Hydraulic Modelling

Margate Rivulet Hydraulic Assessment

NW30106

Prepared for
Kingborough Council

9 September 2021

Cardno®

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Document History

Version	Effective Date	Description of Revision	Prepared by	Reviewed by
R001	25/02/2021	Draft Data Review	SS, PW, DVH	RG
R002	27/04/2021	Draft Model Setup & Methodology	DVH	RG
R003	09/07/2021	Draft Report	SI	RG
R004	24/08/2021	Final Report	SI	RG
R005	09/09/2021	Final Delivery	SI	RG

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1 Introduction

Kingborough Council (council) have engaged Cardno to undertake a hydraulic assessment of the Margate Rivulet catchment located approximately 6km southwest of Kingston, Tasmania. The Rivulet is the major watercourse in the Margate hinterland and outlets to North West Bay with a contributing catchment of approximately 23km^2.

The works completed as part of this Project intends to identify flooding and associated risks across the catchment and inform future planning decisions for the region. Significant urban development which has the potential to occur throughout the catchment, which will have a potential impact on flooding. Council have identified that other aspects currently within the catchment such as the amount of vegetation and erosion may also have an impact on current and future flooding.

Figure 1-1 Mount Wellington - Margate Rivulet Catchment (Cardno, 2021)

1.1 Purpose of this Study

This Project consists of a number of stages including:

> Data Review – assessing the data available and determining the most appropriate information to take forward to the flood modelling;

> Hydrological Modelling – deriving flows which represent flood events so that these can be introduced to the hydraulic model with additional consideration to urban development and climate change;

> Hydraulic Modelling – determining flood risk in the catchment as a result of these flows (for example flood depth, velocity and hazard) with impacts of urban development and climate change assessed;

> Flood Mapping – preparing GIS and mapped outputs to illustrate the hydraulic modelling findings; and

> High-Level Vegetation and Erosion Assessments – undertaking a MCA to determine areas of risk for Council.

1.2 Related Documents

The following documents should be referred to in conjunction to this report:

> Data Review report – dated 26 February 2021 (file reference NW30106_R001_Data_Review_Margate_Rivulet.pdf)

> Model Setup and Methodology Report – dated 27 April 2021 (file reference NW30106_R002_Model_Setup_&_Methodology_Margate_Rivulet.pdf)

1.3 Study Area

The study area for the Project is shown in Figure 1-2 below and includes the following:

> Indicative catchment for Margate Rivulet;

> A refined hydrological model boundary for Margate Rivulet; and

> Council's drainage network.

