Shaping the Future

PRAHRAN MAIN DRAIN FLOOD MAPPING

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Melbourne Water

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1. INTRODUCTION

Cardno Lawson Treloar were engaged by Melbourne Water to undertake flood mapping of the Prahran Main Drain.

In order to fulfil one of its service commitments outlined in the Waterways and Drainage Operating Charter (June 1999), Melbourne Water is progressively protecting all vulnerable properties within its urban drainage catchments that are at risk of significant flooding.

A property is defined as vulnerable if, during a 100-year Average Recurrence Interval (ARI) storm event:

- The flow would inundate the main floor of the principal building (typically a residence), or
- If the usual access to and from the principal building would be cut-off by deep or fast flowing water, presenting a safety hazard to occupants, as defined by Melbourne Water's current safety criteria.

The Prahran Main Drain network is a branched and highly modified network that commences near the corner of High St and Northcote Rd and ends up at the Yarra River near the corner of Chapel St and Alexandra Pde. It services the suburbs of Toorak, Prahran and South Yarra. The total catchment area of the highly urbanised catchment is approximately 730.5 hectares, consisting of medium and high density residential and commercial developments. The drainage system consists of reinforced concrete pipes that ultimately discharge into the Yarra River near Willesmere Road.

The Prahran Main Drain network is comprised primarily of concrete or brick pipes. The network consists of numerous drainage assets including the:

- Prahran Main Drain (Commencing at High st)
- The parallel Williams Road Diversion Drains (Commencing near the corner of Williams Rd and Cassell St and ending at the Yarra River).
- Essex St Main Drain (commencing at the corner of Williams Rd and Erica St and joining the Prahran Main Drain near Surrey Rd North)
- The Surrey Rd Relief Drain (Commencing from the Essex St Main Drain at the corner of Bendigo St and Princes St and rejoining at Surrey Rd North prior to the connection with the Prahran Main Drain.

The purpose of this project is to investigate the extent of flooding in the Prahran Main Drain catchment. Flood mapping for the Prahran Main Drain catchment in accordance with the brief has been undertaken for both existing land use and proposed future land use conditions in the catchment under current conditions as well as predicted climate change conditions. The study area and underground drainage networks that were used in the hydraulic model are shown in Figure 1.1.

The first step in the process is to undertake hydrologic modelling to determine the flows from each subcatchment. These flows are then used in the hydraulic modelling along with the topography and pipes to determine flood extents and levels.

1.1 Scope of Works

The scope of services as defined in the tender documents includes the following:

- Incorporation of the LIDAR data (provided by Melbourne Water) and other ground survey data (where appropriate) to create a Digital Terrain Model of the catchment.

- Review the existing RORB model and adapt it to determine hydrological flows for the existing flooding conditions. Subdivide catchments to take Council drainage into account, where appropriate, and edge-match the catchment boundary.
- Develop a 2D hydraulic model to assess extent and depth of flooding for the storm events specified in the project brief for two scenarios including both existing conditions and the specified climate change scenario.
- For each scenario provide discharge information and probability flood levels for properties and floors for the range of storm events.
- Assess Flood Risk and Safety Risk categories and types as defined in appendices C and D of the project brief.

2. CATCHMENT AND STORMWATER SYSTEM DATA

2.1 Summary of Data Sources

The following data was acquired for use in the study:

- Cadastral, elevation and drainage alignment information was provided by Melbourne Water, in the form of digital GIS (MapInfo) tables (supplied via CD by Melbourne Water, January 2008);
- Aerial survey, undertaken for Melbourne Water in DXF format (supplied via CD by Melbourne Water, February 2008)
- Drainage design plans were supplied in digital picture format by Melbourne Water for the Melbourne Water assets (supplied via CD by Melbourne Water, February 2008); and
- Aerial photography and orthophotography from 2004 (supplied on CD by Melbourne Water, January 2008).

2.2 Site Inspections

A thorough site reconnaissance was undertaken in order to become familiar with local topography and physical features of the site. The field inspection was carried out on 23 April 2008.

The location of significant topographical features was noted. These included:

- A large construction site within the Como Complex (corner Malcolm St and Chapel St), where there is a large deep hole in the ground during construction
- Como Park at the downstream end of the Williams Rd diversion drain
- Various sections of the railway line
- Road overpass along Chapel St over the railway

2.3 Survey Data and Digital Terrain Model

Aerial survey data was supplied by Melbourne Water, enabling the development of a fine scale Digital Terrain Model (DTM) to define the existing overland drainage network.

2.3.1 Digital Terrain Model

A comprehensive digital terrain model (DTM) was compiled from the survey data. The digital elevation model (DEM) was constructed as a rectangular grid of elevations that were sampled from the DTM. This defined the topography of the catchment. The DEM extent used in the study is shown in Figure 2.1. A 3 m grid cell size was adopted, as this is considered to offer a resolution fine enough to appropriately define topographical features such as roads and open drains.

3. HYDROLOGIC MODELLING

3.1 Introduction

The general approach to hydrologic modelling was that typical of similar catchment studies in both the urban and rural regions of Victoria. Details of the approach and results are provided in the following sub-sections

3.2 Catchment and Sub-catchment Definition

Catchment boundaries were based on the underground drainage layout. This method was chosen as the resolution of the model is sufficient to ensure that the flows are evenly distributed across the catchment.

The DEM (section 2.3.1) was used to create contour data and define slopes and topographical features. A total of 36 sub-catchments were used to define the drainage properties of the catchment. The sub-catchment boundaries are largely unchanged from those previously defined by CMPS&F (1997) however the catchment boundary and those sub-catchments that are bordering the catchment were edge-matched to property boundaries. The sub-catchment boundaries are shown in Figure 3.1.

3.3 Review of Catchment Fraction Impervious

Melbourne Water supplied a draft set of impervious fractions to be used in the hydrological model, for both the existing and ultimate developed conditions scenarios. These values were assessed and slightly adjusted where necessary using the method described below (Section 3.3.1). The updated fraction impervious values were used in the hydrological model (Section 3.3.2).

3.3.1 Method of Assessment

The Fraction Impervious (FI) data for each subcatchment was calculated by Melbourne Water using the Planning Model (MapBasic program) based on Planning Zones. Cardno Lawson Treloar assessed the appropriateness of the FI assigned to each property by:

- Consideration of actual site-use via aerial photography (both that supplied by Melbourne Water and more recent aerial photography available through Google Earth) for sites zoned ‘Residential’, ‘Public Land’ or ‘Special Purpose’,
- Consideration of current Planning Scheme zones, particularly where these differed from Planning Model zones,
- Consultation with council as to the future development direction of the area

The FI was amended for properties that cover a significant proportion of the subcatchment and that were deemed to have a significantly different FI to that assigned by the Planning Model. The total FI was then recalculated for each subcatchment. This method of analysis was implemented for both ‘Existing’ and ‘Ultimate’ conditions.

3.3.2 Summary of Fraction Impervious Amendments

Table 3.1 shows those properties and catchments where changes were made to the Planning Model default Fraction Impervious (FI). The locations are shown in Figure 3.2. More detailed tables showing zoning breakdowns for each RORB subcatchment are given in Appendix A.

Table 3.1 - Summary of Fraction Impervious Amendments – Existing and Ultimate conditions

Subcatchment	Description	Planning Model Zone	Site Area (ha)	Planning Model FI	Adjusted FI	Sub-catchment change in FI	Reason for Adjusting FI
AD	Apartment blocks surrounded by parkland	iCbRt	5.56	0.66	0.36	10%	Apartment block surrounded by parkland was zoned as high density residential for inner areas, which was inappropriate for this site

Please note that differences between recent aerial photography available on Google Earth and aerial photography provided by Melbourne Water were taken into account. The more recent information from Google Earth was used if a difference between datasets was observed. MapInfo polygons identifying location of the sites are included in the electronic data provided with this report.

A summary of the sub-catchment characteristics is provided in table 3.2.

Table 3.2 – RORB sub-catchment parameters

Sub-Area	Area (ha)	Impervious Area	Impervious fraction
A	14.3	9.70	68%
B	43.3	24.75	57%
C	30.2	18.34	61%
D	23.3	10.52	45%
E	22.4	11.88	53%
F	39.0	18.27	47%
G	14.9	8.45	57%
H	22.8	11.80	52%
I	17.9	8.23	46%
J	12.8	7.08	55%
K	4.4	2.34	53%
L	22.4	9.64	43%
M	3.9	2.65	67%
N	11.0	6.41	58%
O	20.8	8.46	41%
P	24.0	16.54	69%
Q	3.1	2.34	76%
R	23.4	17.34	74%
S	25.2	18.93	75%
T	35.3	27.23	77%
U	17.7	13.91	79%
V	15.7	11.46	73%
W	9.5	6.79	72%
X	13.2	9.66	73%
Y	13.8	10.35	75%
Z	33.9	23.40	69%
AA	14.4	10.79	75%
AB	25.9	19.15	74%
AC	13.3	10.49	79%
AD	16.0	10.40	65%
AE	11.5	8.92	78%
AF	13.3	9.85	74%
AG	20.5	13.27	65%
AH	26.4	20.51	78%
AI	15.4	6.79	44%
AJ	14.1	5.26	37%
Total	**689**	**432**	**63%**

3.4 Hydrological Model Establishment

The RORB hydrological model version 6 (Laurenson, Mein and Nathan, 2005) was used for this study. RORB calculates flood hydrographs from storm rainfall hyetographs and can be used for modelling natural, part urban and fully urban catchments. RORB is an industry standard model that has been used widely in previous studies undertaken by Melbourne Water.

The sub-catchment characteristics described in table 3.2 were used in the RORB model and the RORB vector is shown in appendix B.
RORB allows for the modification of a number of hydrological parameters for calibration purposes including:

- Coefficient of runoff;
- Initial rainfall loss;
- Variation of the stream lag parameter 'k_c' (affecting the routing time of flow through a sub-catchment);
- The non-linearity factor 'm'.

The RORB parameters used in the modelling are shown in table 3.3. The 'Intensity Frequency Duration' (IFD) coefficients listed in table 3.4 were used for the generation of design storm events. The current condition IFDs are taken from AR&R Vol 2 (1987), whilst the climate change condition IFDs are the current condition values multiplied by 32% as advised by Melbourne Water. Figure 3.3 shows the RORB reach alignments and nodes used in the project. The k_c value was obtained through the process described in Section 3.5 below. The 'm' parameter was specified by Melbourne Water.

Table 3.3 – RORB Parameters

RORB Vector	kc	m
Prahran Main Drain	9.5	0.8

Table 3.4 – IFD Coefficients (after AR&R 1987)

Parameter	Current Conditions Value	Climate Change Scenario Values
$^{2}I_{1}$	18.9	24.95
$^{2}I_{12}$	3.81	5.03
$^{2}I_{72}$	1.13	1.49
$^{50}I_{1}$	38.7	51.08
$^{50}I_{12}$	7.09	9.36
$^{50}I_{72}$	2.21	2.92
G	0.35	0.35
F2	4.29	4.29
F50	14.9	14.9

Table 3.5 shows the coefficients of runoff adopted for each storm duration and recurrence interval. The initial rainfall loss was set to 10 mm for each storm event.

Table 3.5 – RORB Coefficients of Runoff

	Storm Duration (minutes)							
ARI Event	15	20	25	30	45	60	90	120
5-Year	0.25	0.25	0.25	0.25	0.25	0.24	0.24	0.22
10-Year	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.30
20-Year	0.45	0.45	0.45	0.45	0.45	0.45	0.42	0.4
50-Year	0.55	0.55	0.55	0.55	0.52	0.5	0.48	0.45
100-Year	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60

3.5 Hydrological Model Validation

The Prahran Main Drain, like many other urban drainage networks, is ungauged. As such, the rational method (Pilgrim, 1998) was used to estimate catchment flows and verify the modelled design event flows.

The Melbourne Water specified procedure was used to estimate the time of concentration for the catchments to assist with the rational method calculations, a sample calculation is shown in appendix C. The procedure gives an indicative time of concentration for the Prahran Main Drain Catchment of 42 minutes in the 100-year ARI event. The RORB model was run with various k_c values until the peak flows at various locations throughout the catchment matched those determined by the rational method. The lag parameter in RORB, k_c, was determined by an iterative approach to be 7 in order for the peak RORB flow to be comparable with the rational method at the locations detailed in table 3.6. A sensitivity analysis of the impact of various methods of calculating the time of concentration is found in Section 6.

Peak flows and times of concentration in the existing scenario are shown in table 3.6. The difference between the flows from the Rational Method and RORB at the outfall of the Prahran Main Drain and locations along the branches occur due to assumptions made within the Rational Method approach. The Rational Method assumes that there is only one main flowpath through the catchment, interspersed with shorter reaches connecting relatively small subcatchments to the dominant flowpath. The Prahran Main Drain catchment has two well defined branches that converge toward the downstream end of the catchment as well as a separate minor branch. As flows are introduced to the hydraulic model at various points throughout the catchment, it is important to match the RORB flows at each major branch and at the commencement of the Melbourne Water Drainage network, rather than at the outlet.

If RORB flows are made to match with the Rational Method flows at the outlet, flow rates in the upper catchment become less as the lag parameter k_c is increased. As the resolution of the hydraulic model inflows is at the subcatchment scale, it is appropriate to use a k_c value that produces flows at the correct order of magnitude at the subcatchment inflow points.

Table 3.6 –RORB comparison to rational method, existing scenario

	RORB Model Design Storm Durations										
Location and Rational method tc	**15 min**	**20 min**	**25 min**	**30 min**	**45 min**	**60 min**	**90 min**	**120 min**	**RORB Peak (m^3/s)**	**Rational method (m^3/s)**	**Diff. in flow**
Kooyong Rd at Railway overpass, 27 mins	21.2	21.9	22.4	21.2	19.2	19.6	19.4	19.2	**22.39**	**20.64**	**-1.75**
Prahran Main Drain @ intersection of Orrong/Malvern, 42 mins	34.3	35.7	38.1	36.7	35.0	37.5	36.0	37.5	**38.13**	**29.62**	**-8.51**
Prahran Main Drain @ intersection of Willliams/Cassell, 49 mins	37.6	42.6	45.2	46.6	47.1	49.0	48.2	47.6	**48.96**	**45.64**	**-3.32**
Williams Rd near Gooch St, 20 mins	11.1	11.4	11.1	10.5	10.1	10.0	10.1	10.4	**11.40**	**14.35083**	**2.95**
Surrey Rd Relief Drain @ intersection of Malvern/Bendigo, 32 mins	12.5	13.9	14.7	14.1	14.1	15.2	14.9	14.9	**15.20**	**20.04**	**4.83**
Surrey Rd Relief Drain @ intersection of Surrey/Garden, 41 mins	30.2	32.4	34.2	33.1	33.0	35.2	34.7	35.0	**35.25**	**50.17**	**14.92**
Intersection of Essex st Main Drain and Prahran Main Drain, 57 mins	60.8	68.6	76.7	78.0	80.0	85.0	81.3	82.7	**85.01**	**89.84**	**4.83**
Yarra outlet of Prahran Main Drain, 65 mins	57.5	65.9	73.6	76.4	80.0	84.5	80.6	81.7	**84.52**	**82.56**	**-1.97**

In comparing the rational method results and the RORB results in Table 3.6 it is considered that the RORB model provides an appropriate estimation of flows, suitable for the purposes of this study.

In this study, RORB has been used to generate excess rainfall hydrographs at the outlet of each sub-catchment. Varying the RORB lag parameter k_c changes the speed at which the water flows through the catchment and this parameter is used to verify the RORB model. It can be seen from table 3.6 that the peak flow at various subcatchment outlets is not reproduced consistently by a single $k_c$value, as k_c is an area dependant variable. These differences are not considered significant given the use of the SOBEK model described below.

The SOBEK hydraulic model calculates the speed at which water flows based on the de Saint Venard hydraulic equations and is considered to give a better representation of flow attenuation through the catchment. Flows at the outlet of each sub-catchment were extracted from the RORB model for use as inflow boundaries to the hydraulic model. The hydraulic model will give an accurate description of both the surface and underground flows (see section 4). It should be noted that any flow attenuation, storage and routing within the pipe network and overland flow areas are considered in the combined one and two dimensional hydraulic model description.

3.6 Probable Maximum Flood

The Probable Maximum Flood (PMF) for the Prahran Main Drain catchment was estimated using the Generalised Short-Duration Method (GSDM) (BoM, 2003). The following factors were used in this computation.

