Elizabeth Street, Melbourne Flood Modelling Report

August 2017

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PROJECT DETAILS

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Cover Image: Elizabeth Street in Flood Image, December 5, 1882. By Alfred Martin Ebsworth. Available State Library of Victoria Website.

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EXECUTIVE SUMMARY

The Elizabeth Street flood modelling project is an extension of the City of Melbourne's Integrated Climate Adaptation Model (ICAM) project. The ICAM project was completed by a team lead by the University of Melbourne and supported by Water Technology, Grace GIS and Moroka with advice provided by Melbourne Water, CSIRO and other experts from across Australia and Internationally. Water Technology's involvement in the ICAM project comprises of the construction of multiple broad-brush rainfall on grid 1D/2D TUFLOW models across the entire City of Melbourne, utilising the most recent city-wide LiDAR and both City of Melbourne and Melbourne Water drainage assets, in order to compare various scenarios. The Elizabeth Street Flood Model utilises the same information as the ICAM project, but with an increased level of detail. In contrast to the ICAM project, the Elizabeth Street project incorporates a detailed review of results, terrain and hydraulic controls.

The project scope has been split into two stages. The first stage focuses on delivering flood modelling and mapping to the catchment. The second stage considers mitigation options, particularly the use of water sensitive urban design methods to treat nuisance flooding within the catchment, traditional infrastructure solutions has also been considered.

Stage 1 focuses on providing existing conditions flood modelling and mapping for the Elizabeth Street Catchment using Rainfall on Grid methodology which has been discussed with Melbourne Water and agreed as the most suitable approach for this project. The Stage 1 includes:

- A review of any previous RORB modelling;
- Compare building blockage methods;
- Calculation of Climate Change rainfall;
- Upgrade of existing (ICAM) model to appropriate standard;
- Sensitivity testing of roughness, variations in rainfall and land mapping/losses;
- Flood level calibration to March 2010 storm event;
- Existing conditions modelling for the 5; 10; 20; 50; 100 year ARI and 1972 events;
- Climate change scenarios modelling including a 10% increase on rainfall intensity;
- Flow verification to the Rational Method.

Stage 2 explores the effect of a range of green infrastructure scenarios on flooding within the Elizabeth Street catchment. The following four green infrastructure scenarios will be tested for the 20 year ARI 2-hour event using the approved existing conditions model set up in Stage 1;

- Green roofs distributed throughout the lower end of the city;
- Distributed storage approach. Storage applied to buildings via planning requirements and a tree pit program;
- The City of Melbourne built and planned high level works (i.e. removing water volume or adding storage volume to the model); and,
- Model the above three scenarios together to see the maximum potential benefit.

The green roofs are more effective in reducing flooding when compared to the distributed storages approach tested in this study. The green roofs tested on the upper half of the catchment show flood reductions comparable to the distributed storages which have been applied across the entire catchment. The Council mitigation works targeting 27 sites across the catchment provide a good flood reduction considering the extent of the measures. While combining the three green infrastructure measures together provides the largest flood reduction; it does not appear to be the most optimal approach as it would require a large investment on green infrastructure for a small flood reduction in comparison.

GLOSSARY OF TERMS

Annual Exceedance Probability (AEP)	Refers to the probability or risk of a rainfall event of a given magnitude (intensity and duration) occurring or being exceeded in any given year. A 90% AEP event has a high probability of occurring or being exceeded; it would occur quite often and would be a relatively minor rainfall event. A 1% AEP event has a low probability of occurrence or being exceeded; it would be rare but it would be likely to cause extensive damage.
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level. Introduced in 1971 to eventually supersede all earlier datum's.
Average Recurrence Interval (ARI)	Refers to the average time interval between a given flood magnitude occurring or being exceeded. A 10 year ARI flood is expected to be exceeded on average once every 10 years. A 100 year ARI flood is expected to be exceeded on average once every 100 years. The AEP is the ARI expressed as a percentage.
Cadastre, cadastral base	Information in map or digital form showing the extent and usage of land, including streets, lot boundaries, water courses etc.
Catchment	The area draining to a site. Generally relates to a particular location and may include the catchments of tributary streams as well as the main stream.
Design flood	A significant event to be considered in the design process; various works within the floodplain may have different design standards. A design flood will generally have a nominated AEP or ARI (see above).
Discharge	The rate of flow of water measured in terms of volume over time. It is to be distinguished from the speed or velocity of flow, which is a measure of how fast the water is moving rather than how much is moving.
Flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or overland runoff before entering a watercourse and/or coastal inundation resulting from elevated sea levels and/or waves overtopping coastline defences.
Flood damage	The tangible and intangible costs of flooding.
Flood hazard	Potential risk to life and limb caused by flooding. Flood hazard combines the flood depth and velocity.
Flood mitigation	A series of works to prevent or reduce the impact of flooding. This includes structural options such as levees and non-structural options such as planning schemes and flood warning systems.
Floodplain	Area of land which is subject to inundation by floods up to the probable maximum flood event, i.e. flood prone land.
Flood storages	Those parts of the floodplain that are important for the temporary storage, of floodwaters during the passage of a flood.
Freeboard	A factor of safety above design flood levels typically used in relation to the setting of floor levels or crest heights of flood levees. It is usually expressed as a height above the level of the design flood event.
Geographical information systems (GIS)	A system of software and procedures designed to support the management, manipulation, analysis and display of spatially referenced data.

Hydraulics	The term given to the study of water flow in a river, channel or pipe, in particular, the evaluation of flow parameters such as stage and velocity.
Hydrograph	A graph that shows how the discharge changes with time at any particular location.
Hydrology	The term given to the study of the rainfall and runoff process as it relates to the derivation of hydrographs for given floods.
Intensity frequency duration (IFD) analysis	Statistical analysis of rainfall, describing the rainfall intensity (mm/hr), frequency (probability measured by the AEP), duration (hrs). This analysis is used to generate design rainfall estimates.
TUFLOW	A hydraulic modelling tool used in this study to simulate the flow of flood water through the floodplain. The model uses numerical equations to describe the water movement.
Ortho-photography	Aerial photography which has been adjusted to account for topography. Distance measures on the ortho-photography are true distances on the ground.
Peak flow	The maximum discharge occurring during a flood event.
Probability	A statistical measure of the expected frequency or occurrence of flooding. For a fuller explanation see Average Recurrence Interval.
Risk	Chance of something happening that will have an impact. It is measured in terms of consequence and likelihood. For this study, it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
RORB	A hydrological modelling tool used in this study to calculate the runoff generated for design rainfall events.
Runoff	The amount of rainfall that actually ends up as stream or pipe flow, also known as rainfall excess.
Stage	Equivalent to 'water level'. Both are measured with reference to a specified datum.
Stage hydrograph	A graph that shows how the water level changes with time. It must be referenced to a particular location and datum.
SWMP	Stormwater management plan
Topography	A surface which defines the ground level of a chosen area.

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1. INTRODUCTION

Water Technology has been commissioned by the City of Melbourne, in conjunction with Melbourne Water, to prepare a detailed flood assessment for the Elizabeth Street Catchment in Melbourne's Central Business District (CBD).

Elizabeth Street is positioned on what would have once been a natural watercourse, originally known as Williams Creek. With significant flooding seen in flash flooding events in 1882, 1972 and more recently, the 2010 and 2011 storms, the 1972 event is remembered as the most dramatic on record, when 78.5 mm of rain fell within the CBD in one hour, with flood depths estimated to have reached a height of 1.5 meters in some locations.

Given the location of the catchment, traditional mitigation options of large flood storage basins or new conveyance infrastructure are not viable options. This study will quantify the potential magnitude of flooding within the catchment and look towards utilising whole of water cycle management tools and water sensitive urban design to reduce the frequency of flooding, particularly in the lower ARI events.

2. SITE

The subject site is located within Melbourne's Central Business District. It has a catchment of approximately 320 ha and drains an area defined by the University of Melbourne Parkville Campus to the north, The Royal Exhibition Building and Carlton Gardens to the east, the Yarra River to the south and William Street through the CBD to the west. Melbourne Water's Elizabeth Street Drain runs in a south easterly direction from Victoria Street through to its Yarra River outlet under Flinders Street Station. With the main leg of the pipe aligned on the east side of Elizabeth Street, the pipe is augmented on the south side from Bourke Street through to Flinders Street where the two assets meet before running beneath the railway lines and discharging. Refer to Figure 2-1 for the subject site location.

2.1 Topography

1 m resolution LiDAR information provided by Grace GIS was used to represent the existing conditions terrain as shown in Figure 2-2.

2.2 Catchment Characteristics

The Elizabeth Street Drain is located in a high-density residential, commercial and industrial development in Melbourne and Carlton, comprising a relatively steep catchment, and extending from Melbourne University to Flinders Street. The Elizabeth Street drain runs along the east side of Elizabeth Street from Victoria Street to a Yarra River outfall south of Flinders Street Station, with a second branch running along the west side of Elizabeth Street from Bourke Street to Flinders Street (1996/97 Drainage Study). The Melbourne Water pipe diameters range from 950 mm to 2150 mm.

The northern reaches of the catchment are drained through council drains along various streets, including Leicester, Bouverie, Cardingan, Lygon and Victoria Streets.

Areas east of Swanston Street and the Carlton Gardens are drained to the south through council drains, however when the drain capacity is exceeded, water flows overland through Little Bourke and Bourke Streets toward Elizabeth Street.

Figure 2-1 Location Plan

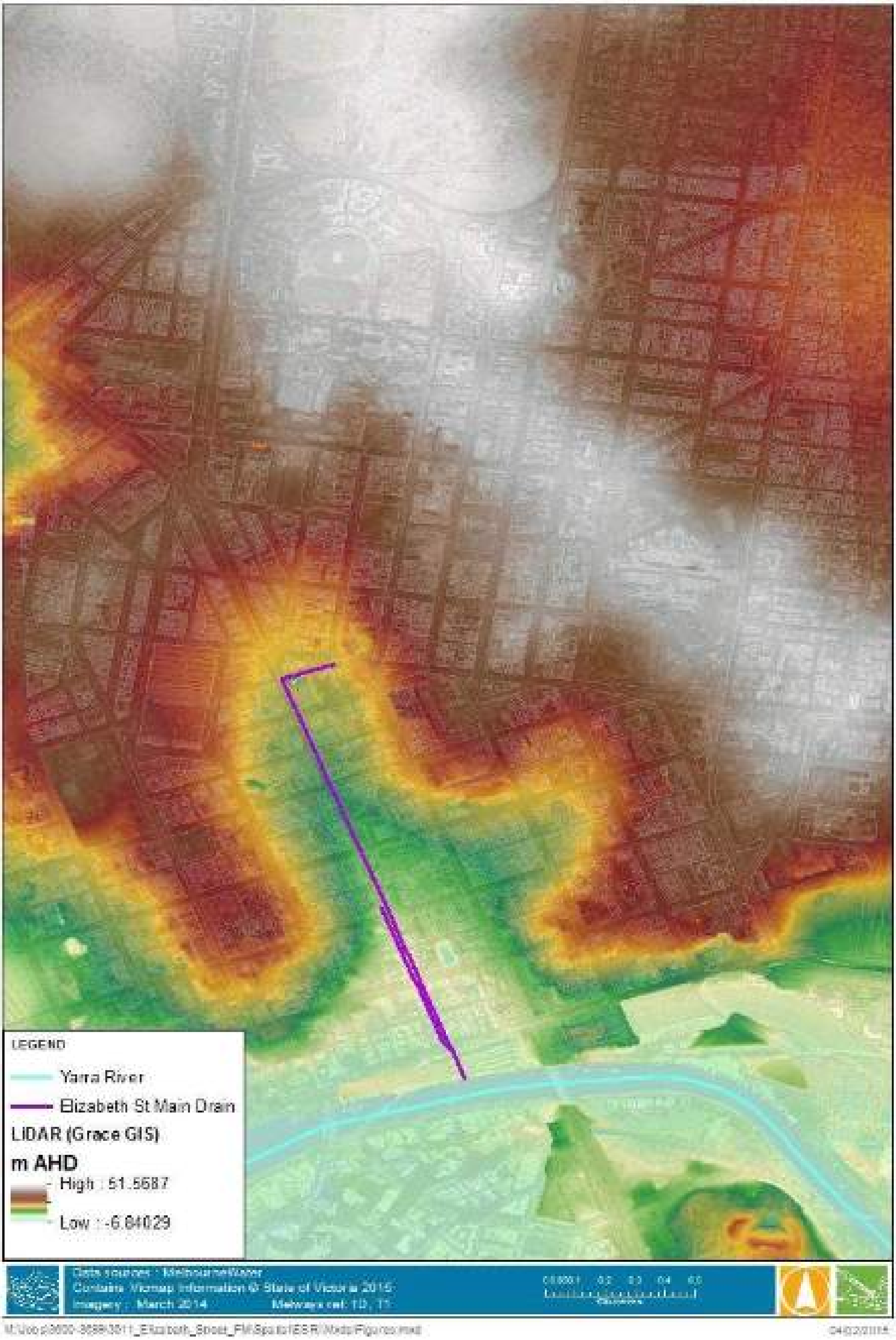

Figure 2-2 Topography

3. AVAILABLE INFORMATION REVIEW AND SITE VISIT

3.1 Project Inception Meeting

A project inception meeting was held on the 10th February 2015. The meeting was attended by key Melbourne Water, City of Melbourne and Water Technology project staff.

Water Technology provided a summary of the proposed hydraulic modelling approach to Melbourne Water and City of Melbourne, and a discussion was held around the following points:

1. Proposed overall hydrologic and hydraulic modelling approaches, i.e. models to be used, 2D model info (cell sizes, 1D components, structures etc.), 1D model info (cross-section locations and widths, structures, method of producing the 1m grid points data from the 1D results);
2. Proposed methodology for estimating the sub-area Fraction Impervious values;
3. Proposed approach for estimating Time(s) of Concentration, if applicable to the project;
4. Proposed approach to modelling residential, commercial and industrial properties and buildings - different approaches may need to be adopted for different areas depending on whether flows can get into or beneath buildings or whether the buildings will completely block overland flows;
5. Anticipated approach to obtaining tailwater levels for the project (to make sure both parties are aware of how this is to be done); and,
6. Any issues associated with the data that have not already been addressed.

Minutes of this meeting can be found in Appendix E.

3.2 Site Visit

A site visit was undertaken by Water Technology on the 18th February 2015 to review the existing conditions. The Water Technology project team were joined by representatives from the City of Melbourne and Melbourne Water.

Key hydraulic structures / crossings, areas with recent development and areas of known flooding were visited.

This process provided invaluable input to the project. Gaining an understanding of the key areas of flooding early in the project was critical to determining the most appropriate methodology to move forward with. Water Technology staff also gathered information on the terrain, vegetation and soil characteristics of the study area, focusing on critical inputs to the modelling stages such as Manning's roughness coefficients, pipe and culvert locations and characteristics as well as key topographical influencers of overland flow paths. Photos from the site visit can be found in Appendix D.

3.3 Available data review

Key data used in this investigation (and its source) is shown in Table 3-1. The following Sections cover each area of focus in the investigation and nominate key data collected and how it was used.

Table 3-1 Data References

Data	Date Received	Source
COM Boundary (updated)	20/11/14	Grace GIS
Drainage pits and pipes layer	20/11/14	Grace GIS
Drainage pumping station	20/11/14	Grace GIS
Drainage litter trap	20/11/14	Grace GIS
Calibration Data from Melbourne Water	9/1/15	MW
Land use/ land cover map	12/1/15	Grace GIS
Calibration Data	23/1/15	WT
Updated pipe information	27/1/15	Grace GIS
DEM	28/1/15	Grace GIS
MW Yarra levels	3/2/15	MW
Calibration data – LiDAR & aerials	3/2/15	WT
Revised MW tech guidelines	3/2/15	MW
GPT locations	3/2/15	CoM
Updated pipe info	4/2/15	CoM
Updated pipe info	17/2/15	Grace GIS
GPTs	17/2/15	CoM
Yarra levels	17/2/15	MW
DBYD	23/2/15	DBYD
Fraction Impervious and roughness polygons	26/2/15	Grace GIS
Pipe data	2/3/15	Grace GIS
Raw pipe data	3/3/15	GraceGIS
Pour Points for ICAM & Subcatchments	6/3/15	GraceGIS
Degraves St Underpass Plans	24/3/15 & 16/4/15	CoM
Yarra Levels	25/3/15	MW
2010 Radar Data	10/4/15	BoM
Casino Gauge Tidal Data	15/4/15	WT
Survey	23/4/15	CoM
ARI Prediction	14/5/15	MW
Climate Change Report	13/5/15	Penny Whetton
Review of Sensitivity Analysis	19/5/15	Moroka

3.3.1 External Catchment flows

There are no external catchment inflows into the Elizabeth Street Catchment.

3.3.2 Existing Conditions Rain-on-Grid modelling

Several data sets were analysed to help schematise the detailed rain-on-grid model. Key items that need to be represented in the modelling included:

Runoff Characteristics - GIS data:

- Land use mapping polygons provided by Grace GIS on 26th February 2015;
- Geo-referenced Aerial Image – Captured on 31/3/2014 at 25 cm resolution, supplied by DEPI; and,
- VicMap Base data – Land parcels, roads, designated waterway features, planning layers and overlays etc., supplied by DEPI.

GIS data was used to describe the physical catchment conditions, these included, relative imperviousness and roughness.

Terrain data (topography);

- As indicated in Section 0.

Asset Data (Pits, Pipes Crossings);

- Provided by Grace GIS on 2nd March 2015.

Boundary Conditions

- Yarra River flood levels at various ARIs provided by Melbourne Water on 17/2/15.

Despite the significant amount of data supplied by the City of Melbourne and Melbourne Water, in many cases data gaps exist. In most cases this was in the form of missing inverts.

4. KEY ASSUMPTIONS

A number of key assumptions underpin the model, including the following:

1. Interaction between the surface and ground water has not been modelled;
2. Modelled scenarios did not account for potential pipe blockages;
3. No underground car parks have been considered in the model;
4. The hydrology and hydraulics of the Yarra River were not analysed as part of this project and were adopted from previous modelling completed by Melbourne Water;
5. 1987 IFD rainfall parameters were used in the modelling; and,
6. No kerb and channels were stamped onto the roadways.

Many of these key assumptions could be included in the model if required at a later stage.

Additionally, other assumptions are detailed in sections below throughout the report as relevant.

5. HYDROLOGICAL MODELLING REVIEW

5.1 Overview

RORB (*Laurenson et al 2005*) is a non-linear rainfall runoff and streamflow routing model for calculation of flow hydrographs in drainage and stream networks. The model requires catchments to be subdivided into subareas, connected by conceptual flow reaches. Design storm rainfall is input to the centroid of each pre-defined subarea. Loss parameters are applied to the model depending on the ARI event being studied and are then deducted by RORB with the excess runoff being routed through the conceptual reach network.

The hydrological modelling of various catchments throughout Melbourne was undertaken by CMPS&F in 1996-1997, with the Elizabeth Street Drain catchment study methodology and results as detailed in the Melbourne Water Drainage Survey 1996/97 report and the RORB model, provided by Melbourne Water to Water Technology on the 9th January 2015.

Water Technology has undertaken a review of the existing RORB model and associated report and a summary of the review is provided in this Section.

5.2 Existing Model

Figure 5-1 shows the CMPS&F RORB model sub-catchments and reach details as provided by Melbourne Water to Water Technology. The sub-catchments were provided to CMPS&F by Melbourne Water originally. Drainage survey plans were used to model the pipe network within the catchment. The catchment was broken down as follows in Table 5-1.

Table 5-1 CMPS&F 1996/97 Existing Conditions RORB model catchment breakdown

Landuse Category	Area (Ha)	Assumed Fraction Impervious (FI)
Residential	48.4	48.5% (based on existing 45%, but 10% will be converted to dual occupancy, with an 80% impervious fraction)
Schools, hospitals and similar institutions	31.3	45%
Commercial	20.8	75%
Industrial	191.8	80%
Reserves/open space	12.9	10%
Total	305.2	68%

RORB model modelling parameters were used as described in Table 5-2.

Table 5-2 Existing RORB modelling parameters

Kc	m	Initial Loss (mm)	RoC Q_{100}
3.7	0.8	15 (pervious) 0 (impervious)	0.6 (pervious) 0.9 (impervious)

It is noted that the following assumptions were made in the Drainage Survey 1996/97 report:

- Pipe systems are capable of accommodating the full 100 year peak discharge;

- No retarding basins in Elizabeth Street; and,
- The RORB model includes the Western branch drain upstream of Melbourne Water's drainage limit to Therry Street, in order to account for its effect on overland flows. The RORB modelling has also accounted for flows diverted out of the catchment by a council drain under Swanston Street.

Overland flows and pipe flows were split in the model; however, overland flows along roads were generally assumed to be "lined or piped". The exception to this was in flat areas of shallow sheet flow which was assumed to be "excavated but unlined".

5.2.1 IFD Parameters and Rainfall Intensities

Neither the report nor the RORB model provided the IFD parameters used to generate rainfall intensities in RORB, however the report made reference to the fact that the design rainfall intensities were obtained using methods from AR&R 1987.

No Climate Change modelling scenarios were undertaken.

Information on the critical storm duration, temporal pattern details, areal pattern details, areal reduction factor and loss factor details was not provided in either the report or the RORB model. It is assumed that the AR&R 1987 method was used to calculate the Areal Reduction Factor.

It is also assumed that Temporal Patterns were fully filtered.

5.2.2 Fraction Impervious Data

According to the report, Fraction Impervious (FI) data used was based on each major landuse based on zonings extracted from data planning database provided by Strategem Infobase on 28 November 1996 and are shown in Table 5-1. It was noted in the report that there may have been localised adjustments to the FI values, e.g. a golf course is classified as commercial, but the FI is significantly less than 75%.

Table 5-4 provides the sub-catchment data used in the RORB model by CMPS&F.

Water Technology have undertaken a review of the fraction impervious within each sub-catchment, based on the Melbourne Water MUSIC Guidelines as shown in Table 5-4, as a method of comparison for the fraction impervious. It is understood that the fraction impervious determined in this Section will be compared to the results obtained from remote sensing, undertaken by Grace GIS, as discussed in Section 6.

Table 5-3 Melbourne Water MUSIC Guidelines Fraction Impervious Values

Zone	Zone Code	Description	Normal Range	Typical Value
Residential 1 & 2 Zone	R1Z	Moderate range of densities (800 – 4000 m^2)	0.4 – 0.5	0.45
Mixed Use Zone	MUZ	Mix of residential, commercial, industrial and hospitals	0.6 – 0.9	0.7
Business 1 Zone	B1Z	Main zone to be applied in most commercial areas	0.7 – 0.95	0.9
Business 2 Zone	B2Z	Offices and associated commercial uses	0.7 – 0.95	0.9

Zone	Zone Code	Description	Normal Range	Typical Value
Business 3 Zone	B3Z	Offices, manufacturing industries and associated use	0.7 – 0.95	0.9
Business 4 Zone	B4Z	Mix of bulky goods retailing and manufacturing industries	0.7 – 0.95	0.9
Education	PU2Z	Schools and universities	0.6 – 0.8	0.7
Health and Community	PU3Z	Hospitals	0.6 – 0.8	0.7
Transport	PU4Z	Railways and tramways	0.6 – 0.8	0.7
Cemetery/crematorium	PU5Z	Cemeteries and crematoriums	0.5 – 0.7	0.6
Local Government	PU6Z	Libraries, sports complexes and offices/depots	0.5 – 0.9	0.7
Other Public Use	PU7Z	Museums	0.5 – 0.8	0.6
Public Park and Recreation Zone	PPRZ	Main zone for public open space, incl golf courses	0.0 – 0.2	0.1
Road Zone – Category 1	RDZ1	Major roads and freeways	0.6 – 0.9	0.7
Road Zone – Category 2	RDZ1	Secondary and local roads	0.5 – 0.8	0.6
Capital City Zone	CCZn	Special Use Zone for land in Melbourne's central city	0.7 – 0.9	0.8
Special Use Zone	SUZ3	Development for specific purposes	0.5 – 0.8	0.6
Docklands Zone	DZ3	Special Use Zone for land in Docklands area	0.7 – 0.9	0.8
Commonwealth Land	CA	Army barracks, CSIRO	0.5 – 0.8	0.6
Commercial Zone 1 (note not in MUSIC Guidelines)	C1Z	Main zone to be applied in most commercial areas	0.7 – 0.95	0.9
General Residential Zone (note not in MUSIC Guidelines)	GRZ1	Moderate range of densities (800 – 4000 m^2)	0.4 – 0.5	0.45

Table 5-4 RORB Sub-catchment Data

Sub-catchment	Area (km^2)	RORB Average Percentage Impervious (%)	Water Technology Average Percentage Impervious (based on MW MUSIC Guidelines 2010 and aerial imagery) (%)
A	0.28	50	75
B	0.34	54	84

Sub-catchment	Area (km^2)	RORB Average Percentage Impervious (%)	Water Technology Average Percentage Impervious (based on MW MUSIC Guidelines 2010 and aerial imagery) (%)
C	0.3	75	80
D	0.29	56	88
E	0.3	77	88
F	0.24	80	90
G	0.31	50	64
H	0.25	80	90
I	0.18	80	83
J	0.26	80	90
K	0.28	80	90

As can be seen from Table 5-4, the majority of the fraction impervious values have increased. This is caused by a combination of industry standards increasing since the original RORB model was prepared, and also development within the catchment. This may result in the 1996/97 RORB model results showing lower peak flows than what could be expected if updated to the revised 2015 FI values. This variation in FI could also impact catchment response and coincident timing of flows, further impacting peak flow rates across all ARI events and storm durations.

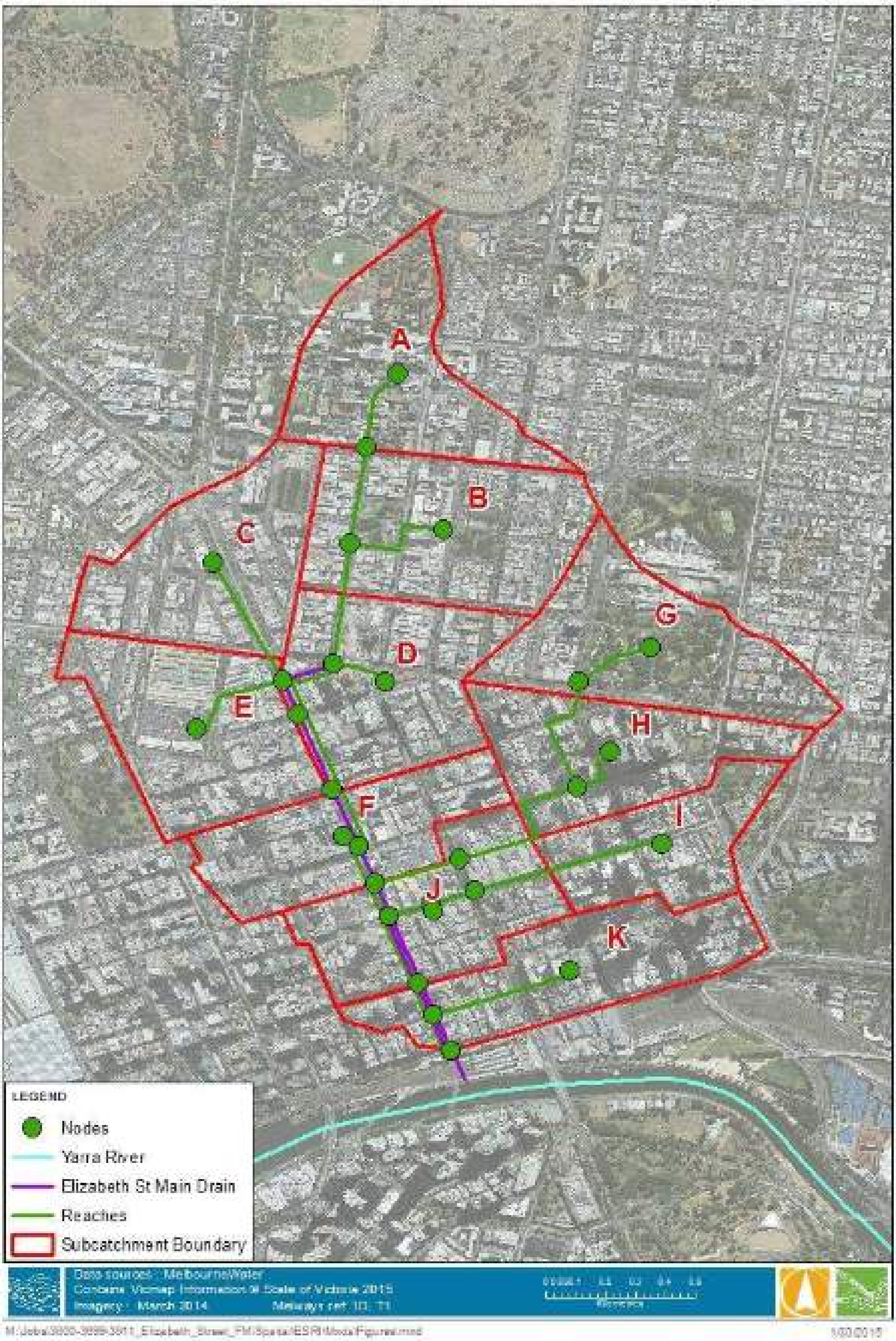

Figure 5-1 1996/97 CMPS&F RORB Model (provided by Melbourne Water, 9th January 2015)

5.2.3 Runoff Coefficients

Other than the runoff coefficients provided in Table 5-2, no other runoff coefficient information was provided.

The runoff coefficient used by the RORB model appears to be 0.6 for pervious area runoff, regardless of the ARI. This is different from current 2015 industry standard, shown in **Error! Not a valid bookmark self-reference.**. Subsequently, the peak flow results provided for the 20 and 50 year ARI events shown in Table 5-7 are likely to be higher than the results obtained if the model was to be run with the lower pervious area runoff coefficients.

Table 5-5 Runoff Coefficient for ARI events for Urban Catchments (Melbourne Water, 2012)

ARI Event	Runoff Coefficient
5 year	0.25
10 year	0.35
20 year	0.45
50 year	0.55
100 year	0.60

5.2.4 Calibration/Reconciliation

As per Melbourne Water's requirements, the undiverted RORB model was reconciled to the 100 year ARI peak discharge calculated using the Rational Method as described in the 1996/97 report.

For larger systems, particularly those with significant lengths of natural streams, the calibration process also utilised typical RORB parameters provided by Melbourne Water, determined based on calibration of some of the larger streams around metropolitan Melbourne, for which recorded flow data was available.

The time of concentration was calculated using a combination of the pipe velocities and allowances as follows:

- Pipe system velocities for calculating time of concentrations were calculated using EXTRAN-XP;
- Flow velocities in council drainage systems generally calculated assume a Colebrook White roughness coefficient of 1.5mm, a pipe diameter of 600mm and a pipe friction slope equal to 50 – 100% of the ground slope; and,
- An allowance of 7 minutes for runoff to reach the upstream limit of the piped drainage system was included in the time of concentration calculation. The time of concentration used in the Rational Method calculation was determined to be 27 minutes.

The following parameters were used in the Rational Method calculation:

- Fraction Impervious values are as per Section 0.
- Reaches are as described in Section 0.
- The Runoff Coefficient of 0.79 was calculated using the method described in Chapter 14 of AR&R 1987.
- A rainfall intensity of 79 mm/hr was used in the Rational Method calculation.

The results of the calibration are as per Table 5-6.

Table 5-6 Existing RORB model calibration

Rational Method Peak 100 year ARI flow (m^3/s)	Undiverted Model Peak 100 year ARI flow (m^3/s)	Diverted Model Peak 100 year ARI flow (m^3/s)
52.6	52.4	43.3

5.2.5 Results

The 1996/97 CMPS&F existing conditions RORB model provides the results shown in Table 5-7.

Table 5-7 Existing RORB model results (CMPS&F, 1996/97)

Location	20 year (m3/s)	50 year (m3/s)	100 year (m3/s) PIPED	100 year (m3/s) OVERLAND
Corner Victoria Parade and Therry Street	7.5	8.6	3.2	6.8
Corner Elizabeth Street and Little Bourke Street	22.0	27.4	17.1	18.1
Corner Elizabeth Street and Flinders Street	27.5	35.0	21.2	22.1

These peak flows were based on proposed future landuse conditions based on zonings at the time.

5.3 Summary

In summary, the existing RORB model is acceptable for use as an order of magnitude check for flows at certain points in the model.

6. HYDRAULIC MODELLING

The following outlines the hydraulic modelling approach, which has been confirmed by both Melbourne Water and the City of Melbourne.

6.1 Overview of Rain on Grid Modelling

The Direct Rain on Grid Method utilises the capability of the hydraulic modelling software to incorporate rainfall into the hydraulic model, requiring minimal hydrological input in the form of hyetographs. After subtracting initial losses, the hyetographs are applied directly on the 2D domain in the hydraulic model. Fraction Impervious (FI) and Runoff Coefficient (RoC) values are applied inside the hydraulic model.

There are a number of advantages of the Direct Rain on Grid Method compared with traditional methods and these include:

- A rainfall-runoff hydrologic model such as a RORB model is not required nor is a detailed analysis of sub-catchments;
- Flows are applied to the model at all points and so there is no reliance on empirical relationships; and,
- Catchment storage areas are more accurately defined.

6.1.1 Methodology

The basic hydrologic model provided design rainfall hyetographs for input to the hydraulic modelling as part of the Direct Rainfall on Grid method. The hyetographs were extracted from AusIFD Software using the 1987 AR&R method and processing tools developed by Water Technology.

Rainfall is input into the model via 2d_rf layers, linked to the hyetographs generated using rainfall intensities generated from the AR&R IFD data. As the catchment is in an urban environment, and therefore relatively small, no areal reduction factors are used. Runoff coefficients will be calculated using Equation 1. Fraction impervious values have been determined based on remote sensing undertaken by Grace GIS, noting that where polygons were too small for the grid size, they were deleted and the areas filled in from the closest and most relevant surrounding cell. Where data was unavailable, planning zones obtained from VicMaps were used to determine the fraction impervious, correlated to the fraction impervious values provided in Melbourne Water's MUSIC Guidelines 2010 and adjusted based on aerial data available from March 2014. This can be found in Figure 6-1.

Rainfall for the calibration run is based on BOM Radar data which allows the rainfall to be varied in space and time.

Losses will be applied to represent infiltration losses based on the fraction impervious and runoff coefficients. Evapotranspiration losses will not be considered as the Elizabeth Street catchment is quite peaky and will not allow time for evapotranspiration processes to occur.

Equation 1 Runoff Coefficient Calculation for Rainfall Layers

$$ROC_{TOTAL} = (FI \times 0.9) + \left[(1 - FI) \times ROC_{perv}\right]$$

Figure 6-1 Fraction Impervious Plan

6.1.2 IFD Parameters

IFD Parameters were determined at the centroid of the catchment using the Bureau of Meteorology IFD Program with a latitude and longitude of 37.84°S and 144.98°E.

AusIFD Software used IFD parameters to generate hyetographs for each required ARI event and duration. ARR 1987 Temporal patterns were used. These were then converted to an appropriate format for the TUFLOW hydraulic model input.

6.1.3 Losses

Rainfall losses were incorporated in the modelling in two forms, initial loss (IL) and Runoff Coefficient (RoC). Rainfall Runoff coefficients were set in accordance with Melbourne Water guidelines (MWC, 2014).

The IL values as in agreement with Melbourne Water for design storm events are presented in Table 6-1.

Table 6-1 Initial loss values

Storm Event (ARI)	Initial Losses (mm)	RoC
5 years	0.6	0.25
10 years	0.6	0.35
20 years	0.6	0.45
50 years	0.6	0.55
100 years	0.6	0.60

Rainfall Runoff coefficients were calculated in accordance with Melbourne Water guidelines (MWC, 2014).

6.1.4 Pre-wet

A pre-wet of the catchment has been undertaken prior to the actual event to remove minor depressions in the topography.

A small amount of rain (3 – 4 mm) has been applied over 10 minutes, and the model run for 12 hours to allow only filled-depressions to remain.

6.2 Overview of TUFLOW Model

The hydraulic model routes the design flood hyetographs, obtained from IFD rainfall, along the proposed infrastructure and any associated overland flow path. The hydraulic model, TUFLOW, was employed in this investigation.

TUFLOW is a widely used hydraulic model that is suitable for the analysis of overland flows in urban areas. TUFLOW has three main inputs:

- Topography and drainage infrastructure data;
- Roughness; and,
- Boundary conditions.

The TUFLOW model was used to route flows within the catchment. Flow was routed along one-dimensional (1D) elements as pipes. Where the capacity of the 1D elements was exceeded, the excess flows are routed overland in a two dimensional (2D) domain. The TUFLOW model outputs flood depths, elevations and velocities.

A detailed 2D (two dimensional) TUFLOW[1] model has been created to simulate existing conditions. The 2D model will allow for the accurate representation of the 5, 10, 20, 50 and 100 year ARI flood extent associated with the Melbourne Water's Elizabeth Street Main Drain.

A rain-on-grid approach was employed in this model. The advantage of this type of model is that no assumption needs to be made regarding the catchment delineation; the topography, roughness and 1D networks will contribute to this delineation as the model runs.

6.3 Hydraulic model construction and parameters

The TUFLOW model was constructed in MapInfo V12.0. This section details key elements and parameters of the TUFLOW model.

6.3.1 Model Version

The double precision version of the latest TUFLOW release was used for all simulations (TUFLOW Version: 2013-12-AE-iDP).

6.3.2 2D Grid Size and Topography

A single 2D domain was used with a grid size of 2 m. The 2d_zpt file was populated with elevations from the LiDAR data obtained from Grace GIS on the 28th of January 2015. Note that Grace GIS have produced three versions of the LiDAR:

- Raw data;
- Weeded out version; and,
- Flow paths version.

Water Technology have used the weeded out version in the modelling. Additionally, initial model results indicate that there are a number of deep holes on construction sites around the catchment. These have been smoothed over with z-shapes to remove any unrealistic ponding. The roughness has been adjusted accordingly over these locations. It is noted that there were gaps in the LiDAR where data was missing. Z-shapes were used to smooth over these areas, so as to reduce instability or inaccuracy in the model.

Where there are steps leading down to underground toilets in the model, e.g. north of Bourke Street on Elizabeth Street, z-shapes have been used to block out these holes in the topography. In reality, water will enter and pond at the bottom of these steps.

Underground car parks were also blocked out to prevent deep pools forming in the model. The main underground car park on Elizabeth Street actually has flood gates on it, so this is a reasonable assumption in this case. None of the other underground car parks along key flow paths appeared to have flood gates, however they have still been blocked out. This was done because there is insufficient information available about the size and depths of these car parks, and it will be impossible to determine how much water enters and ponds in these carparks without additional survey.

Kerb and gutter stamping has not been used, as the model grid is not fine enough to use this information. ARR Project 15 recommends a number of options for the representation of buildings in 2D modelling:

a) Set the building elevations to pad or floor level;
b) Raise the grid to represent the building;
c) Could model the building floor levels, and walls with openings; or
d) Could model the buildings as porous elements.

[1] TUFLOW is a standard hydrodynamic modelling package used extensively by Melbourne Water to undertake urban flood investigations.

It is advised not to null cells in direct rainfall models so this has not be done.

Option b was used to test the sensitivity of the representation of buildings, as compared to the general approach which was to model the buildings using roughness.

Option b requires a fine mesh to ensure model stability with the building heights in the CBD, so this option has been explored as a sensitivity run to determine what impact this has on the flow values. Input from Melbourne Water has been sought to ensure the model response time to rainfall on taller buildings is appropriate. The building elevations have been raised above the anticipated flood level, but not to their full extent, as this will produce stability issues within the model, given the height of the buildings within the CBD.

Options c and d allow flows through buildings, resulting in more accurate representation of hazards and risk to life. However, without specific information on each building within the catchment, these are not appropriate options.

Note that residential, commercial and industrial properties and buildings will be modelled the same way. There is not really a difference between these building types within the CBD.

6.3.3 1d Network

Pit and pipe data has been obtained from Grace GIS for both Melbourne Water and City of Melbourne pipe networks. Grace GIS have inferred missing data such as the pipe and pit invert information using the cover rules shown in Table 6-2. The data has been checked to ensure there are no clashes between Melbourne Water and City of Melbourne pipes, and key drainage and overland flow paths have had invert levels reviewed to ensure the flow will be directed downstream, without downstream invert levels higher than upstream invert levels, Additionally, where non-standard, or very small, pipe sizes were indicated in the data obtained from Grace GIS (0.105, 0.2, 0.12, 0.147, 0.125, 0.13, 0.075, and 0.15 m), these values were compared with those from the City of Melbourne and corrected where necessary.

A plan of open and closed pits has been prepared for the purposes of the model, and can be seen in Figure 6-2.

Underpasses under Flinders Street Station and the Degraves underpass have also be modelled as 1D networks. This data was based on information received from the City of Melbourne.

Losses have been applied as per the standard Melbourne Water method found in the Land Development Manual.

GPTs have not been included as there is insufficient information available about them for hydraulic modelling purposes.

Open sewer pits have been ignored for the purposes of this project.

Pits have had depth-varying flow relationships applied to them, depending on whether they are grated side entry pits, side entry pits, double grated side entry pits or overflow kerb pits. For the overflow kerb pits on Elizabeth Street, they have all been assumed to be of rectangular shape, on-grade with the street, and a longitudinal grade of 1% for the purpose of calculating the relationship.

Table 6-2 Assumed Depth of Cover

Pipe Diameter (mm)	Assumed Depth of Cover (mm)
Less than or equal to 900 mm	600
Greater than 900 mm	750

Connectivity to the 2D will be achieved using SX and CN lines for underpasses and outflow points, and SX connections for pits.

Loss parameters around building structures are managed in 2D by TUFLOW with no additional losses. 1D losses are applied as per the standard method.
Other important parameters to note include the following:

1. In order to improve the stability of the model, storage was included at each node;
2. Pits that are blocked are modelled as if they are not blocked;
3. It is assumed that in the data provided by the City of Melbourne (CoM), nodes denoted as "LT" (Lane type) or "U" (unknown) are sealed if grate information is not provided. The exception is within the University of Melbourne, for which they are modelled as open, with an average grate size of 900 mm * 450 mm;
4. It is assumed that pits within the Royal Exhibition Buildings Gardens are as per council information provided. These were not inspected on site;
5. Tram drainage has not been incorporated into the model, however tram stops have been;
6. All base flow is ignored;
7. Pits provided by Grace GIS that didn't have a pit provided in the CoM data were labelled as a GSEP, and where there was 2 pits that didn't have a corresponding pit, one was labelled as a node;
8. 1D HT conditions were imposed at 1D outlets based on the obvert of the downstream end of the pipe outlets;
9. Pipes with a length shorter than 10 m were scaled up to have a minimum length of 10m, to ensure model stability;
10. Pit classes provided by CoM have had assumed grate dimensions applied in the model as per Table 6-3; and,
11. It is assumed that Side Entry Pits (SEP) are 0.9 m long by 0.11 m high at the entrance in the kerb.

Table 6-3 Pit Grate Dimensions

Class	Grate width	Grate length
Grated Manhole (provided and assumed)	600	600
Grated OFK (assumed and provided)	430	910
Junction, Junction pits (provided) (UNO)	0	0
Double grated OFK (assumed)	430	910
Double GSEP (provided and assumed)	Varies	Varies
Grated kerbside (provided and assumed)	Varies	Varies
Grated pit (assumed)	600	600
GSEP – where no info, 900 * 430	Varies	Varies
Lane type	Varies	Varies
Run through inlet	0	0
Run through outlet	0	0
Side entry pit	Varies (938)	Varies (545)
System node	0	0
Trench Grate	Varies (4.5)	Varies (0.5)
Undershot Pit	Varies	Varies

6.3.4 Plot Output Lines

PO lines have been set up to record flow and water surface elevations at strategic locations throughout the model as per Figure 6-3, which also shows the final modelling results from the 100 year ARI event.

Additionally, another PO layer with recording points suitable for the ICAM model has been created and included in this report for your information, as per Figure 6-4.

Figure 6-2 City of Melbourne and Melbourne Water Pits

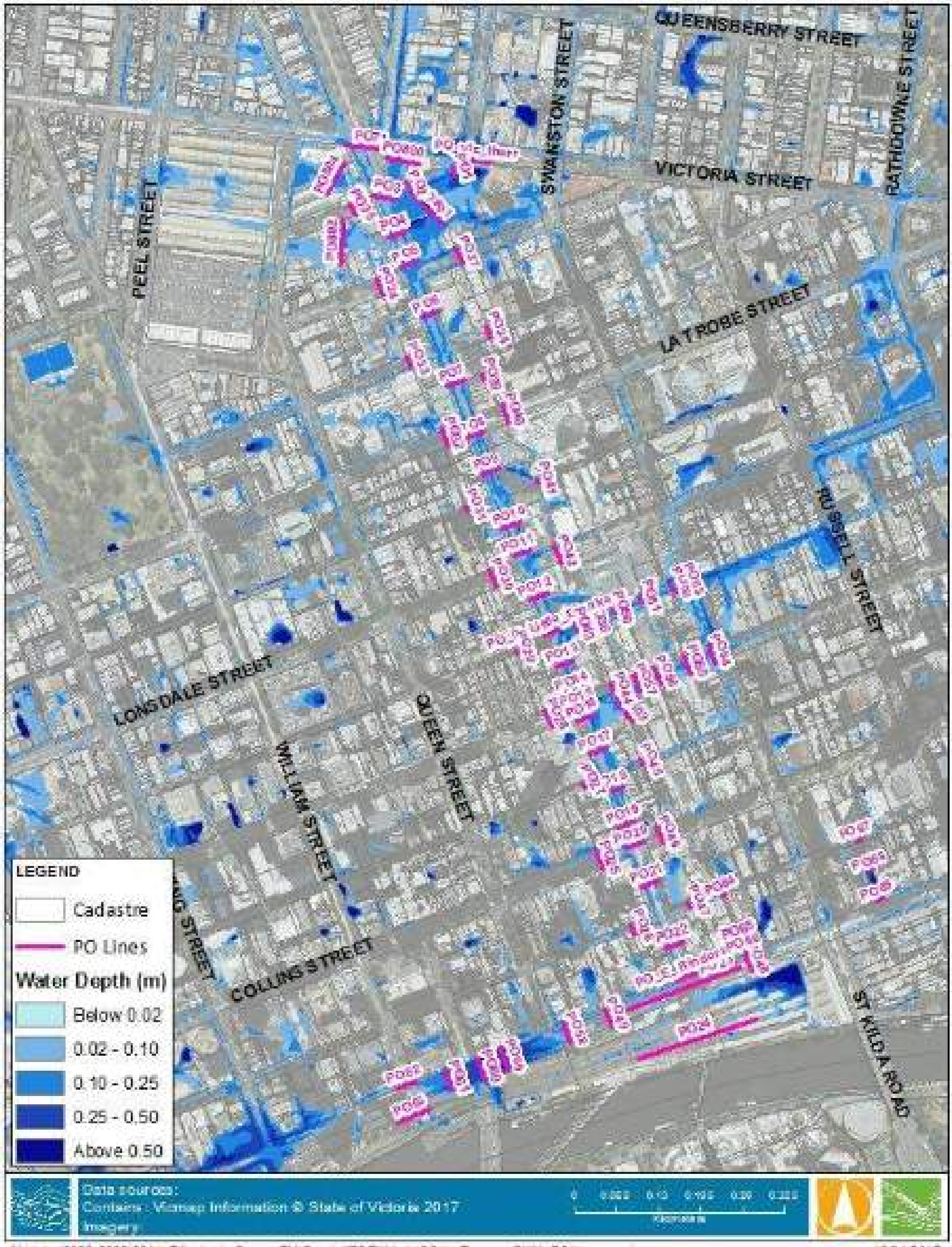

Figure 6-3 PO Line Locations

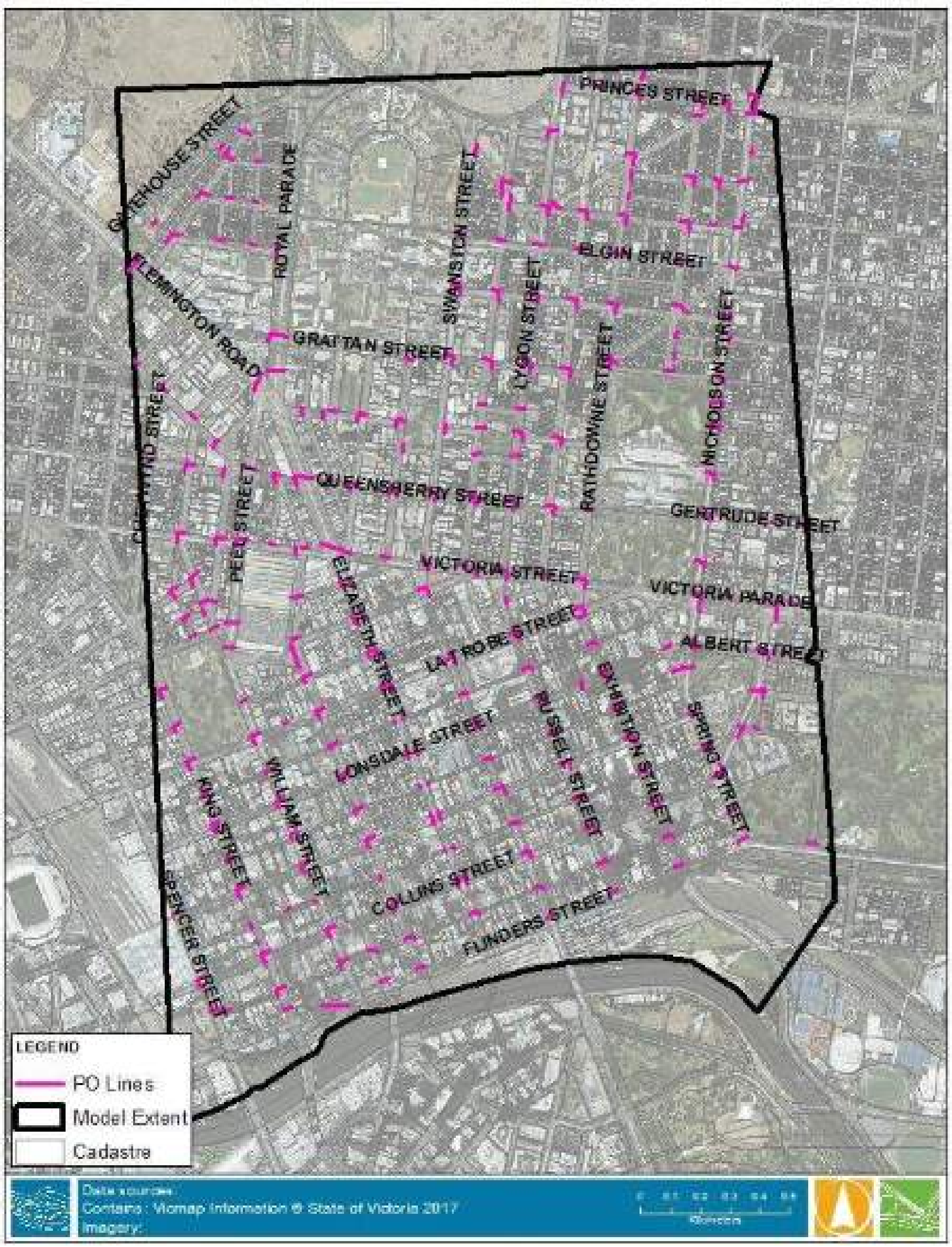

Figure 6-4 **ICAM PO Line Locations**

6.3.5 Roughness

For the 2D domain, 2d_mat files were produced by Grace GIS as described below. The Manning's values are specified in the .tmf TUFLOW model file.

Land use zonings prepared by Grace GIS were used to determine the Manning's roughness coefficients as per Table 6-4 based on Table 3.2 of Melbourne Water's Guidelines and Specifications for Flood Modelling. Refer to Figure 6-5 for the layout of the Manning's roughness polygons.

It is noted in ARR Project 15 that for direct rainfall modelling, 'n' values may be input into the model in a few ways:

a) Standard 'n' process;
b) Vary 'n' values for buildings depending on whether they are in the floodplain or not. This allows a very low value of n to be used for buildings to represent fast runoff from the building's roof outside the floodplain, and a high value to represent the much higher resistance to flow within the floodplain. With this option, building elevations should be set to building pad or floor level; or,
c) Vary 'n' with depth of flow.

As little data exists for Options b and c above, Option a has been utilised in this model.

For the 1D domain, Manning's roughness coefficient of 0.013 has been applied for concrete pipes and 0.017 for brick pipes.

Table 6-4 Manning's n Roughness Coefficients

TUFLOW .tmf Code	Land Use	Manning's n Roughness Coefficient
1	Residential – urban (higher density) (buildings and landscaping footprints modelled together)	0.350
2	Residential – rural (lower density) (buildings and landscaping footprints modelled together)	0.150
3	Residential – urban (higher density) (buildings and landscaping footprints modelled separately)	0.400
4	Residential – urban (higher density) (buildings and landscaping footprints modelled separately)	0.100
5	Residential – rural (lower density) (buildings and landscaping footprints modelled separately)	0.400
6	Residential – rural (lower density) (buildings and landscaping footprints modelled separately)	0.050
7	Industrial/commercial	0.300
8	Significant drainage easement	0.050
9	Open space or waterway – minimal vegetation	0.040
10	Open space or waterway – moderate vegetation	0.060
11	Open space or waterway – heavy vegetation	0.090
12	Open water with reedy vegetation	0.065
13	Open water with submerged vegetation	0.020
14	Car park/pavement/wide driveways/roads/tramways	0.0250
15	Railway Line	0.125
16	Concrete lined channels	0.016

It is noted that the roughness assigned to the cemetery is 0.1, given the density of the site.

