WATER TECHNOLOGY
WATER, COASTAL & ENVIRONMENTAL CONSULTANTS

Expert Opinion - Flooding and Drainage

Amendment C407 to the Melbourne Planning Scheme

Victorian Planning Authority

Panel Hearing

January 2022

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1 REPORT AUTHOR

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Qualifications:

- B.E. (Hons), University of Melbourne, 1993
- MEngSci, Monash University, 2000

Affiliations:

- Fellow, Institution of Engineers Australia, Chartered Professional Engineer.
- Member, River Basin Management Society
- Member, Engineers Australia, Victorian Water Engineering Branch Committee
- Member, Society for Sustainability and Environmental Engineering of Engineers Australia
- Member, Stormwater Victoria
- Member, Australian Water Association
- Member, International Association for Hydraulic Research

Area of Expertise

Key areas of expertise relevant to this report are summarised below.

- Assessment of drainage and flood related issues;
- Expert witness for drainage and flood related issues at environmental effects panels, planning panels and civil hearings.

Statement of Expertise

With my qualifications and experience, I believe that I am well qualified to provide an expert opinion on drainage and flood matters relative to Amendment C407 to the Melbourne Planning Scheme.

2 REPORT CONTRIBUTORS

Bertrand Salmi
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15 Business Park Drive
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Qualifications:

- Bachelor (Hons) of Ecological Sciences (Environmental Sciences), University of Edinburgh 2006
- Master of Sciences, Water Resource Engineering Management, Heriot Watt University 2007

Area of Expertise:

Key areas of expertise relevant to this report are summarised below.

- Assessment of flood and stormwater management;
- Application of GIS.

Scope of contribution:

Bertrand assisted in the preparation of the report, including data review and figure preparation, under my supervision.

3 SCOPE OF REPORT

In relation to Amendment C407 to the Melbourne Planning Scheme, I have been engaged to act as an independent expert on drainage and flooding issues relevant to the proposed implementation of the Arden Structure Plan (August 2021).

I have been asked to review the Arden Macaulay Precinct Flood Management Strategy (Engeny, August 2021) and prepare an expert witness statement with respect to Amendment C407 to the Melbourne Planning Scheme. Specifically, I have been requested to provide my opinion in relation to the following questions:

- Are the RORB and TUFLOW software modelling programs appropriate to assess the flood impacts of development within Arden? Has the modelling covered the area of interest including upstream and downstream of the precinct?
- Is the flood frequency analysis on flow gauge data, used by Engeny to verify the AECOM RORB model reliability, adequate for that purpose?
- Were the refinements to the model made by Engeny sufficient to ensure the modelling was fit for purpose and do you consider the overall modelling parameters to be sufficiently robust to inform the Arden drainage strategy?
- Can measures be put in place to adequately respond to the flooding depths contemplated by the Arden drainage strategy and related modelling, within the Arden precinct?
- Are the Nominal Flood Protection Levels sufficiently conservative? Given that the strategy will be implemented over time, what is the likely consequence for design flood levels within the precinct and how can these be managed?
- Would you make any recommendations with respect to any further work or modelling required to augment the drainage strategy?

4 BASIS OF THIS REPORT

This report is based on a review of draft Amendment C407 to the Melbourne Planning Scheme supporting information and technical reports, including:

- Arden Precinct Structure Plan (August 2021)
- Arden Precinct Background Report (August 2021)
- Arden Macaulay Precinct Flood Management Strategy (Engeny, August 2021)
- Arden Public Realm and Open Space Strategy (AECOM, July 2020)
- Review of additional available information, including:
  - LiDAR (topographical survey) and VicMap data
- Submissions received in respect of Amendment C407 to the Melbourne Planning Scheme
- Relevant guidelines and standards, including:
  - City of Melbourne's *Stormwater Drainage Design Guidelines* (2019)
  - DELWP's *Guidelines for Development in Flood Affected Areas* (2019)
  - *Urban stormwater: best practice environmental management guidelines* (Victorian Stormwater Committee, 1999)

This report has been prepared in accordance with the relevant procedures and practice notes applied by Planning Panels Victoria on Expert Evidence. I have read the "Guide to Expert Evidence" and am aware of my overriding duty to assist the Panel on matters relevant to my expertise.

5 INTRODUCTION

I have been instructed by Harwood Andrews on behalf of the Victorian Planning Authority to provide expert evidence in relation to relevant drainage and flooding matters associated with the proposed Amendment C407 to the Melbourne Planning Scheme.

6 BACKGROUND

6.1 Arden Precinct

Arden Precinct is a 44.6 ha urban renewal precinct located in North Melbourne, as shown in Figure 6-1. The Arden Precinct is located west of North Melbourne's established residential area and south of the Macaulay urban renewal precinct. The Arden precinct is generally bounded by Macaulay Road to the north, Macaulay Road and Dryburgh Street to the east, Upfield railway line to the south/south-west and the Citylink (toll road) and Langford Street to the west. Notable features of this precinct include:

- North Melbourne Recreation Reserve and North Melbourne Recreation Centre and Pool
- Moonee Ponds Creek, which is a highly modified waterway running north to south from Macaulay Road to Dynon Road
- Sections of CityLink tollway and Upfield railway corridors

Current zoning – shown in Figure 6-2 – includes the following zones:

- Mixed Use Zone (predominantly surrounding Laurens Street)
- Public Use Zone 4 (Arden Central land owned by VicTrack)
- Public Parks and Recreation Zone (North Melbourne Recreation Reserve and Clayton Reserve)
- Road 1 Zone (Macaulay Road as far as Boundary Road and Dryburgh Street)
- Industrial 1 Zone (industrial properties fronting the south side of Arden Street and along Munster Terrace)
- Industrial 3 Zone (Arden North)
- Commercial 3 Zone (properties fronting the south side of Macaulay Road west of Boundary Road)

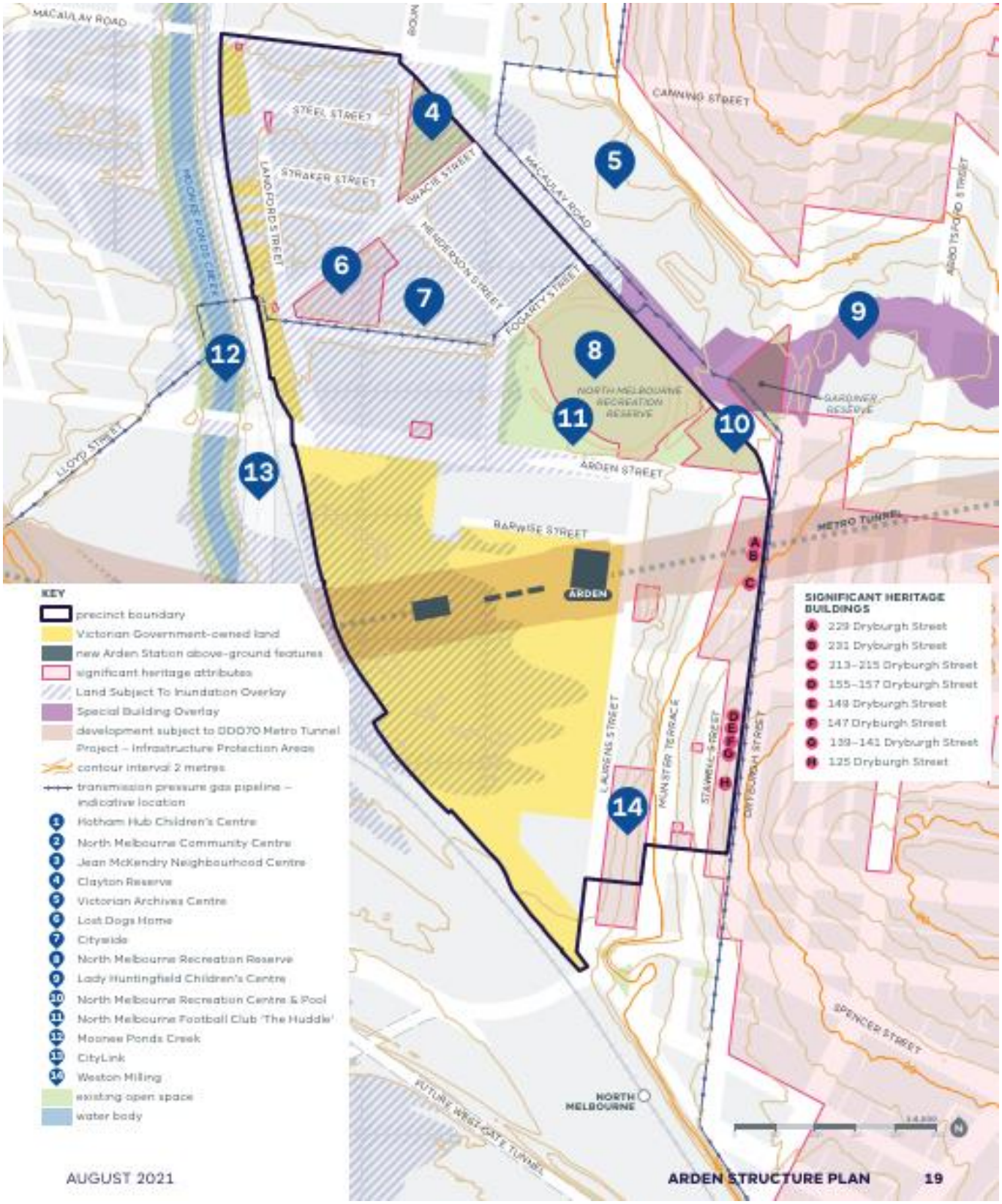

Figure 6-1 Arden Precinct

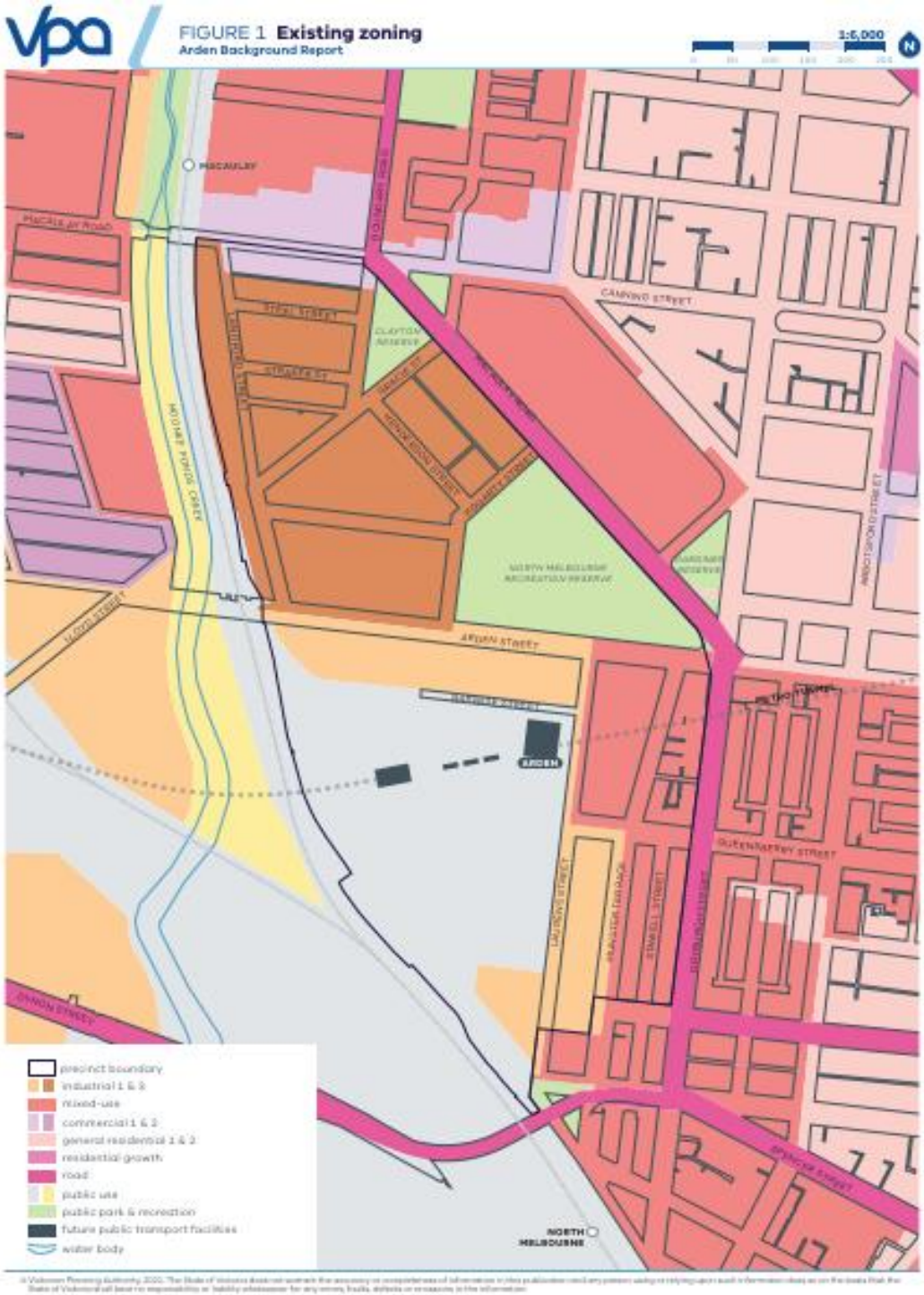

Figure 6-2 Current Zoning

The precinct contains the following overlays:

- Heritage Overlay (HO869, HO1092, HO1111, HO1095, HO1110, HO455, HO1096, HO1106, HO286, HO473, HO305)
- Flood-control Overlays:
  - Land Subject to Inundation Overlay (LSIO)
  - Special Building Overlay (SBO)

- Development Contributions Plan Overlay (DCPO3, DCPO2)
- Design and Development Overlay (DDO26, DDO31, DDO32, DDO66, DDO63-A3, DDO70)
- Parking Overlay (PO12)
- City Link Project Overlay
- Environment Audit Overlay
- Environmental Significance Overlay (ESO2)
- Special Controls Overlay (SCO22)

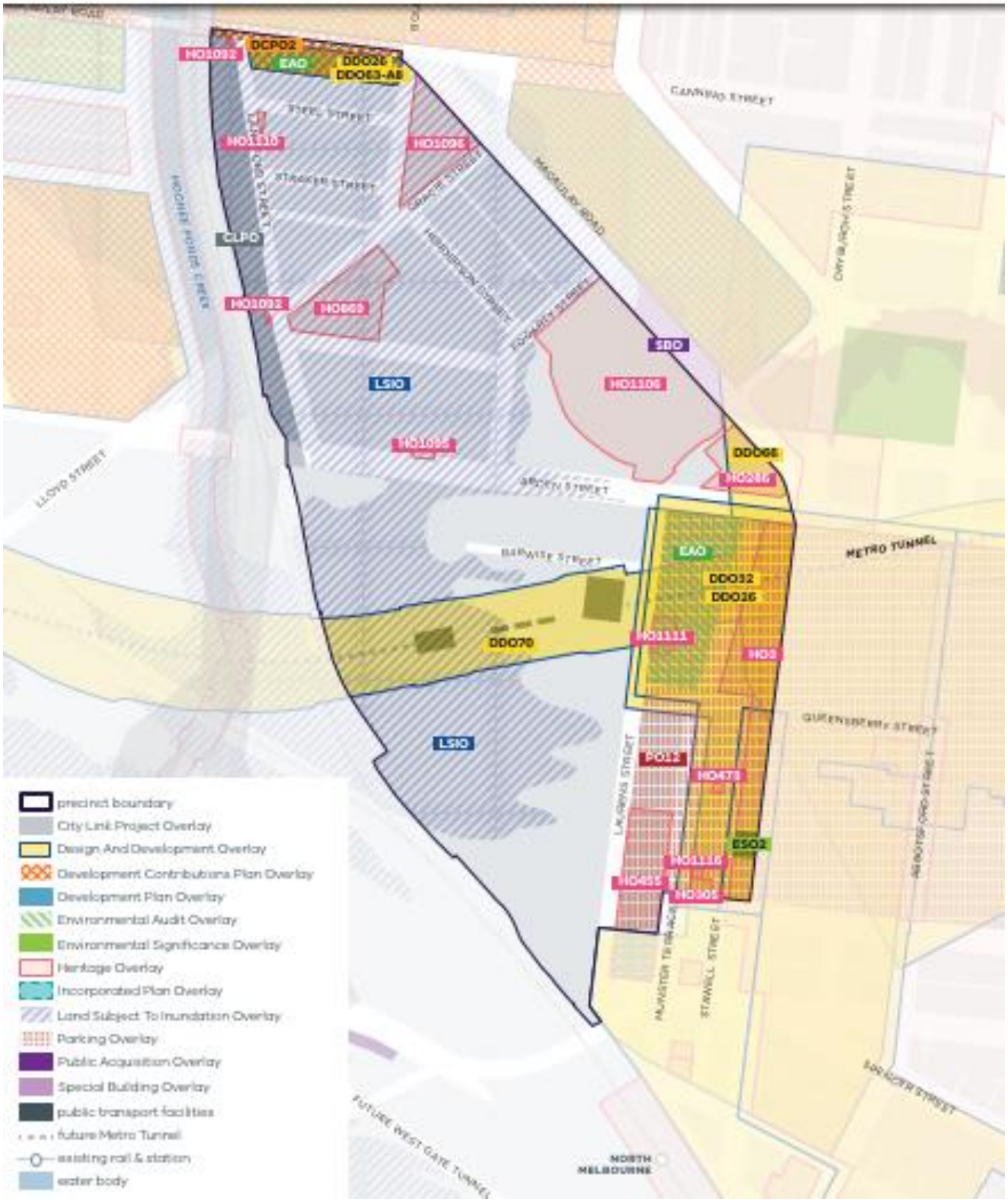

Figure 6-3 Current Overlays

6.2 Proposed Amendment

The Amendment proposes to introduce planning controls to implement the Arden Structure Plan, August 2021 (Structure Plan). In particular, the Structure Plan divides the Arden precinct into four precincts – Arden North, Arden Central – Innovation, Arden Central – Mixed-Use, and Laurens Street.

Proposed planning change include:

- Rezoning land to the Special Use Zone;
- Applying overlays including:
  - A Design and Development Overlay1
  - A Buffer Area Overlay
  - An Environmental Audit Overlay
  - A Development Contributions Overlay
  - Public Acquisition Overlay;
- Revising local planning policy.

I also understand that it is proposed to revise the LSIO which applies to the precinct in line with updated 1% AEP design flood modelling, via the proposed Amendment C384 to the Melbourne Planning Scheme led by the City of Melbourne. This would be a significant change as much of the precinct was formerly a low-lying wetland and a significant area is prone to flooding, as shown in Figure 6-4 and discussed in the following section.

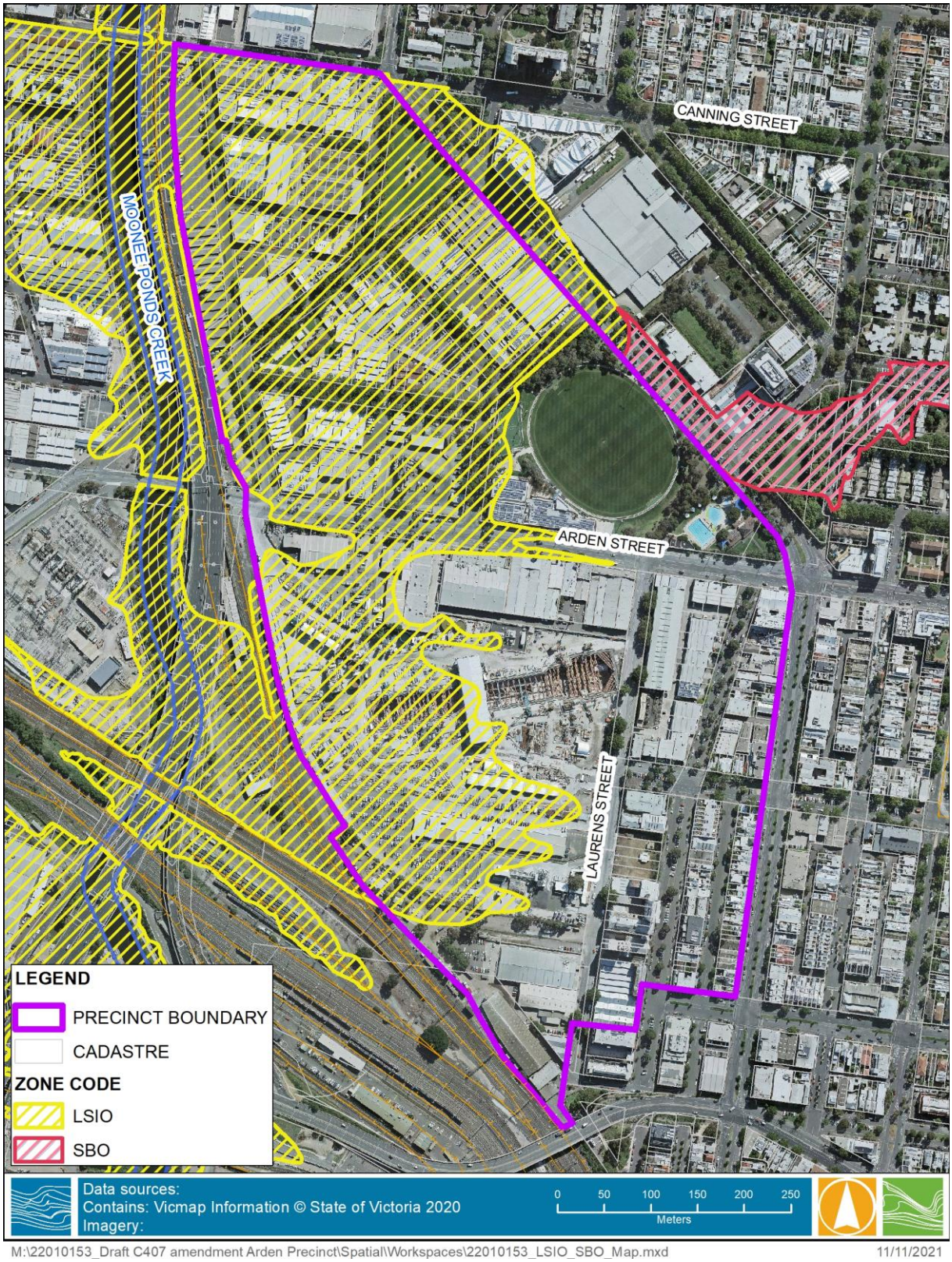

Figure 6-4 Current Flood Overlays

6.3 Amendment C384

Amendment C384 seeks to update the flood overlay maps and schedules to ensure new developments respond to existing and future flood risk. Relevant to the Arden Macaulay Precinct, the following planning scheme overlays are proposed to be implemented as part of Amendment 384:

- Land Subject to Inundation Overlay Schedule 3 (LSIO3), a Melbourne Water referral overlay relating to Moonee Ponds Creek.
- Special Building Overlay Schedule 2 (SBO2), a Melbourne Water referral overlay relating to the Arden Street Main Drain overland flow path.
- Special Building Overlay Schedule 3 (SBO3), a City of Melbourne referral overlay relating to overland flow associated with some parts of City of Melbourne's drainage system.

Amendment C384 is currently being exhibited.

7 FLOOD MANAGEMENT PLAN

Engeny have prepared the Arden Macaulay Precinct Flood Management Strategy (August 2021), to support the re-development of the Arden Precinct, as well as the adjacent Macaulay Precinct to the north and west. This is a critical piece of work, as the Arden and Macaulay Precincts have significant areas liable to flooding (see Figure 7-1) and, as highlighted in the flood management strategy, "*the severity of flooding is not compatible with development*".

The Flood Management Strategy identifies both structural and non-structural mitigation measures, to allow development to take place within the precinct. Figure 7-2 shows the layout of the proposed working drainage strategy. Importantly, the drainage strategy was prepared with allowance for 2100 climate conditions. This incorporates sea level rise, resulting in elevated tailwater conditions in Port Phillip and the Yarra River, along with increased storm rainfall intensity. Proposed drainage infrastructure includes:

- Upgraded levees along Moonee Ponds Creek (see Figure 7-3);
- New flood storage retardation basins, both above and below ground;
- Upgrades to the six existing stormwater pump stations within the precinct and one new pump station;
- Gravity pipe upgrades to cater for local runoff, including pressuring part of Melbourne Water's Arden Street Main Drain.

Detailed hydrologic and hydraulic modelling has been undertaken to understand and optimise the impacts of the proposed drainage infrastructure.

Additionally, the City of Melbourne and Melbourne Water are aiming to implement new flood related planning scheme overlays, based on the 1% AEP design storm for the year 2100 climate change scenario across the precinct (and wider municipality) via Amendment C384. These are discussed in Section 0.

I note that the flood investigation covers both the Arden and Macaulay Precincts. It is necessary that the two areas are combined in this way as they are explicitly linked in a hydrologic sense. It would not be possible to effectively investigate drainage in one precinct without considering what is happening in the neighbouring area.

