Technical Report: Australian Rainfall and Runoff Sensitivity Analysis

Project: V3000_111 City of Melbourne Planning Scheme Overlays	**Date:** 22 July 2020
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Subject: ARR2019 sensitivity analysis	

INTRODUCTION

The City of Melbourne and Melbourne Water have prepared an update to the extents of the Land Subject to Inundation Overlay (LSIO) and Special Building Overlay (SBO), which are proposed to be included in the City of Melbourne Planning Scheme through Amendment C384. The overlays are based on a number of previous flood modelling studies undertaken within the City of Melbourne in accordance with Australian Rainfall and Runoff (ARR) 1987, and include an 18.5 % increase in rainfall intensity due to the predicted impacts of climate change by the year 2100.

ARR2019 has been released since the development of the flood models that have been used as the basis of updating the LSIO and SBO. This technical report documents the outcomes of a sensitivity analysis undertaken by Engeny Water Management (Engeny) to examine the impact of ARR2019 in comparison to ARR1987, based on the results of flood modelling for the Arden Macaulay Precinct / Moonee Ponds Creek model, which is one of six flood models that will be used to delineate the LSIO and SBO. A key objective is to determine whether it is justifiable to apply ARR1987 to delineate the LSIO and SBO, based on differences predicted between the flood mapping results of ARR2019 and ARR1987 for the Arden Macaulay Precinct / Moonee Ponds Creek model.

The Arden Macaulay Precinct / Moonee Ponds Creek flood modelling is based on RORB and TUFLOW. Two RORB models have been used as part of the modelling, one for the overall Moonee Ponds Creek catchment (developed by Melbourne Water) to provide an inflow to Moonee Ponds Creek at Flemington Road and one for the local catchment draining into Moonee Ponds Creek downstream of Flemington (developed by AECOM). A combination of runoff excess hydrographs and routed flows have been used from the local catchment RORB model.

ARR1987 HYDROLOGY MODELLING

Key parameters adopted in the ARR1987 modelling, consistent with previous studies using these models, are outlined below:

- Moonee Ponds Creek RORB model:
  - IFD data for the centroid of the Moonee Ponds Creek catchment
  - kc: 26.0
  - m: 0.8
  - Initial loss: 15 millimetres
  - Pervious area 1 % annual exceedance probability (AEP) runoff coefficient: 0.65
  - Areal reduction factors based on ARR87 Bk II, Figs 1.6 and 1.7
- Local catchment RORB model:
  - IFD data for the centroid of the local catchment RORB model
  - kc: 3.4
  - m: 0.8
  - Initial loss: 10 millimetres
  - Pervious area 1 % AEP runoff coefficient: 0.6
  - Areal reduction factors based on ARR87 Bk II, Figs 1.6 and 1.7

The key results from the Moonee Ponds Creek RORB model in terms of the peak flow in Moonee Ponds Creek at Flemington Road are:

- Existing climate conditions: 217 m^3/s
- 18.5 % climate change scenario: 263 m^3/s

ARR2019 HYDROLOGY MODELLING

Both the Moonee Ponds Creek and local catchment RORB models were updated to ARR2019, including updated design rainfall data, temporal patterns and hydrological losses.

Table 1 provides a comparison of 1 % AEP design rainfall depths between ARR1987 and ARR2019 for standard storm durations for the Moonee Ponds Creek catchment. It should be noted that a change in rainfall depth is unlikely to result in the same percentage change in flooding due to the different temporal patterns and approach to hydrological losses between ARR1987 and ARR2019.

Table 1 Comparison of design rainfall depths for the Moonee Ponds Creek catchment

Storm Duration	ARR1987 Design Rainfall Depth (mm)	ARR2019 Design Rainfall Depth (mm)	Change
10 min	23.0	24.3	+5.7 %
30 min	38.3	39.5	+3.3 %
1 hour	49.6	49.5	-0.2 %
2 hour	61.6	60.7	-1.5 %
3 hour	69.3	68.6	-1.0 %
6 hour	84.0	85.9	+2.3 %
12 hour	104.6	109.0	+4.2 %

Initial and continuing losses for effective impervious areas and indirectly connected areas are based on values recommended in ARR2019. For rural areas, as a starting point, initial and continuing loss values were adopted based on the datahub values. For the Moonee Ponds Creek RORB model the datahub losses for rural areas are:

- Initial loss: 12 millimetres
- Continuing loss: 1.9 millimetres

Areal reduction factors (ARF) for the Moonee Ponds Creek RORB model have been based on the approach outlined in ARR2019 for the total catchment of Moonee Ponds Creek. For the 2 hour duration event (which is critical for the Moonee Ponds Creek catchment), this results in a reduction in ARF from 0.91 for ARR1987 to 0.78 for ARR2019.