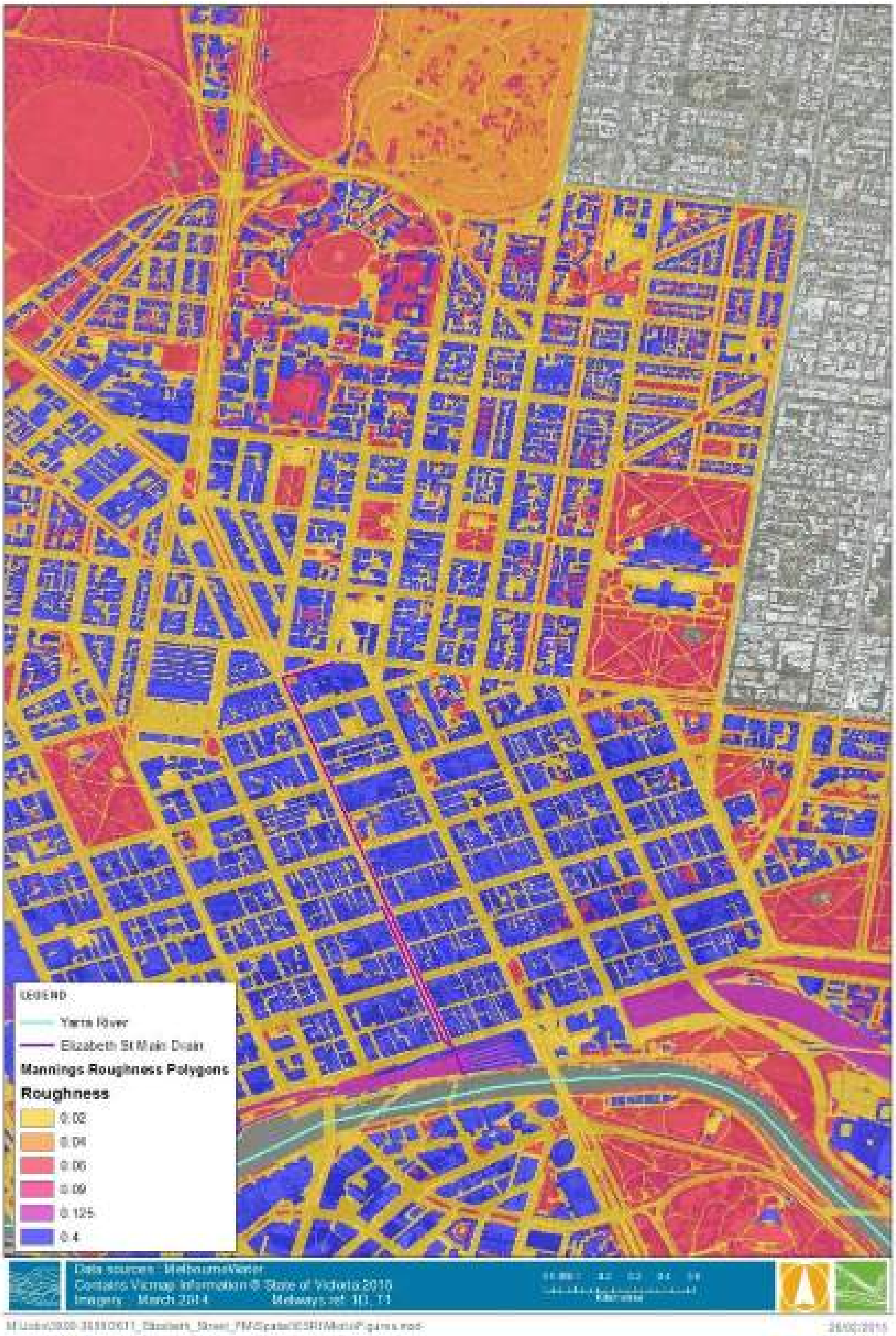

Figure 6-5 Manning's Roughness Polygons

6.3.6 Pit Configuration

Pits along the 1D pipe section were connected to the 2D using the "SX" option for the 1d_nwk pit Conn_2D attribute.

6.3.7 Boundary Conditions

Inflow is via direct rainfall generated from AR&R 1987 IFD data.

HT boundaries have been included at the Yarra River based on information provided by Melbourne Water.

Water Technology proposed a methodology for setting the initial tailwater levels within the ICAM models, including the Elizabeth Street Catchment, for the three major water courses within the model. These are the Yarra River, Maribyrnong River and Moonee Ponds Creek.

Water Technology identified that there are three options for setting the tailwater levels as follows:

1. Utilising only the supplied flood water elevations, as received 27th March 2015 from Melbourne Water;
2. Using the 1.6 m AHD level of Port Phillip Bay described in the Melbourne Water Corporation Flood Mapping Projects; Guidelines and Technical Specifications November 2016; or,
3. Combining the flood levels with the bay level described within the above guidelines; that is, using the supplied flood water elevations where these are above the bay level, and using the bay level elsewhere as the minimum tailwater level.

The first option using only the flood levels was not recommended as the lower extents of the models contain tailwater levels lower than the prescribed bay level. These levels also don't cover the full extent of the catchment. Utilising only these levels may result in inaccurate results, and instabilities where data is missing. Therefore, this option was not recommended.

The second option was to use only the prescribed bay level. As this approach fails to consider the impact of flooding in larger events, it was also not recommended.

Water Technology proposed, and Melbourne Water approved, to utilise the third option described above. That is to use the flood levels received on the 27th March 2015 combined with the bay level described in Melbourne Water Guidelines to determine the initial water level. Where flood levels from the supplied data are below 1.6 m AHD, they were replaced with a height of 1.6 m AHD to ensure constancy with Port Phillip Bay tailwater levels. Please note that there is a data gap upstream of the supplied cross sections in the Yarra River, as shown in Figure 6-6 below. This shows the 100 year ARI initial water DEM constructed from the supplied flood levels (outlined above) and the Port Phillip Bay tail water level. The tailwater level has been calculated by combining the prescribed bay level with the modelled flood levels.

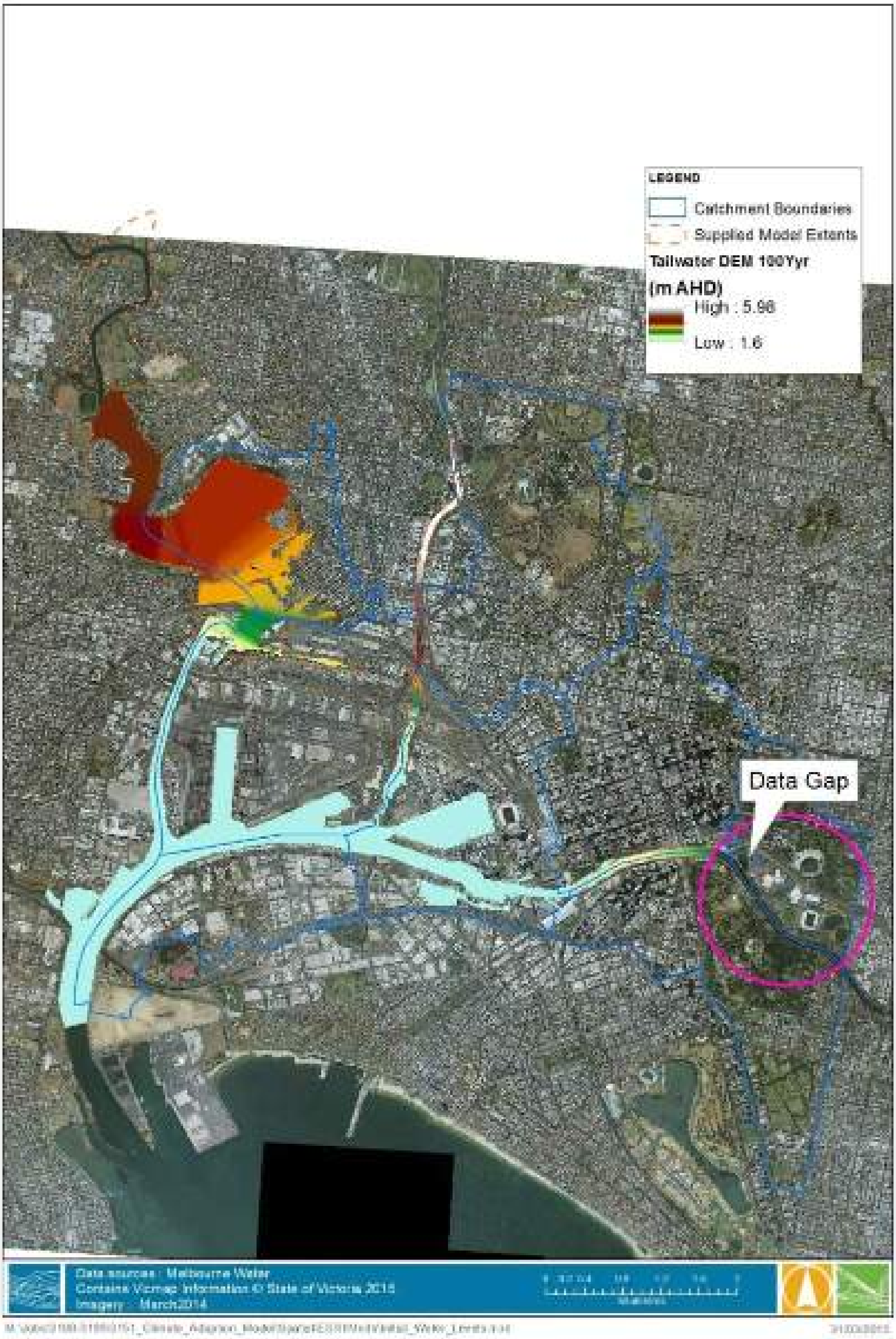

Figure 6-6 Proposed Initial Tailwater DEM

Initial water level DEMs for each AEP event were produced as per the method described above. Note that the Yarra River has not been modelled i.e. upstream inflow, bathymetry and bridges have not been incorporated into the model although the original model that produced the applicable flood levels would have considered these.

1D initial water levels were sampled from the compiled 2D IWL DEMs. These were applied, along with HT boundaries, maintaining this water level for the duration of the model run, at each 1D outlet point outside of the model boundaries.

HQ boundaries have been applied along the model boundaries with a grade of 1 in 100 to allow water to flow out of the model. This HQ boundary has been offset from the assumed catchment boundary to ensure they do not interact with the area of interest. This boundary does not remove any of the water from the catchment, but allows water to flow out of the model unimpeded from areas outside the catchment, as defined by the topography. This has been refined based on preliminary model results.

The TUFLOW input layers used in the existing conditions model is shown below in Figure.

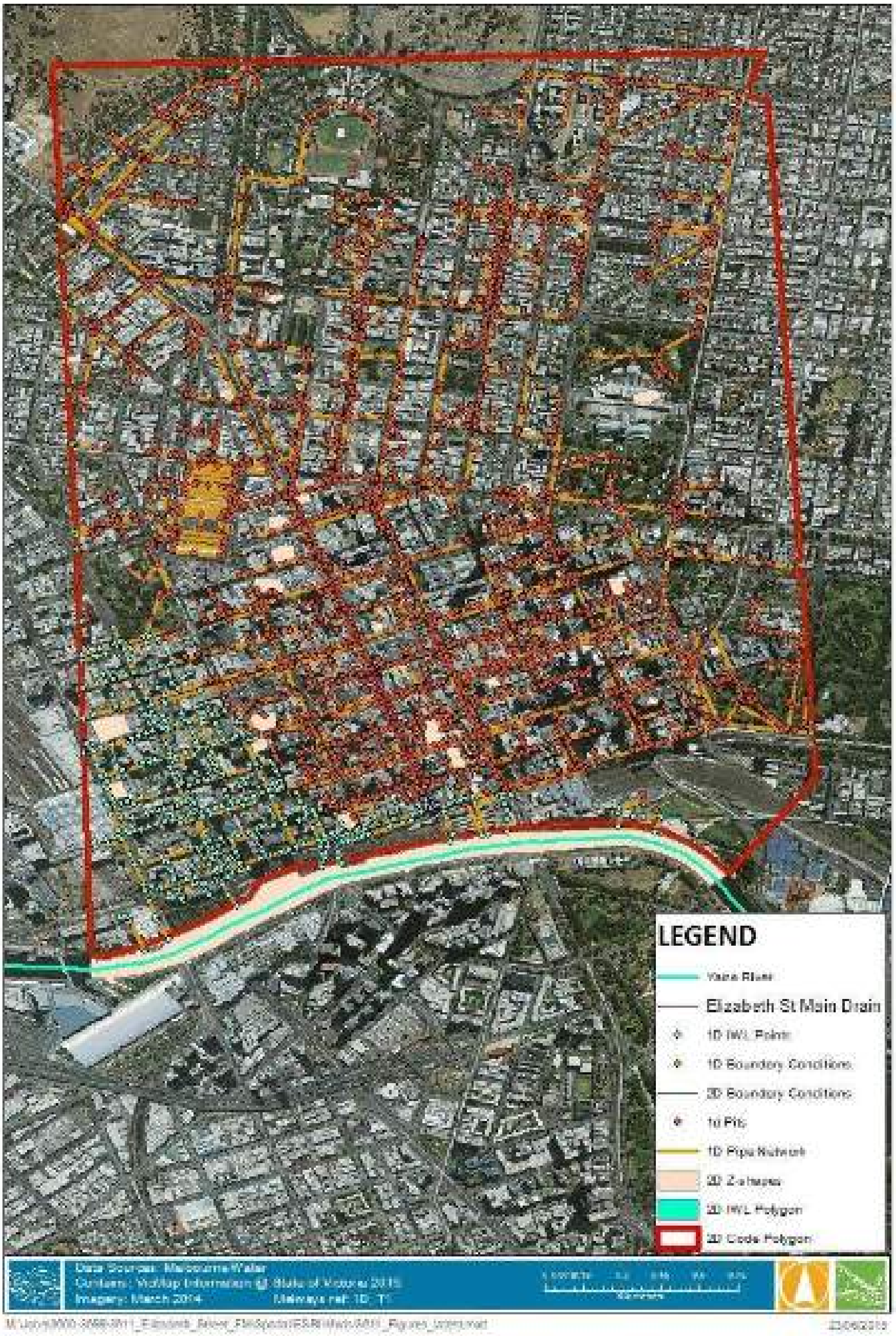

Figure 6-7 TUFLOW Setup

6.4 TUFLOW Model Reconciliation

6.4.1 GIS Processing

The TUFLOW model was set up using a projection in the Map Grid of Australia, Zone 55. All GIS layers were projected within this coordinate range and the projection file read into the TUFLOW Control File (TCF).

6.4.2 TUFLOW Data Processing

The TCF was set up to process the following:

- TUFLOW Event File (TEF) including the ARI and duration of each event;
- TUFLOW Geometry File (TGF) including the cell size, grid size, LiDAR, material roughness GIS layers, initial water levels and Z-shapes used to correct for initial water levels;
- Estry Control File (ECF) including the 1D timestep network, boundary conditions, initial water levels and the location of 1D results;
- TUFLOW Materials File (TMF);
- Plot Output lines;
- 2D boundary conditions including the boundary conditions database and GIS layer; and,
- 2D Simulation parameters, including the timestep, recording times and displays, start times and cell wet/dry depth.

6.4.3 Results Processing

The results to be generated were set up in the TCF including water elevation, velocities, flows, depths, hazard mapping and mass balance checks as described below. The map cutoff depth command in TUFLOW was set to 0.0 m, with all future thinning of results post processed from the full raw dataset. The cell wet-dry depth was set at 0.0002 m as required for the very shallow depths seen in direct rainfall modelling.

6.4.4 Hydraulic Model Application

The TUFLOW model was run for a suite of storm durations for each of the required ARIs in the existing conditions and various scenarios as per Figure 6-8. In initial runs, the suite of storm durations from 10 minutes to 12 hours was run as this is where the peak events occur.

All TUFLOW model runs were controlled through a TUFLOW Event File (.tef) and a series of batch files constructed for use in this project. The use of the .tef file and batch files ensures that the base .tcf (TUFLOW Control File) does not change between runs, with all event specific parameters specified in the .tef file. This reduces the potential for error and also assists in reducing model run and processing times. A full explanation of the use of the .tef files will be provided along with a batch file for future running of the models by Melbourne Water.

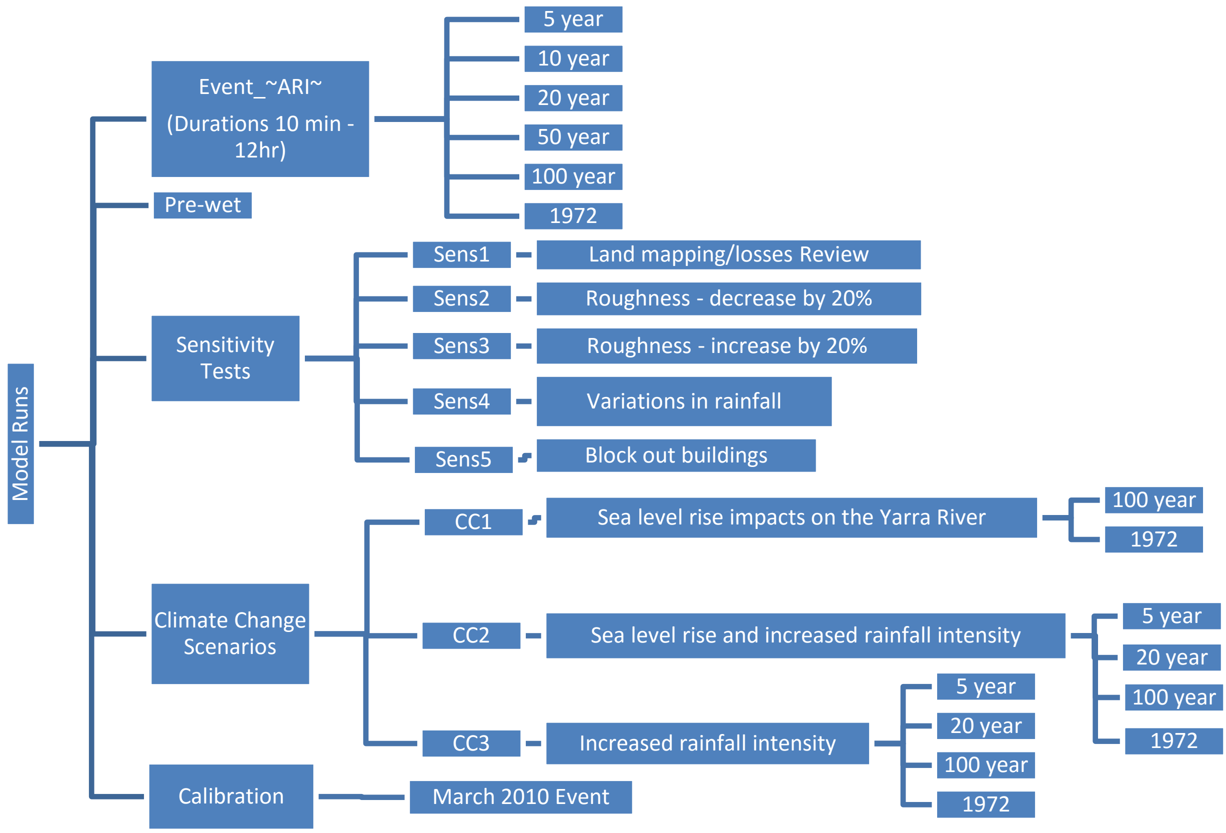

Figure 6-8 Model Scenarios and Events

6.4.5 TUFLOW model checks

The following checks have been undertaken on the TUFLOW model parameters and outputs to ensure the model is fit for purpose:

- 2D grid size is 2 m, within the range of 2-3m for urban catchments;
- 2D time step is 1 s, within the range of ¼ - ½ of the grid size;
- 1D time step is 0.5 s, within the range of 1/10 – 1/5 of the 2D time step;
- Model mass errors generally below 1% ;
- Errors messages do not occur;
- Warning messages are eliminated or explained;
- Pipes flowing full – 359 pipes are less than 10% full. These pipes have been reviewed and they are at the top of catchments/start of drainage lines, so it makes sense that they are not full. The underpasses are also not flowing full, but this is anticipated, given the significant size. Finally, pipes 9248 and 1577 are significantly larger than the pipes immediately upstream, so it stands to reason that they are not flowing full, either. It is also noted that there are some steep pipes in the model. The inverts were inferred by the assumed minimum cover and pipe diameters as described in Section 0, and as such, are a function of the terrain. Unless detailed survey of these inverts is undertaken, this is the best available information. It is also noted that the majority of these steep pipes have quite small diameters, so will have less impact on the results;
- Pipes properly connected; and,

- 2D model extent does not constrain the flood extent.

Checks and fixes were undertaken prior to the final model runs being launched on the locations of any 1D or 2D negative depths, significant depths of water and any warnings and checks contained within the log files. All instabilities have been found and rectified.

Velocity checks were undertaken and pits and pipes examined where velocities were over 5 m/s. The TS file was imported into MapInfo and the relevant pits and pipes reviewed to determine whether the actual maximums were a result of a "wobble" or instability. If so, these were either accepted, if the TS plot showed actual peak velocities less than 5 m/s, or the issue corrected where possible. Generally, where velocities are higher than 5 m/s, it is a result of steep pipes.

Negative flows were reviewed and rectified.

Changes in head greater than 3 m were also reviewed in Excel. The depths of ponding in these locations were reviewed and deemed acceptable given their location both in the 2D topography, and also within the 1D network.

Changes in elevation caused by the Z-shapes were checked and deemed acceptable.

Pipe capacity was reviewed using the CCA results file in MapInfo. Locations where pipes were flowing less full downstream than upstream were reviewed and deemed acceptable, generally owing to increases in cross-sectional area in downstream pipes, or increases in slopes in the pipes.

Based on the above checks, we consider the TUFLOW model to meet the requirements as outlined in the Draft Melbourne Water Guidelines and Technical Specifications (MWC, 2014).

6.4.6 TUFLOW model outputs

TUFLOW provides times-series of depths (m), water surface elevations (m AHD), flow velocities (m/s) and flood hazard (m/s/m) at each link location within the 1D element, and at the grid points within the 2D domain.

The preparation of flood mapping outputs from the TUFLOW results is detailed in Section 9.

The preparation of flood mapping outputs from the TUFLOW results is in accordance with Melbourne Water requirements. Water Technology has filtered any depths below 50 mm in the results and removed puddles less than 100 m^2.

7. SENSITIVITY TESTING

7.1 Overview

ARR Project 15 provides guidance on undertaking sensitivity testing. The following is a brief summary of this information:

To test the sensitivity of a model, the following parameters should be tested:

- Adjust hydraulic roughness parameter values up and down by 20%;
- Increase inflows by 10%;
- For downstream boundaries, not at a receiving water body such as the ocean, vary the stage-discharge or water level upwards to check that the water levels in the area of interest are not greatly affected;
- Apply blockages and greater losses to hydraulic structures and inlets;
- Apply lower discharge coefficients across embankments such as roads;
- Make the model resolution finer to check that the results do not demonstrably change; and,
- Vary the timestep and other computational parameters.

For rain-on-grid, the recommendations are to test the following parameters:

- Rainfall losses;
- Model roughness;
- Representation of roof to catchment outlet drainage system; and,
- Variations in rainfall e.g. spatial application, proportioning of historical rainfall, etc.

The sensitivity testing should focus more on flow generation rather than the peak water levels or depths.

The project scope of works is to undertake sensitivity testing with regard to the following:

- Losses - Standard losses for city catchments may be too high. This is because parks are heavily trafficked and can become compacted and therefore have reduced perviousness over time;
- Roughness is to be increased and decreased by 20% respectively in two additional runs;
- Blockage of buildings will be tested against no blockages; and,
- Rainfall will be spatially varied in the 2010 calibration event according to radar information where possible.

7.2 Sensitivity Testing Results

This following outlines the sensitivity analyses and associated results for the Elizabeth Street Flood Modelling project.

The following sensitivity analyses were undertaken:

- Comparison of 10 mm initial losses to zero initial losses;
- Comparison of a reduction in Manning's roughness by 20% to industry standard roughness;
- Comparison of an increase in Manning's roughness by 20% to industry standard roughness;
- Comparison of a fraction impervious value in parks of 50% to the industry standard 10%; and,
- Comparison of a buildings blocked scenario to a buildings roughened scenario.

The following results of the above comparisons can be found in Appendix A for both the 100 and 5 year ARI, 2 hour duration events:

- Existing depth and velocity (no initial losses) as shown in Figure 10-1, Figure 10-2, Figure 10-18 and Figure 10-19;
- Existing depth (initial losses = 10mm) as shown in Figure 10-5 and Figure 10-20;
- Depth difference plots between existing with initial losses and existing with no losses as shown in Figure 10-6 and Figure 10-21;
- 20% reduction in roughness depth and velocity as shown in Figure 10-10, Figure 10-12, Figure 10-27 and Figure 10-29 ;
- Depth and velocity difference plots between 20% reduction and existing with no losses as shown in Figure 10-11, Figure 10-13, Figure 10-28 and Figure 10-30;
- 20% increase in roughness depth and velocity as shown in Figure 10-14, Figure 10-16, Figure 10-31 and Figure 10-33;
- Depth and velocity difference plots between 20% increase and existing with no losses as shown in Figure 10-15, Figure 10-17, Figure 10-32 and Figure 10-34;
- Increase in fraction impervious from 10% to 50% in parks depth plot as shown in Figure 10-3 and Figure 10-22;
- Depth difference plots between increase in fraction impervious and existing with no losses as shown in Figure 10-4 and Figure 10-23;
- Blocked building depth plot as shown in Figure 10-7 and Figure 10-24; and,
- Blocked building depth and velocity difference plots as shown in Figure 10-8, Figure 10-9, Figure 10-25 and Figure 10-26.

7.3 Discussion

7.3.1 Initial Losses

The 10 mm initial losses scenario does not show the level of flow we would expect to see down Elizabeth Street, particularly between Collins and Flinders Streets. As it is a highly impervious catchment, combined with a quick time of concentration, we believe that an initial loss value of 10 mm is too high. When zero losses were used, the flows increased significantly, more in line with what is expected to flow down Elizabeth Street in such an event.

In order to determine the most appropriate value for initial losses, a detailed calibration of an actual event is required. Whilst the radar data obtained from the Bureau of Meteorology for the March 6th 2010 event has been run through the model, there is a lot of uncertainty around the actual amount of rainfall and the duration during which it occurred. The radar data recording intervals were insufficient to capture the very quick nature of this event, and as a result, the radar data has to be scaled up to see the types of flows we know occurred during the event. As the scaling factor can be determined in a number of ways, and there is insufficient flow or water level gauge data to determine this factor, in this case, we believe that the radar data cannot be accurately used to validate the model. The radar runs, however, have proven to be a great model verification tool.

Another option may have been to use YouTube videos. Whilst there are a number of videos available, the timing of these videos is unknown, so it is unclear whether it is the peak of the event. These videos are able to be used to determine general flow paths and possible depths, but not to accurately validate the model.

Upon discussion of these constraints with Melbourne Water, a value of 3 mm initial loss was suggested by Melbourne Water, with Water Technology asked to justify this value.

A comparison of the rainfall intensity experienced during the March 6th 2010 event to the rainfall intensities in design rainfall ARI events was undertaken. The rainfall intensity experienced was calculated by Melbourne Water and provided to Water Technology on the 14th May 2015. This data has been reproduced and included in an IFD chart as shown in Figure 7-1.

The 6 minute intensities calculated by Melbourne Water are likely to be the most accurate, and therefore, the comparison indicates that the March 6th 2010 event was likely to be around the 1 in 200 year ARI event. As a result, the flows we are seeing down Elizabeth Street with the scaled up Radar may not be too far off the mark. However, this still does not mean we can use the Radar data to validate the initial loss parameter and justify using 3 mm initial losses, as we would be also trying to validate the Radar scaling factor at the same time.

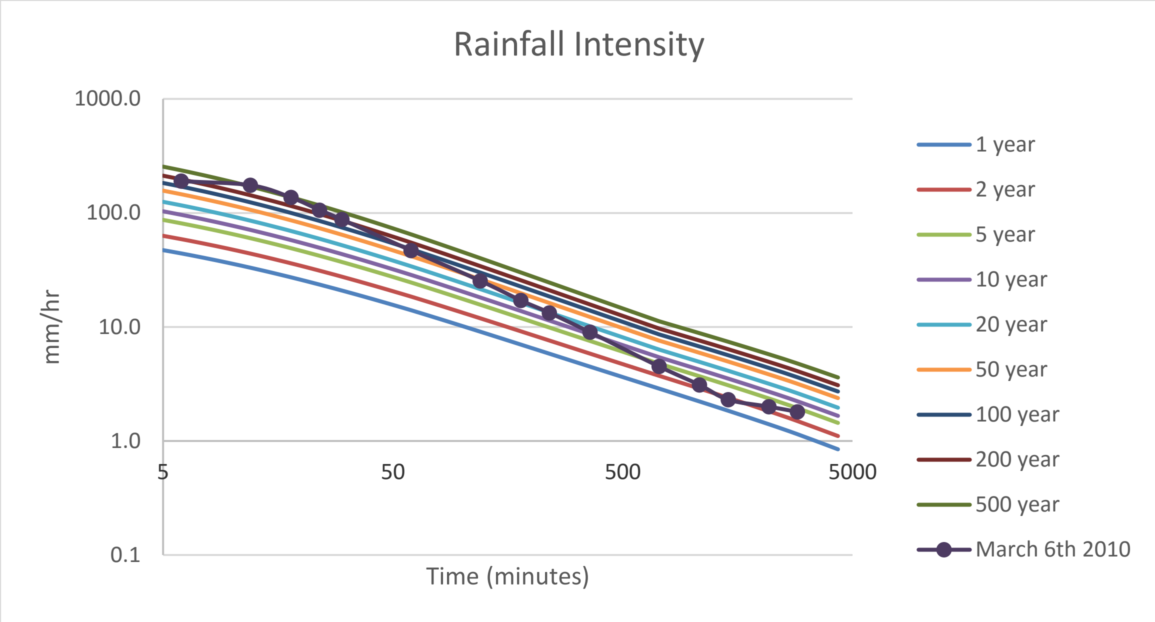

Figure 7-1 IFD Chart

Tony Ladson of Moroka has provided feedback on the initial losses in a memo on the 19th May 2015, as to the most appropriate value to use. A brief summary of this memo has been provided below.

> *Previous initial loss calibration of a RORB model in a highly urbanised gauged catchment, Elster Creek at Head Street, resulted in quite low initial losses for three historic events; 23 March 1974, 25 December 1978 and the 23 January 1991, for which the initial losses were determined to be 5.0 mm, 0 mm and 0.5 mm respectively.*
>
> *An urban runoff review was undertaken by Boyd (Boyd, M. J., M. C. Bufill and R. Knee (1993). "Pervious and impervious runoff in urban catchments." Hydrological Sciences Journal 38(6): 463-478.), in which he analysed 763 events, for which the majority of the initial losses were less than 1 mm. The average weighted initial loss for these events is 0.62 mm. Another paper by Boyd (Boyd et al. 1994) found initial loss to be near 0 mm in urban catchments.*
>
> *Richardson et al. (2004) also undertook research into initial loss values on impervious surfaces (Richardson, L., Hairsine, P. and Ellis, T. (2004) Water farms: a review of the physical aspects of water harvesting and runoff enhancement in rural landscapes. Technical report 04/6. Cooperative Research Centre for Catchment Hydrology.). The results indicate the value for concrete is 1.1 mm and for asphalt is 0.5 mm.*
>
> *A paper by Hollis et al. (1988) shows that initial loss from impervious surface is variable but often very* low *(Hollis, G. E. and J. C. Ovenden (1988). "One year irrigation experiment to assess losses and runoff volume relationships for a residential road in Hertfordshire, England." Hydrological Processes 2: 61-74.).*
>
> *Additionally, there is an Australian Rainfall and Runoff project on losses with specific work on urban catchments (Phillips et al. (2014) Project 6: Loss models for catchment simulation - Urban losses. Engineers Australia.). The results vary between 1 and 5 mm, with an average of 1.75 mm, and in other areas of the report, 1 mm for impervious areas. The report indicates that even this may be too high.*

> *Finally, for calculating design flow estimates, initial loss must be selected based on the 'probability neutral assumption', i.e. we need a design initial loss (along with other design parameters) so that a design rainfall intensity of a certain AEP is turned into a flood of the same AEP. We need to use a burst initial loss rather than a storm initial loss, as the design rainfall depths from ARR are bursts (in general) rather than whole storms. The burst initial loss is smaller than the storm initial loss, particularly for events less than 24 hours as shown by Peter Hill (Hill, P. I., Maheepala, U. K., Mein, R. G. and Weinmann, P. E. (1996) Empiricial analysis of data to derive losses for design flood estimation in South-Eastern Australia. Cooperative Research Centre for Catchment Hydrology.). This indicates that if the initial loss from a complete storm in a historic event is small (1 mm or so), then the design initial loss for the design bursts from ARR should be even smaller.*

Based on Tony's research and the results from the sensitivity analysis, Water Technology recommended, and Melbourne Water approved, an initial loss of 0.6 mm.

7.3.2 Roughness

In terms of the roughness, there are some interesting differences in investigating the sensitivity, making for an interesting commentary. The results are as we expect to see them; that is, a reduction in roughness results in an increase in peak depths and velocities; and an increase in roughness results in a decrease in peak depths and velocities. This is a result of making the model more efficient in the former case, and less efficient in the latter.

However, as there is no real calibration data available, we recommended, and Melbourne Water approved, continuing with the standard roughness values, subject to including additional PO lines, as per the email received 5th June 2015, which can be found in Appendix B.

7.3.3 Fraction Impervious Data

We have also compared the increased fraction imperviousness in parks, and although there are small differences within the parks, the increased imperviousness does not affect the flooding outcome on Elizabeth Street or other key locations within the catchment. For this reason, it is recommended, and approved by Melbourne Water, that the original 10% imperviousness in parks is used for all future runs.

7.3.4 Buildings Blocked

In terms of the blocked buildings, we recommend using the non-blocked building scenario, as there is little impact on the peak depths throughout the main flow paths in the buildings blocked scenario, and only small increases in the velocities along Elizabeth Street in this scenario, as compared to the existing, no losses run. Ideally, a mixture of completely blocked and roughened buildings would be ideal if survey data was available to back up the decision making on a property by property basis. This approach has been approved by Melbourne Water subject to the addition of PO lines, as per the email received 5th June 2015, which can be found in Appendix B.

7.4 Summary

A summary of the approved methodology is as follows:

1. Use an initial loss of 0.6 mm;
2. Use industry standard Manning's roughness values as per the Melbourne Water manual;
3. Use 10% Fraction Imperviousness values in parks; and,
4. Roughen the buildings, without blocking them.

8. VALIDATION

8.1 Overview

ARR Project 15 provides guidance on calibrating a 2D rain-on-grid model. The following is a summary of the information to be considered and utilised during the calibration.

With rain-on-grid calibration, there are a limited number of parameters to alter; roughness, losses and grid/mesh resolution. Usually there is insufficient information to undertake a calibration for rain-on-grid, and thus verification to alternative models, estimated peak flows and volume checks are undertaken. When there is sufficient information, calibration can be undertaken. This information is in the form of:

- Historical hydrologic data, including rainfall, derived flow hydrograph and streamflow, noting that event gauging in streamflow is not a unique point in space and time, rather the sum of velocities * cross-sectional area over a time period. It is also important to note that the derived flow hydrograph is based on a stage-discharge relationship based on this gauge information. Therefore, the model can be calibrated correctly but for the wrong reasons;
- Historical flood behaviour, including continuous water level recorders, maximum height gauges, peak level records, watermarks on structures, anecdotal information and debris marks. Care must be taken in low flow regions as results can be distorted;
- Sources of historical data, including previous studies and reports, community stakeholders, council representatives and records, newspapers, historical records, societies, libraries, the Bureau of Meteorology; state water agencies or corporations, state emergency services, roads/rail authorities and/or other federal/state government departments;
- Observations of the rate of rise of flood waters and the time of the peak, photographs or videos, records or observations on water speeds and/or flow patterns, records of blockage at hydraulic structures such as culverts and gully traps, records and photos of extents of inundation and information on road/rail closures; and,
- Changing conditions, including topographical, bathymetry, control structures e.g. dredging or siltation of river entrances, construction and/or alteration of levees, dams, roads, rail, culverts, bridges, drainage works, development on floodplain, and/or farming practices.

When using this information, it is important to understand the reliability and relevance of the dataset, and to ensure that the spread is considered relevant for the proposed design events.

Errors in calibration are likely to be caused by:

- Inaccurate input data;
- Inaccurate recorded calibration data and observations;
- Unrealistic parameter values;
- Model resolution/schematisation is inadequate;
- Modeller error in developing the model; and/or,
- Hydraulic modelling software is operating beyond its limitations.

For this project, it is noted that the calibration process is more of a verification process. In a standard flood study, gauge data would be used to validate flows and depths at certain points in the model. However, there are no gauges for the Elizabeth Street Catchment. The best information available for this site is as follows:

- BoM rainfall data;
- BoM Radar data;
- Youtube videos; and,
- Photos.

There are limitations associated with each of these datasets as noted in the sections below.

8.2 Validation Data

The March 6th 2010 flood event that occurred in Elizabeth Street has been used to validate the model. Data from rainfall gauges has been used to aid in the preparation of 30 minute and 6 minute interval radar data which was run through the model to simulate the actual event.

It is noted that the latest LiDAR flown in 2014 was used for the validation run as there has not been significant changes affecting either the Fraction Impervious or Roughness values between 2010 and 2014.

The downstream initial water levels were recorded from a gauge situated near Crown Casino, providing the flux throughout the event. An IWL and HT boundary was placed at each outflow point to simulate this.

A number of YouTube videos were used to verify critical flow paths and approximate depths, however, it is unclear whether these videos were recorded during the peak of the event. Photos have the same limitations, and neither can be used to accurately validate the model.

The following rain gauges were used to verify the Radar data.

Table 8-1 Rainfall Gauge Data

Rainfall Gauge	Daily rainfall (mm)		
	4/3/10	5/3/10	6/3/10
Melbourne Botanical Gardens 86232 (1.1 km away)	0.6	1.6	50.4
Prahran 86095 (2.2 km away)	1.0	N/A	N/A
Caulfield 86018 (6.6 km away)	0	0	33.0
Flemington Racecourse 86039 (8.4 km away)	1.4	1.8	44.2

The 30 minute interval Radar data is considered to be more accurate, in terms of rainfall depth, as it is validated to the rainfall gauges over a period of months prior to the event. The 6 minute interval rainfall is, however, considered to be more accurate spatially, as it is recorded more frequently during the event. As a result, the 6 minute Radar datasets, within the relevant 30 minute period, were scaled to match the 30 minute dataset total rainfall for each grid cell. If a value of 0 mm was recorded in the 30 minute dataset, then the 6 minute dataset was scaled to 0 mm. If the 30 minute dataset has a value greater than 0 mm, but the 6 minute dataset has values equal to 0 mm, then the 30 minute total rainfall was uniformly distributed for the 6 minute datasets within the specified 30 minute period. No initial losses were applied to the Radar datasets.

Once this data was run through the model, it was apparent, both from the results and the input Rainfall data, that the total rainfall input into the model was less than that recorded at the closest gauge, Melbourne Botanical Gardens. The total rainfall recorded by the Radar data was approximately 20 mm, and the gauge has it at about 50 mm. As noted in Section 7.3.1, the input rainfall ASCIIs were then scaled up by a factor of 2.5 to achieve the correct rainfall, based on the closest gauge. As the scaling factor can be determined in a number of ways, and there is insufficient flow or water level gauge data to determine this factor, in this case, we believe that the radar data cannot be accurately used to validate the model, other than key flow paths and possible depths. The radar runs, however, have proven to be a great model verification tool.

8.3 Verification

Following the validation, model flows were validated to the following techniques at select locations:

- Available RORB models;

Table 8-2 RORB Model Validation

	RORB		Rain on Grid	
Location	**100 year (m^3/s) PIPED**	**100 year (m^3/s) OVERLAND**	**100 year (m^3/s) PIPED**	**100 year (m^3/s) OVERLAND**
Cnr Victoria Pde and Therry St	3.2	6.8	0.18	1.35
Cnr Elizabeth and Lt Bourke Sts	17.1	18.1	0.76	2.43
Cnr Elizabeth and Flinders Sts	21.2	22.1	0.75	0.63

- Australian Regional Flood Frequency Model (Australian Rainfall and Runoff Project – 2012) – noting that this method is still under development and results are not necessarily accurate.

Table 8-3 Australian Regional Flood Frequency (ARFF) Model Validation

	ARFF			Rain on Grid
Location	**100 year (m^3/s)**	**Lower Confidence Limit (5%) (m^3/s)**	**Upper Confidence Limit (95%) (m^3/s)**	**100 year (m^3/s)**
Catchment	11.5	4.4	30.3	1.38

- The Probabilistic Rational Method.

Table 8-4 Rational Model Validation – Overland Flow

Location	Rational Method (Adam's Method) (m^3/s)	Rational Method (Bransby Williams Method) (m^3/s)	Rain on Grid (m3/s)
Cnr Victoria Pde and Therry St	16.2	17.0	1.35
Cnr Elizabeth and Lt Bourke Sts	25.2	24.3	3.19
Cnr Elizabeth and Flinders Sts	30.3	26.8	1.38

Flood Regression Curves for Victoria produced by the Department of Conservation and Natural Resources cannot be used as there are no flow gauges.

The 100 year ARI Rain-on-grid hydraulic model results show a smaller flood extent than the previous Melbourne Water 100 year ARI flood extent obtained using a direct inflow method. These results were thoroughly discussed with both Melbourne Water and the City of Melbourne at the time. It was agreed that the reduced flood extent is due to the change in modelling technique associated with direct rainfall method which is more representative of the real conditions. In the direct rainfall methodology, rainfall falls onto the catchment before being routing overland and entering the underground network depending on the inlet pit capacity. In the rain-on-grid approach, as opposed to the direct inflow method, ponding in the terrain, inlet pit limit capacity and other terrain obstructions are accounted for.

The review of previous known flood events in the catchment showed that the two largest storms in memory were both well in excess of a 100 year ARI event which may have contributed to the previous expectations of what a large (100 year ARI) event would have looked like in the CBD.

Following the production of the 100 year ARI results, further validation of the model was completed to both the 1972 and 2010 events. In both cases, the model was found to provide a sound representation of each event and hence was considered to be suitable for further use moving forward.

9. HYDRAULIC MODELLING OUTPUTS

9.1 Overview

The following MapInfo table information is provided to Melbourne Water following the Flood Mapping Projects Guidelines and Technical Specifications (Melbourne Water, November 2016) and for each ARI event in all scenarios modelled;

1. 2m grid points table, containing the maximum water level, water depth, velocity, water depth * velocity, and the critical duration of storm corresponding with the maximum water level (note that the requirement is usually 1m grid points, due to the large data set, it was agreed with MW that a 2m resolution would be acceptable;
2. Flood extent table;
3. Flood contour table (0.5 m);
4. Safety Risk in Roads;
5. 2D model direct results prior to processing;
6. TUFLOW model files; and
7. Raw results files (ascii format), containing the maximum water level, water depth, velocity and water depth * velocity

9.2 Existing Conditions Scenario

The existing conditions model was run for the 5, 10, 20, 50 and 100 year ARI events with durations ranging from 10 minutes to 12 hours. The maximum values across all the durations were retained and post-processed to filter out any depth below 50 mm. The flood extents were further cleaned up following this approach and validated with both Melbourne Water and the City of Melbourne:

- Depth filtered and 100 m^2 puddles removed;
- As above and smoothed;
- As above with islands of 100 m^2 removed;
- As above with building footprints removed; and
- As above with building footprints buffered in by 5 metres.

As instructed (see email correspondence in Appendix B), we have provided Melbourne Water with two flood extents for each ARI; the flood extent named "As above with islands of 100 m^2 removed" and "As above with building footprints buffered in by 5 metres"

The existing conditions model was also run for the 1972 event without changing physical characteristics of the model. It was agreed with Melbourne Water to assume that Melbourne CDB would have been highly urbanised in 1972; hence the roughness values were left unchanged compared with the existing conditions model. The 1972 event was closer to a 1 in 500 year event and is responsible for a much larger flood extent than the 1 in 100 year event.

It was agreed with Melbourne Water to run the 1972 event for all the climate change scenarios also.

9.3 Climate Change Scenario

AR&R Project 19 indicates that human activities have contributed to observed climate change. Climate change can alter the prevalence and severity of extreme rainfalls, storm surges and floods, as well as change everyday rainfall frequency, intensity and spatial and temporal patterns, and antecedent conditions including evapotranspiration, humidity and soil moisture conditions. Climate change also has an impact on ocean levels, and joint probabilities of rainfall and storm surges. Recognition of the risks associated with these changes is required for planning and mitigation. Whilst there is a high degree of uncertainty with respect to how IFD parameters change as a result of climate change, research is underway to improve this knowledge gap, in the form of an AR&R project on climate change. It is anticipated that due to moisture and temperature changes in the atmosphere, some IFDs will increase whilst some will decrease. Some of the issues surrounding the knowledge gap include:

- Downscaling large scale observations into local alterations to daily IFD parameters;
- The relationship between daily and sub-daily rainfall durations and how this will change has significant uncertainty;
- Changing antecedent moisture conditions will affect humidity, evapotranspiration and soil moisture, and how this relates to projections for future climate variables and including these in models e.g. loss parameters; and,
- Changes in sea level, storm surge and joint probabilities.

The current available recommendations for climate change scenario modelling are as follows:

- NSW Department of Environment, Climate Change and Water recommends a sensitivity analysis be undertaken using the following parameters:
  - Between 0.18m and 0.91m sea level rise; and,
  - Between 10% and 30% increase in extreme rainfall.

Water Technology have received a memo, found in Appendix C, from Penny Whetton and Leanne Webb (CSIRO), regarding the proposed increases in rainfall and sea level rise to be used in the ICAM project.

The report provides seven scenarios which are applicable at various time slices; 2030, 2050 and 2090, in high and low emissions cases. The scenarios are based on the 2015 CSIRO and BoM projections and associated tools on the Climate Change in Australia website. These scenarios include:

1. Warmer, little rainfall change;
2. Warmer and drier;
3. Hotter, little rainfall change;
4. Hotter and drier;
5. Hotter and much direr;
6. Much hotter and drier; and.
7. Much hotter and much drier.

For each scenario, the likely occurrence time slice, annual maximum temperature change, seasonal maximum temperature change, annual rainfall change, seasonal rainfall changes, the 1 in 20 year rainfall change and the sea level rise is provided in Table 3 of the memo.

Below is an abbreviated version of the table, narrowed down to the 1 in 20 year rainfall change and sea level rise. Note that the sea level rise values are relative to the Williamstown gauge. It is noted that the estimates of extreme rainfall are for a 1 in 20 year event. If used to estimate the 1 in 5, it would be a slight overestimate, and 1 in 100 would be non - conservative.

Table 9-1 Climate Change Scenarios

Scenarios	Occurrence (See Table 1 for details)	1/20 year rainfall change	Sea level rise (cm)
1. Warmer, little rainfall change	2030 2050 2090 (L only)	+9%	0.11 (0.07-0.16) (2030 L)
2. Warmer, drier	2030 2050	+9%	0.12 (0.08-0.17) (2030 H)

	2090 (L only)		
3. Hotter, little rainfall change	2050 (H only) 2090	+15%	0.24 (0.15-0.32) 2050H:
4. Hotter, drier	2050 2090	+15%	0.44 (0.27-0.62) (2090 L)
5. Hotter, much drier	2090 (L only)	+15%	0.44 (0.27-0.62) (2090 L)
6. Much hotter, drier	2090 (H)	+26%	0.59 (0.38-0.81) (2090 H)
7. Much hotter, much drier	2090 (H)	+26%	0.59 (0.38-0.81) (2090 H)

In the Elizabeth Street model, it is proposed to run 3 climate change scenarios as follows:

- Scenario CC1 with increased sea level for the 100 year event;
- Scenario CC2 with increased sea level and increased rainfall intensity for the 5, 20 and 100 year events; and,
- Scenario CC3 with increased rainfall intensity for the 5, 20 and 100 year events.

The standard Melbourne Water climate change values for 2100 are to increase rainfall by 32% and apply a sea level rise of 0.8 m. It was agreed to run the following conditions in the model:

- Increase the sea level by 0.8 m as per Melbourne Water's requirements. This is at the top end of, but still within the range of, predicted sea level rise for the worst case scenario (#7) for 2090 and high emissions conditions. It is likely to be conservative, but was believed to be appropriate, given the level of uncertainty surrounding climate change predictions.

The memo recommends an increase of 26% be applied to rainfall intensity for the 1 in 20 year event, and that the 1 in 1 year event is approximately 2/3 of this value (17.3%). The memo makes no recommendation about the 1 in 100 year event. As a result, Water Technology made the following recommendations as to the increases in rainfall:

- 1 in 5 = 19.2% (based on a linear interpolation from the 1 in 1 (2/3 of 1 in 20 = 17.3%) to 1 in 20 event);
- 1 in 20 = 26% (based on the value in the memo for the 2090, scenario 7); and,
- 1 in 100 = 32% (based on Melbourne Water's value, which is upper limiting). Again, this is the worst predicted scenario, but is deemed appropriate given the level of uncertainty surrounding climate change predictions.

In further discussions with Penny Whetton from CSIRO regarding the assumptions made for this project, Penny commented:

> *The 1/5 and 1/20 values are fine.*
>
> *Your proposed 1/100 year values is certainly plausible, as it may be expected to be larger that the 1/20 year value. I also note that values in excess of the 32% are simulated in some individual models for the 1/20 year event. However, I don't know exactly the percentage change would apply had I been able to calculate the 1/100 year event the same as I did the 1/20 year event. If you proceed with 32% you will need to note some caveats.*

I have since determined that CSIRO is holding modelled changes of 1/100 values calculated using the equivalent approach used for the 1/20. One option, if you have the time for a more consistent approach, would be to get CSIRO to analyse this data. However this would require an small contract with them.

0.8 m is within the projected range for 2090 high emissions given in my document, but at the high end. I think it is reasonable to use this figure for 2090 high emissions case, as long as you note that it is at the high end of the projected range.

We have no reason for saying that the extreme sea level events will get higher by any more than the mean sea level rise, so this concept should not be part of the justification for 0.8 m scenario.

The alternative would be to apply the standard 32% increase to the rainfall across all events.

Melbourne Water approved Water Technology's recommendations on the 5th June 2015, with the exception of the 1 in 5 year event being 20% increased rainfall, to adequately reflect the accuracy/certainty of the proposed increases.

9.4 Green Infrastructure Scenarios

The original proposal submitted by Water Technology for Stage 2 of the Elizabeth Street flood modelling project allowed for the inclusion of up to 300 green interventions to form one mitigation scenario. This one scenario would then be run for the full suite of ARI events and durations and compared to the existing conditions results from Stage 1 of the project.

It was agreed to streamline the flood mitigation scenario by running the 20 year ARI 2 hour event for the following four scenarios:

- **Scenario 1:** Green roofs distributed throughout the upper end of the city as shown in Figure 9-1. We have assumed 7.5mm initial loss which is consistent with initial loss values observed for roofs (Email from Tim Fletcher to James Newton "Re:Elizabeth St flooding (2013-248)", 16 February 2017)
- **Scenario 2:** Distributed storage approach throught the Elizabeth Street catchment as shown in Figure 9-2. We have assumed a storage volume of 8.1 L/m^2 within the City North Urban Renewal area and 4.5 L/m^2 outside of this area as specified by the City of Melbourne. (Email from Barry Fox to Ralf Pfeiderer "RE: Elizabeth Street Green Infrastructure Workshop Outcomes", 21 April 2017). City North covers an area of 130 hectares which has been identified as an urban renewal area that will accommodate more residents and employment growth over the next 30 years.
- **Scenario 3:** City of Melbourne built and planned works as shown in Figure 9-3 and Table 9-2.
- **Scenario 4:** Model the above three mentioned scenarios together to see the maximum potential benefit.

The green roofs, distributed storages and rainwater tanks applied to buildings were modelled as an initial loss in the TUFLOW 2d rf layer (rainfall layer). The upper catchment area with green roofs applied a 7.5 mm initial loss while the areas with distributed storages applied a 8.1 mm and 4.5 mm initial loss inside and outside the City North Urban Renewal area. The tree pits and Carlton Gardens stormwater harvesting scheme were modelled by artificially upsizing the underground drainage pipes to account for storage capturing and storing surface runoff.