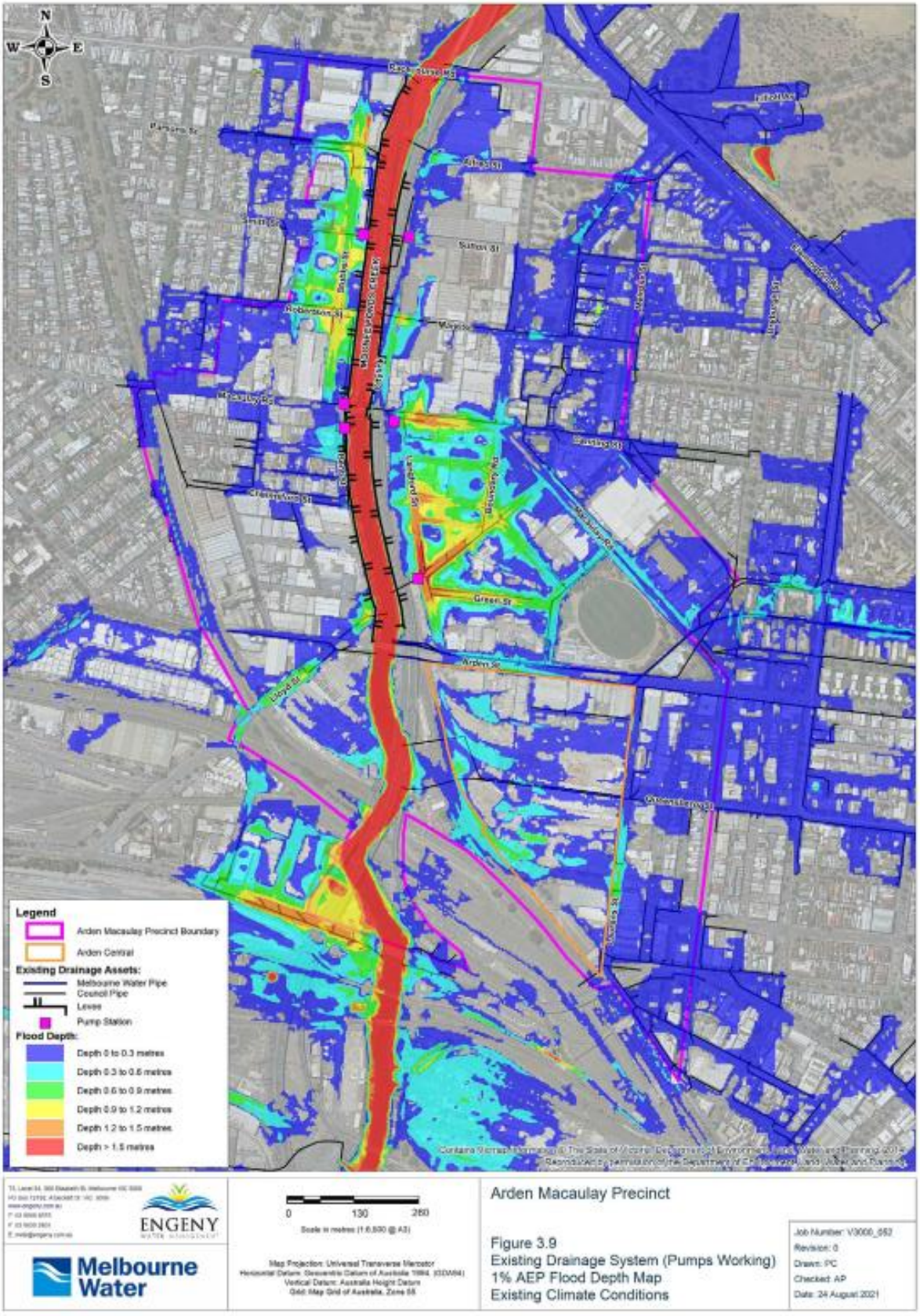

Figure 7-1 1% AEP Flood Extent and Depths for Existing Conditions

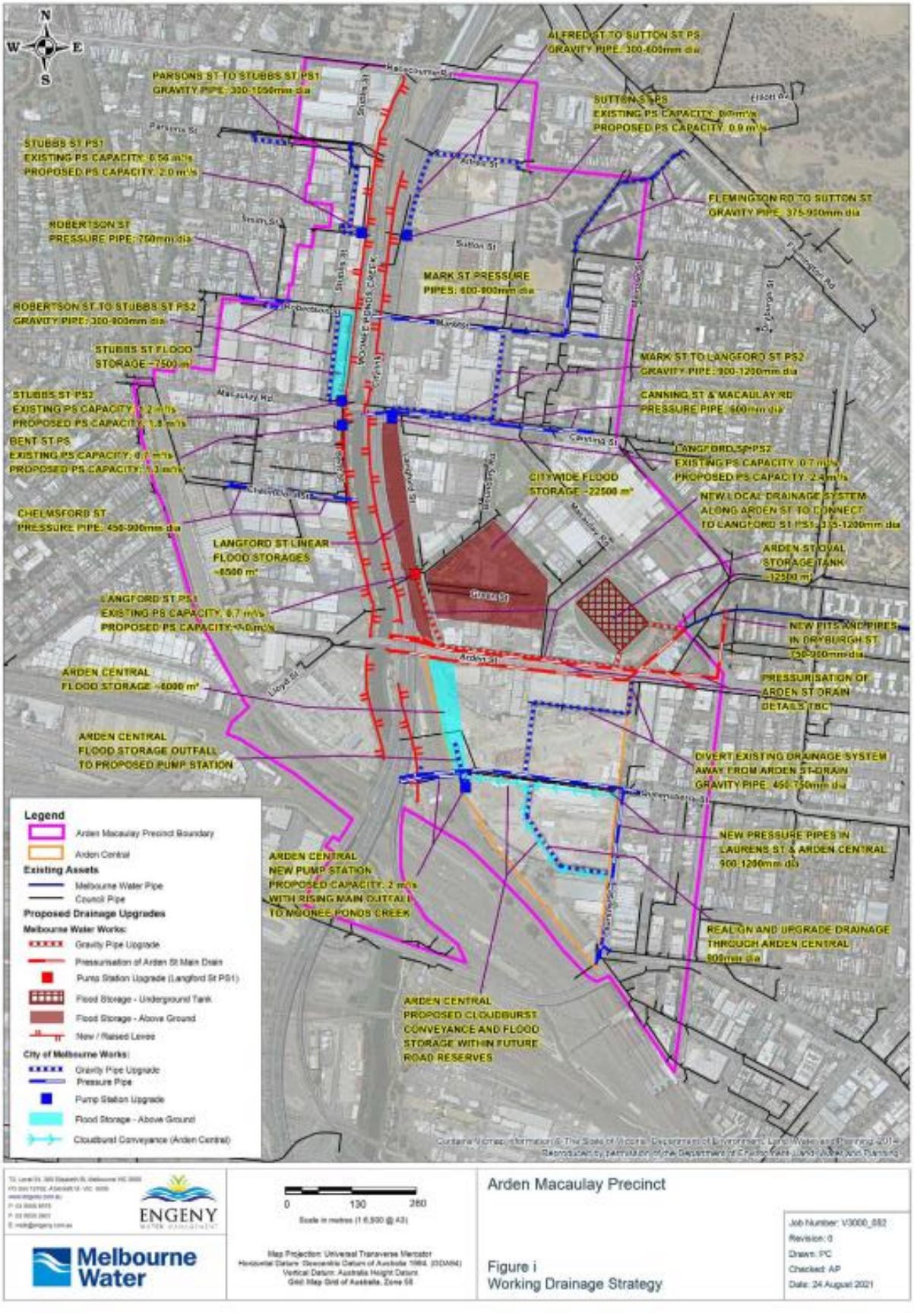

Figure 7-2 Arden Macaulay Precinct Drainage Strategy

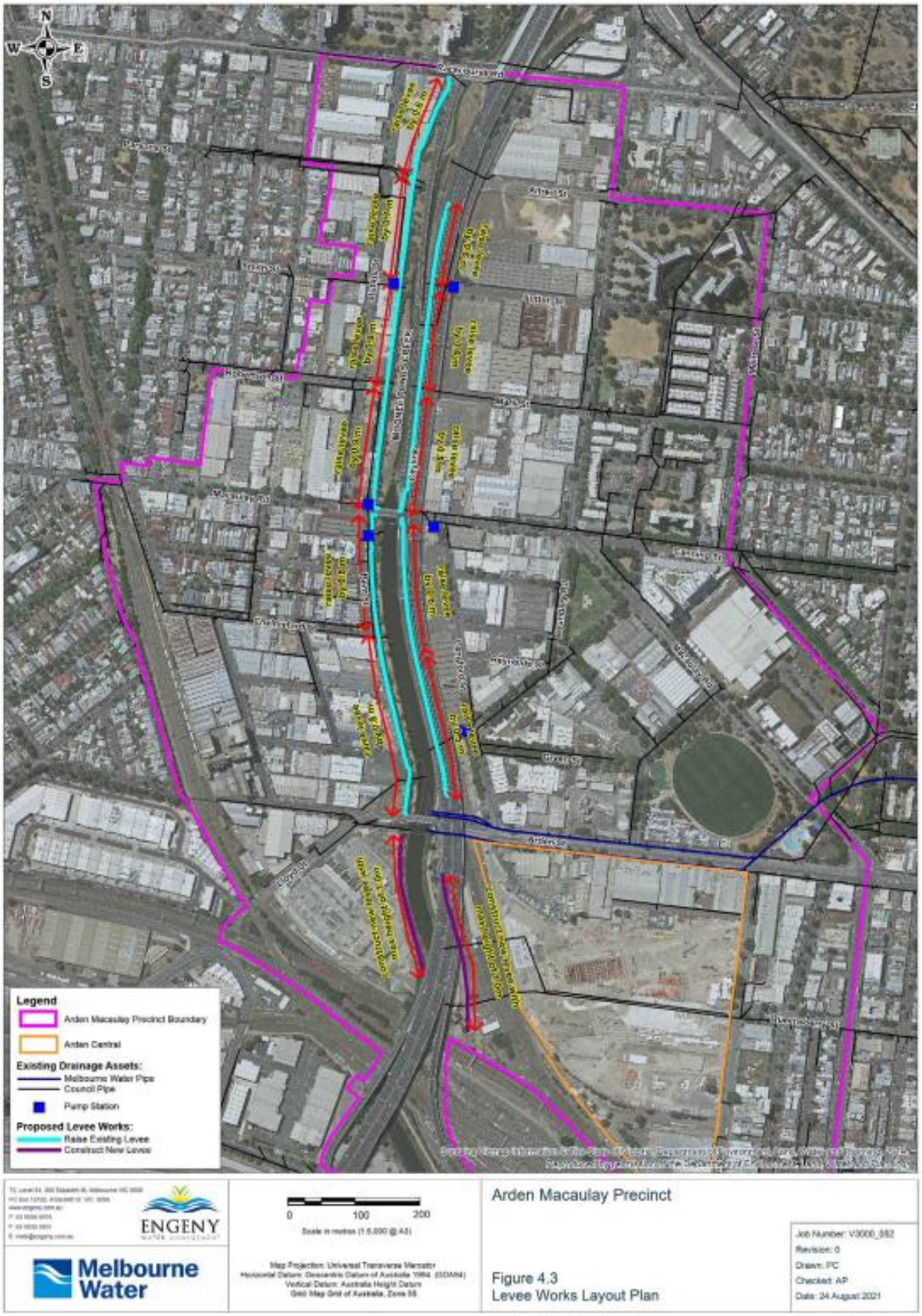

Figure 7-3 Proposed Levee Upgrades

7.1 Flood Modelling

7.1.1 Overview

Flood conditions within the Arden Macaulay Precinct have been assessed under existing conditions and with the drainage strategy in place, using detailed hydrological and hydraulic modelling. Hydrologic modelling determines how much rainfall becomes surface runoff for a particular storm. Current engineering practice typically adopts the “design storm” approach. This applies a theoretical storm with rainfall intensity based on historic rainfall records that relates to a specific probability or likelihood of occurrence. For example, the 1% Annual Exceedence Probability (AEP) design storm is one that has a 1% chance of being expected every year (on average once every 100 years). This is the industry standard approach adopted by Melbourne Water and Councils across Victoria and is consistent with planning regulations and state policy.

Hydraulic modelling typically takes the results of the hydrologic model (the rate and volume of storm runoff) and determines how this flow propagates through the catchment. This can be via pipes, open drains, waterways and overland flow paths. Hydraulic models can also resolve the impacts flow controls such as storages, gates, weirs and pumps.

Flood modelling for the drainage strategy was undertaken using existing hydrological (RORB) and hydraulic (TUFLOW) models developed by AECOM as part of the study documented in the report *Hydrologic and Hydraulic Modelling of Arden Street and E-Gate* (2013). Engeny reviewed these models and they were optimised, using available data, so as to be fit-for-purpose for the Arden Macaulay Precinct flood and drainage investigations. The modelling was undertaken in consultation with Melbourne Water, taking into account their requirements.

7.1.2 Hydrological Modelling

The hydrologic modelling approach was adopted form previous studies for consistency with existing information and investigations in the Moonee Ponds Creek catchment.

In order to validate the Mooney Ponds Creek hydrologic model, flood frequency analysis was undertaken and compared to model outputs. The results of this analysis showed that the peak design flood discharge was consistent for the two approaches and well within acceptable confidence limits. I consider this an appropriate method of hydrologic model validation.