ARR2019 recommends the consideration of spatial variation for catchments exceeding 20 square kilometres, which would include the Moonee Ponds Creek catchment (which has a catchment area of approximately 135 square kilometres). The variation of design rainfall intensity across the catchment was analysed using the IFD data and it was found to be within +/- 5 %. Due to the small variation, a single source of IFD has been used for the Moonee Ponds Creek catchment.

Adopting the above losses and ARFs resulted in a considerable increase in peak flows at Flemington Road (from 217 m^3/s in ARR1987 to 245 m^3/s in ARR2019 for existing climate conditions). In ARR2019, the peak flow is identified as the peak of the median flows for the range of temporal patterns for each storm duration.

There is uncertainty regarding how the ARR1987 Moonee Ponds Creek RORB model was validated. To understand whether the ARR1987 flows were reasonable, Engeny undertook a flood frequency analysis (FFA) on flow gauge data at Flemington Road.

The FFA was undertaken using FLIKE software package to determine peak flow rates for different AEP events based on the provided historical gauged data ranging from July 1991 to

October 2019. The 6 minute interval gauge data was process to determine peak flows for each year in Moonee Ponds Creek at Flemington Road, which ranged from 19 m^3/s to 186 m^3/s.

ARR2019 suggests two probability models as reasonable initial choices for annual maximum flood series, which are the Generalized Extreme Value (GEV) and Log Pearson III (LP III) families. Of the widely used distribution families, the GEV distribution has the strongest theoretical appeal and has gained widespread acceptance. For this investigation the GEV model with LH-moments was adopted. LH-moments can be used to deal with situations where the lower discharges exert undue influence on the fit and give insufficient weight to the higher discharges which are the principal object of interest.

The 1 % AEP flood quantile estimated by the FFA for the GEV model with LH-moments is 207 m^3/s and 192 m^3/s for the LP III model.

Figure 1 presents the flood frequency curve for the GEV model with LH-moments.

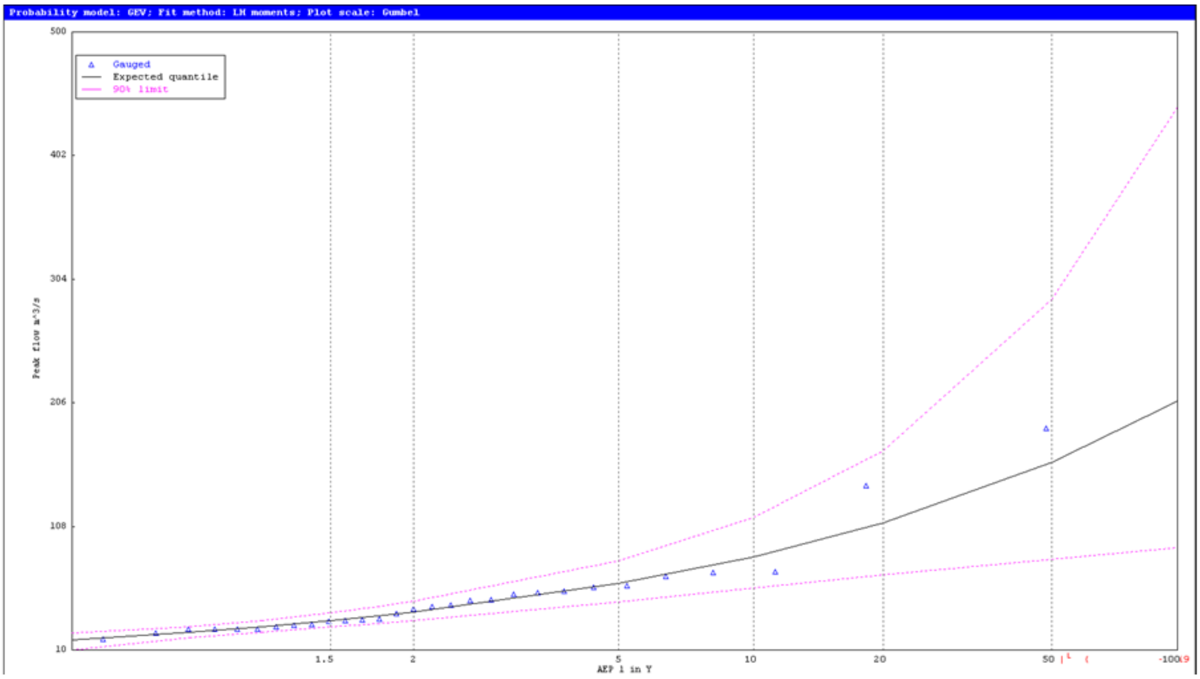


Figure 1 FFA GEV model curve

The flood frequency analysis 1 % AEP flow of 207 m^3/s is an appropriate match to the ARR1987 peak flow (217 m^3/s) and it was therefore decided that it would be appropriate to adjust the ARR2019 losses so that the ARR2019 peak flow matches the ARR1987 peak flow.