Figure 9-1 Flood Mitigation Green Roof Map

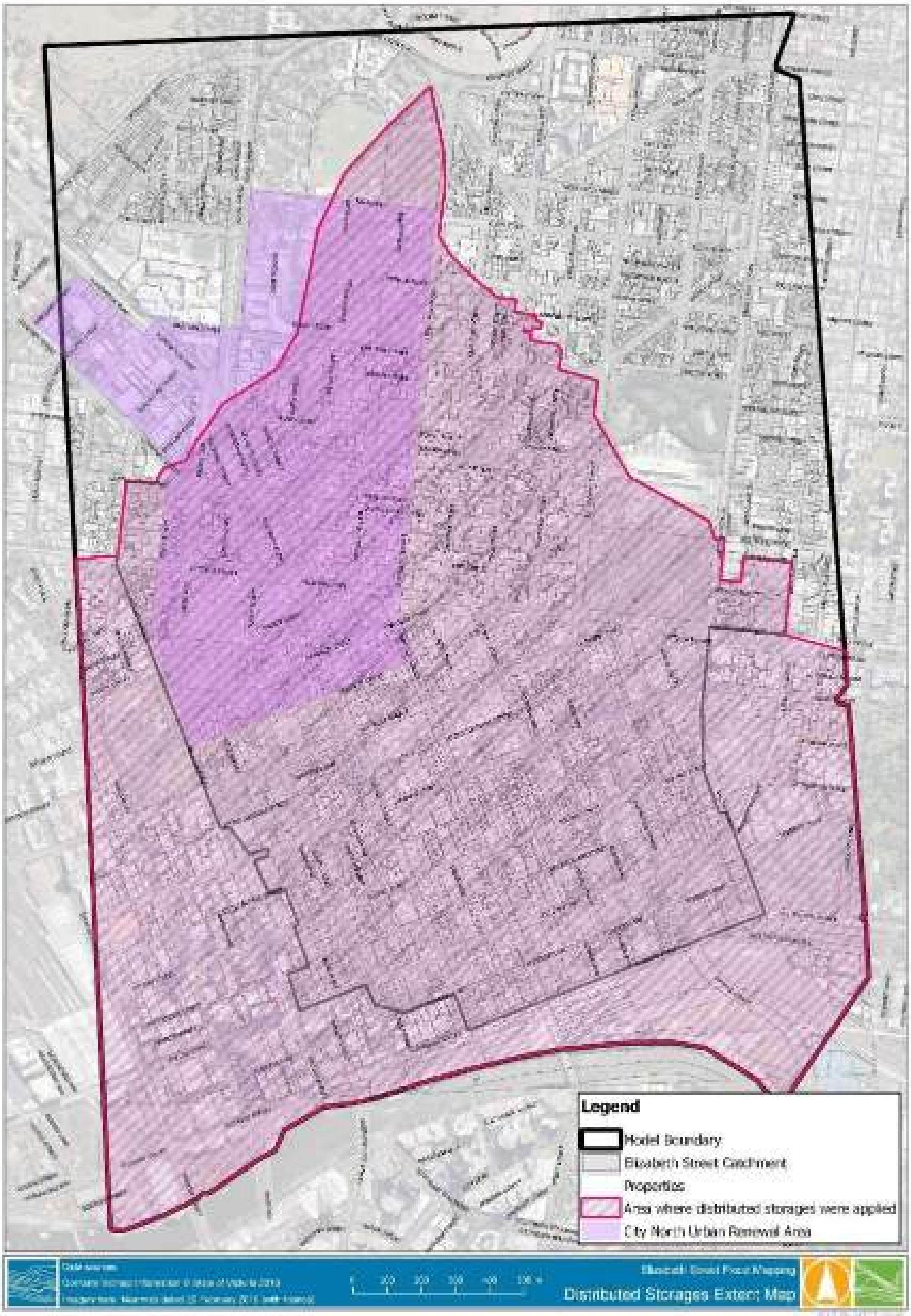

Figure 9-2 Flood Mitigation Distributed Storages Map

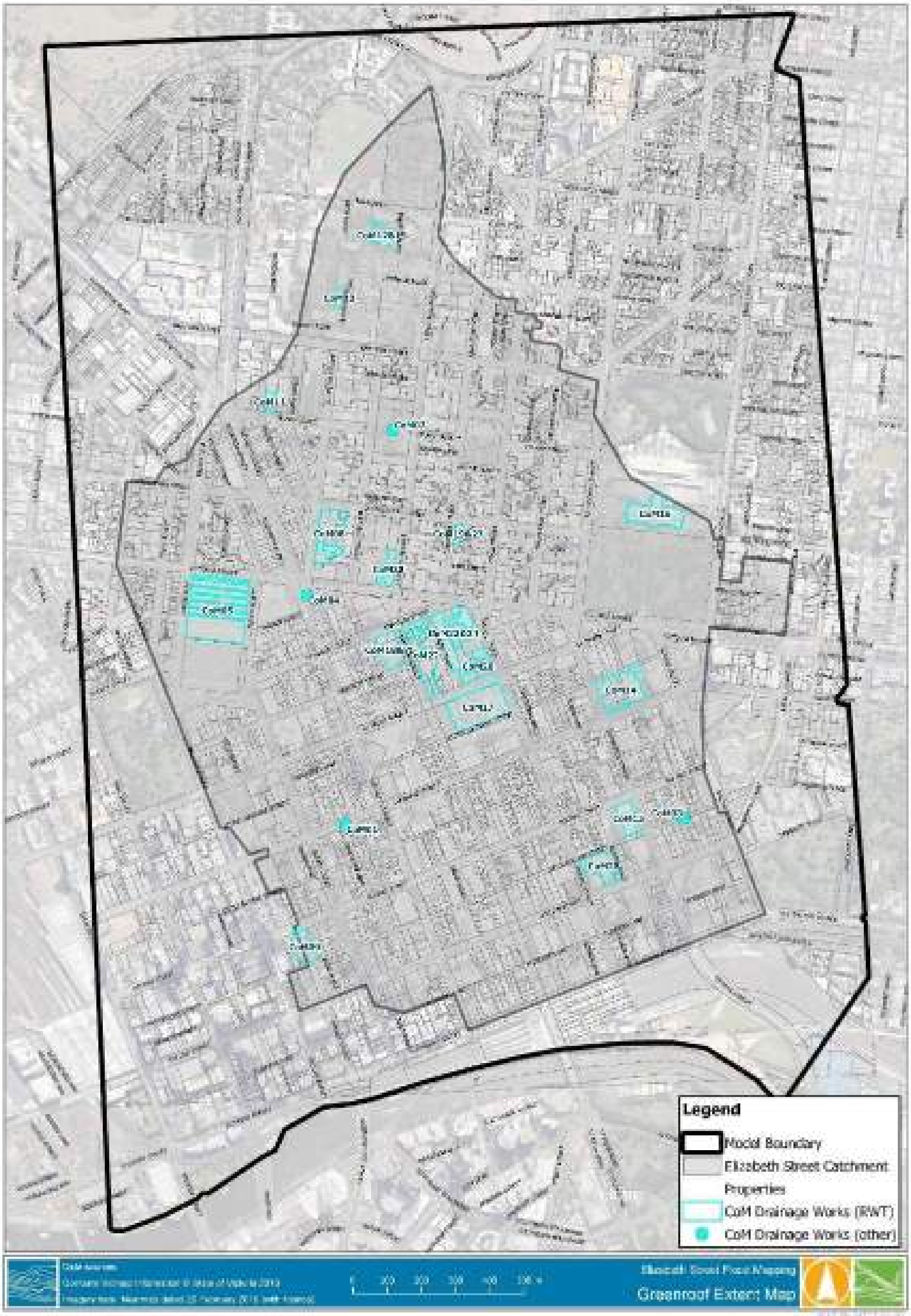

Figure 9-3 Flood Mitigation City of Melbourne Drainage Works Map

Table 9-2 City of Melbourne planned stormwater works

ID	Location	Water Sensitive Urban Design (WSUD) Type	Storage Size (KL)
CoM01	Lt Bourke st - Elizabeth to Queen	Raingarden tree pits	0.6
CoM03	Lt Collins st - Spring to Exhibition	Raingarden tree pits	1.0
CoM04	Victoria St - Cnr of Elizabeth	Inflitration Tree pits	2.9
CoM05	Queen Vic market (Queens St between Therry & Franklin)	Underground tank, Toilet reuse	600
CoM07	Carlton Squares SHS	Stormwater harvesting and reuse schemes	2,000
CoM08	60L Building (60 Leicester St Carlton)	Rainwater reuse, Balckwater recycling	20
CoM09	500 Bourke St	Rainwater	91
CoM10	Building A, University of Melbourne	Rainwater tanks	300
CoM11	Faculty of Economics and Comerce Building, 198 Berekley st	Rainwater tanks, Balckwater recycling, Fire test water reuse	32
CoM12	Melbourne School of Design	Rainwater	750
CoM13	Garden	Rainwater tanks	200
CoM14	Urban Workshop	Blackwater	0.5
CoM15	Southern Cross Tower	Blackwater	0.2
CoM16	REB - Museum (Western Forecourt, Exhibition Building Rathdowne St frontage)	Rainwater tanks	1,500
CoM17	State Library	Rainwater tanks	15
CoM18	Swanston Acedemic Building	Rainwater Tanks	80
CoM19	Advanced Manufacturing Precinct	Rainwater Tanks	20
CoM20	University Lawn		20
CoM22	RMIT Bld 10 376-392 Swanston st	Rainwater tanks	342
CoM23	RMIT Bld 11 377 Russell St	Rainwater tanks	35
CoM24	RMIT Bld 1 124 La Trobe st	Rainwater tanks	20
CoM25	RMIT Bld 100 150 Victoria St	Rainwater tanks	100
CoM26	RMIT Bld 80 445 Swanston St	Rainwater tanks	80
CoM27	RMIT Bld 55 58 Cardigan St	Rainwater tanks	20
CoM28	120-136 Collins st	Rainwater tanks	8

Maximum flood depths, percentage pipe full and difference in flood level maps for each of the four green infrastructure scenarios are presented in Appendix F.

To summarise the results, some the following key figures were extracted from the results across the Elizabeth Street catchment and presented in Figure 9-4;

- **Average reduction in flood depth (m)**: Corresponds to the average decrease in flood depth compared to existing conditions. It was calculated by substracting the maximum flood depth results for each mitigated scenario from the maximum flood depth results for the existing conditions scenario. Any negative values correspond to a reduction in flood depth which is observed in parts of the model. The difference in flood depth results were then averaged across the entire Elizabeth Street catchment to provide the average reduction in flood depth values reported in Figure 9-4 under each scenario.
- **Maximum reduction in flood depth (m)**: Corresponds to the maximum flood depth decrease compared to existing conditions. It was calculated by identifying the highest reduction in flood depth within the Elizabeth Street catchment from the difference in flood depth results calculated previously. This value is not an average across the entire catchment but rather a representation of a local flood reduction impact.
- **Total flood volume (m^3)**: Corresponds to the remaining overland flooding occurring within the Elizabeth Street catchment. It was calculated by multiplying the average flood depth with the flood area for each scenario.
- **Average maximum pipe flow (m^3/s):** Corresponds to the average peak flow in the underground network. It was calculated by averaging the peak flow rate recorded in all pipes within the model.

5% AEP	Existing	Green roof	Distributed Storages	Council Drainage Works	All Combined
Average reduction in depth (m)	N/A	0.006	0.007	0.004	0.016
Maximum reduction in depth (m)	N/A	0.11	0.14	0.38	0.39
Total flood volume (m^3)	21,140	19,240	19,130	19,750	16,000
Average maximum pipe flow (m^3/s)	0.17	0.16	0.16	0.16	0.15

Figure 9-4 Green Infrastructure Scenario Summary Key Figures

The reduction in flood depth and total flood volume of the green roof and distributed storage mitigated scenarios are in the same order of magnitude; even though the green roofs are only considered in the upper parts of the Elizabeth Street catchment.

The Council drainage works scenario is more targeted with a maximum reduction in flood depth of up to 0.38 metres compared to 0.11 metres for the green roof scenario and 0.14 metres for the distributed storages scenario. The overall total flood volume across the entire Elizabeth Street catchment is only slightly more than under the green roof and distributed storages scenarios. With 27 Water Sensitive Urban Design interventions, the Council drainage works scenario nearly achieves the same overall flooding reduction than the large scale green infrastructure scenarios.

As anticipated, combining the three green infrastructure actions into one scenario provides the greatest flood reduction. However, the combined mitigated scenario does not provide all the flooding benefits that each of the other green infrastructure scenarios individually provide. Each of the three individual mitigated scenarios have been modelled as unique losses applied to specific rainfall polygons representing the building footprints within the model. And in some instances, the loss associated with one or two of the mitigated scenarios nulled any rainfall on the building polygon as illustrated in Figure 9-5. In the example below, the addition of the City of Melbourne drainage work intervention together with the green roof and distributed storage does not provide a greater flood reduction benefits.

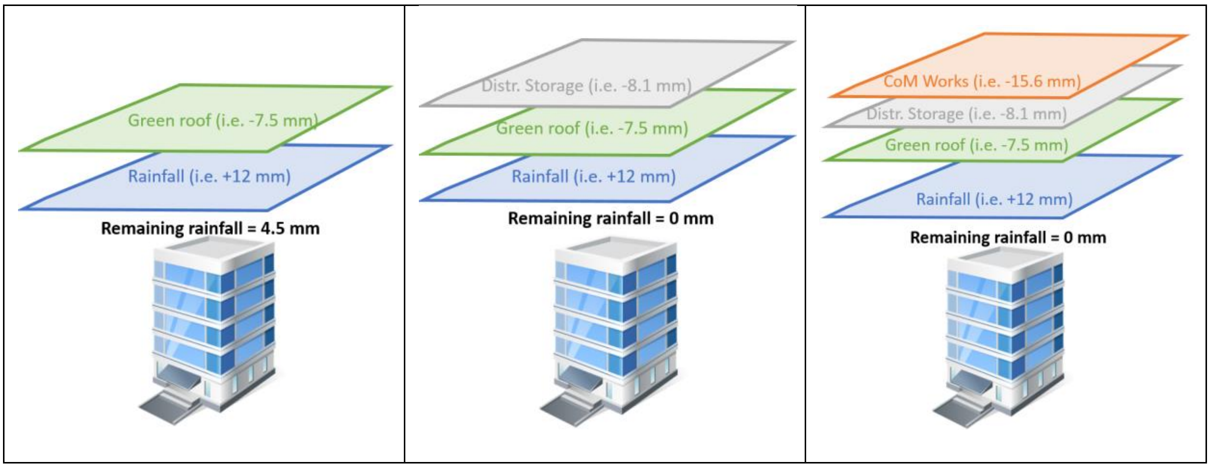

Figure 9-5 Rainfall Loss Individual Versus Combined Mitigated Scenario

The average peak flow in the underground drainage network is nearly unchanged from the existing to the mitigated conditions scenarios over the entire model due to the large number of pipes. Locally larger changes to the underground pipe flow is expected.

Green infrastructure measures directed to an area of the network known to experience overland flooding are a very effective way of targeting flooding problems. For instance, there is significant area flooding on the road from Queensbury Street to Victoria Street through Leicester Street in the 20 year ARI event. The 60 Leicester Street in Carlton rainwater reuse and blackwater recycling scheme provides the best flood reduction on Leicester Street than any other large scale green infrastructure measures tested in this study.

The following areas in the Elizabeth Street catchment show significant flood reduction when combining the green infrastructures together;

- Masson Road in the University of Melbourne Parkville Campus, benefiting from the green roof and distributed storages.
- Corner of Victoria Street and Bouverie Street, benefiting from the green roof, distributed storages and the rainwater tanks on the RMIT building on 150 Victoria Street.
- La Trobe Street near the intersection with Exhibition Street, benefiting from the green roof and distributed storages.
- Exhibition Street section from La Trobe Street and Londsdale Street, benefiting from the green roof and distributed storages.
- Russell Street section from Lonsdale Street and Little Bourke Street, benefiting from the green roof and distributed storages.

The green roof intervention in the northern parts of the catchment have some flood reduction impacts further south in the catchment along Little Bourke Street and the intersection between Bourke Street and Elizabeth Street with flood reduction of up to 0.04m.

At the time of finalising this report, Melbourne Water identified some potential issues with the Elizabeth Street catchment existing conditions TUFLOW model which was used to complete the green infrastructure mitigation analysis. These issues are not yet resolved and are currently under investigation with Melbourne Water. Considering that this analysis was completed between existing and mitigated conditions with the same hydraulic model (with the same potential issues), it is anticipated that the flooding benefits provided by the green infrastructure scenarios are still valid. However, the flood extent shown in this analysis may not truly represent the 5 year ARI events and may correspond to a smaller event. It is recommended to finalised this piece of work given that the unresolved issues may take some time to be addressed. The green infrastructure scenario simulations should be re-run once the existing conditions model issues are resolved to update the flood maps and key figures in Figure 9-4.

10. CONCLUSION

The Elizabeth Street flood modelling project has produced detailed flood modelling of Melbourne CBD under existing and climate change conditions for the 5, 10, 20, 50 and 100 year ARI events as well as 1972 historical event using rain-on-grid approach.

During the first stage of the project, sensitivity analysis was completed by testing some of the key parameters including initial loss, Manning's roughness and fraction impervious values to assist in setting the parameters values for the final runs. It was observed that the 100 year ARI revised flood extent is much smaller than the previous extent Melbourne Water had which is explained by the difference in hydraulic modelling techniques (direct inflow versus rain-on-grid). Hence, the 1972 historical event (closer to a 500 year ARI) was added to the list of modelling scenarios to be run.

The second stage of the project uses the adopted existing condition rain-on grid model developed in Stage 1 to analyse a series of flood mitigation options in the form of green roofs, distribution storages and Council mitigation works. The green roofs were tested on the upper parts of the Elizabeth Street catchment while the distributed storages were applied across the entire catchment. The green roof mitigated measure provided similar overall flooding reduction than the distributed storages approach. The Council mitigation works consisted of 27 stormwater harvesting schemes and reuse as well as infiltration tree pits which provides a more targeted approach reducing flooding locally. The overall flood reduction associated to these 27 measures is nearly as great as the large scale green infrastructure actions. Combining all the green infrastructure measures provides the larger flood reduction; but is not the most optimal approach as it would require significant expenditure when compared to flood benefits.