The original modelling undertaken by Engeny was established in 2016 and based on 2013 work by AECOM. The hydrologic model utilised the Australian Rainfall and Runoff 1987 (Engineer Australia) method and data. This method has been superseded by the Australian Rainfall and Runoff 2019 (Geoscience Australia) version of guidance for flood investigations. The latest ARR guidelines were released between 2016 and 2019, hence would not have been adopted for the AECOM study. In 2016, when Engeny started their investigations, the revised guidelines were not complete and had not been widely adopted by industry.

The present study is a conceptual investigation of flood mitigation options and does not set statutory levels or controls. Given the context of the investigation and the agreement of Melbourne Water (the responsible floodplain and drainage authority), the adoption of ARR 1987 is considered appropriate.

Whilst the ARR 1987 approach was generally adopted for the modelling, it is noted that climate change impacts were considered in accordance with ARR2019. The climate change modelling is consistent with the 18.5% increase in rainfall intensity for 2100 climate change conditions that is documented in the Melbourne Water’s *Technical Specifications for Flood Mapping* (2021).

7.1.3 Hydraulic Modelling

Engeny made some refinements to the adopted hydraulic model, including:

- Update to roughness coefficient maps, to better reflect existing conditions, based on aerial imagery.
- Optimise representation of underground drainage infrastructure (pits and pipes).
- Adjustment to downstream boundary conditions, to ensure the peak of the tide in the Yarra River occurs at the end of the design rainfall storm:
  - This approach results in the peak tide level occurring when flows in Moonee Ponds Creek are close to their peak. Whilst this can be considered a conservative assumption, it is also consistent with good engineering practice.
  - Initial water levels have been adopted for each duration storm to match the starting water level of the cyclical tide and prevent a *"backflow wave" from the downstream boundary condition*. This is considered an appropriate approach.

I note that the modelling methodology deviates from Melbourne Water's *Technical Specifications for Flood Mapping* (2021), including:

- A four-metre grid resolution was adopted. Melbourne Water's specification recommend a grid resolution of two to three metres for urban flood modelling:
  - Engeny considered that the adopted model resolution *allows for an adequate representation of catchment topography and overland flow paths in in the model*". I agree with this assessment.
- Modelling timesteps:
  - I agree that the adopted timesteps are "*reasonable and adjusting the timestep would have little impact on the modelling outputs*".

Model health checks, including review of the pre-simulation warnings and mass errors were undertaken. Based on this review Engeny considered the hydraulic model and its outputs were "*appropriate to form the basis of the planning scheme overlays*". I agree that the overall model setup is appropriate to analyse existing and future flood risk and mitigation within the study area.

8 RESPONSES TO INSTRUCTIONS

In this section I address the specific questions provided in my instructions.

8.1 Are the RORB and TUFLOW software modelling programs appropriate to assess the flood impacts of development within Arden? Has the modelling covered the area of interest including upstream and downstream of the precinct?

RORB is a hydrological modelling software used to assess peak design flood flows for rural and urban catchments. It is widely adopted by industry across Victoria and Australia. It is Melbourne Water's preferred model for hydrologic investigations of flooding and is therefore appropriate for the assessment of flood impacts at Arden.

TUFLOW is a widely used hydraulic software package that is suitable for the analysis of overland flows in urban areas. The TUFLOW model routes flows overland across the topographic surface and through pipe systems to simulate flood extents, depths and velocities. This two-dimensional hydraulic package is consistent with best engineering practice and is widely used across the flood industry in Australia and overseas.

RORB and TUFLOW are Melbourne Water's preferred software for flood mapping, as per Melbourne Water's *Technical Specifications for Flood Mapping* (2021). As such, RORB and TUFLOW software modelling programs are appropriate software to assess the flood impacts of development within Arden.

I consider that the modelling undertaken covers the area of interest (i.e., Arden-Macaulay Precinct) and extends sufficiently upstream and downstream to understand potential impacts on adjacent areas.

8.2 Is the flood frequency analysis on flow gauge data, used by Engeny to verify the AECOM RORB model reliability, adequate for that purpose?

Engeny undertook a flood frequency analysis on flow gauge data provided by Melbourne Water for Moonee Ponds Creek at Mount Alexander Road, to assess AECOM RORB model reliability. The flood frequency analysis identified a 1 % AEP flow of 207 m^3/s, which compared well with the existing conditions peak flow of 217 m^3/s estimated from the RORB model. This was considered well within the confidence limits of the flood frequency analysis and as a result, the RORB model was considered fit-for-purpose.

I have also computed a 1% AEP flow estimate based on the Hydrologic Recipes (CRC Catchment Hydrology 1996) and this confirms that the design flow estimates are reasonable.

The reliability of a flood frequency analysis depends on the quality of flow gauging records and the length of record. Longer records provide tighter confidence limits around estimated design flows for more extreme floods. The length of record for Moonee Ponds Creek at Mt Alexander Road is not documented in the report, however it is unlikely to be greater than 30 or 40 years. Records older that this would not tend to be representative of the current catchment conditions in any event. In practice, any reliable annual series record is useful for flood frequency comparison where available, provided the relative reliability based on the record length is considered.

Based on the above, I consider that the flood frequency analysis on flow gauge data, used by Engeny to verify the AECOM RORB model reliability, is adequate for that purpose.

8.3 Were the refinements to the model made by Engeny sufficient to ensure the modelling was fit for purpose and do you consider the overall modelling parameters to be sufficiently robust to inform the Arden drainage strategy?

As discussed in Section 7.1, Engeny made some refinements to the hydraulic model. The changes made to the model, which included refining roughness assumptions (based on recent aerials) and updates to the pipe network, are expected to have improved the accuracy and reliability of the model. Refinement of the pipe network was critical, particularly as the working drainage strategy incorporates upgrades to the underground infrastructure and relies on the performance of the drainage network to predict flood impacts.

The key purpose of the model informing the working drainage strategy is to assess post-works conditions and the differences between existing and developed conditions. In this regard the differences between scenarios are as important as the absolute hydraulic predictions. Engeny undertook standard model health checks that would be applied for this type of investigation to test the model was fit-for-purpose. I therefore consider the overall modelling parameters to be sufficiently robust to inform the Arden drainage strategy.

8.4 Can measures be put in place to adequately respond to the flooding depths contemplated by the Arden drainage strategy and related modelling, within the Arden precinct?

The proposed Working Drainage Strategy will not eliminate flooding within the Arden precinct. Flood impacts will be significantly reduced compared to existing conditions and to more manageable levels, as shown in Figure 8-2. Additional measures will be required to respond to residual flood risk contemplated by the Arden drainage strategy, post-works, as follows:

- Melbourne Water's requirements:
  - Appropriate freeboard to Nominal Flood Protection Levels, controlled by flood overlays, including:
    - **Land Subject to Inundation Overlay (LSIO)**: 600 mm freeboard above the 1% AEP design flood level (based on year 2100 climate change conditions with a pump failure scenario) is required for habitable building floor levels where buildings are impacted by tidal inundation, flooding from Moonee Ponds Creek or ponded stormwater.
    - **Special Building Overlay (SBO)**: 300 mm freeboard above the 1% AEP design flood level (**based** on year 2100 climate change conditions with a pump failure scenario) is required for habitable building floor levels where buildings are impacted by overland flow paths (from local drainage only).
  - Flood-affected properties will need to ensure access is possible with depth of flooding less than 0.5 m for the 1% AEP storm (when pumps operate effectively). Egress depths greater than 0.5 m may be acceptable if the expected duration is less than one hour.
  - If levees are raised or new levees are constructed, no or minimal freeboard is required from the 1% AEP design flood level (2100 climate change condition with pumps) to the crest of the levee.
- City of Melbourne's requirements:
  - 5% AEP level of service, in which the underground drainage system will convey flows to Moonee Ponds Creek with limited overland flow or ponding in streets and no flooding of private property

I note that these requirements are not entirely consistent with the DELWP Guidelines for Development in Flood Affected Areas, although this may be open to interpretation as no category for urban renewal projects such as Arden is specified. Notwithstanding this, Melbourne Water is the relevant floodplain authority and has the power to apply what it considers to be appropriate conditions for development in the floodplain. I am comfortable that the proposed requirements will appropriately address flood risk for Arden.

The Working Drainage Strategy modelling shows:

- Flood depths greater than 0.5 m for the 1% AEP design flood (when pumps operate effectively) along Langford Street and lasting for just under 1 hr (see Figure 8-1).
    - It is likely that unsafe conditions, not meeting Melbourne Water's requirement re: safety access, occur elsewhere within the Precinct.
- 5% AEP flood extent impacting private properties (see Figure 8-3).

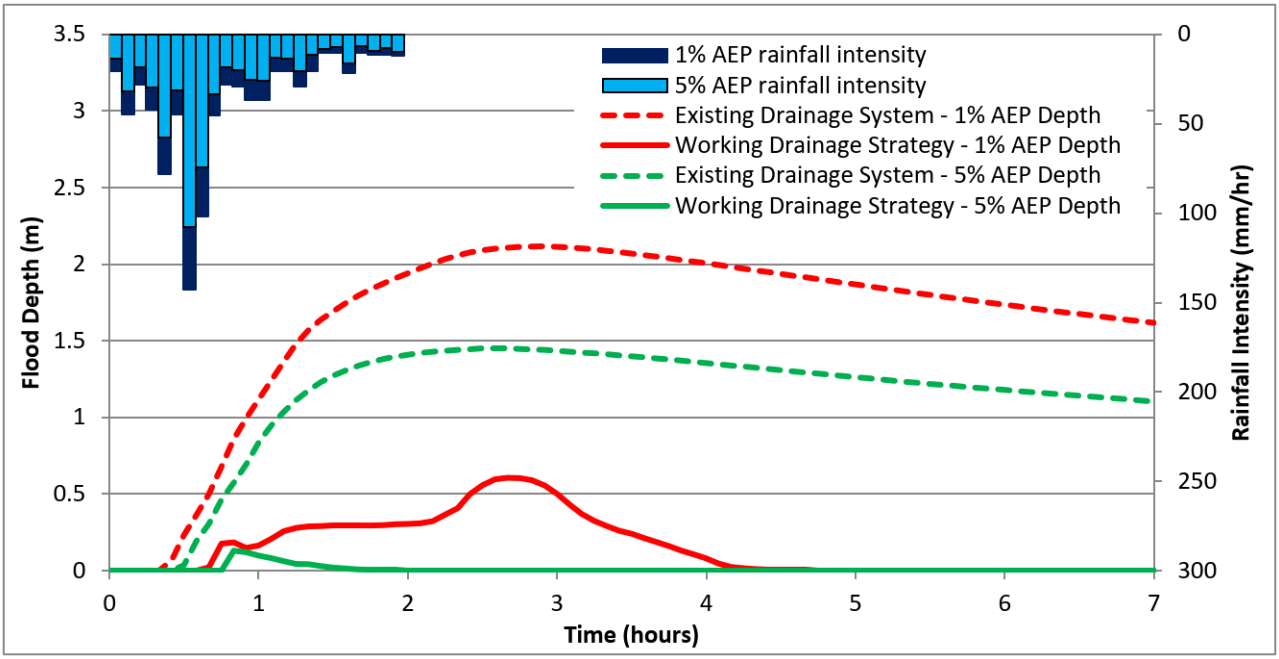

Figure 8-1 Time of Inundation at Langford Street Low Point (source: Engeny, 2021)

Based on the above, it is likely that additional measures will be required to address site-specific flooding issues. This may require additional pipe upgrades (to further alleviate flooding on private properties), raising of roads and paths for access and/or the preparation of Flood Emergency Response Plans as part of a total flood warning system. All of these measures can be considered as part of the planning stage for individual development applications. Alternatively, it may be more appropriate for precinct scale flood response measures to be co-ordinated by Council and Melbourne Water. This would address flood risk at the community scale and not rely on a fragmented approach to flood management with individual properties having separate measures in place. I anticipate the following would occur:

- Stormwater management plans (or similar) will need to be prepared for each development:
    - I note that the *Good Design Guide for Buildings in Flood Affected Areas in Fishermans Bend, Arden and Macaulay* (Melbourne Water, City of Melbourne & City of Port Phillip, June 2021) will provide guidance on how to respond to flood risk for development within these precincts.
- Flood Emergency Response Plans will need to be prepared, in consultation with the relevant floodplain authority, where access is unsafe and/or does not meet Melbourne Water's minimum requirements.

- I note that the Victorian Civil and Administrative Tribunal previously recognised in *Stock Corporation Pty Ltd v Yarra CC [2020] VCAT 958 (4 September 2020)* that development can occur in areas liable to unsafe flooding, provided that a *comprehensive* Flood Emergency Response Plan is prepared to manage the flood risk and minimise the likelihood of needing or requiring the assistance of emergency personnel. Whilst the present amendment process is significantly different to an individual planning application, this is one example of how residual flood risk can be managed through planning conditions.