The final hydrological losses adopted for the ARR2019 Moonee Ponds Creek RORB model are:

- Rural areas initial loss: 28 millimetres
- Rural areas continuing loss: 3.0 millimetres
- Effective impervious areas initial loss: 1.5 millimetres
- Effective impervious areas continuing loss: 0 millimetres

- Indirectly connected areas initial loss: 19.6 millimetres
- Indirectly connected areas continuing loss: 2.5 millimetres

Following the validation of the ARR2019 flows to the ARR1987 flows, the 18.5 % climate change factor was added to the ARR2019 design rainfall.

Table 2 provides a comparison of the peak flows in Moonee Ponds Creek at Flemington Road for ARR1987 and ARR2019.

Table 2 Comparison of peak flows in Moonee Ponds Creek at Flemington Road

Scenario	ARR1987	ARR2019	Change
Existing Climate	217 m^3/s	217 m^3/s	-
18.5 % Climate Change	263 m^3/s	278 m^3/s	+5.7 %

For both ARR1987 and ARR2019, in existing climate and 18.5 % climate change scenarios, the critical storm duration for Moonee Ponds Creek at Flemington Road is the 2 hour event. The higher peak flow in the ARR2019 18.5 % climate change scenario is attributed to the difference in the adopted hydrological losses between ARR1987 and ARR2019.

For the local catchment RORB model the datahub losses were used and for rural areas are:

- Initial loss: 12 millimetres
- Continuing loss: 1.9 millimetres

The local catchment RORB model was originally developed by AECOM and the ARR1987 model was validated at three locations using Rational Method calculations. Use of the Rational Method to validate a model the size of the local catchment is not supported by ARR2019.

It should be noted that while some routed hydrographs are used from the local catchment RORB model, the majority of the outputs that are used from the local catchment RORB model are rainfall excess hydrographs, with routing accounted for in the TUFLOW model. Rainfall excess hydrographs are not dependent on the RORB routing parameter kc. This means that the adopted routing parameter kc in the local catchment RORB model does not have a significant impact on the results of the flood modelling.

There is no available gauge data to use to validate the local catchment RORB model. It was therefore decided to:

- Revise the local catchment RORB model routing parameter kc based on the Yarra and Maribyrnong Catchments regional equation, $kc = 1.19 \times A^{0.56}$
- Use the datahub losses.

The final hydrological parameters adopted for the ARR2019 local catchment RORB model are:

- kc: 4.17
- Rural areas initial loss: 12.0 millimetres
- Rural areas continuing loss: 1.9 millimetres
- Effective impervious areas initial loss: 1.5 millimetres
- Effective impervious areas continuing loss: 0 millimetres
- Indirectly connected areas initial loss: 8.4 millimetres
- Indirectly connected areas continuing loss: 1.3 millimetres

Figure 2 compares the 1 % AEP 2 hour duration hydrographs for ARR1987 and ARR2019 (median temporal pattern) along the Arden Street Drain at Dryburgh Street, for the 18.5 % climate change scenario. The hydrographs show very similar peak flows, but there is a 35 % increase in the volume of the hydrograph in ARR2019 compared to ARR1987.

