.47	2.84	2.11	2.07	2.31	2.53	2.69	3.42	2.91	2.83	2.97	3.10	3.19
HL13	3.26	4.86	4.05	3.15	3.10	3.49	3.85	4.16	4.83	3.92	3.79	4.13	4.46	4.71
HL14	3.23	5.05	4.19	3.24	3.18	3.59	3.96	4.28	5.02	4.04	3.89	4.25	4.60	4.87
HL15	3.22	5.05	4.19	3.24	3.18	3.59	3.96	4.28	5.02	4.04	3.89	4.25	4.60	4.87
HL16	3.38	5.23	4.36	3.36	3.31	3.72	4.10	4.43	5.21	4.19	4.03	4.40	4.76	5.03
HL17	3.74	5.51	4.52	3.43	3.38	3.79	4.19	4.53	5.49	4.31	4.13	4.53	4.91	5.19
HL18	6.5	7.31	6.34	4.93	4.85	5.37	5.84	6.20	7.29	5.98	5.72	6.21	6.61	6.87
HL19	5.28	-	-	-	-	-	-	-	-	-	-	-	-	-
HL20	5.56	6.83	5.84	4.43	4.36	4.89	5.39	5.76	6.81	5.50	5.23	5.74	6.17	6.44
HL21	6.5	7.36	6.38	4.97	4.88	5.40	5.88	6.23	7.34	6.02	5.76	6.24	6.64	6.90
HL22	1.87	3.44	2.80	2.09	2.06	2.30	2.52	2.67	3.39	2.88	2.80	2.94	3.08	3.18
HL23	3.83	5.80	4.85	3.67	3.61	4.07	4.54	4.89	5.78	4.62	4.39	4.85	5.26	5.54
HL24	4.09	5.83	4.89	3.75	3.69	4.14	4.60	4.93	5.81	4.66	4.45	4.90	5.30	5.58
HL25	4.64	5.93	5.03	3.88	3.83	4.31	4.76	5.08	5.90	4.80	4.59	5.03	5.42	5.68
HL26	6.08	6.84	5.85	4.40	4.32	4.89	5.40	5.76	6.82	5.51	5.23	5.75	6.18	6.44
HL27	7.03	7.03	6.07	4.68	4.60	5.14	5.65	6.02	7.02	5.72	5.46	5.97	6.39	6.66
HL28	1.61	3.15	2.50	1.88	1.85	2.06	2.24	2.37	3.08	2.66	2.59	2.71	2.82	2.91
HL29	6.79	7.36	6.38	4.97	4.88	5.40	5.88	6.23	7.34	6.02	5.76	6.24	6.64	6.90
HL30	4.66	5.93	5.03	3.88	3.83	4.31	4.76	5.08	5.90	4.80	4.59	5.03	5.42	5.68
HL31	5.27	5.96	-	-	-	-	-	-	5.96	-	-	-	-	-
HL32	3.22	4.86	4.05	3.15	3.10	3.49	3.85	4.16	4.83	3.92	3.79	4.13	4.46	4.71
HL33	2.06	4.22	3.48	2.61	2.56	2.84	3.09	3.28	4.18	3.43	3.31	3.51	3.70	3.85
HL34	3.82	5.43	4.40	3.33	3.28	3.72	4.16	4.54	5.41	4.21	4.01	4.47	4.91	5.22
HL35	3.83	5.48	4.46	3.35	3.30	3.76	4.24	4.62	5.46	4.26	4.03	4.54	4.97	5.28
HL36	3.74	5.33	4.46	3.42	3.36	3.78	4.17	4.49	5.31	4.27	4.10	4.48	4.86	5.11
HL37	3.83	5.72	4.81	3.79	3.74	4.18	4.57	4.84	5.70	4.65	4.49	4.81	5.20	5.47
HL38	1.52	2.29	1.19	1.18	1.18	1.18	1.18	1.19	2.04	2.03	2.03	2.03	2.03	2.04
HL39	3.31	4.86	4.05	3.15	3.10	3.49	3.85	4.16	4.83	3.92	3.79	4.13	4.46	4.71
HL40	3.82	5.51	4.52	3.43	3.38	3.79	4.19	4.53	5.49	4.31	4.13	4.53	4.91	5.19
HL41	3.36	5.05	4.19	3.24	3.18	3.59	3.96	4.28	5.02	4.04	3.89	4.25	4.60	4.87
HL42	5.55	-	-	-	-	-	-	-	-	-	-	-	-	-

ID	1934 Flood Level	1% AEP w/ 1% AEP SLR Tide	1% AEP w/ 10% AEP Tide					1% AEP w/ 10% AEP SLR Tide					
		Current (Kc=145) River Roughness n = 0.015	Current (Kc=145) River Roughness n = 0.015	Kc=237 River Roughness n = 0.015	Kc = 180 w/ ARF River Roughness n = 0.015	Kc = 180 w/ ARF River Roughness n = 0.020	Kc = 180 w/ ARF River Roughness n = 0.025	Kc = 180 w/ ARF River Roughness n = 0.030	Current (Kc=145) River Roughness n = 0.015	Kc=237 River Roughness n = 0.015	Kc = 180 w/ ARF River Roughness n = 0.015	Kc = 180 w/ ARF River Roughness n = 0.020	Kc = 180 w/ ARF River Roughness n = 0.025	Kc = 180 w/ ARF River Roughness n = 0.030
HL43	1.67	3.45	2.83	2.15	2.12	2.36	2.56	2.71	3.40	2.90	2.82	2.96	3.10	3.20
HL44	5.59	6.84	5.88	4.58	4.50	4.97	5.41	5.73	6.82	5.57	5.32	5.77	6.15	6.40

