



Appendix A. Legislation, policy and guidelines



A.1. Legislation and policy

A.1.1. Victorian

Water Act 1989

The *Water Act 1989* is the primary legislation covering the management of the State's water resources. The stated purposes of the Act include:

- *'to promote the orderly, equitable and efficient use of water resources;*
- *to make sure that water resources are conserved and properly managed for sustainable use for the benefit of present and future Victorians.'*

The Act defines a 'waterway' as follows:

- a) 'a river, creek, stream or watercourse; or*
- b) a natural channel in which water regularly flows, whether or not the flow is continuous; or*
- c) a channel formed wholly or partly by the alteration or relocation of a waterway as described in paragraph (a) or (b);'*

The reaches of the Maribyrnong River, Moonee Ponds Creek and the Yarra River in the immediate vicinity of the Melbourne Metro alignment are designated waterways of Melbourne Water. Section 67 of the *Water Act 1989* requires proponents to receive a Works on Waterways permit prior to commencing works in, under, on or over the bed and banks of a designated waterway.

The Act empowers Melbourne Water to make by-laws 'for or with respect to - (a) the management, protection and use of all lands, waterways and works under the Authority's management and control...'

Melbourne Water has created two by-laws since the Act came into operation. The second of these is entitled 'Waterways, Land and Works Protection and Management'. The objectives of this by-law are stated to be as follows:

- a) 'the management, protection and use of lands, waterways and works under the management and control of Melbourne Water;*
- b) preventing or minimising interference with or obstruction of the flow of water;*
- c) preventing or minimising the silting up of a designated waterway or designated land or works or any injury to or pollution of it or them, including prohibiting the deposit of material in or near it or them;*
- d) prohibiting or regulating the removal of any material from land forming part of a designated waterway or designated land or works;*
- e) regulating activities carried out on land forming part of a designated waterway or designated land or works; and*
- f) the general management and control of any designated waterways or designated land or works, for the purpose of Melbourne Water discharging its functions under the Act.'*

Further, the by-law requires that a person must not:

- a) 'construct, operate, alter, obstruct, interfere with or remove any structures or works or carry out any works in, on, under, or over relevant land, waterways or works; or*
- b) carry out or construct any works that will or are likely to realign a relevant waterway or works without obtaining a permit from Melbourne Water.'*

As such, it is essential that Melbourne Metro would require a permit to be issued by Melbourne Water prior to undertaking work within any of the designated waterways.



Planning and Environment Act 1987

The *Planning and Environment Act 1987* establishes the framework for planning the use, development and protection of land in Victoria. In doing so, it enables the preparation and implementation of the Victoria Planning Provisions (VPPs) and Planning Schemes to regulate the use, development and protection of land. The VPPs include a range of zones and overlays, which planning authorities (normally municipal councils) can select to include in their Planning Schemes.

The VPPs include three surface water related overlays of potential relevance to Melbourne Metro:

- Floodway Overlay (FO)
- Land Subject to Inundation Overlay (LSIO)
- Special Building Overlay (SBO).

These overlays indicate areas that are prone to possible flooding and enable the planning authority to place restrictions or conditions on development proposed to occur within the areas over which the overlays have been placed. Generally, surface water overlays are based on a one per cent AEP flood event. Accordingly, Planning Overlays are used to provide preliminary identification of areas subject to significant surface water inundation. It is noted though, that the overlays are used as a guide for decision making on planning and development issues and, as such, are not considered likely to be an accurate and reliable basis upon which design decisions are made.

Floodway Overlay (FO)

Floodway Overlays generally cover major active flood flow paths and areas of high hazard flooding along significant waterways. The purposes of the FOs are:

- *'To identify waterways, major floodpaths, drainage depressions and high hazard areas which have the greatest risk and frequency of being affected by flooding.'*
- *'To ensure that any development maintains the free passage and temporary storage of floodwater, minimises flood damage and is compatible with flood hazard, local drainage conditions and the minimisation of soil erosion, sedimentation and silting.'*
- *'To ensure that development maintains or improves river and wetland health, waterway protection and flood plain health.'*

Under the *Planning and Environment Act 1987*, a permit is required to carry out any works in an area covered by an FO. This must be referred to the relevant floodplain management authority, in this case Melbourne Water, unless in the opinion of the responsible authority, 'the proposal satisfies requirements or conditions previously agreed in writing between the responsible authority and the floodplain management authority' (DELWP).

Matters to be taken into account in considering any application to carry out works include:

- *'The existing use and development of the land.'*
- *'Whether the proposed use or development could be located on flood-free land or land with a lesser flood hazard outside this overlay.'*
- *'The susceptibility of the development to flooding and flood damage.'*
- *'The potential flood risk to life, health and safety associated with the development. Flood risk factors to consider include:*
 - *The frequency, duration, extent, depth and velocity of flooding of the site and access way.*
 - *The flood warning time available.*
 - *The danger to the occupants of the development, other floodplain residents and emergency personnel if the site or access way is flooded.*
- *'The effect of the development on redirecting or obstructing floodwater, stormwater or drainage water and the effect of the development on reducing flood storage and increasing flood levels and flow velocities.'*



Land Subject to Inundation Overlay (LSIO)

The Land Subject to Inundation Overlay (LSIO) generally covers areas of flood conveyance or flood storage along major waterways or overland flow paths. The purposes of the LSIO are:

- *'To identify land in a flood storage or flood fringe area affected by the 1 in 100 year flood or any other area determined by the floodplain management authority.'*
- *'To ensure that development maintains the free passage and temporary storage of floodwaters, minimises flood damage, is compatible with the flood hazard and local drainage conditions and will not cause any significant rise in flood level or flow velocity.'*
- *'To ensure that development maintains or improves river and wetland health, waterway protection and flood plain health.'*

As with the FO, a permit is required to carry out any works in an area covered by an LSIO. This must again be referred to the relevant floodplain management authority, in this case Melbourne Water, unless in the opinion of the responsible authority, 'the proposal satisfies requirements or conditions previously agreed in writing between the responsible authority and the floodplain management authority' (DELWP, 2015).

Matters to be taken into account in considering any application to carry out works are the same as those for an FO.

Special Building Overlay (SBO)

The Special Building Overlay (SBO) generally covers urban areas subject to flooding from overland flows in excess of the capacity of the formal drainage system. The purposes of the SBO are:

- *'To identify land in urban areas liable to inundation by overland flows from the urban drainage system as determined by, or in consultation with, the floodplain management authority.'*
- *'To ensure that development maintains the free passage and temporary storage of floodwaters, minimises flood damage, is compatible with the flood hazard and local drainage conditions and will not cause any significant rise in flood level or flow velocity.'*

As is the case with the preceding surface water overlays, a permit is required to carry out any works in an area covered by an SBO. This must be referred to the relevant floodplain management authority, in this case Melbourne Water, unless in the opinion of the responsible authority, 'the proposal satisfies requirements or conditions previously agreed in writing between the responsible authority and the floodplain management authority' (DELWP).

Matters to be taken into account in considering any application to carry out works are very similar to those required for land within an FO or LSIO.

Environment Effects Act 1978

The *Environment Effects Act 1978* establishes the framework for public works projects must undertake and submit an EES. The Minister for Planning has required that an EES be prepared and submitted to the Minister for Planning.

The Scoping Requirements issued for the project require specific consideration to be made in relation to hydrology.

The intent of the statement is to assess environmental effects resulting from the proposed works.

Victorian Coastal Strategy 2014

The Victorian Coastal Strategy notes that current Victorian planning benchmarks include planning for climate change-induced sea level rise of at least 0.8 m by 2100. It further notes that while this is an appropriate planning benchmark, sea levels are likely to continue to rise beyond 2100. Allowance for this predicted sea level rise should therefore be taken into account in the impact assessment.



A.2. Standards and guidelines

A.2.1. Australian Rainfall and Runoff

Australian Rainfall and Runoff (ARR) (Engineers Australia) is the 'national guideline for the estimation of design flood characteristics in Australia.' The guideline was first published in 1987 and is currently being revised. ARR provides broad guidance on appropriate techniques and methods for determining design flood flows and levels.

A.2.2. Austroads 'Guide to Road Tunnels' (2010)

While more relevant to design than project impacts, Austroads 2010 publication 'Guide to Road Tunnels' provides guidance on flood immunity standards for road tunnels. No equivalent guide applies to rail tunnels. The document notes that it is produced 'as a general guide, and its application is discretionary. Road authorities may vary their practice according to local circumstances and policies.'

The section of the Guide entitled 'Flood Immunity at the Tunnel Portal' supports a risk-based approach and notes as follows

'Tunnels are significant assets and if inundated by floodwater significant damage to systems may occur and put that segment of the road network out of service while repairs are undertaken. The associated closure time frame may be well in excess of that for the remainder of the road network following a flood event.'

The risk of flood inundation into the tunnel could also create a safety hazard due to the possibility of people being trapped in the tunnel as floodwaters rise outside. The potential flood inflow volume arising from major watercourses could be many times greater than the tunnel's volume, thereby increasing the risk of the tunnel being completely filled during an extreme flood event.'

The level of flood immunity will vary depending on the significance of the tunnel in the network, its location and the cost involved. The critical nature of tunnel operation is such that the risk of flooding from large external sources should be minimal. A risk assessment should be undertaken to identify the appropriate level of risk which will be acceptable to the community. A range of flood immunities for the tunnel portals should be investigated, up to and including the probable maximum flood event. The results of the risk assessment should then be used to determine appropriate flood immunity for the tunnel portals.'

Each tunnel should be assessed on a case by case basis using a risk management approach. The minimum level of flood protection provided by physical means at the tunnel portals should be 1 in 100 year average recurrence interval (ARI). An additional freeboard allowance should be provided for climate change (300 mm minimum).'



Appendix B. Technical details – flood levels and flows



B.1. Introduction and overview

B.1.1. Background

The Melbourne Metro alignment and associated infrastructure potentially interface with a number of waterways and drainage systems. There is potential for infrastructure and construction works to impact on flood and stormwater flows and levels along these systems. There is also potential for flood and stormwaters to impact on project works. This could include inundation of the tunnels and stations, potentially compromising the safety of commuters, rail staff and construction workers, and disrupting rail services. Relevant major waterways and drainage systems in the study area are:

- Maribyrnong River, which is approximately 500 m from the western portal
- Moonee Ponds Creek, which is approximately 100 m from Arden station
- Yarra River. This is approximately 120 m from CBD South Station, and could also potentially impact on the Melbourne Metro tunnels from the cross connection with the existing City Loop tunnels at CBD North station, and the eastern portal at South Yarra
- Major drainage systems along Swanston and Flinders streets in the vicinity of CBD South station
- Hannah Street Main Drain which is approximately 200 m west of Domain station
- Major drainage systems in the vicinity of the eastern portal. These include the Prahran Main Drain and Yarra Street Outfall Drain and their tributary drainage systems
- Graingers Road Main Drain which crosses under West Footscray station at the western turnback.

The project therefore needs to develop flood level estimates along these systems to inform the design. These would be used to:

- Assist in setting flood protection levels for stations and tunnel portals. These levels would need to include allowance for future (Year 2100) climate change, and would need to assess a range of events in the range from one per cent to 0.01 per cent AEP
- Inform assessments of the residual risks associated with adopted tunnel portal and station entrance levels. These levels would also need to include allowance for future climate change, and consider events in the range one per cent to 0.01 per cent AEP
- Establish one per cent AEP baseline flood levels against which project impacts need to be assessed. This would need to consider both existing and future (Year 2100) climate change scenarios.

B.1.2. Purpose of Appendix

This appendix provides:

- Background to the development of design flood flows and levels along these waterways and drainage systems
- Details of the rationale for flood protection of project stations and tunnel portals
- An overview of proposed flood protection and mitigation measures.

The appendix would enable review of the hydrologic and hydraulic methodology, and flood protection and mitigation rationale, by MMRA and third parties (eg Melbourne Water).

B.1.3. Structure of Report

Climate change and tailwater parameters are discussed in Section B.2. Methods used to determine design flows and flood levels along each of the waterways are discussed in sections B.3, B.4, B.5, B.6 and B.7, together with a summary of results. Proposed flood protection and mitigation measures are discussed in Section B.8.



B.2. Climate Change and Tailwater Parameters

B.2.1. Overview

The project needs to adopt climate change parameters as follows:

- Design rainfall intensities for the Year 2100 climate change scenario
- Design Year 2100 tailwater levels to be used in conjunction with peak flood flows, to determine design flood levels.

B.2.2. Design Rainfall Intensities

Melbourne Water has adopted a 32 per cent increase in design rainfall intensities to account for future climate change. This is documented in Section 2.6.3 of 'Melbourne Water Corporation, Flood Mapping Projects, Guidelines and Technical Specifications, March 2015 – Review in Progress'. The document does not provide any basis for this figure. MMRA is proposing to adopt the same 32 per cent increase in design rainfall intensities to account for future climate change. This degree of increase is broadly consistent with other estimates that the project is aware of.

B.2.3. Tailwater Levels

Melbourne Water has adopted the following tailwater levels to be used in conjunction with peak one per cent AEP flood flows:

- Existing conditions – 1.6 m AHD
- Future climate change (Year 2100) conditions – 2.4 m AHD.

These are documented in Appendix B of 'Melbourne Water Corporation, Flood Mapping Projects, Guidelines and Technical Specifications, March 2015 – Review in Progress'. The adopted value for existing conditions is based on Melbourne Water (2012), 'Planning for Sea Level Rise, assessing development in areas prone to tidal inundation from sea level rise in the Port Phillip and Westernport Region'. It comprises a highest observed tide level of 1.4 m AHD at St Kilda, plus a 200 mm 'allowance for wave action'. The future climate change value comprises the existing conditions value, plus an 800 mm allowance based on a predicted increase in mean sea level.

CSIRO (2009) has investigated extreme sea levels at a range of locations in Port Phillip Bay, for both existing conditions and Year 2100 climate change conditions. The nearest relevant location for which levels are reported in the CSIRO study is Williamstown. Relevant levels at Williamstown are as follows:

- One per cent AEP, existing conditions – 1.12 m AHD
- One per cent AEP, Year 2100 climate change – range from 1.94 to 2.52 m AHD. The range is based on climate change projections from four different studies. The two median values are very similar at 2.22 and 2.26 m AHD. The first of these is based on the Intergovernmental Panel on Climate Change (IPCC) 2007 study which incorporated both mean sea level rise and increase in wind speed. The mean sea level increase in this study is 820 mm, which is broadly consistent with the 800 mm recommended for adoption by 2100 in 'The Victorian Coastal Strategy'.

MMRA has adopted parameters based on the CSIRO study, for the one per cent AEP event as follows:

- Existing conditions – 1.12 m AHD
- Future climate change (Year 2100) conditions – 2.25 m AHD.

These are different to the values adopted by Melbourne Water. This is justified for the following reasons:

- None of the relevant sections of the Melbourne Metro study area are subject to purely tidal flooding, so no allowance for wave action is required
- The CSIRO study results imply that this study regarded the highest observed tide level at St Kilda as a statistical outlier



- The CSIRO study is based on hydrodynamic modelling, and thus provides an improved basis for the future climate change tailwater levels, relative to the simple addition of an 800 mm increase in mean sea level.

For events more extreme than one per cent AEP, MMRA has adopted the following tailwater levels for Year 2100 flood assessments, based broadly on the median values from the CSIRO study:

- 0.1 per cent AEP – 2.4 m AHD
- 0.01 per cent AEP – 2.5 m AHD.

Even with adoption of these tailwater levels, resultant flood levels would be conservative. This is because a one per cent AEP storm tide coincident with a one per cent AEP flood peak would generally represent an overall event AEP much rarer than one per cent.

B.3. Maribyrnong River

B.3.1. Overview

The Maribyrnong River is approximately 500 m west of the western portal. The components of the Concept Design which are relevant to the surface water impact assessment are:

- Twin track decline structure and retaining wall along Childers Street to carry the Melbourne Metro tracks from embankment level to below ground. The gradient of the decline structure is three per cent
- Twin track cut-and-cover tunnel from the decline structure to the driven (bored) tunnels entrances (ie tunnels precinct)
- The interface with the TBM driven tunnels occurs adjacent to the railway reserve on the eastern side of Tennyson Street in the 50 Lloyd Street Business Estate.

The Concept Design includes an emergency relief facility/TBM retrieval box located adjacent to the railway reserve on the eastern side of Tennyson Street in the 50 Lloyd Street Business Estate.

The area immediately to the west of the western portal precinct is subject to flooding from the Maribyrnong River, one of metropolitan Melbourne's most significant waterways. Its catchment area upstream of the three parallel railway bridges to the west of the western portal is approximately 1,400 km².

The three existing railway bridges form a significant constriction to flood flows. While there is a large bank of culverts through the embankment that forms the right (west) abutment for two of the bridges (the third – the Regional Rail Link bridge – is a series of bridge spans), the only opening in the left abutment is along Kensington Road. The rail embankment is relatively high and would only be overtopped by an extreme flood event. The floodplain upstream of the bridges is relatively wide and includes Flemington Racecourse on the east bank and parkland on the west bank.

Flood gradients along the Maribyrnong River are relatively flat. Consequently, any flood level increases due to works in the floodplain are likely to propagate upstream for a significant distance.

There have been a range of residential developments and associated compensatory mitigation works constructed along the floodplain upstream of the rail bridges in recent decades. These include, for example, the Edgewater Development. This development included land filling to enable residential development and excavation of the floodplain to provide compensatory flood conveyance and storage.

The Maribyrnong village, on the west bank of the river upstream of Maribyrnong Road, is particularly flood prone.

B.3.2. Previous Studies

There are a number of existing hydrologic and hydraulic models, and previous reports provided for the purposes of this study that included analysis of the Maribyrnong River. These were:



- Hydrological model (RORB) – Melbourne Water, 2014
 - Hydraulic model (HEC-RAS) – Melbourne Water, 2003
 - ‘Maribyrnong River Flood Mitigation Study Report’ – Melbourne and Metropolitan Board of Works (MMBW), 1986
 - The Melbourne Metro Stage 1 ‘Technical Discipline Report’ (Aurecon, Mott McDonald, SKM JV, 2010).
- The Melbourne Metro Stage 1 ‘Technical Discipline Report’ (Aurecon, Mott McDonald, SKM JV, 2010) documented relevant flood levels determined using a range of methods. Results are summarised in Table B-1.

Table B-1 Flood levels (m AHD) – Melbourne Metro Stage 1 ‘Technical Discipline Report’

| Location | 1 per cent AEP flood level – existing | 0.1 per cent AEP flood level –existing | 0.1 per cent AEP flood level – post climate change |
|---|---|--|--|
| Western portal – Maribyrnong River | 2.7 (assumed tailwater level – 1.6 m AHD) | 3.83 (assumed tailwater level 1.6 m AHD) | 4.2 (assumed tailwater level 2.8 m AHD) |

The ‘Melbourne Metro Project – Surface Water Assessment’ report (Aecom, 2013), presented the following flood flows and hydraulic grade line levels downstream of the railway bridge. It is not known how this information was developed. It is also unclear whether or not this included any allowance for future climate change.

Table B-2 Flood Flows and Levels downstream of Railway Bridge (Aecom, 2013)

| Profile | Flow (m ³ /s) | Energy Grade Elevation (m AHD) | Velocity (m/s) |
|--|--------------------------|--------------------------------|----------------|
| 1 Year (50% 10 Year)¹ | 140 | 0.56 | 0.59 |
| 2 Year (interpolated)¹ | 165 | 0.87 | 0.63 |
| 5 Year (interpolated)¹ | 209 | 1.12 | 0.74 |
| 10 Year (33% 100 Year) | 284 | 0.57 | 1.21 |
| 20 Year (50% 100 Year) | 431 | 1.67 | 1.31 |
| 50 Year (80% 100 Year) | 690 | 3.09 | 1.35 |
| 100 Year FL (MWC) (1% AEP) | 850 | 3.70 | 1.26 |
| 200 Year (Aurecon) | 955 | 4.07 | 1.24 |
| 1,000 Year (Aurecon) (0.1% AEP) | 1240 | 4.89 | 1.29 |

Table Notes: 1 Profile data was calculated by AECOM based on Melbourne Water data.

B.3.3. Hydrology

The RORB model (2003) provided by Melbourne Water was used as the basis for determining design flows.

The model provided included existing one per cent AEP rainfall depths. The model was run using these rainfall depths and produced a one per cent AEP peak flow of 908 m³/s at the downstream of the two Maribyrnong Road bridges.

A review of the model found that the design rainfall depth that had previously been adopted was slightly smaller than that which would be obtained by using current methods. This could be due to the fact that the previous model employed a uniform spatial pattern over the Maribyrnong catchment, whereas the updated model used a Generalised Southeast Australia Method (GSAM) spatial pattern. The updated rainfall depth led to a design discharge for the one per cent AEP event of approximately 1,000 m³/s.



In order to assess the risk to the western portal resulting from flooding by the Maribyrnong River, flood levels for more extreme events were required to be estimated. This was performed by firstly deriving design rainfalls for the Year 2100 (ie including allowance for climate change impacts) 0.1 per cent and 0.01 per cent AEP events using standard methods, and using the hydrologic model (RORB) to develop peak flow estimates.