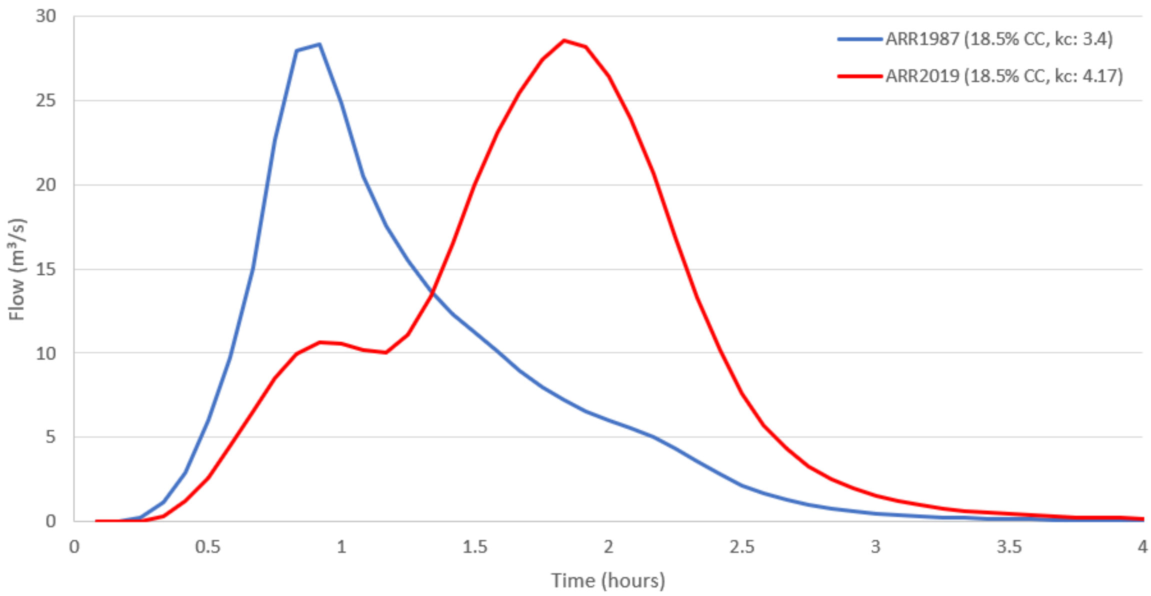


Figure 2 Local catchment RORB model, 1 % AEP 2 hour duration hydrograph comparison along the Arden St Drain at Dryburgh Street

HYDRAULIC MODELLING AND FLOOD MAPPING

Both the ARR1987 and ARR2019 flows identified by the Moonee Ponds Creek and local catchment RORB models have been simulated in the TUFLOW model of the Arden Macaulay Precinct and downstream reach of Moonee Ponds Creek. The setup of the TUFLOW model is identical for ARR1987 and ARR2019, with the exception of reading in different hydrographs. The TUFLOW modelling is based on the six pump stations that service the low lying areas behind Moonee Ponds Creek’s levees between Arden Street and Racecourse Road failing to operate. The pump station failure represents the pumps not turning on during the storm event, but that the penstocks that prevent backflow of water from Moonee Ponds Creek into the local drainage system behind the levees still operate.

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.

For both ARR1987 and ARR2019, the TUFLOW 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.

The use of a cyclical tide boundary is consistent with the methodology of the other flood models that have been used to delineate the LSIO and SBO through Amendment C384 (where the flood model is influenced by tidal impacts).

For ARR1987, standard storm durations from 10 minutes to 12 hours have been simulated in the TUFLOW model. In general, the critical storm duration is 2 hours and storms longer than 12 hours to do not contribute to critical flooding in the study area. The flood map for the ARR1987 scenario represents a combination of the maximum flood level from the range of the storm durations simulated for the 1 % AEP event.

For ARR2019, all 10 temporal patterns for standard storm durations up to and including 2 hour event have been simulated in the TUFLOW model. For storm durations between 3 hours and 12 hours, a single temporal pattern has been simulated in the TUFLOW model. The temporal pattern was selected by using the RORB model to identify the temporal pattern that results in the median volume of runoff that would overflow Moonee Ponds Creek's levees into the urban areas behind the levees. The flood map for the ARR2019 scenario represents a combination of the maximum flood level from the median peak flood level of storm durations up to 2 hours and the peak flood level of storm durations between 3 hours and 12 hours.

Provided with this memorandum are the following flood maps:

- ARR1987 18.5 % Climate Change Scenario, 1 % AEP Flood Depth
- ARR2019 18.5 % Climate Change Scenario, 1 % AEP Flood Depth
- 1 % AEP Flood Difference – Change in Flooding in ARR2019 Compared to ARR1987

The ARR1987 and ARR2019 flood depth maps show consistency in the areas that are predicted to be flood prone in a 1 % AEP event based on ARR1987 and ARR2019 methodologies.

As shown on the flood difference map, the modelling predicts that in the upstream sections of flow paths ARR2019 generally results in higher flood depths compared to ARR1987. The increase in flood depths is typically less than 100 millimetres, with increases just exceeding 100 millimetres in Moonee Ponds Creek upstream of Flemington Road. This is attributed to the higher peak flows in the ARR2019 18.5 % climate change scenario.

In the low-lying areas of the catchment behind Moonee Ponds Creek's levees north of Macaulay Road, the modelling predicts that peak flood depths in the ARR2019 scenario are also higher than ARR1987. The increase in flood depths in the low-lying areas behind the levees north of Macaulay Road is typically 10-30 millimetres.

As the TUFLOW model simulates the pumps failing to operate, flooding in the low-lying areas behind the levees is influenced by:

- the volume of the local catchment runoff
- the volume of creek flow overtopping the levees.

Figure 3 provides a graph showing the rate of flow spilling over the western levee between Racecourse Road and Macaulay Road. This flow then contributes to flooding in the low-lying area behind the levee along Stubbs Street (flooding in this area is also impacted by flow spilling from Moonee Ponds Creek upstream of Racecourse Road and local catchment runoff). The graph shows that the peak flow overtopping this section of the levee is higher in ARR2019 and there is a slightly higher volume spilling over the levee (the area under the hydrograph), with a volume of approximately 138,000 cubic metres spilling over the levee in the ARR2019 modelling compared to 134,000 cubic metres spilling over the levee in the ARR1987 modelling.