- Catchment area = 6.89 km^2
- Duration limit = 4.5 hrs
- Portion of area considered smooth = 1.0
- Portion of area considered rough = 0.0
- Mean elevation = 28 mAHD
- Adjustment for elevation = 0
- Elevation adjustment factor = 1.00
- Moisture adjustment factor = 0.55

Table 3.7 shows the total estimated flow depth from the GSDM for various flow durations. These flow depths were converted to hyetographs (records of rainfall depth over time) and used as storm files in RORB to estimate the peak flow at the required locations through the catchment.

Table 3.7 – PMP Rainfall Estimates

Duration (hours)	Initial depth – smooth (mm)	Rounded PMP Estimate (mm)
0.25	215	120
0.50	320	180
0.75	404	220
1.0	492	270
1.5	520	290
2.0	600	330
2.5	640	350
3.0	672	370
4.0	740	410

4. HYDRAULIC MODELLING

4.1 Introduction

The results from the hydrologic modelling (Section 3) were used as inputs to the hydraulic model. The hydrologic inputs define the magnitude of total storm flow from the various sub-catchments. The overland flow is dynamically computed based on the capacity of the pipe system, once this is exceeded the resultant overland flow patterns are then determined from the two-dimensional hydraulic model.

The WL|Delft 1D2D modelling system, SOBEK, was used to compute the pipe, channel (1D) and overland flow (2D) components of the study. SOBEK is a professional software package developed by WL|Delft Hydraulics Laboratory, which is one of the largest independent hydraulic institutes in Europe (situated in The Netherlands) and is world-renowned in the fields of hydraulic research and consulting (WL|Delft, 2005).

This combined package allows for the computation of channel and pipe flow (including structures such as culverts, weirs, gates and pumps, and pipe details such as inverts, obverts, pipe sizes and pipe material) by the 1D module, which is then dynamically linked to the 2D overland flow module. The 1D and 2D domains are automatically coupled at 1D-calculation points (such as manholes) whenever they overlap each other. The model commences with the 1D component operating as the inflow increases until such time as the pipe or channel is full and overflows, with the flow then moving to the 2D domain. The 1D network and the 2D grid hydrodynamics are solved simultaneously using the robust Delft scheme that handles steep fronts, wetting and drying processes and subcritical and supercritical flows (Stelling, 1999).

The advantages of this system are that the channel/pipe system is explicitly modelled as a sub-system within the two-dimensional overland flow computation. This means that generalised assumptions regarding the capacity of the channel/pipe system are not required. This system employs a unique implicit coupling between the one and two-dimensional hydraulic components that provides high accuracy and stability within the computation.

4.2 Hydraulic Model Establishment

The hydraulic model consists of two main hydraulic components:

- The pit and pipe network; and
- 2D grid of the surface topography.

The establishment of these two components of the model is described in the following section.

4.2.1 Pipe System

The pipe system was described explicitly within the hydraulic model by pipe inverts, diameters and manhole elevations obtained from the Melbourne Water plans (section 2.1). Due to the uncertainty of pipe conditions and providing some conservatism in the analysis, a roughness coefficient (Manning's 'n') of 0.015 was used for all pipes in the model. This is higher than the typical value for concrete pipes in good condition (n=0.011, Chow, 1973) but was considered suitable due to the age of the pipe network and allowance for additional losses due to bends and pits.

Figure 4.1 shows the modelled hydraulic pipe network, the 2D model topography (Section 4.2.2), the sub-catchment inflow points (where the hydrographs generated in the hydrological model are applied to the hydraulic model) and the overland flow reporting stations.

4.2.2 Topography

The major component of the two-dimensional model is the grid that describes the topography of the area. In order to accurately represent the topography within the Prahran drainage network, a detailed Digital Terrain Model (DTM) was compiled from the aerial survey data supplied by Melbourne Water as described in Section 2.3. The model grid parameters are listed in table 4.1.

Table 4.1 – Two-Dimensional Grid Parameters

Grid Parameter	Dimension
Grid Size	3 * 3 metres
X-dimension	900 columns
Y-dimension	910 rows

4.2.3 Hydraulic Roughness

The hydraulic roughness for the overland flow model was described using a two-dimensional roughness map of Manning's "n" values. This was developed by digitising different land-use zones from the digital aerial photographs captured for the aerial survey within a GIS environment (MapInfo). Table 4.2 summarises the land-use for determining roughness. The catchment is generally urbanised with large areas of residential development interspersed with smaller commercial areas. Figure 4.2 shows the hydraulic roughness parameters assumed for the catchment.

Table 4.2 – Two-Dimensional Grid Roughness Classification

Land Use	Calibrated Hydraulic Roughness (Manning's "n")
Car Park	0.022
Commercial	0.5
Wooded Park	0.08
Grassed Park	0.05
Residential	0.15
Roads	0.018
Railway	0.08
Building	0.5

4.3 Tailwater Conditions

The tailwater level in the Yarra River forms the downstream hydraulic control of the Prahran Main Drain. The river is tidal at this location with tidal levels and characteristics identical to those at Williamstown, with a time delay of 10 to 15 minutes (PoMC, 2008). We have chosen to use the Highest Astronomical Tide (HAT) level of 0.52 m AHD as the tailwater condition for the existing conditions model. This tide is the highest level that can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions. It will not be reached every year and is not the extreme level.

In accordance with Melbourne Water's brief, the climate change tailwater condition is assumed to be the HAT level plus an allowance for sea level rise of 0.4 metres. As such, the tailwater condition used for the climate change modelling is 0.92 m AHD

5. RESULTS

5.1 Hydraulic Model Results

The hydraulic model was run for storm durations from 15 to 120 minutes for each of the 5, 10, 20, 50 and 100-year ARI events, along with the PMF, for the existing conditions and the specified climate change scenario.

The two-dimensional, overland flow results are reported as depths and levels (m and mAHD) and flow velocities (m/s) over the entire grid domain at regular time intervals. Time series of water level, depth and flow velocity were also reported at specific locations. The discharge (m^3/s) across specified cross-sections was also recorded during the model simulation and is shown in tables 5.1 and 5.2, for the existing and climate change conditions respectively.

It should be noted that the flood shapes shown are a representation only of the actual flooding conditions in the catchment. The flood shapes are based on the DEM developed for use in the project (Section 2) and do not include consideration of features such as underground carparks.

Figures 5.1 to 5.6 and 5.7 to 5.12 show the maximum flood extents and depths in the existing conditions scenario and climate change scenario respectively, across the modelled flood events. Note that all figures have been filtered to remove depths less than 0.02 m. The critical storm durations for the 100yr ARI event that cause the peak flood level at each grid cell are shown in figure 5.13 for the existing conditions scenario and 5.14 for the climate change scenario.

5.2 Flood Behaviour

Flooding occurs extensively along the main drainage lines as well as flowing along roads and the railway line. The confluence of the Prahran Main Drain (PMD), the Essex St Main Drain (ESMD) and the Surrey Rd Relief Drain (SRRD) experiences extensive flooding that backs up and remains behind the Como complex.

Flow exceeds the capacity of the PMD and the Beatty Avenue Main Drain (BAMD) at the beginning of the pipes, causing water to spill out. Excess flows are partially directed and contained withn the railway line as it is cut into the ground and has high concrete walls on either side. Floodwater is relatively deep in the railway, however flows are able to spill out onto the surrounding roadways near the intersection with Canterbury Road.

There is no flooding along the majority of the Williams Rd Main Drain (WRMD) as it is cut deep though a large hill, however there is extensive flooding near the outlet of the pipe at Como Park. The tailwater level in the Yarra River limits the outlet capacity of the drain, causing the excess flows to enter the steep sided park and fill the available volume. Once the capacity of flood storage in the park is exceeded, water floods the nearby parkland and tennis courts.

There are breakout flows along the Essex St Main Drain and the Surrey Rd Relief Drain, where floods flow both east and west away from the drains before hitting roads, such as Chapel St, that redirect the flow towards the catchment outlet.

TBC

Table 5.1 –Overland Flow, Existing Conditions

Location of reporting station	PMP		100 Year		50 Year		20 Year		10 Year		5 Year	
	Flow (m3/s)	Critical Storm	Flow (m3/s)	Critical Storm	Flow (m3/s)	Critical Storm	Flow (m3/s)	Critical Storm	Flow (m3/s)	Critical Storm	Flow (m3/s)	Critical Storm
Corner of Osment Rd and Mt Pleasant Gr	165.36	60	3.86	25	1.48	25	0.00	0	0.00	0	0.00	0
Corner of Northcote Rd and Elm Gr	125.22	60	7.41	25	4.03	25	0.00	25	0.00	0	0.00	0
Clendon Rd	108.53	60	5.18	60	2.23	25	0.52	25	0.00	0	0.00	0
Beatty Ave	176.50	60	2.65	60	0.56	25	0.00	0	0.00	0	0.00	0
Corner of Orrong Rd and Mandeville Cres	125.28	20	4.11	60	2.02	45	0.17	90	0.00	0	0.00	0
Corner of Canterbury Rd and Lambert Rd	221.89	20	17.82	60	15.07	45	12.99	90	8.64	90	0.86	90
Mathoura Rd rail crossing	33.48	20	0.30	60	0.10	60	0.00	0	0.00	0	0.00	0
Corner of Mathoura Rd and Gordon St	245.89	20	18.02	90	14.25	60	10.60	60	3.08	90	0.00	0
Williams Rd near drain	187.40	30	10.50	60	7.65	45	4.90	60	0.12	90	0.00	0
Como Park	19.05	60	2.26	25	1.90	30	1.41	45	1.53	30	1.27	20
Hawksburn Rd	216.95	25	2.45	60	0.18	45	0.002	60	0.00	0	0.00	0
Corner Newry St and Normanby Pl	174.40	25	6.56	25	4.93	25	3.22	90	1.85	90	0.74	90
Corner of High St and Bendigo St	71.16	25	4.48	60	2.95	60	1.31	90	0.66	25	0.32	90
Corner of Mount St and King St	18.21	20	1.70	60	1.27	60	0.58	60	0.04	60	0.00	0
Commercial Rd near Essex St	54.90	20	1.58	60	0.64	60	0.27	60	0.06	60	0.01	90
Corner of Chapel St and Elizabeth St	83.90	20	2.69	60	1.18	60	0.28	60	0.00	0	0.00	0
Near Corner of Chapel St and Wilson St	31.03	20	1.11	60	0.42	60	0.00	0	0.00	0	0.00	0
Ellis near Surrey Rd	287.56	60	13.07	60	9.74	60	6.42	90	3.90	90	1.40	90
Corner of Garden Rd and Surrey Rd	218.05	60	9.27	60	9.27	60	3.00	90	0.98	90	0.36	90
Confluence of Main Drains and Clara St	228.80	30	11.82	60	7.91	60	3.65	90	1.29	90	0.06	90
Corner of Clara St and Toorak Rd	219.70	25	17.46	60	11.64	60	5.42	60	1.43	90	0.00	0
River St	108.06	30	5.43	25	4.42	60	3.02	60	0.43	60	0.00	0
Como complex	194.24	30	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Melbourne High	1.06	30	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0

Table 5.2 – Overland Flow, Climate Change Conditions

Location of reporting station	PMP		100 Year		50 Year		20 Year		10 Year		5 Year	
	Flow (m3/s)	Critical Storm	Flow (m3/s)	Critical Storm	Flow (m3/s)	Critical Storm	Flow (m3/s)	Critical Storm	Flow (m3/s)	Critical Storm	Flow (m3/s)	Critical Storm
Corner of Osment Rd and Mt Pleasant Gr	250.89	60	7.61	90	4.51	25	1.83	90	0.00	0	0.00	0
Corner of Northcote Rd and Elm Gr	215.69	60	12.17	25	8.19	25	3.48	90	0.27	90	0.00	0
Clendon Rd	184.68	60	10.86	90	6.12	30	2.11	90	0.67	90	0.00	0
Beatty Ave	260.32	60	7.34	90	3.36	60	0.82	90	0.00	0	0.00	0
Corner of Orrong Rd and Mandeville Cres	279.52	60	11.73	60	5.53	45	2.00	90	0.28	90	0.00	0
Corner of Canterbury Rd and Lambert Rd	390.61	60	27.33	60	18.91	45	14.99	60	13.38	90	10.16	90
Mathoura Rd rail crossing	86.03	60	0.51	90	0.35	45	0.16	90	0.00	0	0.00	0
Corner of Mathoura Rd and Gordon St	392.67	60	28.69	60	19.23	90	15.13	90	11.09	90	6.16	90
Williams Rd near drain	289.39	60	17.68	60	11.82	45	7.76	90	5.15	60	1.29	90
Como Park	21.04	30	5.39	90	1.93	25	1.68	60	1.71	20	1.41	20
Hawksburn Rd	330.81	60	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Corner Newry St and Normanby Pl	195.58	60	9.13	90	7.18	25	5.45	90	3.76	90	2.44	90
Corner of High St and Bendigo St	88.03	60	6.98	90	5.23	90	3.45	90	1.75	90	0.86	90
Corner of Mount St and King St	28.72	60	2.20	90	1.85	90	1.37	90	0.74	90	0.17	90
Commercial Rd near Essex St	67.31	60	3.85	60	2.22	60	0.77	60	0.32	90	0.08	90
Corner of Chapel St and Elizabeth St	104.60	20	5.54	60	3.52	60	1.39	60	0.41	60	0.04	90
Near Corner of Chapel St and Wilson St	45.02	60	2.43	60	1.44	60	0.53	60	0.04	60	0.00	0
Ellis near Surrey Rd	397.63	60	19.79	90	15.13	90	11.03	90	7.41	90	5.02	90
Corner of Garden Rd and Surrey Rd	303.60	60	15.61	90	11.15	90	7.22	90	3.95	90	1.72	90
Confluence of Main Drains and Clara St	362.54	60	18.62	90	13.77	90	8.55	90	4.55	90	2.39	90
Corner of Clara St and Toorak Rd	436.25	60	27.59	90	20.25	60	12.65	60	6.61	90	3.21	90
River St	158.39	25	6.53	25	5.61	90	4.73	90	3.51	90	1.94	90
Como complex	307.58	25	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Melbourne High	2.61	20	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0

5.3 Flood Impact on Properties - TBC

TBC

Table 5.3 – Maximum Number of Properties Flooded

	Existing	Climate Change
100-Year ARI		
50-Year ARI		
20-Year ARI		
10-Year ARI		
5-Year ARI		

5.3.1 Safety Risk

Melbourne Water Safety Risk Criteria have been used to map direct, indirect and property safety risk. The criteria are defined in table 5.3 (reproduced from the brief). Each property within the 100-year ARI flood extent was assigned one safety risk classification (the most severe applicable to the property).

Table 5.4 – Melbourne Water Safety Risk Criteria

Safety Risk Category		Definition		
		Velocity * Depth (m^2/s)		Depth (m)
High	3	> 0.8	or	> 0.8
Moderate	2	0.4 – 0.8	or	0.4 – 0.8
Low	1	< 0.4	or	<= 0.4

The definition of each type of safety risk together with the number of properties affected by the safety risk is tabulated below.

Safety Risk to Property – occurs when the flooding is typically at the rear of a property and could pose a hazard for residents within their backyard. Figure 5.6 shows the property safety risk through the catchment. Table 5.4 shows the number of properties in the Kew Main Drain catchment with a property safety risk. Note that properties can have a direct and property safety risk.

Table 5.5 – Property Safety Risk

	Number of Properties	
	Existing Conditions	Climate Change
High		
Moderate		
Low		

Direct Safety Risk – occurs when the usual egress from the property is directly cut off, (all egress is assumed to be via the street frontage, along roads only). Figure 5.7 shows the direct safety risk through the catchment. Table 5.5 shows the number of properties in the Kew Main Drain catchment with a direct safety risk.

Table 5.6 – Direct Safety Risk

	Number of Properties	
	Existing Conditions	Climate Change
High		
Moderate		
Low		

Indirect Safety Risk - In determining the Indirect Safety Risk for a given property, it is necessary to consider the Safety Risk values (maximum of velocity x depth or depth) within the roads leading from the property to "outside the flood shape". "Outside the flood shape" is defined as being "beyond the overall extent of the 1 in 100 year flood shape for the catchment". The indirect safety risk is determined by whether it is possible to travel:

- from the property
- to a point outside the flood shape
- via the roads
- without passing through an area having a Safety Risk greater than 1.