APPENDIX A SENSITIVITY TESTING RESULTS

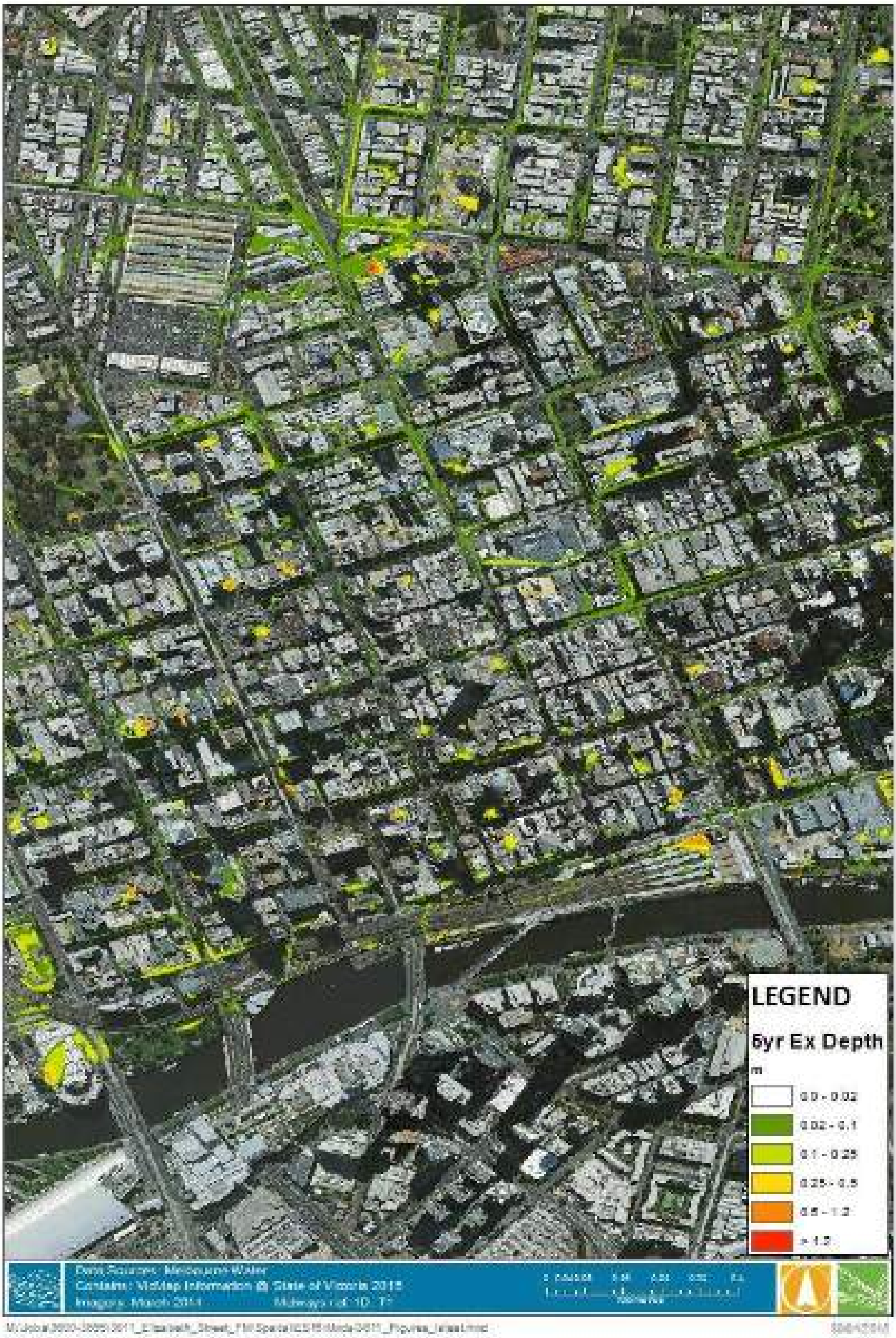

Figure 10-1 5 year Existing Depth Plot

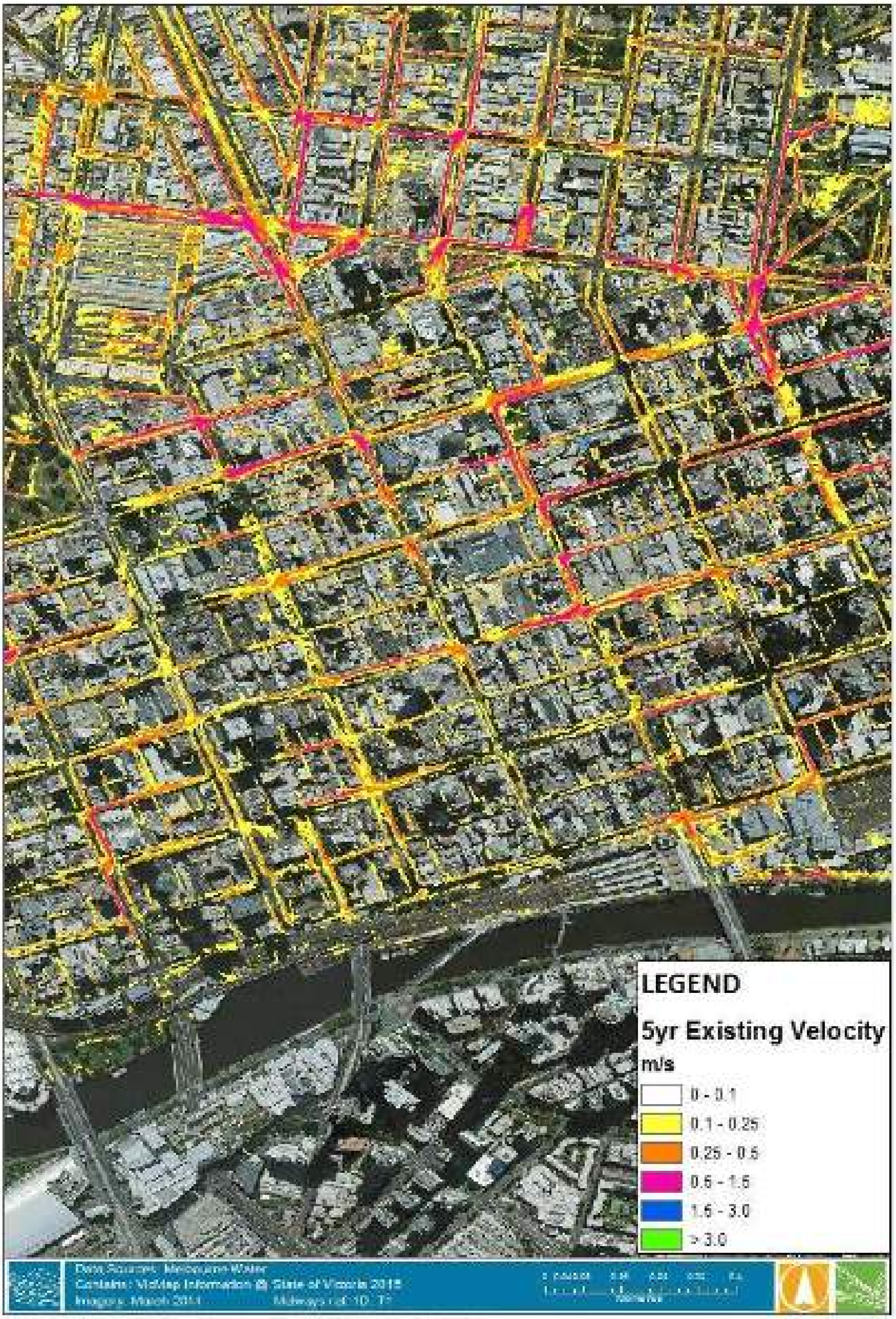

Figure 10-2 5 year Existing Velocity Plot

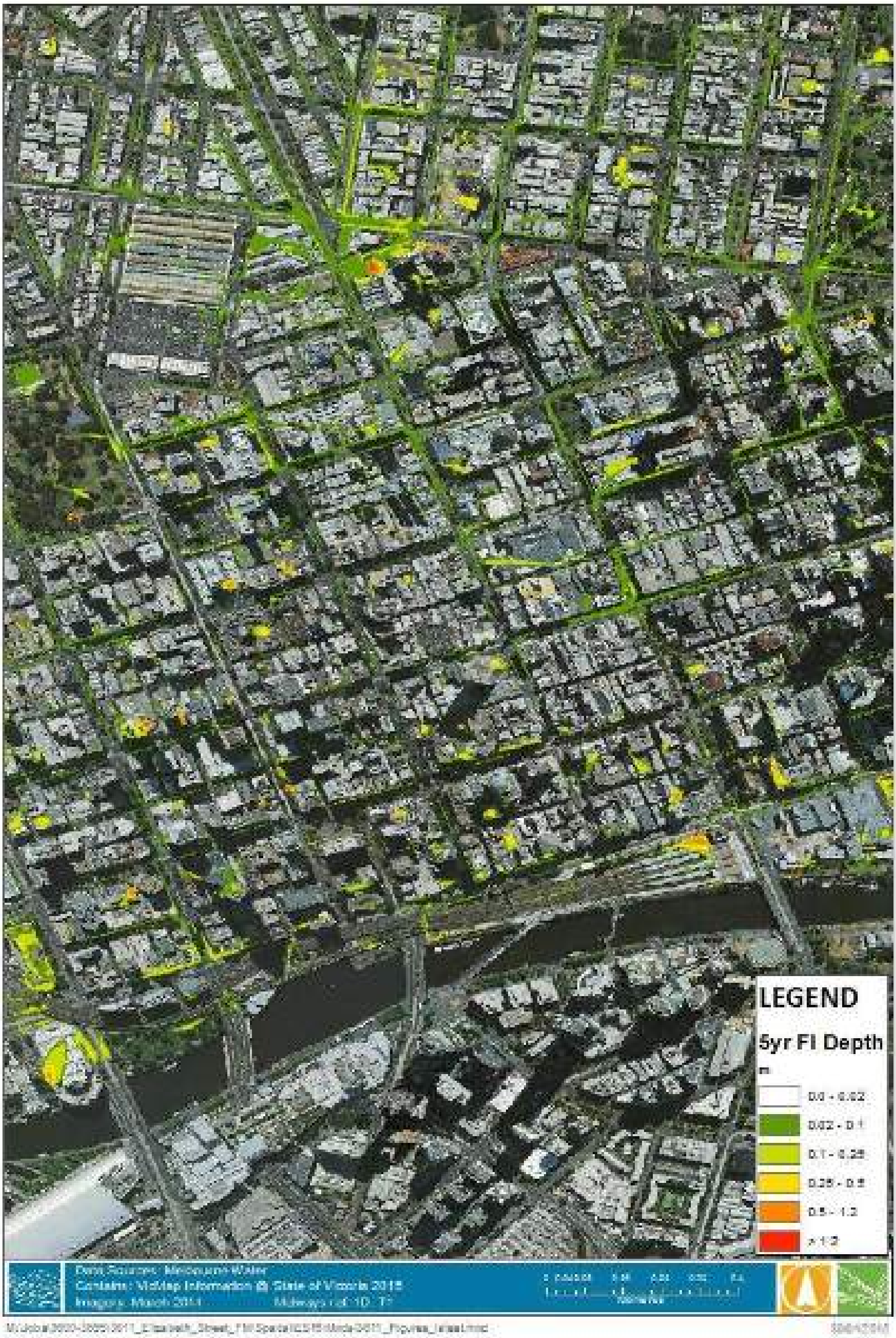

Figure 10-3 5 year Parks 50% Fraction Impervious Depth Plot

Figure 10-4 5 year Parks 50% Fraction Impervious Depth Difference Plot

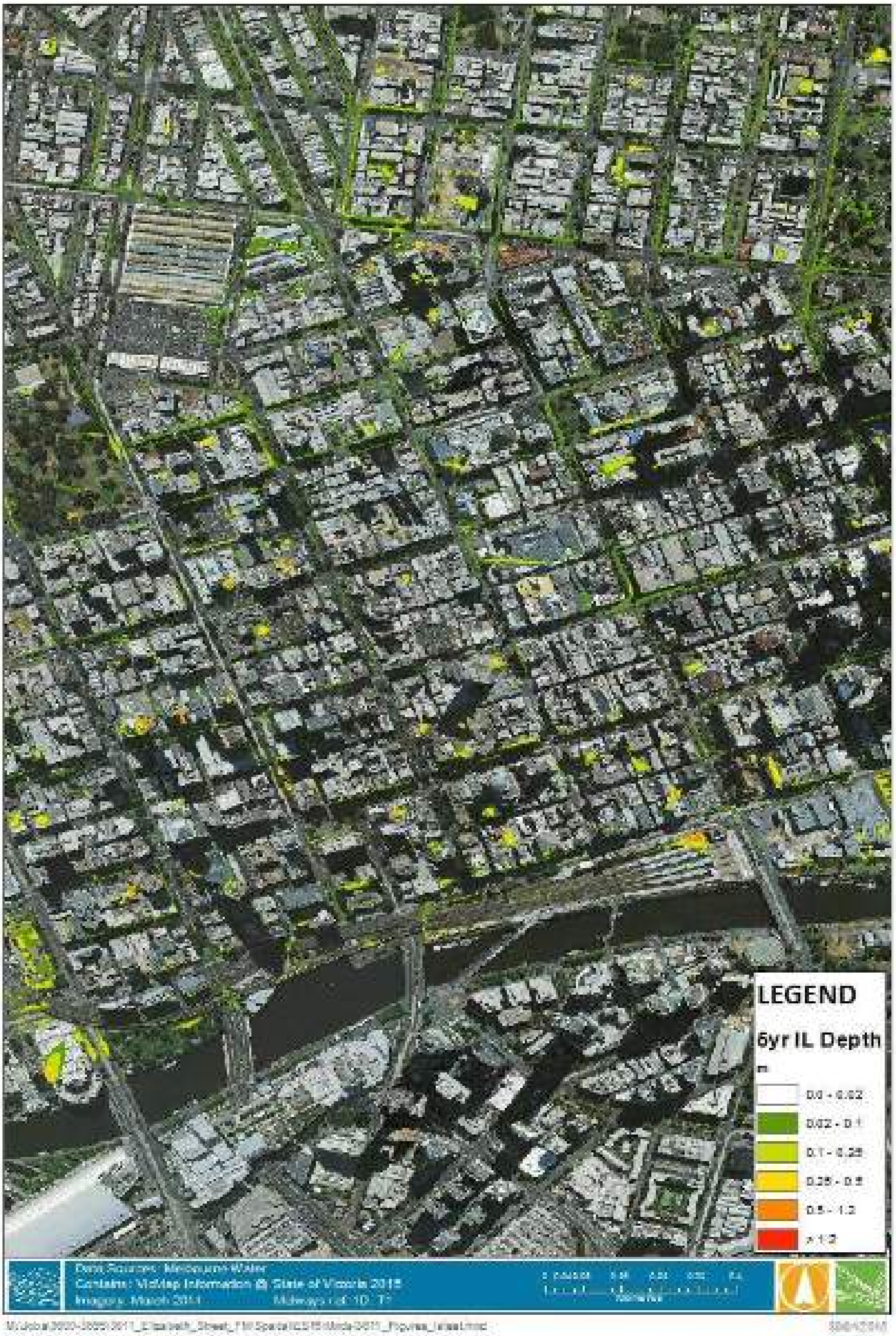

Figure 10-5 5 year 10 mm Initial Losses Depth Plot

Figure 10-6 5 year 10 mm Initial Losses Depth Difference Plot

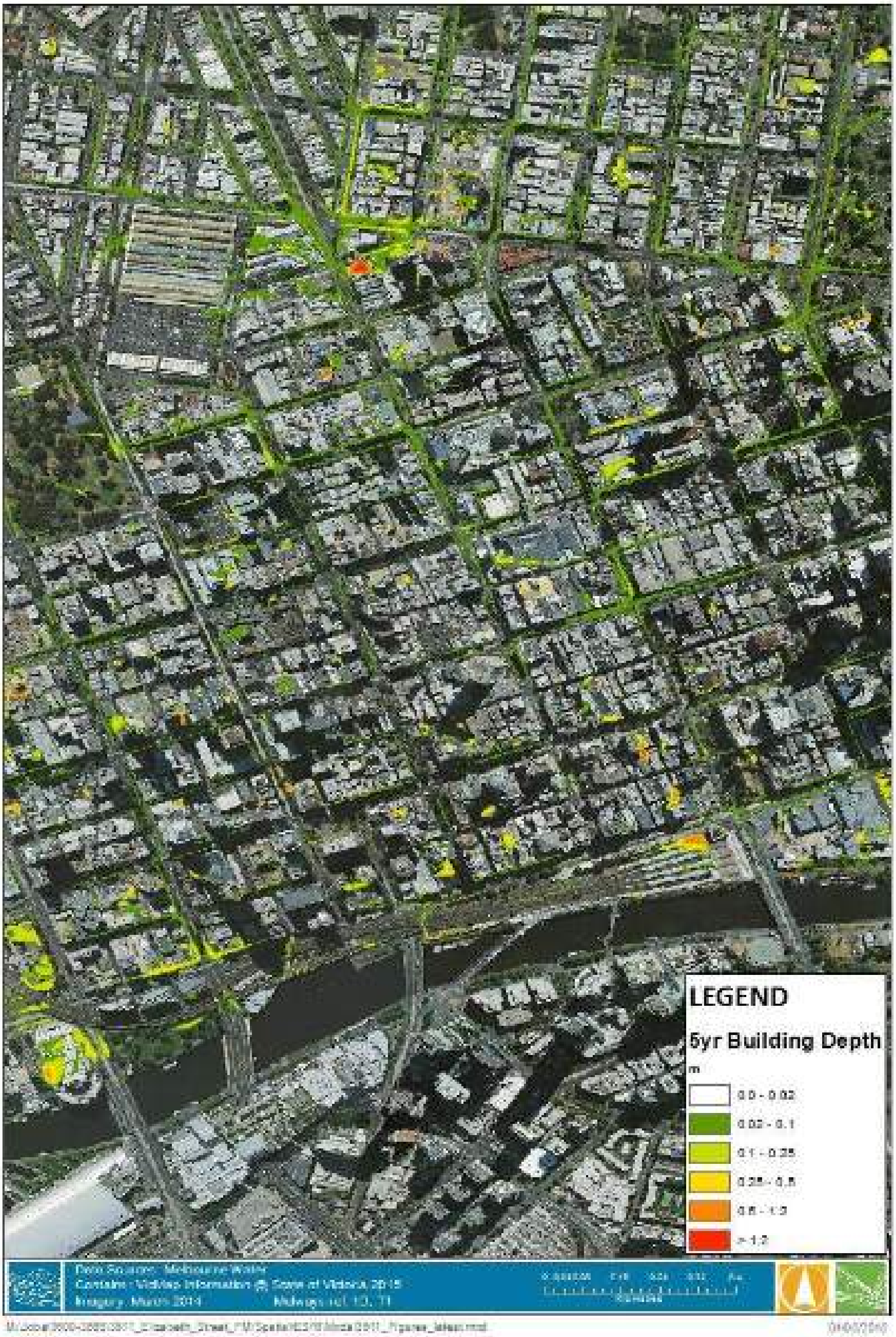

Figure 10-7 5 year Buildings Blocked Depth Plot

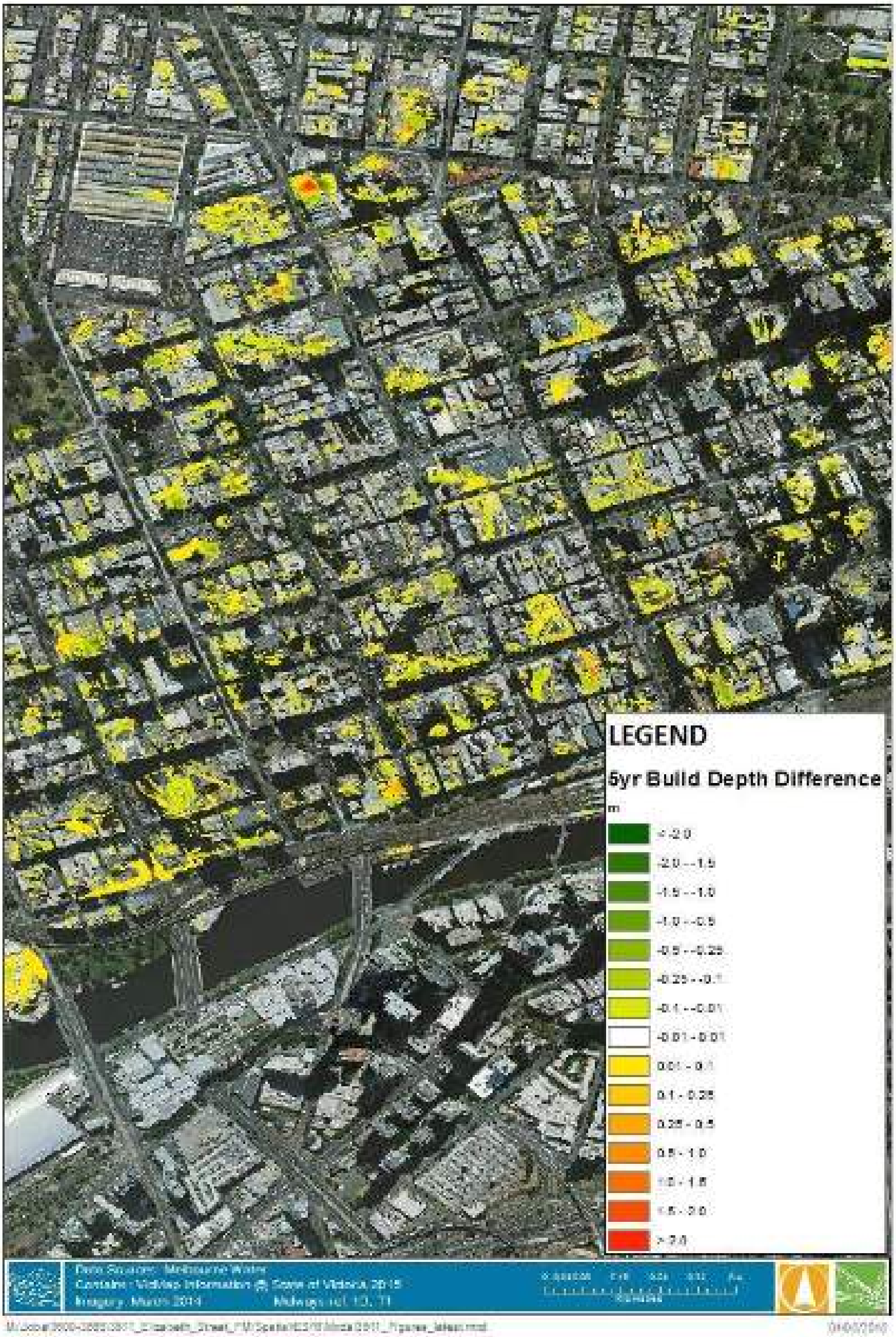

Figure 10-8 5 year Buildings Blocked Depth Difference Plot

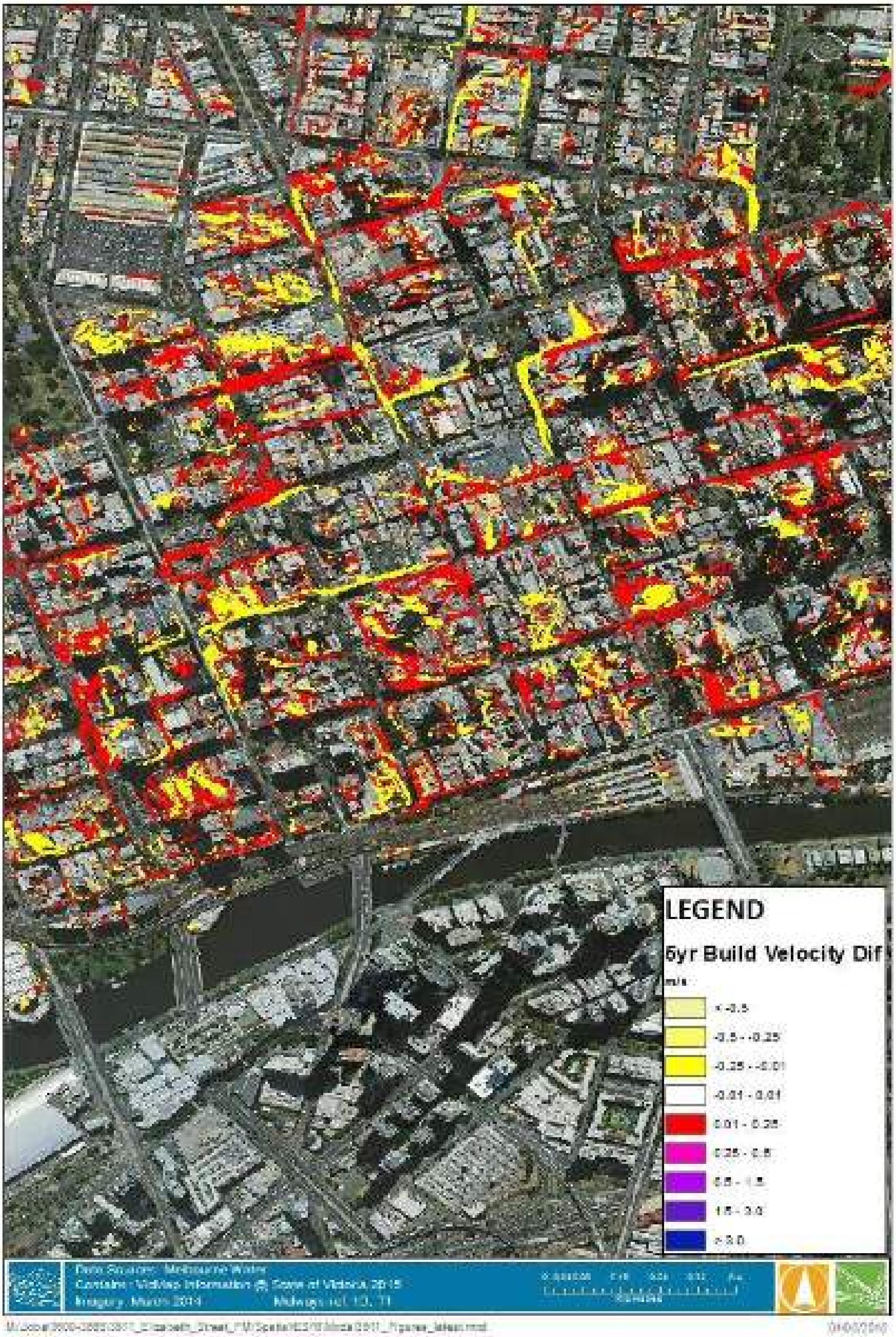

Figure 10-9 5 year Buildings Blocked Velocity Difference Plot

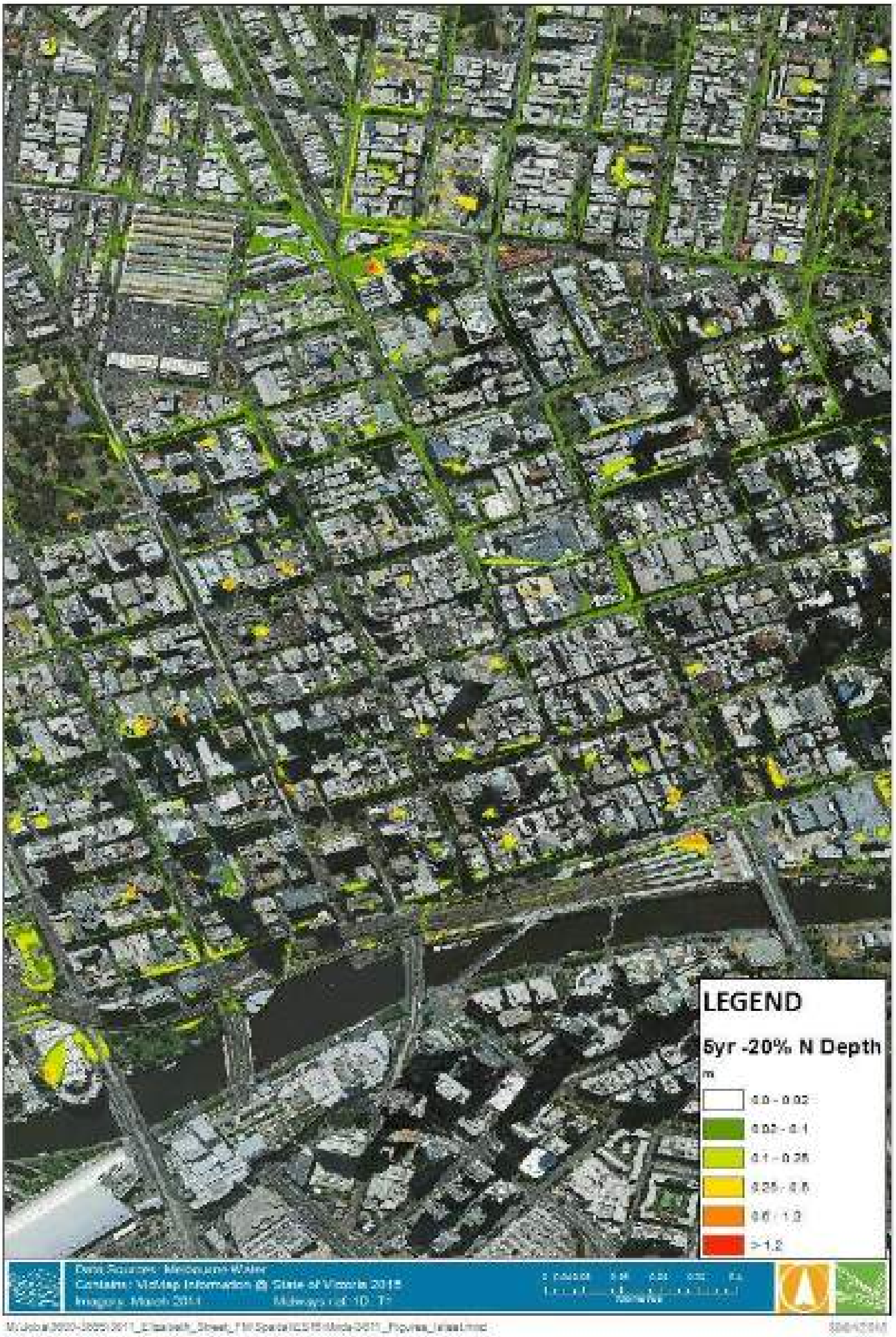

Figure 10-10 5 year 20% Reduction in Roughness Depth Plot

Figure 10-11 5 year 20% Reduction in Roughness Depth Difference Plot

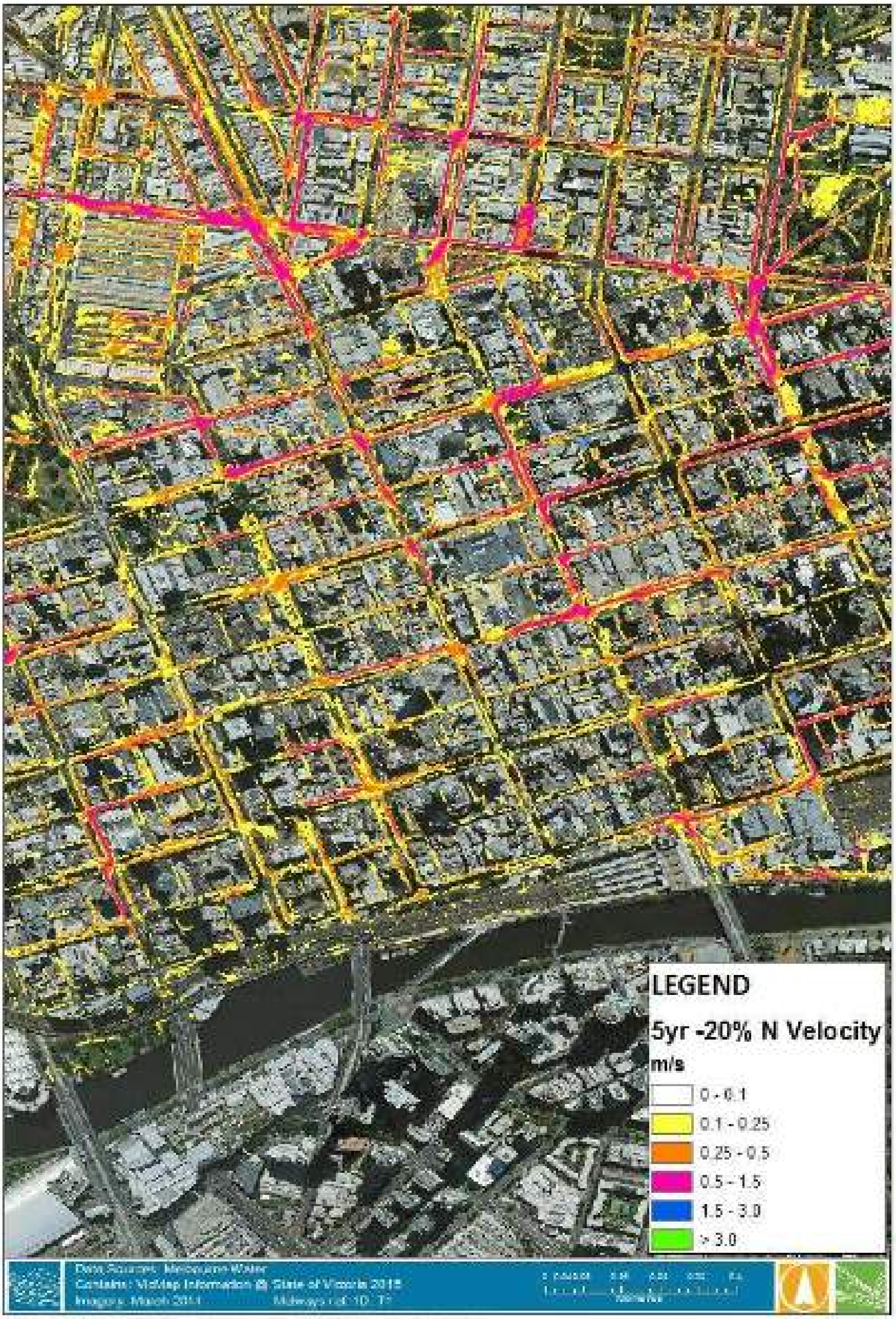

Figure 10-12 5 year 20% Reduction in Roughness Velocity Plot

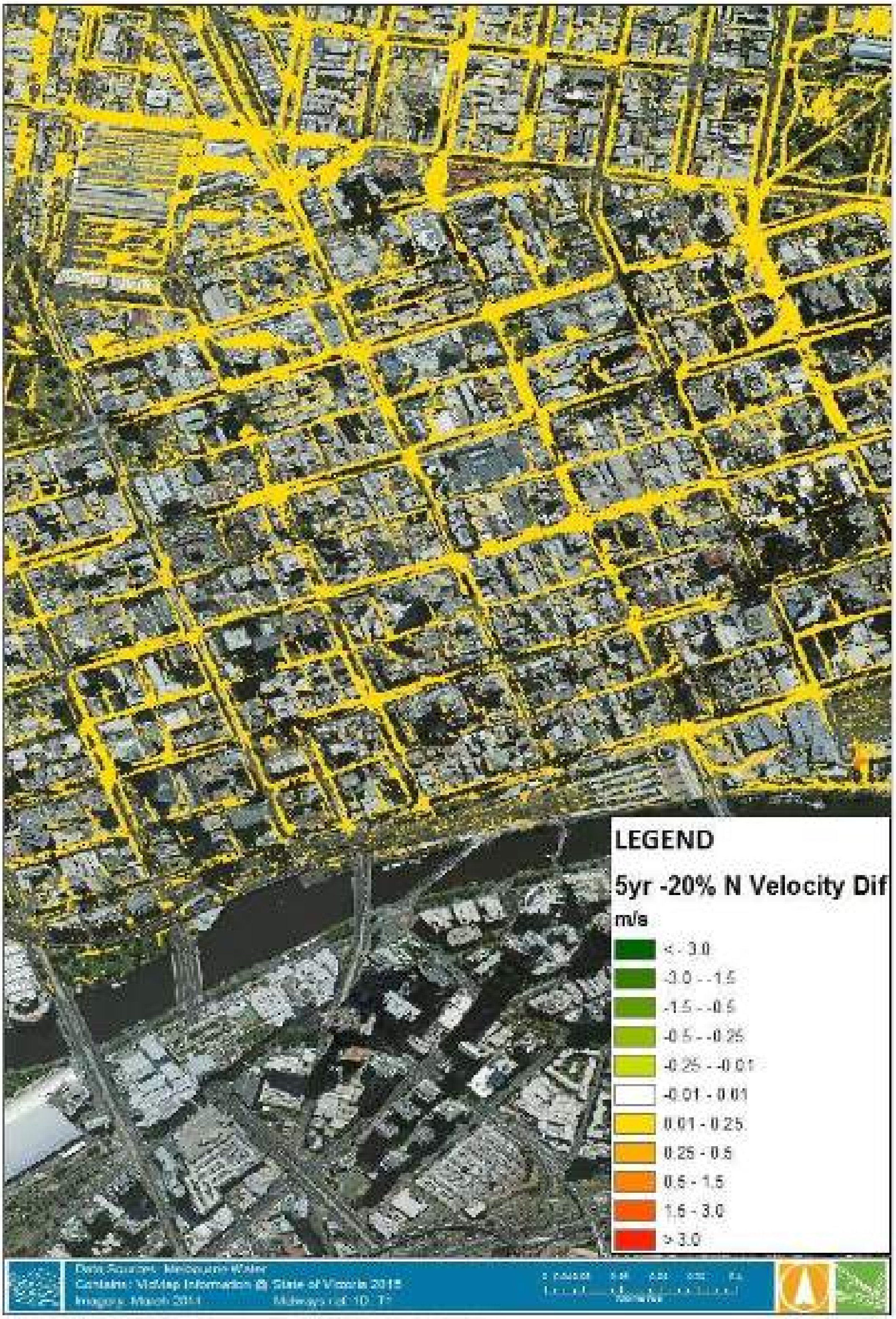

Figure 10-13 5 year 20% Reduction in Roughness Velocity Difference Plot

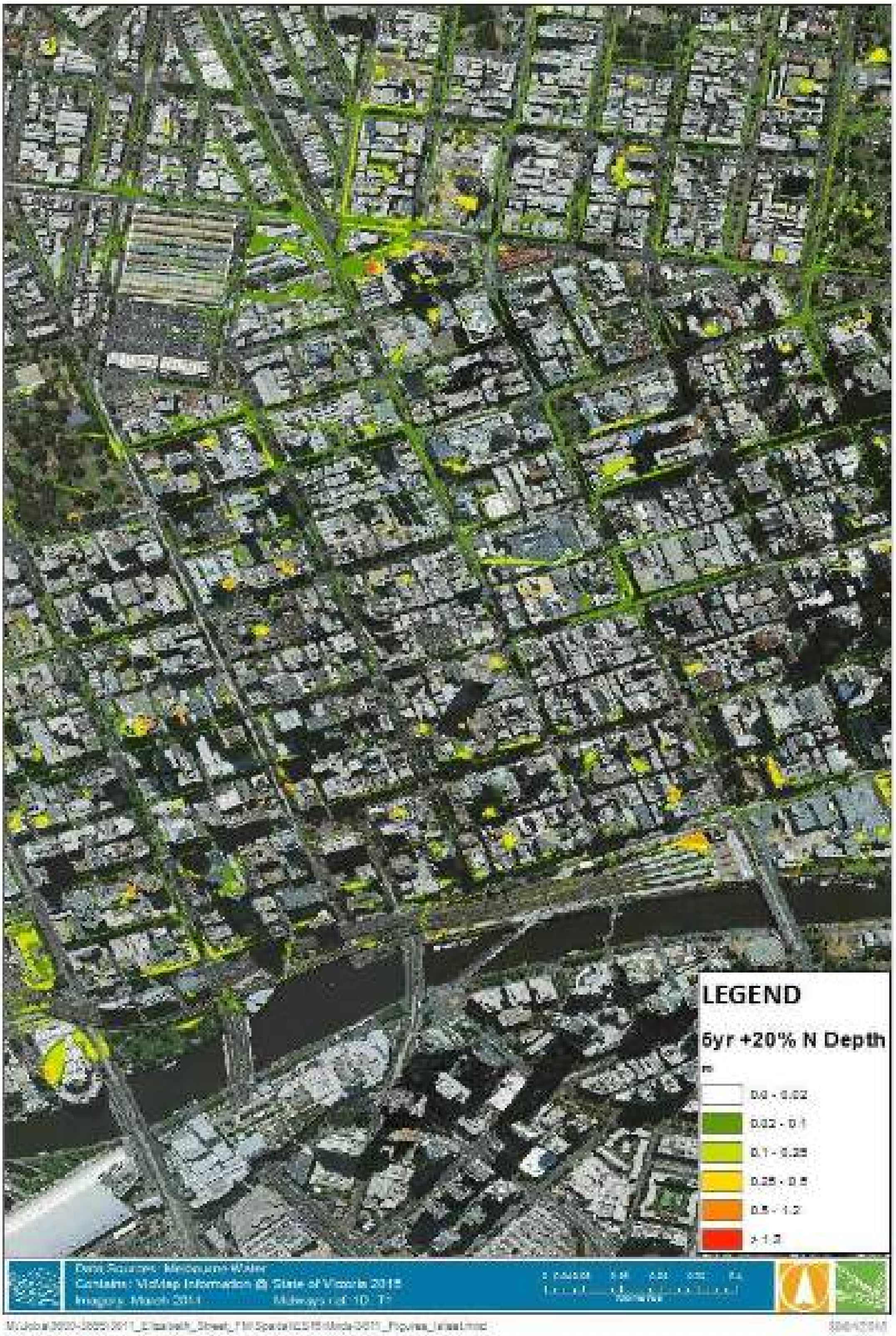

Figure 10-14 5 year 20% Increase in Roughness Depth Plot

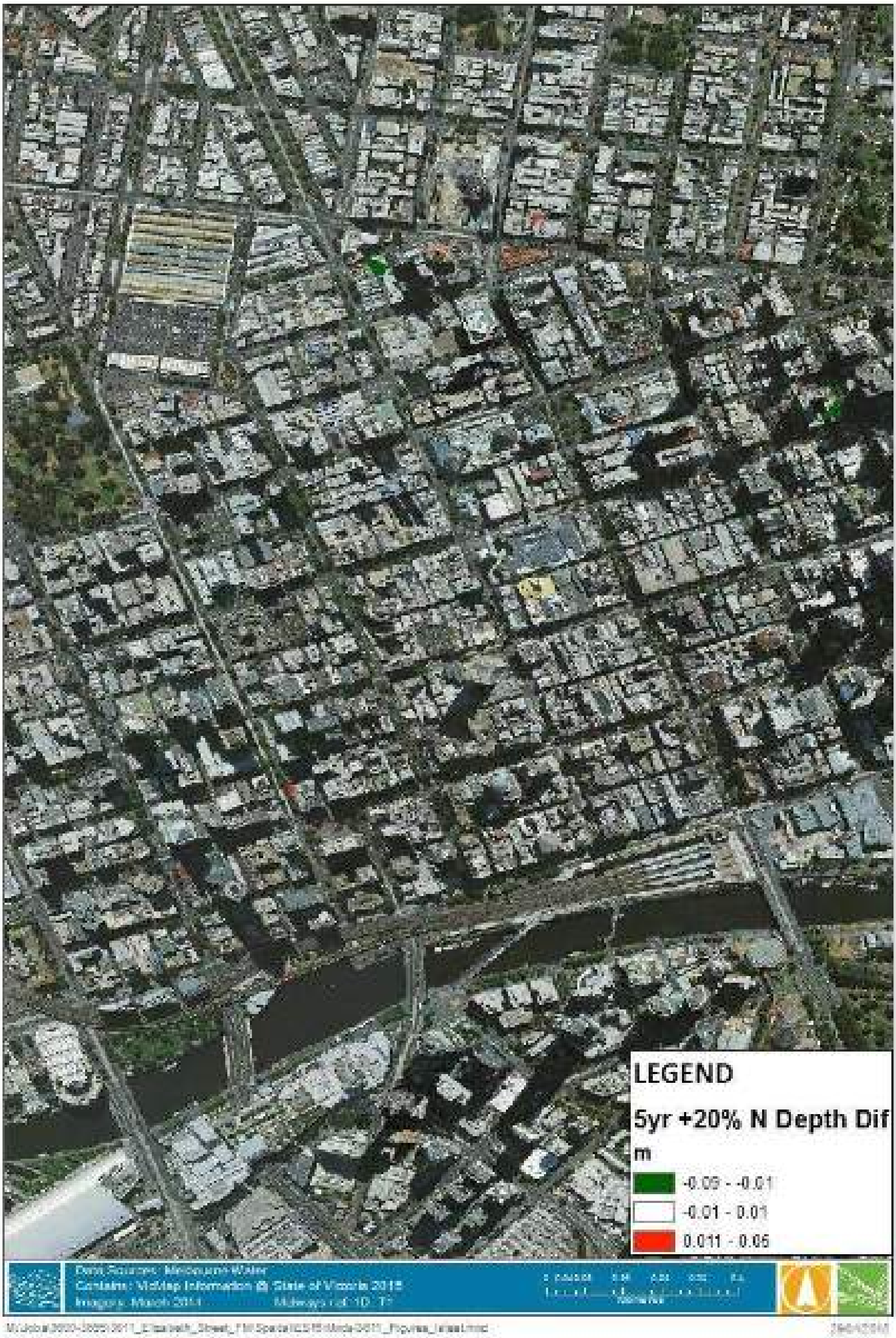

Figure 10-15 5 year 20% Increase in Roughness Depth Difference Plot

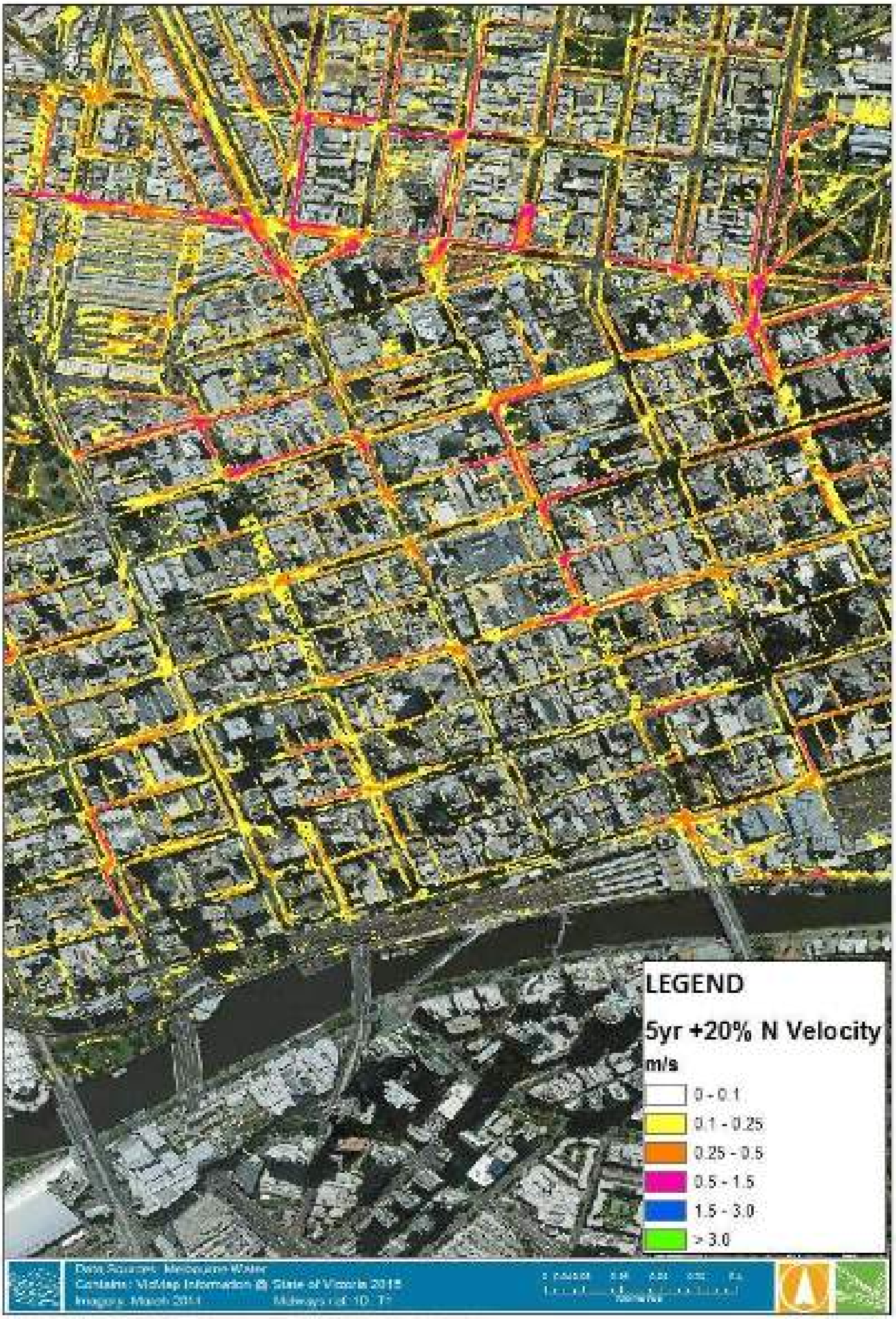

Figure 10-16 5 year 20% Increase in Roughness Velocity Plot

Figure 10-17 5 year 20% Increase in Roughness Velocity Difference Plot

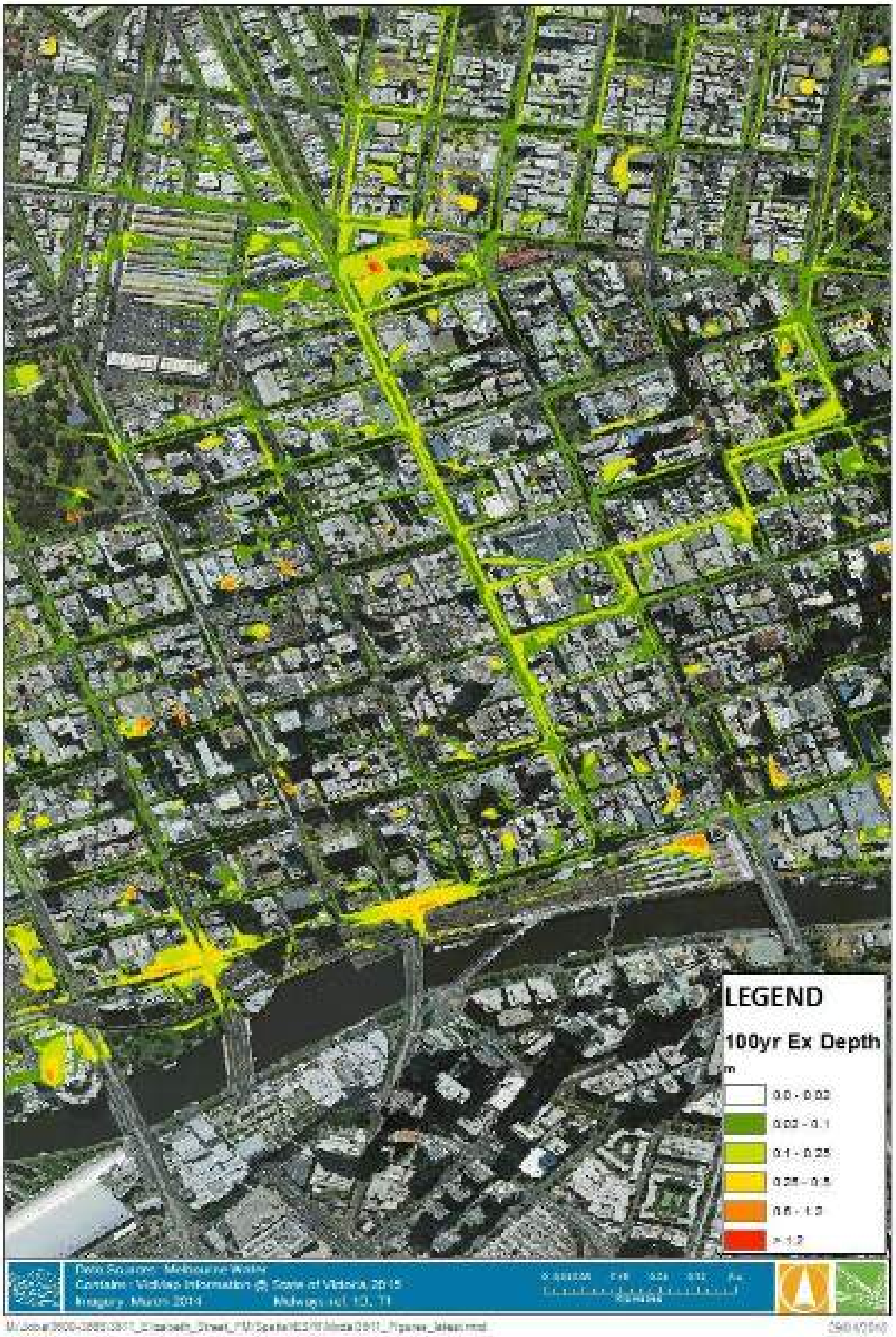

Figure 10-18 100 year Existing Depth Plot

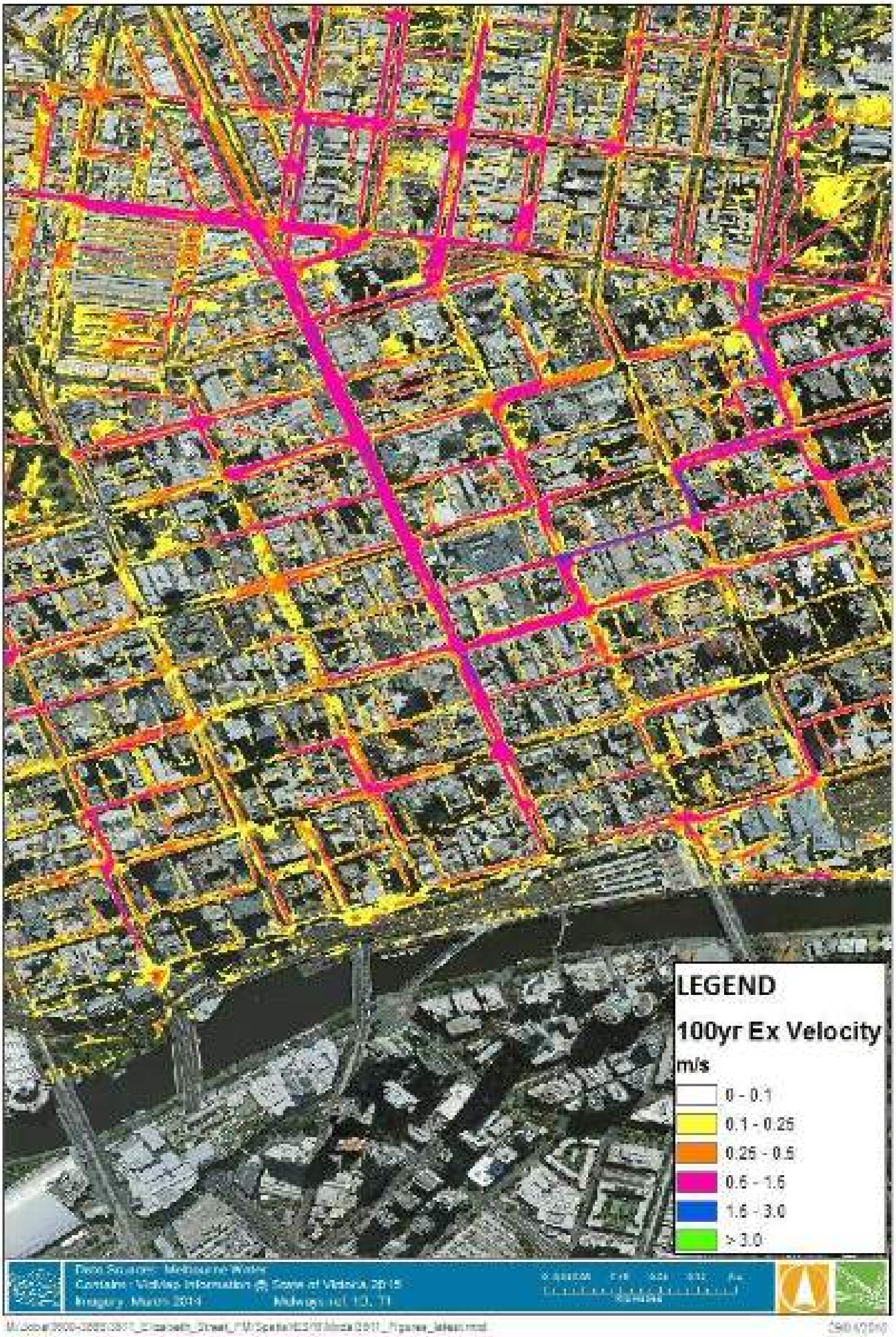

Figure 10-19 100 year Existing Velocity Plot

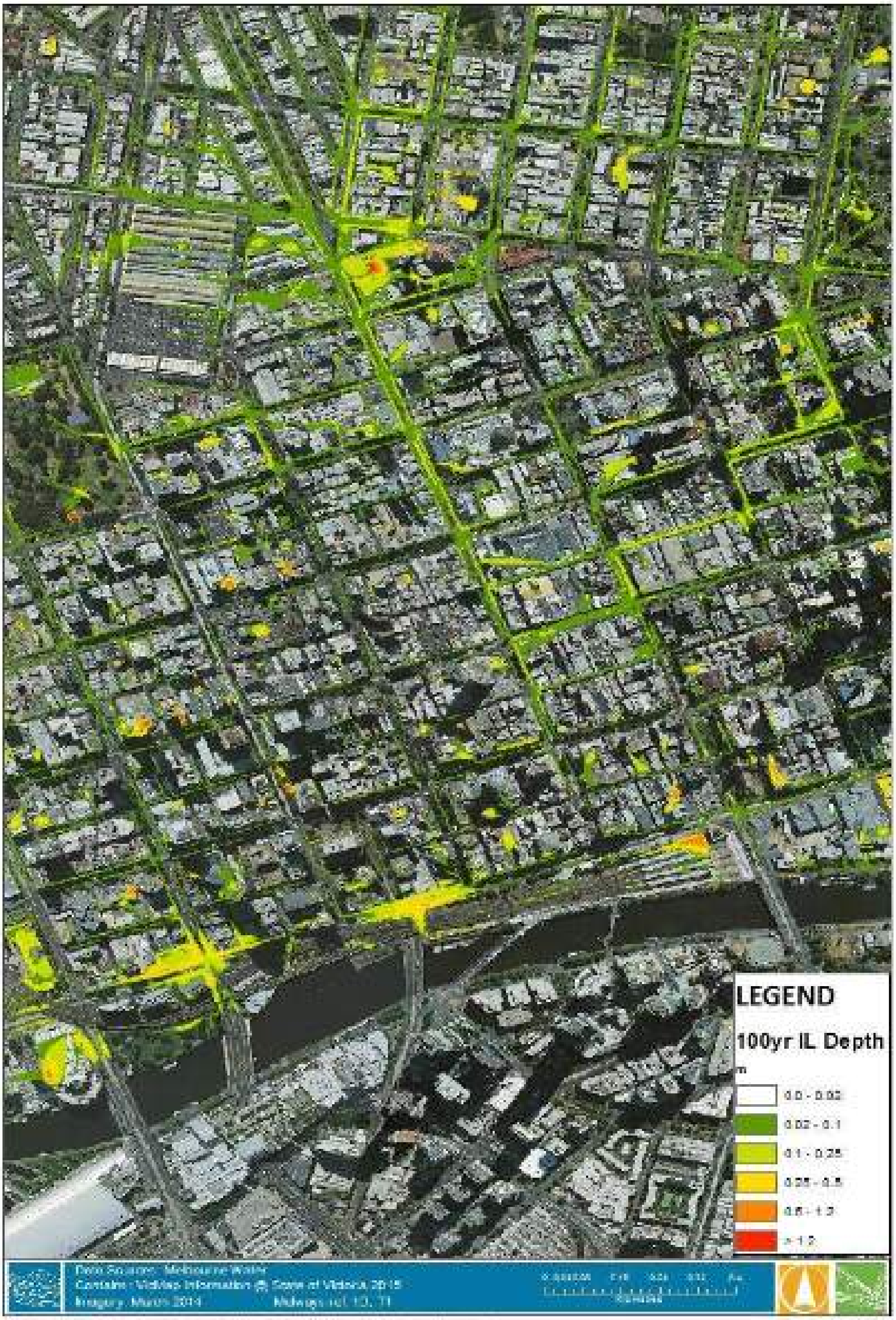

Figure 10-20 100 year 10 mm Initial Losses Depth Plot

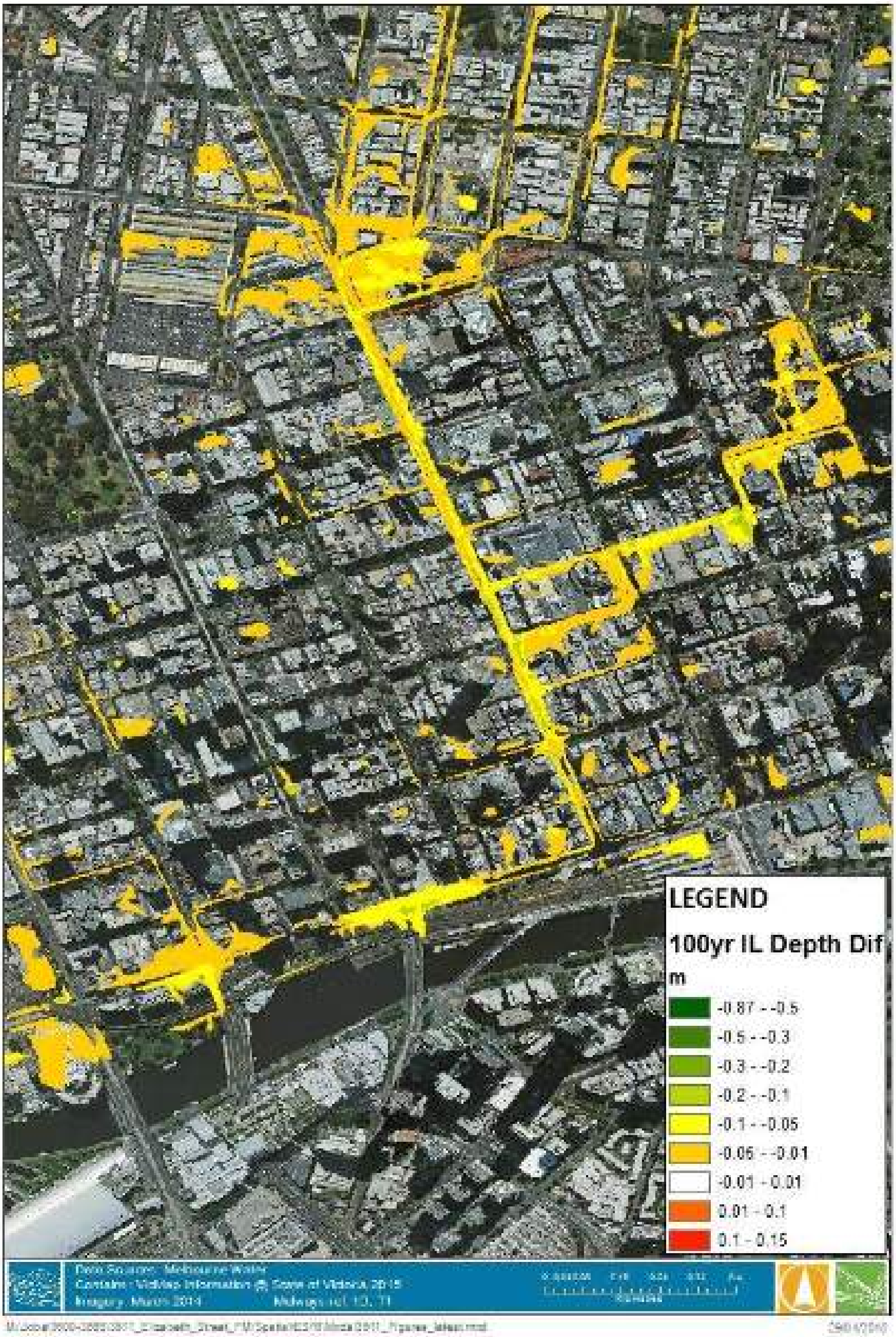

Figure 10-21 100 year 10 mm Initial Losses Depth Difference Plot

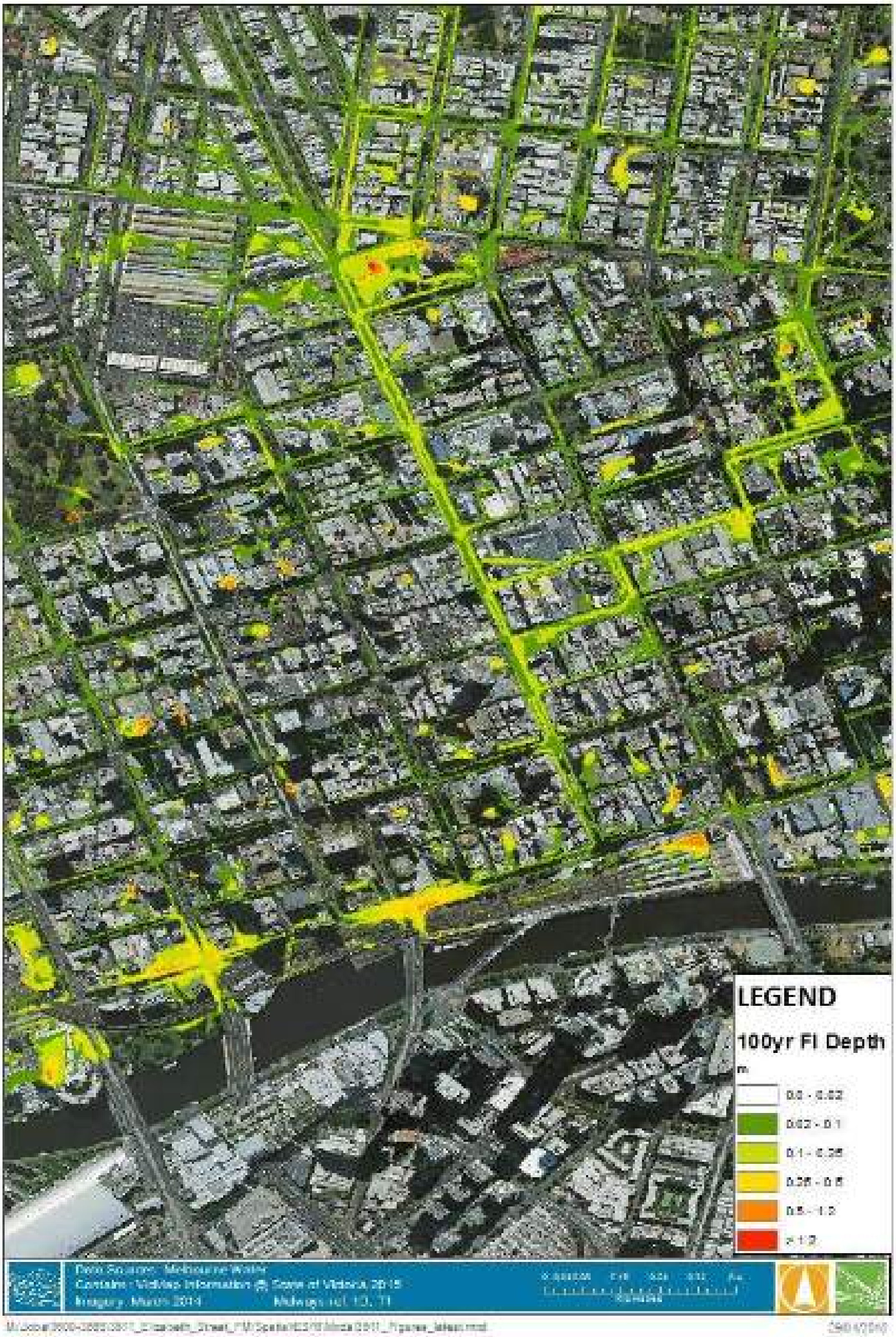

Figure 10-22 100 year Parks 50% Impervious Depth Plot

Figure 10-23 100 year Parks 50% Impervious Depth Difference Plot

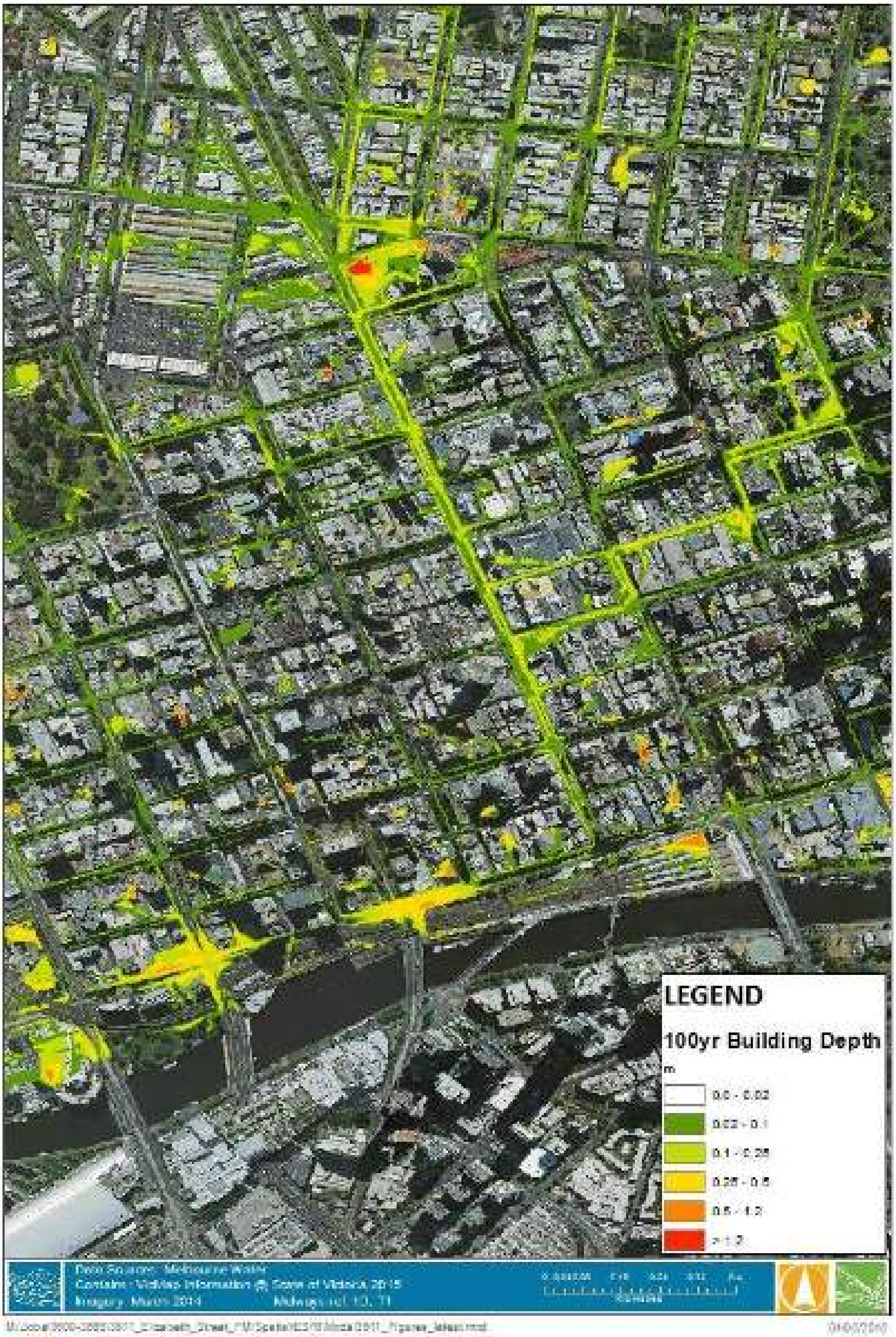

Figure 10-24 100 year Buildings Blocked Depth Plot

Figure 10-25 100 year Buildings Blocked Depth Difference Plot

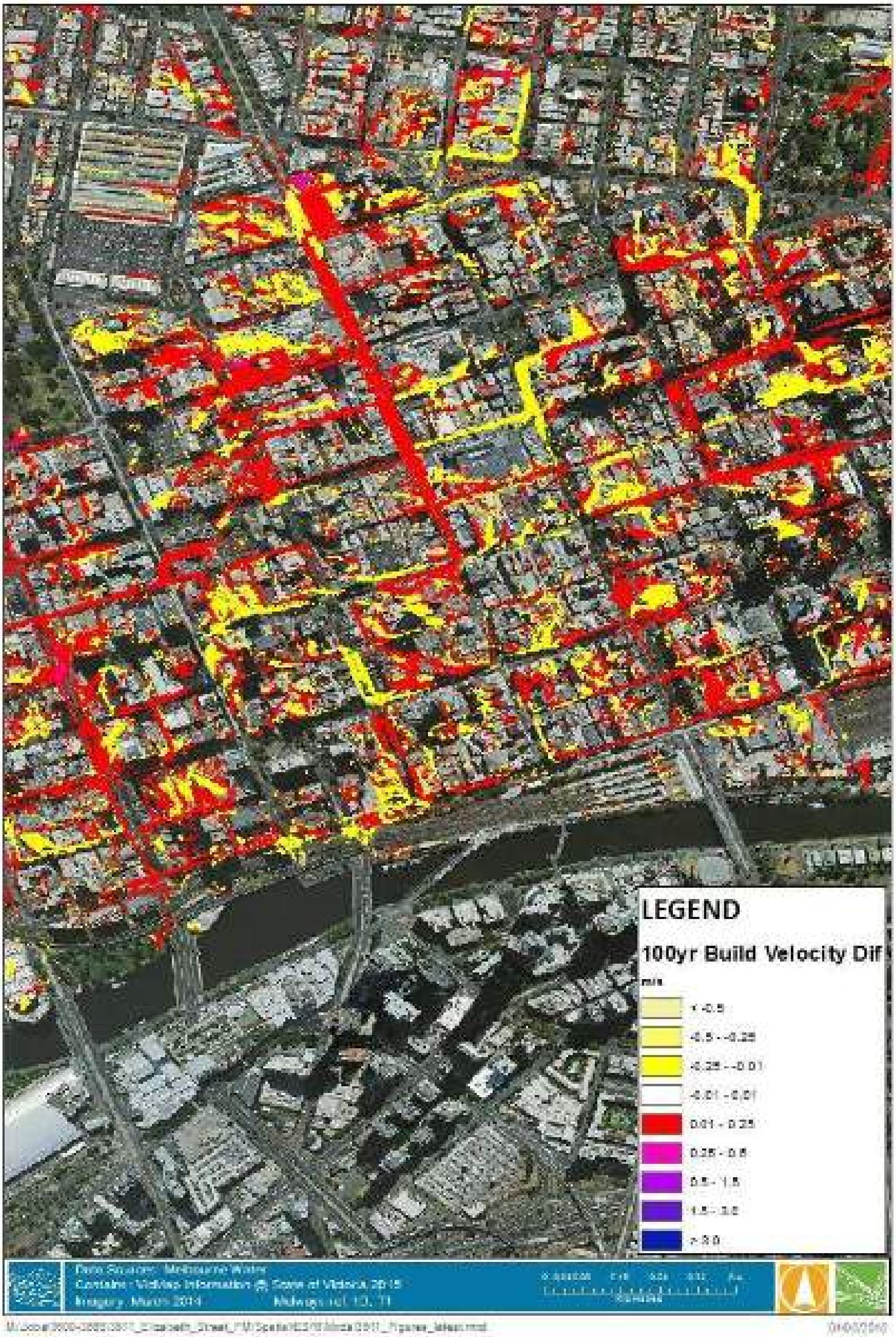

Figure 10-26 100 year Buildings Blocked Velocity Difference Plot

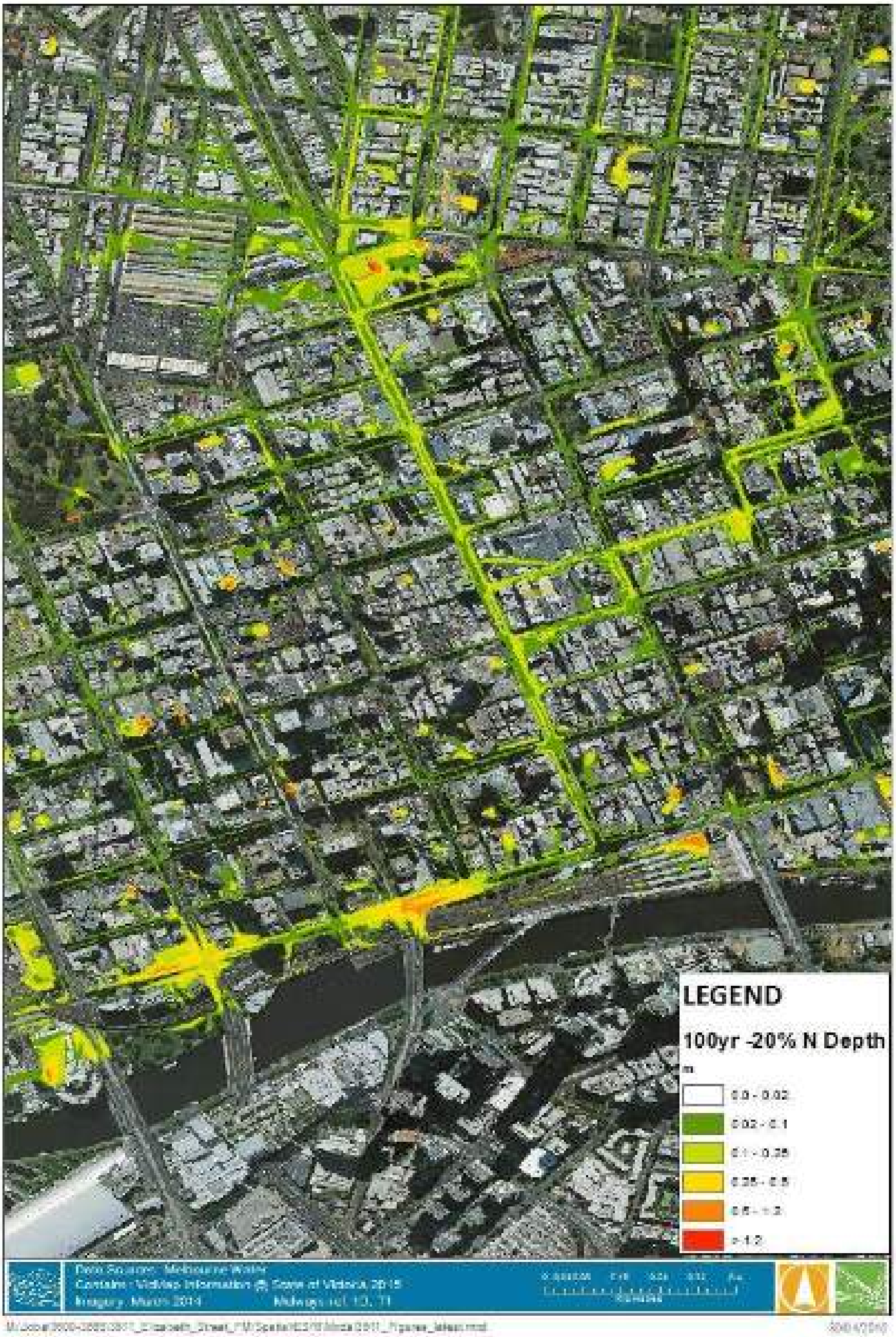

Figure 10-27 100 year 20% Reduction in Roughness Depth Plot

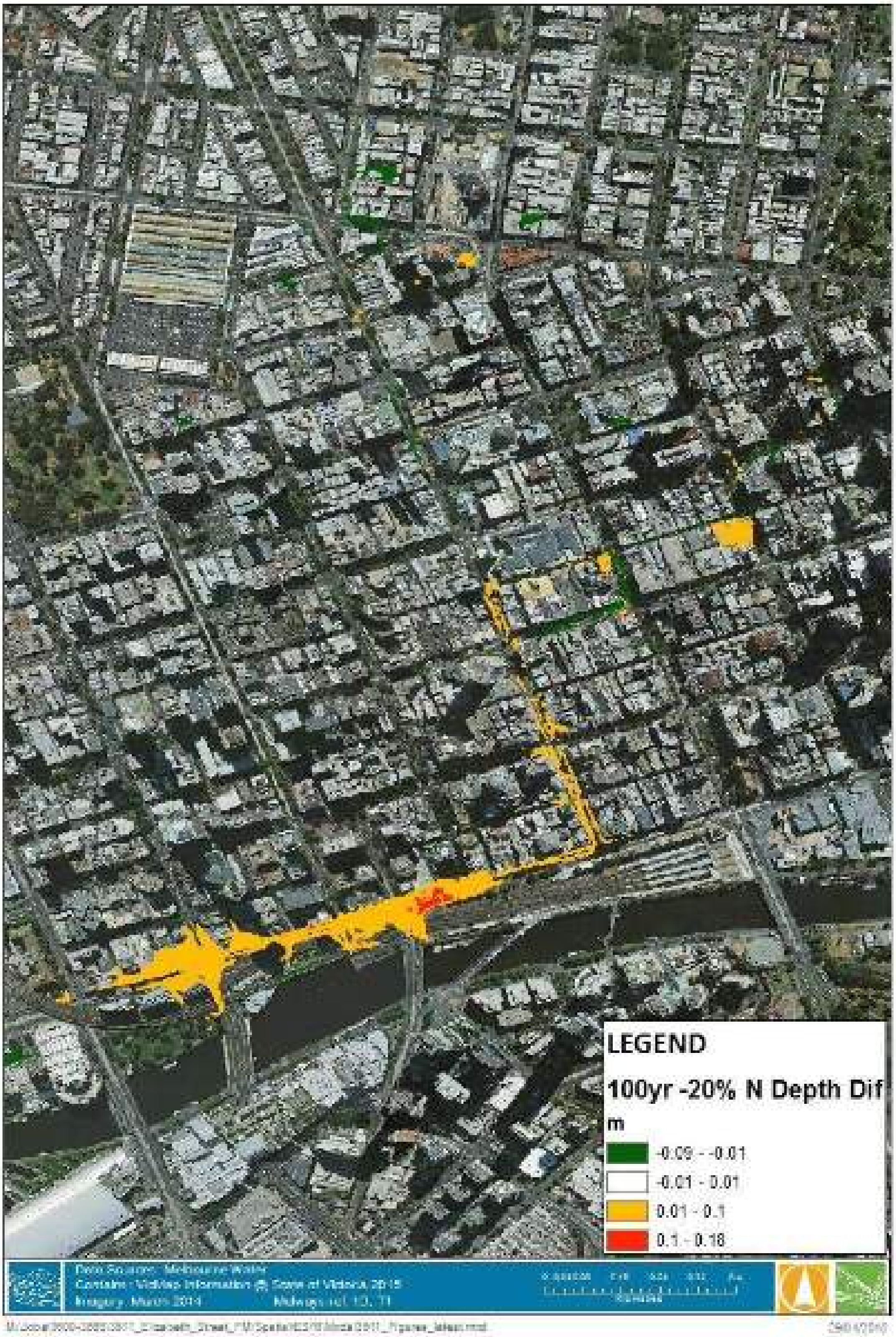

Figure 10-28 100 year 20% Reduction in Roughness Depth Difference Plot

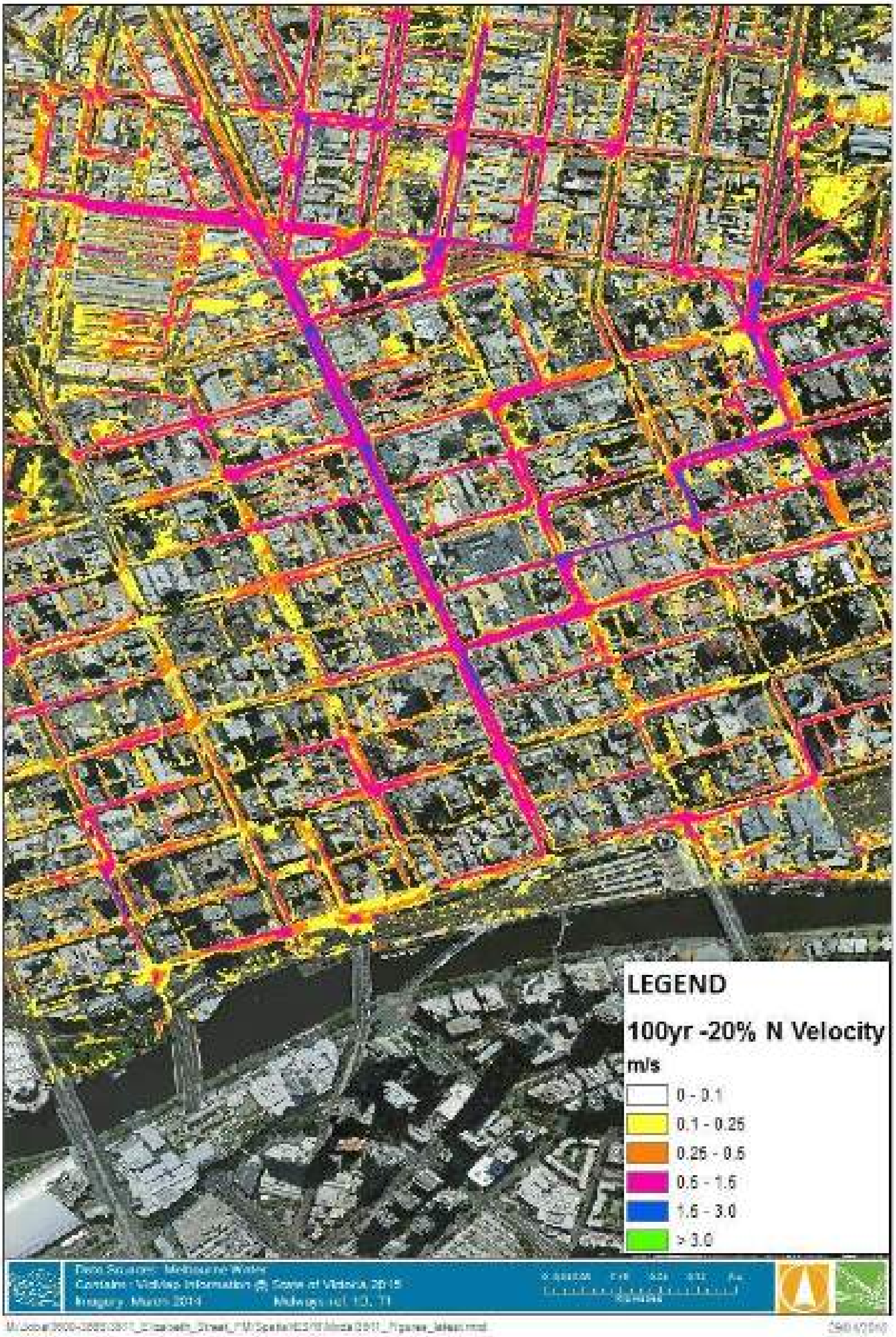

Figure 10-29 100 year 20% Reduction in Roughness Velocity Plot

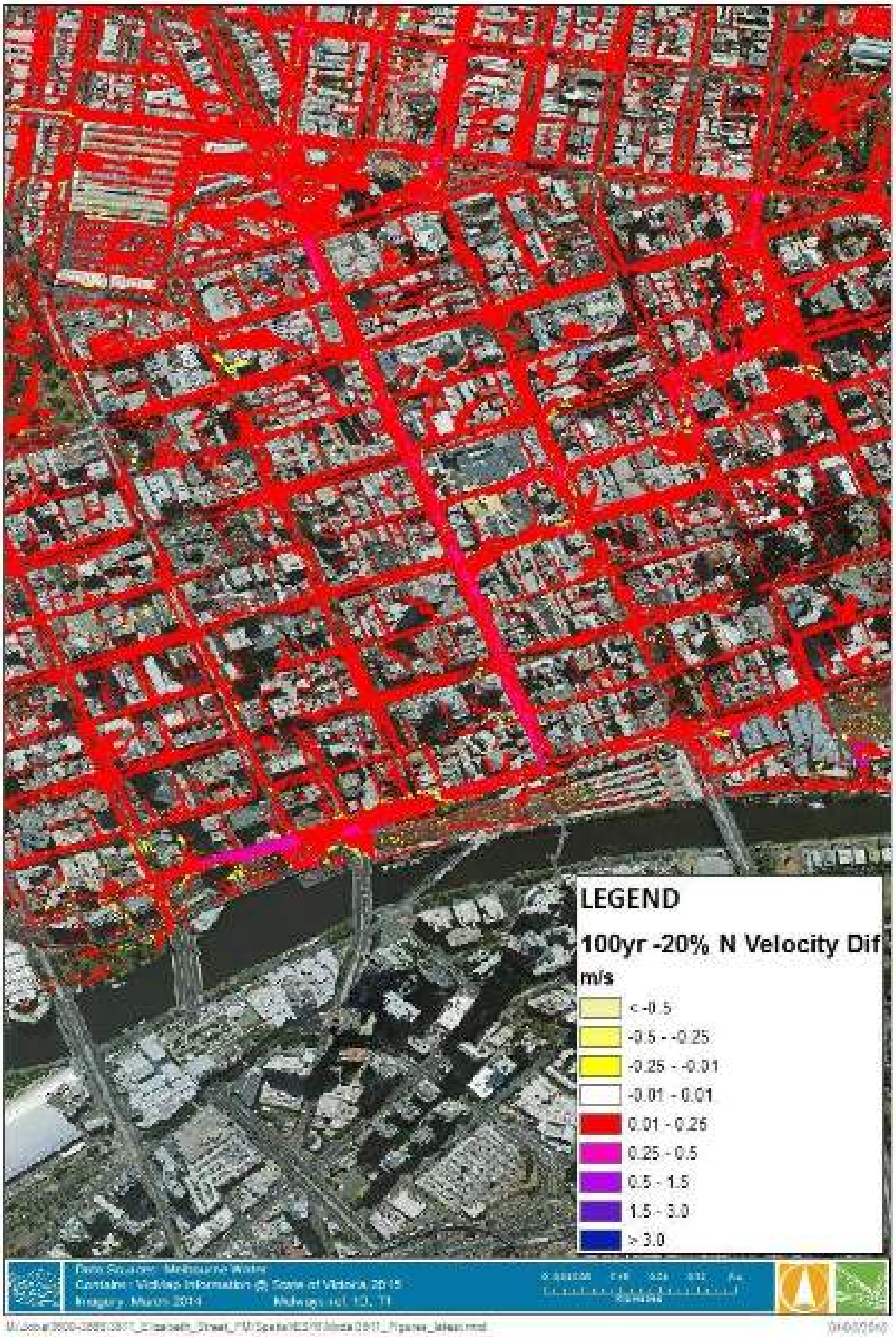

Figure 10-30 100 year 20% Reduction in Roughness Velocity Difference Plot

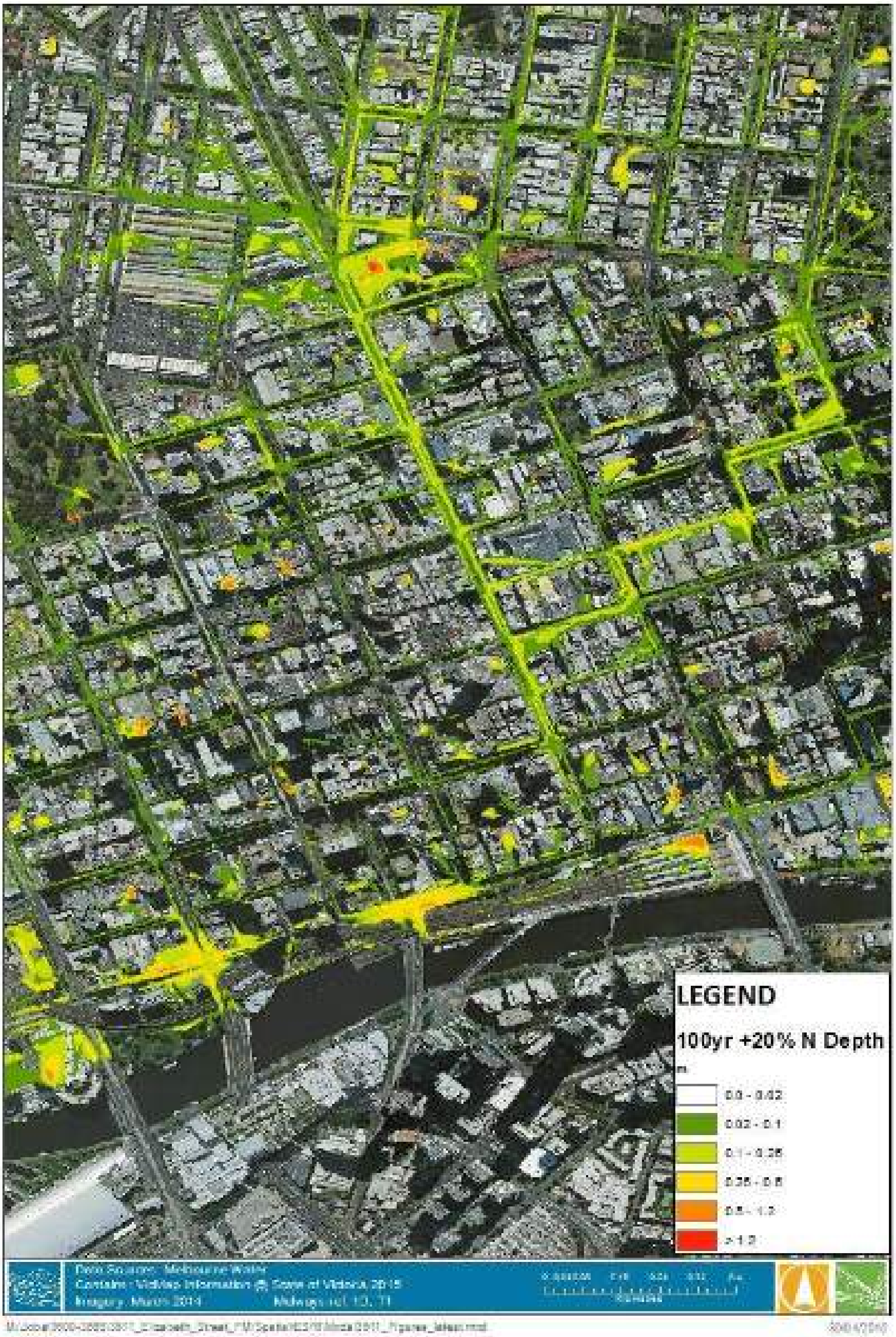

Figure 10-31 100 year 20% Increase in Roughness Depth Plot

Figure 10-32 100 year 20% Increase in Roughness Depth Difference Plot

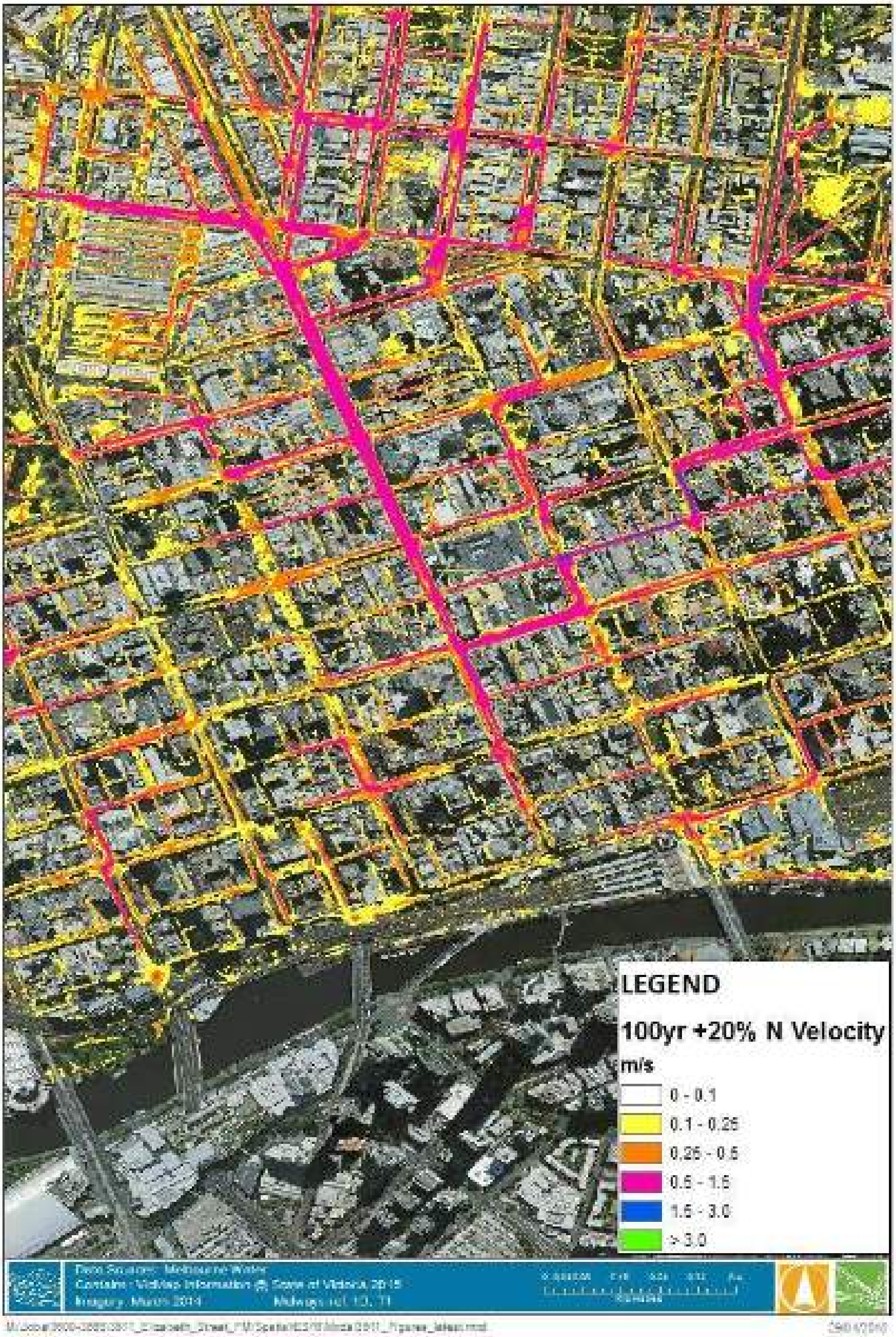

Figure 10-33 100 year 20% Increase in Roughness Velocity Plot

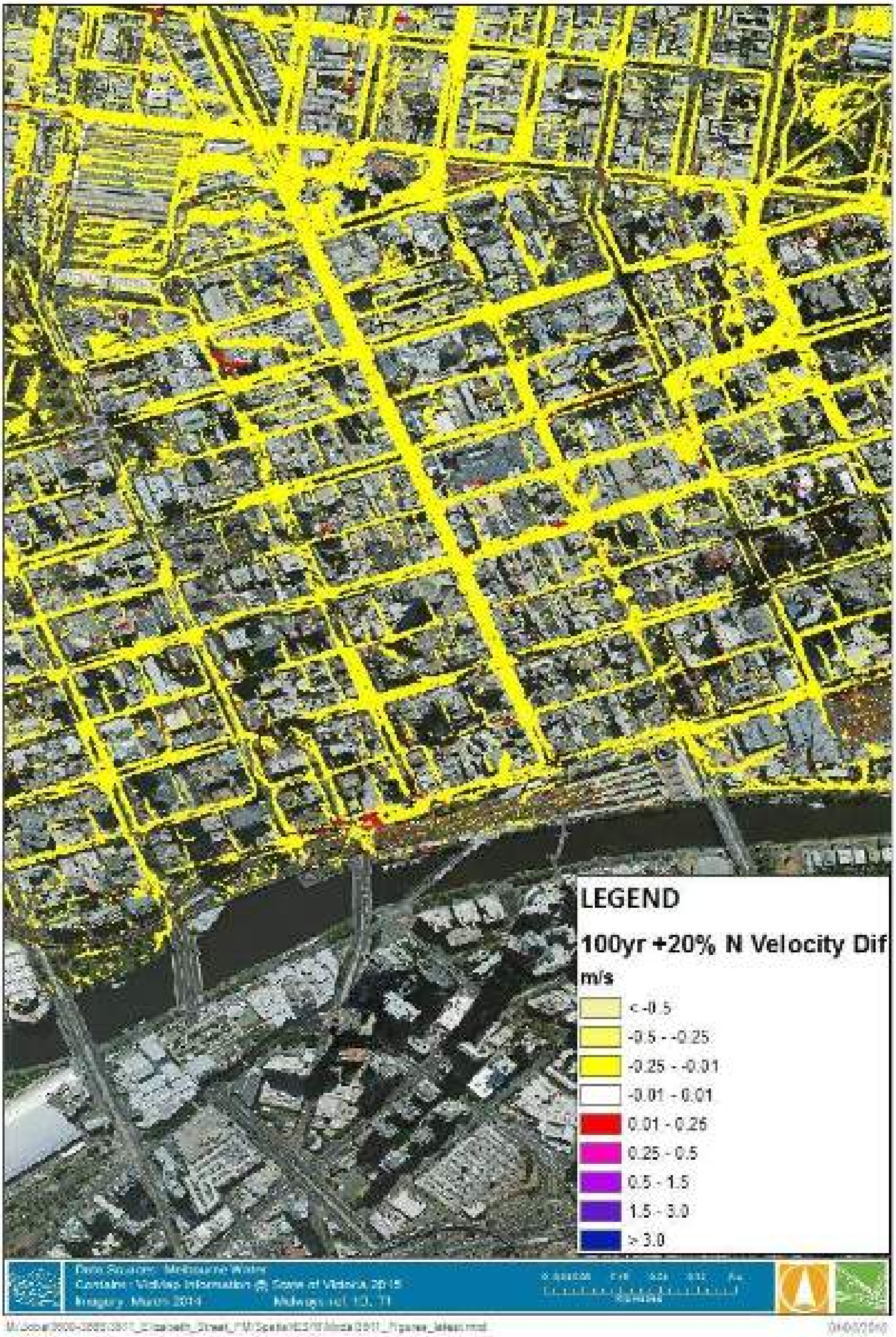

Figure 10-34 100 year 20% Increase in Roughness Velocity Difference Plot

APPENDIX B CORRESPONDENCE RECORDS

From: Denise Hare [mailto:Denise.Hare@watertech.com.au]
Sent: Tuesday, 10 February 2015 5:13 PM
To: Ralf Pfleiderer; Anthony Jessup
Cc: Yvonne Lynch; Luke Cunningham
Subject: Elizabeth Street Inception Meeting Minutes

Hi All,

The meeting followed the draft Hydraulic Modelling Approach memo with the following key items discussed:

- 2m cell size;
- LiDAR – to use the weeded out version, not the raw data or the one with flow paths in it;
    - Note that quite deep holes in areas of construction need to be smoothed over so as to reduce basin effect. These will need to be roughened up as well.
- Building representation – two runs will be done:
    - Increase roughness over building footprints; and,
    - Raise building footprints (not to full height as this causes stability issues in the model).
- 1D network representation:
    - Pipes – need to look at data Jasper will send through and make sure there are no clashes between MW and CoM pipes;
    - GPTs – WT to compare list with Ralf. Consensus was if we have enough data WT will include by increasing losses on pits to account for constriction and expansion losses. Then do a sensitivity test not including them;
    - Open sewer pits – leave out for now;
    - Underpasses – Flinders St – CoM getting plans, if not WT to measure on site. Degraves underpass – see if water gets there on preliminary results to determine if we need to model it; and,
    - No cross-sections/producing 1m grid points data from the 1D results.
- Roughness – waiting on Jasper to send through polygons, will be using the standard approach i.e. no depth varying roughness at this stage;
- Fraction impervious estimation:
    - Grassed areas may have too low FI value assigned (10%). Therefore do two runs – 5 year and 100 year at 10% and another percentage to be discussed with the ICAM team and see if there is a difference.
- Time of Concentration for Rational Calculation – input from Colebrook White calculations or the Adams method;
- Residential, commercial and industrial properties and buildings – not really any difference in the CBD;
- Tailwater levels and boundary conditions:
    - Yarra water levels – MW to confirm which levels to use – the 1934 event or recent modelling;
    - MW to provide smaller ARI water levels;
    - WT to produce an IWL DEM to stabilize and reduce mass error; and,
    - Not modelling inflow in the Yarra as then have to include the bathymetry and bridges and it becomes more complicated.
- Storm durations to be modelled – MW happy for us to run initial runs with all durations and then only run the peaks/around the peaks for remainder of the runs;
- Climate change rise in level – MW to confirm 0.8m post Climate Change workshop next week;
- Rainfall obtained from AR&R for all runs, except the calibration run where there are 2 ways of doing it;

- ○ BOM Radar – spatial and timing – not sure the quality of this data, but we will try this first (check out the radar for the event here: http://www.theweatherchaser.com/radar-loop/IDR024-melbourne/2010-09-03-08/2010-09-04-12); and,
- ○ Spatial variance only based on observations from various points around the catchment.

- Water Tech will be going out to site next week and will have a look at (you're welcome to join us if you'd like):
  - ○ Basement car parks, to see if need to model (potential to use flood gates as mitigation);
  - ○ Pits as to whether they are sealed or not
- PO lines – Water Tech to send through MapInfo layer of PO lines and results, add PO lines up Little Bourke St, and Bourke St Mall; and,
- Filtering of results will be undertaken to remove water below 20 mm depth. Then WT will talk to MW about additional filtering requirements e.g. puddle size/depth options, filtering before overlay.

An updated hydraulic modelling approach memo will be prepared based on this information and the roughness and fraction impervious polygons we receive from Jasper. We will then send it through as a final.

The next meeting will be held to discuss preliminary results, most likely at Water Tech offices so we can go through the results "live".

Please let me know if you have any questions regarding this information.

Denise Hare

Project Engineer | MIEAust CPEng

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web: www.watertech.com.au

From: Anthony Jessup [mailto:Anthony.Jessup@melbournewater.com.au]
Sent: 05 June 2015 11:17
To: Denise Hare; Luke Cunningham
Subject: RE: Elizabeth St - Climate Change and Sensitivity Test Recommendations

Hi Denise and Luke,

Happy to proceed based on the recommendations you have made noting the additional comments I have made below.

1. Use an initial loss of 0.6 mm; **OK**

2. Use industry standard Manning's roughness values as per the Melbourne Water manual **OK**

3. Use 10% Fraction Imperviousness values in parks; **OK**

4. Roughen the buildings, without blocking them; **OK but Water Tech to include additional PO lines where water flows through buildings as previously discussed.**

5. Apply rainfall increases of 19.2%, 26% and 32% for the 1 in 5, 20 and 100 year events respectively, and increase sea level by 0.8 m. **OK but use 20% increase for the 1 in 5 year ARI as per Rod Watkinson's comment: "The 32% is in line with what we've been using as an 'upper' figure for flooding in 2100. The other values seem OK, although 19.2% could be rounded to 20%. I know it would be a theoretically derived value, which came out at 19.2%, but it makes it seem like we know things to a greater accuracy than we actually do!"**

Cheers,

Anthony Jessup | Project Manager, Flood Mapping and Mitigation, Waterways & Land Asset Management | **Melbourne Water** |

Ph: 9679 7367 | 990 La Trobe Street, Docklands 3008 | PO Box 4342 Melbourne VIC 3001 | melbournewater.com.au

From: Anthony Jessup [mailto:Anthony.Jessup@melbournewater.com.au]
Sent: 05 June 2015 10:08
To: Luke Cunningham
Cc: James Newton; Denise Hare
Subject: RE: Eilzabeth St MD modelling

Hi Luke,

Just realised I hadn't replied to your email, sorry about that! It would also be good if you could insert some where water is flowing through buildings at the northern end of Elizabeth St near the Victoria Market (image below). If you notice any other locations where a significant (say greater than the filtering criteria of 0.05m) depth of water is flowing through buildings it would be great to insert them at these locations too.

Thanks!

Anthony Jessup | Project Manager, Flood Mapping and Mitigation, Waterways & Land Asset Management | **Melbourne Water** |

Ph: 9679 7367 | 990 La Trobe Street, Docklands 3008 | PO Box 4342 Melbourne VIC 3001 | melbournewater.com.au

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From: Luke Cunningham [mailto:Luke.Cunningham@watertech.com.au]
Sent: Tuesday, 2 June 2015 3:21 PM
To: Anthony Jessup
Cc: James Newton; Denise Hare
Subject: RE: Eilzabeth St MD modelling

Sure – of course. Just the spot shown below or all buildings with water moving through?

Cheers,

Luke

Luke Cunningham
Group Manager - Stormwater | Senior Engineer | MIEAust

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From: Anthony Jessup [mailto:Anthony.Jessup@melbournewater.com.au]
Sent: Tuesday, 2 June 2015 3:00 PM
To: Luke Cunningham
Subject: RE: Eilzabeth St MD modelling

Hi again,

Thanks for that. But now I have another request!

We're leaning towards using high mannings values to represent building footprints rather than block-outs. If we adopt this approach are you able to add some PO lines where water is shown to flow through building footprints (as shown in the image below). While using a high mannings n will limit flow through the building footprints I'd like to be sure that the flow through these areas is low relative to the flow down the adjacent streets.

Cheers,

Anthony

Anthony Jessup | Project Manager, Flood Mapping and Mitigation, Waterways & Land Asset Management | **Melbourne Water** |

Ph: 9679 7367 | 990 La Trobe Street, Docklands 3008 | PO Box 4342 Melbourne VIC 3001 | melbournewater.com.au

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From: Luke Cunningham [mailto:Luke.Cunningham@watertech.com.au]
Sent: Tuesday, 2 June 2015 1:53 PM
To: Anthony Jessup; Denise Hare
Subject: RE: Eilzabeth St MD modelling

Hi Anthony,

I'll check it out. If it is the blocked scenario, it will still rain on top of the building (we only raise it up a couple of meters) but we definitely wouldn't expect massive flows across them. I'll let you know if I work anything out before Denise is back on Tuesday!

Cheers,

Luke

Luke Cunningham
Group Manager - Stormwater | Senior Engineer | MIEAust

From: Anthony Jessup [mailto:Anthony.Jessup@melbournewater.com.au]
Sent: Tuesday, 2 June 2015 10:33 AM
To: Denise Hare; Luke Cunningham
Subject: Eilzabeth St MD modelling

Hi Guys,

Hope your well. I was having a look at some of the sensitivity run results this morning and have a question regarding the 100b_d points (I assume these points are the depth results from the run that blocked out building footprints?). I understand that shallow sheet flow will occur on top of the building footprints, however I have noticed some areas where depths on top of buildings are greater than 100mm and water appears to be flowing through buildings (see circled areas in the image below).

Any thoughts on why this is occurring?

Cheers,

Anthony

Anthony Jessup | Project Manager, Flood Mapping and Mitigation, Waterways & Land Asset Management | **Melbourne Water** |

Ph: 9679 7367 | 990 La Trobe Street, Docklands 3008 | PO Box 4342 Melbourne VIC 3001 | melbournewater.com.au

From: Barry Fox [mailto:Barry.Fox@melbourne.vic.gov.au]
Sent: Wednesday, 7 December 2016 3:43 PM
To: James Newton <James.Newton@watertech.com.au>
Cc: Rod Watkinson <rod.watkinson@melbournewater.com.au>; Rushiru Kanakaratne <rushiru.kanakaratne@melbournewater.com.au>; Luke Cunningham <Luke.Cunningham@watertech.com.au>; Bandara Rajapakse <Bandara.Rajapakse@melbourne.vic.gov.au>; Michael Norton <Michael.Norton@melbourne.vic.gov.au>; Ralf Pfleiderer <Ralf.Pfleiderer@melbourne.vic.gov.au>
Subject: RE: Elizabeth Street Green Infrastructure Workshop Outcomes

Hi James,

Regarding the suggested flood mitigation interventions that came out of the recent Elizabeth St Green Infrastructure Workshop, I'd like to expand on the last option listed **'Modelling future planning requirement…'** and provide some context on its feasibility.

One of my roles here at CoM is to review and issue drainage approvals for developments for the purpose of both town planning compliance (specific to drainage permit conditions) and building regulation requirements (legal point of discharge). In terms of the planning permit requirements, all new developments are required to incorporate integrated water management systems into their building design for alternative water supply. Naturally the effectiveness of these systems from a flood mitigation perspective relies largely on the water level in the tank at the commencement of the rainfall event. If the tank is full there is no benefit.

To compensate for this, I've been using the legal point of discharge process to require developments to build in additional 'detention storage' into their drainage designs as a flood mitigation measure. Any new development within the Elizabeth St Catchment, is now required to limit their site discharge to Q5 (5min storm duration) and provide detention storage for a Q100 event with an addition 15.5% contingency to account for increased rainfall intensity due to climate change. It's relatively early days in this process but over the last year, 12 developments in the catchment have been advised of these requirements. Some designs are still in development but based on actual approvals to date I'd expect to see approx. 580m^3 of additional detention storage included in the Elizabeth St catchment annually within private development.

Responding to the comment on feasibility of this intervention I'd say it's highly feasible given approvals of these detention storage systems have already been issued, and are generally accepted by engineering consultants and their clients. It would be great to get an understanding of the potential benefit of this as a standalone flood mitigation strategy, in a future scenario where widespread redevelopment has occurred including these onsite detention systems. One way of going about this could be to assume 90% of the City North Urban Renewal Area (see screenshot below) and 50% of the remainder of the catchment has been redeveloped with this level of detention storage.

Happy to hear your thoughts or feedback on this approach.

Regards

Barry Fox | Drainage Engineer | Engineering Services

City of Melbourne | Level 4 Council House 1, 200 Little Collins Street Melbourne 3000 | GPO Box 1603 Melbourne 3001

T: 9658 9850 | F: 03 9658 8886| E: barry.fox@melbourne.vic.gov.au | W: www.melbourne.vic.gov.au

From: Tim Fletcher [mailto:timf@unimelb.edu.au]
Sent: Thursday, 16 February 2017 8:00 AM
To: James Newton <James.Newton@watertech.com.au>; Matthew James Burns <matthew.burns@unimelb.edu.au>; Toby Sterling <toby.sterling@unimelb.edu.au>
Cc: Luke Cunningham <Luke.Cunningham@watertech.com.au>
Subject: Re: Elizabeth St flooding (2013-248)

Hi there James,

Thanks for the update. The initial Loss values we typically see for roofs (not their potential storage capacity, but their probabilistic (median) initial loss) is around 5 – 10 mm; a fairly safe number would be 7.5 or 8 mm.

Of course, there is then a storage/attenuation function of the roof once it is discharging, being a function of the substrate depth and hydraulic conductivity. For simplicity, I imagine you'll just work with the initial loss?

Kind regards,

tim

From: Celine Marchenay [mailto:Celine.Marchenay@watertech.com.au]
Sent: Thursday, 16 March 2017 3:02 PM
To: Rushiru Kanakaratne
Cc: Rod Watkinson
Subject: RE: Elizabeth St Handover

Hi Rushiru,

Sure, we can format both “As above with islands of 100m2 removed” and “As above but buffer by 5m” MapInfo tables.

Yes, the 50 year ARI existing conditions is included.

Regards,

Celine Marchenay
Project Engineer

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From: Rushiru Kanakaratne [mailto:rushiru.kanakaratne@melbournewater.com.au]
Sent: Thursday, 16 March 2017 2:58 PM
To: Celine Marchenay <Celine.Marchenay@watertech.com.au>
Cc: Rod Watkinson <rod.watkinson@melbournewater.com.au>
Subject: RE: Elizabeth St Handover

Hi Celine,

Can we get both the “As above with islands of 100m2 removed” and “As above but buffer by 5m” tables in that format? We haven’t decided which of these we will ultimately use.

Also, is the 50yr ARI event included?

Regards,

Rushiru Kanakaratne | Senior Investigations & Project Engineer, Flood Mapping & Mitigation | Asset Management Services, Service Delivery | **Melbourne Water**

T: (03) 9679 7049 | 990 Latrobe Street, Docklands 3008 | PO Box 4342 Melbourne VIC 3001 | melbournewater.com.au

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From: Celine Marchenay [mailto:Celine.Marchenay@watertech.com.au]
Sent: Thursday, 16 March 2017 9:17 AM
To: Rushiru Kanakaratne
Cc: Rod Watkinson
Subject: RE: Elizabeth St Handover

Hi Rushiru,

James handed over the project to me yesterday and I will be working on processing all the results over the next couple of weeks.

For the existing conditions results; James created the following 5 flood extents for each of the events (5y; 10y; 20y; 100y and 1972);

- Depth filtered and 100m2 puddles removed – 5y_poly.TAB; etc.
- As above but smoothed – 5y_poly_sm.TAB; etc.
- As above with islands of 100m2 removed – 5y_poly_sm_gp.TAB; etc.
- As above with BFs clipped out – 5y_poly_sm_gp_build.TAB; etc.
- As above but buffer by 5m – 5y_poly_sm_gp_build_buf.TAB; etc.

I understood that the final flood extent should follow the MW technical specification 2016 naming/format convention. Could you please tell me which of the flood extent you would like formatted using the naming/format convention? Thank you

Regards,

Celine Marchenay
Project Engineer

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APPENDIX C CLIMATE CHANGE MEMORANDUM

Climate change scenarios for the City of Melbourne

Penny Whetton and Leanne Webb
Penny Whetton and Associates (PW), 14 Stirling, Footscray, Vic 3011; ABN: 46114173257

This document

The task of providing climate change scenarios by PW for use with ICAM model was specified in detail through the course of meetings with Yvonne Lynch and ICAM team members in February and March 2015. This process included providing advice on how to represent climate change in the ICAM model. An outline of proposed scenarios was provided on the 27 March and approved. Populating these scenarios could not be undertaken by PW until the relevant data were accessible through CSIRO's Climate change in Australia website, publicly released on April 8.

Climate change scenario task

For ICAM modelling of soil moisture/tree survival, microclimate and potable water consumption, the following are required for current and future climate (cite Matt paper):

- The minimum annual rainfall for AEPs of 1%, 2%, 5%, 10%, and 20%. The year is a calendar year (Jan-Dec).
- The minimum annual summer rainfall for AEPs of 1%, 2%, 5%, 10%, and 20%. The year is a water year (Jul to Jun) and summer is defined by the months: Dec, Jan, and Feb.
- The longest contiguous period of days without rain (> 1mm) in a year for AEPs of 1%, 2%, 5%, 10%, and 20%. The year is a calendar year (Jan-Dec).
- The maximum annual daily temperature for AEPs of 1%, 2%, 5%, 10% and 20%. The year is a water year (Jul to Jun) and only the summer months are considered.
- The maximum annual 5-day temperature for AEPs of 1%, 2%, 5%, 10% and 20%. The year is a water year (Jul to Jun) and only the summer months are considered.

For each of these, it was decided that with the ICAM team (meeting of 27 march), the ICAM team would source a daily temperature and rainfall time series for Melbourne, analyse it for the extremes required, PW would provide change factors for the each of the future scenarios which the ICAM team would apply to the data set and reanalyse for the extremes. To meet this task PW needed to supply changes in seasonal mean maximum temperature and seasonal percentage rainfall.

For ICAM modelling of drainage/flooding changes in magnitude of 5, 20, 100 annual return period daily falls are required for each future scenario as are values of mean sea level rise. In the meeting with the ICAM team at the Water Technology office (19 March), it was indicated that PW could readily supply the 20 year values, but would provide advice on developing relevant estimates for the other periods. Mean sea level rise would be provided by PW.

Time slices for the future scenarios were discussed at the meeting of 27 March and agreed to be 2030, 2050 and 2090. It was agreed that we would consider two scenarios representing low and high emissions of greenhouse gases (RCP4.5 and RCP8.5, respectively) (Van

Vuuren et al., 2011). It was also agreed that the number of future climate scenarios would be limited to as small a set as possible, whilst still representing variation in time and emission scenario, and differences between models.

Development of a set of scenarios

The scenarios developed here are based on the (CSIRO and BoM, 2015) projections and associated tools on the [Climate Change in Australia website](). In turn these are based the climate change simulations with the latest ensemble of global climate models, known as CMIP5 (Meehl and Bony, 2011), and as used in the latest assessment report of the IPCC (IPCC, 2013).