Firstly, the design rainfall depths without climate change were multiplied by 1.32, to account for the increase of 32 per cent accepted as part of the current study. In accordance with current best practice and as stipulated in ARR (1999), the outputs of the CRC-FORGE project were used to estimate the design rainfall depths for the 0.1 per cent AEP event. The Probable Maximum Precipitation (PMP) was estimated using the GSAM (BoM, 2006). The 0.01 per cent AEP design rainfall depth was derived by interpolating between the 0.05 per cent (2,000 year ARI) and the PMP.

The structure of the hydrologic model supplied by Melbourne Water was considered appropriate for the one per cent AEP event, however for less frequent events a minor modification was applied to account for the different flood behaviour of these larger events. This comprised addition of a conceptual storage to account for the significant floodplain storage between the Maribyrnong Road crossing and the rail crossing. This includes areas in and around Flemington Racecourse.

The hydraulic model (see below) was used to derive an elevation-discharge relationship for this conceptual storage. An elevation-storage relationship was developed using available topographic information. The design rainfall depths were then used as inputs to this modified hydrologic model, to provide peak flows for use as inputs to the hydraulic model. Modelled peak flows compared favourably with those derived from a frequency analysis of the gauged flow records at the Keilor gauge (refer to Figure B-1).

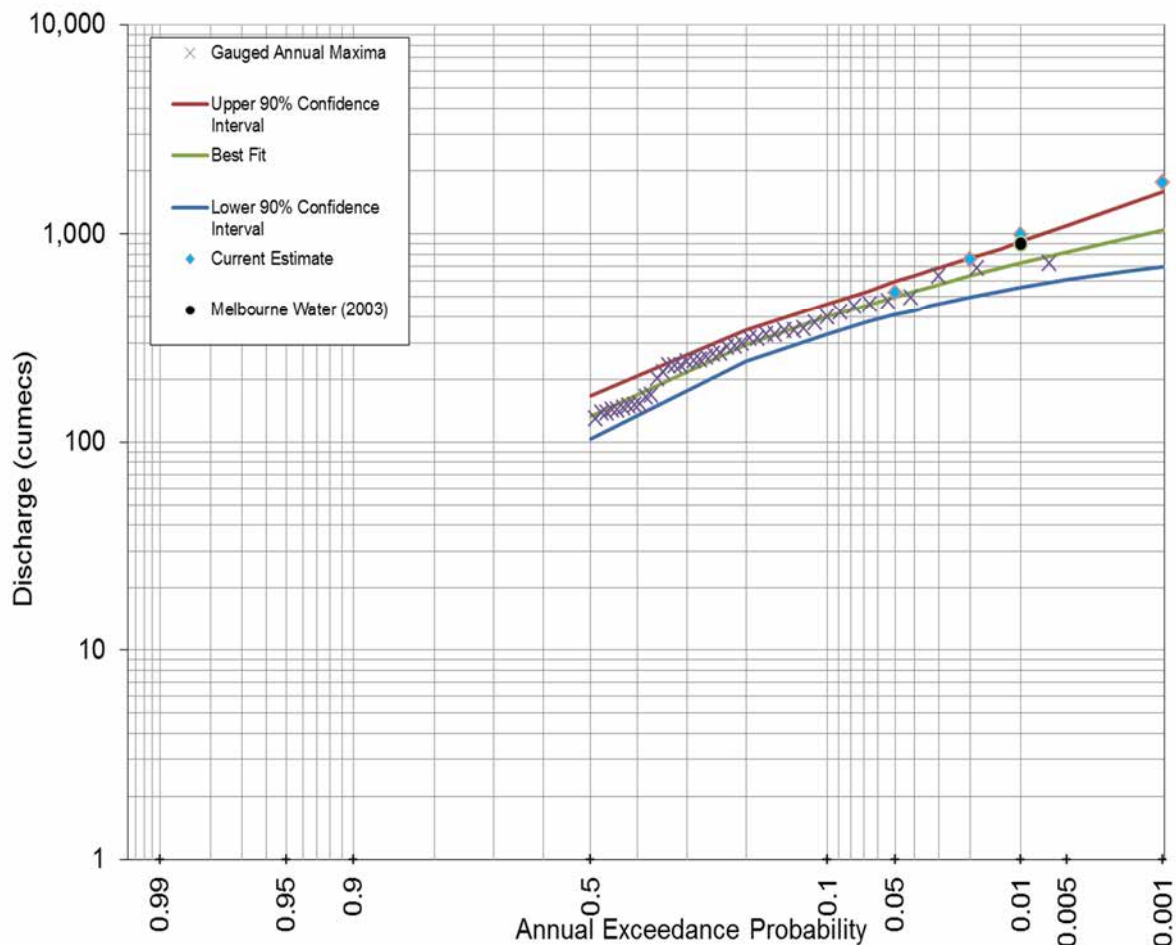


Figure B-1 Frequency analysis of Keilor gauge with estimates of design flows



B.3.4. Flood Levels

The HEC-RAS model provided by Melbourne Water was used as the basis for determining the one per cent AEP flood level on the Maribyrnong River adjacent to the western portal. Whilst much of the data and assumptions included in the model were assumed to be correct, some elements of the model were specifically reviewed. These included, in particular, the extent of the model downstream of Footscray Road and the extents of some of the cross sections.

The tailwater levels used in the model were as discussed in Section B.2.3 above. A sensitivity analysis was also undertaken which showed that the flood level upstream of the railway bridge is relatively insensitive to the adopted downstream boundary level. For downstream boundary levels of 0.91, 1.22 and 1.60 m AHD, the respective one per cent AEP flood levels (using Melbourne Water's 850 m³/s (unknown basis) as a steady-state flow) at the rail crossing were 2.55, 2.65 and 2.80 m AHD respectively.

The existing Melbourne Water hydraulic model terminates at the rail bridge upstream of Footscray Road. Given the downstream boundary was based on tide levels in Port Phillip Bay, it was considered prudent to extend the model further downstream to the confluence with the Yarra River. Extending the model would ensure that additional hydraulic losses from the Footscray Road bridge and the river channel and floodplain downstream of this bridge would be accounted for. Given no bathymetric survey data was available for this section of the river, the model was extended using LiDAR data for the overbank areas, and river channel sections based on the most downstream existing model cross section. Given this section of the river is relatively short compared with the overall length of the model, the lack of accurate survey data in the channel is unlikely to significantly impact the results. As no feature survey information was available for the Footscray Road bridge, it was input to the model based on LiDAR survey, aerial imagery, Google Street View imagery and site photos.

It was also considered appropriate to truncate some of the cross sections within the model to better represent the probable path of flood waters through the model, particularly in the areas immediately upstream and immediately downstream of the Sunbury line and adjacent rail bridges. Furthermore, the representation of the existing Sunbury line and adjacent rail bridge had not included the opening where the line passes over Kensington Road. Therefore, this opening was also included in the model.

The model was run for the one per cent AEP existing and Year 2100 scenarios. The model was also run iteratively to determine the flow at which the rail embankment would just be overtopped. The AEP of this event was determined by interpolation between Year 2100 one per cent and 0.1 per cent AEP flow estimates. Results are presented in Table B-3.

Table B-3 Adopted Flood Levels and Flows

| Flood event AEP (%) | Conditions | Peak flood level (m AHD) | Peak flood flow (m ³ /s) |
|--|---|-----------------------------|-------------------------------------|
| 1 | Existing | 3.1 | 1,000 |
| 1 | Year 2100 (ie including allowance for climate change) | 4.7 | 1,650 |
| 0.9 (event that just reaches the top of the embankment) | Year 2100 | 5.3 | 1,700 |
| 0.1 | Year 2100 | Not determined ¹ | 2,600 |
| 0.01 | Year 2100 | Not determined ¹ | 4,100 |

Note 1 – The structure of the HEC-RAS model is not appropriate to allow determination of flood levels for events that overtop the rail embankment.



B.4. Moonee Ponds Creek

Arden station would be located in the floodplain of Moonee Ponds Creek.

MMRA provided hydrologic and hydraulic models used for previous studies of Moonee Ponds Creek and these were used as the basis for determining flood levels along the Creek. A hydrologic model of Moonee Ponds Creek upstream of Mount Alexander Road was obtained from Melbourne Water and also used.

The report on the hydrologic and hydraulic modelling of Moonee Ponds Creek undertaken for the project is reproduced in full as Section B.9. Key results are summarised in Table B-4.

Table B-4 Adopted discharges and related flood levels in Moonee Ponds Creek

| Scenario | Flow at Mount Alexander Road* (m ³ /s) | Flood Level** (m AHD) |
|---|---|-----------------------|
| 1% AEP – existing | 220 | 3.1 |
| 1% AEP – Year 2100 (ie including allowance for climate change impacts) | 310 | 3.4 |
| 0.1% AEP – Year 2100 | 460 | 4.3 |
| 0.01% AEP – Year 2100 | 730 | 5.1 |

* Flow under existing catchment development conditions at Mount Alexander Road. This location has been selected as flows are essentially confined to the creek channel at this point. Downstream of here, flows spread out onto the floodplain on either side of the creek and peak flow locations are thus more difficult to specify

** Peak flood levels in Moonee Ponds Creek adjacent to Queensberry Street

B.5. Yarra River

B.5.1. Overview

The Yarra River is approximately 120 m from CBD South station. It could also potentially impact on the Melbourne Metro tunnels from the cross connection with the existing City Loop tunnels at CBD North station, and the eastern portal at South Yarra.

The project requires determination of design flows and levels along the lower Yarra River for the following events:

- One per cent AEP – existing conditions
- One per cent, 0.1 per cent and 0.01 per cent AEP – Year 2100 (ie including allowance for climate change impacts).

B.5.2. Previous Studies and Data Analysis

Despite its prominence and importance to Melbourne, the flooding characteristics of the Yarra River have not been as extensively studied as those of many of the other smaller waterways in and around the metropolitan area. Consequently, its flood behaviour is not particularly well understood and current models have not been able to adequately represent historical flood events using physically realistic parameters. The models and reports that include analysis of the Yarra River provided for the purposes of this study are:

- Hydrological model (RORB) – Melbourne Water, 2010
- Hydraulic model (HEC-RAS) – Melbourne Water, 2010
- 'Yarra River Flood Mapping Hydrologic and Hydraulic Study Report' – S P Goh and Associates (on behalf of Melbourne Water), 2010. This was prepared as part of Melbourne Water's overall flood mapping project from the Spencer Street Bridge to the Upper Yarra Reservoir



- 'Melbourne Metro Stage One, Tunnel and Underground Station Drainage' – Aurecon, Mott MacDonald, SKM and Grimshaw JV (2010)
- 'Flood of November 1971, Yarra River Basin', Melbourne and Metropolitan Board of Works, 1971
- The Flood Victoria Website – <http://www.floodvictoria.vic.gov.au>
- A range of flow data and recorded flood levels along the Yarra River, provided by Melbourne Water
- Flow data along the Yarra River from on-line sources.

Goh Study, 2010

The Goh 2010 investigation developed and calibrated a RORB model of the catchment and then used flows derived from the RORB model to estimate flood levels using a HEC-RAS model.

The RORB modelling initially focussed on calibration to gauged flows from the 1934 and 1971 flood events. While reasonable flow estimates were available for a number of stream gauges in the catchment for the 1971 event, very little gauged flow information was available for the 1934 event. While a gauged flow hydrograph was said to be available for the 1934 event at Johnston Street, few details are available regarding how this was derived and its accuracy is unknown. Reasonable calibrations to gauged flows were initially achieved for both events. However, when modelled flows were then input to the HEC-RAS model, difficulties were found in reproducing recorded flood levels using what were regarded by the study as reasonable upper bound estimates of Manning's hydraulic roughness coefficient. The study then concluded that the gauged flow estimates in both events were likely to be too low, due to gauging errors. What were regarded by the study as reasonable Manning's *n* parameters were then selected based on aerial photography, and the RORB model was then recalibrated, such that the resultant flows and selected Manning's roughness parameters provided a reasonable match to recorded flood levels. The resultant modelled flows at the gauges were then, however, significantly higher than the gauged flows.

The finally adopted RORB model parameters were as follows:

$K_c = 145$; $m = 0.8$; Initial loss (upstream of Yarra Glen) = 30 mm; Initial loss (downstream of Yarra Glen) = 15 mm; Runoff coefficient = 0.6

Design rainfalls were then determined for a range of events up to the one per cent AEP event. These were then input to the RORB model and used to determine design flows. These design flows were then input to the HEC-RAS model and used to determine design levels. It should be noted that it appears that no Areal Reduction Factors (ARFs) were applied to the design rainfall estimates.

MMBW 1971

The Melbourne and Metropolitan Board of Works (1971) report, 'Flood of November 1971, Yarra River Basin', notes as follows: 'Comparison of the peak discharge at Warrandyte, for example, with the peaks of previous floods enabled the expected return period of 15 years to be calculated for this station'. No details of the peaks of the previous floods were provided, nor of the analysis used to arrive at this conclusion.

Flood Victoria 2010

The 'Flood Victoria' website (<http://www.floodvictoria.vic.gov.au>) lists 'known major floods in Victoria, with an average recurrence interval (ARI) of 20 years or greater. This information is compiled and maintained by the Department of Sustainability and Environment' (now DELWP), and was last updated in 2010. The site lists eight riverine floods on the Yarra at 'Melbourne'. The website is not specific about the exact location of 'Melbourne', and it is unclear whether or not Warrandyte is deemed to be included. The earliest event listed was in 1863 and the latest in 1959. The 1971 flood is not listed, which implies that the authors of the site believed that the 1971 flood was less than a 20 year ARI event. The site attaches ARIs to each of the eight events. The largest was said to be the 1863 event (>100 year ARI) and the 1934 event was said to be a 100 year ARI event. The site does not provide any explanation of methods used to assign ARIs to these events, or the exact location that the ARIs apply to ('Melbourne', Warrandyte or other). The AJM JV surface water team contacted the DELWP Floodplain Management Group to obtain further details. However, DELWP advised that it was unsure of the source of the information or of how the ARIs had been derived.



Gauge Analyses

Flood frequency analyses were undertaken for two sites along the Yarra for which reasonable periods of flow records were available, as follows:

- Warrandyte. The data used was as follows:
 - 1970 to 2015 – instantaneous peak flows at the Warrandyte gauge
 - 1900 to 1933, and 1959 to 1969 – mean daily flows at the Warrandyte gauge, factored up by the ratio of peak instantaneous flow to peak mean daily flow for each year from 1970 to 2015. This was found to be a very consistent ratio, and appears most unlikely to be a source of any significant error.
 - 1946 to 1958 – peak mean daily flows at the Yering gauge, factored up to peak instantaneous flows at Warrandyte. There was found to be a very consistent relationship between flows at these two gauges. This record includes the significant 1952 flood.
 - 1934 flood. This was included using two different methods:
 - The modelled estimate in the Goh report
 - The modelled estimate in the Goh report, reduced by 30 per cent. The 30 per cent was selected as the order of difference between gauged and modelled flows at gauge locations in the Goh report.
- Yering. This comprised a mean daily flow record from 1946 to 1964. Mean daily flows were factored up to peak instantaneous flows using the same relationship as was derived for Warrandyte. The record included two major floods – 1952 (the Flood Victoria website reported this as an 80 year flood) and 1959 (20 year flood). Results are presented as Figures B-2, B-3 and B-4.

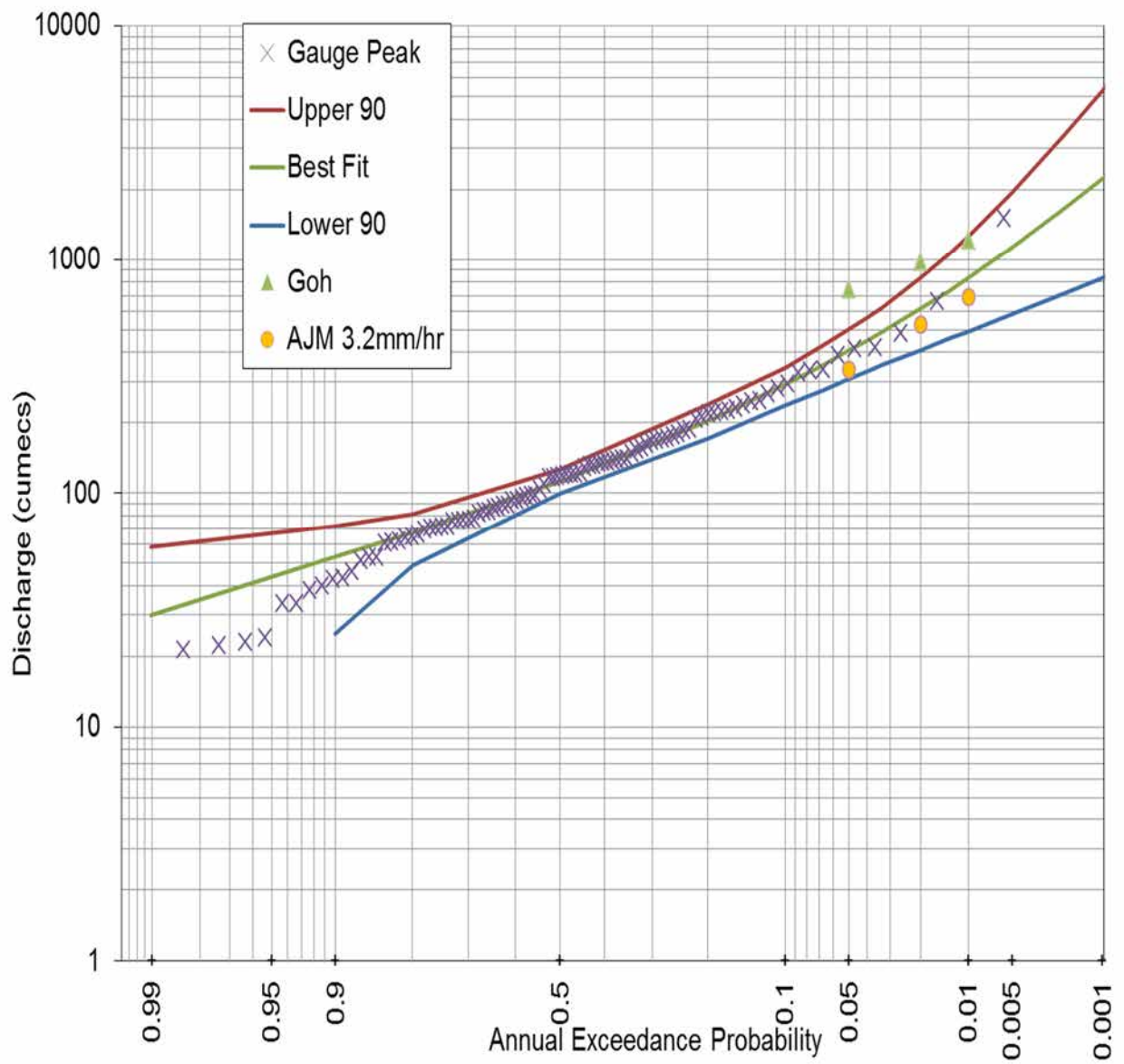


Figure B-2 Flood Frequency Analysis – Warrandyte – 1934 flood as reported in Goh report