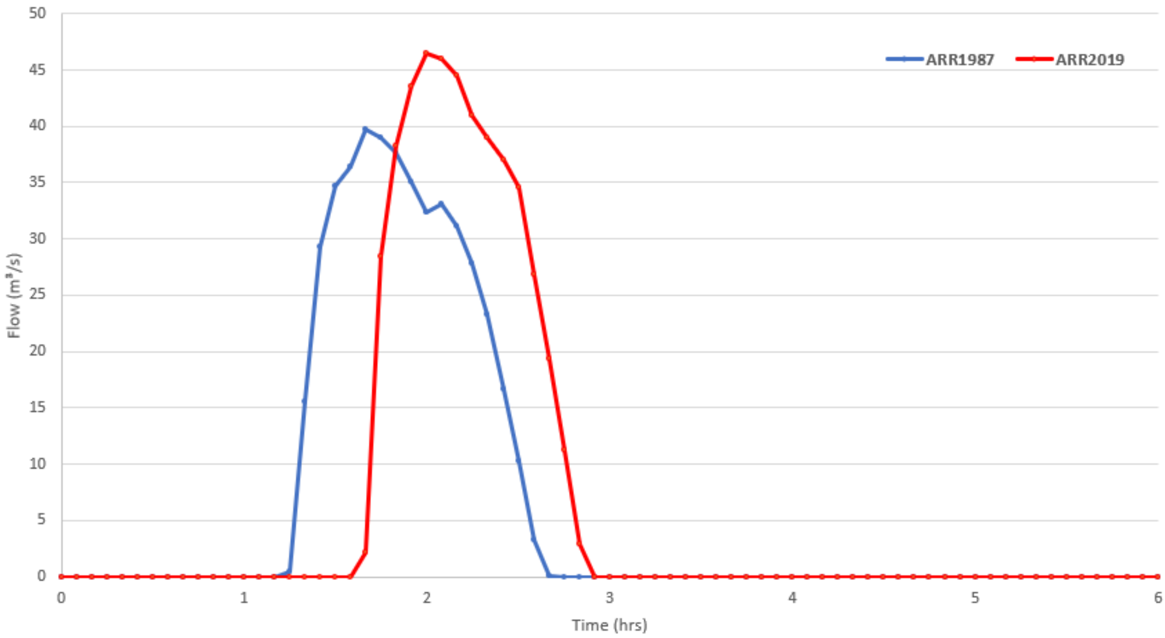


Figure 3 Flow Overtopping Western Levee between Racecourse Rd and Macaulay Rd (1 % AEP 2 hour event, 18.5 % climate change scenario)

In addition to the higher flows from Moonee Ponds Creek entering the area around Stubbs Street, there is also a higher volume of runoff from the local catchment (refer to previous Figure 2).

Along Moonee Ponds Creek and in the low lying areas behind the creek's levees south of Macaulay Road, the modelling predicts that there is a very close match between the ARR2019 and ARR1987 results (typically within +/- 10 millimetres, with an area within +/- 70 millimetres). While there is a higher volume of runoff from the local catchment entering these areas in the ARR2019 modelling compared to the ARR1987 modelling, the peak flows in Moonee Ponds Creek south of Macaulay Road are very similar (within 1 %) and the volume of flow of the Moonee Ponds Creek hydrograph for the 2 hour event is marginally (6 %) less in ARR2019 compared to ARR1987. Results in this area may also be more influenced by the relative timing of peak flows in the creek and the peak tidal level.

SUMMARY

Based on the analysis summarised in this memorandum, the key conclusions are as follows:

- A comparison of 1 % AEP design rainfall depths between ARR1987 and ARR2019 for standard storm durations for the Moonee Ponds Creek catchment shows that the difference is within +/- 6 %. It should be noted that a change in rainfall depth is unlikely to result in the same change in flooding due to the different temporal patterns and approach to hydrological losses between ARR1987 and ARR2019.

- When the Moonee Ponds Creek RORB model was updated to ARR2019 with the datahub hydrological losses, a considerable increase in peak flows at Flemington Road occurred (from 217 m^3/s in ARR1987 to 245 m^3/s in ARR2019 for existing climate conditions). The results of a flood frequency analysis compared well to the ARR1987 peak flow and it was therefore decided that it would be appropriate to adjust the ARR2019 losses so that the ARR2019 peak flow matches the ARR1987 peak flow.

- While the ARR2019 validation means that the existing climate flows are essentially the same for ARR1987 and ARR2019, when the 18.5 % climate change increase in rainfall is added, the peak ARR2019 flow is higher than ARR1987 (278 m^3/s compared to 263 m^3/s). The higher peak flow in the ARR2019 18.5 % climate change scenario is attributed to the difference in the hydrological losses between ARR1987 and ARR2019.