To develop the small set of scenarios the climate futures approach (Clarke et al., 2011, Whetton et al., 2012) is employed, using the current version of the Climate Futures tool on the CCIA website. This tool enables a small set of the descriptions of the future climate based on set categories of temperature and rainfall change (e.g. +0.5 to +1.5 °C is 'warmer', +1.5 to +3.0 °C is 'hotter', rainfall change of -5 to -15 % is 'drier', etc, see tables below) are populated by current CMIP5 climate model results for a given date and emission scenario. Valid scenarios for a date and emission scenario are those categories populated by a minimum proportion of model results. The numerical values for a range of variables required by the applications described above are then drawn from the results of the models populating each square.

For this project, annual maximum temperature and rainfall change are used as the classifying variables, as these are highly relevant to the subsequent ICAM modelling. The set of CMIP5 models used is indicated in the Table A1 in the Appendix and comprises 36 models for RCP4.5 and 37 for RCP8.5. This set of models has undergone thorough evaluation for the Australian region (CSIRO and BoM, 2015). The region used in the analysis is the 'Southern Slopes Victoria West' sub-cluster (SSWW) (CSIRO and BoM 2015), which is the smallest region containing Melbourne available on the CCIA website (Figure 1).

Figure 1 Southern Slopes (Victoria West) sub-cluster, including the city of Melbourne, is indicated by the grey shading.

Table 1 shows the relevant climate scenarios for the Melbourne region developed using the Climate Futures tool. For each of the three time slices, and for each of the potential climate classifications shown in the grid, a subset is highlighted. The highlighted subset represents those for which at least a minimum number of models have results falling in that square of the grid. The actual number of models is shown in Table A2 in the Appendix, with the minimum number of models set at four or greater (more than 10% of total) for the scenario to be counted as being relevant for a given time slice and emission scenario. Note that Table A2 also indicates where this condition was met only for one emission scenario.

As can be expected, scenarios describing more moderate climate change (e.g. 'warmer and little change') are most prevalent in the near future (2030) though for later in the century under low emissions only these conditions can persist. On the other hand, scenarios containing the most extreme changes (e.g. 'much hotter and much drier') are only projected for late in the century and under high emissions.

For each of the scenarios highlighted in Table 1, development of representative climate change projections is required for application in the ICAM modelling. The following three sections describe the method employed to produce projection described in Table 3 for each of the variables; temperature, rainfall, extreme rainfall and sea level rise.

Table 1: Definition of climate scenarios based on projected mean rainfall and maximum temperature change and the results of CMIP5 models for the Melbourne region (Southern Slopes Victoria West; CSIRO and BoM, 2015). Dark green denotes cases populated by model results for both high (RCP8.5) and low (RCP4.5) emission cases, light green are cases conditional on emission scenario (as indicated) and no shading and solid text indicate cases populated by less than 5% of models. Full model counts, and model mean projected changes for each case are given in the Appendix (Table A2).

2030		Maximum Temperature – Annual daily maximum (°C)			
		up to +0.5 °C	+0.5 °C to +1.5 °C	+1.5 °C to +3.0 °C	More than +3.0 °C
Rainfall change Annual (%)	+5 % to +15 %	Slightly warmer and little change	Warmer and wetter	Hotter and wetter	Much hotter and wetter
	-5 % to +5 %	Slightly warmer and little change	Warmer, little rainfall change	Hotter, little rainfall change	Much hotter, little rainfall change
	- 5 % to -15 %	Slightly warmer	Warmer and drier	Hotter and drier	Much hotter and drier
	less than -15 %	Slightly warmer and much drier	Warmer and much drier	Hotter and much drier	Much hotter and much drier

2050		Maximum Temperature - Annual daily maximum(°C)			
		up to +0.5 °C	+0.5 °C to +1.5 °C	+1.5 °C to +3.0 °C	More than +3.0 °C
Rainfall change Annual (%)	+5 % to +15 %	Slightly warmer and little change	Warmer and wetter	Hotter and wetter	Much hotter and wetter
	-5 % to +5 %	Slightly warmer and little change	Warmer, little rainfall change	Hotter, little rainfall change High emissions only	Much hotter, little rainfall change
	- 5 % to -15 %	Slightly warmer	Warmer and drier	Hotter and drier High emissions only	Much hotter and drier
	less than -15 %	Slightly warmer and much drier	Warmer and much drier	Hotter and much drier	Much hotter and much drier

2090		Maximum Temperature – Annual daily maximum (°C)			
		up to +0.5 °C	+0.5 °C to +1.5 °C	+1.5 °C to +3.0 °C	More than +3.0 °C
Rainfall change Annual (%)	+5 % to +15 %	Slightly warmer and little change	Warmer and wetter	Hotter and wetter (less 5% of models)	Much hotter and wetter
	-5 % to +5 %	Slightly warmer and little change	Warmer, little rainfall change Low emissions only	Hotter, little rainfall change	Much hotter, little rainfall change
	- 5 % to -15 %	Slightly warmer	Warmer and drier Low emissions only	Hotter and drier	Much hotter and drier High emissions only
	less than -15 %	Slightly warmer and much drier	Warmer and much drier	Hotter and much drier Low emissions only	Much hotter and much drier High emissions only

Maximum temperature and precipitation change values

For annual and seasonal temperature and rainfall change, all model results falling under a particular scenario (regardless of the emission scenario or date) are averaged. The resulting values for each scenario are shown in Table 3. Note that as it is the annual values of temperature and rainfall change that are used for classification (and not the seasonal values), seasonal changes can differ significantly from the annual values. This is to be expected, and indeed shows how models typically distribute annual changes across the seasons.

Extreme rainfall

Model simulated values of the change in the 1-in-20 year extreme rainfall is also available in the Climate Futures tool. Similar to the results for mean temperature and rainfall, these results are averaged. However, as the number of models for which this data was available was much more limited (19 models) and for some scenarios unavailable, a slightly different approach was used (See Appendix TableA3). Results were averaged for each of the temperature categories (i.e. slightly warmer, warmer, hotter and much hotter) across all annual rainfall categories. This results in extreme rainfall projections that only vary with temperature and not annual rainfall. This approach also reflects that extreme rainfall change is predominantly a thermodynamic response of the climate system.

1 in 5 year and 1 in 100 extreme rainfall results are not available amongst the CSIRO and BoM (2015) products, and thus cannot be supplied using the methodology employed here. Changes to the 1 in one year daily fall in 2090 are graphed in the regional reports and typically this change is around 2/3 of the 1 in 20 year change. This fits with the general trend for the changes to extreme rainfall to increase for increasing return period. This means that if 1 in 20 year values were used to represent the 1 in five year changes this would represent a slight overestimate, and if it was used to represent the 1 in 100 year event it would be somewhat conservative.

Sea level rise

Sea level rise scenarios represented here in Table 3 are taken directly from Table 8.1.2 in CSIRO and BoM (2015), selecting the site of Williamstown (Vic.) as most relevant. Note that although there is a correlation between regional warming and sea level rise, this correlation is not strong, and quite different sea level rises can potentially be associated with some of the scenarios in Table 1. For example, the 'Warmer and Drier' scenario can occur in conjunction with sea level rise projected for 2030, but also those for 2050, or even 2090 (under low emissions). However, for the purpose of the keeping the scenarios simple, only one sea level rise set of values is associated with each scenario, with this chosen to match the date and emission scenario for which the given scenario is most populated.

Table 2: Projected sea level rise relative to 1995 at Williamstown (from CSIRO and BoM, 2015) for three future time periods under low (L; RCP4.5) and high (H; RCP8.5) emissions scenarios.

Period	RCP4.5 (L)	RCP8.5 (H)
2030	0.11 (0.07-0.16)	0.12 (0.08-0.17)
2050	0.21 (0.13-0.29)	0.24 (0.15-0.32)
2090	0.44 (0.27-0.62)	0.59 (0.38-0.81)

Table 3: Scenario classifications and corresponding projections (see Table A2 for details).

Scenarios	Occurrence (See Table 1 for details)	Annual max temp. change °C	Seasonal max temp change °C	Annual Rainfall change %	Seasonal rainfall changes %	1/20 year rainfall change	Sea level rise (cm)
1. Warmer, little rainfall change	2030 2050 2090 (L only)	+1.0	Sum: 1.1 Aut: 0.9 Win: 0.8 Spr: 1.0	-1	Sum: -1 Aut: 1 Win: 1 Spr: -4	+9%	0.11 (0.07-0.16) (2030 L)
2. Warmer, drier	2030 2050 2090 (L only)	+1.1	Sum: 1.3 Aut: 1.1 Win: 0.9 Spr: 1.2	-9%	Sum: -9 Aut: -8 Win: -6 Spr: -14	+9%	0.12 (0.08-0.17) (2030 H)
3. Hotter, little rainfall change	2050 (H only) 2090	+2.0	Sum: 2.2 Aut: 2.0 Win: 1.8 Spr: 2.1	-1%	Sum: -1 Aut: 2 Win: 2 Spr: -7	+15%	0.24 (0.15-0.32) 2050H:
4. Hotter, drier	2050 2090	+2.0	Sum: 2.3 Aut: 1.9 Win: 1.7 Spr: 2.0	-10%	Sum: -8 Aut: -10 Win: -7 Spr: -14	+15%	0.44 (0.27-0.62) (2090 L)
5. Hotter, much drier	2090 (L only)	+2.0	Sum: 2.2 Aut: 2.0 Win: 1.9 Spr: 2.2	-17%	Sum: -20 Aut: -17 Win: -13 Spr: -19	+15%	0.44 (0.27-0.62) (2090 L)
6. Much hotter, drier	2090 (H)	+3.6	Sum: 4.0 Aut: 3.5 Win: 3.2 Spr: 3.7	-11%	Sum: -12 Aut: 0 Win: -10 Spr: -20	+26%	0.59 (0.38-0.81) (2090 H)
7. Much hotter, much drier	2090 (H)	+3.9	Sum: 4.3 Aut: 3.8 Win: 3.4 Spr: 4.3	-25%	Sum: -14 Aut: -25 Win: -21 Spr: -38	+26%	0.59 (0.38-0.81) (2090 H)

IPCC (2013) *Climate Change 2013: The Physical Science Basis*. In: *STOCKER, T. F. D. QIN G.-K. PLATTNER M. TIGNOR S. K. ALLEN J. BOSCHUNG A. NAUELS Y. XIA V. BEX and P. M. MIDGLEY (eds.)* Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. (Cambridge University Press: Cambridge, UK, and New York, NY, USA.).

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Van Vuuren, D.P. Edmonds, J. Kainuma, M. Riahi, K. Thomson, A. Hibbard, K. Hurtt, G.C. Kram, T. Krey, V. and Lamarque, J.-F. (2011) The representative concentration pathways: an overview. *Climatic Change*, **109**, 5-31.

Whetton, P. Hennessy, K. Clarke, J. McInnes, K. and Kent, D. (2012) Use of Representative Climate Futures in impact and adaptation assessment. *Climatic Change*, **115**, 433-442.

How the apply the scenarios

The changes in table three are to be applied to the observed data base in use to produce a future climate date base to be used in subsequent calculations. Temperature changes are applied as an increment and percent rainfall changes as a ratio.

The changes in the table are relative to a baseline of 1986-2005. With regard to rainfall change, any differences in modelled climate between this period and the observed baseline period used would be small compared to natural variability and may be ignored. However, this is not the case for temperature change. This means that when applying these changes to the Melbourne observed record for 1989-2014, the additional model warming between 1950 and 1995 (baseline for the projections) needs to be added to the projected warming given in Table 3. Relevant graphs in CSIRO and BoM indicate this additional warming to be around 0.3 C.

Acknowledgements

Coupled Model Intercomparison Project (CMIP): We acknowledge the World Climate Research Programme's Working Group on Coupled Modelling, which is responsible for CMIP, and we thank the climate modeling groups for producing and making available their model output (Table 1A). For CMIP the U.S. Department of Energy's Program for Climate Model Diagnosis and Intercomparison provides coordinating support and led development of software infrastructure in partnership with the Global Organization for Earth System Science Portals.

The product was based on data available on the Climate Change in Australia website under a commercial license. Data as available from the Climate Change in Australia website or 'Site' (URL http://www.climatechangeinaustralia.gov.au/) were developed through the Centre for Australian Weather and Climate Research and were supported by funding from the Commonwealth of Australia. Copyright as may be applicable and subject to item is owned by CSIRO and the Bureau of Meteorology. The Data may include data and intellectual property from third parties including: i. Global Climate Model results (CMIP3 data and CMIP5 data) provided through the Coupled Model Intercomparison Project (CMIP3 http://www-pcmdi.llnl.gov/ipcc/info_for_analysts.php#Terms_of_use ; CMIP5: http://cmippcmdi.llnl.gov/cmip5/terms.html), and ii. NRM Regional Boundaries (http://www.environment.gov.au/fed/catalog/search/resource/details.page?uuid={448223897 32B-420D-A4C8-9A6E8A38D4EC})

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Clarke, J.M. Whetton, P.H. and Hennessy, K.J. (2011) *Providing Application-specific Climate Projections Datasets: CSIRO's Climate Futures Framework*. In: Chan, F. Marinova, D. and Anderssen, R. S. (eds.) MODSIM2011, 19th International Congress on Modelling and Simulation. (Modelling and Simulation Society of Australia and New Zealand: Perth, Western Australia)http://www.mssanz.org.au/modsim2011/F5/clarke.pdf

CSIRO and BoM (2015) *NRM climate change projections project*, (CSIRO Marine and Atmospheric Research and Bureau of Meteorology (CAWCR) and the Department of the Environment: Melbourne, Australia) Available: URL: http://climatechangeinaustralia.com.au/.

APPENDIX D SITE VISIT PHOTOS (18TH MARCH 2015)

Figure 0-1 Grated kerb pit on Flinders Street, adjacent Degraves Street Underpass

Figure 0-2 Outlets to Yarra River (view from Southbank)

Figure 0-3 Typical grated kerb pits and lane-type pits

Figure 0-4 Stewart Street, looking up toward Franklin Street

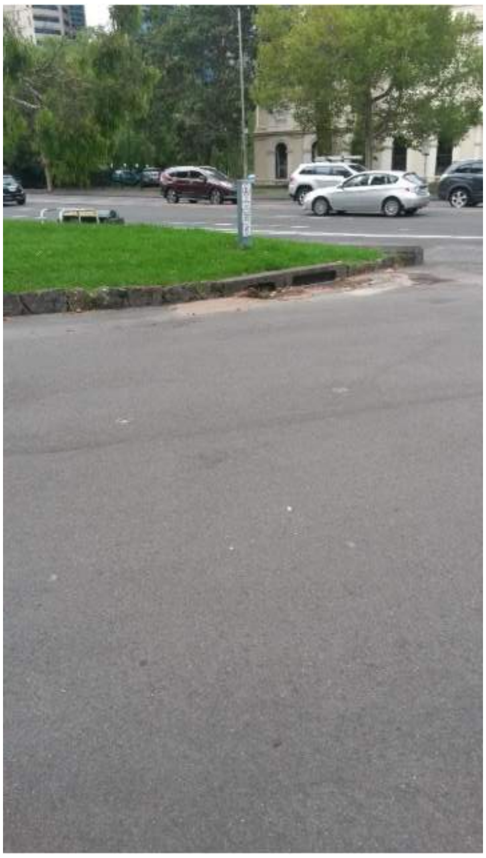

Figure 0-5 Double Side Entry Pits at Carlton Gardens entrance

Figure 0-6 Entrance to car park on Elizabeth Street, near Little Collins Street

Figure 0-7 Williams Street outlet to Yarra River

APPENDIX E FLOOD MITIGATION MEMORANDUM

WATER TECHNOLOGY
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MEMORANDUM

From James Newton & Luke Cunningham | Water Technology
Date 08 December 2016
Subject Elizabeth Street Green Infrastructure Workshop Outcomes

N.B. Updated sections from previous memo noted in blue. Removed sections are crossed out.

1 SUGGESTIONS FROM WORKSHOP

- **Lonsdale Street & Therry Street pipe duplication.** Duplication to assess whether it makes a difference. Was previously suggested by (GHD?).

  Feasibility: Easy to model, has a potential to pick up a lot of that northeast overland flow path and help encourage it into the drainage network. Could help use a bit of the capacity in the Elizabeth St MD.

- **Queen Victoria renewal.** Will be updated in the coming years (2-5yrs). There is an existing storage tank there, but it is unmaintained. There is an opportunity to size (order of magnitude) a storage system onsite. The carpark is also predicted to be removed and turned into a park, which would provide a surface for re-use.

  Feasibility: Relatively easy to model, and is a realistic option given the renewal. Would put Council in a place where they would be prepared with their storage/re-use requirements in a few years time when the renewal goes ahead.

- **Storage at Melbourne University.** Suggestion that an underground smart tank will be built into the university pervious areas. Can be modelled, will just have to understand the release regime a bit better before we manipulate the model.

  Feasibility: Can be modelled, will just have to understand the release regime a bit better before we work at manipulating the model. Not an unrealistic option.

- **Park expansions (Lincoln & Argyle).** More pervious area, potential for tanks.

  Feasibility: As we understand this is going ahead. Unsure on what this would require from a modelling perspective and the magnitude of mitigation we are anticipating.

- **Tank at Exhibition Gardens.** Suggestion that a tank could be built into the gardens. Ralf has suggested that there is a small existing tank.

  Feasibility: Could be an option if it provides enough benefit. Is relatively straightforward to model.

- **Distributed tanks which are connected throughout the city.** Difficult to model and difficult to implement.

  Feasibility: Fairly unrealistic, difficult to model the benefits also.

- **Melbourne Metro.** Considering incorporating green solutions into their capital works. Ralf commented that the MMRA already has sustainability goals to meet best practice.

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Feasibility: Would need more details to appreciate the modelling component of it.

- **Green roofs.** There was a comment that an assessment has been undertaken on the structural integrity of many of the CBD buildings, with the outcomes suggesting that many of the buildings had capacity to take more load (such as green roofs). It may be difficult to incentivise owners, given that many of them are private spaces. This could be modelled by an initial loss method, would need to determine what would be an appropriate amount.

  Feasibility: This could be modelled by an initial loss method, would just need to determine what would be an appropriate amount. More difficult to implement, given the fact that the buildings are privately owned.

- **Driverless cars removing the need for carparks.** The suggestion was that it would free up a lot of underground space in the city. Very difficult to model.

  Feasibility: Fairly unrealistic, difficult to model the benefits also.

- **Green Tram lines.** Green infiltration areas/storages incorporated into the design.

  Feasibility: A realistic option, both in practice and in the model.

- **WSUD Tree Pits.** Tree pits were suggested; these could be modelled in bulk to determine their effectiveness.

  Feasibility: A realistic option, both in practice and in the model. It is doubtful that these would remove flooding up to the 20 year ARI, but they could contribute some mitigation nonetheless.

- **Modelling future planning requirements (a set storage per #sqm of development).** Ralf mentioned that there had been a requirement for Fisherman's Bend to incorporate a storage rate depending on the amount of land developed. He suggested that something similar would be possible for the CBD, with any development/retrospective works to require an amount of storage. We could look at modelling this to justify implementing such a policy.

  Feasibility: Water Technology has modelled similar setups in the past. Unsure on how realistic this is from a policy/planning perspective.

2 DISCUSSION

The original proposal submitted by Water Technology for Stage 2 of the Elizabeth Street flood modelling project allowed for the inclusion of up to 300 green interventions to form one mitigation scenario. This one scenario would then be run for the full suite of AEP events and durations and compared to the existing conditions results from Stage 1 of the project. To get the most out of the approved budget, Water Technology propose some changes to the original scope as shown below:

- Run the 20 year ARI (5% AEP) 2 hour event for four scenarios:
  - Three scenarios testing three selected mitigation solutions to determine their benefit. At this stage, Water Technology would recommend:
    - Green roofs distributed throughout the lower end of the city. Would need to make a decision on how many to implement and what loss to apply for each.
    - Distributed storage approach. Storage applied to buildings via planning requirements ~~and a tree pit program~~. Roll out of 580 m²/year as per email from Barry Fox. 90% of buildings in the City North Urban Renewal Area and 50% in the remainder.

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    - CoM built and planned works (to a limit) – will be high level; i.e. adding in a pipe or removing volume from a model (i.e. removing water volume or adding storage volume). We won't have the budget to accurately input designs into the model.
    - All: model the above three mentioned scenarios together to see the maximum potential benefit.
- Meeting to discuss results (phone)

3 WHAT IS REQUIRED

- Ralf to provide guidance on what mitigation options have been constructed or are planned. If a storage based solution, please provide the storage volume. If conveyance based, please provide the pipe details.
- Green roof option – Water Tech to talk to Uni of Melbourne to discuss appropriate losses to apply. We would suggest we then apply this to every building to see if there is a benefit or not. Otherwise, please provide details of how they will be distributed within the catchment.
- Confirmation that we should test for the 20 year ARI event (5% AEP)
- MW have mentioned that utilising the existing capacity in the drain would be worthwhile. The easiest way to test the impact would be to add pits to Elizabeth Street or upsize the existing ones – is this a scenario we'd like to run also?
- Are Lincoln and Argyle parks included in Ralf's list of built or planned works?
- Is it worthwhile us contacting Metro Rail to determine if any green infrastructure is being included? We have a modelling contact but can contact someone else if there is a more appropriate person.

4 WHERE TO FROM HERE

- Based on the above, we will run 4 scenarios (maybe 5 if the pit scenario is included), one of which will be a combination of all options.
- We will then meet to discuss the results and choose a final run to go ahead with as a combination of the scenarios.
- The table below is from our original proposal which shows Task 15 as being the modelling of the options. We've spent around half of this on workshops and meetings etc. so the budget is quite tight to bring these intervention measures in. With the budget remaining for this task we have around $15 to add each intervention measure to the model so we'll need to keep it very high level. Clarity around whether the University will be involved and whether there is hence additional budget to further refine options would be appreciated.