The value of the Indirect Safety Risk is to be the highest Safety Risk value of the roads involved. Table 5.6 shows the indirect safety risk for the catchment. Figure 5.8 shows the location of the properties with an indirect safety risk.

Table 5.7– Indirect Safety Risk

	Number of Properties	
	Existing Conditions	Climate Change
High	0	
Moderate	0	

5.3.2 Flood Risk

Each property has been designated a flood risk category. The flood risk categories are defined and the number of properties in each category is shown in table 5.7. Note that as no floor levels are available at this time, these tables have not been completed fully. Figure 5.9 shows flood risk through the catchment for the existing conditions.

Table 5.8 – Flood Risk

Flood Risk Category	Definition	Number of properties	
		Existing	Climate Change
1	Property Flooded, floor level > 100-year flood level*		
2	Property Flooded, floor level < 100-year flood level		
3	Property Flooded, floor level < 50-year flood level		
4	Property Flooded, floor level < 20-year flood level		
5	Property Flooded, floor level < 10-year flood level		
6	Property Flooded, floor level < 5-year flood level		

* Includes properties without surveyed floor levels

6. SENSIVITY ANALYSIS

A sensitivity analysis was undertaken to determine the impact of changing the time of concentration on the results of the hydraulic model.

6.1 Calculation of Time of Concentration

The time of concentration (t_c) is a measure of the time it takes a droplet of water landing at the farthest point of catchment to travel to the catchment outlet. t_c can be calculated using a number of approaches including:

- Kinematic Wave Equation
- Adams Method
- Manning's Equation for flow in pipe
- Friends Method

It is important to note that the time of concentration should be representative of the combined effects of both overland and underground flow components. Cardno Lawson Treloar used the kinematic wave approach as described in Australian Rainfall and Runoff (1998) to estimate the t_c for the Prahran Main Drain catchment. This method yielded a t_c of 67 minutes and the corresponding flows (calculated using the Rational Method) were used to calibrate a RORB model, which produced the flow inputs into the hydraulic model. A 67 minute time of concentration equated to a k_c value in RORB of 9.5 to match the rational method estimate of flows.

An alternate way calculation of t_c was undertaken based on the pipe flow velocity as calculated by the Manning's Equation. The time taken for the water to travel down the existing Melbourne Water Pipe was found in the SOBEK model to be approximately 22 minutes. The t_c for the upstream catchments not serviced by the Main Drain was estimated by assuming a 600mm diameter pipe at a slope equivalent to the natural surface, for which the calculations are shown in table 6.1. This was found to be 13 minutes. The time taken for water to flow from a roof to the drainage network was estimated at 7 minutes. This calculation gives t_c of 42 mins. This t_c was then used to in the Rational Method to calculate a flow to flow to which a RORB model could be calibrated. The corresponding Kc is 7.

Table 6.1 – Pipe Flow, Assumed Time of Concentration

Parameter	Equation	Result
Area, A (m^2) =	$\pi \times r^2$	0.283
Perimeter (m) =	$\pi \times D$	1.885
Hydraulic Radius, R =	$\frac{A}{P}$	0.150
Slope =		0.01
n =		0.016
Flow, Q (m3/sec) =	$\left(A \times R^{\frac{2}{3}} \times S^{\frac{1}{2}}\right) \div n$	0.499
Velocity, V (m/sec) =	**Error! Objects cannot be created from editing field codes.**	1.764
Distance (m) =		1400
Time (min) =	$\left(\frac{dis\tan ce}{V}\right)$/60	13

6.2 Results

The 100yr 60 minute rainfall event was run for each t_c value described above. Figure 6.1 shows the difference in depth between the flows generated by the differing t_c's. It is clear that mostly the difference is within +/- 5cm, however a greater difference is noted in a small number of locations. Table 6.2 shows the differences in flow at locations throughout the catchment. It shows that, as expected, the flows with the lower t_c are greater, however as an absolute the differences are relatively small.

Thee differences are caused by the lower k_c value in RORB decreasing the attenuation of the flood wave, thereby causing a greater volume of water to spill into the 2D domain as the pipe capacity is achieved earlier in the hydrograph. This is particularly evident in areas where storage of floodwater is a concern.

Table 6.2 – Flows and differences for each T_c

Location	Flow with T_c= 67 (m^3/s)	Flow with T_c= 42 (m^3/s)	Absolute difference (m^3/s)	% difference
Corner of Osment Rd and Mt Pleasant Gr	3.59	4.83	1.25	26
Corner of Northcote Rd and Elm Gr	6.44	7.54	1.1	15
Clendon Rd	5.17	6.26	1.09	17
Beatty Ave	2.64	4.02	1.38	34
Corner of Orrong Rd and Mandeville Cres	4.1	5.14	1.04	20
Corner of Canterbury Rd and Lambert Rd	17.81	18.57	0.76	4
Mathoura Rd rail crossing	0.3	0.37	0.07	19
Corner of Mathoura Rd and Gordon St	17.45	18.54	1.09	6
Williams Rd near drain	10.49	11.25	0.76	7
Como Park	0.49	1.6	1.11	69
Hawksburn Rd	2.51	3.2	0.69	21
Corner of High St and Bendigo St	4.86	5.46	0.6	11
Corner of Mount St and King St	1.79	1.91	0.12	6
Commercial Rd near Essex St	2.19	2.58	0.39	15
Corner of Chapel St and Elizabeth St	3.38	3.85	0.47	12
Near Corner of Chapel St and Wilson St	1.36	1.55	0.19	12
Ellis near Surrey Rd	16.09	19.13	3.04	16
Corner of Garden Rd and Surrey Rd	12.09	14.69	2.6	18
Confluence of Main Drains and Clara St	13.99	15.94	1.94	12
Corner of Clara St and Toorak Rd	21.14	23.25	2.12	9
River St	5.43	5.58	0.15	3
Como complex	0	0	0	0
Melbourne High	0	0	0	0

There is no significant difference in the hydraulic model results between the two methods of calculating time of concentration. This is due to the majority of the flow attenuation being accounted for in the hydraulic model. It should be noted that due to a lack of gauged flows in the Prahran Main Drain a calibration of the RORB model is not possible.

7. REFERENCES

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Stelling, G.S. Kernkamp, H.W.J and Laguzzii M.M. (1999) Delft Flooding System - A Powerful Tool for Inundation Assessment Based Upon a Positive Flow Simulation, Hydroinformatics Conference, Sydney NSW.

WL|Delft Hydraulics Laboratory, (2005) Sobek Advanced Version 2.10.000.RC01, WL|Delft Hydraulics Laboratory.