- The modelling predicts that there is a reduced volume of flow (but higher peak flow) in ARR2019 compared ARR1987 for the Moonee Ponds Creek hydrograph for the critical duration storm event (2 hours), but higher volume of runoff in the local catchment RORB model in ARR2019 compared to ARR1987.

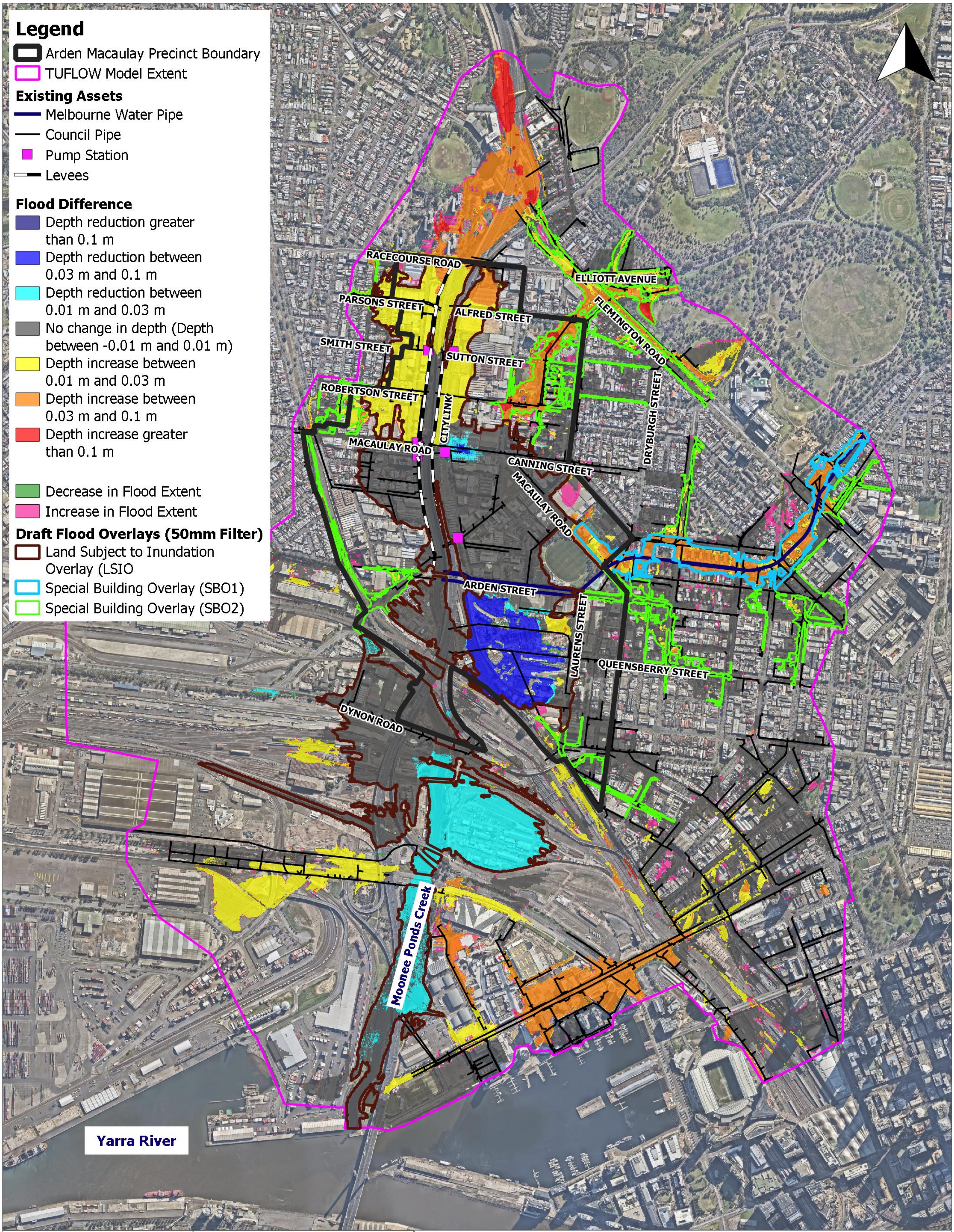
- For the Arden Macaulay Precinct / Moonee Ponds Creek model, there is consistency in the areas that are predicted to be flood prone for the 18.5 % climate change scenario based on ARR1987 and ARR2019 methodologies and the predicted difference in peak flood depths between ARR2019 and ARR1987 is generally within +/- 100 millimetres. As the results of ARR1987 are within reasonable tolerance of ARR2019, Engeny's opinion is that using ARR1987 to delineate the LSIO and SBO for the Arden Macaulay Precinct / Moonee Ponds Creek is acceptable.