Task 15	Allowance for the adding of 100 treatment options (storage, PI etc.) to the model	$ 9,140		0%	$ -	$ 9,140	Water Technology
Task 16	Run for entire scenario (all ARIs, all durations) - price per scenario	$ 7,390		0%	$ -	$ 7,390	Water Technology
Task 17	Work with Water Technology to identify intervention scenarios (including locations) and parameterise flood models (UoMC)	$ 6,780		0%	$ -	$ 6,780	University of Melbourne
Task 18	Review and integration of flood management results in reporting and into ICAM model (UoMC)	$ 5,390		0%	$ -	$ 5,390	University of Melbourne
Task 19	Processing and provision of Stage 2 results	$ 11,115		0%	$ -	$ 11,115	Water Technology
	Total Water Technology	$ 27,645			$ -	$ 27,645	Water Technology
	Total University of Melbourne	$ 12,171			$ -	$ 12,171	University of Melbourne
	Total	$ 39,816		0%	$ -	$ 39,816	

FIGURE 2 STAGE 2 – FLOOD MITIGATION: GREEN INFRASTRUCTURE

APPENDIX F GREEN INFRASTRUCTURE RESULTS

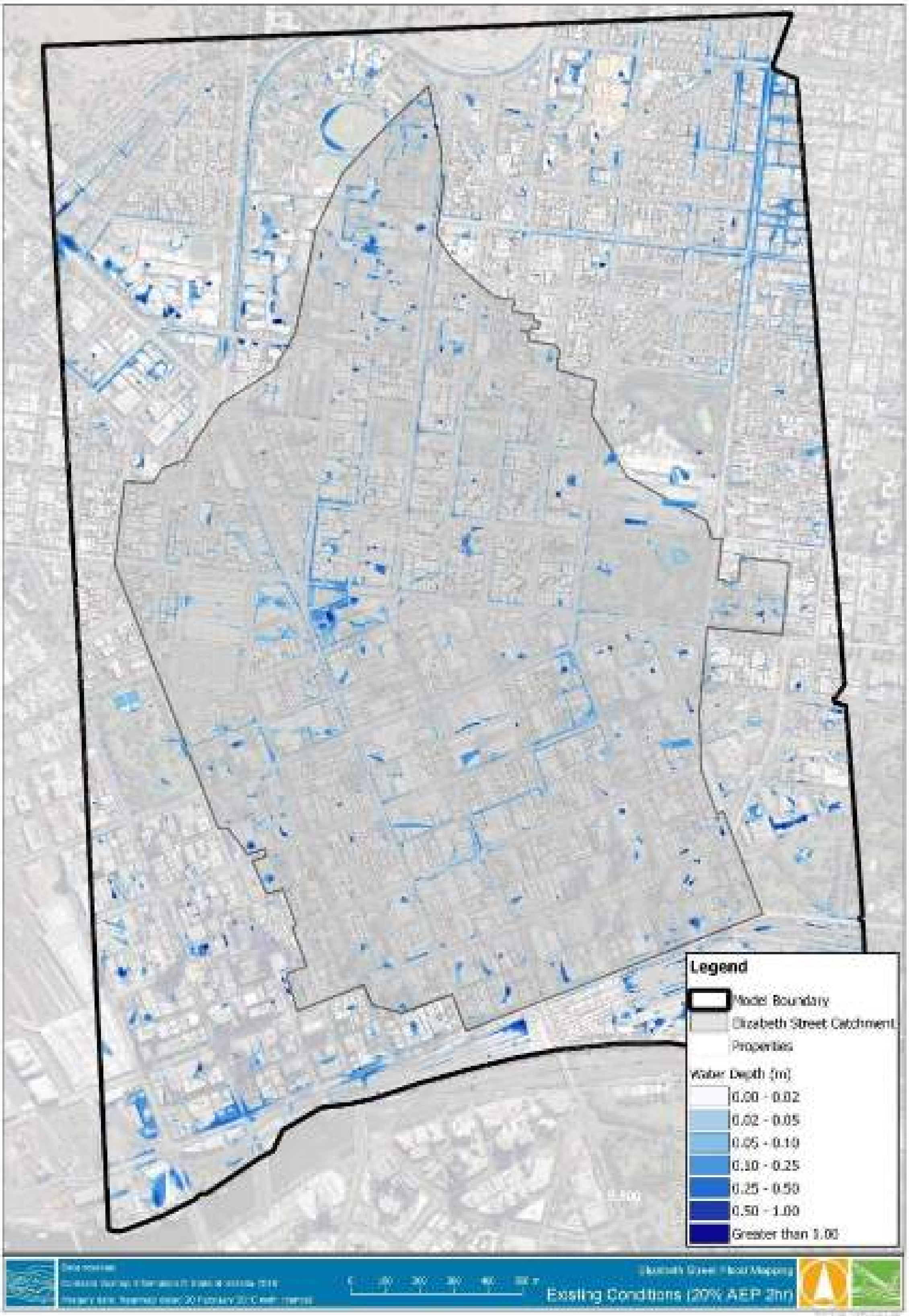

Figure 0-8 20 year 2 hour Maximum Water Depth (Existing Conditions)

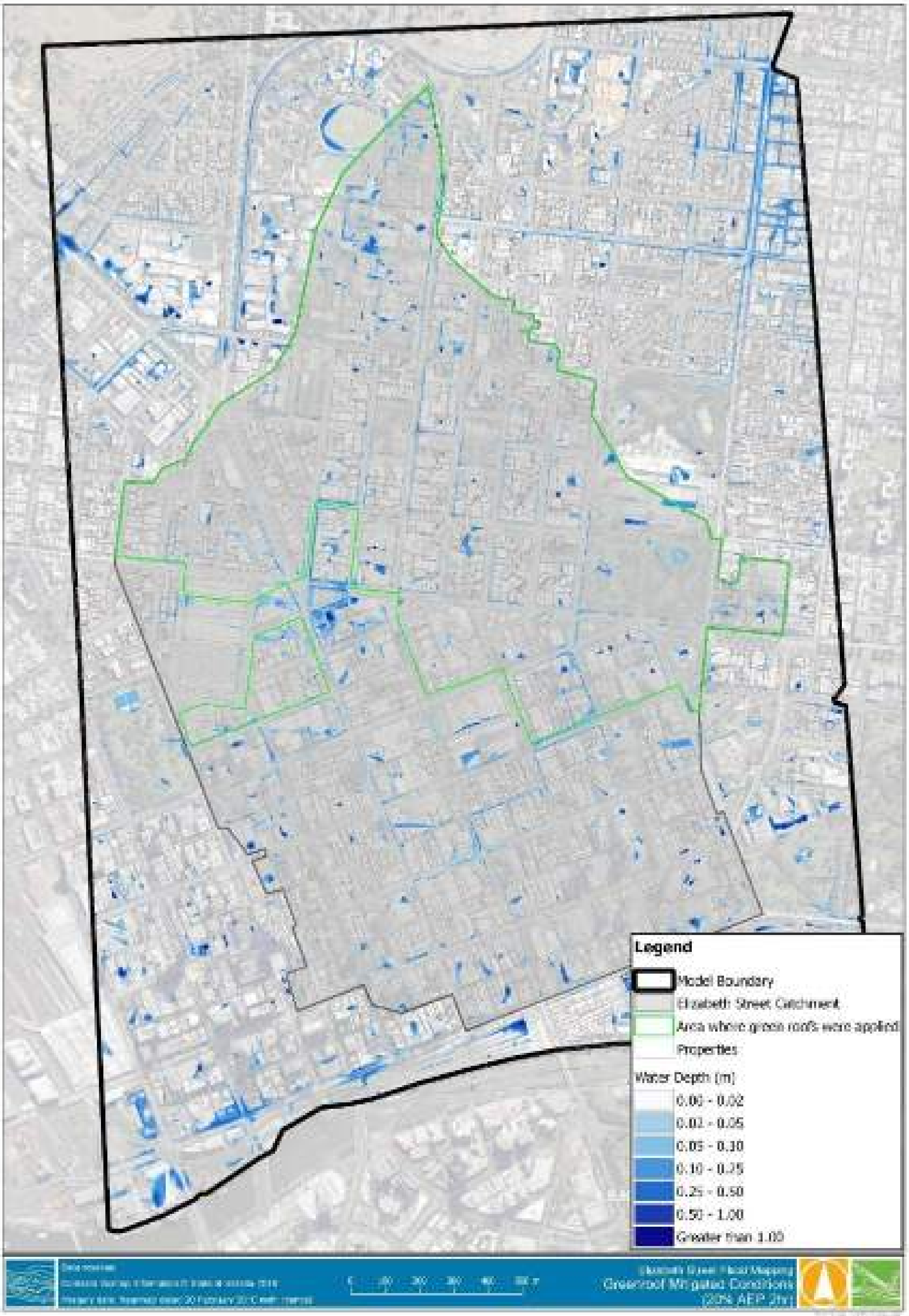

Figure 0-9 20 year 2 hour Maximum Water Depth (Greenroof Mitigated Conditions)

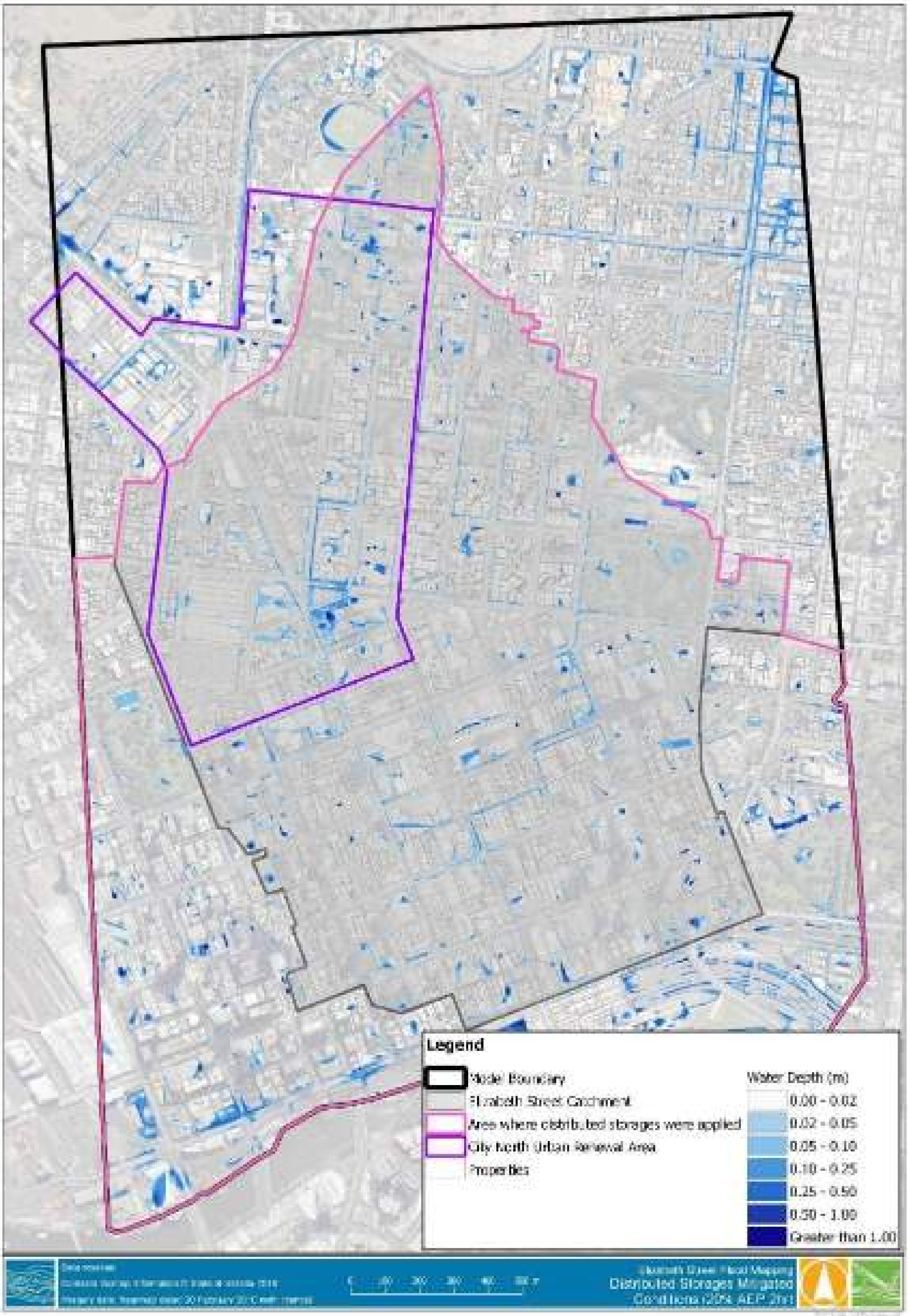

Figure 0-10 20 year 2 hour Maximum Water Depth (Distributed Storages Mitigated Conditions)

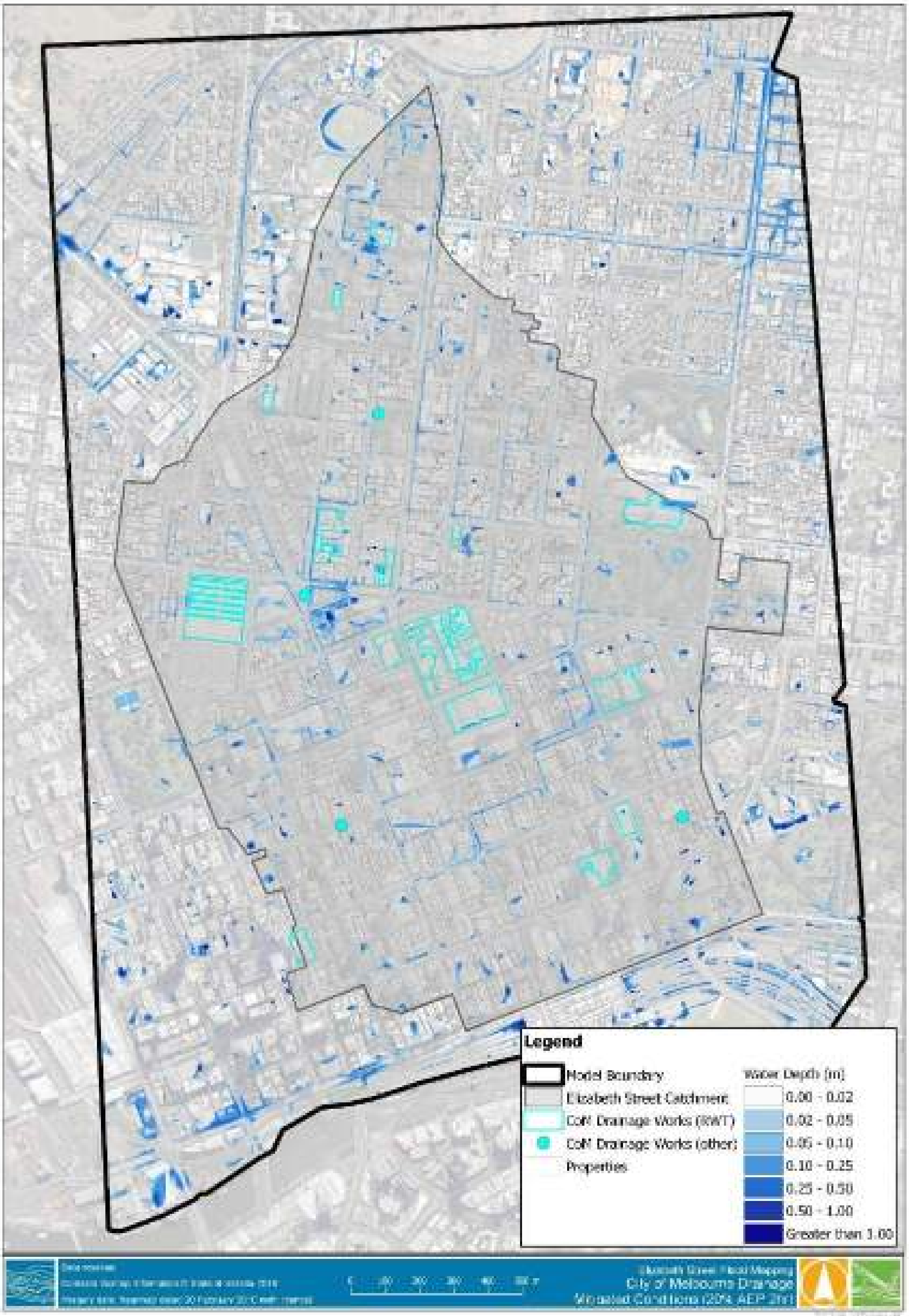

Figure 0-11 20 year 2 hour Maximum Water Depth (City of Melbourne Drainage Works Mitigated Conditions)

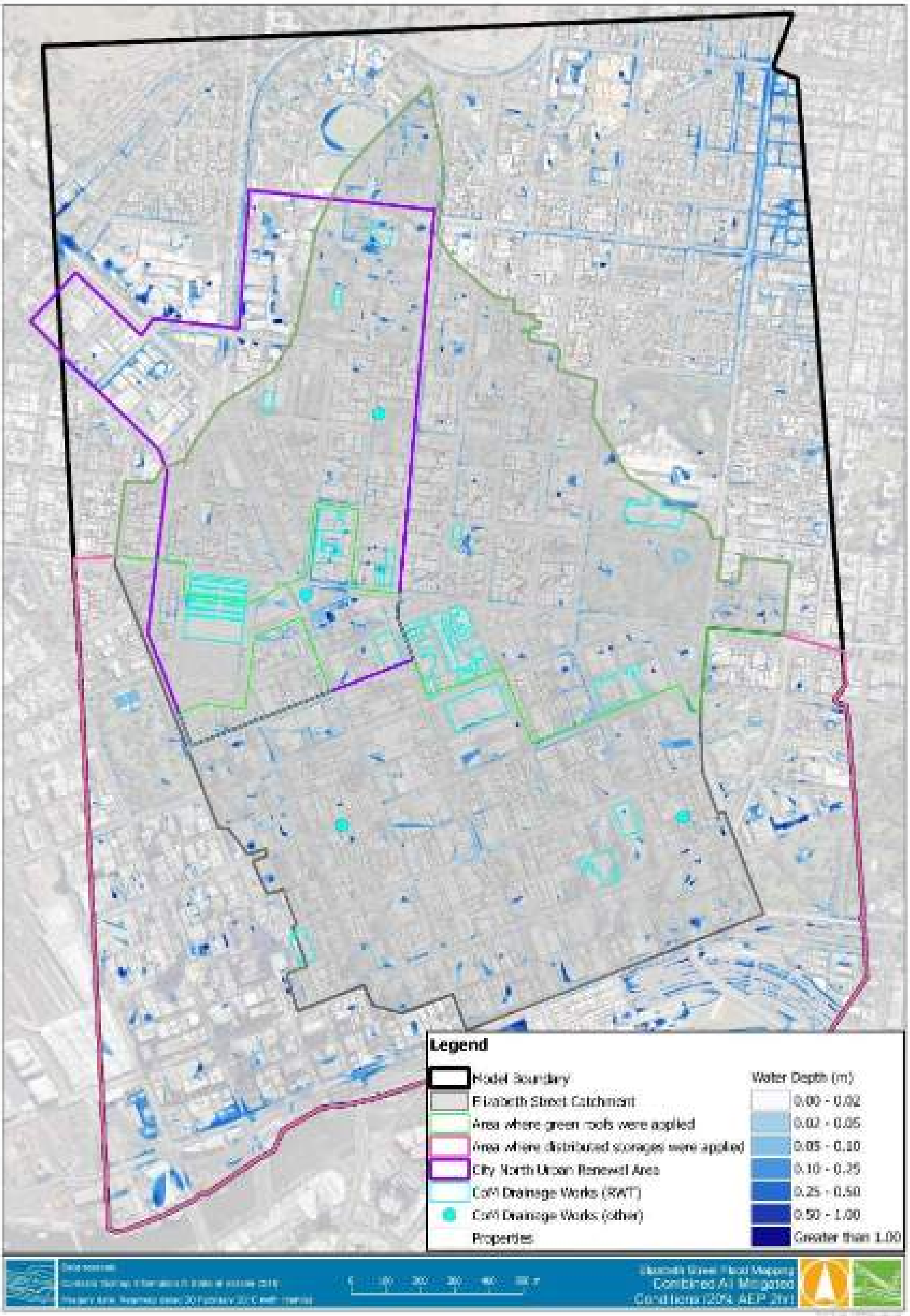

Figure 0-12 20 year 2 hour Maximum Water Depth (All combined Mitigated Conditions)

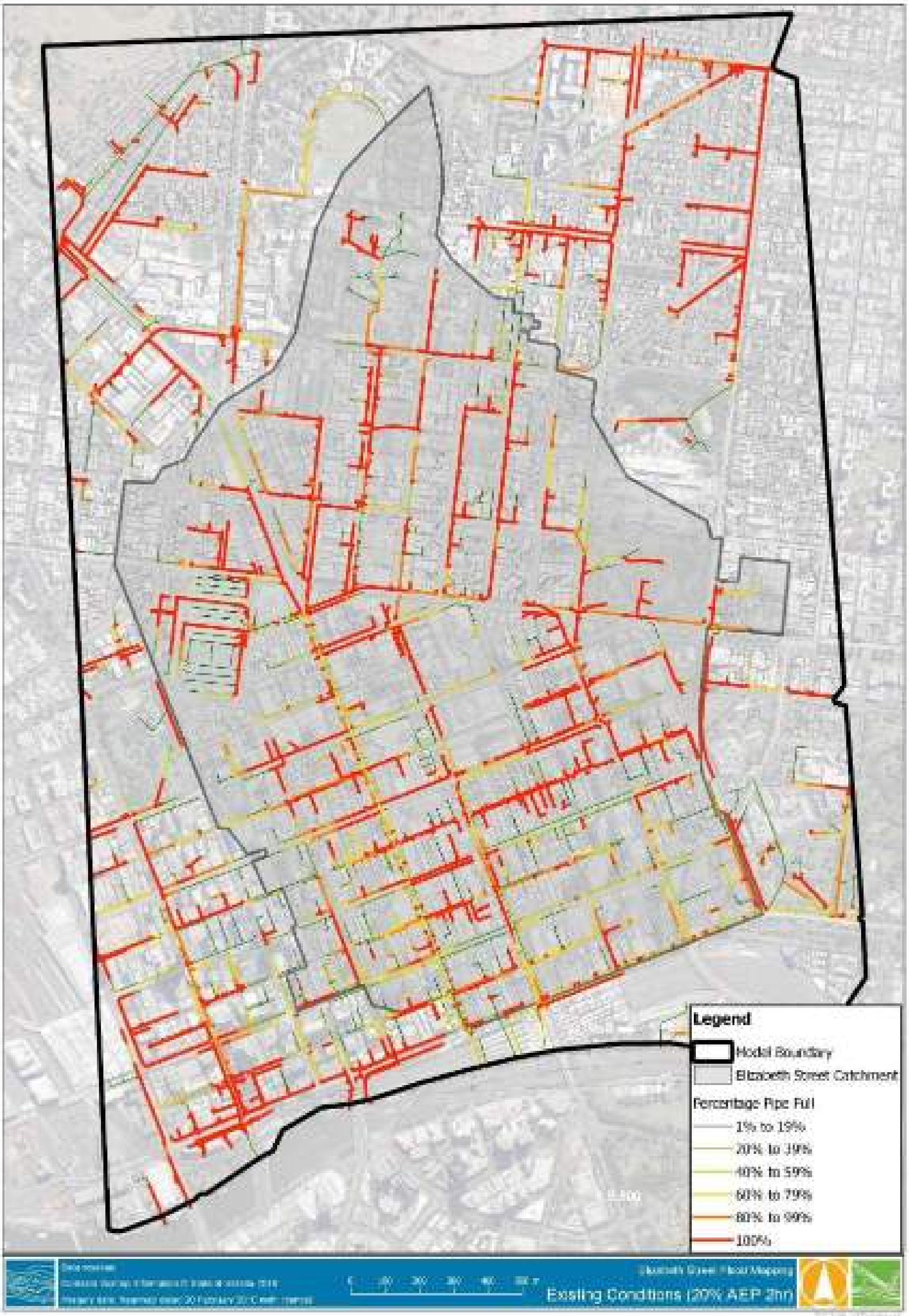

Figure 0-13 20 year 2 hour Maximum Percentage Pipe Full (Existing Conditions)

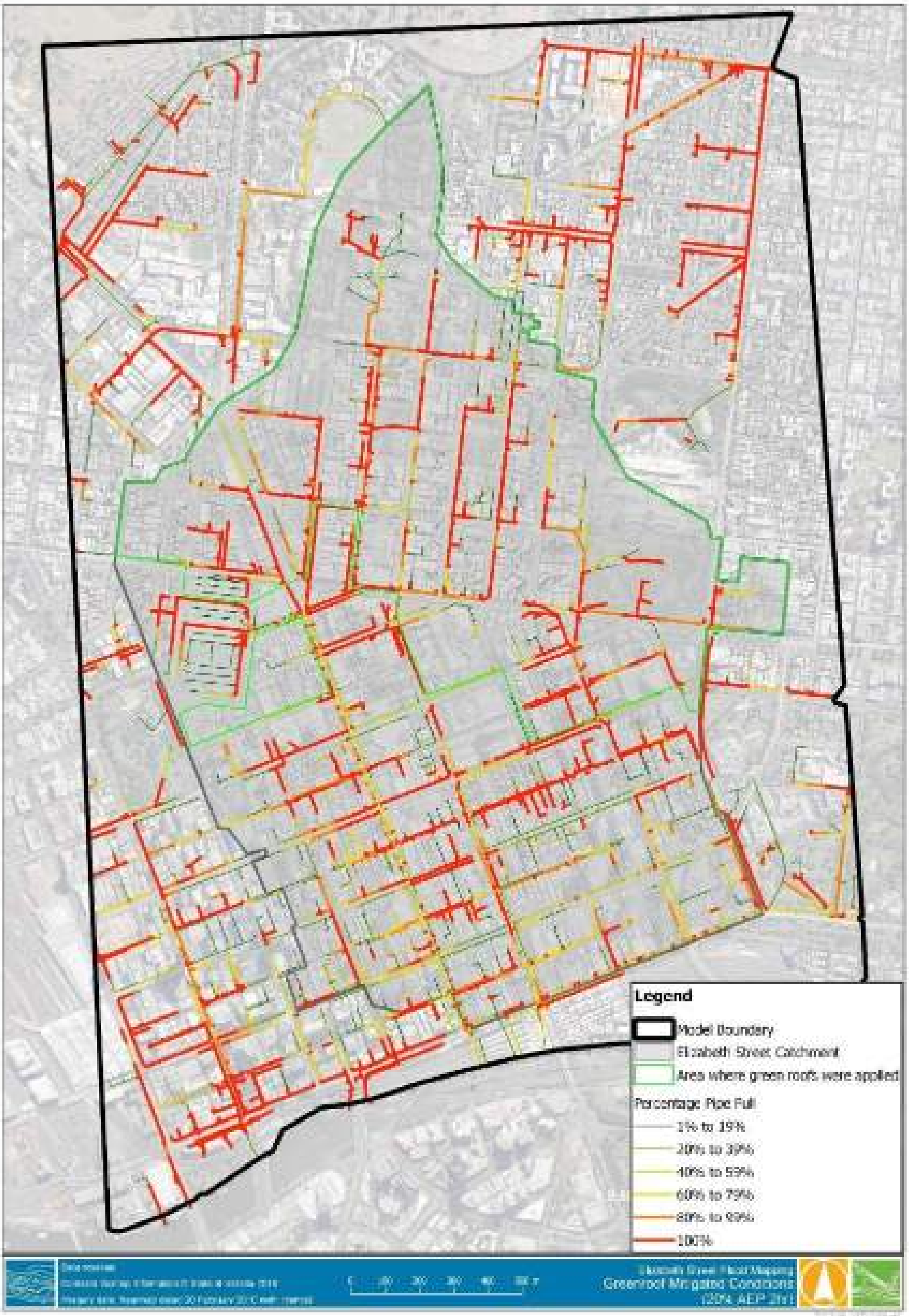

Figure 0-14 20 year 2 hour Maximum Percentage Pipe Full (Greenroof Mitigated Conditions)

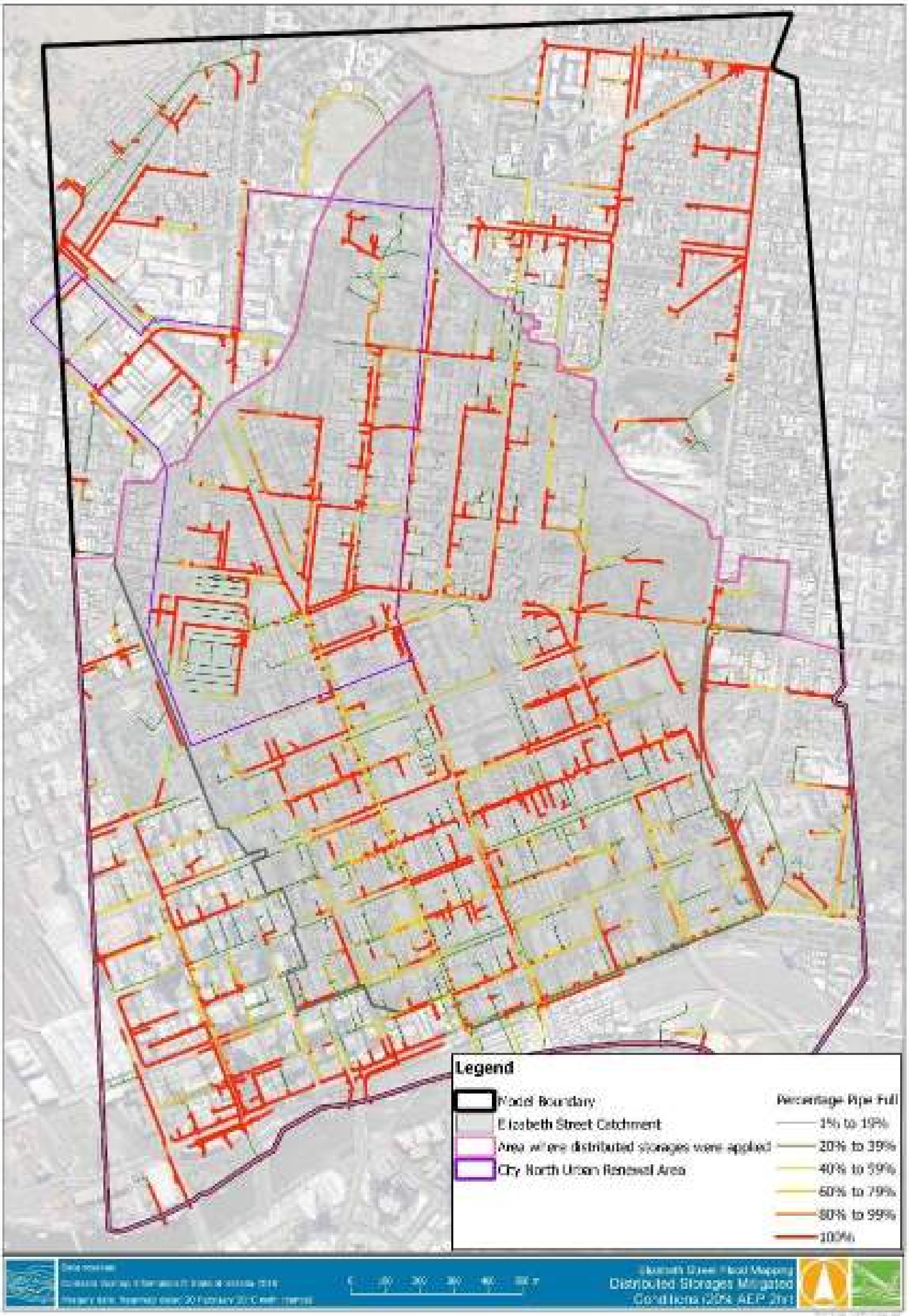

Figure 0-15 20 year 2 hour Maximum Percentage Pipe Full (Distributed Storages Mitigated Conditions)

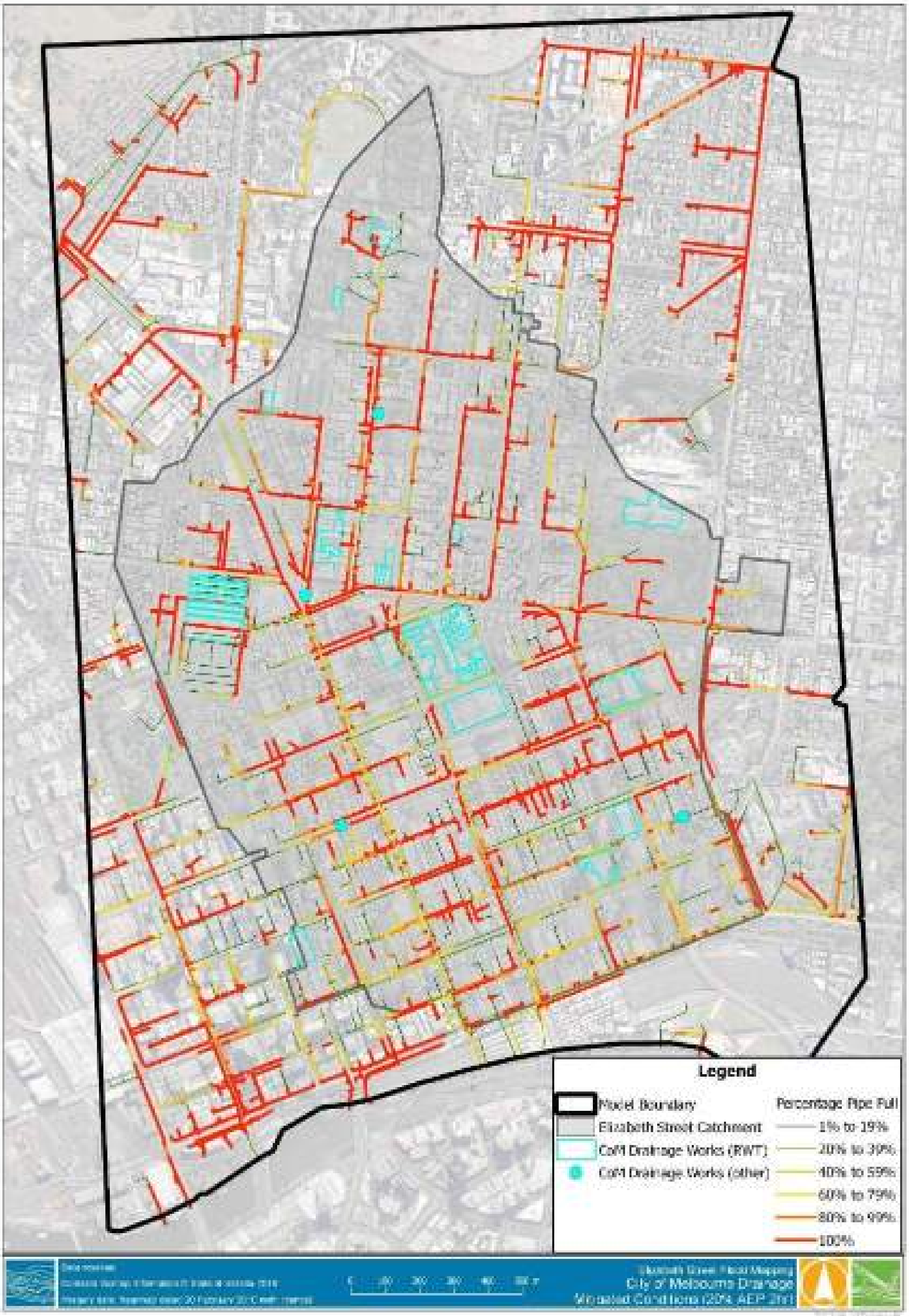

Figure 0-16 20 year 2 hour Maximum Percentage Pipe Full (City of Melbourne Drainage Works Mitigated Conditions)

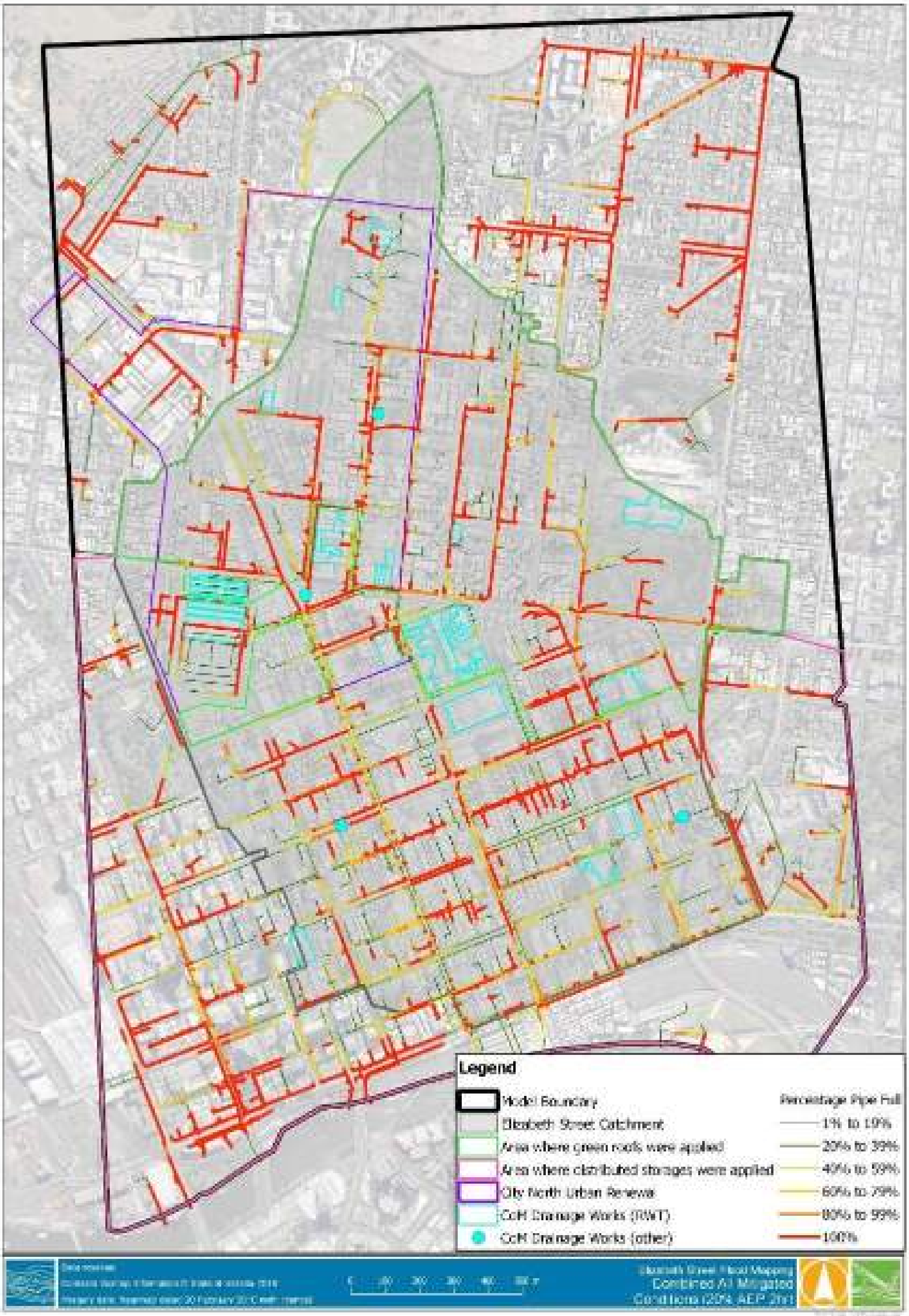

Figure 0-17 20 year 2 hour Maximum Percentage Pipe Full (All combined Mitigated Conditions)

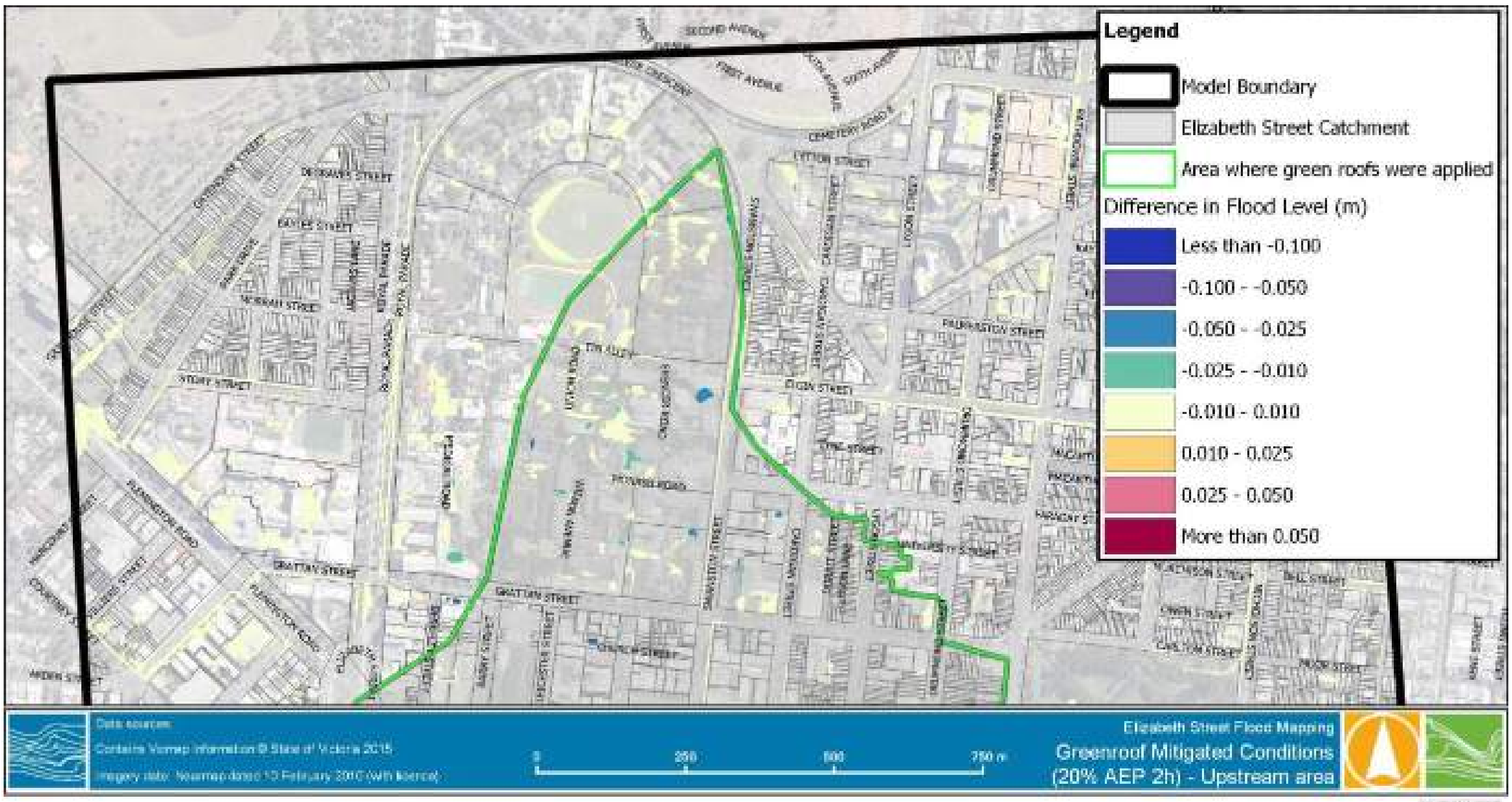

Figure 0-18 **20 year 2 hour Difference in flood level Upstream of the Catchment (Greenroof versus Existing Conditions)**

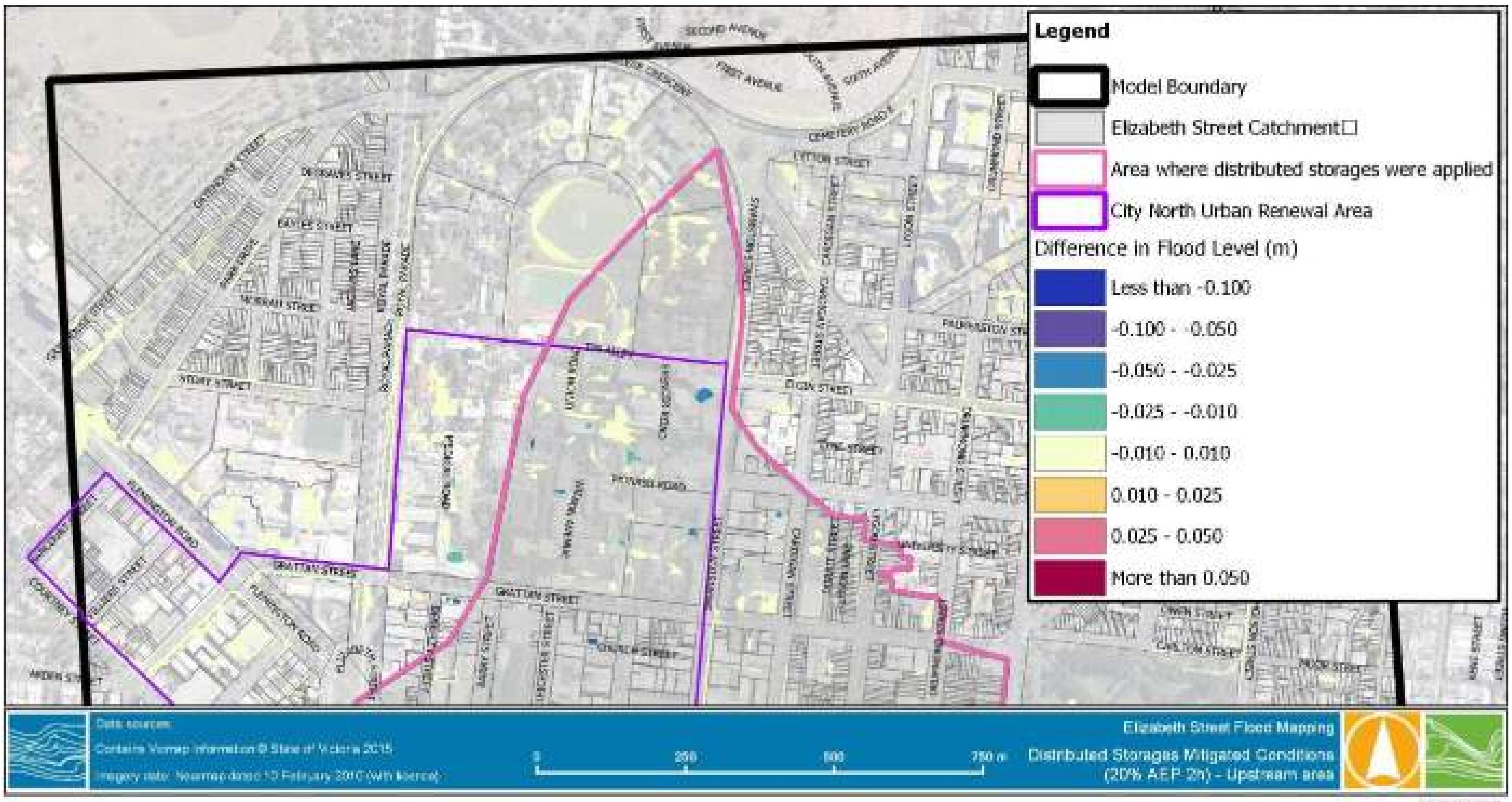

Figure 0-19 **20 year 2 hour Difference in flood level Upstream of the Catchment (Distributed storages versus Existing Conditions)**

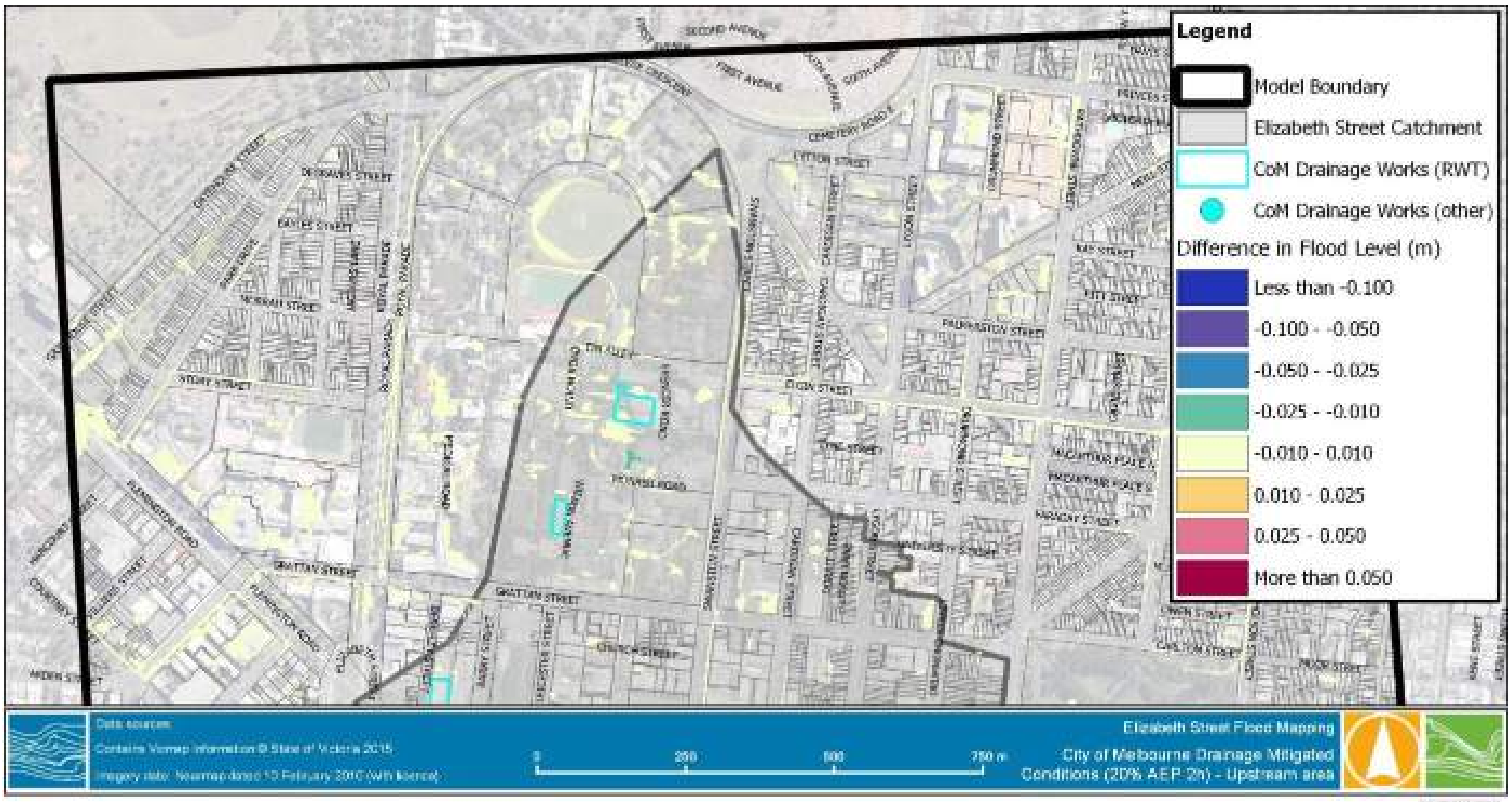

Figure 0-20 20 year 2 hour Difference in flood level Upstream of the Catchment (City of Melbourne Drainage Works versus Existing Conditions)

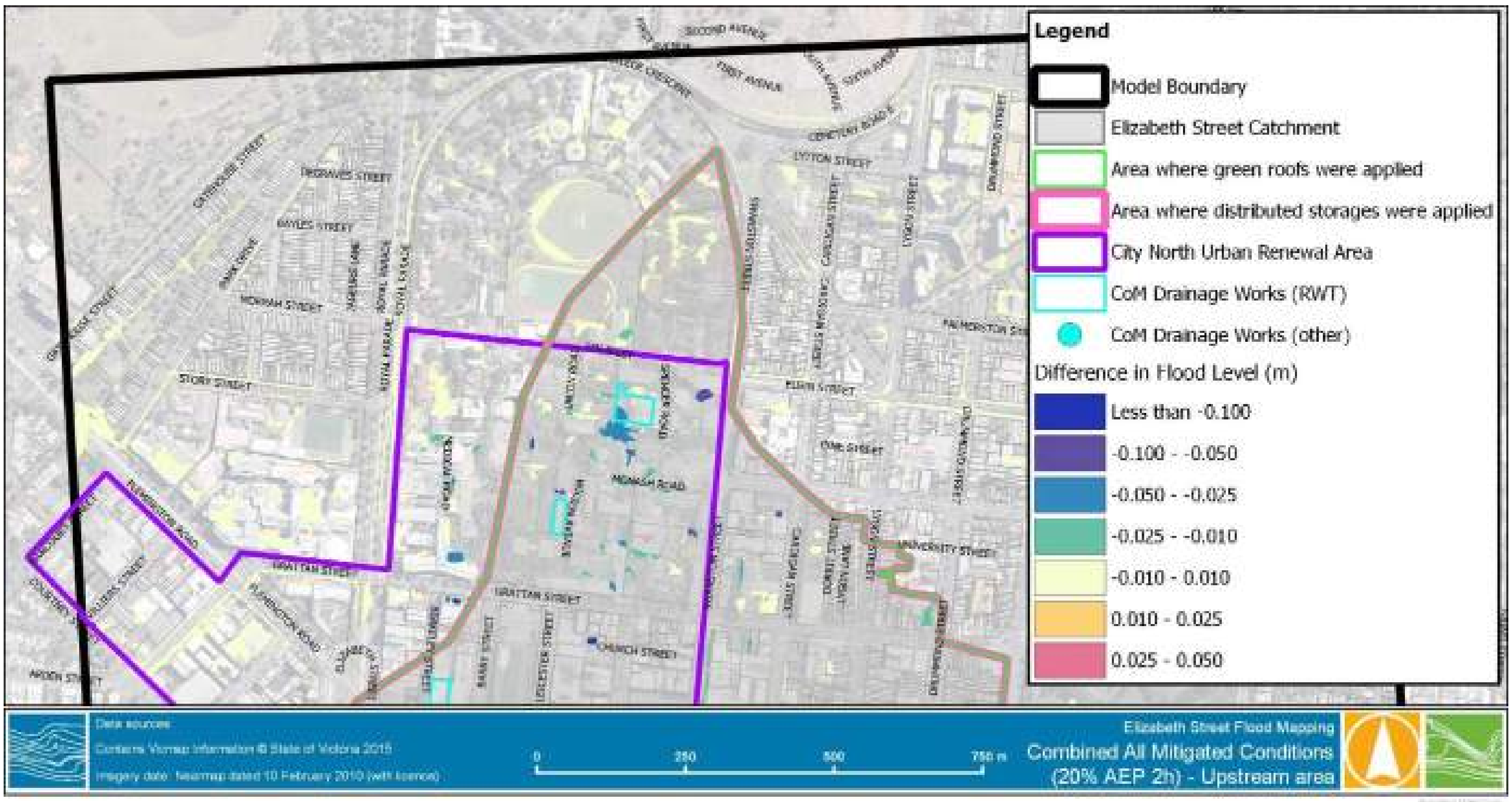

Figure 0-21 20 year 2 hour Difference in flood level Upstream of the Catchment (All combined versus Existing Conditions)

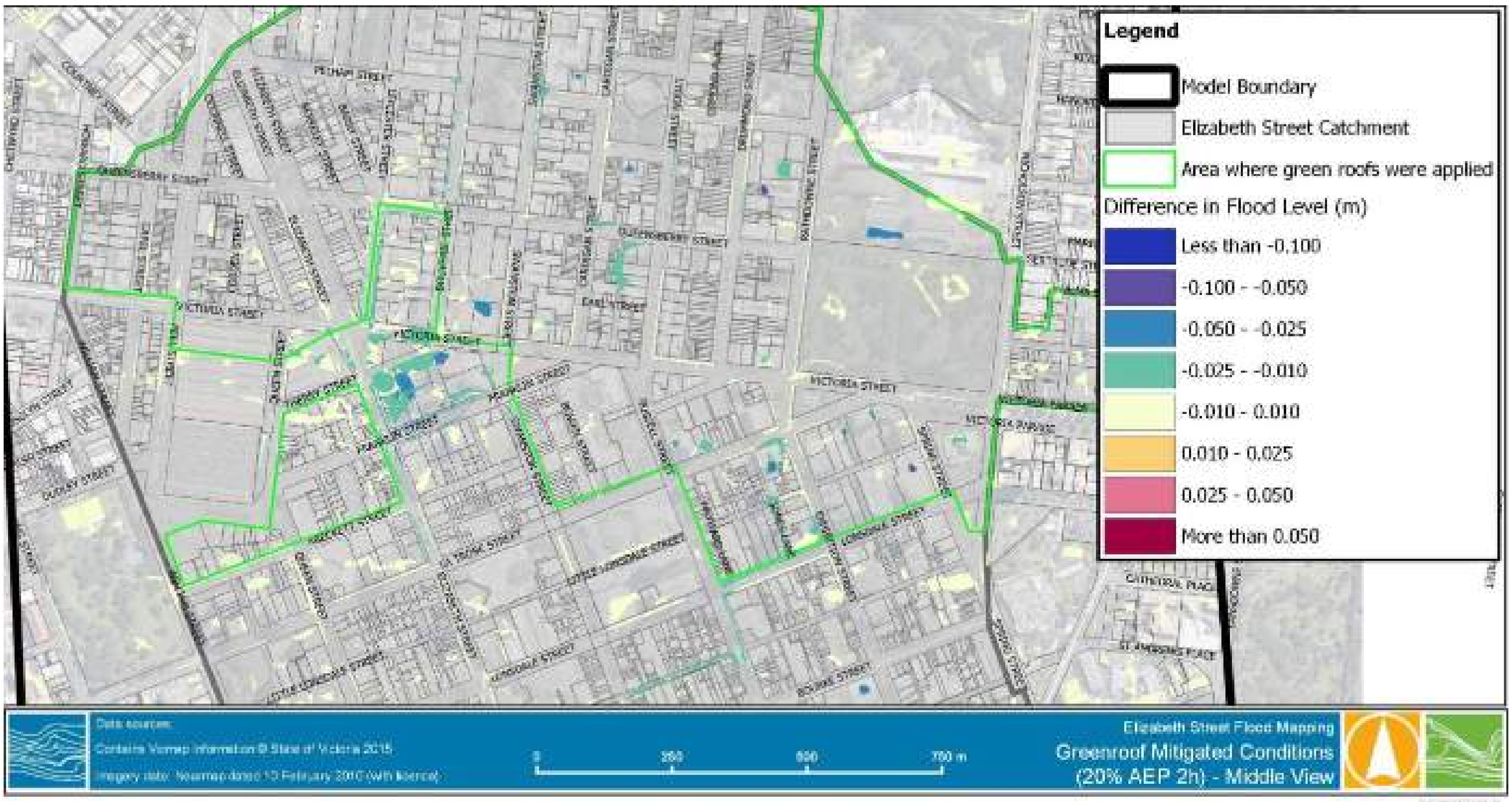

Figure 0-22 20 year 2 hour Difference in flood level Middle of the Catchment (Greenroof versus Existing Conditions)