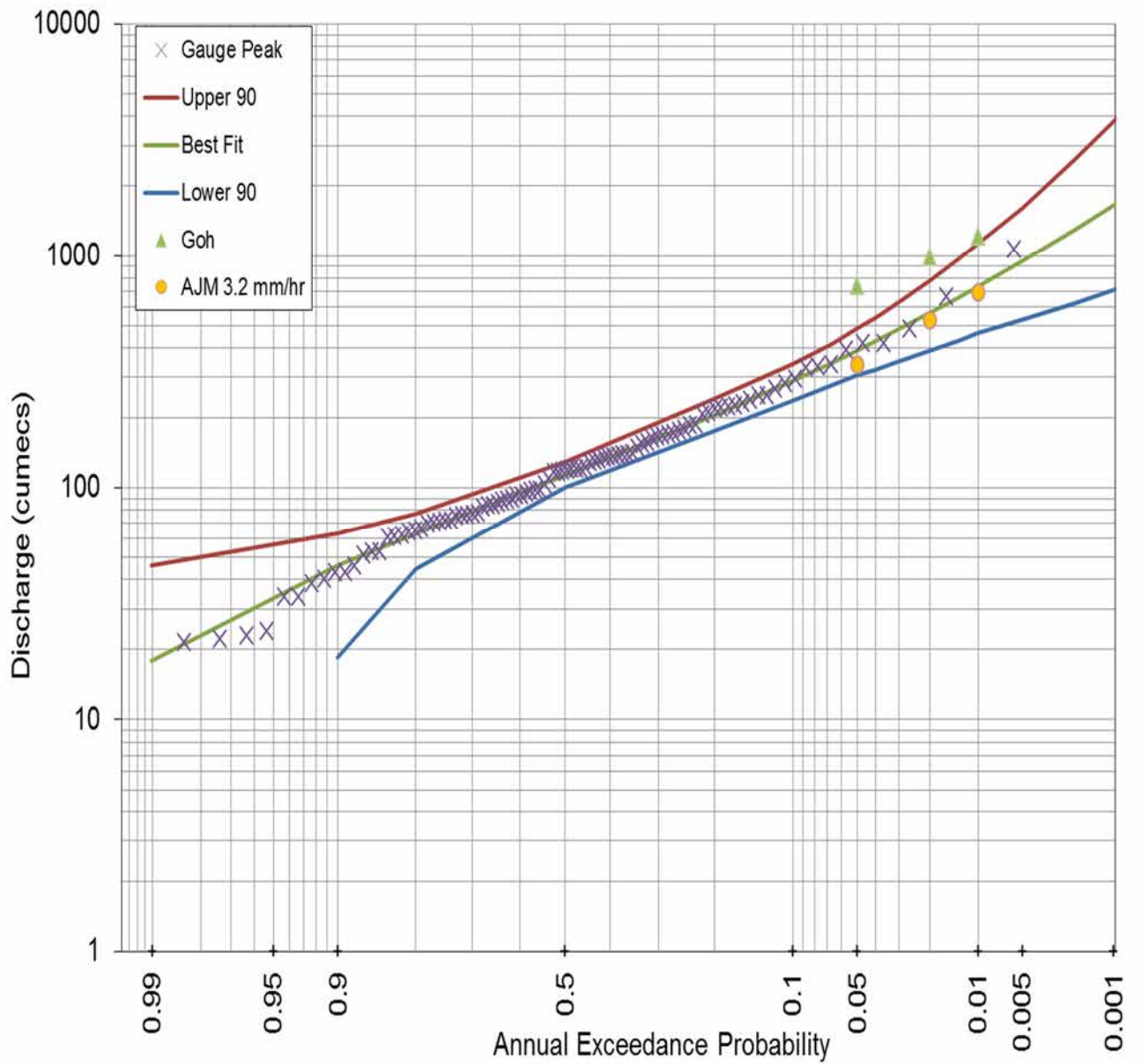


Figure B-3 Flood Frequency Analysis – Warrandyte – 1934 flood 30% less than reported figure in Goh report

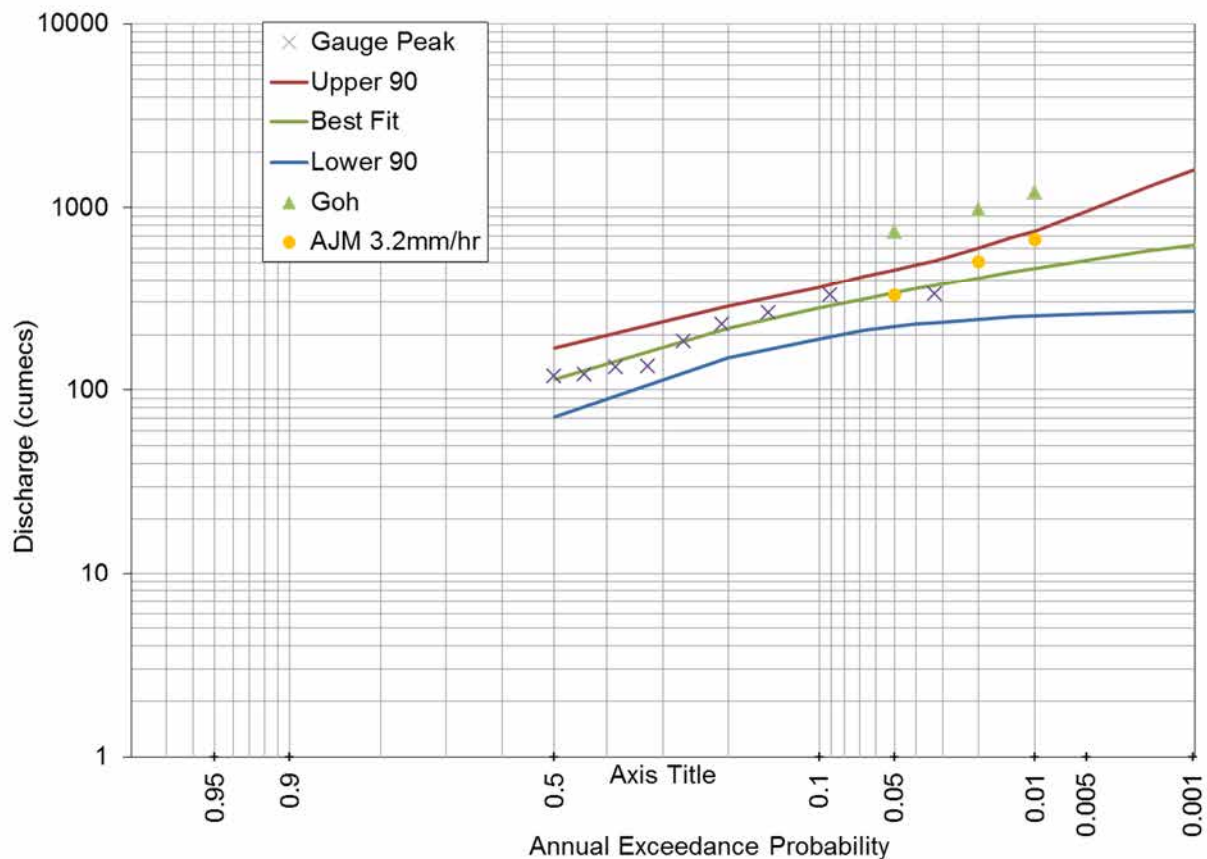


Figure B-4 Flood Frequency Analysis – Yering

The major conclusions from these analyses were as follows:

- Warrandyte:
 - The analyses indicate five per cent, two per cent and one per cent AEP flows that are typically of the order of 80 per cent lower than the flows adopted in the Goh study
 - The results were insensitive to the two methods used to include the 1934 flood
 - The 1934 event shows up as a significant outlier. The frequency analysis suggests that this was of the order of a 500 year event.
- Yering: Two such large floods in this 18-year record (1952 and 1959) would suggest that this was typically a wetter-than-average period. Despite this, the frequency analysis suggests design flow peaks very significantly lower (around 100 per cent lower – ie half) than those adopted by the Goh study.

Summary

There are clearly some significant discrepancies between a number of these sources of information.

- Discrepancies between reports and gauge frequency analyses
- Discrepancies between reported and gauged 1934 and 1971 peak flows. Both the 1934 and 1971 peak flows that the Goh study adopted to match levels at the gauges are significantly higher than the actual gauged flows.

As described above, the previous modelling presented in the Goh report derived rainfall information for the 1934 and 1971 events from isohyetal maps. Rainfall depths were applied to the centroid of each of the 551 RORB centroids over the entire catchment. This represents an acceptable method to applying a spatial pattern to event rainfalls in the RORB model. However, the previous modelling does not appear to have applied ARFs to the design rainfalls. Not applying ARFs to the design rainfall depths implies that the frequency of event rainfall depths (for example one per cent AEP) is occurring everywhere in the catchment



concurrently, which is clearly unrealistic. ARR therefore prescribes application of ARFs to design rainfall estimates before adopting a final design rainfall estimate for use in a hydrologic model.

The Yarra catchment is approximately 4,000 square kilometres in area and the ARF that should be applied (refer ARR) to the design rainfall for the critical duration one per cent AEP event for a catchment of this size is approximately 0.85. Table B-5 describes the ARFs adopted for the current study. The 0.01 per cent AEP (10,000 year ARI) event design rainfall depth is calculated by interpolating between the 0.1 per cent AEP depth and the Probable Maximum Precipitation (PMP) estimate.

Table B-5 Rainfall Areal Reduction Factors

| Event | Goh Study | Current Study |
|--------------------|-----------|---------------|
| 1% AEP (72-hour) | 1.00 | 0.85 |
| 0.1% AEP (48-hour) | 1.00 | 0.80 |

A comparison of the final adopted design rainfall depths for the Yarra catchment from the previous modelling and the current modelling is shown in Table B-6.

Table B-6 Design Rainfalls

| Event | Goh Study (mm) | Current Study (mm) |
|------------------|----------------|--------------------|
| 1% AEP (72-hour) | 234.5 | 187.9 |

As can be seen from Table B-6, the previously adopted design rainfall depth is significantly higher (by approximately 25 per cent) than the currently adopted design rainfall depth. A significant portion of this difference can be explained by not applying an ARF to this design rainfall. For comparison, if the currently adopted design rainfall had been applied without applying the ARF in Table B-5, it would have resulted in a design rainfall of 221 mm, bringing it much closer to the previously adopted value. The remaining difference in design rainfall depth could most likely be described by the deriving depths based on isohyetal contours as compared to using gridded data obtained from the BoM, as in the current study. A 25 per cent reduction in design rainfall is likely to result in a much greater than 25 per cent reduction in design flow.

By far, the major reason for the very large discrepancies between the design flow estimates in the Goh report and those indicated by the frequency analysis appears to be the lack of application of appropriate ARFs to design rainfalls in the Goh study.

B.5.3. Design Flows

Overview

The RORB model provided by Melbourne Water was adopted for use in determining design flows. The Kc and m values used by Melbourne Water were also retained. Different loss rates and design rainfalls were used.

Design Rainfall Estimates

Design rainfall estimates for events from five per cent AEP (20 year ARI) to the PMP were calculated. For frequencies up to the one per cent AEP, the design rainfalls were obtained from the BoM 2013 IFD information available online. For frequencies between the one per cent and the 0.05 per cent (2,000 year ARI) AEP events, CRC-FORGE was used. Given the size of the area of the Yarra catchment, the Generalised Southeast Australia Method (GSAM) (BoM, 2006) was employed to calculate the PMP design rainfall estimates. For AEPs between the 0.05 per cent and the PMP (found to be approximately 700,000 year ARI), design rainfall depths were found by log-log interpolation, as recommended in Book VI of Australian Rainfall and Runoff (ARR), 1999.



ARFs were applied to the design rainfall estimates according to the 'Victoria' section of the CRC-FORGE project in accordance with ARR, 1999. Upon applying the ARFs, final design rainfall estimates were adopted for use in the RORB model.

Loss Rates

As described above, the original RORB model was run using an initial loss, runoff-coefficient loss regime. This is considered appropriate for events up to approximately the one per cent AEP, which was the focus of the Goh report. However, for more extreme flood events, such as the 0.1 per cent and 0.01 per cent events, a runoff coefficient loss regime is not considered appropriate given the likely level of saturation a catchment would experience during such an event.

Therefore, prior to applying the final design rainfall depths to the RORB model, it was considered appropriate to prepare a representative initial loss, continuing loss combination for use in calculating discharges for these less frequent design events.

A simple calibration was performed on the critical duration hydrograph for the one per cent AEP event resulting from the previous modelling to arrive at a reasonable initial loss and continuing loss rate. In this case, the initial loss was not altered from the Goh study and the appropriate continuing loss value was found to be 3.2 mm/hr both upstream and downstream of Yarra Glen. The calibrated hydrograph used in this process is shown in Figure B-5. The RORB hydrograph selected was the most downstream output, the outfall of the Yarra into Port Phillip Bay. As can be seen, the resulting continuing loss regime presents a good fit to the previously adopted loss regime.

The final design rainfall depths were varied spatially, according to the GSAM spatial pattern, and entered as inputs into the RORB model using the continuing loss regime described above. The same K_c and m values were used as in the Goh report.

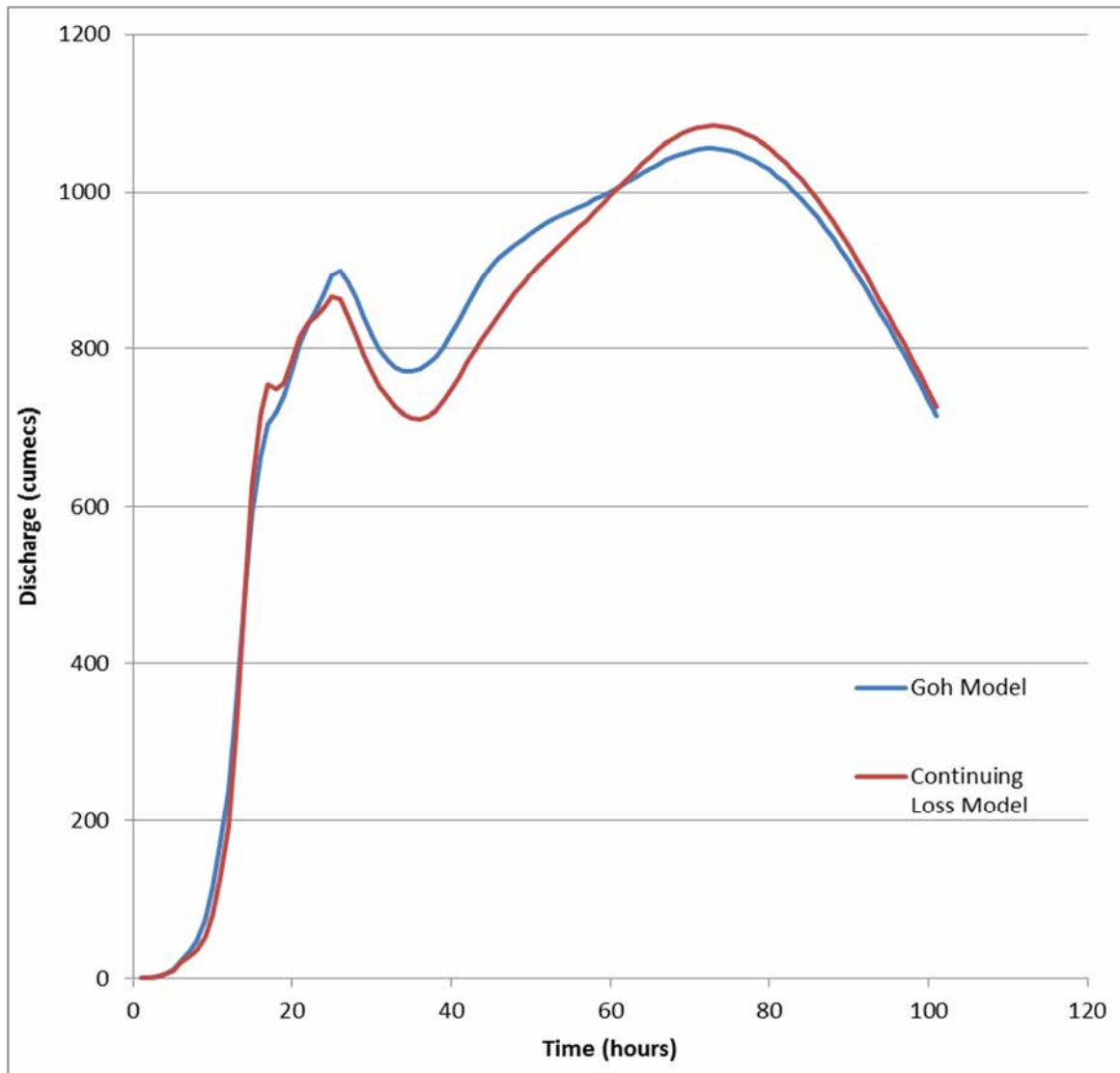


Figure B-5 Derivation of continuing loss RORB model for use in extreme events

As can be seen from Figure B-2, the design flood peaks based on an initial loss rate of 3.2 mm/h were very similar to those indicated by the gauge frequency analysis. It was therefore decided to retain a continuing loss rate of 3.2 mm/hr. The resultant design discharges are also shown on Figure B-4 and Figure B-5. The design peak flows resulting from this new continuing loss parameter all lie within the 90 per cent confidence interval of the frequency analysis for the gauge.

Results

The resultant RORB model was used to determine design flows in the lower reach of the Yarra, between South Yarra and Princes Bridge. Results are presented as Table B-7.

Table B-7 Estimated Lower Yarra River Design Flows

| Event | Design Flow (m ³ /s) |
|--|---------------------------------|
| 1% AEP – existing | 850 |
| 1% AEP – Year 2100 (ie including allowance for climate change impacts) | 1,300 |
| 0.1% AEP – Year 2100 | 2,000 |
| 0.01% AEP – Year 2100 | 3,500 |



B.5.4. Design Flood Levels

The HEC-RAS model provided by Melbourne Water did not include any overbank areas of the lower Yarra and was therefore not deemed appropriate for determination of flood levels for the required events. A coarse TUFLOW model of the lower Yarra was therefore developed specifically for the purposes of the project. Hydraulic roughnesses were estimated from aerial photography. Resultant flood levels are presented in Table B-8.

Table B-8 Estimated Lower Yarra Design Flood Levels (m AHD)

| Event | Immediately upstream of Princes Bridge | Immediately upstream of South Yarra Rail bridge |
|--|--|---|
| 1% AEP – existing | 2.3 | 3.5 |
| 1% AEP – Year 2100 (ie including allowance for climate change impacts) | 3.8 | 5.2 |
| 0.1% AEP – Year 2100 | 5.4 | 7.3 |
| 0.01% AEP – Year 2100 | 7.2 | 10.1 |

The model shows that flows would breakout from the Yarra to the south downstream of Princes Bridge, towards Domain station. Indicative flood extents near Domain station in Year 2100 one per cent, 0.1 per cent and 0.01 per cent AEP events are shown on Figure B-6.



Figure B-6 Indicative extents of Year 2100 1%, 0.1% and 0.01% AEP flood events near Domain station



B.6. CBD South Station

B.6.1. Overview

The CBD South Station and associated entrances would lie beneath Swanston Street between Collins and Flinders Streets. There are two large surface water drains that run north to south along Swanston Street and there is an associated overland flow path.

Design flows and levels along Swanston Street were determined for the following events:

- one per cent AEP – existing conditions
- one per cent and 0.5 per cent AEP – Year 2100.

Melbourne Water, in association with the City of Melbourne, has developed a TUFLOW model of the CBD area to assess existing flows up to the one per cent AEP. This was made available to MMRA to assist in assessing the likely flood impacts of CBD South station.

An early iteration of the CBD South station Concept Design was proposed as a cut-and-cover construction, which would have required significant amendment to the existing drainage regime and assessment of this impact was the primary aim of the subsequent modelling. This has changed, such that the station construction now has a minimal impact at the surface and the main issue is now confirming likely flood levels at the junction of Swanston Street and Flinders Street. This is to inform setting of the station entrance levels, particularly at the south western entrance next to the Nicholas Building just to the south of Flinders Lane.

B.6.2. Analysis

The TUFLOW model was updated to include more accurate pipe data in Swanston Street and to assess the 0.5 per cent AEP flood flows. Figure B-7 below shows the predicted flood levels between Flinders Lane and Swanston Street.

The station entrance is from a new laneway south of the Nicholas Building. The predicted 0.5 per cent AEP flood level at the laneway entrance point is 8.0 metres AHD.



Figure B-7 Predicted Flood Levels - Lower Swanston Street



B.7. Eastern Portal

B.7.1. Overview

The decline structure at the eastern portal lies close to a low point on the existing rail track as it crosses under Chapel Street. As well as track drainage, the piped drainage from Chapel Street, south of the railway, connects to the track and then travels east towards Surrey Street. One of the key issues for the eastern portal is, therefore, consideration of the potential for runoff from the surrounding areas entering the tunnel from this low point. This would involve overland flow from the drainage system in Chapel Street flowing onto the track and then overflowing into the decline structure area. In addition, the risk of local flooding from the track drainage at the low point under Chapel Street also needs to be considered.

Determination of design flows and levels at the eastern portal from the stormwater drainage system were determined for the following events:

- one per cent AEP - existing conditions
- one per cent and 0.5 per cent AEP – Year 2100.

B.7.2. Analysis

Two studies have been undertaken:

- A two dimensional (2D) detailed hydraulic model using SOBEK of the Chapel Street drainage area to assess overland flow risks
- An analysis of the local rail track drainage to assess flood volumes from the piped system.

Figure B-8 shows the output from the SOBEK model for the 0.5 per cent AEP flood event. This demonstrates that the eastern portal is not at risk from overland flooding in the general area, in this event.



Figure B.8 Predicted 0.5 per cent AEP Flood Depths and Extents near eastern portal

The local drainage pipe network runs north along Chapel Street, descending to the low point on the rail track under Chapel Street and then runs east towards Surrey Road. As piped drainage systems are typically designed for a 20 per cent AEP flood event, this means that the tracks should flood for larger events. The 2D modelling summarised above demonstrates that flows from Chapel Street are limited to the capacity of the pipe, which means that flows that could cause flooding can only come from the tracks and a small area adjacent to them. An analysis of this area shows that the predicted flood volume for the manholes in the track under Chapel Street for a Year 2100 0.5 per cent AEP flood is around 1,000 m³. The available storage volume between the low point and the initial level of the decline structure is 6,000 m³ showing that the risk is minimal.