- In the areas of the Arden Macaulay Precinct / Moonee Ponds Creek model that are more sensitive to peak flows (free draining overland flow paths), the ARR2019 18.5 % climate change scenario results in slightly higher flood depths (typically within 100 millimetres) compared to ARR1987 18.5 % climate change scenario. This is due to the higher peak flows in the ARR2019 18.5 % climate change scenario compared to the ARR1987 18.5 % climate change scenario. It is reasonable to expect similar results in free draining flow paths in urban areas represented in the other flood models being used define the LSIO and SBO.

- The outcomes of the modelling are less consistent in the areas of the Arden Macaulay Precinct / Moonee Ponds Creek model that are more sensitive to flood volumes (the low-lying areas behind the levees). Areas behind the levees north of Macaulay Road show increased flood depths in ARR2019 (typically within 10-30 millimetres), which is due to higher peak flows overtopping the levees and higher local catchment runoff volumes. Downstream of Macaulay Road, the there is a close match between the ARR2019 and ARR1987 in the low-lying areas behind the levees (typically within +/- 10 millimetres, with an area within +/- 70 millimetres). This is due to the lower volume of the Moonee Ponds Creek hydrograph in ARR2019 and potentially due to the relative timing of peak flows in the creek and the peak tidal level.

RECOMMENDATION

Based on the sensitivity analysis, which shows that the results of ARR1987 are within reasonable tolerance of ARR2019 for the Arden Macaulay Precinct / Moonee Ponds Creek model, Engeny believes that it is acceptable to use ARR1987 to update to the extents of the LSIO and SBO in the City of Melbourne Planning Scheme through Amendment C384.



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ENGENY

Melbourne Water

250 0 250 m

Scale in metres (1:12500@ A3)

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

City of Melbourne Flood Overlays

Figure 1
1 % AEP Flood Difference (ARR2019 Minus ARR1987)
Cyclical Tail Water Level (10% AEP Sea Level Rise)
Pump Failure, 18.5% CC

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Revision: 0
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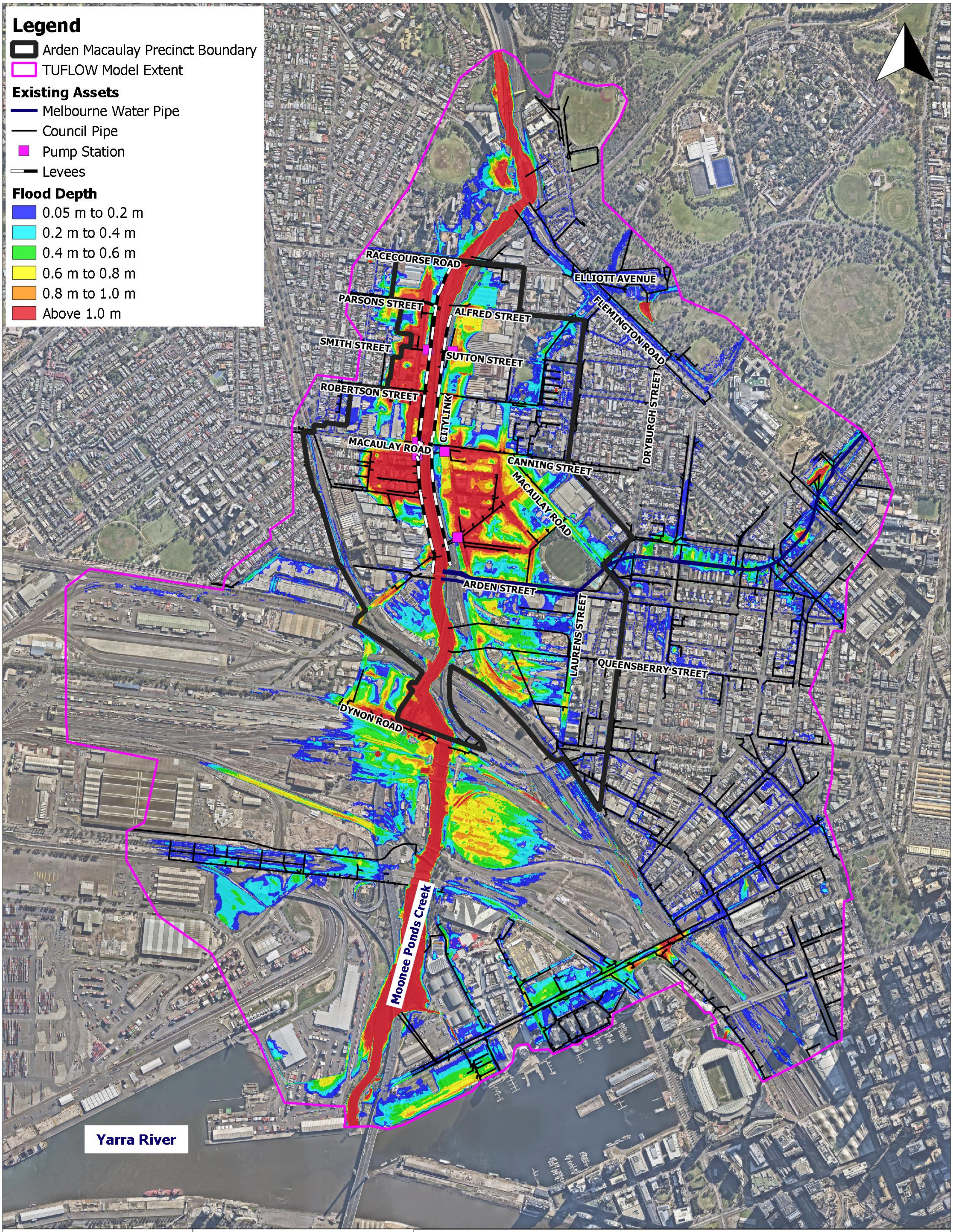