FIGURES

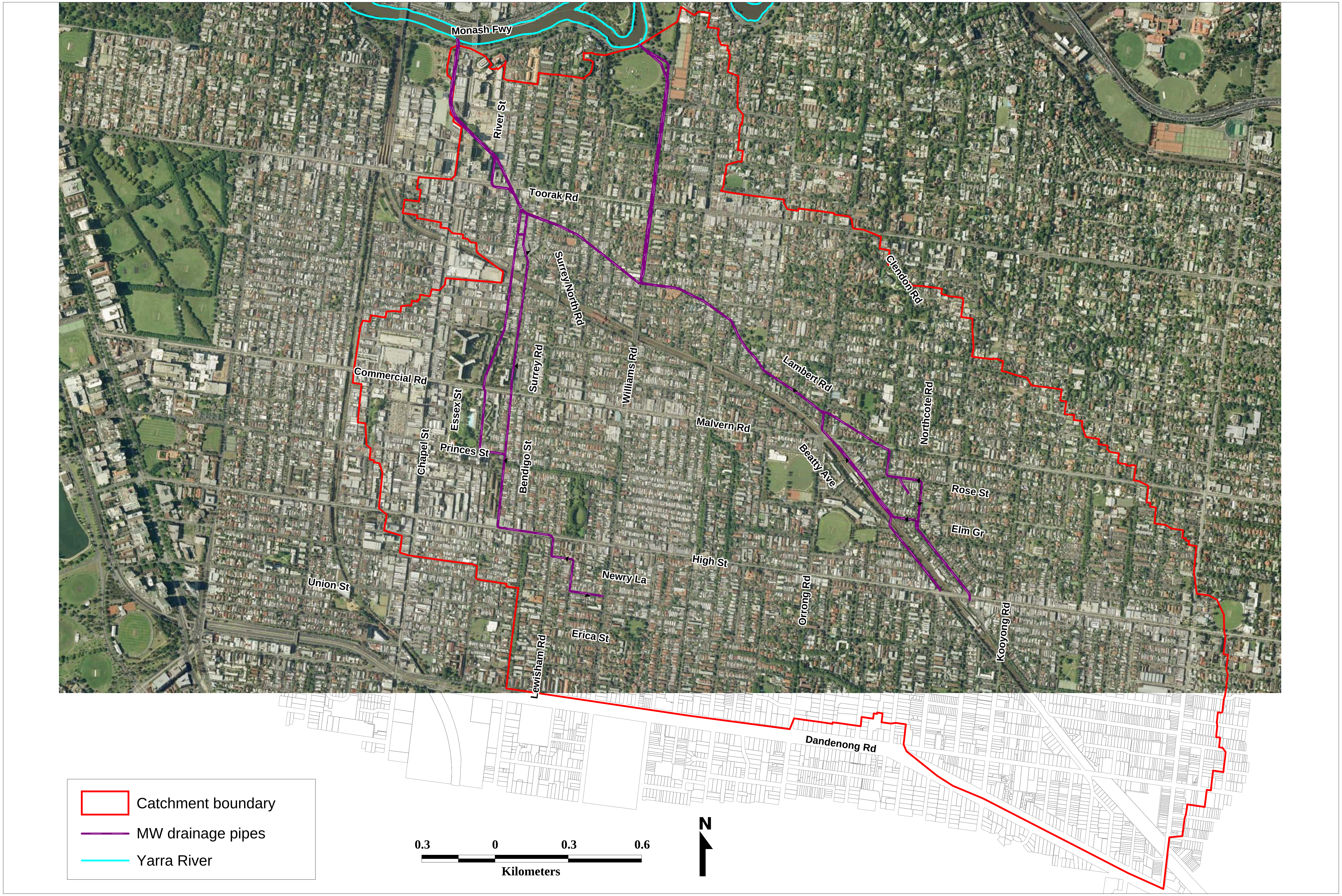

Figure 1.1 - Prahran Main Drain Study Area

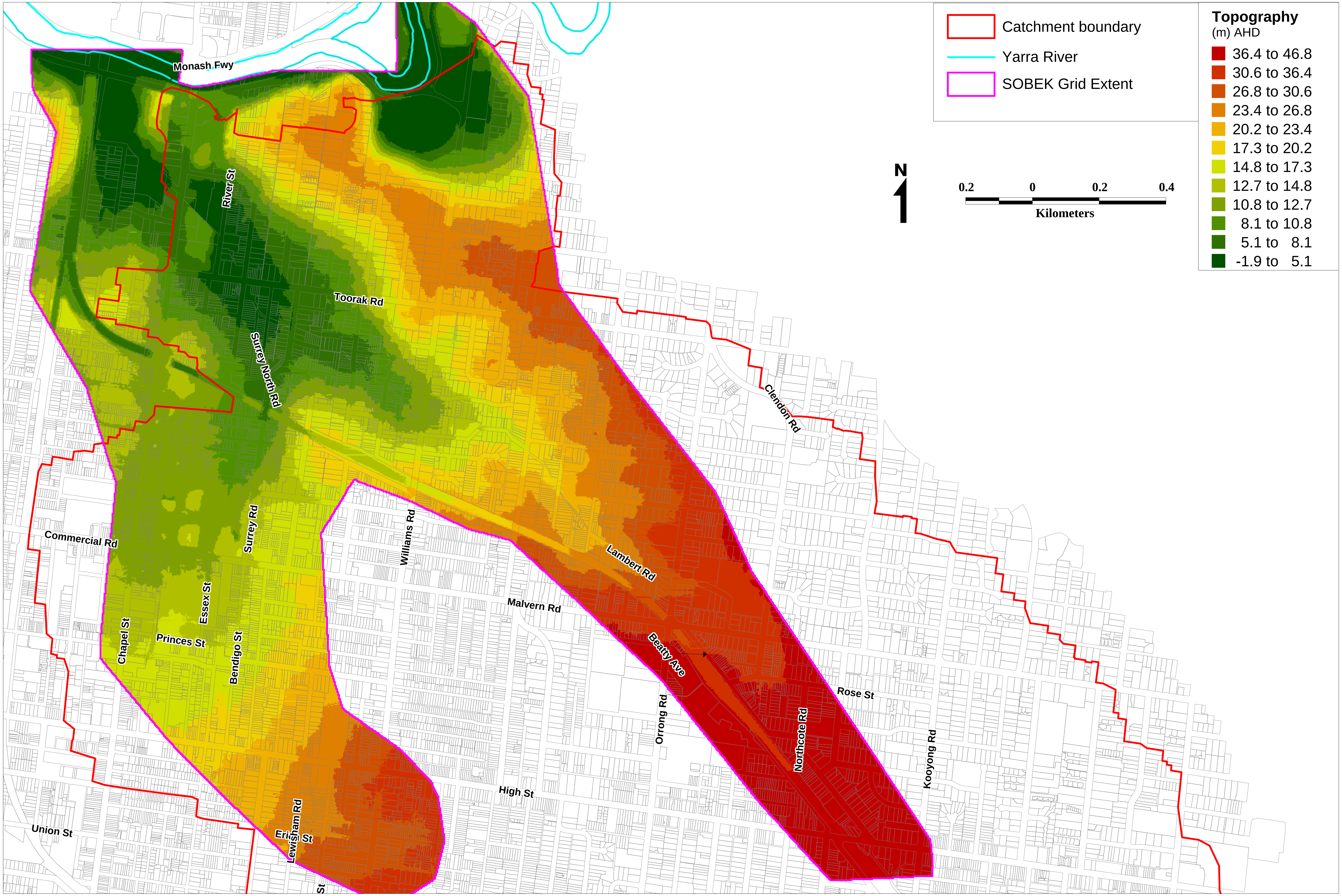

Figure 2.1 - Digital Elevation Model

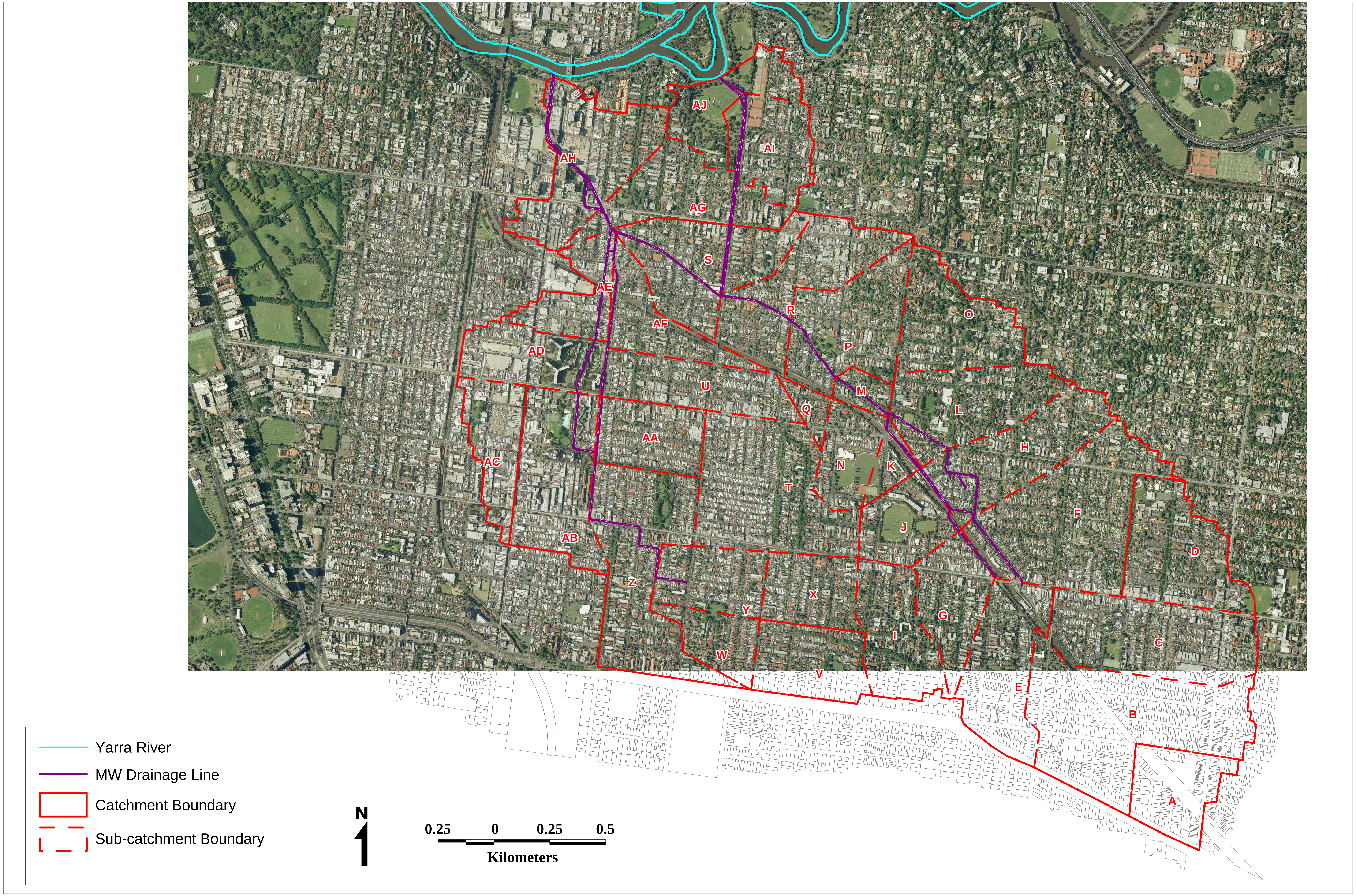

Figure 3.1 - RORB Sub-Catchment Layout

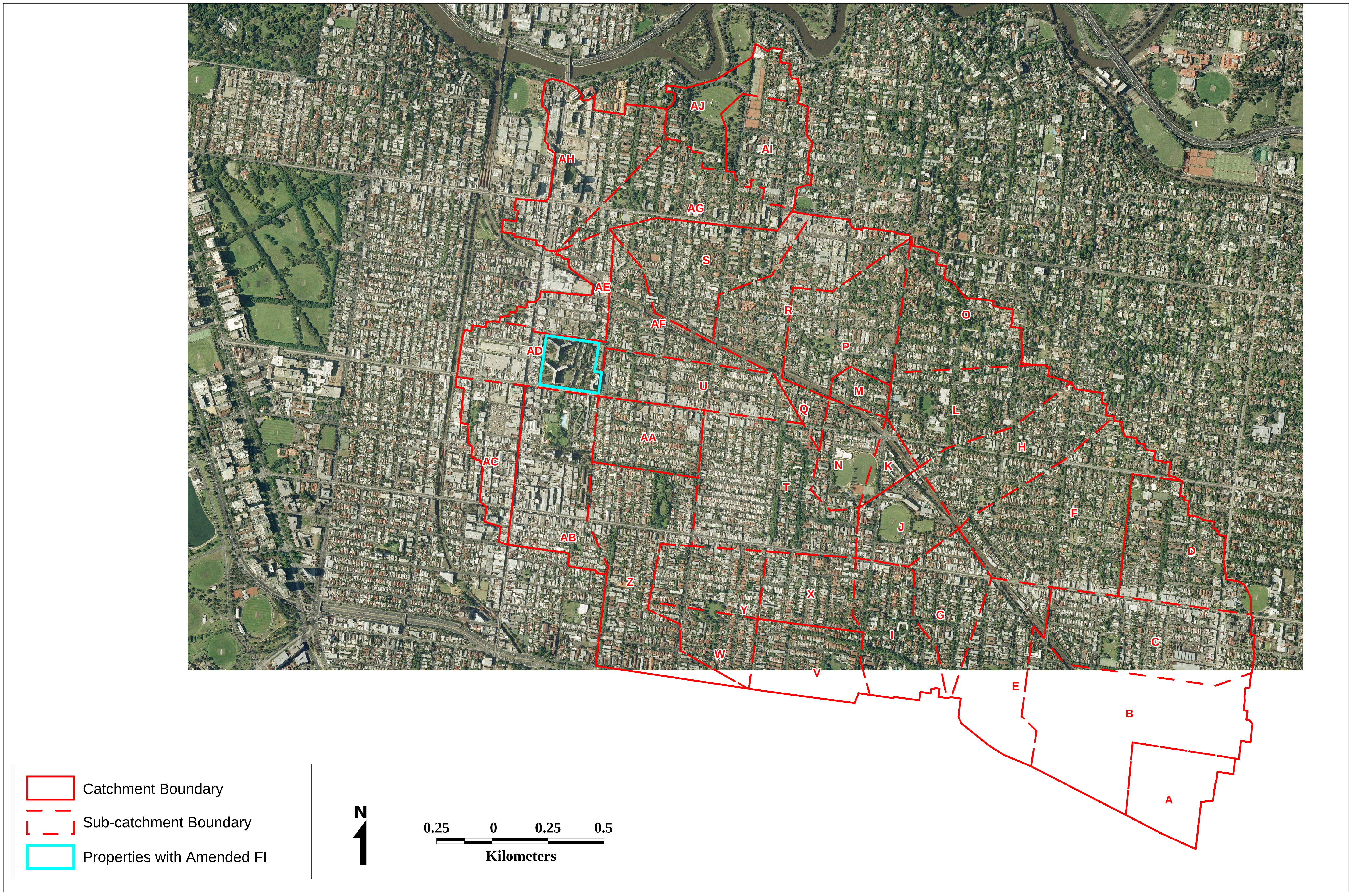

Figure 3.2 - Properties with Amended Fractions Impervious

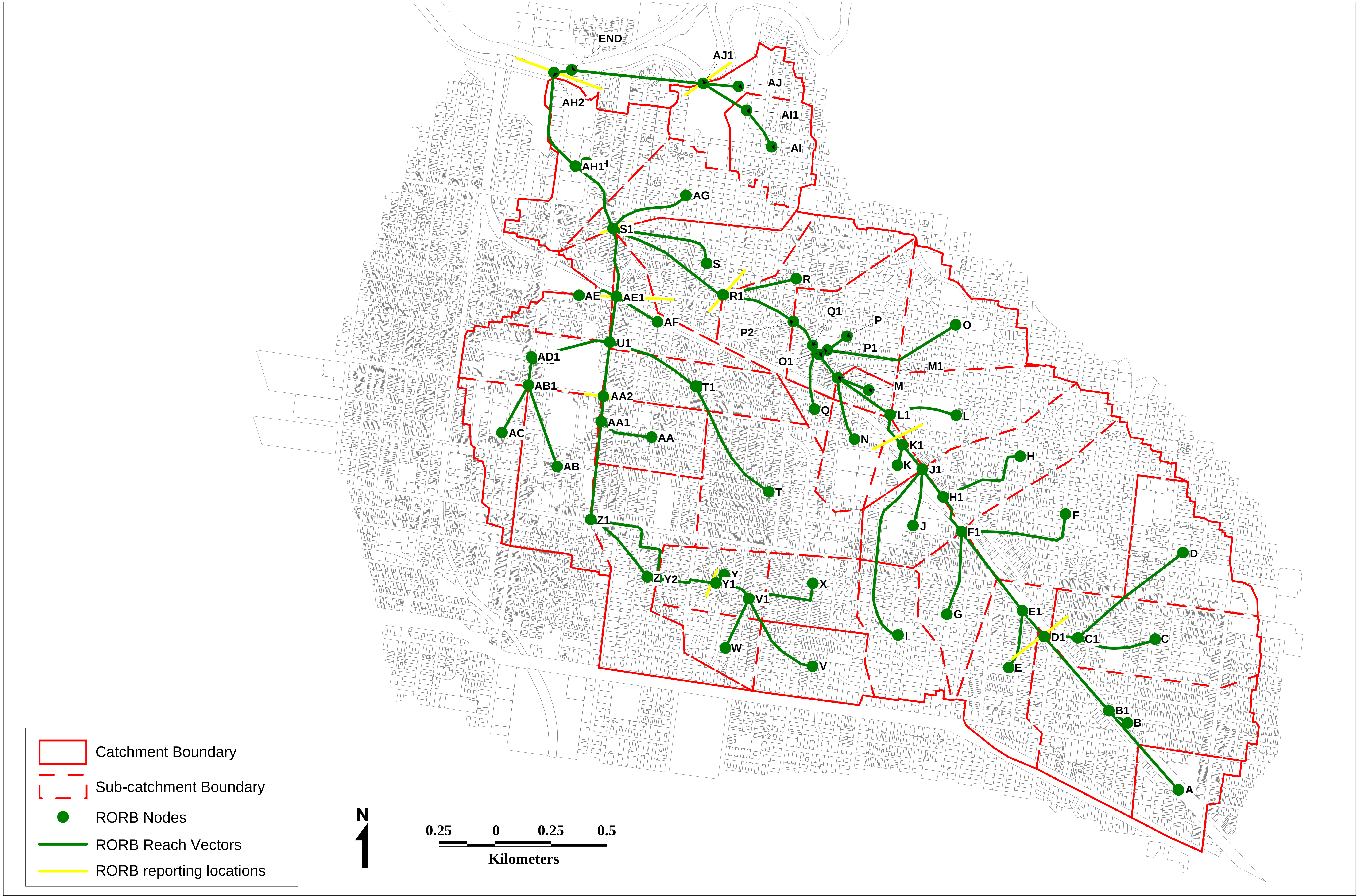

Figure 3.3 - RORB Vectors

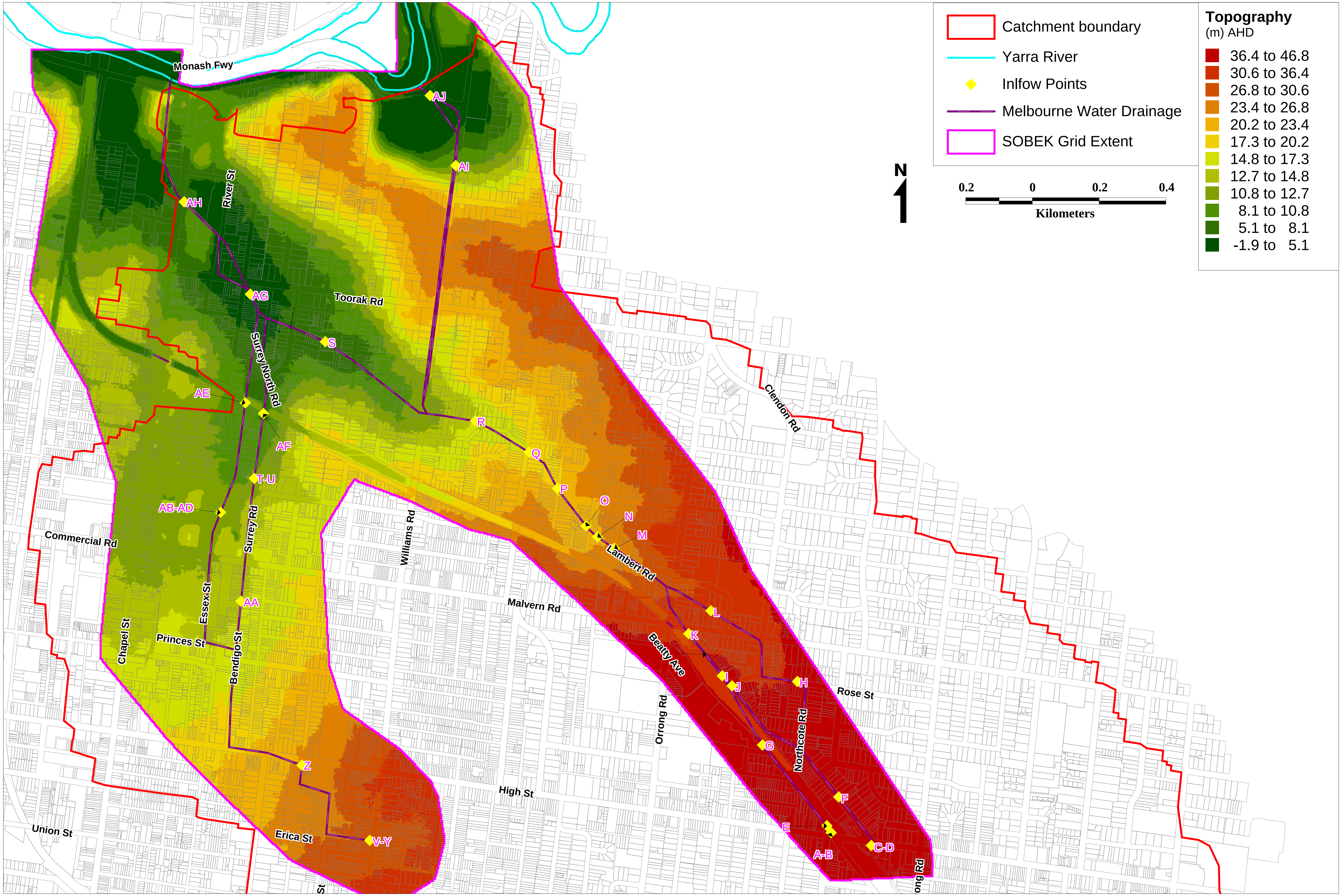

Figure 4.1 - SOBEK model

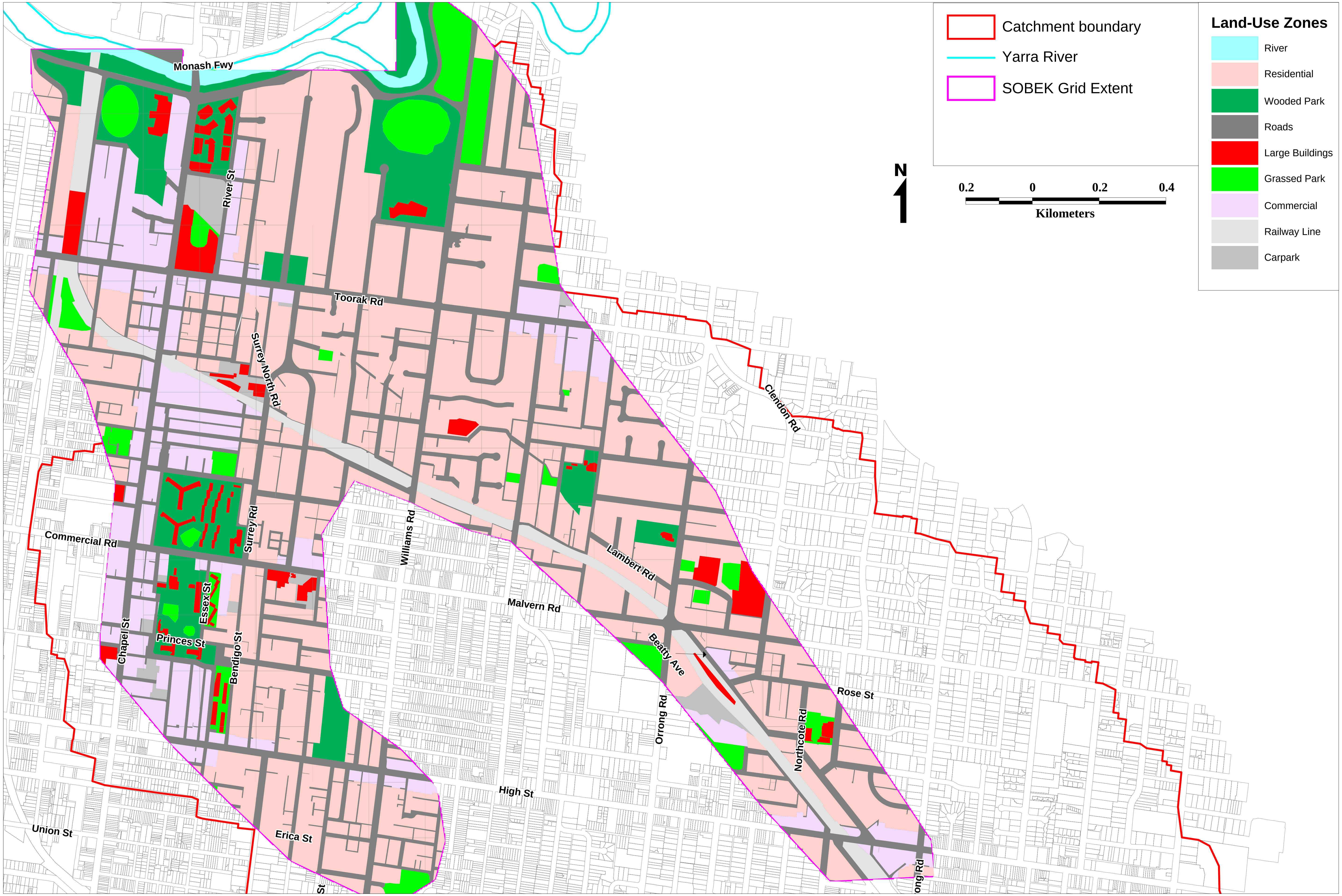

Figure 4.2 - Land-use zones

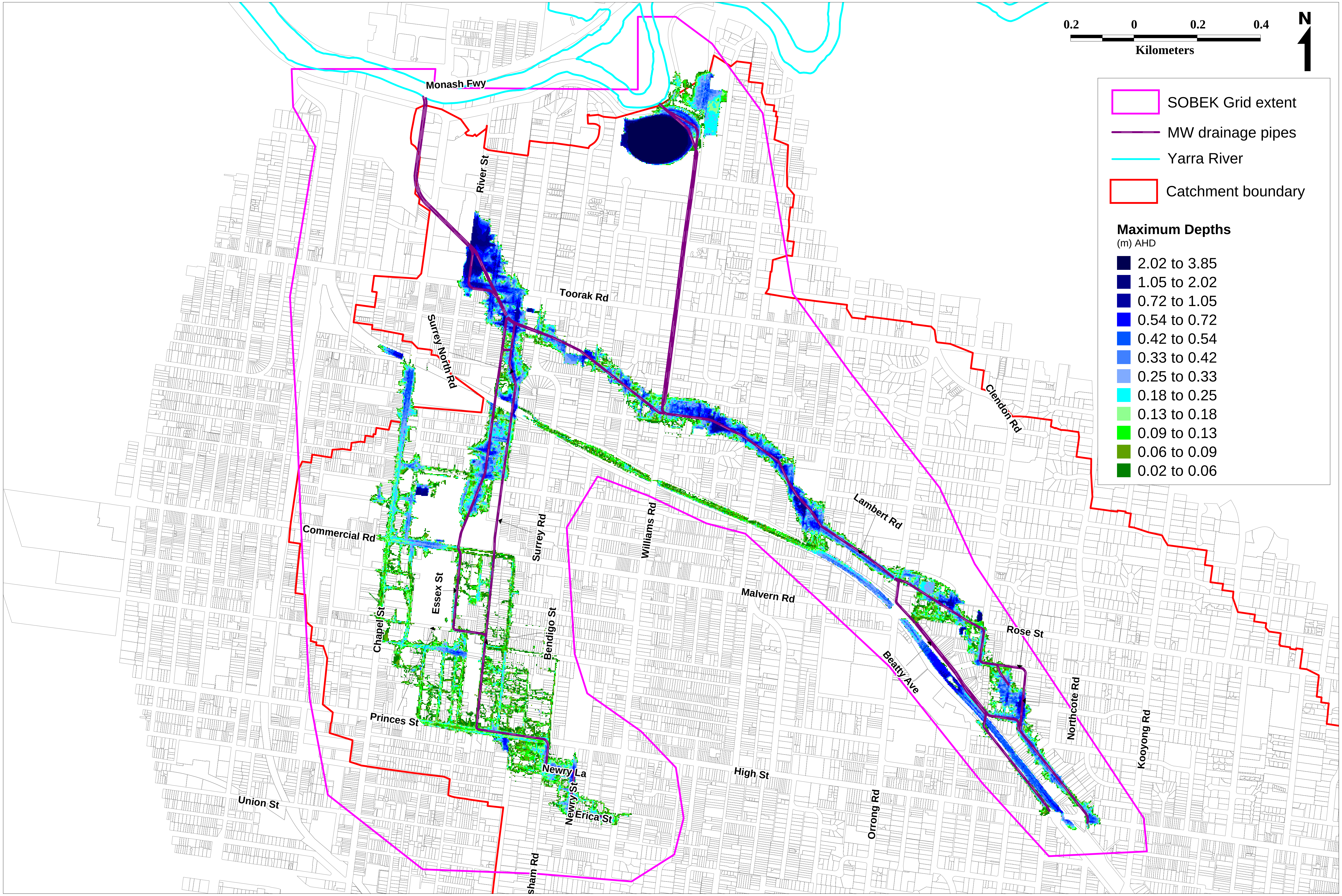

Figure 5.1 - 100 Year Flood Extent and Depth Existing Scenario

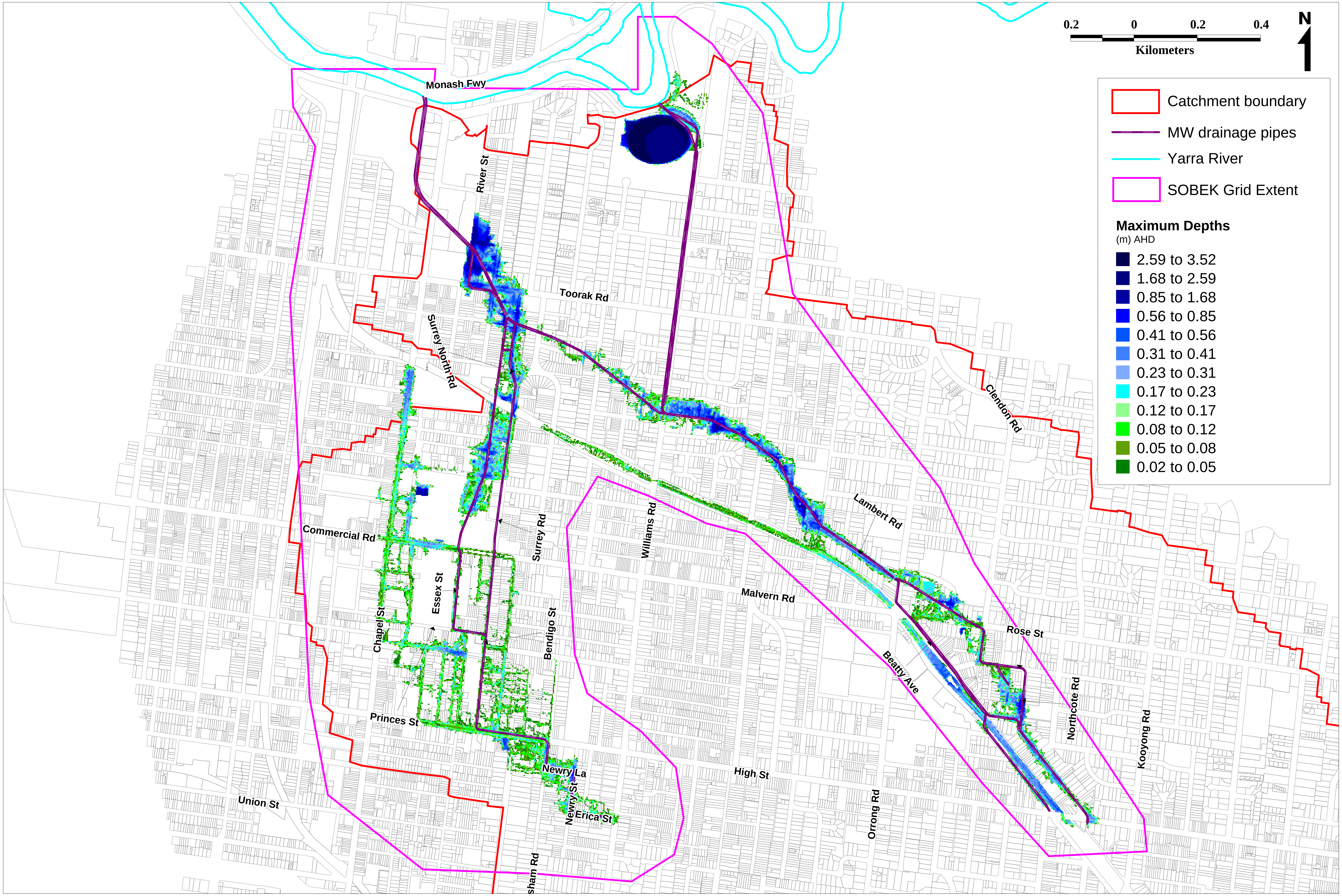

Figure 5.2 - 50 Year Flood Extent and Depth Existing Scenario

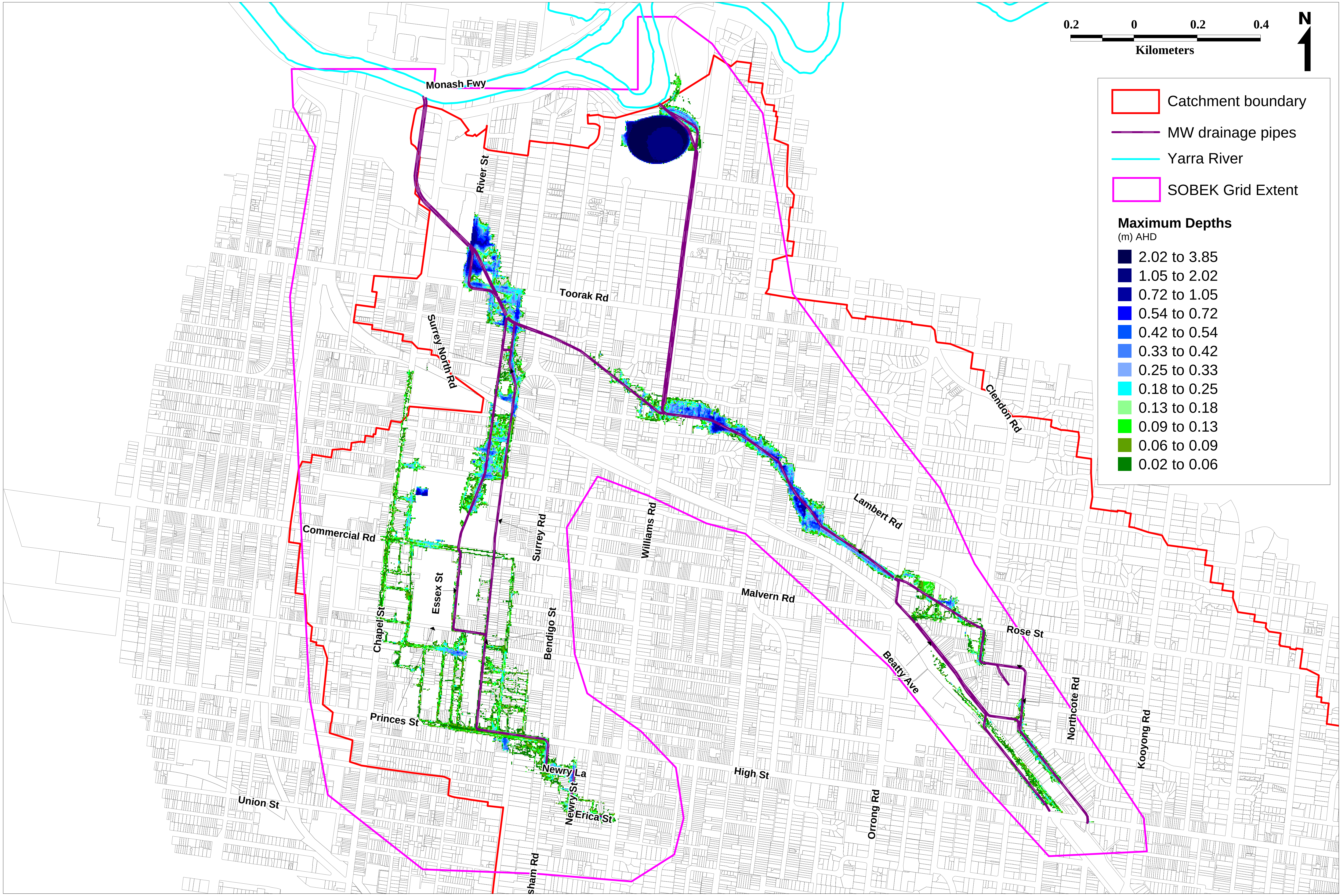

Figure 5.3 - 20 Year Flood Extent and Depth Existing Scenario

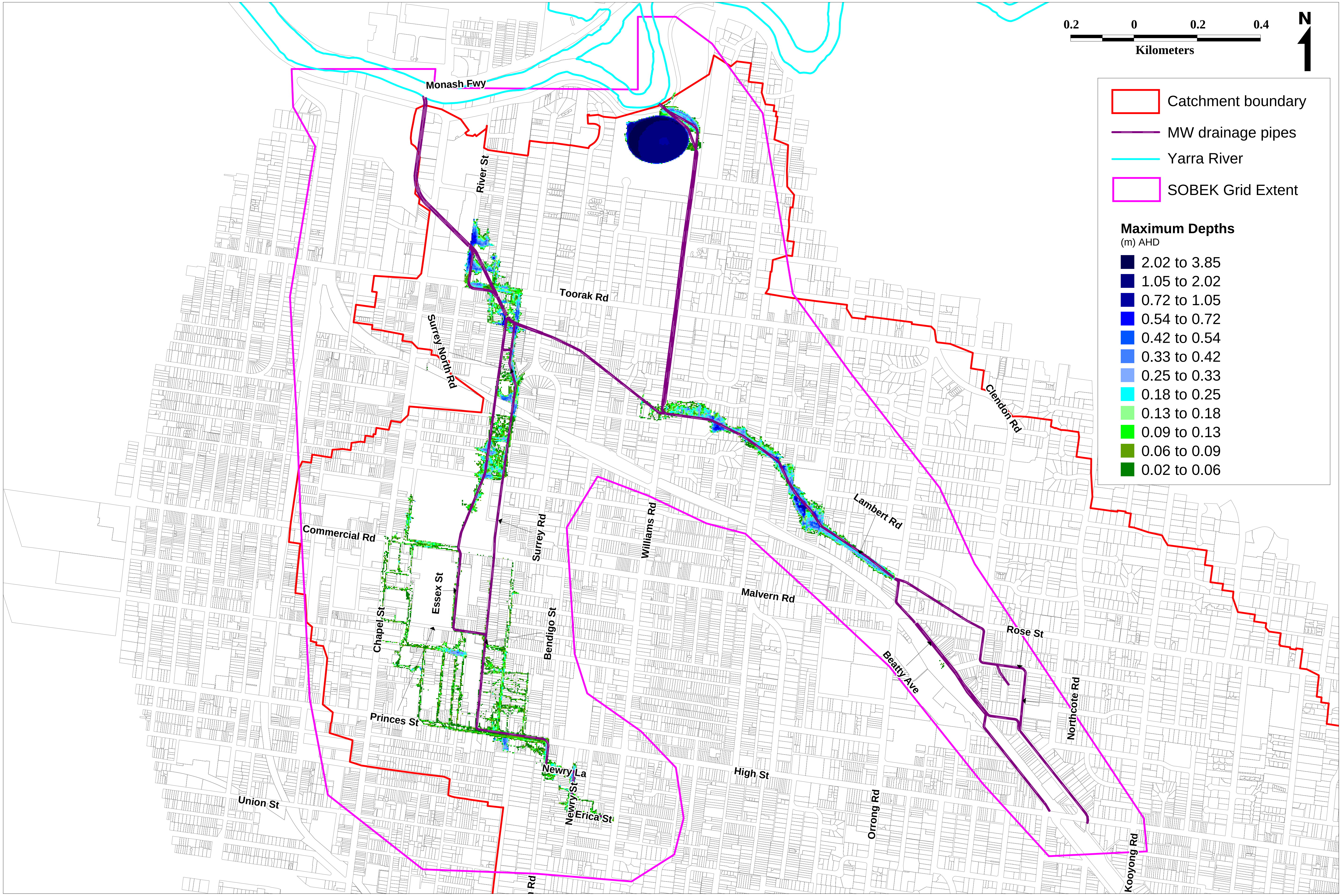

Figure 5.4 - 10 Year Flood Extent and Depth Existing Scenario

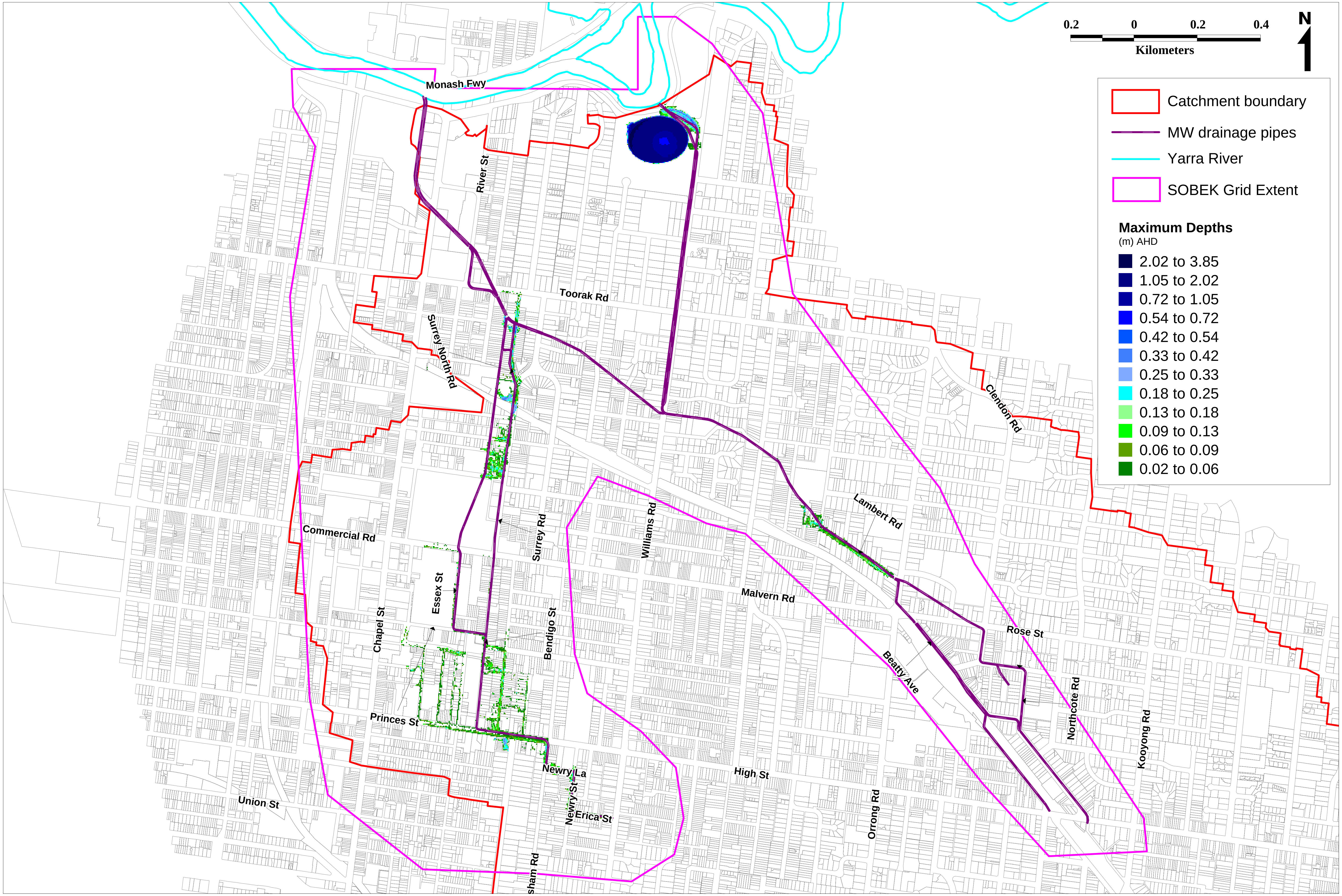

Figure 5.5 - 5 Year Flood Extent and Depth Existing Scenario

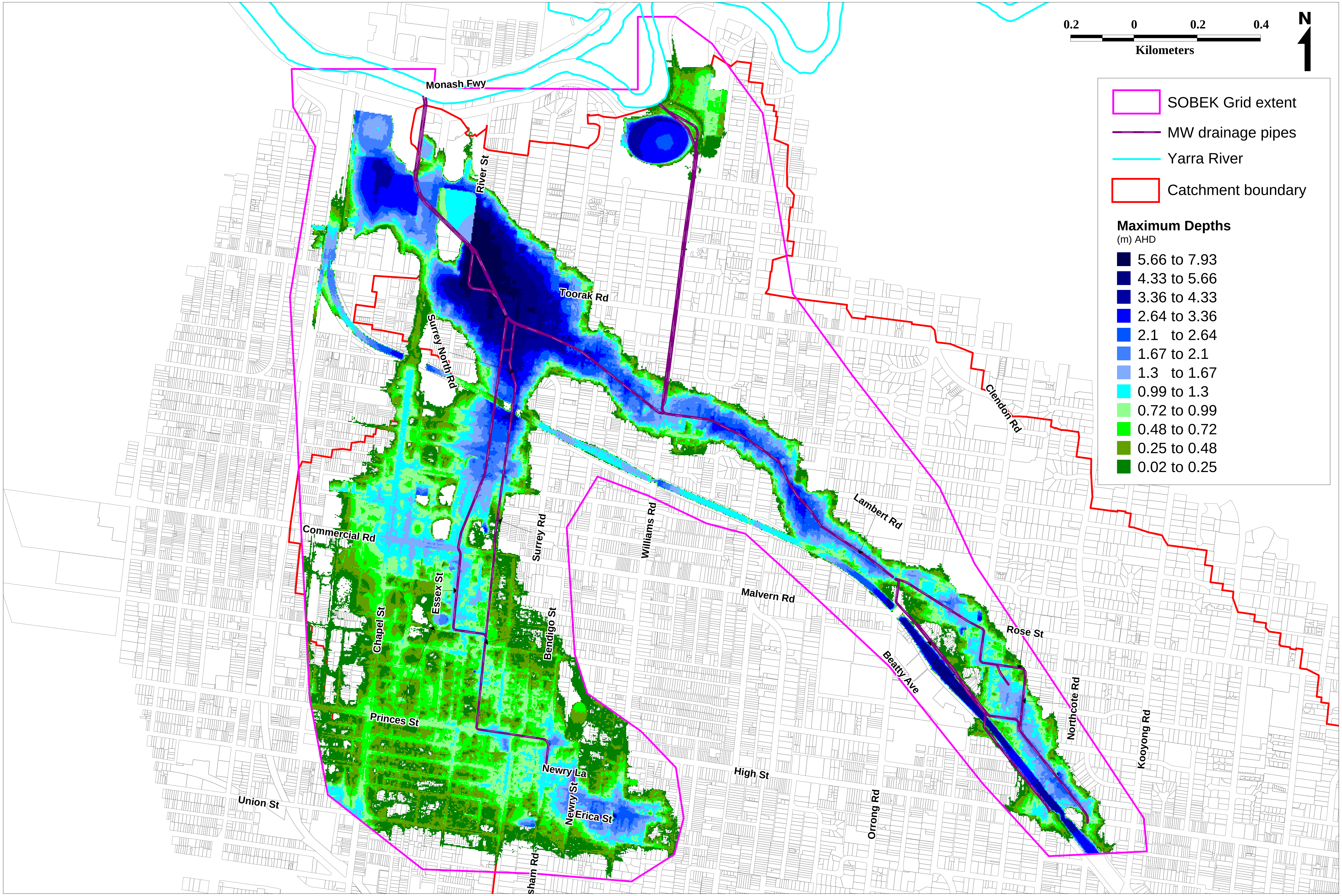

Figure 5.6 - Probable Maximum Flood Extent and Depth Existing Scenario

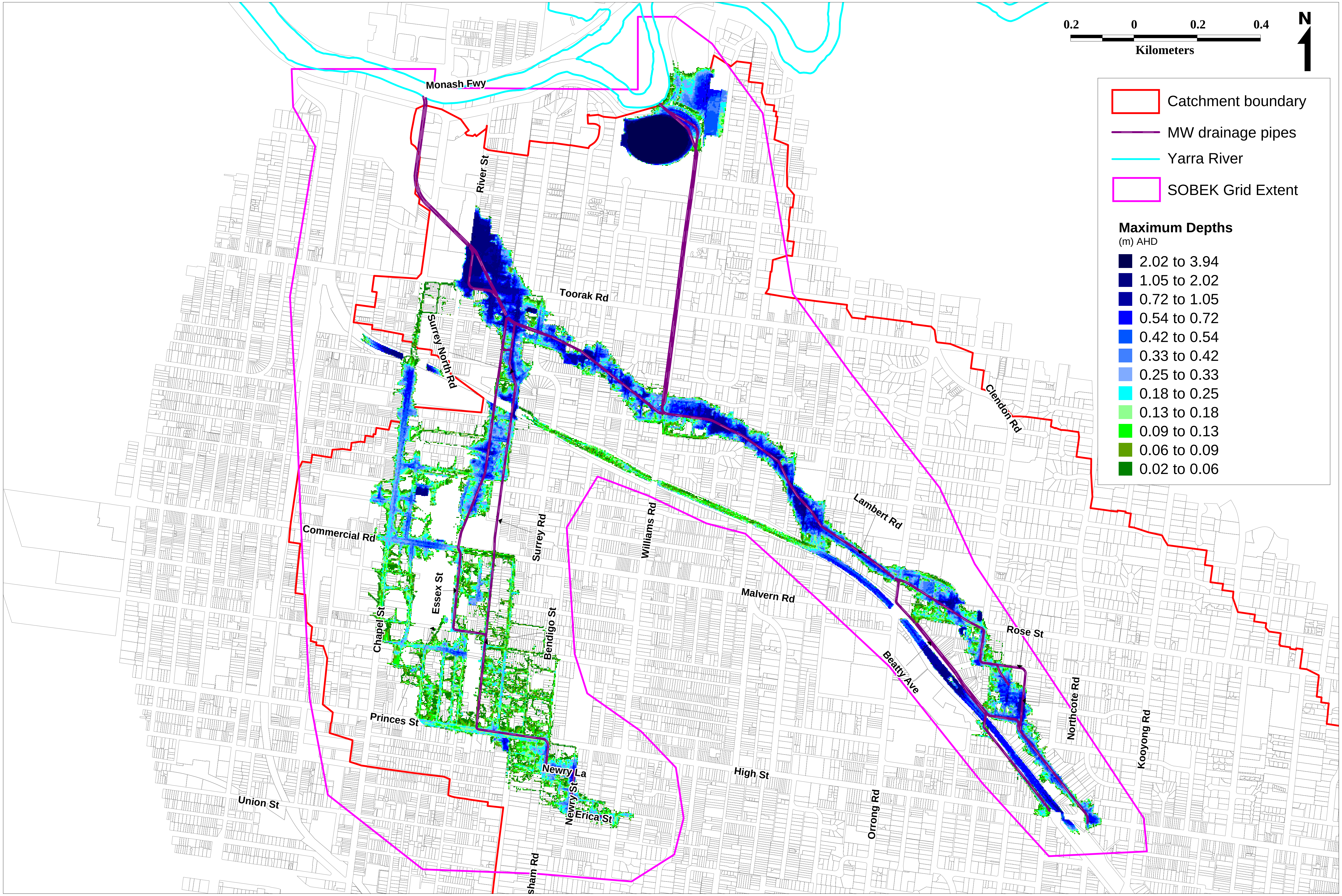

Figure 5.7 - 100 Year Flood Extent and Depth Climate Change Scenario

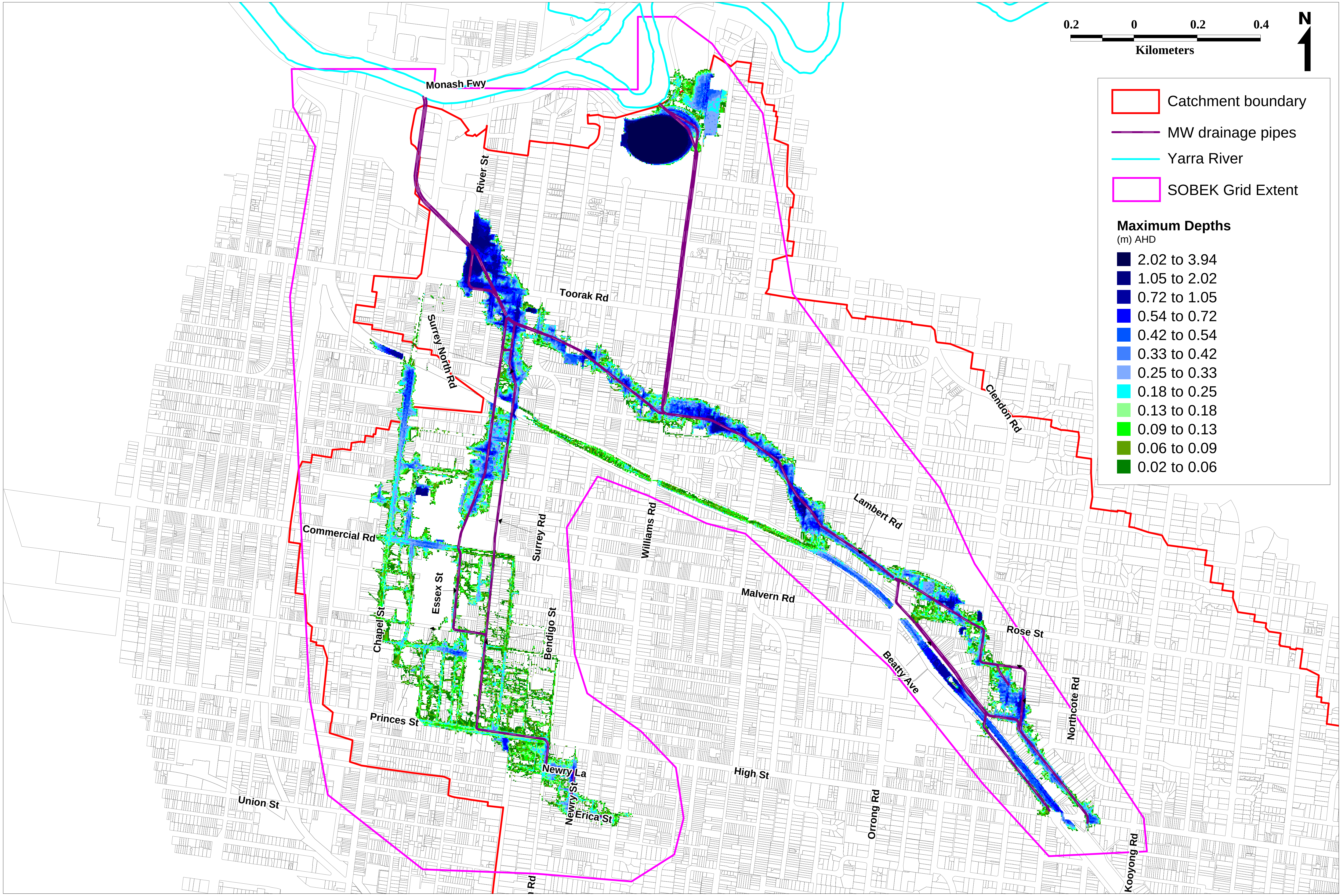

Figure 5.8 - 50 Year Flood Extent and Depth Climate Change Scenario

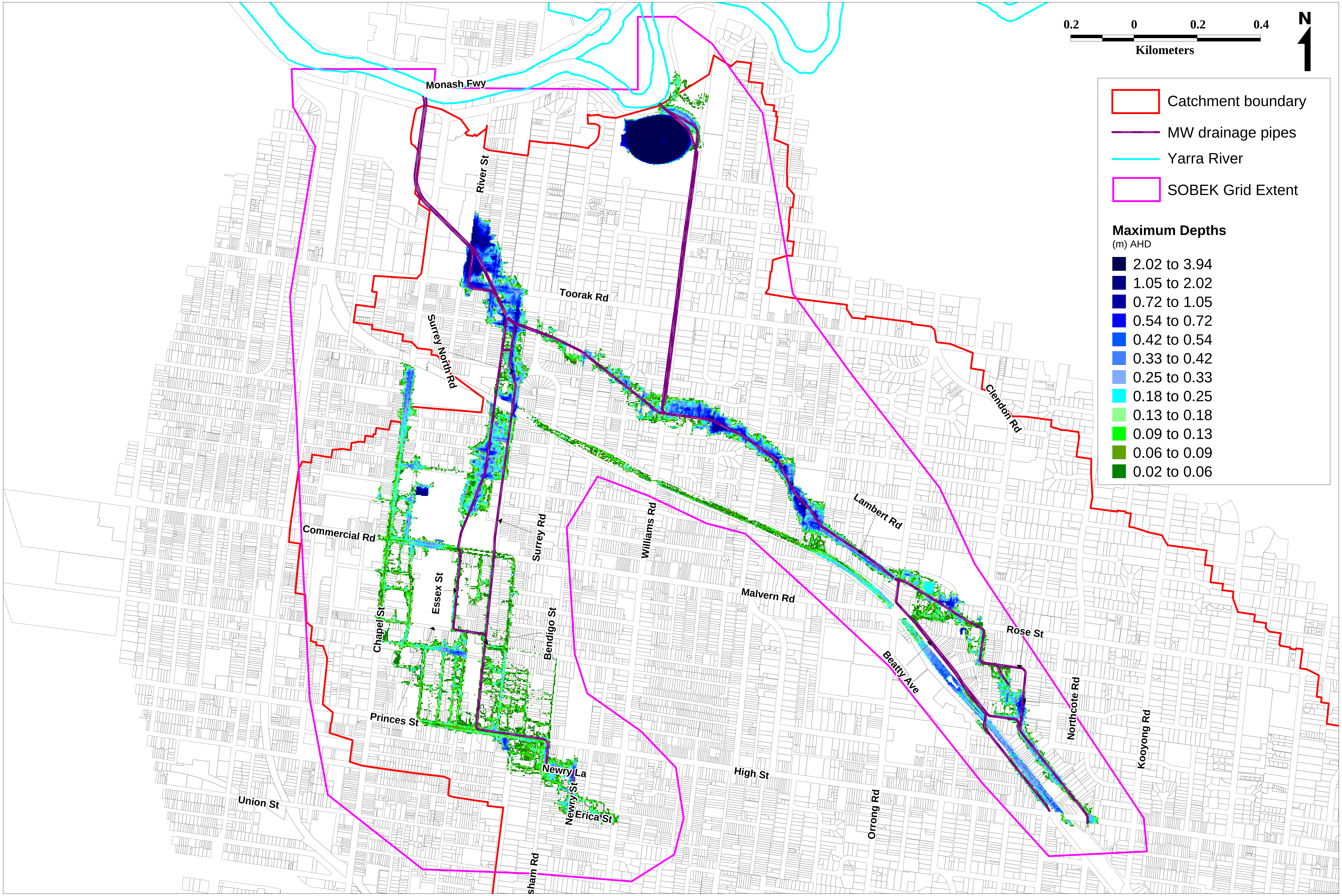

Figure 5.9 - 20 Year Flood Extent and Depth Climate Change Scenario

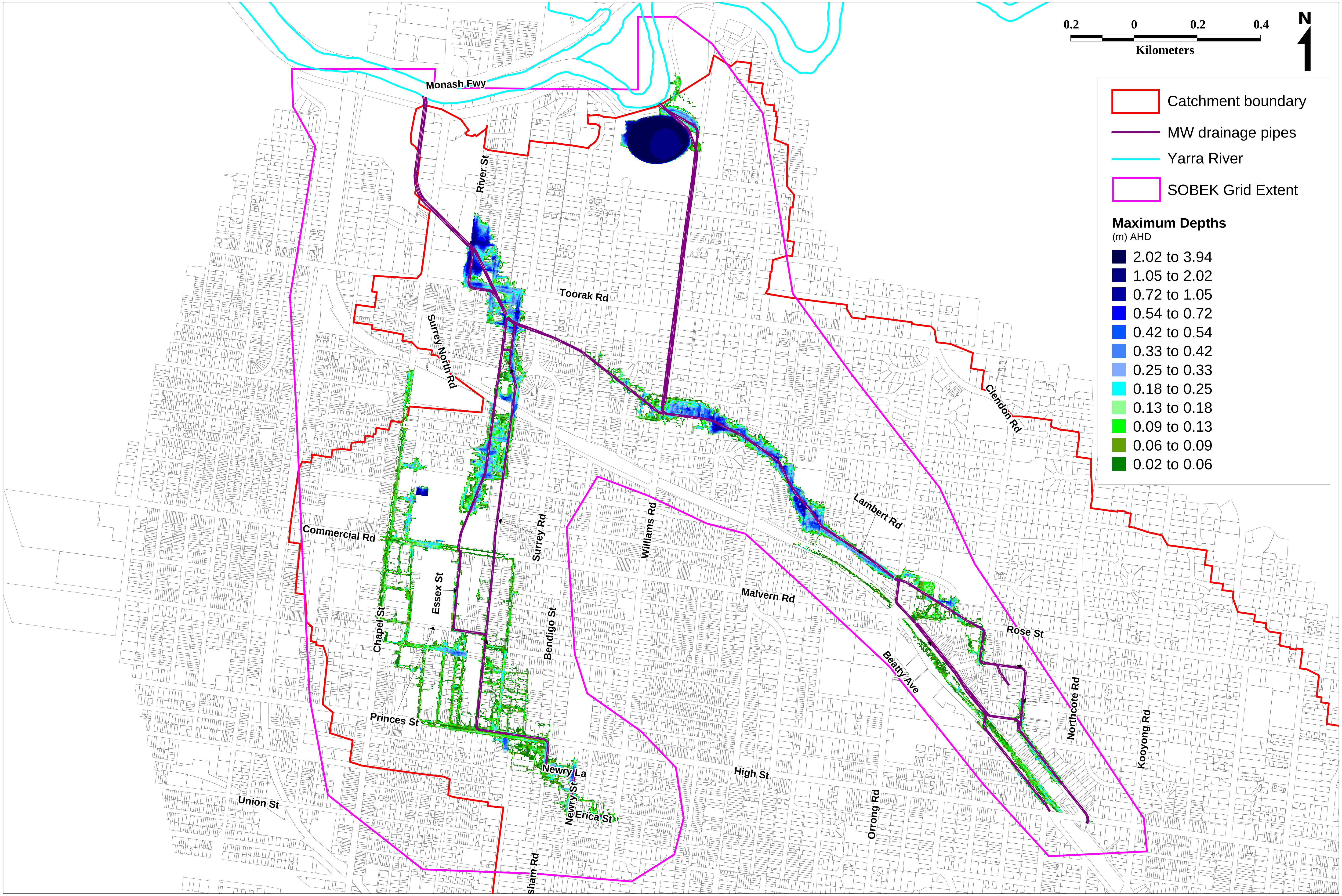

Figure 5.10 -10 Year Flood Extent and Depth Climate Change Scenario

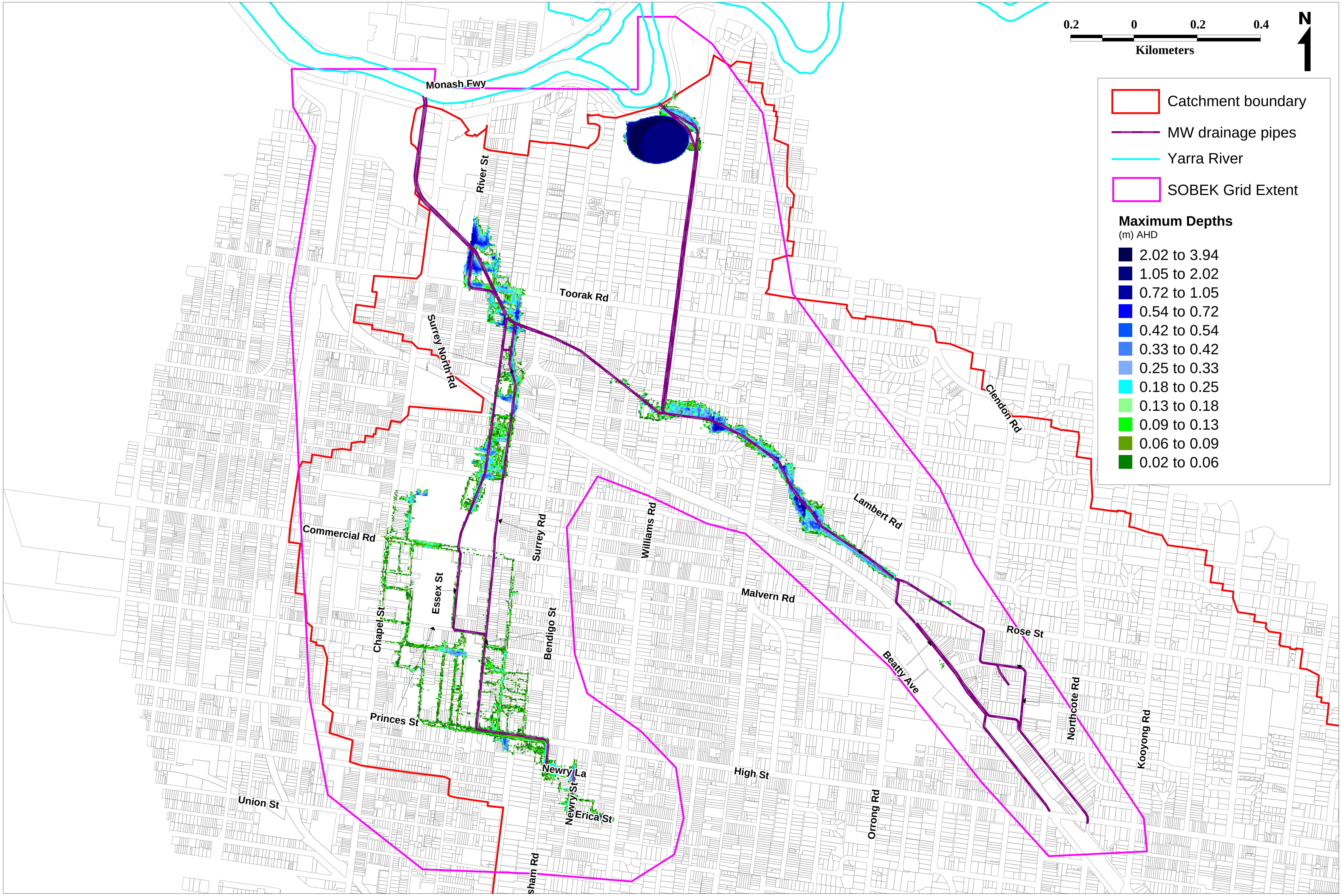

Figure 5.11 - 5 Year Flood Extent and Depth Climate Change Scenario

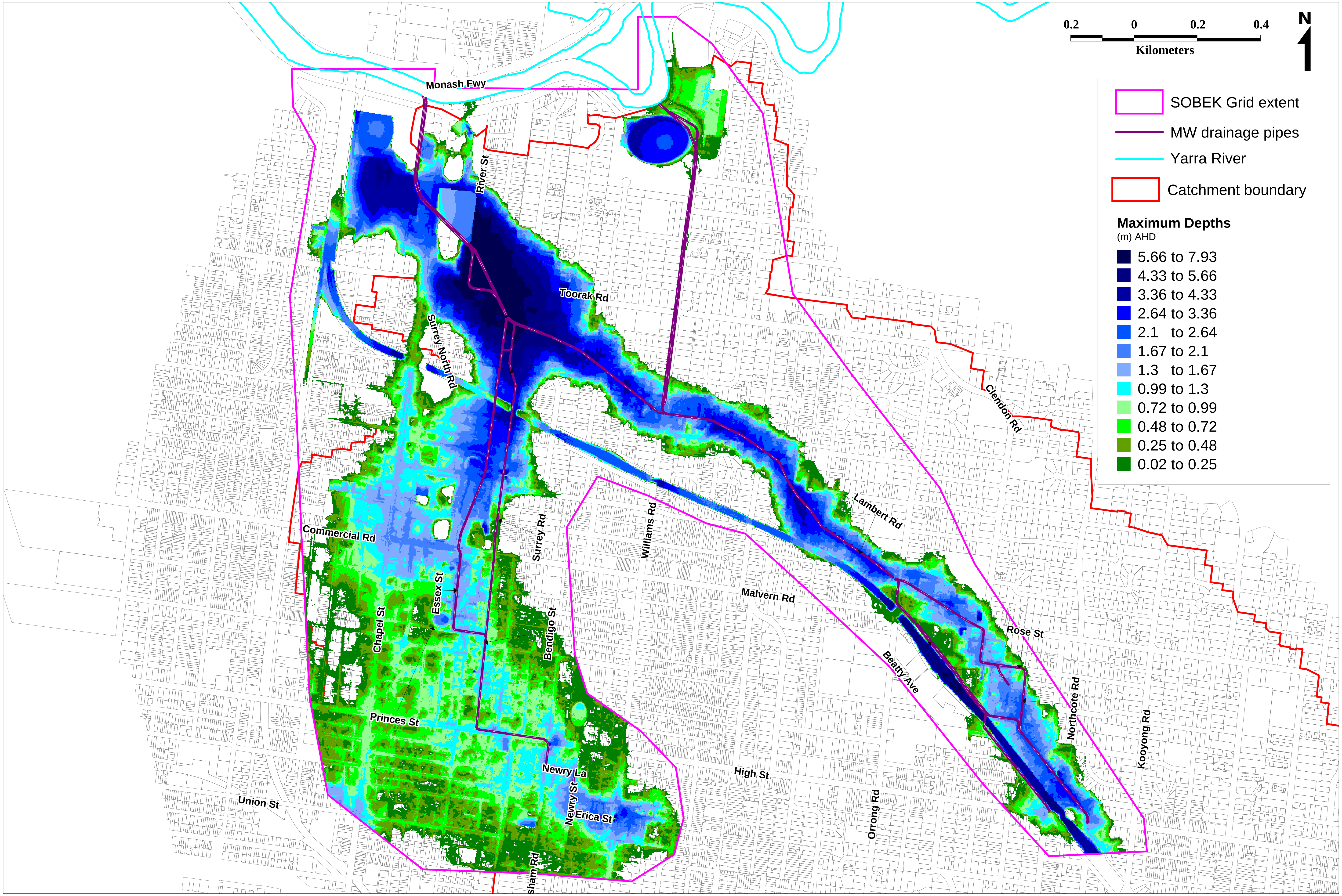

Figure 5.12 - Probable Maximum Flood Extent and Depth Climate Change Scenario

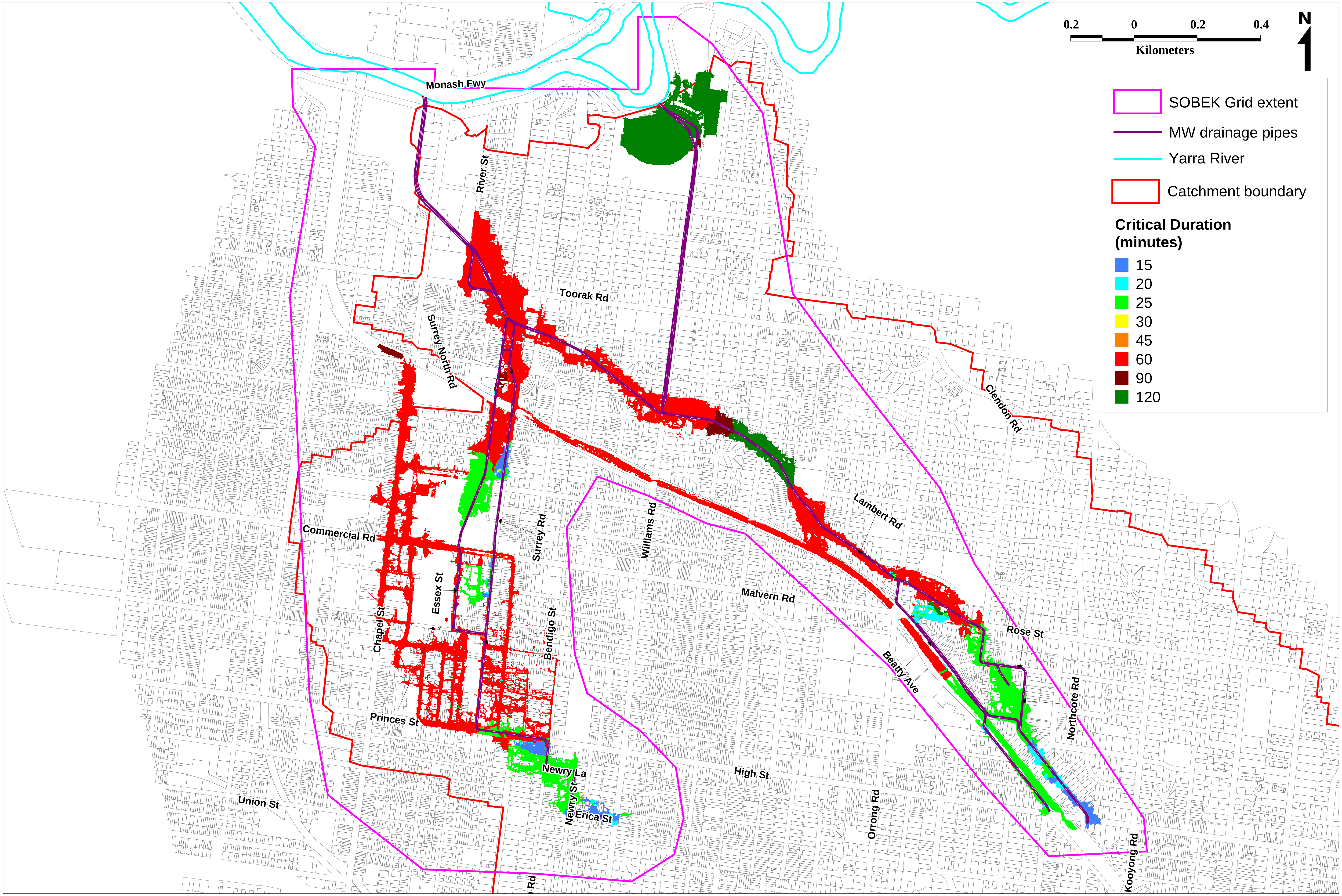

Figure 5.13 - 100 Year Critical Durations Existing Scenario

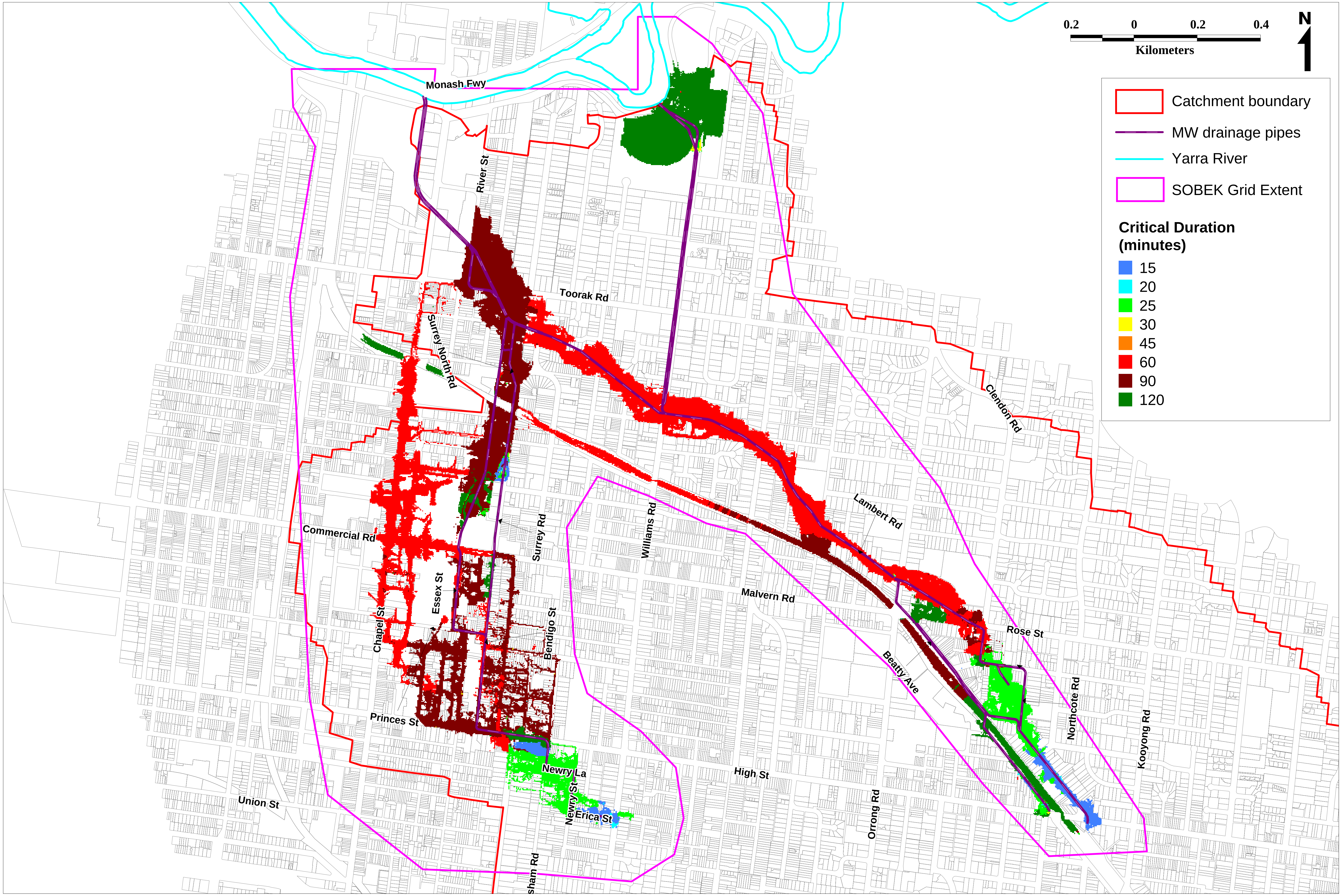

Figure 5.14 - 100 Year Critical Durations Climate Change Scenario

APPENDIX A

Amended FI Breakdown

SubArea	Drain_ID	Total Area	TotalImp Area	TotalImp Frac	CLT_Amended _TotalImpArea	CLT_Amended _TotalImpFrac