B.8. Design and Risk Implications and Mitigation Measures

B.8.1. Tunnels

As discussed previously, the Melbourne Metro tunnels are potentially subject to flooding from the existing City Loop tunnels through the underground interconnection at CBD North station. The flood level at which the lowest City Loop tunnel portal near Federation Square would commence to flood is approximately 3.3 m AHD. This corresponds to an event more frequent than a Year 2100 one per cent AEP Yarra River flood. This would result in inundation of the Melbourne Metro tunnels in a relatively short time frame following initial inundation of the portals.

This could be mitigated by flood gates to prevent flooding of the City Loop tunnel portals. These would comprise installing watertight gates at the ends of the cut-and-cover sections of the portals, to prevent any floodwaters entering the tunnels in a flood event, when the gates were closed. The gates would need to be permanently in place at the tunnel portals and would need to be periodically tested to ensure they were



operating satisfactorily. They would be closed in advance of a potential flood event, based on flood warning advice from relevant authorities.

B.8.2. Western Portal

Potential flooding of the western portal during construction has the potential to cause significant inundation of the tunnels in a relatively short time frame (hours). This could pose a significant risk to construction workers. The area on the north side of the rail embankment is currently subject to flooding in an event more frequent than a one per cent AEP flood event. Measures need to be put in place to ensure the portal is protected from flooding in at least the one per cent AEP flood event during construction. The potential impacts associated with larger flood events should also be recognised. Floodwaters would generally be expected to rise relatively slowly in this floodplain area, consequently many hours warning would generally be available to enable evacuation and other necessary emergency measures to be put in place in advance of a flood peak. Required measures would include a flood warning system and emergency evacuation procedures.

Potential flooding of the tunnels from the portal during operation also has the potential to cause significant inundation of the tunnels in a relatively short time frame. This could pose a significant risk to commuters and rail staff, and significant disruption to rail services. Even relatively shallow inundation of the portal could cause major flooding of the tunnels in a relatively short time frame (tens of minutes to hours).

The proposed works include a retaining wall along Childers Street, on the upstream side of the new embankment and decline structure. The crest level of this retaining wall is proposed to be 5.3 m AHD. It would be difficult to increase this level any further without very adverse aesthetic impacts. The Year 2100 one per cent AEP flood level is 4.7 m AHD, so in the absence of any additional mitigation works, the permanent portal would be protected against flooding from the Maribyrnong River in an estimated one per cent AEP (100 year ARI) event, under Year 2100 conditions, with a 600 mm freeboard allowance. It is proposed that automatic flood gates be installed to protect the portal against flooding from more extreme events. These gates would extend to the full height and width of the portal and thus provide protection against even the most extreme flood event.

Major Maribyrnong River flood flow paths in this area are through the main channel rail bridges and along Kensington Road. None of the construction or infrastructure works would be located such that they would obstruct flows through any of these major flood flow paths. Construction of the western portal would, however, result in some loss of floodplain storage. In the absence of mitigation, this would result in minor increases in downstream flood flows, and upstream and downstream flood levels. This would need to be mitigated by provision of some compensatory flood storage. The volume of compensatory flood storage required is approximately 9,000 m³, based on loss of flood storage below the Year 2100 one per cent AEP flood level of 4.7 m AHD. A number of options have been considered, however the proposed location of the storage is still to be confirmed.

Apart from the river flood risk, the tunnels also need to be protected from general stormwater flooding risks. The decline structure would be designed to have a cut-off drain at the entrance to the tunnel, designed to intercept drainage up to the 0.5 per cent AEP rainfall event. The collected flows would then be pumped back to the existing drainage system, with balancing storage. The City of Melbourne has indicated that flows should be limited to 16 L/s and this means that a balancing storage of 180 m³ would be required. As is the case with the compensatory flood storage, a number of options have been considered, however the proposed location of the storage is still to be confirmed. One potential alternative would be to provide storage above the cut-and-cover tunnel section immediately to the east of the decline structure.

B.8.3. Arden Station

Potential flooding of the Arden station box during construction has the potential to cause significant inundation of the box and adjacent sections of tunnels in a relatively short time frame (tens of minutes to hours). This could pose a significant risk to construction workers. Much of the area in the vicinity of the station box is subject to flooding in a one per cent AEP flood event. Measures need to be put in place to



ensure the station box is protected from flooding in at least the one per cent AEP flood event during construction. The potential impacts associated with larger flood events should also be recognised. Floodwaters would be expected to rise relatively quickly in this floodplain area and little warning would generally be available to enable evacuation and other necessary emergency measures to be put in place in advance of a flood peak.

Potential flooding of the station and tunnels from the station entrances during operation also has the potential to cause significant inundation of the project's underground assets in a relatively short time frame. This could pose a significant risk to commuters and rail staff, and significant disruption to rail services. Even relatively shallow inundation of the station entrances has the potential to cause major flooding of the station and tunnels in a relatively short time frame (tens of minutes to hours).

The Arden station entrance and emergency access point are both to be raised 2.2 m above the adjacent Laurens Street footpath level to provide flood protection. This equates to a level of 4.7 m AHD, and is thus above the Year 2100 0.1 per cent AEP flood level of 4.4 m AHD, and 1,300 mm above the Year 2100 one per cent AEP flood level of 3.4 m AHD. As noted above, flood warning times available to enable emergency management measures to be put in place in advance of a flood would be expected to be relatively short. In addition to suspension of rail services, emergency management measures could include, for example, emergency sandbagging or automated flood gates on the station entrances.

Major Moonee Ponds Creek and overland flow paths in this area are generally along the main creek channel and along Arden Street and other roads to the north of the station site. None of the construction or permanent infrastructure works would be located such that they would obstruct flows through any of these major flood flow paths. Construction of the station (station box and precast concrete segment facility) would, however, result in some loss of floodplain storage. In the absence of mitigation, this would result in minor increases in downstream flood flows, and upstream and downstream flood levels. This would need to be mitigated by provision of compensatory flood storage. The volume of flood storage required is approximately 6,000 m³ (based on existing one per cent AEP flood levels).

The permanent station works are predominantly underground and would thus have no impact on surface flows. The only exceptions to this are the station entrance, emergency egress point, chillers and vent shaft. The areas occupied by these are, however, very small and would result in a required flood storage of approximately 1,600 m³ (based on Year 2100 one per cent AEP flood level).

The substation would also not obstruct flows along any major flood flow paths. Construction of the substation would, however, result in some very minor loss of floodplain storage. In the absence of mitigation, this would result in minor increases in downstream flood flows and upstream and downstream flood levels. This would need to be mitigated by provision of compensatory flood storage. The volume of flood storage required is very small – less than 200 m³ (based on Year 2100 one per cent AEP flood level).

B.8.4. CBD Stations

As discussed above, the Melbourne Metro tunnels are potentially subject to flooding from the existing City Loop tunnels through the underground interconnection at CBD North station. The lowest of the City Loop tunnel portals near Federation Square is subject to flooding from the Yarra River in a Year 2100 one per cent AEP Yarra River flood event. If flooding thresholds were exceeded this would result in inundation of the Melbourne Metro tunnels in a relatively short time frame. This could be mitigated by flood gates to prevent flooding of the City Loop tunnel portals.

Potential flooding of CBD South station and adjoining sections of the tunnels from the Yarra River from the station entrances during construction or operation has the potential to cause significant inundation of the tunnels in a relatively short time frame. This could pose a significant risk to construction workers, commuters and rail staff, and significant disruption to rail services. Even relatively shallow inundation of the entrances could cause major flooding of the station and tunnels in a relatively short time frame (tens of minutes to hours) once threshold flood levels were reached.



The ground levels at the station entrances under the Concept Design are all above 6.9 m AHD. The ground levels at the station entrances are all therefore very close to or above the estimated Year 2100 0.01% AEP Yarra River flood level of 7.2 m AHD upstream of Princes Bridge. As noted above, many hours warning time would generally be available to implement emergency management measures to be put in place in advance of a more extreme flood to reduce the risk of station flooding and inundation of tunnels. In addition to suspension of rail services and station evacuation, these could include, for example, automated flood gates, or emergency sandbagging.

The station entrances would need to be raised slightly to provide an appropriate level of immunity from local stormwater flows, to be determined by flood immunity risk assessment.

B.8.5. Domain Station

The level at the top of the stairs leading to the station entrance in the Albert Road Reserve, located on the corner of Albert Road and St Kilda Road, is approximately 6.0 m AHD. This level is well above the estimated peak flood level for the 0.01 per cent AEP event from the Yarra River (including allowance for climate change).

B.8.6. Eastern Portal

The ground level of the highest point along the rail cutting between the eastern portal and the Yarra River is approximately 7.15 m AHD, immediately south of Toorak Road. The portal would therefore be immune from flooding from the Yarra River in approximately a 0.1% AEP event (1,000 year ARI event) under Year 2100 conditions. A flood immunity risk assessment is required to determine whether this is acceptable. Up to three day's warning is likely to be available in advance of such an event because it relates to floodwaters emanating from the Yarra River. At a very minimum, it is recommended that a flood warning system be implemented, such that rail services could be suspended and the tunnel and stations evacuated, in advance of an extreme flood. If the risk associated with more extreme floods is not deemed to be acceptable due to the very low frequency, emergency management measures such as sandbagging or flood gates and emergency evacuation procedures, would need to be put in place to protect the tunnel from flooding in more extreme events.

The tunnels need to be protected from general stormwater flooding risks. The decline structure would be designed to have a cut-off drain at the entrance to the tunnel, designed to intercept drainage up to the 0.5 per cent AEP rainfall event. The collected flows would then be pumped back to the existing drainage system, with balancing storage. The City of Stonnington has indicated that flows should be limited to 10 L/s and this means that a balancing storage of 60 m³ is required.



B.9. Attachment A



Melbourne Metro Rail Project
Arden Station Flood Levels
MMRA

20 April 2016
Reference:
CMS332569

Aurecon Jacobs Mott MacDonald
in association with Grimshaw





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1 Introduction

1.1 Overview

The Aurecon Jacobs Mott McDonald Joint Venture (AJM JV) was commissioned by Melbourne Metro Rail Authority (MMRA) to determine flood levels in the vicinity of a number of potential Arden station locations in the broad area between the existing Macaulay and North Melbourne Stations, as shown on Figure 1-1.

These flood levels were required for both:

- The one per cent Average Exceedance Probability (AEP) flood event, under existing conditions
- The one per cent, 0.1 per cent, and 0.01 per cent AEP flood events, under Year 2100 conditions, taking account of increases in rainfall intensities and sea levels associated with climate change.

A one per cent AEP flood event is one which has a one per cent chance of being equalled or exceeded in any given year – this is sometimes also referred to as the 100 year Average Recurrence Interval (ARI) flood event.

1.2 Flooding Characteristics

This area is subject to flooding from one or both of two sources:

- Flows in excess of the capacity of the Moonee Ponds Creek channel
- Inflows from the local sub-catchments on either side of the Creek.

The major inflows to the area are from Moonee Ponds Creek upstream of Mount Alexander Road. The catchment area of Moonee Ponds Creek to this point is 148 km².

The areas of the local sub-catchments on the eastern and western sides of the Creek between Mount Alexander and Footscray Roads are six and three square kilometres respectively. Many of the drainage systems that service these local sub-catchments are equipped with pumped outfalls, and flows from the local sub-catchments are pumped into the Creek at times when Creek levels are too high to allow discharge by gravity. Many of the pumps are old and unreliable. The most significant system servicing the local sub-catchment on the east side of the Creek is Melbourne Water's Arden Street Main Drain. The location of this is shown on Figure 1-1.

Moonee Ponds Creek itself in this area is a heavily modified man-made channel. Between Footscray and Macaulay Roads it comprises a large permanent waterway, typically around 30 m wide and approximately two metres deep with relatively small overbank areas to a total typical width of around 60 m. Upstream of Macaulay Road it comprises a very small low flow channel, typically around two metres wide and one metre deep, and larger overbank areas to a typical total width of around 50 m.

The Creek has levees along one or both banks through much of the reach of interest, in particular the reach between Arden Street and Racecourse Road. The locations of these levees are shown on Figure 1-1.

For much of the duration of major flood flows, flood levels in the Creek are typically higher than those in the local catchments behind the levees. This is due to the capacities of the pump stations being insufficient to discharge peak flood flows. This results in floodwaters ponding behind the levees until they are either pumped to the Creek, or able to discharge by gravity via piped systems as the Creek flood levels recede.

The hydraulic capacity of the Creek channel is constrained by a number of:



- Bridges – Mount Alexander Road, Racecourse Road, Macaulay Road, Arden Street, Dynon Road, Footscray Road, a number of rail bridges between Arden and Footscray Roads, and a number of pipe bridges
- Bridge piers which support the Melbourne City Link elevated roadway and its entry and exit ramps.

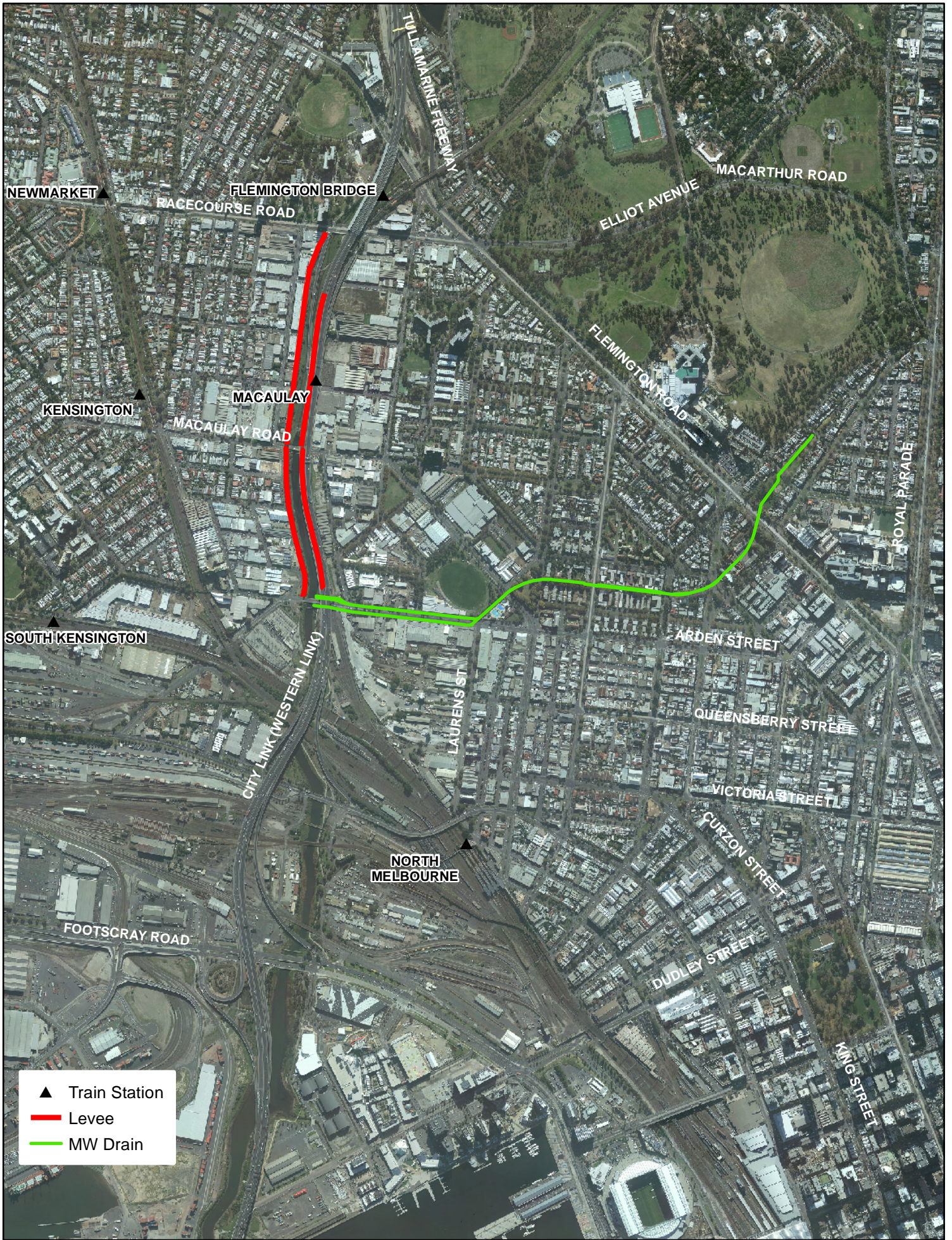


Figure 1.1
Study Area



0 0.075 0.15 0.3 km

1:15,000 at A4

Projection: MGA Zone 55



2 Previous Investigations

2.1 Melbourne Metro Stage 1 Study (2010)

An investigation undertaken for Melbourne Metro Stage 1 (ref 1) quoted a one per cent AEP flood level for Arden station of 2.75 m AHD. This is understood to have been determined based on a Melbourne Water hydraulic model of Moonee Ponds Creek, using a constant coincident water level of 1.6 m AHD at the confluence of Moonee Ponds Creek and the Yarra River.

The report states that this model was insufficiently detailed to enable determination of 0.1 per cent AEP flood levels. A Year 2100 0.1 per cent AEP flood level was therefore determined by arbitrarily adding 1.5 m to the existing one per cent AEP flood level to produce a resultant level of 4.25 m AHD.

2.2 Melbourne Metro Study (2013)

AECOM undertook some preliminary assessments of surface water issues as part of some preliminary studies for Melbourne Metro in 2013 (ref 3). No flood levels for Moonee Ponds Creek were included in the report on this study.

2.3 AECOM Study (2013)

AECOM (ref 2) has undertaken hydrologic and hydraulic modelling to determine flood levels under existing physical conditions for a range of flood events (ten per cent, one per cent, 0.5 per cent and 0.2 per cent AEP) and future scenarios taking account of progressive increases in rainfall intensities and sea levels associated with climate change (current, Year 2040, Year 2070 and Year 2100).

This modelling was undertaken using RORB hydrologic modelling software and Tuflow hydraulic modelling software.

The AECOM study included development of a RORB hydrologic model to determine the local catchment inflows between Mount Alexander and Footscray Roads. It is understood that inflow hydrographs from Moonee Ponds Creek upstream of Mount Alexander Road were determined by scaling a one per cent AEP hydrograph provided by Melbourne Water.

The Tuflow model simulated the overbank and creek topography, the levee systems, and a number of the more significant piped drainage systems. It should be noted however that it was conservatively assumed in consultation with the City of Melbourne that the pumps would not be operating during any of these flood events.

The existing conditions modelling assumed a constant coincident water level of 1.22 m AHD at the confluence of Moonee Ponds Creek and the Yarra River. This was reported to be the current ten per cent AEP extreme sea level in Port Phillip Bay. For the Year 2100 modelling, 0.8 m was added to this to give a resultant constant downstream water level of 2.02 m AHD. The same downstream boundary levels were used for modelling of all AEP events. The hydrological modelling assumed Year 2100 rainfall intensities 32 per cent higher than existing. The report states that all these assumptions are in accordance with Melbourne Water's specifications for hydraulic modelling of systems that outfall to Port Phillip Bay.

The modelling assumed that a two hour storm duration event was critical for all AEP events, for both existing conditions and future scenarios.



3 Current Investigations

3.1 Overview

The hydrologic and hydraulic models from AECOM's 2013 studies were obtained, and used as the basis for determining flood levels for the current investigation. A hydrologic model of Moonee Ponds Creek upstream of Mount Alexander Road was obtained from Melbourne Water, and also used for the current study.

Whilst much of the data and assumptions included in the models were assumed to be correct, some elements of the models were specifically reviewed. These included, in particular:

- The downstream boundary conditions that were used for both existing conditions, and Year 2100 conditions
- The design rainfall inputs. The previous modelling did not include the 0.1 per cent or 0.01 per cent AEP events, for either existing or future scenarios, so the hydrologic models were rerun for all AEP events, for both existing and future scenarios.

3.2 Downstream Boundary Levels

As outlined in Chapter 2, the previous investigations of Moonee Ponds Creek have assumed a range of different coincident levels at the mouth of the Creek as follows:

- One per cent AEP event, existing conditions – tailwater levels of:
 - 1.22 m AHD, reported to be the ten per cent AEP extreme sea level in Port Phillip Bay
 - 1.6 m AHD. This was based on Melbourne Water (2012) "Planning for Sea Level Rise, assessing development in areas prone to tidal inundation from sea level rise in the Port Phillip and Westernport Region" (ref 11)
- One per cent AEP event, Year 2100 conditions – 2.02 m AHD. This was based on 1.22 m AHD, plus an assumed increase in mean sea level of 800 mm.

A coarse analysis was undertaken to determine the likely order of sensitivity of flood levels at a range of potential Arden station locations to different assumed tailwater levels. This was undertaken using a simple one-dimensional HEC-RAS model of flows that would be contained within the Creek channel and levees. This showed that for a range of tailwater levels of 700 mm, the range of flood levels in the Creek due west of the western end of Queensberry Street would be of the order of 400 mm. This indicates a moderate level of sensitivity, and therefore a need to adopt realistic downstream boundary levels for each scenario.