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1 % AEP Flood Depth (ARR1987)
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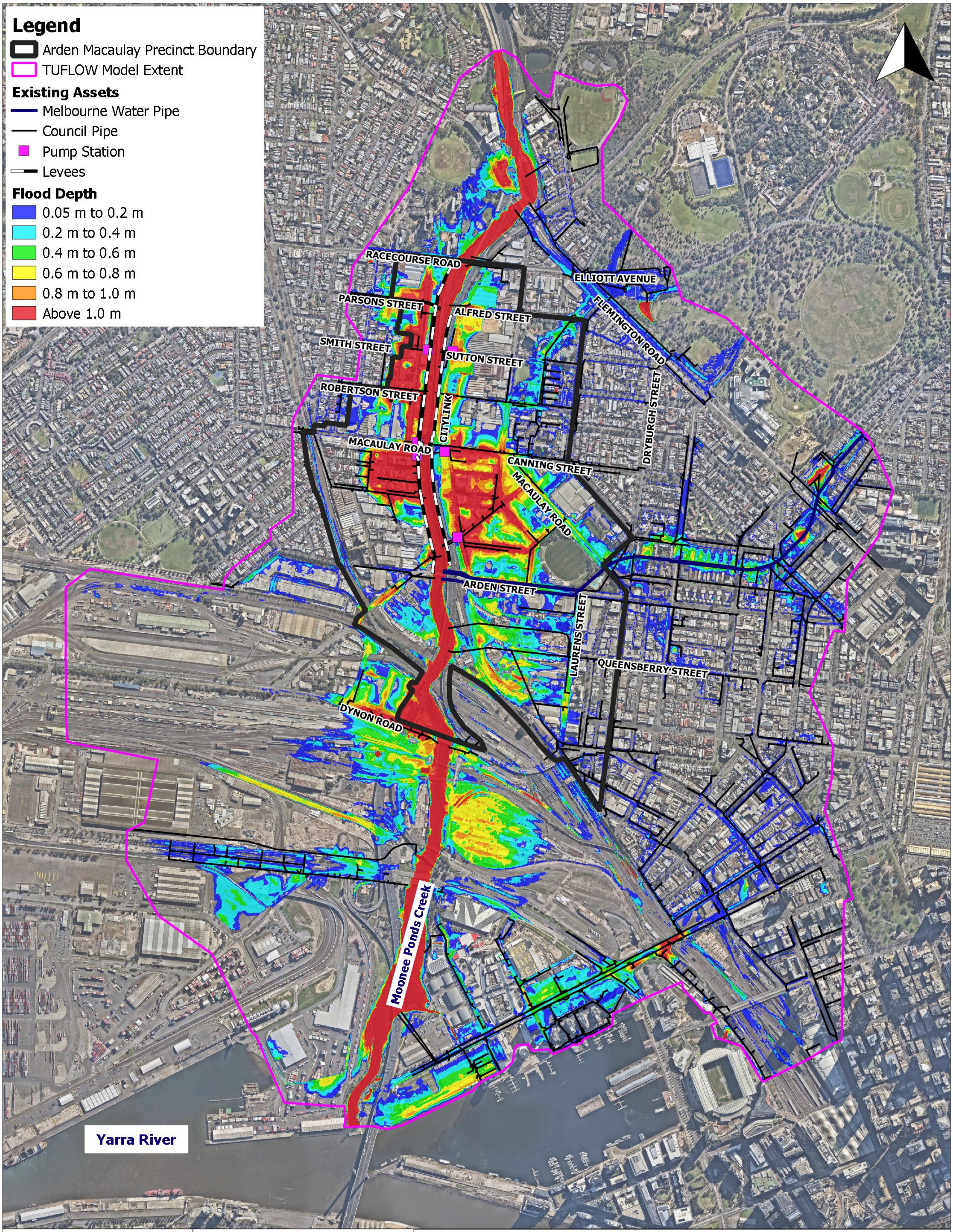

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City of Melbourne Flood Overlays

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