A	4811	14.26	9.70	0.68	9.70	0.68
B	4811	43.25	24.75	0.57	24.75	0.57
C	4811	30.18	18.34	0.61	18.34	0.61
D	4811	23.27	10.52	0.45	10.52	0.45
E	4811	22.38	11.88	0.53	11.88	0.53
F	4811	39.02	18.27	0.47	18.27	0.47
G	4811	14.95	8.45	0.57	8.45	0.57
H	4811	22.81	11.80	0.52	11.80	0.52
I	4811	17.93	8.23	0.46	8.23	0.46
J	4811	12.85	7.08	0.55	7.08	0.55
K	4811	4.39	2.34	0.53	2.34	0.53
L	4811	22.41	9.64	0.43	9.64	0.43
M	4811	3.94	2.65	0.67	2.65	0.67
N	4811	11.02	6.41	0.58	6.41	0.58
O	4811	20.79	8.46	0.41	8.46	0.41
P	4811	24.01	16.54	0.69	16.54	0.69
Q	4811	3.07	2.34	0.76	2.34	0.76
R	4811	23.38	17.34	0.74	17.34	0.74
S	4811	25.20	18.93	0.75	18.93	0.75
T	4811	35.33	27.23	0.77	27.23	0.77
U	4811	17.72	13.91	0.79	13.91	0.79
V	4811	16.91	12.40	0.73	12.40	0.73
W	4811	9.47	6.79	0.72	6.79	0.72
X	4811	13.20	9.66	0.73	9.66	0.73
Y	4811	13.75	10.35	0.75	10.35	0.75
Z	4811	36.35	24.97	0.69	24.97	0.69
AA	4811	14.38	10.79	0.75	10.79	0.75
AB	4811	47.08	34.66	0.74	34.66	0.74
AC	4811	29.45	23.20	0.79	23.20	0.79
AD	4811	16.03	12.07	0.75	10.40	0.65
AE	4811	11.51	8.92	0.78	8.92	0.78
AF	4811	13.33	9.85	0.74	9.85	0.74
AG	4811	20.49	13.27	0.65	13.27	0.65
AH	4811	26.40	20.51	0.78	20.51	0.78
AI	4811	15.40	6.79	0.44	6.79	0.44
AJ	4811	14.07	5.26	0.37	5.26	0.37

APPENDIX B

RORB Vectors

```
Prahran
C Created February 2008, JLR, Cardno Lawson Treloar, Melbourne
C Reach Type Flag,          all reach type 3
3
C The Control Vector
C Eastern Section
1,0.47,0.5,-99,                 Gen H'graph from Sub-area A
3,                              Store H'graph
1,0.1,4.5,-99,                  Gen H'graph from Sub-area B
4,                              Add running H'graph
5,0.438,0.6,-99,        Route H'graph from B1-D1
7
A-B
3,                              Store H'graph
1,0.358,2.1,-99,        Gen H'graph from Sub-area C
3,                              Store H'graph
1,0.603,1.2,-99,        Gen H'graph from Sub-area D
4,                              Add running H'graph
7
C-D
5,0.151,3.3,-99,        Route H'graph from C1-D1
4,                              Add running H'graph
5,0.151,0.5,-99,        Route H'graph from D1-E1
7
A-D
3,                              Store H'graph