Based on the flood strategy developed, Melbourne Water's flood management policy and contemporary floodplain management practice, I consider that measures can be put in place to adequately respond to the flooding depths contemplated by the Arden drainage strategy within the precinct. These will be a combination of structural drainage works (as detailed in the Arden Macaulay Precinct Flood Management Strategy) and non-structural measures, implemented through planning processes at both a precinct and local level.

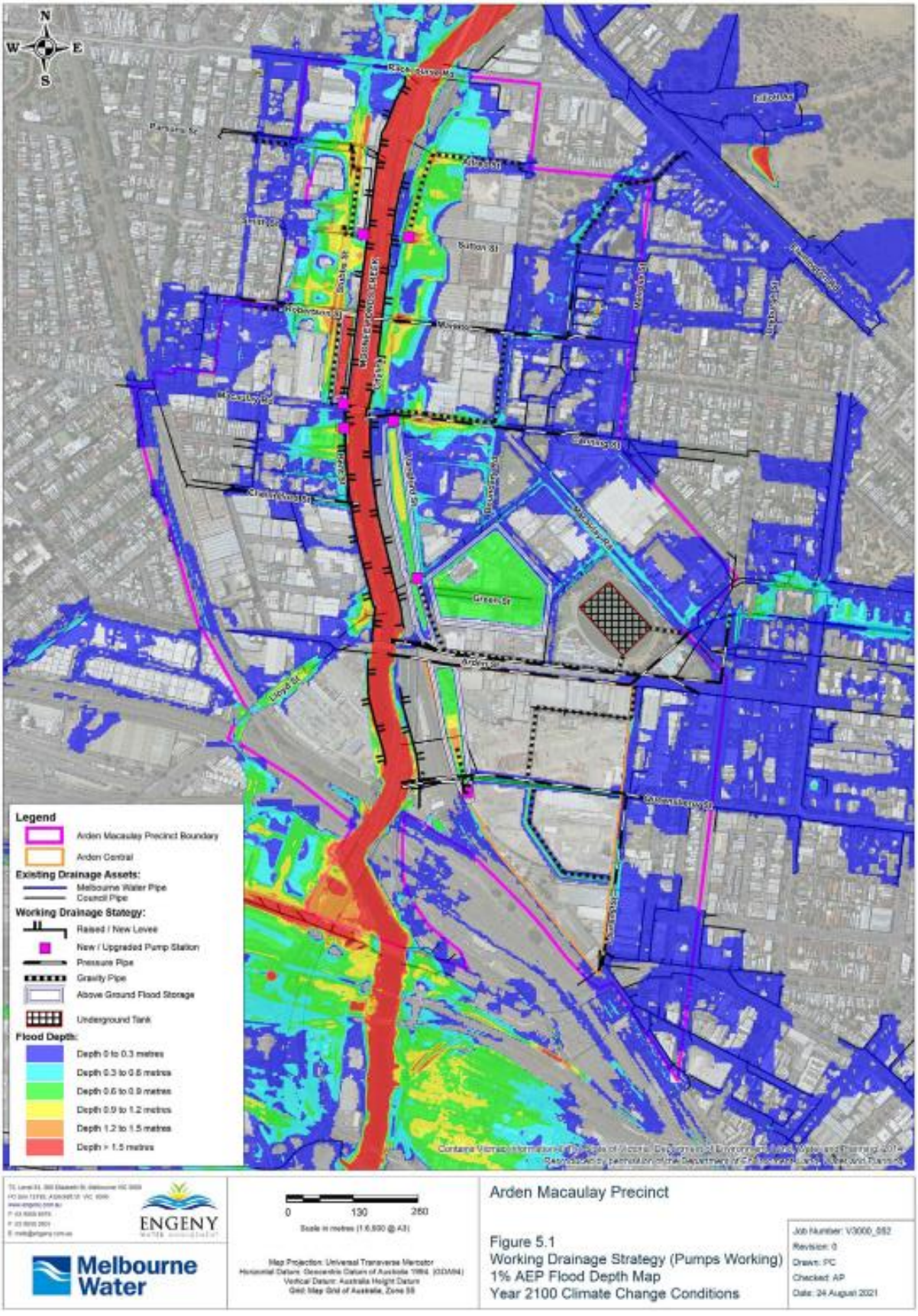

Figure 8-2 1% AEP (with Climate Change) Flood Extent and Depths – with Drainage Strategy in Place

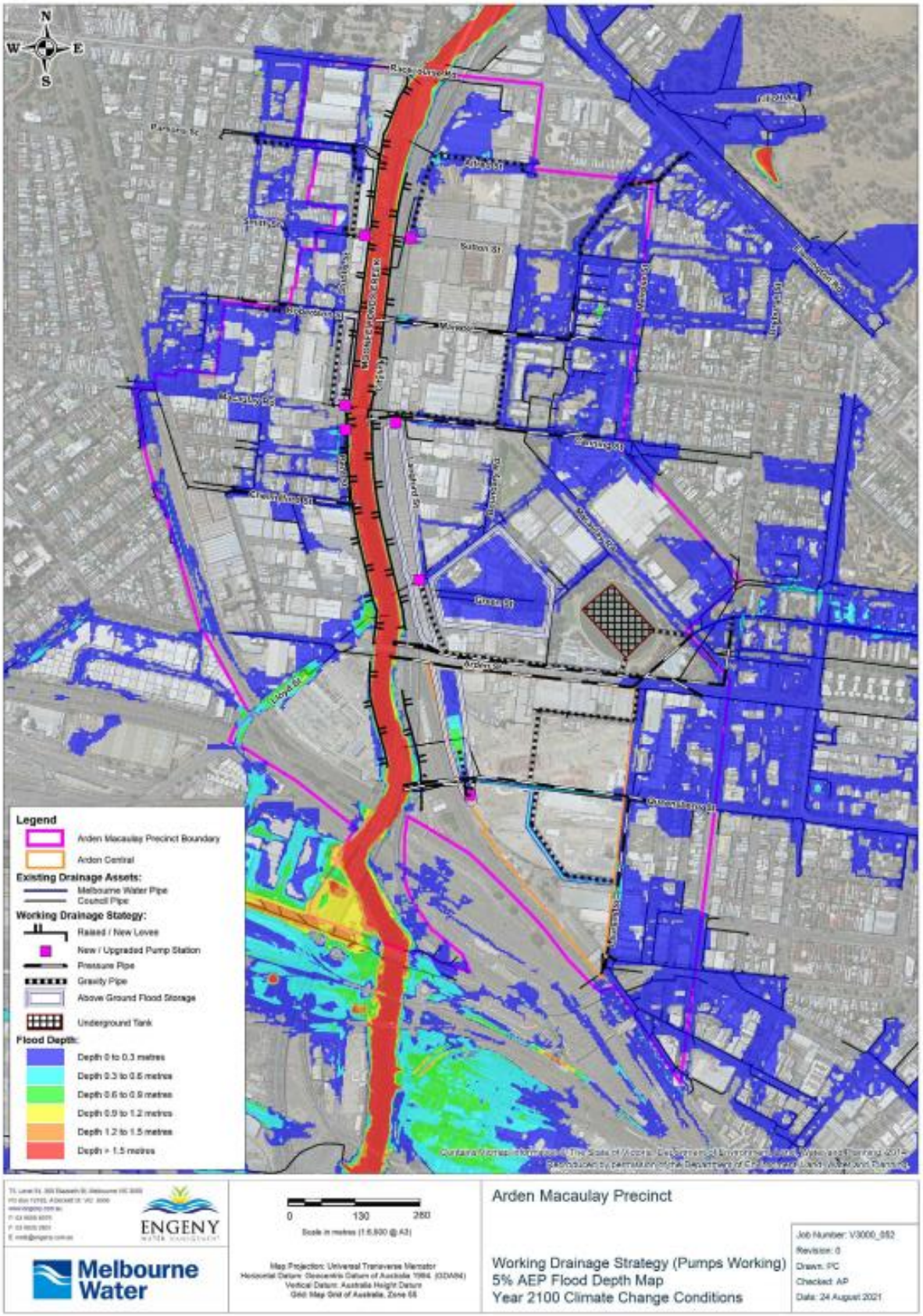

Figure 8-3 5% AEP (with Climate Change) Flood Extent and Depths – with Drainage Strategy in Place

8.5 Are the Nominal Flood Protection Levels sufficiently conservative? Given that the strategy will be implemented over time, what is the likely consequence for design flood levels within the precinct and how can these be managed?

Minimum Finished Floor Levels (FFL) for buildings within flood-prone areas will be set via the planning system through referrals to Melbourne Water. Special Building and/or Land Subject to Inundation Overlays will trigger the referral process for development in flood affected areas (for the 1% AEP design storm), to ensure new developments are designed to manage flood risk with appropriate permit conditions.

Amendment C384 seeks to update the flood overlay maps and schedules to ensure new developments respond to existing and future flood risk. Effectively, Finished Floor Levels will be set to the applicable Nominal Flood Protection Levels (i.e., 1% AEP flood levels + freeboard). The flood modelling supporting the revised planning overlays within Arden (based on Arden Macaulay Precinct & Moonee Ponds Creek Flood Modelling, Engeny 2020) will be used to inform Nominal Flood Protection Levels. It is important to note that Amendment C384 is based on the 1% AEP with climate change case (i.e., 18.5% increase in rainfall intensity by the year 2100) for the existing condition scenario. The overlays themselves do not set the Nominal Flood Protection Level. Through the permit referral process, Melbourne Water can provide updated design flood levels if new information becomes available, regardless of whether the flood overlay has been updated or not.

I consider this approach is appropriate given that the Arden Macaulay Precinct working drainage strategy will likely be implemented over several years and existing baseline modelling will provide conservative Nominal Flood Protection Levels (as it is based on 2100 climate change conditions). Whilst future works may be well planned, there is no guarantee that the works would be in place at a particular time in the future, hence planning advice needs to consider the existing conditions along with any likely future changes. This approach may, have the following implications:

- As the working drainage strategy is implemented, design flood levels may change within the Arden Macaulay Precinct, in areas protected by the mitigation works. This in turn may change minimum Finished Floor Levels for new development.
    - The City of Melbourne and Melbourne Water can manage this risk by keeping up-to-date flood maps, to ensure Finished Floor Levels reflect flood risk (at the time of the application) and benefits from the drainage works.
    - Modelling should also reflect any changes in the drainage design.
- Should Amendment C384 and the Amendment C407 (with the current working drainage strategy) be adopted, it will be important that flood information relied upon by the City of Melbourne and Melbourne Water to manage flood risk for properties subject to inundation in the 1% AEP design flood are kept up-to-date. There are mechanisms, other than the Planning Scheme, to ensure Finished Floor Levels are above Nominal Flood Protection levels, such as the *Building Regulations* 2018:
    - Council is required under the *Building Regulations* 2018 to make an up-to-date copy of each designated special area map applicable to its municipal district that has been prepared under these regulations (#148), available to the public for inspection.
    - This will be especially important for any areas where flood risk increases as a result of the implementing the Arden Macaulay Precinct flood strategy.
        - It is important to note that the 1% AEP flood levels increase for areas outside of the Arden Precinct. These are shown by the warm tone colours in Figure 8-4.

- Some of the predicted increases are up to 500 mm, which would be greater than the freeboard allowed for in overland flow areas (typically 300 mm) and the majority of the freeboard allowed for riverine flooding areas (typically 600 mm).