CSIRO (ref 4) has investigated extreme sea levels at a range of locations in Port Phillip Bay, for both existing conditions, and Year 2100 conditions. The nearest relevant location for which levels are reported in the CSIRO study is Williamstown (refer Figure 3-1).

Relevant levels are as follows:

- One per cent AEP, existing conditions – 1.12 m AHD
- One per cent AEP, Year 2100 conditions – range from 1.94 to 2.52 m AHD. The range is based on climate change projections from four different studies. The two median values are 2.22 and 2.26 m AHD. The first of these is based on the Intergovernmental Panel on Climate Change (IPCC) 2007 study which incorporated both mean sea level rise and increase in wind speed. The sea level increase in this study is 820 mm, which is broadly consistent with the 800 mm recommended for adoption by 2100 in The Victorian Coastal Strategy (ref 5).

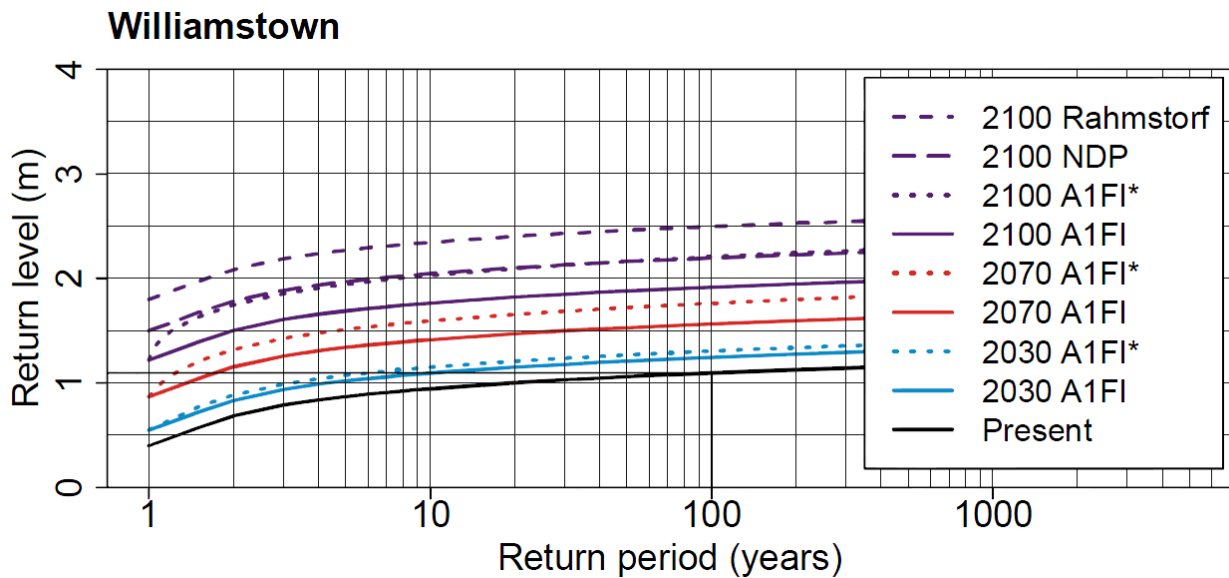


Figure 3-1 Storm Surge Height Return Period Curves for Williamstown (after Ref 4)

Whilst some correlation might be expected between flood flows in Moonee Ponds Creek and extreme storm surge events in Port Phillip Bay, perfect correlation would certainly not be expected. Therefore adopting, for example, a one per cent AEP peak flow in Moonee Ponds Creek coincident with a peak one per cent AEP level in Port Phillip Bay is considered a very conservative approach, and likely to result in an overall event far rarer than one per cent AEP. Nevertheless, some degree of conservatism is considered warranted for the project, and the tailwater levels adopted for each scenario are presented in Figure 3-1.

Table 3-1 Adopted Coincident Tailwater Levels – Mouth of Moonee Ponds Creek

| Scenario | Assumed Tailwater Level (m AHD) | Basis |
|--------------------------------------|---------------------------------|--|
| 1% AEP – existing | 1.22 | Aecom (ref 2), and very close to CSIRO (ref 4) 1% AEP extreme Bay level of 1.12 m AHD) |
| 1% AEP – Year 2100 climate change | 2.25 | Median CSIRO (ref 4) |
| 0.1% AEP – Year 2100 climate change | 2.4 | Median CSIRO (ref 4), extrapolated from Figure 3-1 |
| 0.01% AEP - Year 2100 climate change | 2.5 | Median CSIRO (ref 4), extrapolated from Figure 3-1 |

3.3 Extreme Event Rainfall

For the one per cent AEP event, the design rainfall depths were estimated from intensity-frequency-duration (IFD) data developed by the Bureau of Meteorology (2013, ref 6) as part of revisions to *Australian Rainfall and Runoff*. A regional approach for estimating design rainfall depths developed by Jordan et al. (2005, ref 7) was adopted for durations between 0.5 and six hours (inclusive) and AEPs between one per cent and 0.05 per cent (inclusive). The growth factors developed by Jordan et al. (2005) were scaled relative to the one per



cent AEP for compatibility with the recently revised IFD data. This involved multiplying the one per cent AEP design rainfall by the ratio of the 0.1 per cent AEP growth factor to the one per cent AEP growth factor to generate a point rainfall depth for the 0.1 per cent AEP event.

Point rainfall estimates were converted to catchment average values using areal reduction factors appropriate for the Victoria. Conceptually, these factors account for the fact that larger catchments are less likely to experience high intensity storms over the whole of the catchment. Areal reduction factors were obtained from Siriwardena and Weinmann (ref 8).

Probable Maximum Precipitation (PMP) estimates for durations of six hours or less were obtained by applying the Generalised Short Duration Method (GSDM) as outlined by the Bureau of Meteorology (2003, ref 9). The interpolation procedure as recommended in *Book VI of Australian Rainfall and Runoff* (ref 10) was used to interpolate between the 0.05 per cent AEP and PMP depths to obtain the 0.01 per cent AEP design depths.

3.4 Critical Storm Duration

As noted previously in Section 2.3, the previous AECOM studies assumed that the critical storm duration for assessment of flood levels was two hours for all events and scenarios. The validity of this assumption was assessed by also modelling a one per cent AEP six hour storm duration, and comparing resultant flood levels with those for a one per cent AEP two hour storm duration. This was undertaken for existing conditions, ie no allowance for climate change. Results are presented in Appendix A.

The results show that peak flood levels are generally higher for the two hour storm duration in the following locations:

- Along the outer margins of the floodplain. In these locations, flooding is associated with overland flow along streets, and this is unaffected by ponding in the floodplain areas closer to the Creek. Peak flows will generally be higher in the shorter two hour event than in the six hour event. These two factors then combine to produce lower flood levels in the longer duration six hour event.
- Along the upper reaches of Moonee Ponds Creek, particularly upstream of Macaulay Road. This is upstream of the most significant inflows from the adjacent floodplains. This is due to peak flows from Moonee Ponds Creek upstream of the study area being higher for the two hour event than for the six hour event.

In the flood plain areas immediately adjacent to the Creek, peak flood levels are generally higher in the six hour event than in the two hour event. The differences in flood levels between the two events are however relatively small, and generally less than 100 mm. In these areas, peak flood levels are largely determined by flood volume rather than peak flood flows. This is because overland flows are unable to drain to the Creek when Creek levels are high, and this situation persists for longer periods in the six hour storm than in the two hour storm. Overall flood volume will be greater in the six hour duration event, than in the two hour duration event, hence flood levels in these areas will be higher.

In summary, flood levels are generally higher in the two hour storm than in the six hour storm. In locations where this is not the case, the difference in flood levels between the two events is generally relatively small, and less than 100 mm. This small difference is considered to be beyond the level of accuracy of the modelling. Whilst six hour and other storm durations could be modelled for all four flood event scenarios events under consideration, this is not considered warranted. It is instead recommended that an appropriate freeboard allowance be included in all design decisions related to flood levels determined as part of the current investigation.

3.5 Results

Resultant flood levels are presented in Table 3-2. Flood levels and depths for each of the four modelled flood scenarios are shown on Figures 3-2 to 3-25 inclusive.



In setting any infrastructure design levels it is recommended that a minimum of 600 mm freeboard be added to the adopted flood levels.

Table 3-2 Resultant Flood Levels on Moonee Ponds Creek due west of Western end of Queensberry Street

| Scenario | Flood Level (m AHD) |
|---|----------------------------|
| 1% AEP – existing | 3.1 |
| 1% AEP – Year 2100 (i.e. including allowances for the impacts of climate change) | 3.4 |
| 0.1% AEP – Year 2100 | 4.3 |
| 0.01% AEP - Year 2100 | 5.1 |

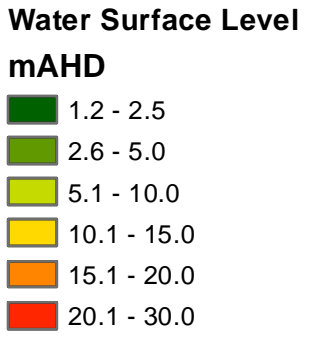
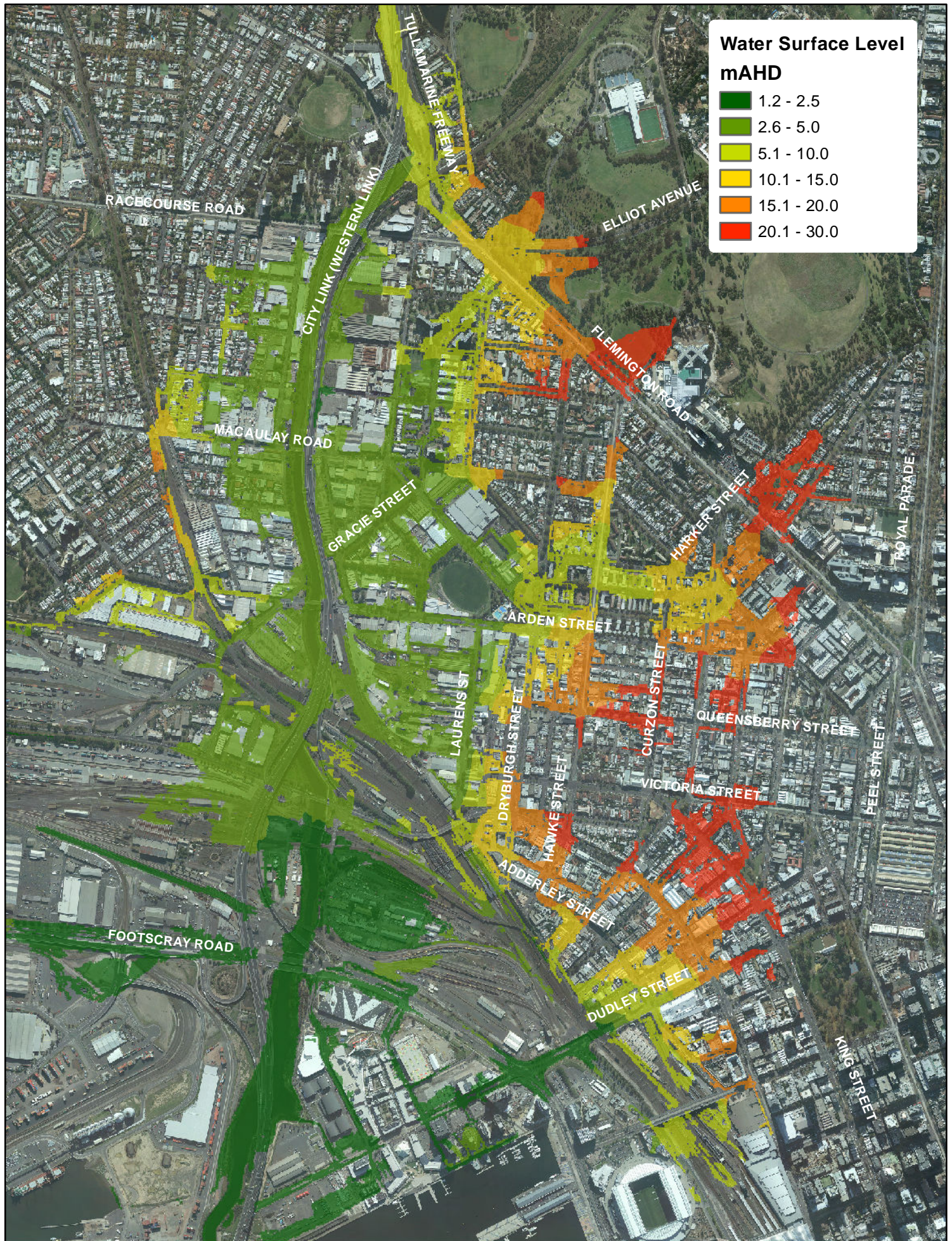


Figure 3.2

Arden-Macaulay Precinct Peak Water Surface Levels

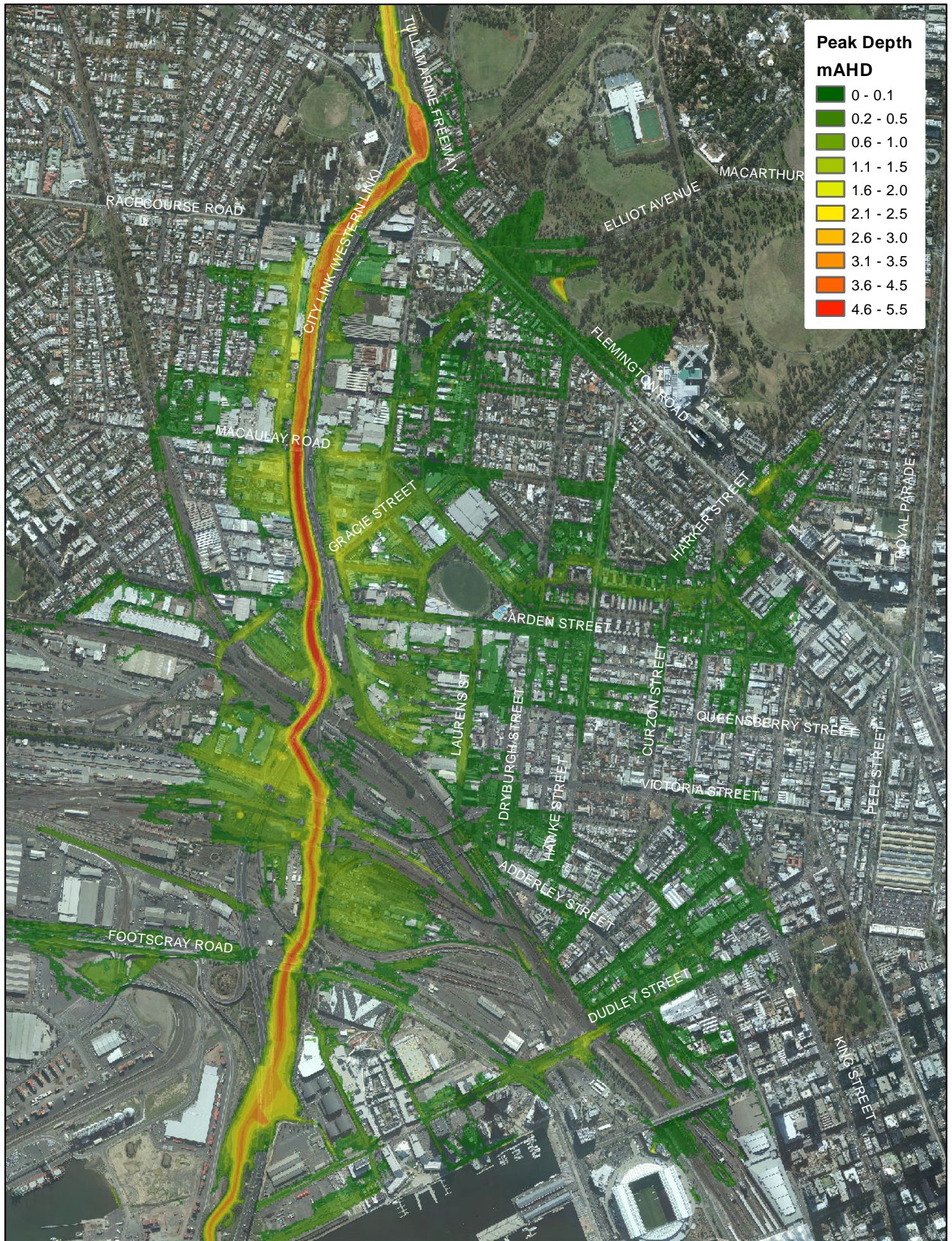
Existing Conditions 1% AEP



0 0.075 0.15 0.3 km

1:15,000 at A4

Projection: MGA Zone 55



**Peak Depth
mAHD**

| |
|-----------|
| 0 - 0.1 |
| 0.2 - 0.5 |
| 0.6 - 1.0 |
| 1.1 - 1.5 |
| 1.6 - 2.0 |
| 2.1 - 2.5 |
| 2.6 - 3.0 |
| 3.1 - 3.5 |
| 3.6 - 4.5 |
| 4.6 - 5.5 |

Figure 3.3

Arden-Macaulay Precinct Peak Depth

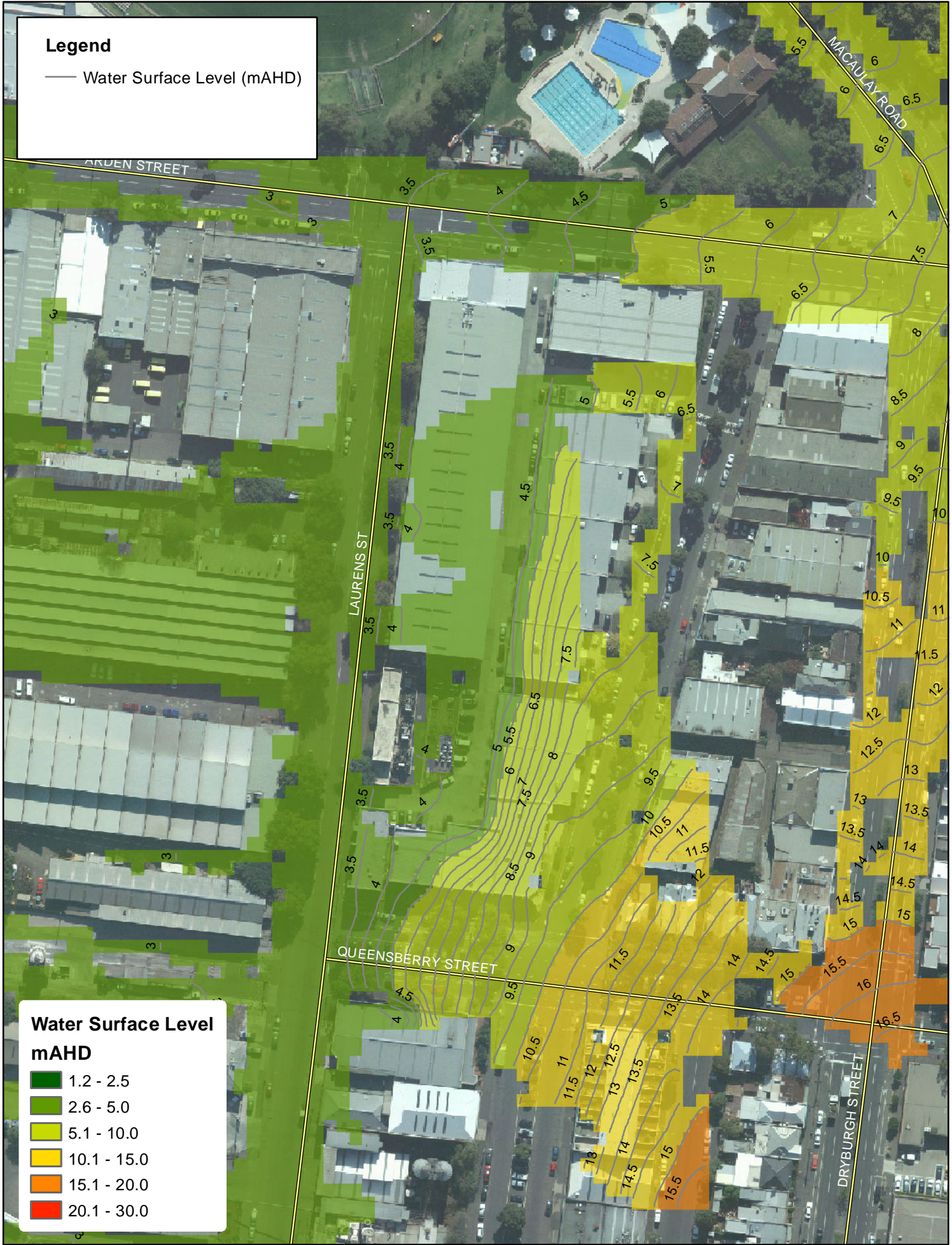
Existing Conditions 1% AEP



0 0.075 0.15 0.3 km

1:15,000 at A4

Projection: MGA Zone 55



Legend
 — Water Surface Level (mAHD)