1,0.266,1.1,-99,        Gen H'graph from Sub-area E
7
E
4,                              Add running H'graph
5,0.445,0.9,-99,        Route H'graph from E1-F1
3,                              Store H'graph
1,0.558,2.6,-99,        Gen H'graph from Sub-area F
7
F
4,                              Add running H'graph
3,                              Store H'graph
1,0.38,1.1,-99,                 Gen H'graph from Sub-area G
7
G
4,                              Add running H'graph
5,0.187,2.4,-99,        Route H'graph from F1-H1
3,                              Store H'graph
1,0.442,2.8,-99,        Gen H'graph from Sub-area H
7
H
4,                              Add running H'graph
5,0.155,0.6,-99,        Route H'graph from H1-J1
3,                              Store H'graph
1,0.859,0.2,-99,        Gen H'graph from Sub-area I
7
I
4,                              Add running H'graph
3,                              Store H'graph
1,0.255,0.8,-99,        Gen H'graph from Sub-area J
7
J
4,                              Add running H'graph
5,0.139,0.7,-99,        Route H'graph from J1-K1
3,                              Store H'graph
1,0.093,3.8,-99,        Gen H'graph from Sub-area K
```

7
K
4, Add running H'graph
7
Intersect of Orrong and Malvern Rd
5,0.161,2.8,-99, Route H'graph from K1-L1
3, Store H'graph
1,0.303,1.5,-99, Gen H'graph from Sub-area L
7
L
4, Add running H'graph
5,0.286,2.1,-99, Route H'graph from L1-M1
3, Store H'graph
1,0.149,2,-99, Gen H'graph from Sub-area M
7
M
4, Add running H'graph
3, Store H'graph
1,0.287,4,-99, Gen H'graph from Sub-area N
7
N
4, Add running H'graph
5,0.135,1.5,-99, Route H'graph from M1
3, Store H'graph
1,0.62,1.7,-99, Gen H'graph from Sub-area O
7
O
3, Store H'graph
1,0.107,0.9,-99, Gen H'graph from Sub-area P
7
P
4, Add running H'graph
5,0.043,9.3,-99, Route H'graph from O1-P1
4, Add running H'graph
5,0.049,1,-99, Route H'graph from P1-Q1
3, Store H'graph
1,0.288,3.1,-99, Gen H'graph from Sub-area Q
7
Q
4, Add running H'graph
5,0.141,0.5,-99, Route H'graph from Q1-P2
5,0.342,1.5,-99, Route H'graph from P2-R1
3, Store H'graph
1,0.338,2.4,-99, Gen H'graph from Sub-area R
7
R
4, Add running H'graph
7
Near corner of Williams Rd and Cassell St