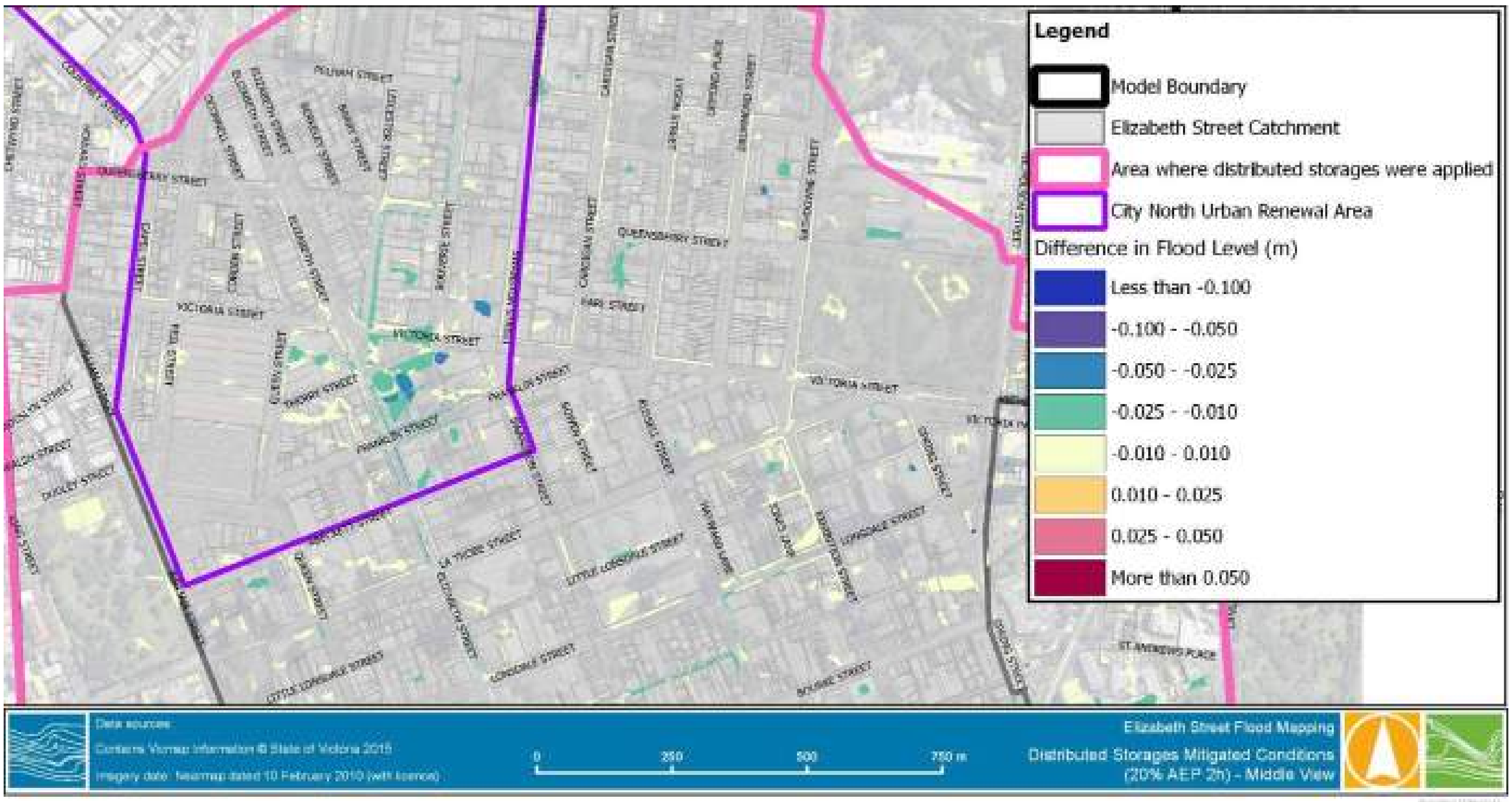

Figure 0-23 20 year 2 hour Difference in flood level Middle of the Catchment (Distributed storages versus Existing Conditions)

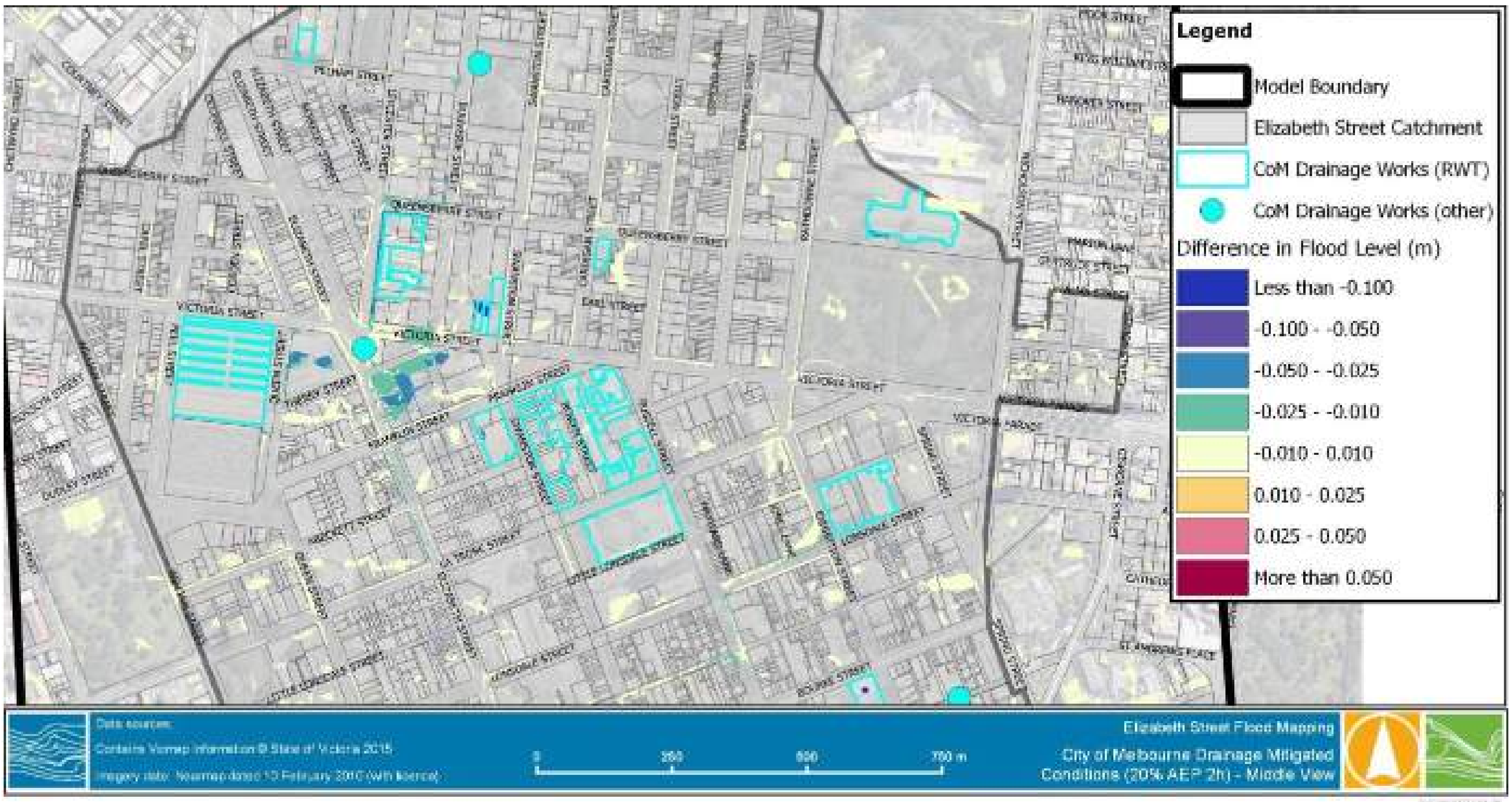

Figure 0-24 20 year 2 hour Difference in flood level Middle of the Catchment (City of Melbourne Drainage Works versus Existing Conditions)

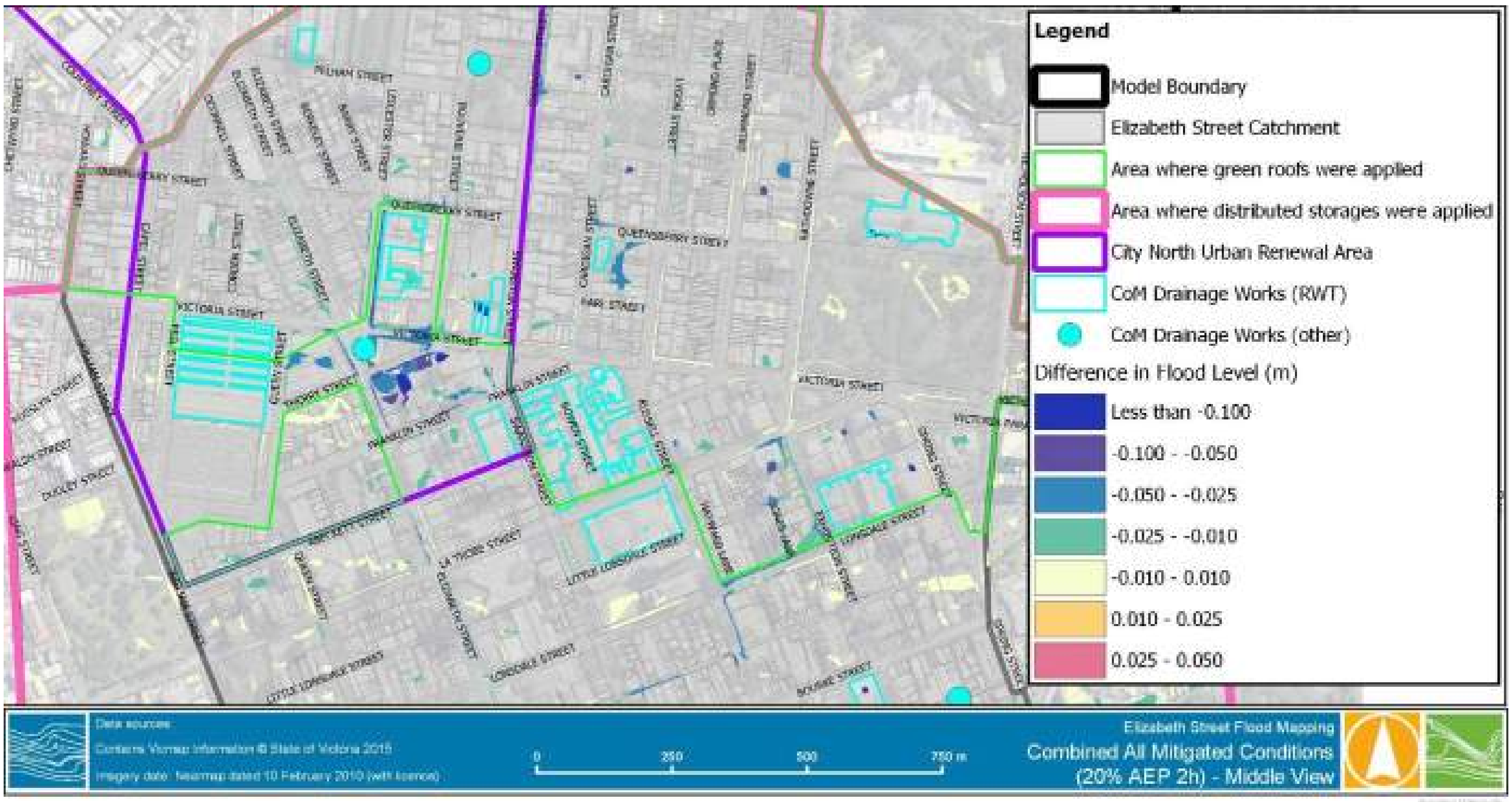

Figure 0-25 20 year 2 hour Difference in flood level Middle of the Catchment (All combined versus Existing Conditions)

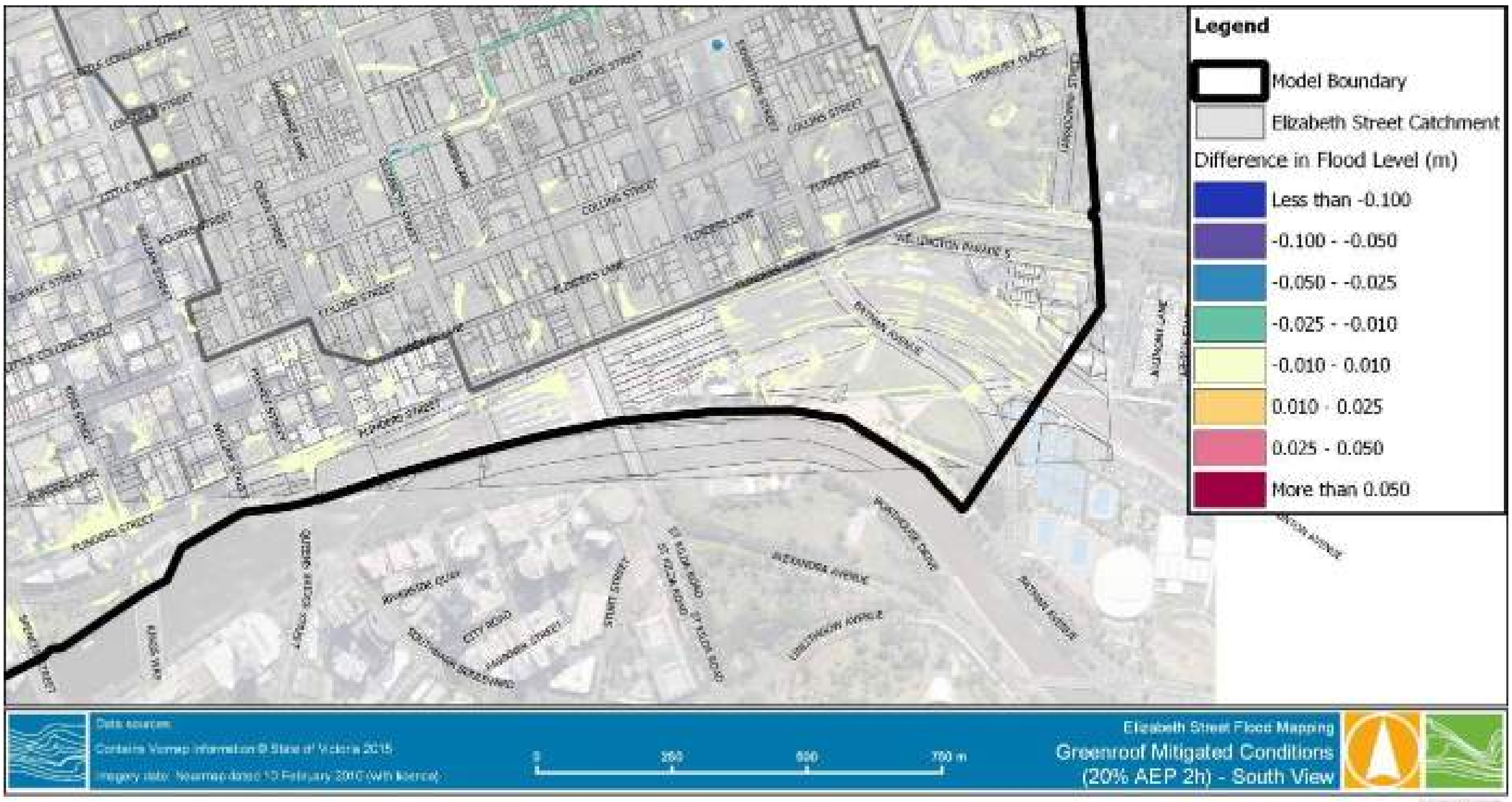

Figure 0-26 20 year 2 hour Difference in flood level Downstream of the Catchment (Greenroof versus Existing Conditions)

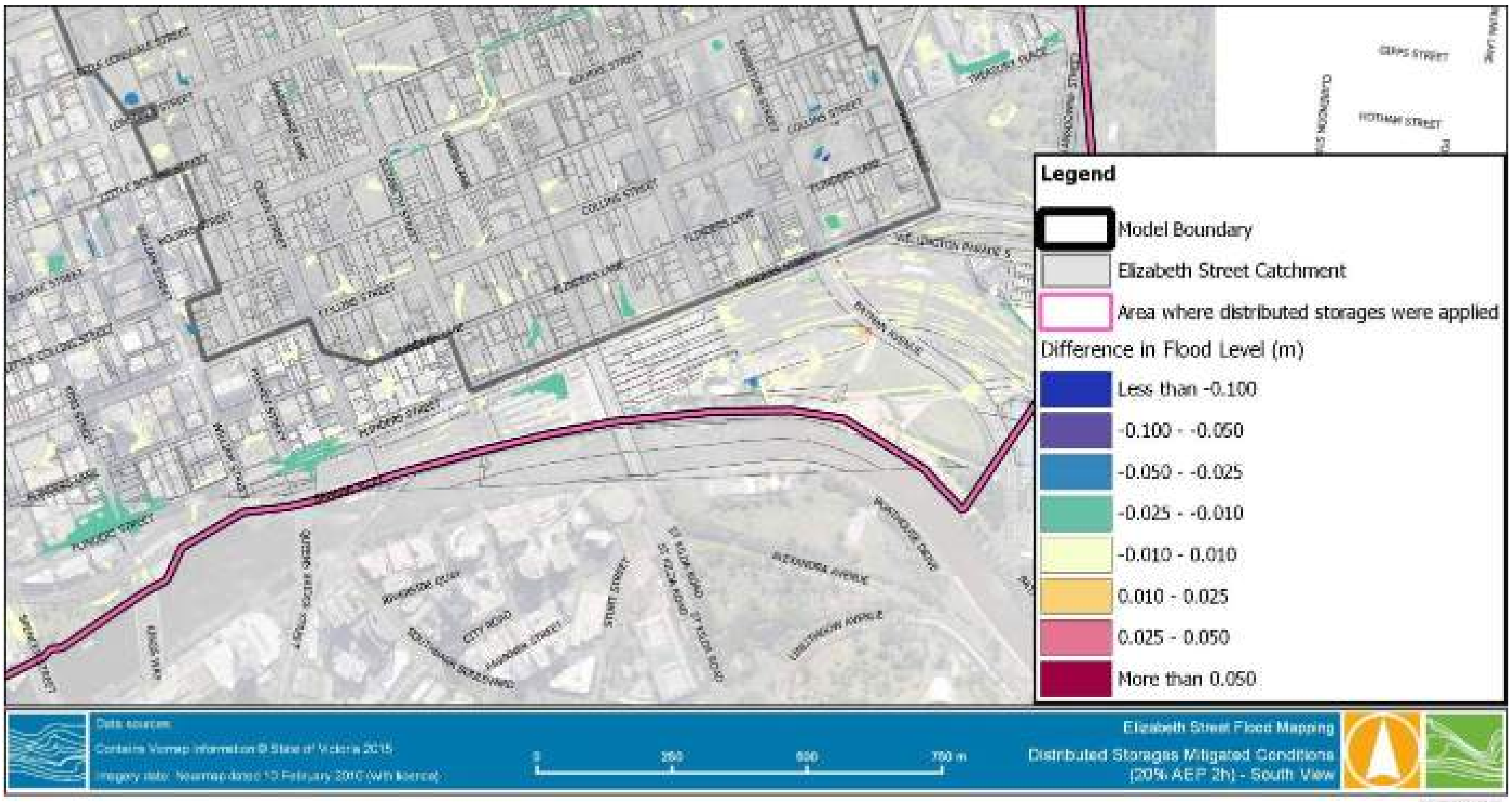

Figure 0-27 20 year 2 hour Difference in flood level Downstream of the Catchment (Distributed storages versus Existing Conditions)

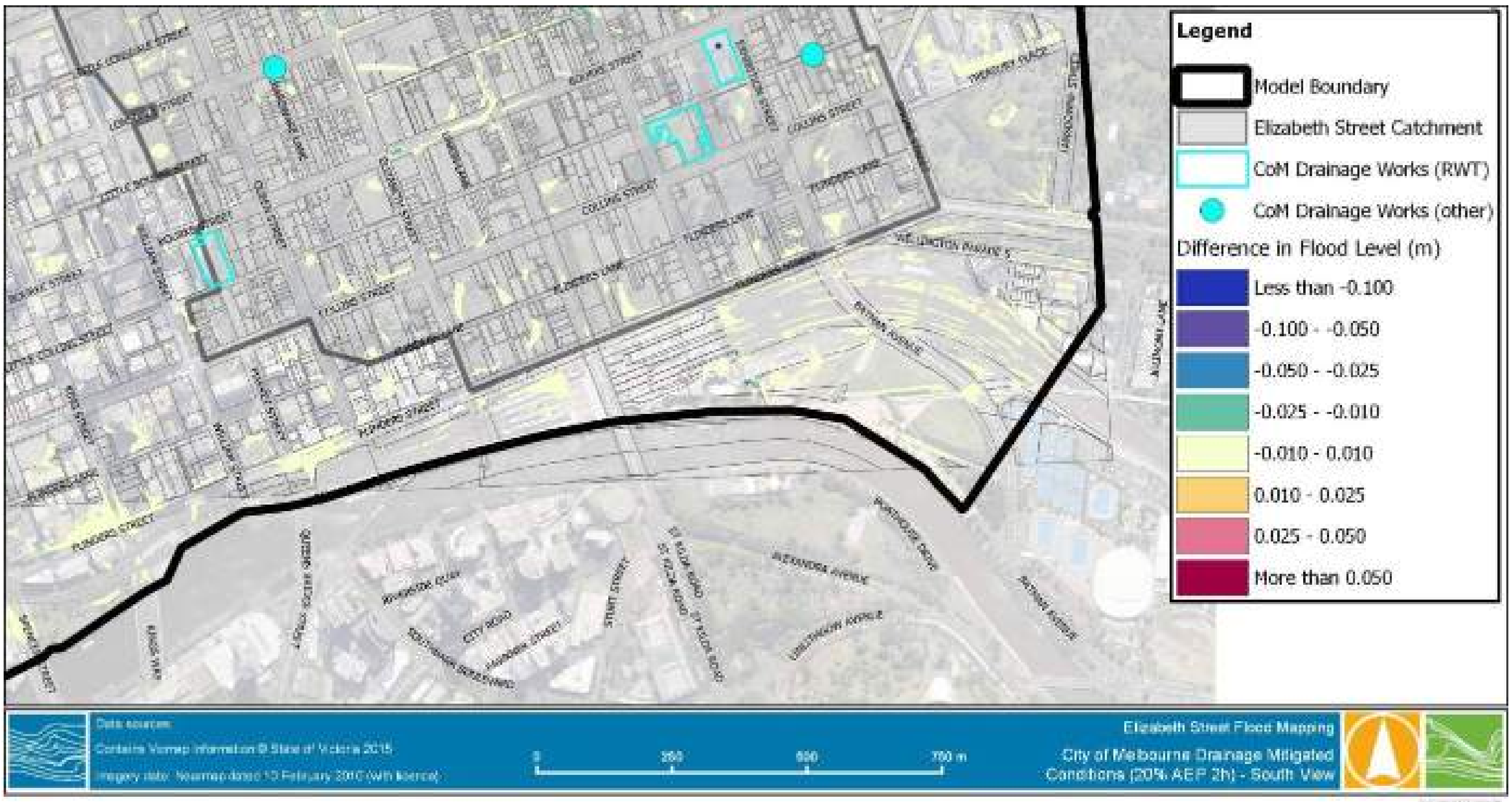

Figure 0-28 20 year 2 hour Difference in flood level Downstream of the Catchment (City of Melbourne Drainage Works versus Existing Conditions)

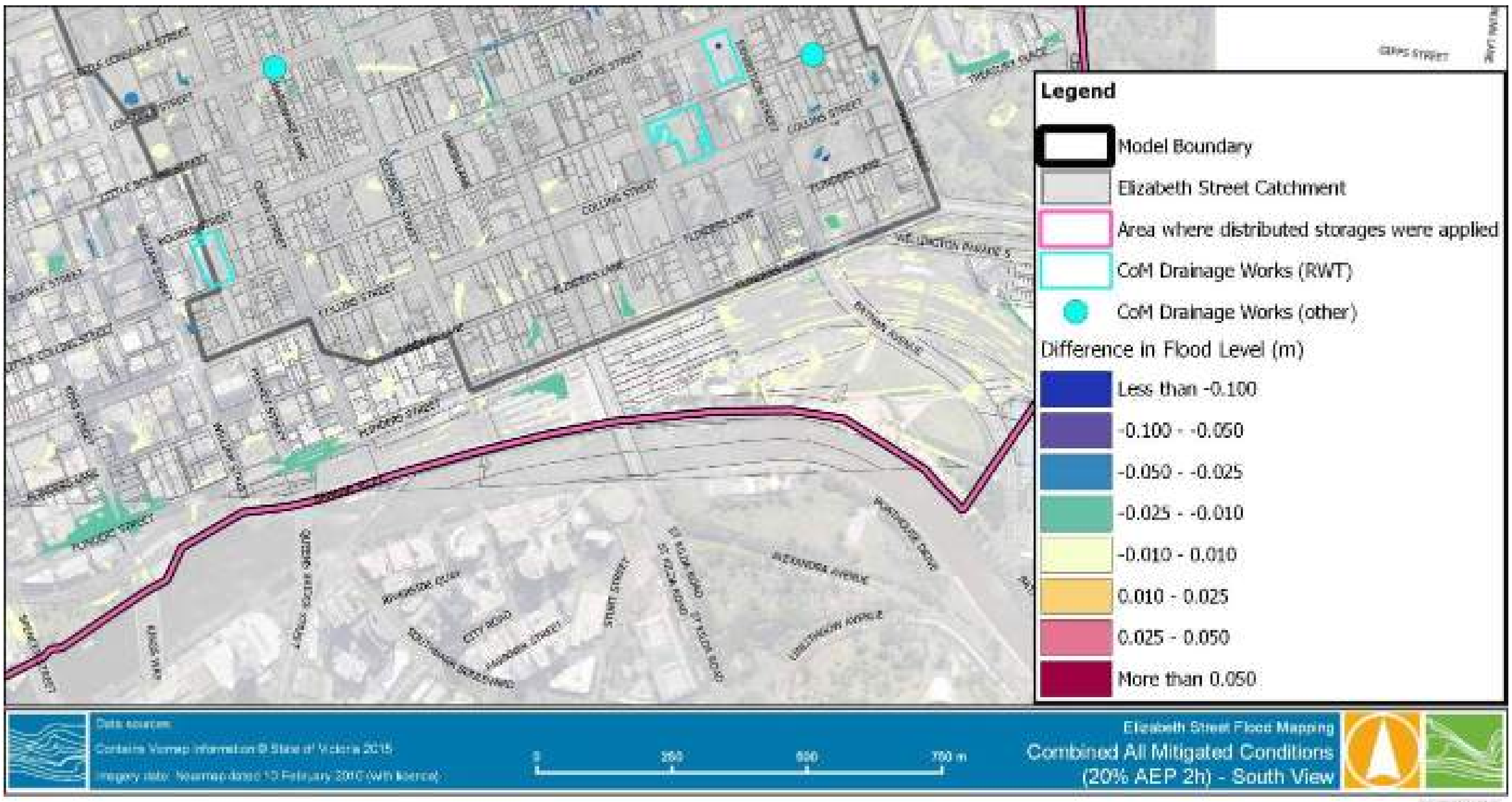

Figure 0-29 20 year 2 hour Difference in flood level Downstream of the Catchment (All combined versus Existing Conditions)

ADDENDUM

To Ruwan Jayasinghe (Melbourne Water); Alex Barton (Melbourne Water) and Sanjeeva Rajapakse (City of Melbourne)

From Celine Marchenay (Water Technology)

Date 20 December 2019

Subject Addendum to Elizabeth Street, Melbourne Flood Modelling Report (Water Technology, August 2017)

This is an addendum to the Elizabeth Street, Melbourne Flood Modelling Report (3611_01_R01_v07.pdf) completed by Water Technology and issued on August 2nd 2017 to Melbourne Water (MW) and the City of Melbourne (CoM).

In the period from 2014 to 2017, Water Technology constructed a 1D/2D rain-on-grid TUFLOW model using the ARR 1987 methodology to provide existing conditions flood modelling and mapping for the Elizabeth Street Main Drain (MD) catchment. This was followed by additional simulations of green infrastructure scenarios in 2017/18 and local flood impact assessments for the Elizabeth Street Streetscape Improvements projects. In June 2017, issues were raised by MW concerning the Elizabeth Street MD TUFLOW model, flagging significant impact on modelled flood levels throughout the catchment. Since then, most of these modelling concerns/issues have been addressed and corrected by Water Technology and Grace GIS. A summary of the issues that were raised are presented in Table 1-1.

Table 1-1 Elizabeth Street MD Model Issues

Issue #	Issue Type	MW Comment
1	**Main drain geometry**	Both main pipes under Elizabeth Street and one of the pipes under Swanston Street are ovoids. However, the model has them as rectangular culverts. We believe this will vastly overestimate their capacity and will result in less overland flow in the model than there should be.
2	**Form losses**	Form losses were added to pits on top of the automatic Englehund losses. Is there a reason for this?
3	**Pits**	R pits are used in the model; but they also reference the pit database. Were these supposed to be Q pits? Also, R pits model the pit in the vertical (typical side entry). Grated pits are best modelled as W pits.
4	**Pipe lengths**	There is a distinct mismatch between pipe lengths in the model and their GIS lengths. Pipes with lengths less than 10 m have their length stated as 10 m or more (sometime 100 m). This will have an impact on the pipe conveyance and the storage.

Issue #	Issue Type	MW Comment
5	**Additional nodal area**	The TUFLOW model has high nodal area multipliers added to the 1d network (5x – 20x). This will increase the storage of the network substantially and reduce the flooding shown. We think the amount of ANA, which has been added to the model globally, is too excessive for it to be acceptable.
6	**A few other network issues were identified**	■ A number of unnecessary breaks in network (i.e. where there is a change in pipe angle) ■ 55 pipes that have the obvert sticking out of the ground at the US, DS or both ends ■ 694 pipes that have adverse grade ■ 12 pipes that have a flat grade ■ 14 pipes with duplicate vertices at top or bottom end - will affect Englehund losses

1 HYDRAULIC MODELLING REVISION

1.1 TUFLOW Set-up Corrections Following MW Review Comments

The following changes were applied in the model to rectify the issues raised by MW which are summarised in Table 1-1;

- Issue 1 "**Main drain geometry**": The Elizabeth Street Main Drain is an ovoid brick barrel drain running along Elizabeth Street from Terry Street in north end of the CBD all the way to the Yarra River at Flinders Street Station. The ovoid main drain is composed of;
  - A larger ovoid barrel on the eastern side of Elizabeth Street (size ranging from W 1,219 mm x H 1,829 mm at Terry Street to W 2,184 mm x H 2,591 mm at Flinders Street) running all the way from Terry Street to Flinders Street;
  - A smaller ovoid barrel on the western side of Elizabeth Street (size ranging from W 1,270 mm x H 1,905 mm at Bourke Street Mall to W 1,575 mm x H 1,930 mm at Flinders Street) running from Bourke Street Mall to Flinders Street; and
  - Only one connection between the two Elizabeth Street barrel drains at Flinders Street before the combined underground ovoid barrel drain (W 2,896 mm x H 3,696 mm) outfalls to the Yarra River.

  To accurately represent the main drain shape and wetted area, the Elizabeth Street Main Drain was represented in TUFLOW as an irregular shaped culvert (i.e. type 'I' in the 1d_nwk layer). Each irregular culvert is linked to a 1D cross-section line object (1d_xs) type "HW" where the first two columns of the associated .csv files represent the elevation and width.

  Checks against the Manning's equation were undertaken to verify that the 1d_nwk 'I' type pipe is carrying the expected capacity (of the Elizabeth Street Main Drain).
- Issues 2 "**Form losses**"
  - Manual (standard) form losses have been removed from the original model. As suggested during the first peer review of the hydraulic model and results (refer to Appendix B), MW recommended that pit losses not be applied across the entire network to fully engage the underground drainage network.

- Issues 3 "**Pits**"
  - The 'R' type pits have been changed to 'Q' type where the Inlet Type is 'GSEP', 'DGSEP' or 'OFK' using the inlet pit curves established in 2015.
- Issues 4 "**Pipe lengths**"
  - The mismatch between modelled pipe lengths and the pipe GIS lengths were caused by geometry issues. This systematic error was caused by geometry related issues (unnecessary vertices) in the original GIS pipe dataset, which once removed via automatic GIS manipulation allowed for the correct interpolation of the GIS pipe length in MapInfo.
- Issues 5 "**Additional nodal area**"
  - All 'additional nodal area' has been removed from the hydraulic model - The 'ANA' attribute is set to 0.
- Issues 6 "**A few other network issues were identified**

  Grace GIS was commissioned to undertake this work and have been addressing the modelling issues together with Water Technology. The following checks were completed;

  - The unnecessary breaks in the 1D GIS network (i.e. where there is a change in pipe angle) have been extensively cleaned-up.
  - There is one pipe with reverse grade corresponding to the Flinders Street pedestrian underpass stairs going up towards the Yarra River Flinders Walk, hence this pipe does not require any correction. The underpass have been modelled as rectangular culvert sloping downwards at Flinders Street and sloping upwards at Flinders Walk as shown in Figure 1-1.

Figure 1-1 Flinders Street Underpass Schematic

  - There are 2 pipes with the inlet ends sticking out of the ground;
    - One pipe corresponds to the Flinders Street pedestrian underpass stairs at Flinders Street side (refer to Figure 1-1) which does not require any correction.
    - One pipe corresponds to the MW combined Elizabeth Street Main Drain ovoid barrel (W 2,896 mm x H 3,696 mm) under Flinders Street station. The upstream invert level field provided by MW in the GIS layer means that the upstream barrel obvert sticks out of the ground by approximately 300 mm. This upstream pipe obvert has been left as is (sticking out of the ground) in the model, as it does not compromise the modelling results being located at the outfall of the model and having no surface (1D/2D) connection at the upstream node.

- There are 17 pipes with the outlet ends sticking out of the ground, all located at the outlet of the model and do not need any corrections.
- There are 6 pipes with no grade (i.e. upstream invert level equal to the downstream invert level) as a results of the GIS post-processing. These pipes are only 225 mm or 300 mm diameter RCP's and are location at upstream ends of the catchment; hence are not expected to significantly affect the modelling results. Furthermore, until the Council's drainage network is surveyed for input to the model, the capacity of the modelled underground drainage network will only be an estimate, based on a standard pipe cover approach in this model (i.e. 600 mm cover for pipes with heights less or equal to 900 mm and 750 mm cover for pipes with heights greater than 900 mm) and interpolation of the inverts.

A view of the revised TUFLOW model set-up is presented in Figure 1-2 and Figure 1-3.

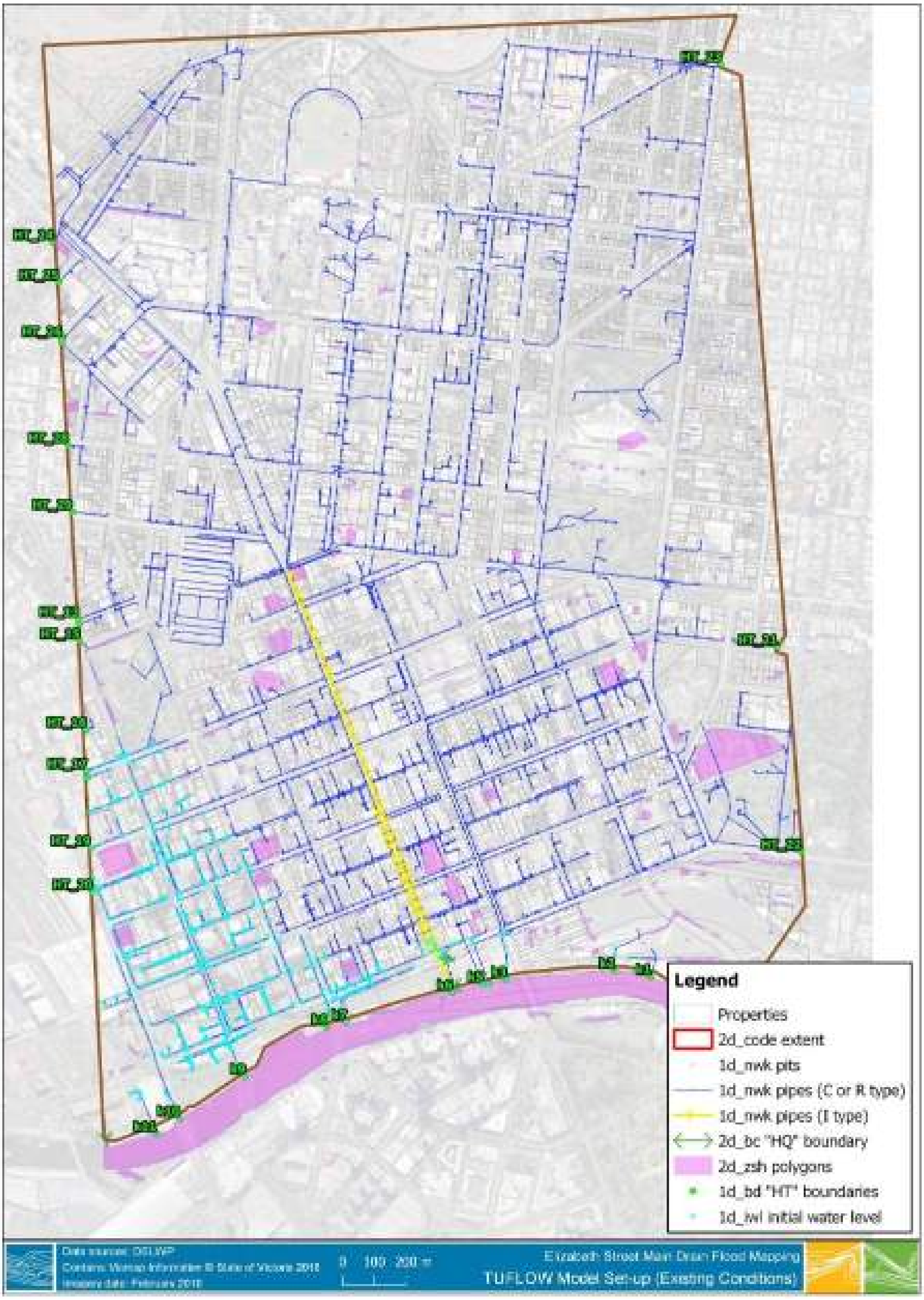

Figure 1-2 TUFLOW Model Set-up (entire model extent)

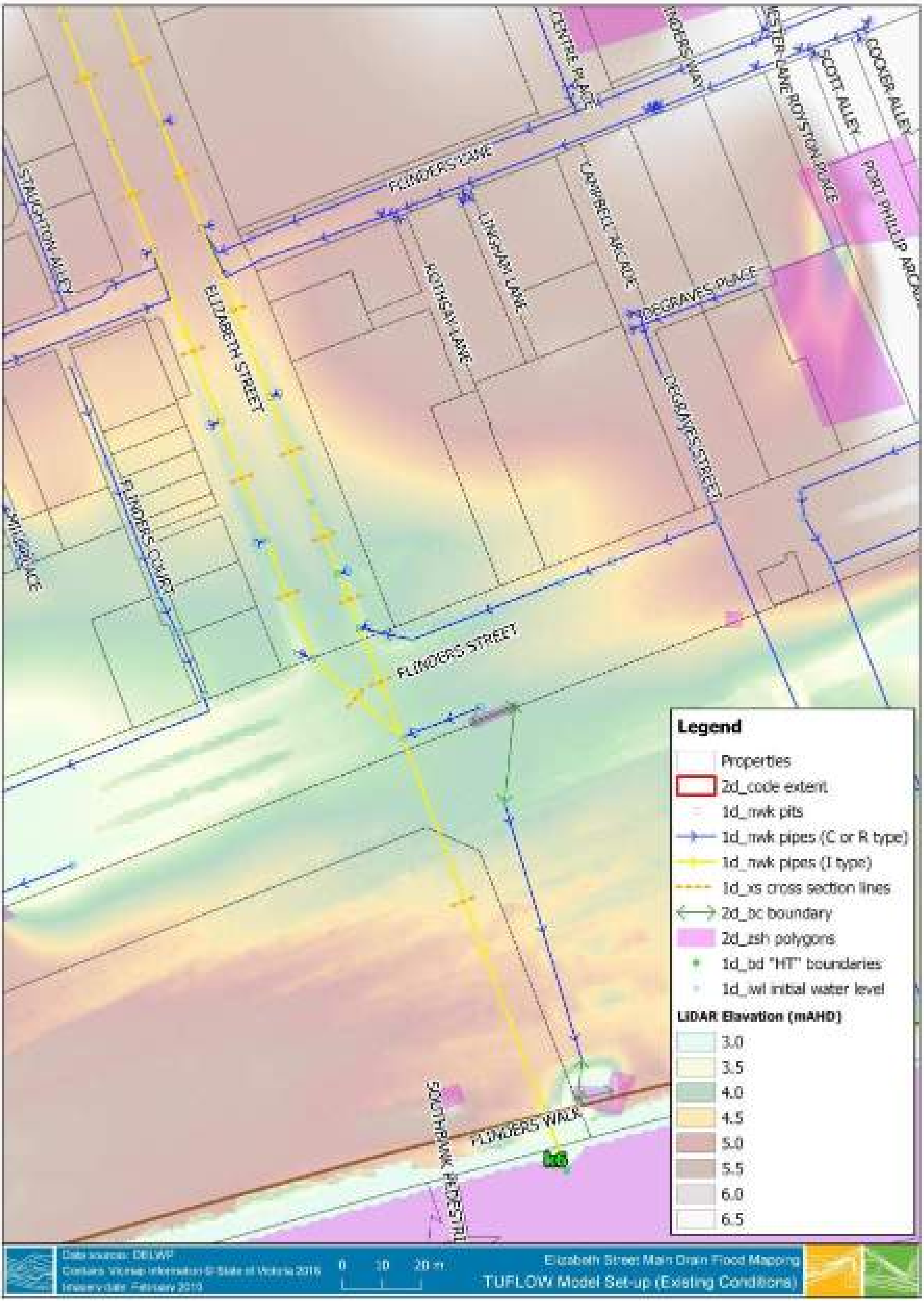

Figure 1-3 TUFLOW Model Set-up (detailed view of the Flinders Street – Elizabeth Street intersection)

1.2 Tailwater Level Correction

As agreed with Melbourne Water during the development of the 2014-2017 TUFLOW hydraulic model of Elizabeth Street Main Drain, the tailwater levels applied in the model were derived from;

- The ICAM (Interactive Climate Adaptation Model) TUFLOW models - The ICAM TUFLOW models were used to derive the 'HT' boundaries (constant tailwater levels) at the outlets of the model excluding the ones along the Yarra River. The ICAM TUFLOW models cover the three major watercourses (Yarra River, Maribyrnong River, Moonee Ponds Creek, the two latest being outside of the model) and includes the Elizabeth Street catchment.
  - The 1D boundary condition and 'HT' constant tailwater level at the corner of Flemington Road and Murphy Street (1d_bc Name attribute "HT_24") has been adjusted from 23.32 m AHD to 19.50 m AHD to match the 1% AEP flood level from the ICAM model. The original (higher) tailwater level caused instabilities in the model and did not correlate with the adjacent 1D boundary tailwater level.
- The Yarra River revised Flood Study (recently completed by MW) 10% AEP flood levels + climate change scenario 2 were set for the 'HT' boundaries at the Yarra River outfalls, and range from 2.05 to 2.37 m AHD as shown in Table 1-1.

Table 1-1 Yarra River Tailwater Levels Conditions

1d_bc 'HT' Name	Tailwater level (m AHD)
d1 (Existing Conditions Base Case 'ExBC' scenario) k1 (Existing Conditions Climate Change 'ExCC' scenario)	2.37
d2 (Existing Conditions Base Case 'ExBC' scenario) k2 (Existing Conditions Climate Change 'ExCC' scenario)	2.37
d3 (Existing Conditions Base Case 'ExBC' scenario) k3 (Existing Conditions Climate Change 'ExCC' scenario)	2.32
d4 (Existing Conditions Base Case 'ExBC' scenario) k4 (Existing Conditions **Climate Change** 'Ex**C**C' scenario)	2.33
d5 (Existing Conditions Base Case 'ExBC' scenario) k5 (Existing Conditions **Climate Change** 'Ex**C**C' scenario)	2.33
d6 (Existing Conditions Base Case 'ExBC' scenario) k6 (Existing Conditions Climate Change 'ExCC' scenario)	2.26
d7 (Existing Conditions Base Case 'ExBC' scenario) k7 (Existing Conditions **Climate Change** 'Ex**C**C' scenario)	2.16
d8 (Existing Conditions Base Case 'ExBC' scenario) k8 (Existing Conditions **Climate Change** 'Ex**C**C' scenario)	2.15
d9 (Existing Conditions Base Case 'ExBC' scenario) k9 (Existing Conditions Climate Change 'ExCC' scenario)	2.11
d10 (Existing Conditions Base Case 'ExBC' scenario) k10 (Existing Conditions **Climate Change** 'Ex**C**C' scenario)	2.08
d11 (Existing Conditions Base Case 'ExBC' scenario) k11 (Existing Conditions **Climate Change** 'Ex**C**C' scenario)	2.05

1.3 Other Schematisation Changes

Instabilities in the model occurred in sections of the underground (1d) network along Elizabeth Street, associated to high velocities within short pipe links in the model. To resolve those instabilities, the 1d network (pits and pipes) schematisation was altered by removing several junction pits and associated small pipe sections with the addition of connector (link type 'X') as shown in Figure 1-4.

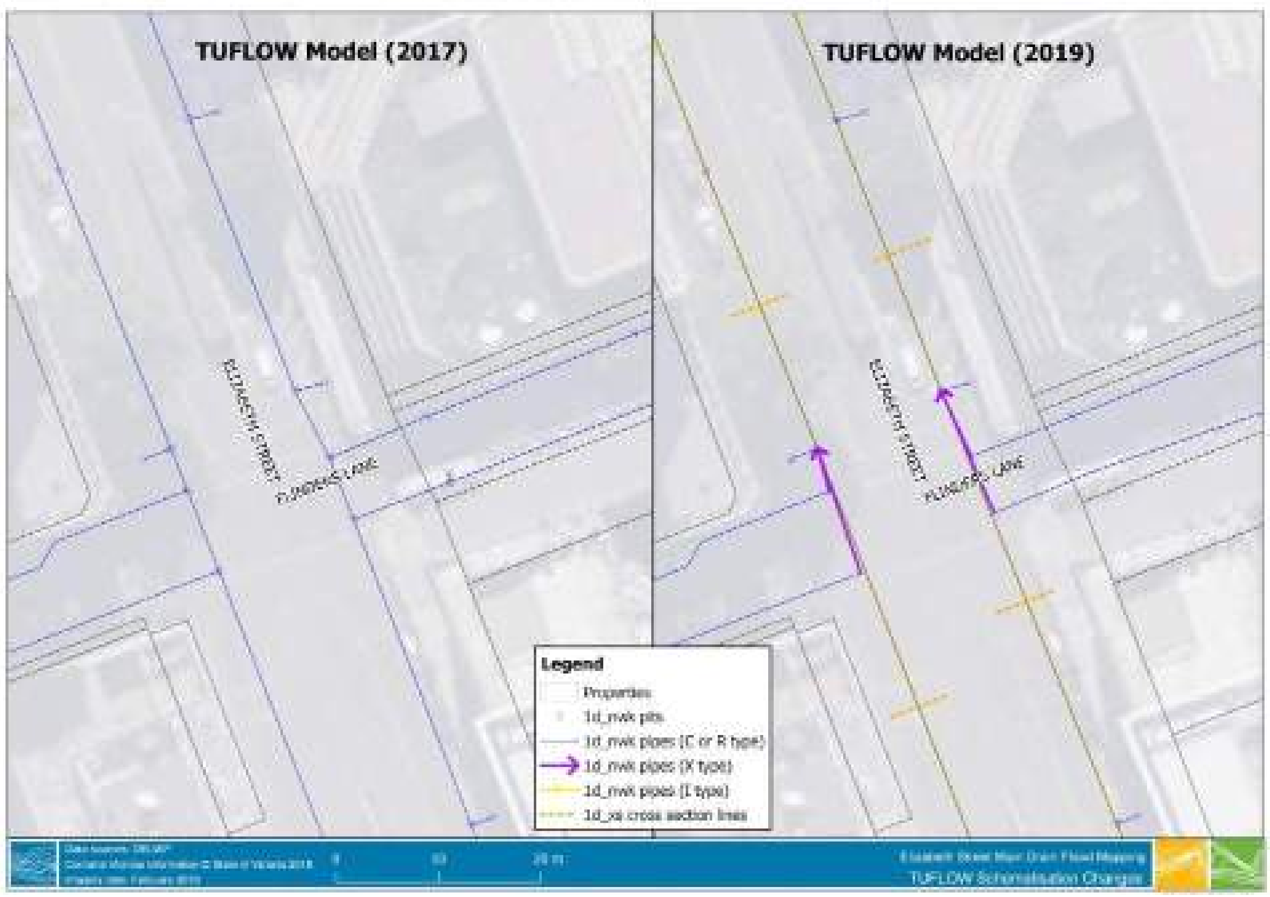

Figure 1-4 Other Schematisation Changes in the Model

1.4 Depth-varying Roughness

As part of MW peer review comments (refer to email communication provided in Appendix B and Appendix C), depth varying roughness was applied over the building footprints with low Manning's roughness values applied to low depth (to imitate the faster runoff response associated to rainfall on roofs) and higher Manning's roughness values to high depth (to act as a blockage by the building faces).

Depth varying roughness was applied to building footprints with Manning's value (n) following the following settings;

- n = 0.02 for depths up to 0.05 m;
- n= 0.40 for depths = to 0.051 m or greater; and
- n linearly varying from 0.02 to 0.40 as depth increases from 0.05 m to 0.051 m.

The depth varying Manning roughness relationship is plotted in Figure 1-5.

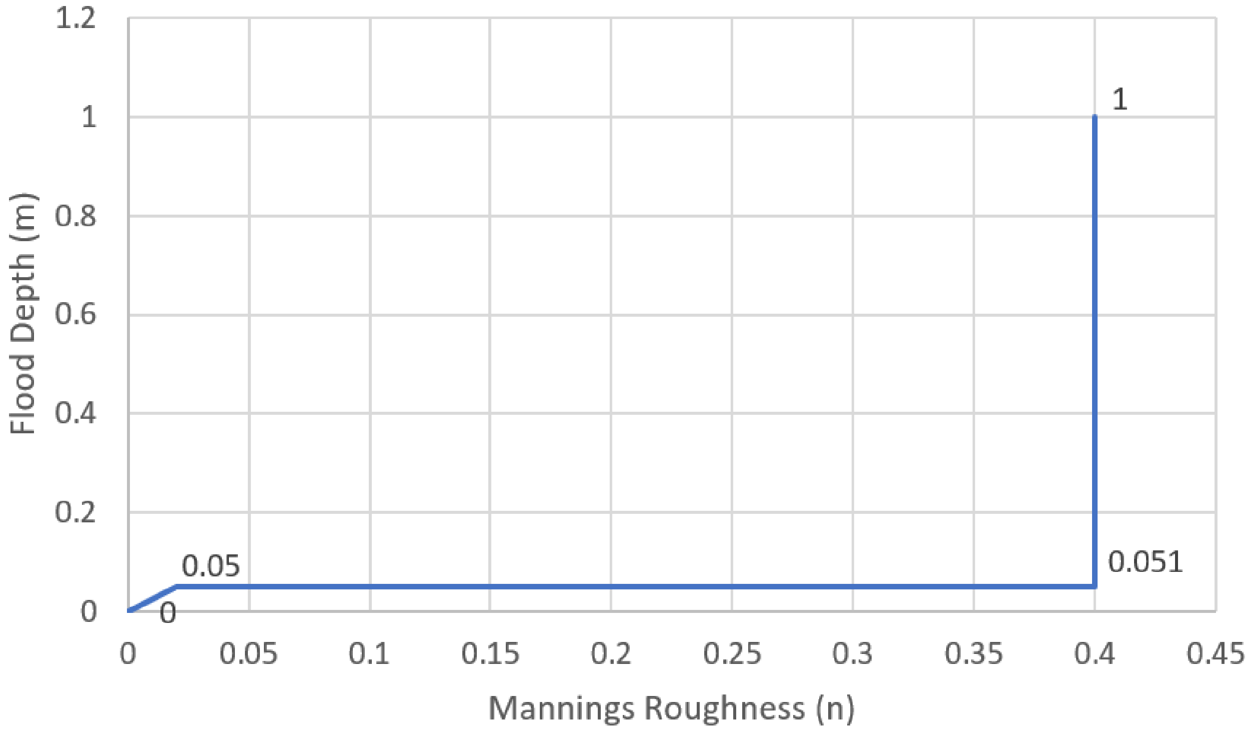

Figure 1-5 Depth Varying Roughness Relationship over Building Footprints.

1.5 Climate Change Assumption

As requested by MW (refer to email communication provided in Appendix A), a 18.5% increase in rainfall intensity was applied to the 2d_rf (rainfall file) by setting the f2 multiplier factor to 1.185.

1.6 Pre-wet

As per the 2017 modelling assumptions, a pre-wet of the catchment has been undertaken 4 hours prior to the actual event to remove minor depressions in the topography. A small amount of rain (3 mm) has been applied over 10 minutes, and the model run to allow only filled depression to remain.

1.7 TUFLOW Version and Build

All simulations have been completed using TUFLOW version TUFLOW_2018-03-AE on Classic Build.

1.8 Simulations Work Program

Table 1-2 presents the full suite of simulations to be completed as part of the Elizabeth Street Main Drain catchment flood modelling and mapping program.

Table 1-2 Simulation Summary Table

Event	Duration	Scenario	Status
100y ARI	**15 min to 12 hour**	**Existing Conditions Base Case (ExBC)**	**Completed (20/12/2019)**
100y ARI	**15 min to 12 hour**	**Existing Conditions Climate Change (ExCC)**	
50y ARI	15 min to 12 hour	Existing Conditions Base Case (ExBC)	To be completed in early 2020 as part of Stage 2
50y ARI	15 min to 12 hour	Existing Conditions Climate Change (ExCC)	
20y ARI	15 min to 12 hour	Existing Conditions Base Case (ExBC)	
20y ARI	15 min to 12 hour	Existing Conditions Climate Change (ExCC)	
10y ARI	15 min to 12 hour	Existing Conditions Base Case (ExBC)	
10y ARI	15 min to 12 hour	Existing Conditions Climate Change (ExCC)	
5y ARI	15 min to 12 hour	Existing Conditions Base Case (ExBC)	
5y ARI	15 min to 12 hour	Existing Conditions Climate Change (ExCC)	

2 HYDRAULIC MODELLING CHECKS

The MW TUFLOW Audit spreadsheet has been used internally to review the latest model set-up and results. A screenshot of the TUFLOW Audit Spreadsheet for this model is provided in Table 2-2.