**Water Surface Level
 mAHD**

- 1.2 - 2.5
- 2.6 - 5.0
- 5.1 - 10.0
- 10.1 - 15.0
- 15.1 - 20.0
- 20.1 - 30.0

Figure 3.4

Arden-Macaulay Precinct Peak Water Surface Level

Existing Conditions 1% AEP



0 0.0075 0.015 0.03
 km

1:1,500 at A4

Projection: MGA Zone 55



Legend
 — Peak Depth (mAHD)

**Peak Depth
 mAHD**

- 0 - 0.1
- 0.2 - 0.3
- 0.4 - 0.5
- 0.6 - 0.7
- 0.8 - 0.9
- 1 - 1.1

Figure 3.5

Arden-Macaulay Precinct Peak Depth

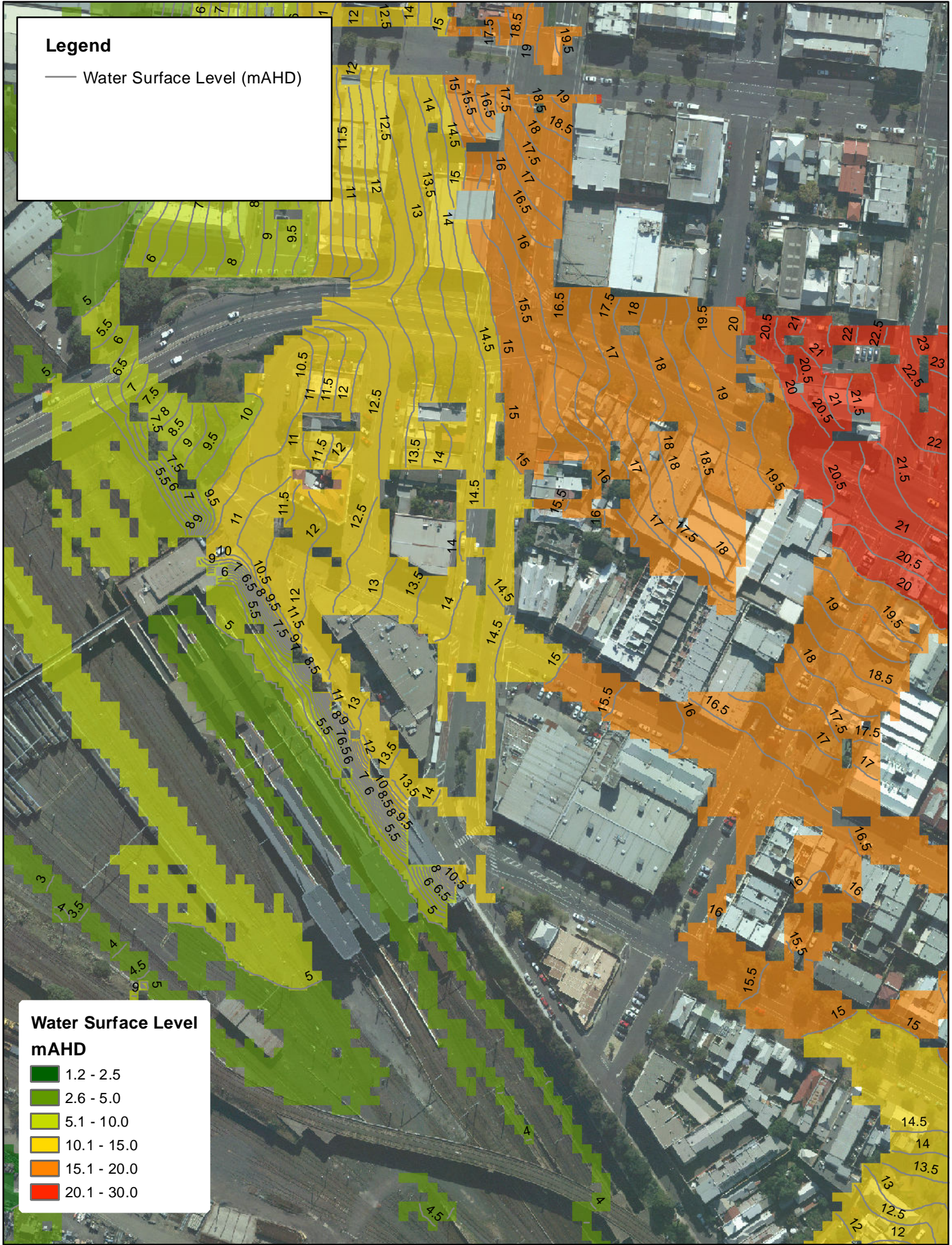
Existing Conditions 1% AEP



0 0.0075 0.015 0.03
 km

1:1,500 at A4

Projection: MGA Zone 55



Legend
 — Water Surface Level (mAHd)

**Water Surface Level
 mAHd**

- 1.2 - 2.5
- 2.6 - 5.0
- 5.1 - 10.0
- 10.1 - 15.0
- 15.1 - 20.0
- 20.1 - 30.0

Figure 3.6

Arden-Macaulay Precinct Peak Water Surface Level

Existing Conditions 1% AEP



0 0.01 0.02 0.04
 km

1:2,000 at A4
 Projection: MGA Zone 55



Figure 3.7

Arden-Macaulay Precinct Peak Depth

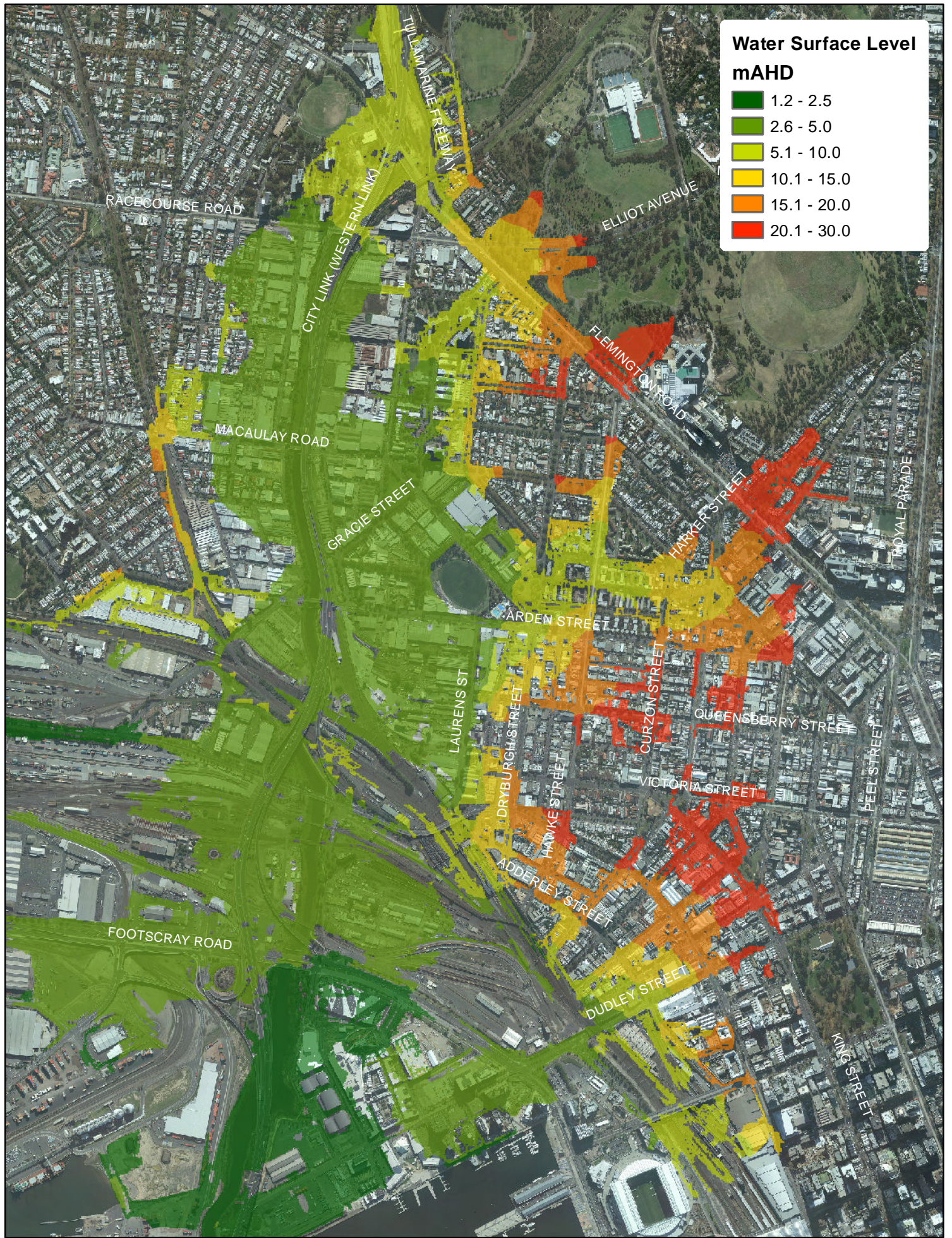
Existing Conditions 1% AEP



0 0.01 0.02 0.04
km

1:2,000 at A4

Projection: MGA Zone 55



**Water Surface Level
mAHd**

- 1.2 - 2.5
- 2.6 - 5.0
- 5.1 - 10.0
- 10.1 - 15.0
- 15.1 - 20.0
- 20.1 - 30.0

Figure 3.8

Arden St Precinct Peak Water Surface Levels

Year 2100 1% AEP



0 0.075 0.15 0.3 km

1:15,000 at A4

Projection: MGA Zone 55



**Peak Depth
mAHD**

| |
|-----------|
| 0 - 0.1 |
| 0.2 - 0.5 |
| 0.6 - 1.0 |
| 1.1 - 1.5 |
| 1.6 - 2.0 |
| 2.1 - 2.5 |
| 2.6 - 3.0 |
| 3.1 - 3.5 |
| 3.6 - 4.5 |
| 4.6 - 5.5 |

Figure 3.9

Arden-Macaulay Precinct Peak Depth

Year 2100 1% AEP



0 0.075 0.15 0.3 km

1:15,000 at A4

Projection: MGA Zone 55

Legend

— Water Surface Level (mAHD)

Water Surface Level

mAHD

- 1.2 - 2.5
- 2.6 - 5.0
- 5.1 - 10.0
- 10.1 - 15.0
- 15.1 - 20.0
- 20.1 - 30.0



Figure 3.10

Arden-Macaulay Precinct Peak Water Surface Level

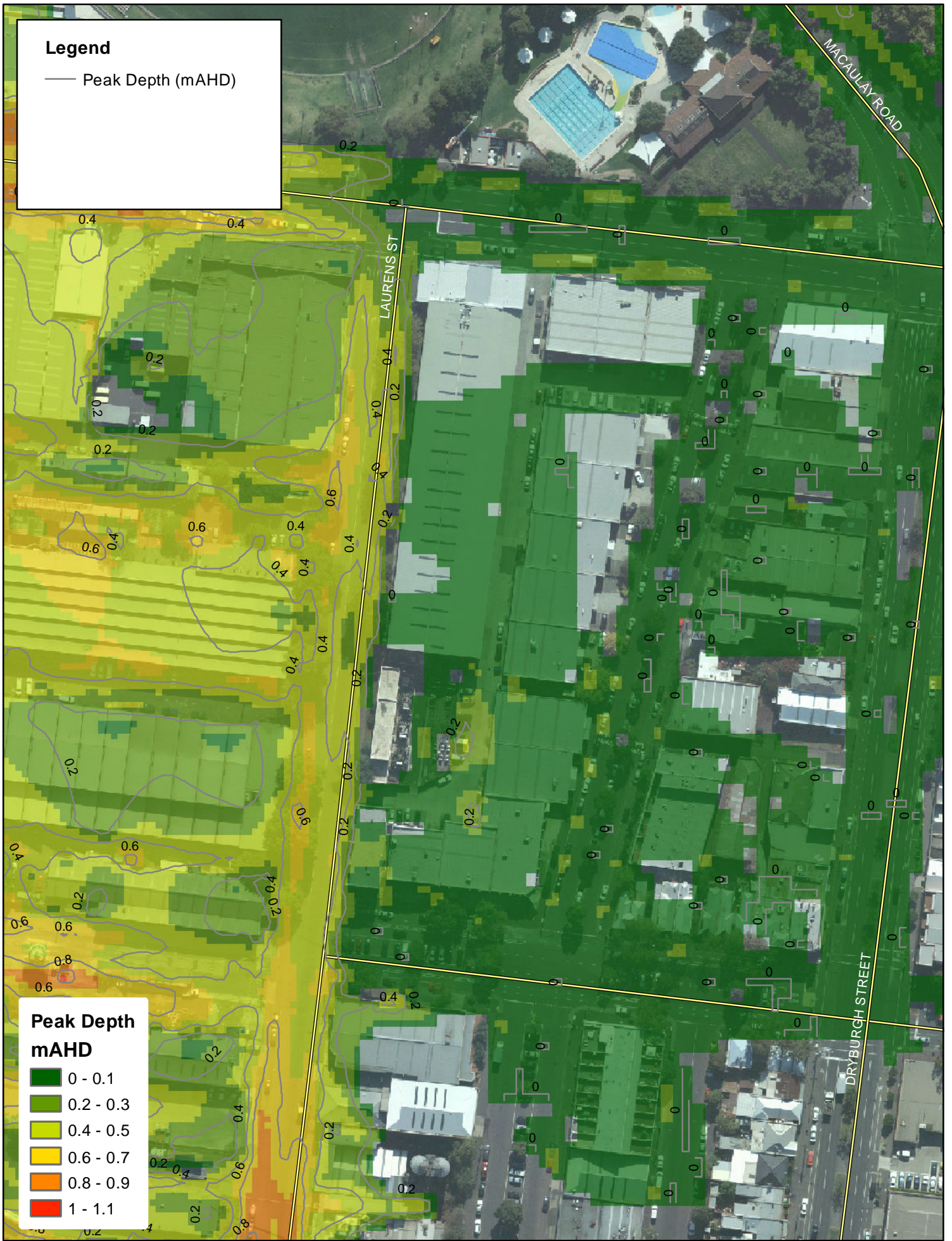
Year 2100 1% AEP



0 0.0075 0.015 0.03
km

1:1,500 at A4

Projection: MGA Zone 55



Legend
 — Peak Depth (mAHD)

**Peak Depth
 mAHD**

| |
|-----------|
| 0 - 0.1 |
| 0.2 - 0.3 |
| 0.4 - 0.5 |
| 0.6 - 0.7 |
| 0.8 - 0.9 |
| 1 - 1.1 |

Figure 3.11

Arden-Macaulay Precinct Peak Depth

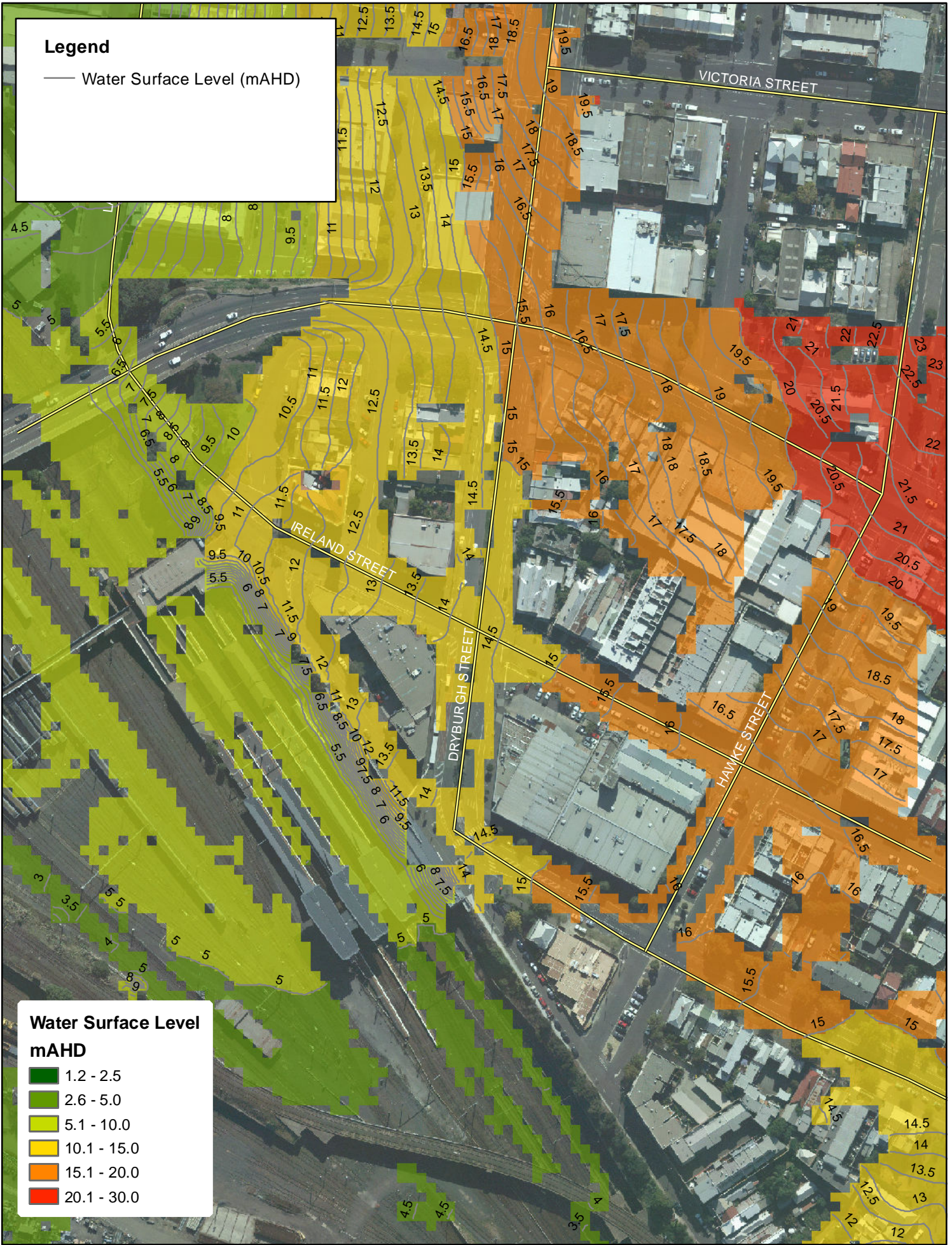
Year 2100 1% AEP



0 0.0075 0.015 0.03 km

1:1,500 at A4

Projection: MGA Zone 55



Legend
 — Water Surface Level (mAHd)

**Water Surface Level
 mAHd**

- 1.2 - 2.5
- 2.6 - 5.0
- 5.1 - 10.0
- 10.1 - 15.0
- 15.1 - 20.0
- 20.1 - 30.0

Figure 3.12

Arden-Macaulay Precinct Peak Water Surface Level

Year 2100 1% AEP



0 0.01 0.02 0.04 km

1:2,000 at A4

Projection: MGA Zone 55



Figure 3.13

Arden-Macaulay Precinct Peak Depth

Year 2100 1% AEP



0 0.01 0.02 0.04 km

1:2,000 at A4

Projection: MGA Zone 55

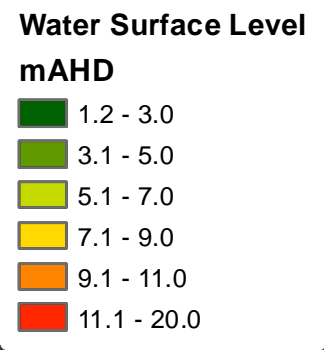
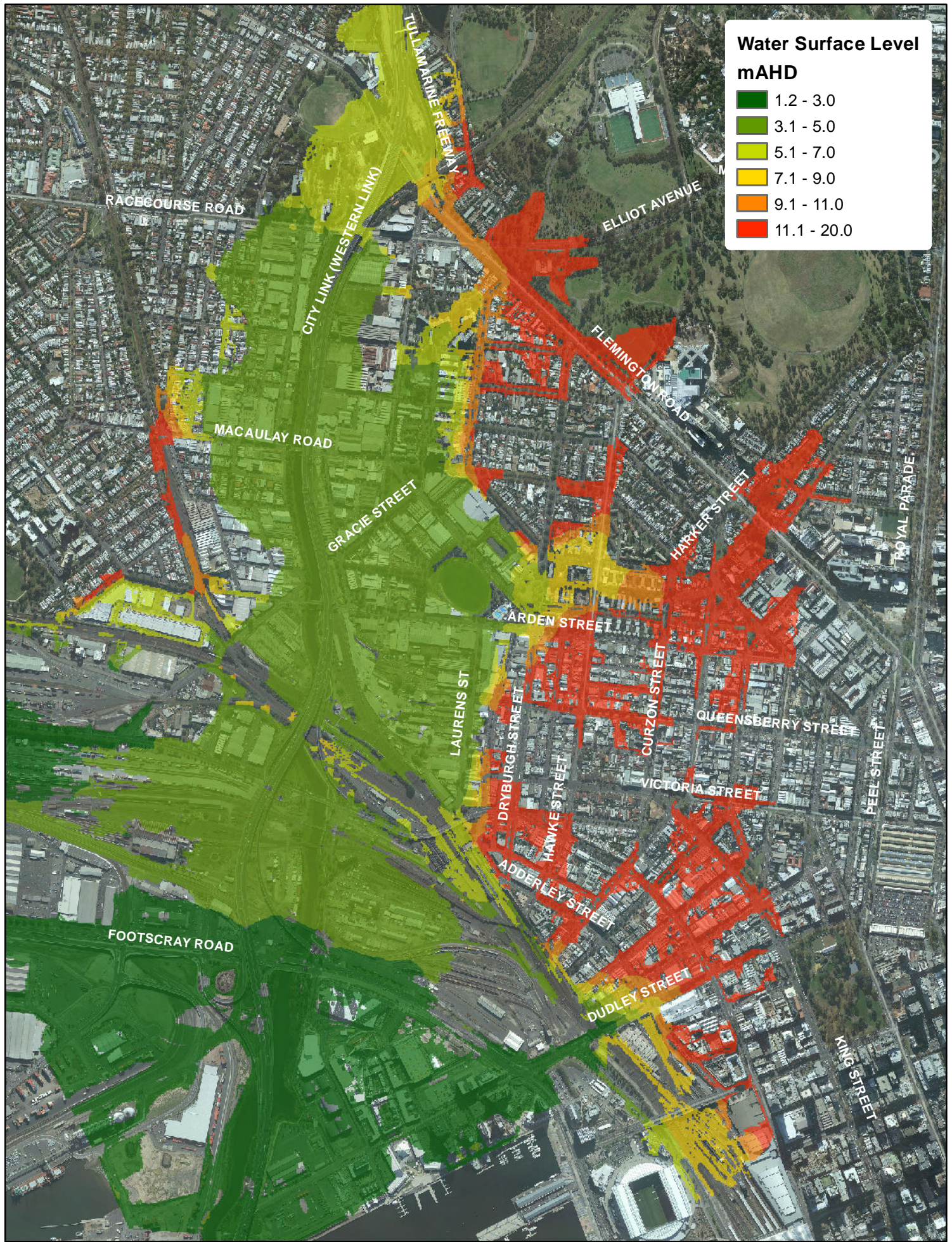