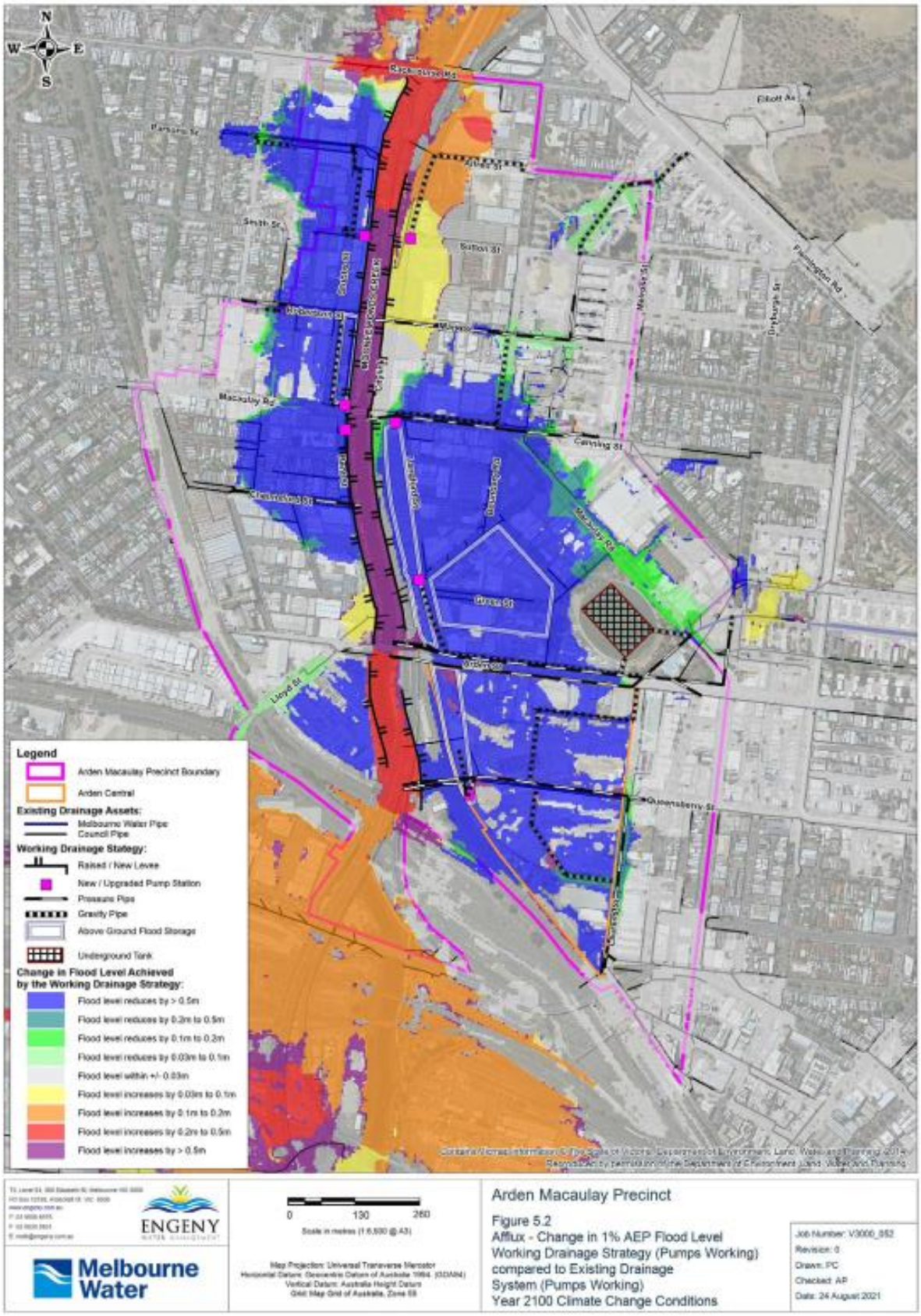

Figure 8-4 Afflux Map, 1% AEP Design Storm (source: Engeny, 2021)

8.6 Would you make any recommendations with respect to any further work or modelling required to augment the drainage strategy?

The Arden Macaulay Precinct Flood Management Strategy modelling (see Figure 8-4) predicts there to be significant peak flood level increases (afflux) upstream and downstream of the Arden Macaulay Precinct, including areas not currently covered by an SBO/LSIO. This shows broad areas of 100 to 200 mm predicted increase downstream, with up to 500 mm and greater in isolated locations. There are also predicted to be increases within the strategy area itself, however these are generally considered acceptable, as residual flood risks can be managed through the redevelopment process. It is a standard requirement of Melbourne Water and Council – in accordance with DELWP's *Guidelines for Development in Flood Affected Areas* (2019) – that there is no increase in peak design flood levels on adjoining land over a range of storm magnitudes and in particular for the 1% AEP design storm.

Figure 8-4 provides an afflux map which shows the potential impact of the flood mitigation works within the Arden and Macaulay Precincts for the 1% AEP design storm, 2100 climate conditions. It is evident that there is generally a significant reduction in flood levels across the Arden North and Arden Central precincts, as shown with the blue and green colours across the precincts. As noted above, there are also detrimental impacts upstream and downstream of the Arden and Macaulay Precincts, as shown with the yellow, orange, red and purple colours. The afflux shown in Figure 8-4 exceeds acceptable limits for development.

It is important that this external impact is addressed prior to the implementation of the flood management strategy. Investigations to date have clearly focussed on the development of a working strategy to mitigate flooding within the Arden and Macaulay precincts. Through the detailed design and implementation process for the flood management strategy, Melbourne Water will need to further investigate the external impacts and ensure they are appropriately addressed.

The assessment of external impacts should involve:

- Identifying the full extent of potential flood impact (afflux) upstream and downstream.
- Determine different levels of impact and which areas and landowners are affected.
- Explore mitigation options to address impacts. This could include:
  - Agreements (dispensation) of affected landowners (public or private).
  - Optimisations of the working drainage strategy to reduce off-site impacts.
  - Local mitigation measures for areas outside the Arden and Macaulay precincts to address flood impacts at the local or site scale. This could include options such as bunding or flood proofing.

Whilst the proposed working drainage strategy for the Arden Macaulay Precinct does not comply with all four design criteria for flood management outlined in DELWP's *Guidelines for Development in Flood Affected Areas* (2019), I believe that this can be achieved. It is recognised that the currently predicted afflux is not a consequence of the proposed Arden development, but rather a consequence of the mitigation measures to facilitate that development. Under the proposed flood management strategy there will be residual flood risks that are to be managed largely through non-structural measures. This may include planning instruments along with measures such as community flood awareness and preparedness. This process will be managed by Melbourne Water as the responsible floodplain and drainage authority as described in Melbourne Water's Arden Precinct Flood Management Policy (Jan 2022).

If external impacts cannot be mitigated, the possibility exists to "scale back" the proposed precinct flood mitigation works to find an acceptable solution. This may result in a greater level of residual flood risk in the Arden Precinct which could be managed in a similar way to that which is current proposed.

I recommend that the following additional work be undertaken:

- Further modelling to refine and optimise (where possible) the Arden Macaulay Precinct Drainage Strategy to minimise external flood impacts. I consider that this can occur without any changes to the Arden Structure Plan as it would only involve modifications the current design, within existing footprints.
- Explore what agreements and/or dispensations may be sought from affected landowners where unacceptable flood impacts are predicted.

9 SUBMISSIONS

I have responded to issues raised by submissions related to Amendment C407, as relevant to my expertise, in Table 9-1. Please note that I have grouped similar flooding and drainage issues together, where appropriate.

Table 9-1 Summary of Matters Raised in Submissions

Concerns Raised	Comments
Naturalisation of Moonee Pond Creeks	The Flood Management Strategy outlines a number of options considered to reduce the impact of the increased flood levels in Moonee Ponds Creek due to the levee upgrade, including works within Moonee Ponds Creek. These options (e.g., creek widening) were ultimately discounted, generally due to the limited benefits they provide, existing constraints (e.g., buildings) and/or their high costs or uncertainty regarding engineering feasibility.
Levee upgrades will result in the loss of existing vegetation	The details of levee design and construction will be a matter for subsequent detailed investigations. Such works would typically require standard approvals related to engineering and environmental aspects.
Amendment C407 does not propose any modification to the flooding provisions that currently apply throughout the precinct, despite the degree to which the management of flooding and drainage has influenced the development of the Arden Structure Plan and the associated planning controls	Amendment C384 seeks to update the flood overlay maps and schedules to ensure new developments are designed appropriately, considering existing flood risk. It does not, however, account for changes in flood risk as a result of the proposed working drainage strategy once implemented. The flood modelling clearly indicates that the proposed works will influence flooding within Arden Precinct, as development progresses and flood mitigation measures are implemented. Risks associated with this are discussed in Section 8.5, noting that Melbourne Water and City of Melbourne will need to keep up-to-date flood information, to ensure NPFLs are informed by latest flood intelligence. I consider it appropriate that flood-related aspects of the planning scheme are addressed in a separate Planning Amendment.

Concerns Raised	Comments
Pollution/littering as a result of the development	It is evident that the Ardent Precinct Structure Plan intends to promote a high standard of Integrated Water Management practice. This is identified in Strategy 19.43, which aims to "*facilitate integration of water sensitive urban design into streets and green links including along the Fogarty Street and Queensberry Street urban boulevards and Arden Street*". The URCRS allows for the provision of water quality treatment projects. Individual developments are expected to require WSUD measures (in accordance with Planning Scheme requirements and relevant policy) to achieve appropriate water quality outcomes. Every new development would be required to be supported by a stormwater management plan (or equivalent), which will identify measures required to meet Best Practice stormwater management objectives. These will likely include stormwater harvesting systems and *in-situ* water quality treatment assets (such as raingardens).
Distributed RWTs may impact on water yield of centralised water re-use systems (and thus their economic value).	It will be important for the relevant authorities, including City West Water, City of Melbourne and Melbourne Water to work collaboratively to identify the most holistic integrated water management options and rainwater/stormwater harvesting solutions, to benefit the wider community. In general, the upstream stormwater catchments, along with the excess urban runoff from the precinct will be sufficient to supply both lot-scale and centralised stormwater harvesting schemes.

Concerns Raised	Comments
Proposed changes in zoning and land use from largely industrial to a mixed use residential and innovation precinct will require a change to the level of service for flood protection.	Level of service for flood protection is dependent on land use and localities. The City of Melbourne's *Stormwater Drainage Design Guidelines* (2019) require: • New Council drains constructed within high density or growth areas (CBD, Southbank, Docklands, Arden Macaulay and Fishermans Bend) are to be designed for a 5% AEP capacity with an additional allowance for increased rainfall intensity due to climate change; • Council drains constructed in all other areas are to be designed for a 10% AEP capacity with an additional allowance for climate change. The proposed changes in zoning and land use from largely industrial to a mixed use residential and innovation precinct would indeed require a change to the level of service for flood protection however, this has been allowed for in the specified level of service for the precinct (i.e., 5% AEP for minor drainage, 1% AEP for major drainage). Additionally, industrial areas typically have a greater level of service for minor drainage (10% AEP to 5% AEP) compared to residential area (typically 20% AEP). The level of service for flood protection (major drainage) would remain the 1% AEP, as currently proposed in the flood management plan for the Arden Macaulay Precinct. The present, historic drainage infrastructure does not meet current levels of service.

10 CONCLUSIONS

With respect to the proposed Amendment C407 to the Melbourne Planning Scheme and surface water management issues, I make the following conclusions:

- The Arden Precinct is located in an area with significant legacy flood risk.
- Due to the nature of development and built form, the opportunities for flood mitigation are highly constrained.
- The flooding and drainage investigations undertaken for the Arden Macaulay Precinct Flood Management Strategy are detailed and of an appropriate method and standard to support the Arden Structure Plan.
- Extensive mitigation option testing has been undertaken to achieve a practical drainage strategy.
- The proposed strategy options are an appropriate response to flood mitigation for the precinct. Whilst alternative options could be formulated, the justification for the adopted measures is sound.
- There will be residual flood risk after full implementation of the mitigation scheme. This residual flood risk should be managed through appropriate non-structural mitigation measures such as planning controls and flood response plans.
- Potential flood risk increases outside of the Arden Precinct, attributable to the proposed mitigation measures, should be addressed before the mitigation proceed.

11 DECLARATION

I have made all the inquiries that I believe are desirable and appropriate and that no matters of significance which I regard as relevant have, to my knowledge, been withheld from the Planning Panel.

Warwick A Bishop

B.E. (Hons), MEngSci, FIEAust

24 January 2022

APPENDIX A – CV

WARWICK BISHOP

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Director

BE (Hons), MEng Sci (Water)

FIEAust, CPEng, NER

QUALIFICATIONS

- Bachelor of Engineering with Honours (Civil), University of Melbourne, 1992
- Masters of Engineering Science (Water), Monash University, 1999

AFFILIATIONS

- Fellow, Institution of Engineers, Australia, Chartered Professional Engineer
- Member, International Association for Hydraulic Research
- Member, Australian Water Association
- Member, River Basin Management Society
- Member, Stormwater Victoria
- Member, Engineers Australia Victorian Water Engineering Branch Committee

SUMMARY

Warwick is a Director of Water Technology and has over 25 years' experience in hydrologic and hydraulic investigations, specialising in the development and calibration of rural and urban hydrologic and hydrodynamic models and their application to flooding, water quality, sediment transport and environmental values. He also has extensive experience in coastal and estuary modelling including wave, current and oil spill investigations. He has worked extensively in the Murray Darling Basin, principally on environmental hydraulic investigations for the Living Murray Program. Warwick was contributed to the most recent revision of Australian Rainfall and Runoff, providing input to the reference document on 2D hydraulic modelling of rural and urban areas. Warwick worked in the Flood Intelligence Unit of SES during the 2011 floods and is regularly called on to provided expert evidence in surface water matters at VCAT and planning panels.