At the date of submission of this addendum report (dated 20 December 2019), only the 100 year ARI ‘ExBC” and ‘ExCC’ simulations have been completed and issued to MW and CoM. A summary of all the simulations negative depth (1D and 2D) and mass error final values are presented in Table 2-1.

Table 2-1 100 year ARI ‘ExBC’ and ‘ExCC’ Negative Depth and Mass Error Summary Table

e1	e2	s1	s2	1D Negative Depth	2D Negative Depth	Mass Error
100y	15m	ExBC	CPU	0	0	**-0.77%**
100y	20m	ExBC	CPU	0	0	**-0.83%**
100y	25m	ExBC	CPU	0	0	**-0.82%**
100y	30m	ExBC	CPU	0	0	**-0.79%**
100y	45m	ExBC	CPU	0	0	**-0.78%**
100y	1h	ExBC	CPU	0	0	**-0.76%**
100y	1.5h	ExBC	CPU	0	0	**-0.64%**
100y	2h	ExBC	CPU	0	0	**-0.69%**
100y	3h	ExBC	CPU	0	0	**-0.60%**

e1	e2	s1	s2	1D Negative Depth	2D Negative Depth	Mass Error
100y	4.5h	ExBC	CPU	0	0	-0.58%
100y	6h	ExBC	CPU	0	0	-0.56%
100y	9h	ExBC	CPU	0	0	-0.58%
100y	12h	ExBC	CPU	0	0	-0.65%
100y	15m	ExCC	CPU	0	0	-0.87%
100y	20m	ExCC	CPU	0	0	-0.92%
100y	25m	ExCC	CPU	0	0	-0.91%
100y	30m	ExCC	CPU	0	0	-0.89%
100y	45m	ExCC	CPU	0	0	-0.86%
100y	1h	ExCC	CPU	0	0	-0.84%
100y	1.5h	ExCC	CPU	0	0	-0.77%
100y	2h	ExCC	CPU	0	0	-0.74%
100y	3h	ExCC	CPU	0	0	-0.64%
100y	4.5h	ExCC	CPU	0	0	-0.60%
100y	6h	ExCC	CPU	0	0	-0.57%
100y	9h	ExCC	CPU	0	0	-0.87%
100y	12h	ExCC	CPU	0	1	-0.61%

Table 2-2 MW TUFLOW Audit Spreadsheet (Existing Base Case Conditions, 100 year ARI only)

SUMMARY OF TUFLOW MODEL CHECKS			
FILE LOCATIONS			
Design report:	19010018_M01_v02.PDF		
Model files:	Raw	To be provided in zip file with deliverables	
	MWC Checks	n/a	
Review workspace:	n/a		
	Techspec Ref.	*This column should be a value or either 'Yes' or 'No'*	**Comments (if required):**
MODEL			
Tuflow version:			
Does model run?		Yes	
Are TUFLOW control file commands acceptable?		Yes	Forgot to remove any HPC/GPU related commands in the final version of the model. Will do in the Stage 2 work (with 5y, 10y, 20y, 50y)
Terrain Representation (2d Domain)			
Is the cell size appropriate?	Section 5.6.3.5 Section K.4	Yes	
Is grid orientation appropriate?		Yes	
Are applied terrain modification layers working as intended?	Section 5.6.7 Section K.5	Yes	
Are all required terrain modifications applied?	Section 5.6.7 Section K.5	Yes	
Are the manning's values in the TMF file appropriate?	Section 5.6.3.6	Yes	Yes, manning's avlues are appropriate; however not set in the TMG file but in a .csv file to apply depth varying roughness for building footprints.
Is the default Material correct?		Yes	
Is / are the Materials Layer(s) reasonable?		Yes	
Drainage Network Representation (1d Domain)			
Are the pipe/channel alignments correct?		Yes	Spot checks completed at trunk mains
Are pipes connected throughout system (any snapping issues)?		Yes	Spot checks completed at trunk mains
Is network free of grade or cover issues?		Yes	Original pipe slope inference by GraceGIS has been further revised using InfoWorks ICM on a case by case basis by plotting long sections and adjusting invert levels.
Do drainage network asset sizes make sense (i.e. increase as move down system)?		Yes	Further checks were completed by exporting the TUFLOW in InfoWorks ICM and running built-in validation tools checking for abnomanlies like downstream pipe smaller and than upstream before adjusting slope assumptions.
Are pipe lengths defined properly?		Yes	All pipes were originally set to the automatic GIS length. When TUFLOW pipe length are no longer exacyely equal to the automatic GIS length (after slightly relocating the pipe alignment), the difference in length is negligeable. Checked that the total volume of underground storage between the TUFLOW pipe length and autimatic GIS length (together with the wetted surface area) are similar; difference has been calculated to be less than 0.04%.
Are pipe manning's' appropriate?		Yes	For building footprints, depth varying roughness manning's values applied with sharp change from n=0.02 to n=0.40 between depth 0.050m and 0.051.
Is the loss approach appropriate?		Yes	No losses applied to pits to fully engaged the underground drainage network.
Is the pipe geometry appropriate for Engelund losses?		Yes	Use of connector link type 'X to avoid adding any unrelatistic bend in the pipe alignment.
Are pipe losses set correctly?		Yes	
Are contraction coefficients appropriate?		Yes	
Is pit modelling approach appropriate?	Section 5.6.3.4	Yes	
Are pit loses set appropriately?	Section K.13	Yes	
Any ANA added? Is it appropriate?	Section K.14	Yes	
Are entry/exit losses set for pipes that have SX outlets?		Yes	
Boundary Condition Representation			
Do tailwater level(s) or slope for HQ appear correct?		Yes	
Is the downstream boundary a sufficient distance away from the study area?		Yes	
Do inflows appear correct?		Yes	
Is the flow distribution acceptable?	Section K.12	Yes	
Are the 1d-2d linkages drawn appropriately? (pits vs SX points/lines)		Yes	
Are there Z flags on SX lines? Are the zpt adjustments reasonable?		Yes	
Are there terrain adjustments at 1d-2d linkages? Are they appropriate?		Yes	Q' type pits have an upstream invert level set to 0.1 to drop the terrain and force water into the pits as part of the 1d-2d linkage ('SXL' Conn_1D_2D)
Are reasonable IWL conditions applied?		Yes	
Are undrained depressions addressed if rainfall-on-grid or 2d_sa ALL polygons are used?	Section K.20	Yes	Restart file approach described this in the report.
TUFLOW Run Files			
Is 1D time-step within 1/10 and 1/5 of the 2D time-step?	Section K.6	Yes	
Is 2D time-step within 1/5 and 1/2 of the grid cell size?	Section K.6	Yes	
Do run files seem reasonable? (i.e. change to defaults or non-standard commands)		Yes	
LOG FILE			
Does MI Projection Check == Error (not Warning)?		Yes	
Does MI Save Date == Error (not Warning or Off)		Yes	
Is the snap tolerance not adjusted from its default value?		Yes	
Is maximum Mass Error appropriate (usually not > 1.2%)?	Section 5.6.5	Yes	All Mass Error below 0.95%
Is the in / out volume change gradual?		Yes	
Are there no Negative Depth Warnings?		No	There is no negative depth in all runs except the 100y 12hr 'ExCC' run which has only 1 2D negative depth deemed acceptable.
Messages Layer			
Are there no ERRORs in the messages layer?		Yes	
CHECK 2118 and WARNING 2118: Are ZC values lowered by a reasonable amount and do the lowered cells match the neighbouring terrain?		Yes	No drastic ZC adjustments
WARNING 1100: Are the invert mismatches acceptable?		Yes	
CHECK 1401 and CHECK 1402: Are these failures in automatic manholes creation ok?	Section K.13	Yes	
CHECK 1111: Are these overwrites mistakes or by design?		Yes	
Are the other Checks and Warnings in the messages layer acceptable?		Yes	
RESULTS			
Are there PO lines at all key locations?	Section 5.6.6	Yes	
Are pipes flowing full where expected (refer to _CCA.mif)?		Yes	
Do Maximum Water Surface Levels appear OK?		Yes	
Do Maximum Velocities appear OK?		Yes	
Do flows in pipes and channels appear OK?		Yes	
Do extents seem reasonable and appear in correct order (Q100 >Q50>Q20, etc.)		Yes	Cheked that Q100y 'ExCC' (climate change scenario) > Q100y 'ExBC' (base case scenario) for same duration

3 CONCLUSION

This memorandum is an addendum to the Elizabeth Street, Melbourne Flood Modelling Report (3611_01_R01_v07.pdf) completed by Water Technology and issued on August 2nd 2017 to Melbourne Water (MW) and the City of Melbourne (CoM).

This document summarises the remedies and changes made to date to the existing Elizabeth Street Main Drain TUFLOW model prior to issuing the final flood modelling results for the existing conditions base case and climate change scenarios on December 20, 2019.

Yours sincerely

Celine Marchenay
Principal Engineer and Group Manager

Celine.Marchenay@watertech.com.au

WATER TECHNOLOGY PTY LTD

APPENDIX A – MW CLIMATE CHANGE RAINFALL INTENSITY EMAIL DATED 19 JUNE 2019

Celine Marchenay

From:	Merran Price <merran.price@melbournewater.com.au>
Sent:	Wednesday, 19 June 2019 9:29 AM
To:	Celine Marchenay
Cc:	Belinda Tam; Ruwan Jayasinghe; Luke Cunningham (Luke.Cunningham@melbourne.vic.gov.au)
Subject:	Elizabeth St MD Flood Mapping Project
Follow Up Flag:	Follow up
Flag Status:	Completed

Hi Celine

With regards to the climate change component of this project. The value to use for the rainfall intensity increase by 2100 is 18.5%.

The rainfall intensity increase by 2100 value was determined using the updated information (May 2019) in the Data hub.

Regards

Merran

Merran Price BE(Hons) MIEAust
Asset Practitioner - Mapping and Modelling Engineer, Flood Information, Asset Management Services, Service Delivery Group | **Melbourne Water**
T: (03) 9679 7466 | e: merran.price@melbournewater.com.au
990 Latrobe St, Docklands 3008 | PO Box 4342 Melbourne VIC 3001 | melbournewater.com.au

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APPENDIX B - MW TUFLOW REVIEW COMMENTS EMAIL DATED 24 OCTOBER 2019

Celine Marchenay

From: Rushiru Kanakaratne <Rushiru.Kanakaratne@melbournewater.com.au>
Sent: Thursday, 24 October 2019 10:10 AM
To: Celine Marchenay
Cc: Ruwan Jayasinghe; Ken Tchung
Subject: Elizabeth Street MD Flood Mapping

Hi Celine,

I went through the TUFLOW model and I have a few concerns I've detailed below.

I am still worried about the flood levels that are coming from this model. The 100yr flood depths in Elizabeth Street are too low.

Also, can you confirm that the final modelling will be done with Classic, not HPC?

TCF Commands

The flowing TCF commands should not be in the final TUFLOW model. Can you remove these and change the data where necessary such that the model runs without the need for these commands.
MI Projection Check == Warning
Check MI Save Date == Warning
Snap Tolerance == 0.01

Please use FLT files (not ASC) for gridded outputs from TUFLOW.

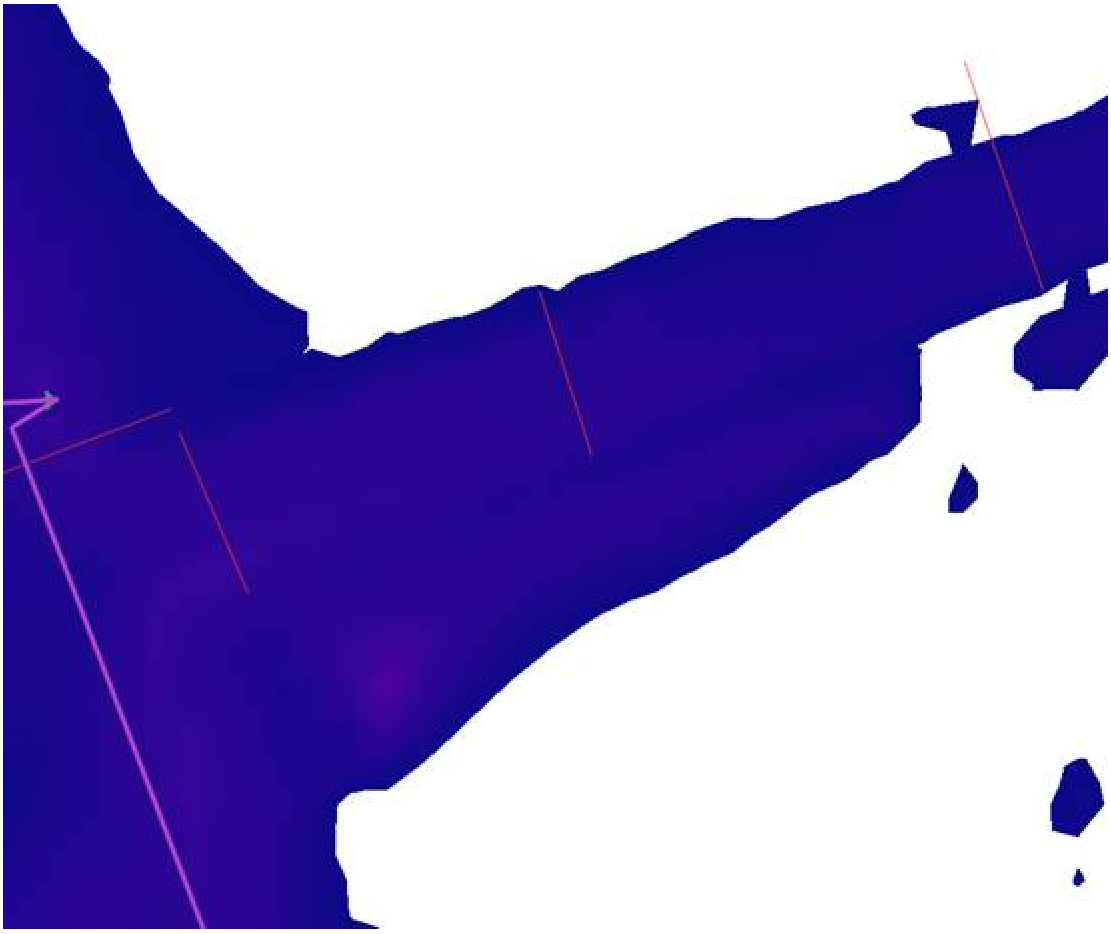
Also add the RFC and RFR map output types to the output type list. They are useful when doing rainfall on grid modelling. (For XMFD outputs)

ECF Commands

Add the following command to the ECF file. It is useful to pick up orphan pits.
PIT NO 1D CONNECTION == ERROR

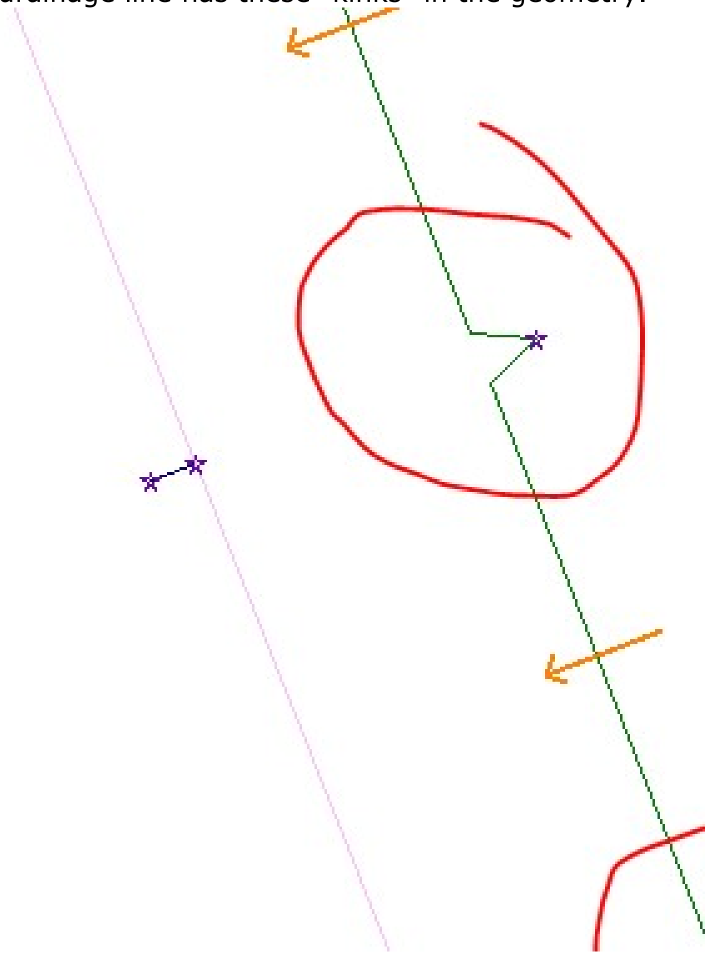
PO Lines

The model you sent for review didn't have the 2d_po tables in the mi folder. Please make sure these tables are part of the final submission.
From the results data you sent across I can see some of the PO lines don't span the full flow path (see the image below). Please do a review of the PO lines and extend them as required.

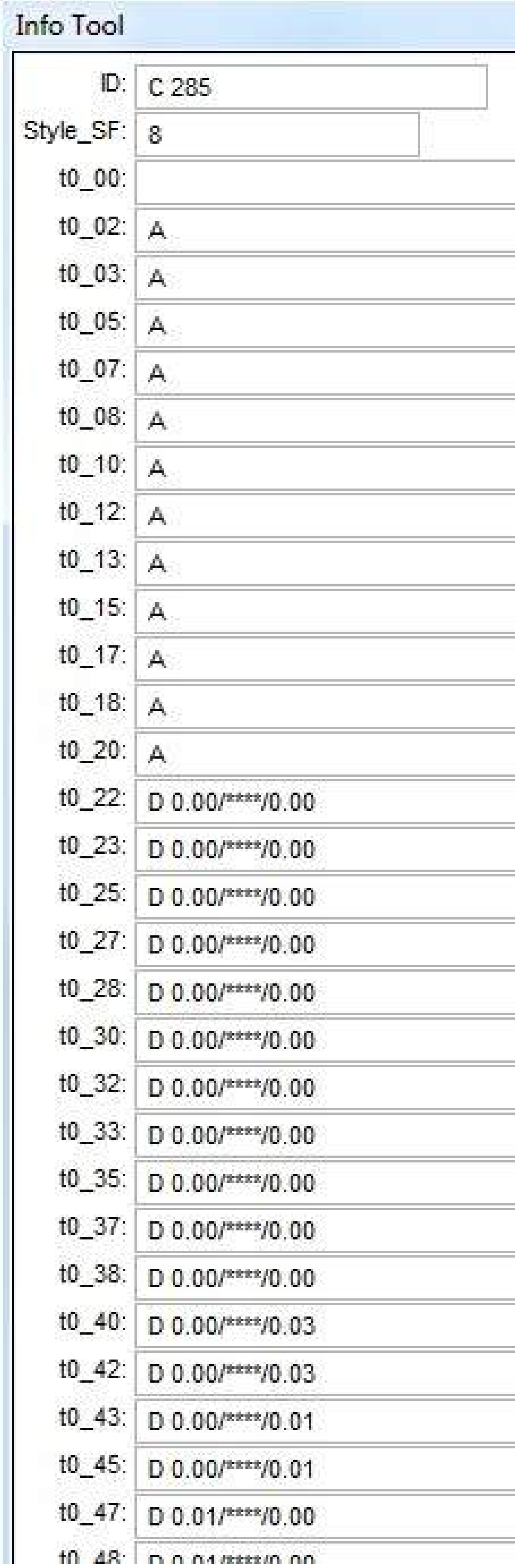


1d nwk issues

The main drainage line has these "kinks" in the geometry.



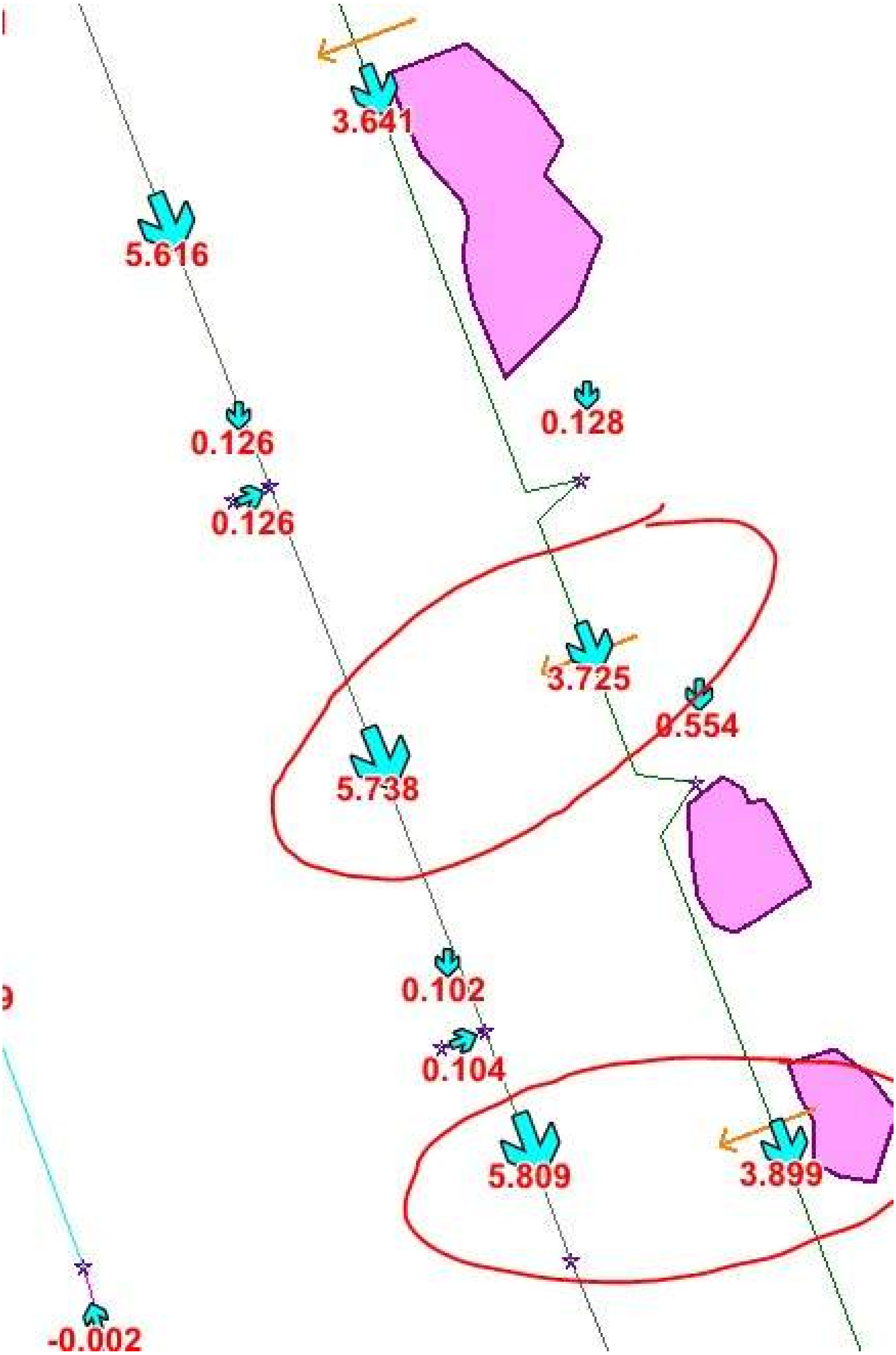
This is not appropriate since this changes how TUFLOW calculated losses for that pit using the Engelund method. TUFLOW thinks there is an actual bend in the pipe and adds very high losses. You can see thin in TSL file.



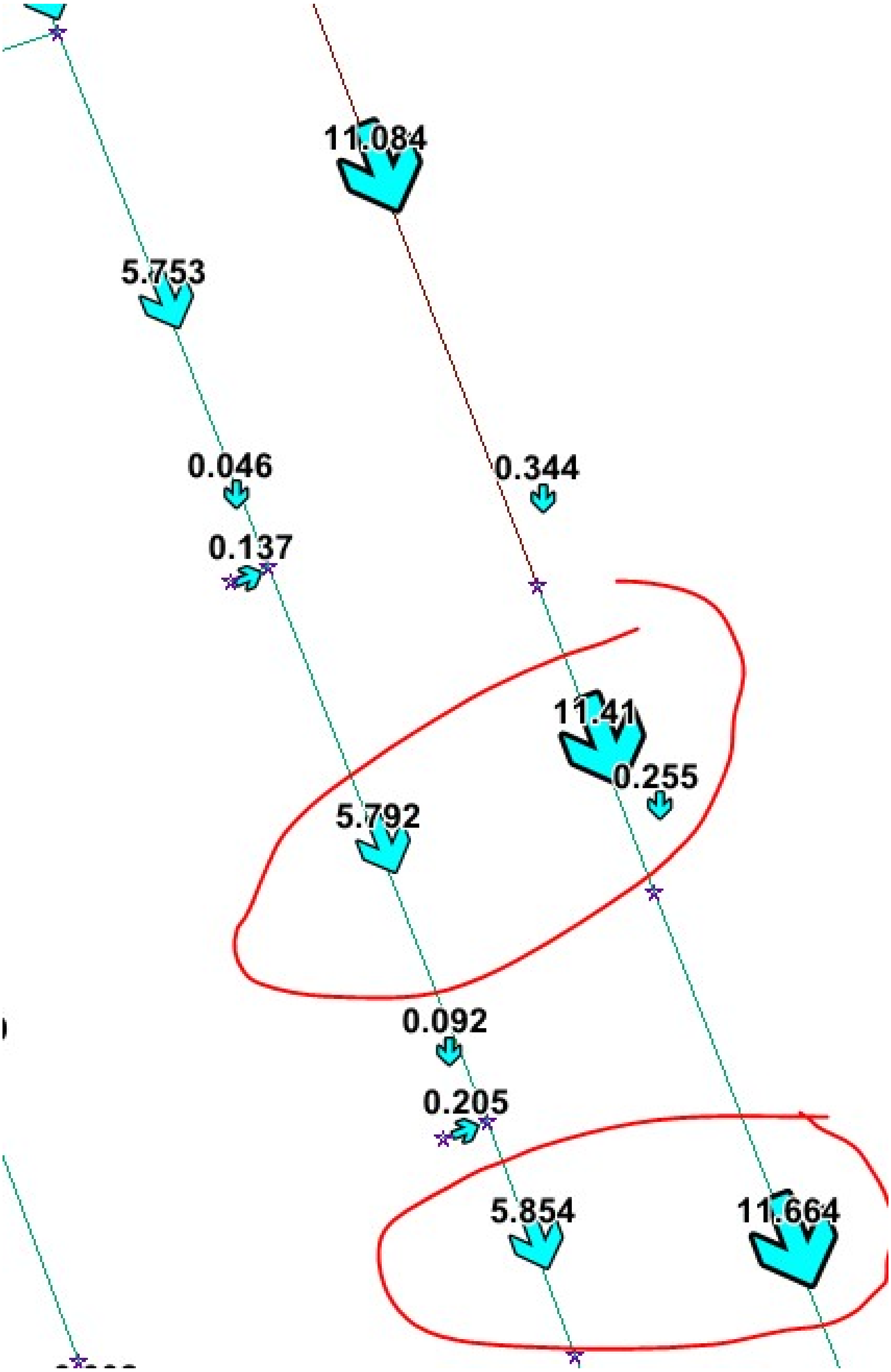
Info Tool

ID:	C 285
Style_SF:	8
t0_00:	
t0_02:	A
t0_03:	A
t0_05:	A
t0_07:	A
t0_08:	A
t0_10:	A
t0_12:	A
t0_13:	A
t0_15:	A
t0_17:	A
t0_18:	A
t0_20:	A
t0_22:	D 0.00/****/0.00
t0_23:	D 0.00/****/0.00
t0_25:	D 0.00/****/0.00
t0_27:	D 0.00/****/0.00
t0_28:	D 0.00/****/0.00
t0_30:	D 0.00/****/0.00
t0_32:	D 0.00/****/0.00
t0_33:	D 0.00/****/0.00
t0_35:	D 0.00/****/0.00
t0_37:	D 0.00/****/0.00
t0_38:	D 0.00/****/0.00
t0_40:	D 0.00/****/0.03
t0_42:	D 0.00/****/0.03
t0_43:	D 0.00/****/0.01
t0_45:	D 0.00/****/0.01
t0_47:	D 0.01/****/0.00
t0_48:	D 0.01/****/0.00

Also if you look at the flow in the main barrel, you can see that the flow in the pipe drops significantly near these kinks. The smaller barrel is actually taking more water!



I ran a sensitivity model with the kinks removed and the flows changed to something more sensible.



If you need to connect to a pit that's away from the main channel, and you don't want to use short pipe lengths to avoid instabilities, consider using X connectors (type 'X' 1d_nwk lines) to connect them to the main trunk.

The losses associated with the council drains that you've modified to remove short pipe lengths might also have a similar impact on flood behaviour. Try connecting them with X connectors as well.

Please do a review of the rest of the network to ensure that the geometry is appropriate. It's important to keep in mind that the Engelund losses are based on the geometry.

<u>Manning's values</u>

The high manning's values used to represent the buildings in the city are interacting adversely with the rainfall on grid approach of introducing flow. The water that falls on these high manning's areas are being attenuated and this removes the quick response you'd expect from an urbanised catchment.

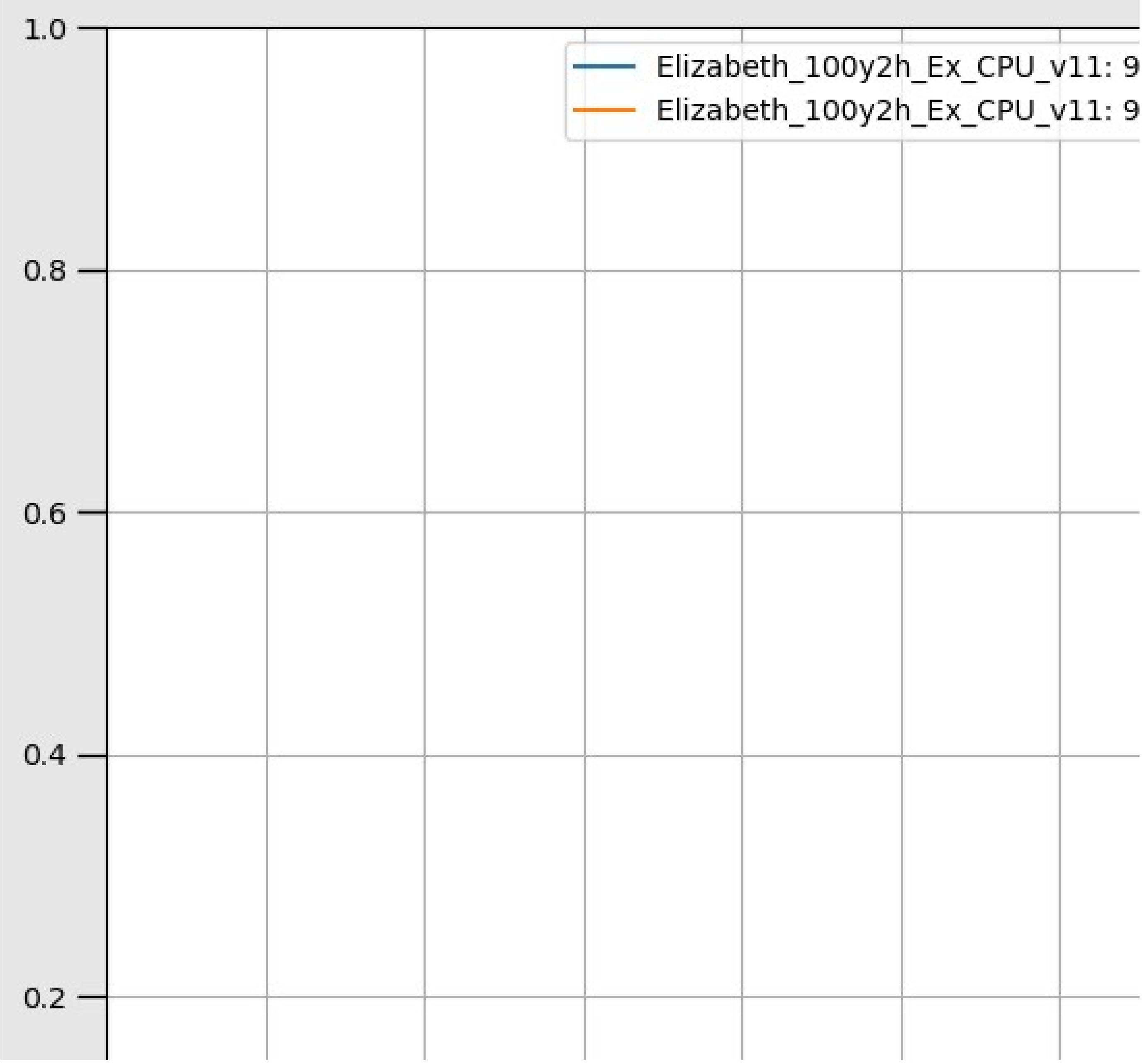
I recommend using a depth varying manning's approach, with a low manning's value for shallow depth. I did some sensitivity with a manning's value of 0.02 for depths less than 50mm. This means that if the depths are small (i.e. rainfall on roofs), TUFLOW will convey that flow very fast off the property simulating the roof drainage infrastructure of the buildings. When the depths are high, the water will be attenuated as per a blockage. The depth varying manning's should only be done for building material types, not to all materials.

I think this will be crucial in getting flood depths in Elizabeth Street that are sensible. My sensitivity model shows depths in Elizabeth Street at the southern end almost doubling.

<u>Pit losses</u>

You've added large pit losses for pits at the start of the networks. While these losses are appropriate from a design sense, I don't think we should be using them in our modelling. This is a rain on grid model and we already have trouble fully engaging the pipe network due to the lack of detail at pits, and the lack of any direct connection from buildings. Therefore keeping the pits loss free will compensate this to a degree.

I ran a sensitivity model to test this. The result of removing the losses is minor, but I think the cumulative effect will be non-negligible.



HQ Line

Can you please split the HQ line along the Yarra to separate the actual overland flow outflow locations from the rain on grid "trickle outflow" locations. This is because HQ applies the same water level to all selected cells and having different flow locations be part of the same HQ line can cause errors at the boundary. I don't think this will have a material effect on the final results but it's an easy enough fix to do to be safe.

If you are running HPC be especially careful with long HQ lines. HPC has issues with how it process long HQ lines.

Restart Files

I am guessing the restart files are there to fill depressions to reduce excessive storage in the model area. Can you please confirm this? Also can you include the reasoning behind this in your report/memo.

Please implement these changes into the model and run a couple of key durations? We are still waiting for Yarra River levels. This way we can be ready for production runs when the Yarra levels are available.

Regards,

Rushiru Kanakaratne | Asset Practitioner
990 Latrobe Street, Melbourne 3008 | PO Box 4342 Melbourne VIC 3001 | melbournewater.com.au

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APPENDIX C - MW TUFLOW REVIEW COMMENTS EMAIL DATED 14 NOVEMBER 2019

Celine Marchenay

From:	Rushiru Kanakaratne <Rushiru.Kanakaratne@melbournewater.com.au>
Sent:	Thursday, 14 November 2019 12:00 PM
To:	Celine Marchenay
Subject:	RE: Elizabeth Street MD Flood Mapping
Attachments:	Elizabeth St v12 - TUFLOW Model Review.xlsx

Hi Celine,

Sorry for the delay in getting back to you. Got pull away on another job.

I went through and filled in the MW QA spreadsheet. Nothing much in there. Please take a look at the few comments.

Regarding your question about existing vc CC for solving instabilities, yes I agree running the CC rainfall will weed out more issues than running just current climate. Also try running the 2h duration. I round that is more critical than the 3h.

Regards,

Rushiru Kanakaratne | Asset Practitioner | T: (03) 8615 5014
990 Latrobe Street, Melbourne 3008 | PO Box 4342 Melbourne VIC 3001 | melbournewater.com.au

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From: Celine Marchenay [mailto:Celine.Marchenay@watertech.com.au]
Sent: Monday, 4 November 2019 4:37 PM
To: Rushiru Kanakaratne
Subject: RE: Elizabeth Street MD Flood Mapping

Hi Rushiru,

You can download the bc_dbase using this LINK
Enjoy the day off tomorrow!

Regards,

Celine Marchenay
Group Manager ISWM | Principal Engineer

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From: Rushiru Kanakaratne <Rushiru.Kanakaratne@melbournewater.com.au>
Sent: Monday, 4 November 2019 4:23 PM
To: Celine Marchenay <Celine.Marchenay@watertech.com.au>
Subject: RE: Elizabeth Street MD Flood Mapping

Hi Celine,

Can you send me the bc_dbase as well please? I want to run the 2h duration to compare with my other runs here.

Regards,

Rushiru Kanakaratne | Asset Practitioner | T: (03) 8615 5014

SUMMARY OF TUFLOW MODEL CHECKS

FILE LOCATIONS

Design report:	<Insert link to consultant's study report associated with modelling>	
Model files:	Raw	<Insert link to raw model data supplied by consultant>
	MWC Checks	<Insert link to modified or copied model data used as part of review>
Review workspace:	review workspace>	

	Techspec Ref.	*This column should be a value or either 'Yes' or 'No'*	**Comments (if required):**
MODEL			
Tuflow version:			
Does model run?		Yes	
Are TUFLOW control file commands acceptable?		Yes	Remove any HPC/GPU related commands in the final version of the model. Also remove ~s2~ from the final production run file name(s)
Terrain Representation (2d Domain)			
Is the cell size appropriate?	Section 5.6.3.5 Section K.4	Yes	
Is grid orientation appropriate?		Yes	
Are applied terrain modification layers working as intended?	Section 5.6.7 Section K.5	Yes	
Are all required terrain modifications applied?	Section 5.6.7 Section K.5	Yes	
Are the manning's values in the TMF file appropriate?	Section 5.6.3.6	No	Rather than having the depth varying manning's values gradually change from low to high from 0.05m to 0.1m, consider having a sharp change (say from 0.05m to
Is the default Material correct?		Yes	
Is / are the Materials Layer(s) reasonable?		Yes	
Drainage Network Representation (1d Domain)			
Are the pipe/channel alignments correct?		Yes	Only spot checks done
Are pipes connected throughout system (any snapping issues)?		Yes	Only spot checks done
Is network free of grade or cover issues?		N/A	Not checked
Do drainage network asset sizes make sense (i.e. increase as move down system)?		Yes	Only spot checks done
Are pipe lengths defined properly?		Yes	Only spot checks done
Are pipe manning's' appropriate?		Yes	Only spot checks done
Is the loss approach appropriate?		Yes	Only spot checks done
Is the pipe geometry appropriate for Engelund losses?		Yes	Only spot checks done
Are pipe losses set correctly?		Yes	Only spot checks done
Are contraction coefficients appropriate?		Yes	Only spot checks done
Is pit modelling approach appropriate?	Section 5.6.3.4	Yes	
Are pit loses set appropriately?	Section K.13	Yes	
Any ANA added? Is it appropriate?	Section K.14	Yes	
Are entry/exit losses set for pipes that have SX outlets?		Yes	
Boundary Condition Representation			
Do tailwater level(s) or slope for HQ appear correct?		Yes	
Is the downstream boundary a sufficient distance away from the study area?		Yes	
Do inflows appear correct?		Yes	
Is the flow distribution acceptable?	Section K.12	Yes	
Are the 1d-2d linkages drawn appropriately? (pits vs SX points/lines)		Yes	
Are there Z flags on SX lines? Are the zpt adjustments reasonable?		Yes	
Are there terrain adjustments at 1d-2d linkages? Are they appropriate?		N/A	
Are reasonable IWL conditions applied?		Yes	
Are undrained depressions addressed if rainfall-on-grid or 2d_sa ALL polygons are used?	Section K.20	Yes	Restart file approach. Please describe this in the report.
TUFLOW Run Files			
Is 1D time-step within 1/10 and 1/5 of the 2D time-step?	Section K.6	No	Consider lowering the 1d timestep to resolve instabilities
Is 2D time-step within 1/5 and 1/2 of the grid cell size?	Section K.6	Yes	
Do run files seem reasonable? (i.e. change to defaults or non-standard commands)		Yes	
LOG FILE			
Does MI Projection Check == Error (not Warning)?		Yes	
Does MI Save Date == Error (not Warning or Off)		Yes	
Is the snap tolerance not adjusted from its default value?		Yes	
Is maximum Mass Error appropriate (usually not > 1.2%)?	Section 5.6.5	No	Has to be addressed before production runs
Is the in / out volume change gradual?		Yes	
Are there no Negative Depth Warnings?		No	Has to be addressed before production runs
Messages Layer			
Are there no ERRORs in the messages layer?		Yes	
CHECK 2118 and WARNING 2118: Are ZC values lowered by a reasonable amount and do the lowered cells match the neighbouring terrain?		Yes	No drastic ZC adjustments
WARNING 1100: Are the invert mismatches acceptable?		No	Some mismatches are a bit high. See the WARNING 1100 tab.
CHECK 1401 and CHECK 1402: Are these failures in automatic manholes creation ok?	Section K.13	No	There are some manhole creation failures. Please review
CHECK 1111: Are these overwrites mistakes or by design?		N/A	No CHECK 1111 messages
Are the other Checks and Warnings in the messages layer acceptable?		Yes	
RESULTS			
Are there PO lines at all key locations?	Section 5.6.6	Yes	
Are pipes flowing full where expected (refer to _CCA.mif)?		Yes	
Do Maximum Water Surface Levels appear OK?		Yes	
Do Maximum Velocities appear OK?		Yes	
Do flows in pipes and channels appear OK?		No	See 1d flows tab
Do extents seem reasonable and appear in correct order (Q100 >Q50>Q20, etc.)		N/A	Not checked

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MEMORANDUM

To Alex Barton, Asset Practitioner (Flood Mapping & Modelling)

From Celine Marchenay, Group Manager ISWM, Water Technology

Date 09 April 2020

Subject Elizabeth Street Main Drain Catchment Flood Modelling

Water Technology has provided the following clarifications in response to MW and CoM (RAIN Consulting) review comments on the Elizabeth Street, Melbourne Flood Modelling report completed by August 2017 by Water Technology.

	Description
MW/CoM Question	Please explain in a little more detail what the "weeded" version of the LiDAR represents. What has been "weeded"? Just the buildings? (Page 18)
WT Clarification	Water Technology Spatial and GIS experts confirm that typically 'weeded out' means ground Digital Elevation Model (i.e. from LiDAR) which has been processed to remove the buildings and vegetation. However; Water Technology engineers involved in the earlier stages of the hydraulic model between 2015 and 2017 no longer work at with us. Hence; this further clarification should be able to be verified by Luke Cunningham (RAIN Consulting) and/or Joshphar (Jasper) Kunapo (GRACE Detailed-GIS Services) who were leading the project at the time.
MW/CoM Question	Non blockage of pipes: Please confirm that this applies only to pits that have a physical and non deliberate blockage (i.e. Not pits that have been blocked deliberately as part of drainage works). (Page 20, item 2)
WT Clarification	No pit has had blockage applied to deliberately or non-deliberately in the latest hydraulic model issues to MW in December 2019 and currently been run under all the additional ARI and events. I am not aware of any pits that had deliberately been blocked in 2015 to 2017.
MW/CoM Question	There is a note saying the cemetery has a Manning's of 0.1 applied, Fig 6-5 suggests something lower. Please confirm if this is having any material influence on the final PSA extents being produced. (Page 25-26)
WT Clarification	I confirm that a Manning's value of 0.1 was applied over the cemetery and that Figure 6-5 is outdated.

19010018_M03_v01.docx

	Description
MW/CoM Question	We believe an updated version of this figure would be very useful to show the new runs completed - is that possible? (Page 32, Fig 6-8)
WT Clarification	Revised Figure 6-8 is presented in Appendix A. Existing Base Case Scenarios simulations and results have been delivered in December 2019; Water Technology is now half-way through Stage 2 of the project re-running the Existing Conditions Climate Change simulations.

I trust this provides some clarifications to your questions. Let me know if you require additional information.

Yours sincerely

Celine Marchenay
Principal Engineer and Group Manager

Celine.Marchenay@watertech.com.au

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19010018_M03_v01.docx

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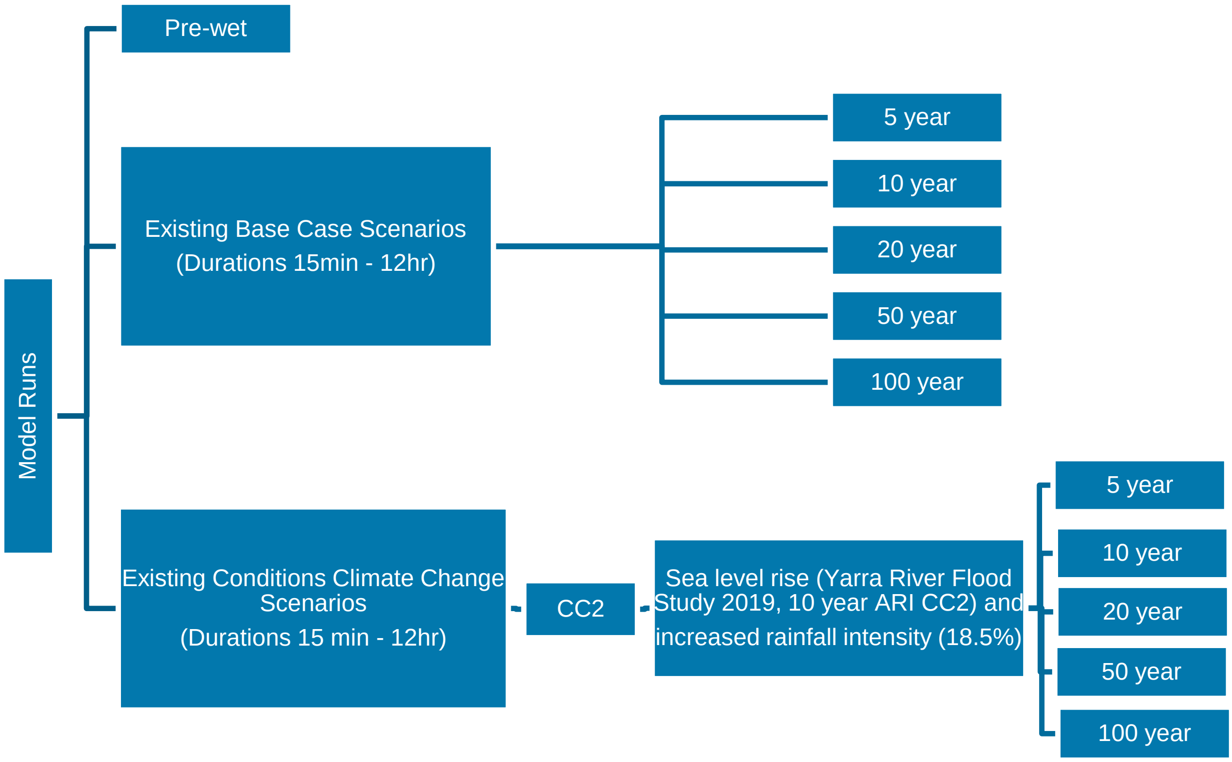
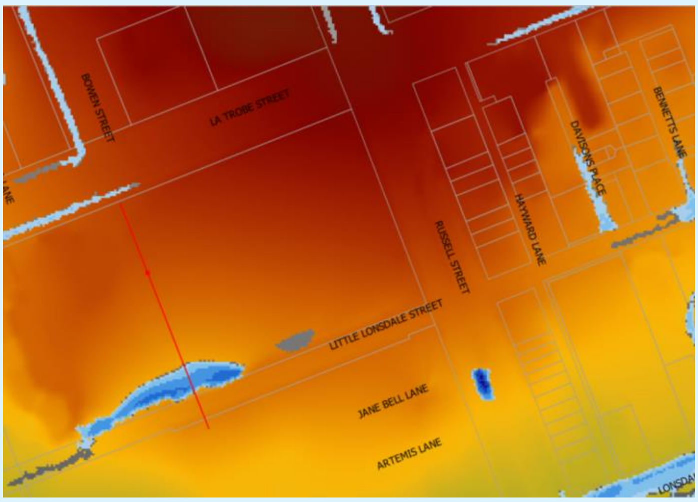
APPENDIX A – ELIZABETH STREET MELBOURNE FLOOD MODELLING REPORT (WATER TECHNOLOGY, AUGUST 2017) FIGURE 6-8 MODEL SCENARIOS AND EVENTS REVISION


Model Runs
Pre-wet
Existing Base Case Scenarios
(Durations 15min - 12hr)
5 year
10 year
20 year
50 year
100 year
Existing Conditions Climate Change Scenarios
(Durations 15 min - 12hr)
CC2
Sea level rise (Yarra River Flood Study 2019, 10 year ARI CC2) and increased rainfall intensity (18.5%)
5 year
10 year
20 year
50 year
100 year

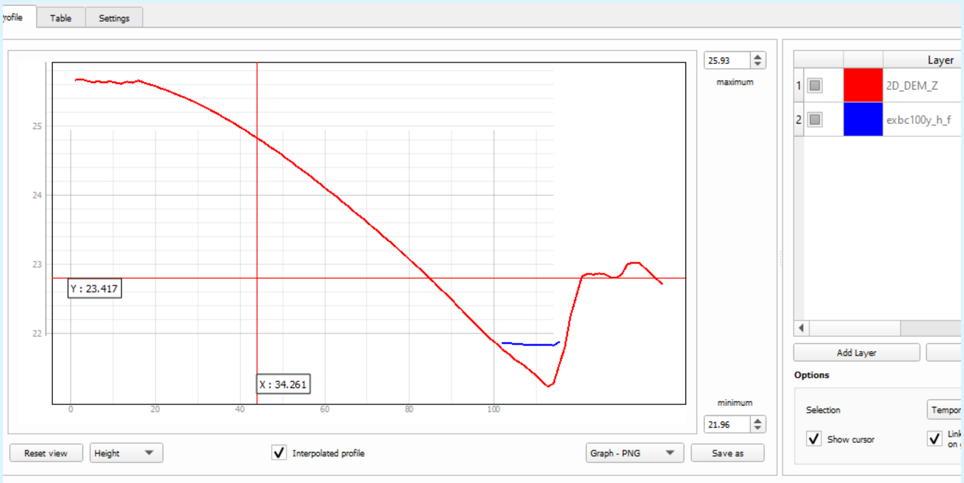
MEMORANDUM

To	Alex Barton, Asset Practitioner (Mapping & Modelling)
From	Celine Marchenay, Group Manager ISWM, Water Technology
Date	13 February 2020
Subject	Elizabeth Street Main Drain Catchment Flood Modelling

Water Technology has provided the following clarifications in response to MW review comments on the Elizabeth Street Main Drain Catchment Flood Modelling submission (100 year ARI, Existing Conditions Base Case ‘ExBC’ and Existing Conditions Climate Change ‘ExCC’ scenarios) delivered by Water Technology in December 2019 – February 2020.

	Description
MW Comment	Please provide a polygon showing the area in which the results be trimmed to.
WT Clarification	Please refer to 3_Filter_Polygon.zip provided.
MW Comment	Restart file depths out the front of the State Library on Little Lonsdale Street are deep at time 0. Does Water Technology believe that this will have a measurable impact on the final flood extent? If yes, to what extent?
WT Clarification	The restart file aims to fill up the small depressions in the terrain so that the rainfall applied through the hyetograph timeseries does not get artificially trapped into ponds without routing to the downstream drainage network (overland and/or underground). The restart file depth at this location is high as the topography (from LIDAR) shows a 2 to 2.5 m trench along Little Lonsdale St. If anything, the restart file depth at this location fills up part of the depression as it is intended to do; however is this specific depression realistic or not is another question. 

19010018_M02_v01.docx

	Description
	 When looking closer on Google Street view at this location, it appears that the depression represented in the LiDAR dataset corresponds to an underground restaurant / facility located below the State Library building on Little Lonsdale Street as shown below; 
MW Comment	The filtering will remove many of the deep puddles where buildings are. This will remove volume from the model which ultimately would have runoff. How has this volume been accounted for?
WT Clarification	The filtering process has removed any depth below than 50 mm and puddles less than 100 m^2. These "small" puddles (noise) can be left in the final flood maps; but often show isolated ponding which is not connected to underground drainage network or overland flow path. The total volume of water on the catchment when filtering out puddles smaller than 100 m^2 is approximately 146,500 m^3 while the volume is approximately 160,000 m^3 when filtering puddles smaller than 1 m^2. We estimated the volume of runoff filtered out to be around 9% of the total volume of stormwater runoff left. While this volume of runoff is removed from the final extent, it is disconnected and often occur along the

	Description
	kerb channels and in between buildings. It is reasonable to expect that during a storm event, some rainfall runoff would be trapped in between buildings without all draining to the downstream drainage network. The ponding over buildings is often larger than 100 m^2 and has been left in the final flood extent; however in most cases is disconnected to the rest of the network and does not contribute to the runoff. The modelling approach of not blocking the building footprints is a decision made and agreed by MW in June 2015 which has not been altered in this revision of the flood model.
MW Comment	Some pipes at the upstream ends of networks of laneways are not running full. Does Water Technology believe this will impact the flood extent? If yes, to what extent?
WT Clarification	Pipes not running full under the 100 year ARI only occurs at the upstream ends of the networks where in most cases there is no overland flooding which should be conveyed underground; hence Water Technology does not believe this will significantly impact the flood extent. It is likely caused by incorrect pit types (i.e. grated pits represented as junctions and missing direct connections from the buildings to the council pits/pipes network. To account for the lack of detail at pits and the lack of any direct connection from buildings, MW previous reviewer recommended that the pit loss be removed to fully engage the drainage network which occur at the downstream ends of the network.

I trust this provides some clarifications to your questions. Let me know if you require additional information.

Yours sincerely

Celine Marchenay
Principal Engineer and Group Manager

Celine.Marchenay@watertech.com.au

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