Figure 3.14

Arden-Macaulay Precinct Peak Water Surface Level

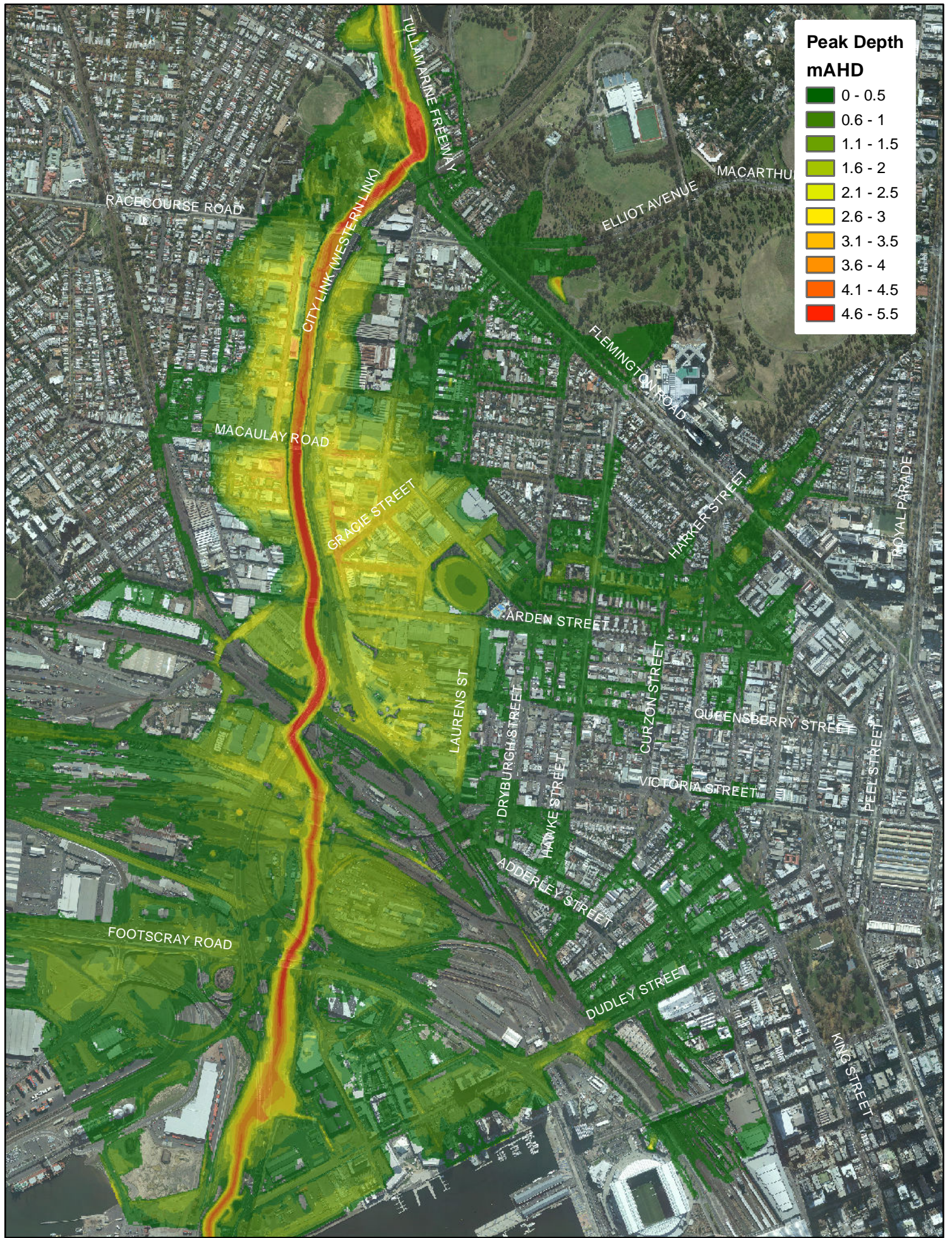
Year 2100 0.1% AEP



0 0.075 0.15 0.3
km

1:15,000 at A4

Projection: MGA Zone 55



**Peak Depth
mAHD**

| |
|-----------|
| 0 - 0.5 |
| 0.6 - 1 |
| 1.1 - 1.5 |
| 1.6 - 2 |
| 2.1 - 2.5 |
| 2.6 - 3 |
| 3.1 - 3.5 |
| 3.6 - 4 |
| 4.1 - 4.5 |
| 4.6 - 5.5 |

Figure 3.15

Arden-Macaulay Precinct Peak Depth

Year 2100 0.1% AEP



0 0.075 0.15 0.3 km

1:15,000 at A4

Projection: MGA Zone 55

Legend

— Water Surface Level (mAHD)

**Water Surface Level
mAHD**

- 1.2 - 2.5
- 2.6 - 5.0
- 5.1 - 10.0
- 10.1 - 15.0
- 15.1 - 20.0
- 20.1 - 30.0



Figure 3.16

Arden-Macaulay Precinct Peak Water Surface Level

Year 2100 0.1% AEP



0 0.0075 0.015 0.03
km

1:1,500 at A4

Projection: MGA Zone 55



Figure 3.17

Arden-Macaulay Precinct Peak Depth

Year 2100 0.1% AEP



0 0.0075 0.015 0.03 km

1:1,500 at A4

Projection: MGA Zone 55

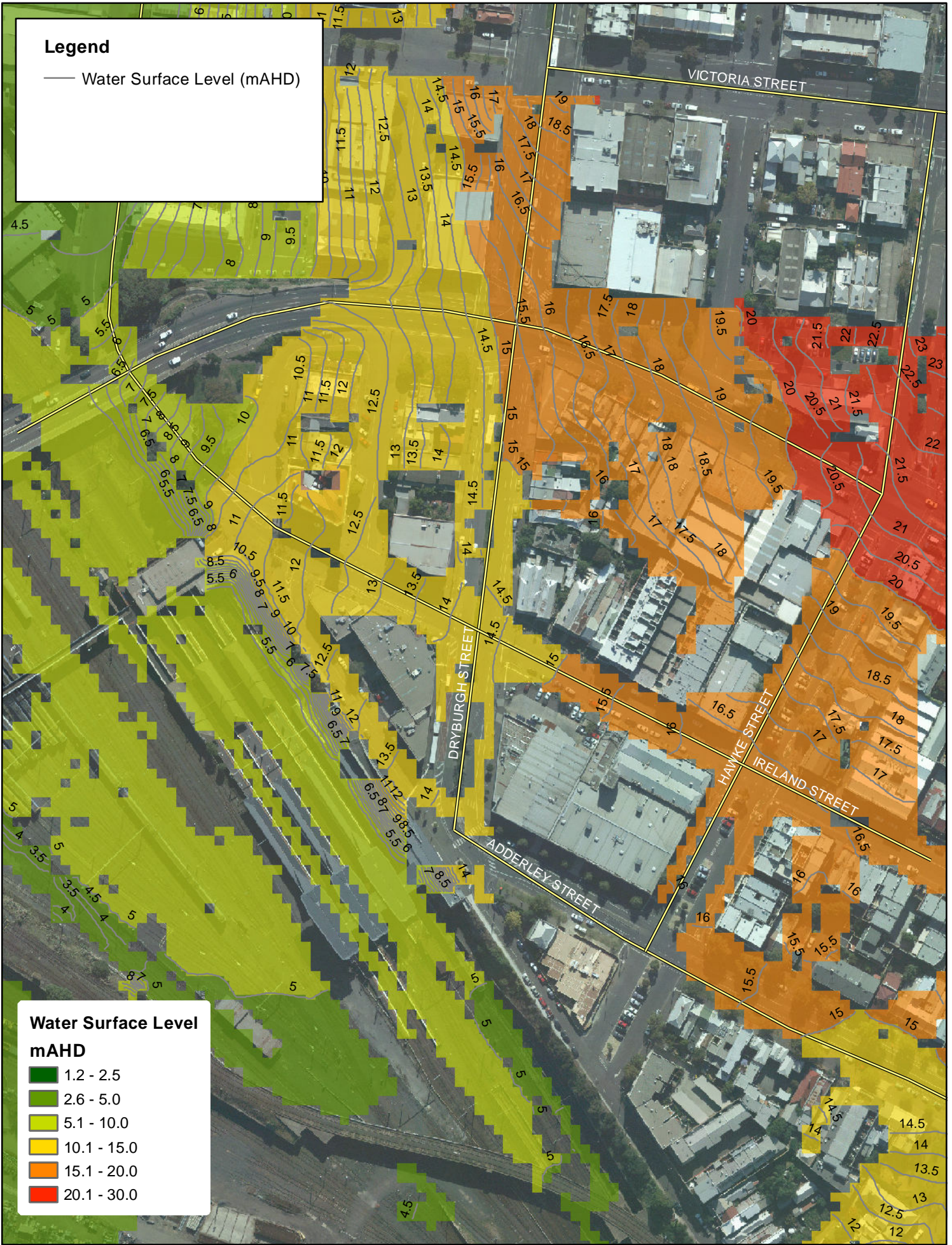


Figure 3.18

Arden-Macaulay Precinct Peak Water Surface Level

Year 2100 0.1% AEP



0 0.01 0.02 0.04 km

1:2,000 at A4

Projection: MGA Zone 55



Legend
 — Peak Depth (mAHd)

**Peak Depth
mAHd**

| |
|-----------|
| 0 - 0.1 |
| 0.2 - 0.3 |
| 0.4 - 0.5 |
| 0.6 - 0.7 |
| 0.8 - 0.9 |
| 1 - 1.1 |

Figure 3.19

Arden-Macaulay Precinct Peak Depth

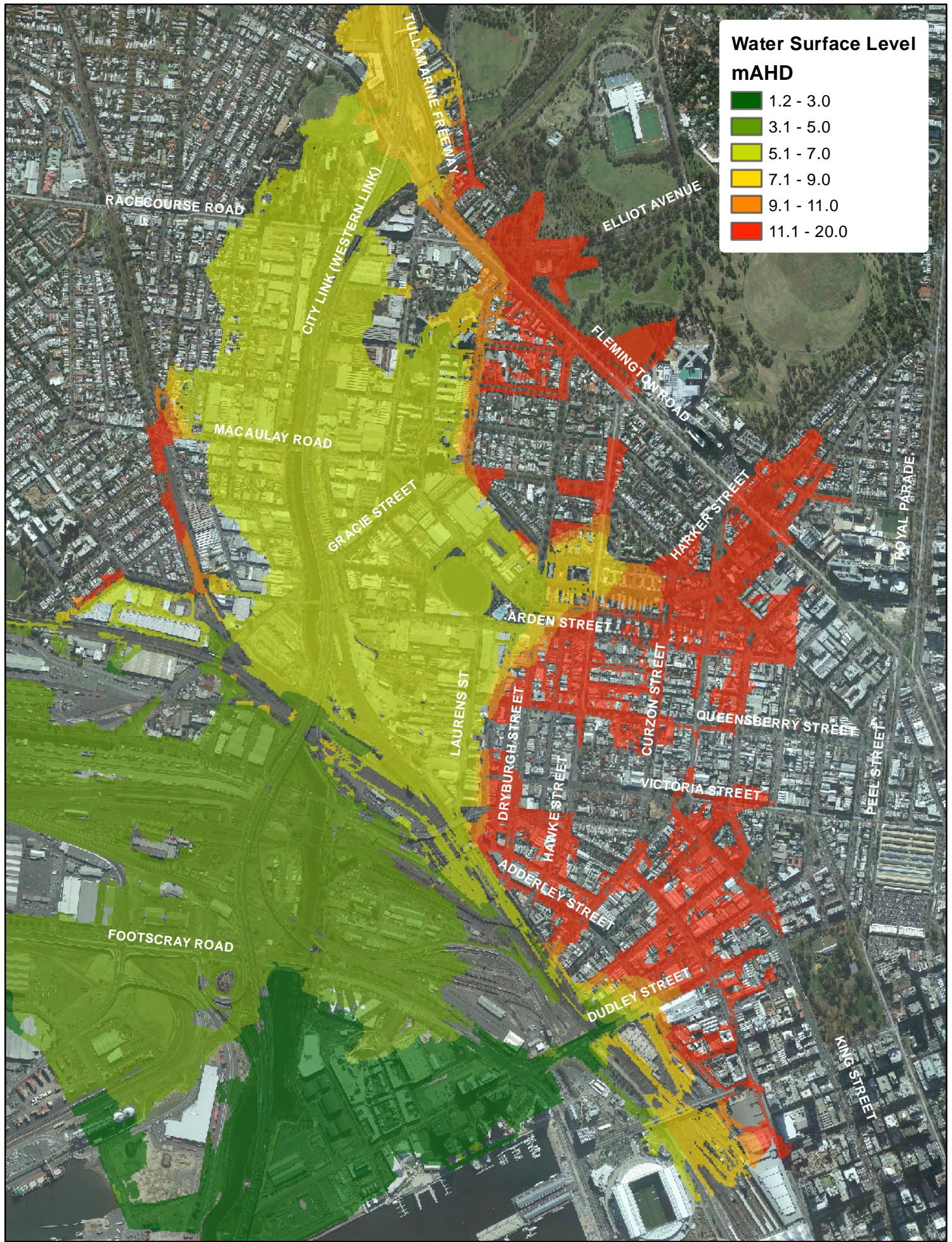
Year 2100 0.1% AEP



0 0.01 0.02 0.04 km

1:2,000 at A4

Projection: MGA Zone 55



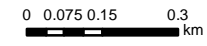
**Water Surface Level
mAHd**

- 1.2 - 3.0
- 3.1 - 5.0
- 5.1 - 7.0
- 7.1 - 9.0
- 9.1 - 11.0
- 11.1 - 20.0

Figure 3.20

Arden-Macaulay Precinct Peak Water Surface Level

Year 2100 0.01% AEP



1:15,000 at A4
Projection: MGA Zone 55

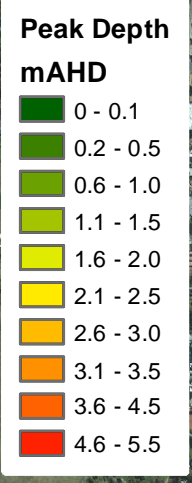
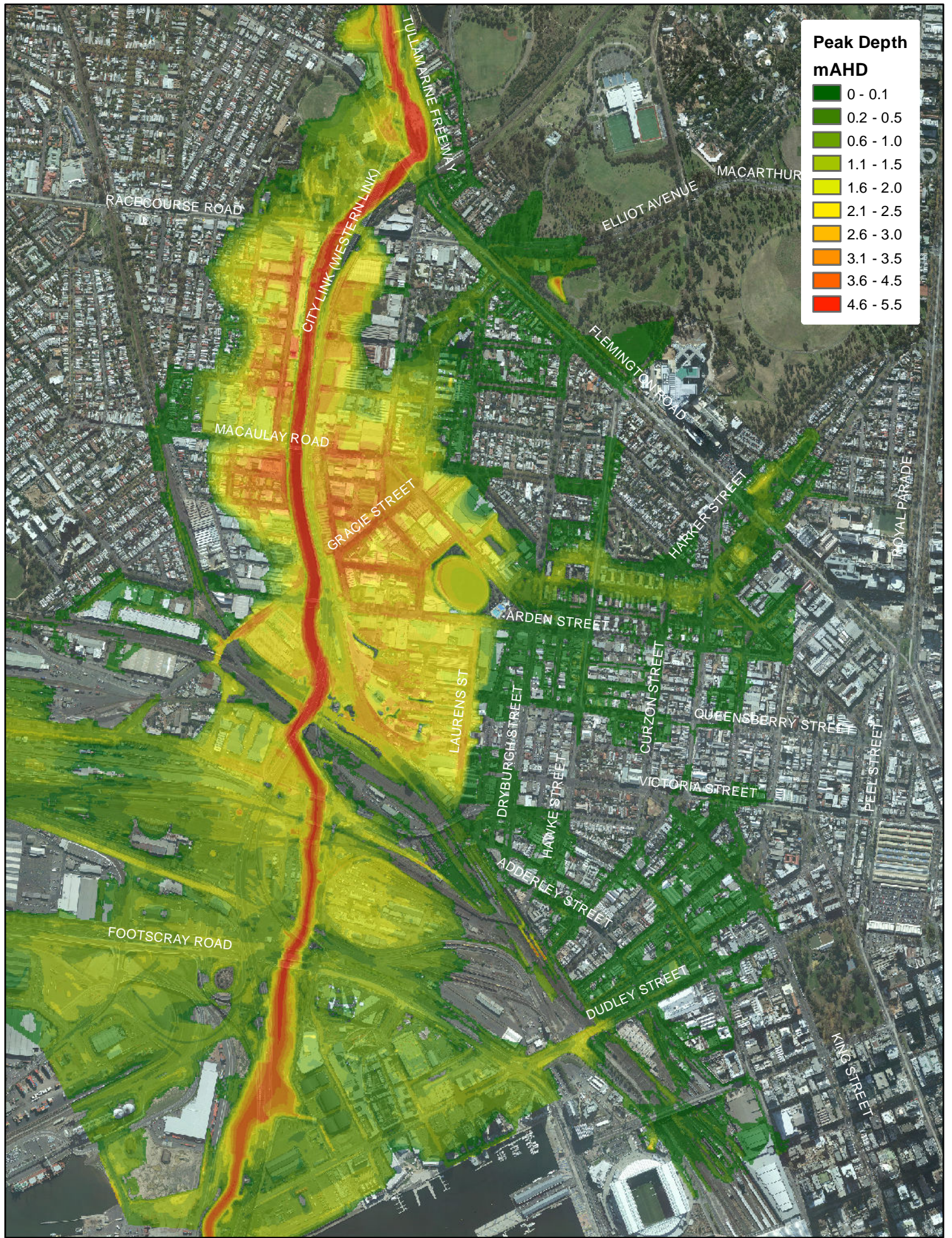
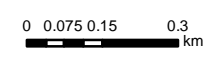


Figure 3.21

Arden-Macaulay Precinct Peak Depth

Year 2100 0.01% AEP



1:15,000 at A4
Projection: MGA Zone 55

Legend

— Water Surface Level (mAHD)