5,0.579,0.8,-99, Route H'graph from R1-S1
3, Store H'graph
1,0.49,1,-99, Gen H'graph from Sub-area S
7
S
4, Add running H'graph
3, Store H'graph
C South-Eastern Branch
1,0.586,1.6,-99, Gen H'graph from Sub-area T
3, Store H'graph
1,0.012,2.6,-99, Gen H'graph from Sub-area U
4, Add running H'graph

7
T-U
5,0.435,1.7,-99, Route H'graph from T1-U1
3, Store H'graph
C Southern Branch
1,0.434,0.7,-99, Gen H'graph from Sub-area V
3, Store H'graph
1,0.243,0.6,-99, Gen H'graph from Sub-area W
4, Add running H'graph
3, Store H'graph
1,0.357,0.7,-99, Gen H'graph from Sub-area X
4, Add running H'graph
5,0.173,0.9,-99, Route H'graph from V1-Y1
3, Store H'graph
1,0.051,1,-99, Gen H'graph from Sub-area Y
4, Add running H'graph
7
V-Y
5,0.274,0.9,-99, Route H'graph from Y1-Y2
5,0.528,1.1,-99, Route H'graph from Y2-Z1
3, Store H'graph
1,0.364,1.6,-99, Gen H'graph from Sub-area Z
7
Z
4, Add running H'graph
5,0.44,1,-99, Route H'graph from Z1-AA1
3, Store H'graph
1,0.244,1.4,-99, Gen H'graph from Sub-area AA
7
AA
4, Add running H'graph
5,0.112,0.1,-99, Route H'graph from AA1-AA2
7
Corner Malvern Rd and Bendigo St
5,0.244,1,-99, Route H'graph from AA2-U1
4, Add running H'graph
3, Store H'graph
C South-Western Branch
1,0.692,0.9,-99, Gen H'graph from Sub-area AB
3, Store H'graph
1,0.504,0.5,-99, Gen H'graph from Sub-area AC
4, Add running H'graph
5,0.127,0.1,-99, Route H'graph from AB1-AD1
3, Store H'graph
1,0.01,0.1,-99, Gen H'graph from Sub-area AD
4, Add running H'graph
7
AB-AD
5,0.358,0.4,-99, Route H'graph from AD1-U1
4, Add running H'graph
C Joined Southern section
5,0.207,0.7,-99, Route H'graph from U1-AE1
3, Store H'graph
1,0.175,0.9,-99, Gen H'graph from Sub-area AE
7
AE
4, Add running H'graph
3, Store H'graph
1,0.217,0.7,-99, Gen H'graph from Sub-area AF
7
AF

```
4,                              Add running H'graph
7
Corner Surrey and Garden St
5,0.309,0.5,-99,        Route H'graph from AE1-S1
4,                              Add running H'graph
3,                              Store H'graph
C Joined Southern and Eastern sections
1,0.373,2.4,-99,        Gen H'graph from Sub-area AG
7
AG
4,                              Add running H'graph
7