2.7 Southbank City Link Tunnel Portal results

Table 7 Southbank City Link Tunnel Portal Flows & Volumes

Scenario	Kc & ARF	Hydrology	Tide	River Roughness (Manning's 'n')	Peak Flow (m^3/s)	Peak Volume (m^3)
1	Current (Kc=145 w/o ARFs)	1% AEP CC (18.5% increase rainfall intensity)	1% AEP SLR	0.015	-292.0	-51,296,280
2	Current (Kc=145 w/o ARFs)	1% AEP CC (18.5% increase rainfall intensity)	10% AEP SLR	0.015	-270.6	-46,754,266
3	Kc=237 w/o ARFs	1% AEP CC (18.5% increase rainfall intensity)	10% AEP SLR	0.015	-104.5	-14,283,613
4	Kc=180 w/ ARF	1% AEP CC (18.5% increase rainfall intensity)	10% AEP SLR	0.015	-36.2	-9,027,424
5	Current (Kc=145 w/o ARFs)	1% AEP Base Case	10% AEP	0.015	-87.4	-9,669,632
6	Kc=237 w/o ARFs	1% AEP Base Case	10% AEP	0.015	0.0	0
7	Kc=180 w/ ARF	1% AEP Base Case	10% AEP	0.015	0.0	0
4*	Kc=180 w/ ARF	1% AEP CC (18.5% increase rainfall intensity)	10% AEP SLR	0.015	-36.2	-9,027,424
8	Kc=180 w/ ARF	1% AEP CC (18.5% increase rainfall intensity)	10% AEP SLR	0.02	-120.2	-17,174,045
9	Kc=180 w/ ARF	1% AEP CC (18.5% increase rainfall intensity)	10% AEP SLR	0.025	-159.5	-26,489,967
10	Kc=180 w/ ARF	1% AEP CC (18.5% increase rainfall intensity)	10% AEP SLR	0.03	-194.9	-36,132,012
7*	Kc=180 w/ ARF	1% AEP Base Case	10% AEP	0.015	0.0	0
11	Kc=180 w/ ARF	1% AEP Base Case	10% AEP	0.02	-1.0	-84,797
12	Kc=180 w/ ARF	1% AEP Base Case	10% AEP	0.025	-29.5	-1,967,656
13	Kc=180 w/ ARF	1% AEP Base Case	10% AEP	0.03	-55.7	-6,188,394
14	Current (Kc=145 w/o ARFs)	10% AEP CC (18.5% increase rainfall intensity)	10% AEP SLR	0.015	0.0	0
15	Kc=180 w/ ARF	10% AEP CC (18.5% increase rainfall intensity)	10% AEP SLR	0.02	0.0	0
16	Kc=180 w/ ARF	10% AEP CC (18.5% increase rainfall intensity)	10% AEP SLR	0.03	0.0	0

3. Preliminary thoughts on scope of model extension for discussion.

The following are some preliminary thoughts on the extension of the Lower Yarra model to include the Banksia Street gauge. It is understood that this extension is primarily to enable a comparison of modelling parameters over a larger length of river to provide a greater understanding and confidence in the conclusions being made about the suitability of these modelling parameters.

3.1 RORB

3.1.1 Expected tasks

1. Modification to cat file to provide required inflows (no change to dav) and or use NELP RORB model.
2. Rerun hydrology with additional print out locations and required parameters

3.1.2 To be confirmed

Scenarios and parameters to be tested?

3.2 TUFLOW

It is anticipated that the extended model would be run in the latest version of HPC TUFLOW.

3.2.1 Model extents

The extent of the 'existing condition, models, are:

- Lower Yarra model extends for 13.9 kms of the Yarra River.
- NELP Yarra model extends for 31.6 kms extends upstream of Banksia Street Gauge to approximately Fran Court

The options for combined model length are as follows:

1. 42.4 km if extended to include Banksia St Heidelberg (229135A)
   a. may require minor changes to inflow hydrographs
   b. faster run time smaller extent
2. 48.8 km if including all and extending up to Fran Court
   a. No changes to boundary conditions
   b. Slightly longer run time
3. 68 km if extended to Forbes St Warrandyte Gauge (229200B) (also includes Fitzsimons Lane Templestowe 229142A)

3.2.2 Expected Tasks

1. Combine existing terrain models
2. Adopt a common loc line and grid:
   – Adopt loc line from Lower Yarra

  - Check and revise NELP structure representation with new grids
  - Check and revise NELP terrain modifications with new grids
3. Merge materials layers
4. Add key structure and terrain between detailed sections of existing models
   - Details of additional structure to be provided by Melbourne Water
   - Level of detail for initial runs to be discussed and agreed.
     - Consider rough initial runs
     - Refine if required for current purpose
5. Debugging and refinement to enable running in latest version of HPC TUFLOW.
6. Identify additional reporting locations
7. Production runs
8. Checking results
9. Produce comparative tables and long sections between runs and 1934 historic flood levels
10. Discussions
11. Documentation

3.3 Current Exclusions

Current thinking has the following exclusions:

- No update for ARR2019.
- Modelling is not for flood mapping purpose.
- No significant iteration or calibration process allowed for at this stage.
- No modelling of historic events.
- No detailed assessment or survey of recorded flood levels.
- No flood frequency analysis at the gauges.
- Use existing terrain data in models no addition of additional bathymetric survey, structure survey or new Lidar sources.
- Checking and review to identify problems in commercial software packages.