PROFESSIONAL HISTORY

2009 to present	Director, Senior Principal Engineer, Water Technology Pty Ltd
2003-2009	Senior Engineer, Water Technology Pty Ltd
2001-2003	Victorian Water Resources Manager, Lawson and Treloar Pty Ltd
1997-2001	Senior Engineer, Lawson and Treloar Pty Ltd
1993-1997	Engineer, Lawson and Treloar Pty Ltd

SPECIALIST AREAS OF EXPERTISE

- Wetland, WSUD and water quality investigations
- Surface water investigations of urban and rural floodplains, rivers and wetlands
- Modelling of flooding, environmental flows, water quality and sediment transport
- Urban flood mapping, flood mitigation and stormwater treatment
- Integrated Water Management
- Investigations of estuary and coastal hydraulics
- Expert witness reports

RECENT MAJOR PROJECTS

STORMWATER PROJECTS (FLOODING, DRAINAGE AND WSUD) WATER TECHNOLOGY

Glen Eira WSUD Opportunities – Project director for an options study looking at the potential effectiveness of WSUD measures for flood mitigation. A local case study was undertaken with preliminary hydrologic and hydraulic modelling.

PNG LNG Condensate Fate Modelling – Project Director for hydrologic and hydraulic assessment of potential condensate spill scenarios for Gas Pipeline Development. One and two-dimensional models as well as mixing zone calculations were performed.

Buckland Park Development, Lower Gawler River – Detailed hydraulic investigation of a large new residential area in a floodplain environment. Development of flood mitigation measures including levees and channels.

Inverloch, Broadbeach Resort – Management of flooding issues related to a coastal development on the South Gippsland Coast. Hydrodynamics of the ocean, estuary, creek and township drainage systems have been taken into account to develop an overall flood risk assessment and appropriate land development level. Also included full drainage and WSUD design for the development.

Hoppers Lane (Werribee) – Development of a surface water management strategy for a mixed-use development including full WSUD treatment.

Keysborough South – Development of surface water management strategy for a large residential rezoning. This strategy has been adopted by Melbourne Water as input to their drainage scheme.

Stamford Park – Floodplain and wetland design for an industrial development adjoining a community park area for Knox Council.

The Strand Traralgon – Development of surface water models and WSUD design (wetlands) to provide treatment for a challenging site, constrained by existing drainage infrastructure and major easements.

Ocean View Lakes Entrance Stormwater Management Plan - Project director for development plan for a residential subdivision. Included design of wetland systems and retarding basin controls.

Cowes WEMP – Project Director in the development of a Water Efficiency Management plan for development in Cowes, use of probabilistic rainfall model PURRS.

Darebin Creek –1d Model (HEC-RAS) construction of waterway and analysis of bridge level assessment for Darebin Creek. Project Director.

Azola Waters, Pakenham – Functional design of Wetlands system for retirement village. Ongoing water quality assessment using various monitoring equipment. Project Manager/Director.

Cuttriss Street Flood investigation, Inverloch – Use of Mike Storm Pipe (Mouse) and two-dimensional (Mike21) linked model for urban storm water flooding. Project Director.

Brookfield Lakes, Bairnsdale, Stormwater Management Plan - Development plan for residential subdivision. Included design of wetland systems and retarding basin controls. Project Director.

Donga Road main drain catchments drainage study (City of Greater Geelong) - GIS analysis and hydraulic modelling of urban floodplain. Use of TUFLOW as predominate 2d/1d modelling package. Project Director.

STORMWATER PROJECTS (FLOODING, DRAINAGE AND WSUD) LAWSON AND TRELOAR

Sanctuary Lakes Water Quality – Management of a detailed water quality investigation including complex eutrophication modelling of the large lake system and analysis of the upstream wetlands

Sandhurst Estate – Management of hydrologic, hydraulic and water quality investigations for a large residential and golf course development in Melbourne's SE. This investigation included two-dimensional hydraulic analysis, a dynamic-pump system for lake top-up and eutrophication modelling in order to predict future water quality impacts.

Knox Golf Course – Development, calibration and application of a detailed MIKE 21 model of Monbulk Creek/Ferny Creek floodplain to assess flood impacts of a proposed golf course.

Oyster Cove Development, Coomera River QLD – Development of detailed MIKE 21 sub-models to calibrate roughness over residential developments.

Nerang River Floodplain – Major involvement in the development and application of a large, detailed 2-dimensional model of the Nerang River Floodplain. Analysis of impact of developments on flooding and investigation of mitigation options.

Heritage Golf and Country Club – Development of a MIKE 11 model to assess flood conditions in the Yarra River floodplain for design input.

Graceburn Creek, Healesville – development and application of a two-dimensional numerical model of a floodplain for risk assessment, regarding a proposed development. Believed to be the first application of two-dimensional hydraulic modelling on a floodplain in Victoria (1994).

FLOODPLAIN INVESTIGATIONS WATER TECHNOLOGY

Project Director for a hydraulic modelling study of the Pike River floodplain (SA MDB NRM Board). Development and calibration of a MIKE FLOOD model of the floodplain and use to inform the concept design of environmental regulators.

Project Director for a hydraulic modelling study of the South Australian Katfish Demonstration Reach (DEH). Development and calibration of a MIKE FLOOD model of the floodplain. This model was used to test a number of management scenarios.

Lyndhurst Drainage Strategy - Project Director of modelling waterway works for design of Retarding basins and wetlands for the Lyndhurst drainage scheme. Innovative use of linear waterways/wetlands for storage using two-dimensional hydraulic modelling.

Chowilla Floodplain Hydrodynamic Model – Supervision of the provision of detailed modelling services for this important floodplain system on the Murray River in South Australia, near the Victorian/NSW Border.

Port Fairy Flood Regional Study – A comprehensive review of flood risk to the township of Port Fairy and surrounding areas was undertaken. This included detailed hydrologic and hydraulic modelling, mapping and flood damages analysis. In addition, an extensive investigation of the potential impacts of climate change was undertaken.

Boggy Creek Wetland Review – Hydrologic and hydraulic review of translocated high-value wetland plots in Seaford adjacent to major road development. Working with ecologists to determine appropriate hydrologic regime.

Swan Hill Levee Audit – Investigation of the status of the existing town levee around Swan Hill through the use of a detailed two-dimensional hydraulic model. Assessment of levee system performance and recommendations for future flood mitigation works.

Beaufort Flood Study – Management of a comprehensive hydrologic and hydraulic study of the Beaufort township including investigation of 4 creeks that flow through the town. Resolution of complex design hydrology inputs to the township.

Dennington Flood Study – Detailed two-dimensional hydraulic model developed to describe inundation of the Merri River floodplain and provide planning information for future growth area near Warrnambool in south-west Victoria.

Applying Modelling Tools to Investigate Water Management in the Gunbower Forest – Project manager for the development of a detailed hydraulic model of Gunbower Forest. The model has been calibrated against a number of historic flood events and will be used to assess the effectiveness of a number of potential water management options. These options seek to improve the flooding regime of the forest through the use of environmental flow allocations. The required flooding is determined through a set of ecological objectives. Working closely with ecologists to determine hydrologic regime.

Hydraulic Modelling for Lindsay, Mulcra and Wallpolla Islands – This project involves the development of a linked one and two-dimensional model of these important floodplain and wetland environments that are included as one of the significant environmental assets or “icon sites” along the Murray River. This area has significant environmental values that suffer from reduced flooding due to river regulation. The hydraulic model will be used to test different management scenarios for floodplain improvement.

Murray River Regional Flood Study – Cobram to Tocumwal – Specialist modelling input is being provided for this project with an extensive one and two-dimensional model being developed including the Murray River channel and floodplain. The study area features many man-made controls such as levee banks and irrigation supply channels that dominate the topography. Once established the modelling will be used to develop flood management scenarios on a regional scale.

Investigations into Preferred Water Management Options in Gunbower Forest, 2D Modelling - Project management of the hydraulic modelling of the impact and effectiveness of proposed management options to improve watering of the wetlands and floodplain within Gunbower Forest.

Glenelg Hopkins CMA Rural Drainage Areas, Water Quality Impact Studies – Hydrologic and water quality analysis of four rural drainage areas specifically to examine the impacts of rural drainage on stream health of the main receiving waters.

Living Murray Hydraulic Investigation, Environmental flow for Barmah Millewa Wetland System – Project and technical management of this significant study within the Murray River system. The project involves the development and calibration of a detailed one and two-dimensional hydrodynamic model of the Barmah Millewa Forest for the purposes of determining the impact and effectiveness of various environmental flow management scenarios.

Lower Gawler Flood Mitigation Study – Detailed hydraulic modelling of the Lower Gawler River floodplain to investigate the effectiveness of various flood mitigation measures. A combined one and two-dimensional hydraulic model was employed.

Scoping Study for Best Management Options for Rural Drainage, Eumeralla and Nullawarre Drainage Areas – Major rural drainage study covering some 18,000 Hectares in south-west Victoria. Processing of ALS/Lidar survey data to assist in detailed hydrologic and hydraulic modelling. Investigation of water quality and environmental impacts of drainage practices and options for implementation of best management practices.

South Warrnambool Flood Study – Management of an urban hydraulic and flood mapping study of a major coastal township. Integration of a variety of survey data sources and a development of a two-dimensional hydrodynamic model.

Geelong Bypass Hydrology and Hydraulics – Management of the investigations of waterway requirements for this major freeway planning study. Numerous crossings analysed with a variety of techniques ranging from simple one-dimensional to fully two-dimensional models.

FLOODPLAIN INVESTIGATIONS LAWSON AND TRELOAR

Point Roadknight Drainage Investigation – Development of a detailed pipe and overland flow model for the assessment of flood extents and investigation of potential mitigation options.

Lake Burrumbeet and Burrumbeet Creek Floodplain Management Plan – Project and technical management of a comprehensive hydrologic and hydraulic modelling study. Assessment of economic, social and environmental impacts also determined.

Morambro Creek Surface Water Allocation – A rigorous hydrological approach was applied to a large catchment in south-east SA utilising a spatially distributed, GIS based hydrologic Model (SWAT). The results will be used in determining future allocation of water rights in the catchment.

Glass's Creek and Bell Street Flood Mitigation Studies – Detailed hydrology and hydraulic modelling has been undertaken in order to develop appropriate mitigation strategies for two densely developed urban areas in Melbourne. The two-dimensional overland flood models are coupled with detailed pipe network modelling to provide a robust and accurate analysis tool.

Princes Freeway (Pakenham Bypass), Cardinia Creek Crossing – Detailed hydrologic and hydraulic investigation of a proposed crossing of a particularly sensitive creek environment was undertaken. This involved fine-grid two-dimensional modelling.

Little Lang Lang River Waterway Mapping – A combined one and two-dimensional hydrodynamic model of this rural catchment was developed and results integrated into Melbourne Water's GIS system.

Albury-Wodonga Bypass Hydrology and Hydraulics – Development of a detailed two-dimensional hydraulic model for the assessment of alignment options. The development of detailed hydraulic performance criteria for alignment assessment was also undertaken.

City of Kingston, Flood Mitigation Assessment – Detailed flood modelling of various mitigation options. Utilising local catchment hydrologic and hydraulic models requiring detailed assessment at the block level combined with complex pump systems.

Breakwater Road Hydrology and Hydraulics – Review of hydrology and detailed hydraulic modelling of a proposed crossing of the Barwon River floodplain. An innovative hydraulic design was necessary in order to provide zero afflux within this sensitive floodplain area.

Shepparton Floodplain Management Investigation for Shepparton City Council – Project management of the hydraulic modelling aspects of the largest rural township flood study undertaken in Victoria.

Princes West Project - Detailed hydrologic and hydraulic assessment of the existing status of the Princes West freeway between Melbourne and Geelong fro VicRoads. Crossing upgrades were designed for varying levels of immunity and various configurations.

Data Consistency Project Stages 7-10 – These projects involved detailed one and two-dimensional urban flood modelling of stormwater surcharges from the various main drain systems.

City of Kingston – Flood Mapping of various locations to supplement Melbourne Water Mapping. Development of local catchment hydrologic and hydraulic models requiring detailed assessment at the block level.

Data Consistency Project Stage 6 – This project involved detailed two-dimensional urban flood modelling of stormwater surcharges from the main drain system. This work formed a pilot study in which Melbourne Water were able to evaluate the benefits of applying two-dimensional modelling to urban areas.

Tambo River Geomorphic Investigation – The 1998 Tambo River event caused significant damage in the floodplain. Specialist two-dimensional hydraulic modelling was undertaken as part of an integrated study approach considering flooding, longer term geomorphological processes and potential waterway management options.

Tuppal and Bullatale Creek Flood Study – Development and calibration of an extensive model of the Tuppal/Bullatale Creek system as well as the Murray and Edward Rivers between Tocumwal and Deniliquin. This model was set-up for the subsequent analysis of floodplain management options through DLWC (NSW).

Strathmerton Route Investigation – Development and calibration of hydraulic models (ranging from steady state backwater to full two-dimensional unsteady models) for subsequent hydraulic design. Both Murray River and floodplain areas have been investigated.

Swan Hill Regional Flood Strategy – Extensive MIKE 11 modelling of Murray/Loddon River system upstream of Swan Hill to assess effects of proposed regional flood strategies.

Traralgon Floodplain Management Study for Shire of Traralgon – As for the Euroa Study, a comprehensive understanding of the flooding mechanisms is being gained through this state of the art fully two dimensional, dynamic flooding investigation.