**Water Surface Level
mAHD**

- 1.2 - 2.5
- 2.6 - 5.0
- 5.1 - 10.0
- 10.1 - 15.0
- 15.1 - 20.0
- 20.1 - 30.0



0 0.0075 0.015 0.03
km

1:1,500 at A4

Projection: MGA Zone 55

Figure 3.22

Arden-Macaulay Precinct Peak Water Surface Level

Year 2100 0.01% AEP

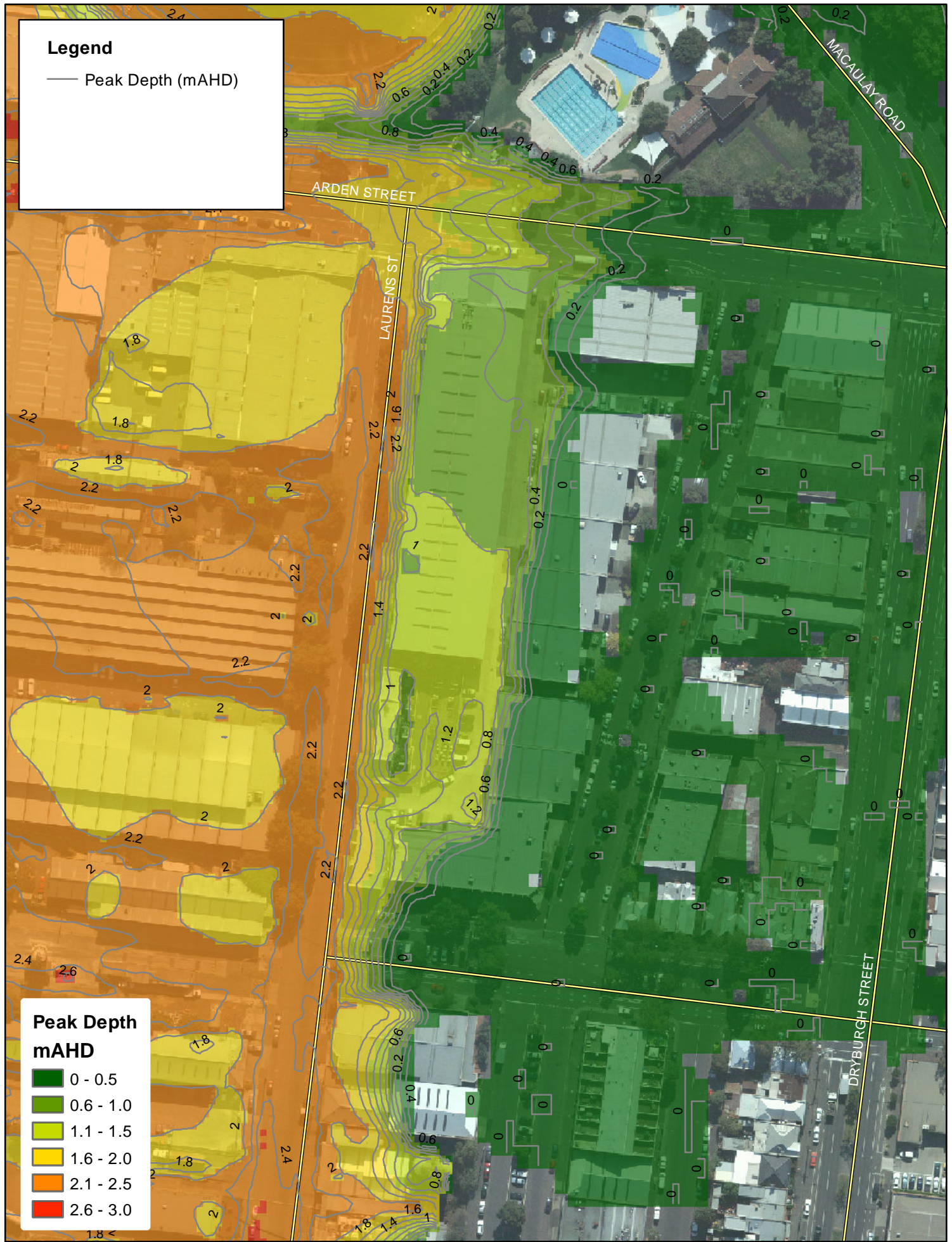


Figure 3.23

Arden-Macaulay Precinct Peak Depth

Year 2100 0.01% AEP



0 0.0075 0.015 0.03 km

1:1,500 at A4

Projection: MGA Zone 55

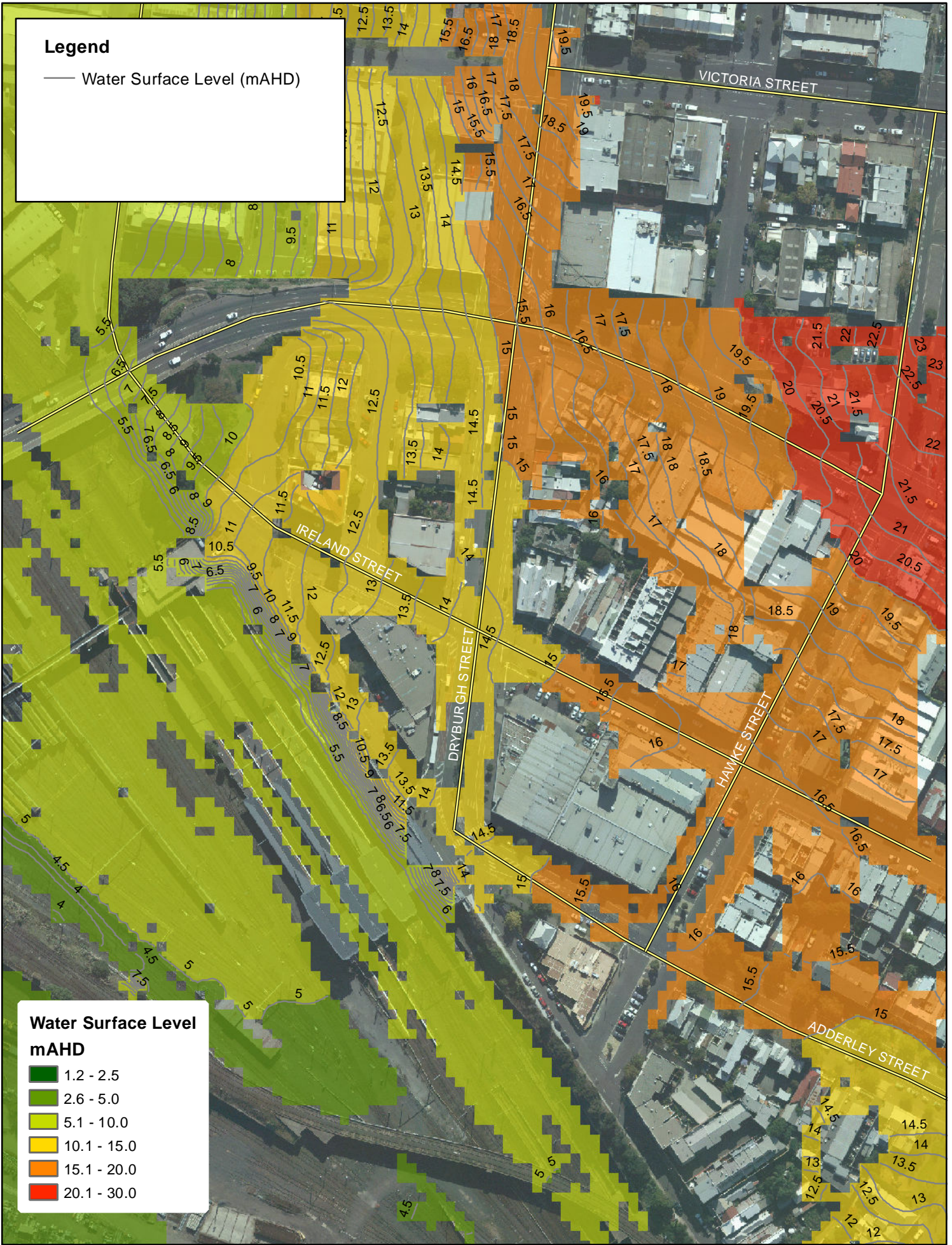


Figure 3.24

Arden-Macaulay Precinct Peak Water Surface Level

Year 2100 0.01% AEP



0 0.01 0.02 0.04 km

1:2,000 at A4

Projection: MGA Zone 55



Legend
 — Peak Depth (mAHD)

**Peak Depth
 mAHD**

- 0 - 0.1
- 0.2 - 0.3
- 0.4 - 0.5
- 0.6 - 0.7
- 0.8 - 0.9
- 1 - 1.1

Figure 3.25

Arden-Macaulay Precinct Peak Depth

Year 2100 0.01% AEP



0 0.01 0.02 0.04 km
 1:2,000 at A4
 Projection: MGA Zone 55



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Appendix C. Peer review report

Melbourne Metro Rail Project

Peer Review Report - Surface Water Impact Assessment

Prepared for:
Secretary for the Department of
Economic Development, Jobs,
Transport and Resources and the
Melbourne Metro Rail Authority

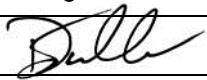
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Report: Melbourne Metro Rail Project
Peer Review Report - Surface Water Impact Assessment

To: Secretary for the Department of Economic Development, Jobs, Transport and Resources and the Melbourne Metro Rail Authority

| DOCUMENT REVISIONS | | | | |
|--------------------|-----------|---|------------|-------------|
| Revision | Date | Details | Checked By | Approved By |
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| 1 | 15/4/2016 | Includes review on behalf of the Secretary for the Department of Economic Development, Jobs, Transport and Resources and the Melbourne Metro Rail Authority | KC, JD | DF |
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| DOCUMENT APPROVAL | | | |
|-------------------|---|----------|---------------|
| Name | Signature | Position | Date |
| David Fuller |  | Director | 15 April 2016 |

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1. INTRODUCTION

1.1 Name and address

David Allan Fuller

Director

DeepRiver Associates Pty Ltd

Unit 1, 16 Powers St, Donvale, VIC 3111

1.2 Summary of qualifications and experience:

1.2.1 I hold the following qualifications:

Bachelor of Science (Physics/Mathematics)

Post-graduate Certificate in Hydrology

Diploma in Statistics

Master of Business Administration

Master of Economics.

1.2.2 For the past 34 years I have been involved in design flood estimation for major infrastructure including dams; flood warning systems; floodplain mapping and management; flood damages assessments; stormwater management; and environmental hydrology. I have worked on major engineering developments across Tasmania, Victoria, South Australia, New South Wales and Queensland. I have worked for environmental and resource management agencies at the State and Federal levels, for local government, for hydroelectric authorities, for regional water supply authorities, for urban developers, and for mining, coal seam gas and energy companies.

1.2.3 My qualifications and experience are detailed in Appendix A.



1.3 Scope

Instructions

1.3.1 I have been retained by Herbert Smith Freehills on behalf of Melbourne Metro Rail Authority & the Secretary to the Department of Economic Development, Jobs, Transport and Resources to prepare this peer review report and, in doing so, to undertake the following tasks:

- Review and comment on the assumptions, methodology, assessment criteria (standards and limits) and scope of the work undertaken in a draft report by AJM to address surface water hydrological issues associated with the project.
- Provide a peer review of the final draft hydrology report including advice as to whether there are any gaps or matters where I disagree with the assessment and which I believe should be addressed.

Assumptions

1.3.2 No substantial technical assumptions were made in forming my expert opinion (refer Appendix B).

People who assisted me in preparation of this report

1.3.3 I have prepared this report based solely on my own expert knowledge. I have not relied upon any other person in making my conclusions.

Documents Relied Upon

1.3.4 Documents relied upon are included in the Bibliography and include a near final version of the surface water report (AJM, 2016)¹.

¹ AJM (2016) is document MMR-AJM-PWAA-RP-NN-000825, dated 24th March 2016



2. OPINIONS

2.1 Summary of Opinions

- 2.1.1 It is my opinion that the near final draft surface water report (AJM, 2016) adequately addresses the EES Scoping Requirement: *Potential effects of construction and construction related works on hydrology* .
- 2.1.2 It is my opinion that the report (AJM, 2016) adequately addresses the following EES Evaluation Objective as it relates to the hydrological aspects of the project.
Hydrology, water quality and waste management – To protect waterways and waterway function and surface water and groundwater quality in accordance with statutory objectives, to identify and prevent potential adverse environmental effects resulting from the disturbance of contaminated or acid-forming material and to manage excavation spoil and other waste in accordance with relevant best practice principles.
- 2.1.3 In particular, it is my opinion that the assumptions, methodology, assessment criteria and scope reported in AJM (2016) are adequate to address the EES Scoping Requirement as outlined above and the EES Evaluation Objective as it relates to the hydrological aspects of the project.
- 2.1.4 It is my opinion that there are no additional matters required to be considered as part of the impact assessment in order to address the EES Scoping Requirement for surface water management as they relate to hydrology. There are no gaps or matters where I disagree with the assessment or which need to be addressed with the extent to which they address hydrology.



- 2.1.5 In my opinion, the authors have taken a suitably conservative approach to assessing the potential impacts of the project on local flood levels and velocities. It is considered unlikely that the actual impacts of the project on local flood levels would exceed those estimated in the report (AJM, 2016).
- 2.1.6 In my opinion the proposed mitigation measures contained in AJM (2016) are sound and appropriate for managing the risk of changes to existing flood levels to either Low or Very Low levels.
- 2.1.7 It is my opinion that the AJM (2016) also provides an insight into the hydrological factors and risks that would be taken into consideration during detailed design to ensure the Melbourne Metro Rail Project operates to meet public safety and operational requirements.



3.COMMENTS ON THE SURFACE WATER IMPACT REPORT

3.1 Scope

- 3.1.1 It is noted that the scope of the report (AJM, 2016) has been limited to the flood related components of surface water management and does not include any consideration of quality or treatment including erosion control related to construction works.
- 3.1.2 The report (AJM, 2016) notes that these other matters are dealt with in the Groundwater, Contaminated Land and Spoil Management, and Aquatic Fauna and River Health reports.
- 3.1.3 It will be important to ensure that those reports address stormwater discharge under various construction and design conditions and that the volumes and peak flow rates of runoff from AJM (2016) are taken into account.
- 3.1.4 For those matters dealt with by AJM (2016), the focus has been on minimising changes to flood velocities, flood volumes and inundation utilising both structural and non-structural methods.
- 3.1.5 As a natural extension to the consideration of the impacts of the project on existing flood levels and velocities during construction and operation, AJM (2016) further investigates preliminary design criteria to protect the Melbourne Metro Rail Project infrastructure and its users.

3.2 Assumptions

- 3.2.1 The assumptions outlined in AJM (2016) are considered appropriate.



3.3 Methodology

3.3.1 The methodology used is consistent with local floodplain management guidelines and Australian risk management standards. It is considered suitable for the purpose of assessment of the project under the *Environment Effects Act 1978*.

Impacts of the Project on Existing Flood Hydrology

3.3.2 The impact of the project on existing flooding was assessed according to the usual Melbourne Water 1 percent AEP standard under both current and future climates (Year 2100).

3.3.3 Although the report relies on existing flood modelling from third parties, the existing flood studies have been subject to peer review by Melbourne Water and the authors have completed sufficient independent evaluation of hydrology and hydraulics to support the conclusions made.

3.3.4 In the absence of any mitigation measures, the authors assessed the risk of changes to local flooding during the construction period as ranging from Medium to Low depending upon the risk event and location considered.

3.3.5 With mitigation measures in place, the risk of changes to local flooding during the construction period are assessed as Low to Very Low.

3.3.6 The key mitigation measure used to achieve this reduction in risk to changes in local flooding during the construction period is the provision of compensatory or balancing flood storage. This is considered appropriate.

3.3.7 During operations, the authors also assessed the residual risks of altering local flood levels and velocities as Low to Very Low with the adoption of mitigation measures as mentioned above. These mitigation measures are also appropriate for operations.



Risks of Flooding on Melbourne Metro Rail Construction and Operations

- 3.3.8 Risks to Melbourne Metro Rail Project construction works are to be minimised by the construction of appropriate levees, barriers and diversions; through the provision of compensatory flood storage; and/or through the adoption of appropriate design flood levels and emergency flood management procedures.
- 3.3.9 With the adoption of these mitigation measures the risk of harm to construction workers is reduced from High or Medium to Very Low for all events considered in the analysis. The mitigation measures proposed are considered appropriate.
- 3.3.10 During operations the key risks of flooding to the Melbourne Metro Rail Project are:
- i) the potential compromise of the safety of commuters or rail staff; and
 - ii) possible short term or long term disruption of rail operations.
- 3.3.11 These risks are related to the potential for riverine flooding from the Yarra River, Maribyrnong River or Moonee Ponds Creek inundating critical infrastructure and/or the entry of flood waters to the tunnels and stations.
- 3.3.12 Mitigation measures are similar to those proposed for construction but include the installation of full height flood gates to protect the tunnels under even the largest conceivable flood event. This is considered an appropriate response to the level of uncertainty associated with riverine flood risk and the major disruption that could be caused if such events do occur.
- 3.3.13 In all events considered in the analysis the assessed operations risk without mitigation measures is High or Medium. Following adoption of the proposed mitigation measures the assessed risk is Very Low in each instance.



3.3.14 It is noted, however, that further work needs to be undertaken during detailed design to establish the final design risk levels for the project.

3.3.15 If operational infrastructure such as flood gates are proposed, it would be expected that regular maintenance operations and emergency management tests would be undertaken to ensure the operation of the infrastructure when needed.



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Victorian Government (2015). *Draft EES Scoping Requirements for Melbourne Metro Rail Project*, October 2015



Appendix A David Fuller Curricula Vitae

A.1.1 Qualifications

I have the following formal qualifications:

Bachelor of Science (Physics/Mathematics), University of Tasmania, 1982

Post-graduate Course in Hydrology, University of New South Wales, 1984

Diploma in Statistics, University of New England, 1988

Master of Business Administration, La Trobe University, 2005

Master of Economics, University of New England, 2014

I have also undertaken the following relevant post-graduate training:

Stochastic Data Generation, University of Melbourne, 1989

Water Quality & Catchment Management, University of Canberra, 1993

A.1.2 Professional Associations

American Geophysical Union

Australian Water and Wastewater Association

International Association of Hydrological Sciences

A.1.3 Employment History

2014 – Current Director, DeepRiver Associates Pty Ltd

2002 – 2014 Senior Principal Consultant, URS Australia Pty Ltd

1991 – 2002 Principal Water Assessment / Manager Land & Water Resource Assessment, Department Primary Industries, Water and Environment, Tasmania

1982 – 1991 Hydrologist / Principal Hydrologist, Hydro-Electric Commission, Tasmania

A.1.4 Key areas of expertise include:

- Flood hydrology including extreme flood estimation, catchment modelling, development of regional estimation procedures, flood frequency analysis and stochastic data generation.
- Stream gauging and water data collection systems
- Water balance and demand modelling including multiple use reservoir systems, yield estimation and drought management.
- Water quality and ecosystem health monitoring and modelling including environmental flow estimation and ecological risk assessment
- Water allocation systems, management and planning.
- Managing trade-offs between resource managers, users, and the environment.
- Hydro-economics & evaluation of water resource investment strategies and programs.
- Development and review of water management policies and strategies.
- Evaluation of water resource investment strategies and programs
- Hydrological statistics, trend analysis and time series modelling

A.1.5 Some relevant project experience includes:

- Expert reviewer, Design Flood Estimation, Stockman Project, Victoria, Independence Group
- Development of Design Flood Estimation Guidelines, Hydro Tasmania
- Floodplain Mapping Projects for Huonville, Latrobe, Deloraine, New Norfolk, City of Charles Sturt, Albury, Longford, Gisborne, City of Knox, Greensvale Reservoir, City of Port Phillip, Yarra City.

- Flood warning systems development and maintenance across urban and peri-urban areas of Tasmania.
- Design Flood Estimation – Lake Glenmaggie, King River Power Development, Anthony-Henty Power Development, Pieman River Power Development, Mt Paris and Cascade Dams.
- Development of Flood Data Books concept in a project funded by Emergency Management Australia
- Committee Member, Development of Australian Flood Management Guidelines
- Review of Mersey-Forth Power Development design flood estimates.
- Member State Flood Warning Consultative Committee, 10 years
- Author, Regional Flood Design Estimation Method for Tasmania
- Review of water management and sustainability issues in the Latrobe Valley, DPI Vic
- Expert reviewer, Water Balance Modelling –Project Nammaldi, Rio Tinto
- Expert reviewer, Water Balance Modelling, Kevin’s Corner Coal Mine, Hancock Coal
- Project Director, Gladstone coal seam gas project water studies and management strategy, Santos
- Review Leader, Impact Assessment of Hydro-reregulation of Tasmania’s Rivers, Basslink Project EIS, Department of Primary Industries, Water and Environment, Tasmania
- Hydrological Peer Review, Optimal Operation of Lake Leake and Tooms Lake, Department of Primary Industries, Water and Environment, Tasmania

- Project Director, Development of Water Balance and Sedimentation Models, Confidential Copper Mine, Indonesia
- Lead Hydrologist, Environmental Impacts of Re-regulating the Menindee Lakes, Government of New South Wales
- Lead Water Specialist, Environmental and Water Management Issues associated with an Ammonia Nitrate Facility, Incitec-Pivot, New South Wales
- Hydrological Reviewer, Impacts of a Proposed Gas Fired Power Station on Wetlands, AGL, Victoria



Appendix B Assumptions

This Appendix contains the assumptions that I have made in completing this report.

- I have assumed that AJM (2016) presents a fair representation of the interactions with Melbourne Water and other regulators; and the criteria used in the project to assess changes in existing flood levels and design flood levels are consistent with interaction as presented.
- I have assumed, that AJM (2016) presents a fair representation of the hydrological and hydraulic modelling undertaken by AJM and that appropriate internal quality control checks have been completed on the detailed modelling.



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