Intersect Essex St Main Drain and Prahran Main Drain
5,0.345,0.5,-99,        Route H'graph from S1-AH1
3,                              Store H'graph
1,0.052,0.1,-99,        Gen H'graph from Sub-area AH
7
AH
4,                              Add running H'graph
5,0.468,1.8,-99,        Route H'graph from AH1-AH2
7
Yarra Outlet major network
5,0.08,0.1,-99,                 Route H'graph from AH2-END
3                               Store H'graph
C Minor Network
1,0.198,3.5,-99,        Gen H'graph from Sub-area AI
7
AI
5,0.228,0.1,-99,        Route H'graph from AI1-AJ1
3,                              Store H'graph
1,0.158,0.3,-99,        Gen H'graph from Sub-area AJ
7
AJ
4,                              Add running H'graph
7
Yarra Outlet minor network
5,0.590,0.9,-99,        Route H'graph from AJ1-END
4,
7
Dummy Total Catchment
C Dummy Total Catchment Hydrograph for modelling stability only. Outlet stations to be recorded are:
C "Yarra Outlet major network" and "Yarra Outlet minor network"
0
C Subcatchment data
0.143,0.433,0.302,0.233,0.224,0.39,0.149,0.228,0.179,0.128,0.044,0.224,0.039,0.11
0.208,0.24,0.031,0.234,0.252,0.353,0.177,0.169,0.095,0.132,0.138,0.364,0.144,0.471
0.294,0.16,0.115,0.133,0.205,0.264,0.154,0.141,-99
C
C Subarea flag and fractions impervious
1
0.680,0.572,0.608,0.452,0.531,0.468,0.565,0.518,0.459,0.551,0.533,0.430,0.673,0.582
0.407,0.689,0.762,0.742,0.751,0.771,0.785,0.733,0.716,0.732,0.752,0.687,0.750,0.736
0.788,0.648,0.775,0.739,0.647,0.777,0.441,0.374,-99
```

APPENDIX C

Sample t_c calculation

Calculating Tc for total Prahran Main Drain		
Catchments A-D - assume a 600mm diameter pipe at the natural slope of the surface		
Diameter (m) =		0.6
area (m2) =	$\pi \times r^{\wedge 2}$	0.283
Perimeter (m) =	π *D	1.885
Hyd Radius =	$\frac{A}{P}$	0.15
Slope =		0.01
n =		0.016
Q (m3/sec) =	$\left(A \times R^{\frac{2}{3}} \times S^{\frac{1}{2}}\right) \div n$	0.499
V (m/sec) =	**Error! Objects cannot be created from editing field codes.**	1.764
Distance (m) =		1400
Time (min) =	(distance/V)/60	13
Time taken for water to flow to that section of pipe as estimated from SOBEK is		
t (mins) =	22	
Time taken for water to flow from roof to pipe is:		
t (mins) =	7	
Total t_c =	42	