Euroa Floodplain Management Study for Shire of Strathbogie – This Floodplain Management Study aimed initially at providing a comprehensive understanding of the damaging and complex flooding regime at Euroa, and subsequently at assessing potential flood protection measures (mitigation schemes, both structural and non-structural and flood warning systems). Full two-dimensional hydraulic modelling was undertaken.

Wangaratta Flood Study, Stage 2 – Application of MIKE 11 model to assess various flood mitigation measures.

Cairns Airport Drainage Study – Development and application of a detailed 2-dimensional model of the Cairns Airport and Lower Barron Delta in order to assess flood/cyclone hydrodynamic conditions at the Airport. Analysis of mitigation options.

Wangaratta Flood Study, Stage 1 – Development and calibration of a MIKE 11 model covering the extensive Ovens/King Rivers floodplain.

Yarra River, Melbourne – Development of a detailed MIKE 21 (two-dimensional) model of the Yarra River to investigate the hydraulic features of a small turning basin/wharf.

Gippsland Lakes System – One-dimensional model developed to analyse the potential impact of sea-level rise on lake levels.

Yarra River, Yarra Glen (VicRoads) – Set up and calibration of both one and two-dimensional models to investigate the impact of a proposed bridge replacement on flood levels.

Lower Loddon River Flood Study – development and calibration of MIKE 11 model covering an extensive floodplain network.

COASTAL/ESTUARINE INVESTIGATIONS WATER TECHNOLOGY

Gippsland Lakes Coastal Hazard Assessment – Project manager for a major hazard assessment project looking at impacts of sea level rise on coastal vulnerability throughout the Gippsland Lakes and Ninety Mile Beach.

Environmental Water Requirements of the Gippsland Lakes – Managed the input of scientific knowledge around hydrodynamics of the lakes and the freshwater/saltwater interface as well as the impacts of reduced freshwater inputs on these flow mechanisms.

Ecological Characterisation of the Gippsland Lakes – Provided hydrodynamic input to a broader characterisation project looking at the various habitats and bio-dependencies in the Gippsland Lakes.

Numerous Coastal Hazard Vulnerability Risk Assessments – assessing the change in risk to coastal inundation and stability due to sea level rise and the resulting change in coastal processes.

COASTAL/ESTUARINE INVESTIGATIONS LAWSON AND TRELOAR

Bass Strait – Three-dimensional model (Delft3D) development and calibration for pipeline design currents prediction.

Tropical Cyclone Thelma, Three-dimensional Current Model – This project involved the set-up and calibration of a three-dimensional hydrodynamic model of the Timor Sea and extraction of currents data.

Mooney Ponds Creek three-dimensional Water Quality Modelling – This project involved modelling of the detailed hydrodynamics of the fresh/salt-water interface in the Yarra River and how this effected the movement of pollutants from storm-water inflows.

Port Catherine Development, W.A. – Detailed three-dimensional hydrodynamic and water quality modelling of a proposed harbour development south of Perth.

Palm Springs Marina, Malaysia – Development of a two-dimensional model to assess effects of marina on local hydraulics.

Corio Bay Sediment Model Verification – Comparison of model predicted and recorded sediment plumes in Corio Bay during channel dredging.

Lake Illawarra/Botany Bay – Application of a two-dimensional water quality model to two large waterways. Long term water quality simulations performed and analysed for risk assessment.

South China Sea – Two and three-dimensional modelling to determine design currents for oil/gas pipelines.

Manila Bay – Analysis of flood behaviour, dredged sediment impacts and flushing characteristics of a proposed area of reclamation in Manila Bay, using one and two-dimensional models.

West Point Wilson hazardous chemicals storage facility – Environmental Effects Statement. Investigation of proposed facilities effect on nearby coastal processes.

East Coast Armaments Complex – Set up of two-dimensional current and wave models to investigate the impacts of proposed port facility.

Port Hedland – Set up and operation of numerical model to investigate Cyclone driven winds and wave set up.

Western Port – Two-dimensional model investigations of the dispersion of pollutants and the flushing characteristics of Western Port under tidal and wind driven currents.

Oil Spill Modelling/Response – Development of oil spill response procedures to perform real-time modelling of oil slick movements in Bass Strait and Western Port.

Western Port – Set up and calibration of a numerical model for the development of tidal and wind driven current fields as input to oil spill modelling.

Port of Geelong – Application of a two-dimensional numerical model to assess impact of a proposed dredging program on suspended sediment loads in Corio Bay.

Bass Strait – Numerical modelling of the flushing characteristics of Bass Strait over a typical year.

EXPERT WITNESS REPORTS

Adams Creek, Lang Lang – Expert evidence related to rural flooding and drainage issues

Donald, NW Victoria – Expert evidence and analysis of flooding issues related to channel networks on farmland in the Wimmera area

St Georges Road Northcote - Expert advice and modelling of an apartment development within SBO

Duncans Road South Werribee – Review of hydraulic conditions, flooding and drainage for a horticulture area. Provision of expert evidence report.

Nunawading – Expert evidence on flooding issues including modelling, for a multi-storey apartment building in a floodway zone

Hagen Park Bangholme – Expert advice and modelling of drainage issues in SE Melbourne

Noonan Grove Woodend - Expert advice and report on surface water management for a residential subdivision

Industrial Subdivision Shepparton/Mooroopna – Expert advice on drainage and flooding issues for land valuation purposes

Dandenong Valley, Scoresby – Expert modelling and report on flooding issues and development capability for land valuation

Coastal Development Paynesville – Expert report and evidence at VCAT on coastal hazard vulnerability for a residential subdivision

School Site Monbulk – Expert report on drainage issues in the Dandenong Ranges

Broken River, Stewarton – Expert modelling/report and evident at VCAT for a rural flooding issue

Toorak Road South Yarra – VCAT report and evidence in relation to redevelopment of a site within an urban area subject to flooding

Hopkins River Warrnambool – Flooding and coastal hazard vulnerability export report and VCAT evidence

Apartment Development Port Fairy – Expert report on flooding issues associated with a proposed apartment complex

Port Fairy (2014) – Expert evidence to VCAT on coastal hazard and flooding for a proposed sub-division in Port Fairy.

Kerang East (2014) – Expert evidence to VCAT on flooding issues along Pyramid Creek arising from 2011 floods.

Woodend (2014) – Expert evidence to VCAT regarding flooding from Five Mile Creek and local stormwater impacts at a development site within Woodend.

Port Fairy Planning Scheme Amendment (2014) – Provided Expert Evidence on flooding to Planning Panels Victoria for Moyne Shire.

Victoria Street Richmond (2016) – Expert Evidence to VCAT on flooding issues related to a multi-storey apartment development next to the Yarra River.

Donnybrook/Woodstock PSP (2016) – Expert evidence to panel hearing in relation to drainage issues for a large greenfield development area.

Manningham (2016) – Provision of peer review of modelling and expert advice to City of Manningham regarding a planning scheme amendment to implement SBO layers into their planning scheme.

Amendment C121 Planning Panel - Leneva Baranduda Precinct – expert advice to the City of Wodonga

PUBLICATIONS

CONFERENCE PRESENTATIONS

BISHOP, W.A., McCOWAN, A. D., SUTHERLAND, R. J., WATKINSON, R. J. - “Application of Two-Dimensional Numerical Models to Urban Flood Studies”, 2nd International Symposium on Urban Stormwater Management, Melbourne 1995.

SOMES, N.L.G., BISHOP, W.A., WONG, T.H.F. - “Numerical Simulation of Wetland Hydrodynamics”, MODSIM 97 International Congress on Modelling and Simulation, Hobart.

BISHOP, W.A., COLLINS, N. I., CALLAGHAN, D. P., and CLARK, S. Q. - “Detailed Two-Dimensional Flood Modelling of Urban Developments”, 8th International Conference on Urban Storm Drainage, Sydney 1999.

SOMES, N.L.G., BISHOP, W.A., WONG, T.H.F. - “Numerical Simulation of Wetland Hydrodynamics”, Environment International, Vol. 25, No. 6/7 pp. 773-779, 1999.

BISHOP, W.A. – “Two-dimensional Modelling for Urban Flood Mapping and Drainage Analysis”, Proceedings, Victorian Flood Management Conference, 2001.

BISHOP, W.A. and CATALANO, C.L., “Benefits of Two-dimensional Modelling for Urban Flood Projects”, 6th Conference on Hydraulics in Civil Engineering, Hobart 2001.

McCOWAN, A.D., BERTON, F.M. and BISHOP, W.A. – “The Application of a Three-dimensional Variable Density Model to Assess Water Quality in an Urban Waterway”, 6th Conference on Hydraulics in Civil Engineering, Hobart 2001.

REHMAN, H.U., ZHANG, S.Y., BISHOP, W.A., BERKFELD, J., “Water Resources Assessment using Soil Water Assessment Tool - A Case Study”, in Proceedings of ICam Catchment Management Conference, University of Western Sydney, Australian Water ssociation, Sydney, 26-28 November 2003.

McMASTER, M.J., PROVIS, D.G., GRAYSON, R.B. & BISHOP, W.A., “Calibration and testing of a hydrodynamic model of the Gippsland Lakes” in Proceedings of MODSIM 2003, Townsville, Australia 14-17 July 2003.

BISHOP, W.A., WOMERSLEY, T.J. & TIERNEY, G, “Flooding Forests - the Hydraulics of Environmental Flows”, Proceedings, 4th Victorian Flood Management Conference, Shepparton 2005.

MUNCASTER, S.H., BISHOP, W.A. and MCCOWAN, A.D., “Design flood estimation in small catchments using two-dimensional hydraulic modelling –A case study”, 30th Hydrology and Water Resources Symposium, Launceston, TAS, December 2006.

BISHOP, W.A. and WOMERSLEY, T.J., “The use of hydraulic models to inform the management of flood dependent ecosystems on the River Murray, South-Eastern Australia”, 6th International Symposium on Ecohydraulics, Christchurch, February 2007.

MUNCASTER, S. H., BISHOP, W. A. and DUGGAN, S.J., “Making the best with what you have - Design flood estimation with and without observed data”, 5th Victorian Flood Management Conference, Warrnambool, October 2007

BISHOP, W.A., CHARTERIS, A.B., MUNCASTER, S.H., WOMERSLEY, T.J., “Impacts of Climate Change on Floodplain Management in Coastal Communities”, 5th Victorian Flood Management Conference, Warrnambool, October 2007.

BISHOP, W.A. and TATE, B. “The Use of Eco-Hydraulics in Managing the River Murray”, 17th QLD Water Symposium, Griffith University, November 2008.

BISHOP, W.A. and WOMERSLEY, T.J., “Port Fairy Regional Flood Study - Dealing with Risk in a Coastal Floodplain”, Jo int 49th Annual Floodplain Management Authorities Conference (NSW) & 6th Biennial Victorian Flood Conference, Albury, February 2009.

BISHOP, W.A., RUSSELL, K.L. and LITTLE, M.J., “Impacts of Sea Level Rise on Flooding in an Estuarine Environment”, Climate Change 2010: Practical Responses to Climate Change Conference, Melbourne, 2010.

MARTIN, J.C., ARROWSMITH, C.L., and BISHOP, W.A., Hydraulic Implications associated with the Placement of Timber Snags in a Developing Anabranch. Proceedings of the Sixth Australian Stream Management Conference, Canberra, Australian Capital Territory, 2011.

BISHOP, W.A., LAW, S.E., NEWTON, J.L., GODFREY, M., “Integrated Water Management Opportunities for Inner Suburban Areas”, WSUD 2013, 8th International Water Senitive Urban Design Conference, Gold Coast, November 2013.

WOMERSLEY, T.J., LEAHY, C., HUDSON, K., ANDERSON, B., KAZAZIC, E., BISHOP, W.A., & MAWER, J., “Proof of concept hydrodynamic model and marine and atmospheric forecast data integration for flood forecasting in the Gippsland Lakes”, 54th Floodplain Management Association Conference, 20-23 May 2014, Deniliquin RSL Club, Deniliquin, NSW

McCOWAN, A.D., LAUCHLAN-ARROWSMITH, C., BISHOP, W.A., “Estimating Future Coastal Inundation and Erosion Hazards”, Australian Coastal Councils Conference, March 2015

COUSLAND, T.J., and BISHOP, W.A., “Transport modelling to verify constructed wetland residence times”, Stormwater 16 – National Stormwater Association Conference, Gold Coast, QLD, September 2016.

CLARK, S., BISHOP, W., CUNNINGHAM, L., TATE, B., DALY, A., “Utilising Hydraulic Grade Line rather than water surface levels for Flood Planning Levels”, 13th Conference on Hydraulics in Water Engineering, Sydney, Nov 2017.

CLARK, S., CUNNINGHAM, L., TATE, B., DALY, A., BISHOP, W., “Flood Planning Levels: Incorporating residual risk considerations”, 13th Conference on Hydraulics in Water Engineering, Sydney, Nov 2017.