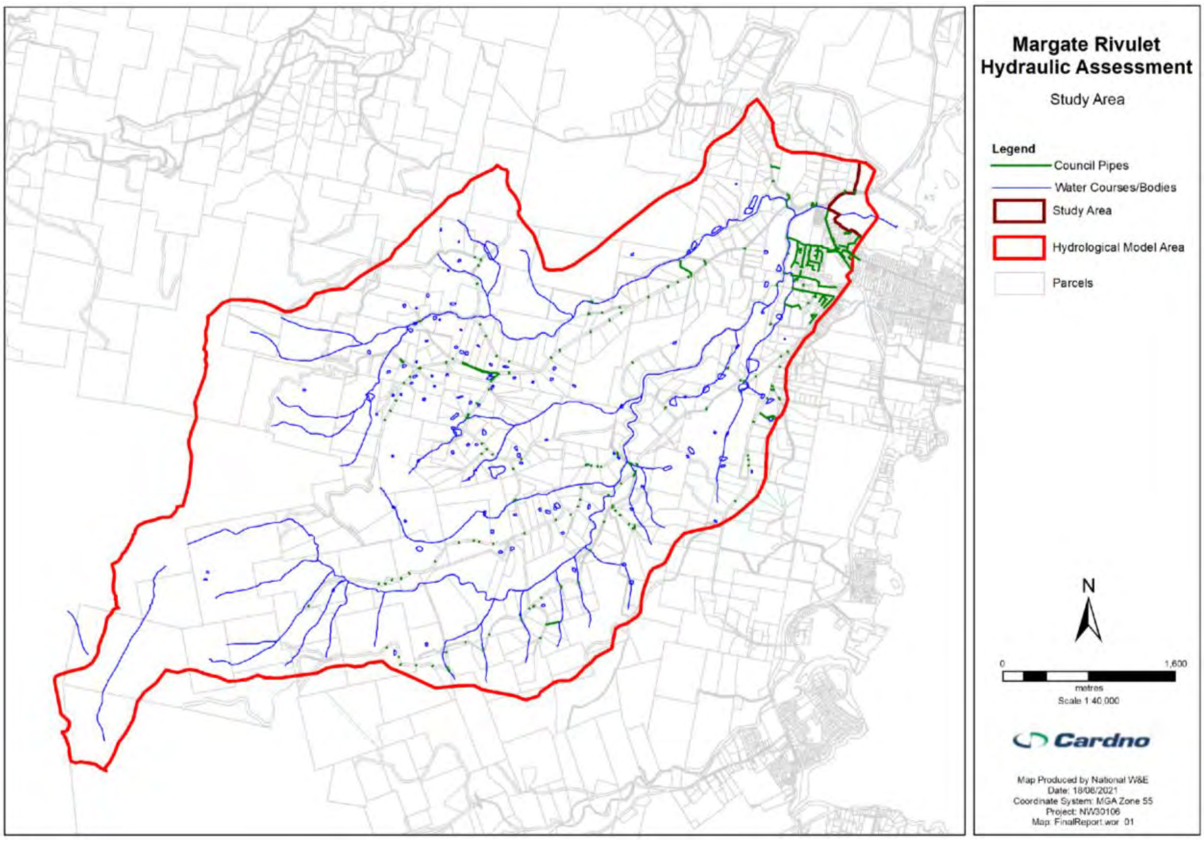


Figure 1-2 Margate Rivulet Study Area

2 Available Information

This section summarises the key information that has been used in this study. A full data review can be found in the Data Review Report (dated 26/02/21) which includes all information provided at Project inception.

2.1 Previous Studies

The following reports have been provided by council for reference in this study:

- Margate Rivulet Flood Plain Study 2006, SKM
- Snug River Flood Study, Kingborough Council 2019

2.2 Topographic Information

LiDAR has been obtained from ELVIS (Elevation Information System) for use in this study. As no single dataset covered the entire study area five separate datasets are required to cover the entire study area, namely:

- Wellington Range 1m LiDAR - Tasmanian Flood Recovery Project from 2019
- Greater Hobart 1m LiDAR - Tas Coastal Project from 2013
- Mt Wellington 1m LiDAR - Forestry Tasmania Project from 2011
- Derwent 1m LiDAR - Climate Futures Project from 2008
- Geoscience Australia 5m LiDAR – National Resampled Project from a collection of datasets

2.3 Aerial Imagery, Parcel and Planning Data

Aerial Imagery of the catchment was obtained from NearMap, while parcel and planning data were obtained from Tasmania's open source public database (The List). This data was used as follows:

- As contextual base map information;
- To ensure the catchment was edge matched to property boundaries where applicable; and
- Estimating the Effective Impervious Area of subareas based on GIS methods provided in Book 5, Chapter 3 of Australian Rainfall and Runoff 2019 Guidelines.

2.4 Pipe and Pit Data

Council have supplied relevant GIS pipe and pit data for the study area. Where pipes were identified to be missing from the supplied dataset, dimensions were captured during the site visit.

2.5 Historical Rainfall Data

Historical Rainfall datasets were provided to Cardno by Kingborough Council for use in validation of the hydraulic model. This included data obtained from the Bureau of Meteorology (BoM) in Pluviograph and Daily formats as well as a hand recorded dataset from a local community member. These are further described in the sections below.

2.5.1 Pluviograph Data

Pluviograph data has been provided for the closest pluviograph station to the catchment, Blackmans Bay Treatment Plant (1998-2018) to derive predicted flow hydrographs for validation/verification of the hydraulic model.

2.5.2 Daily Rainfall Data

Daily rainfall data has been provided for the Sunnyside rainfall gauge (1967-2021), to assist in the validation/verification of the hydraulic model.

2.5.3 Hand Recorded Rainfall Totals

The hand recorded rainfall totals (2008, 2012-2020) have been collected by a local community member in the vicinity of the Sunnyside rainfall gauge.

2.6 Anecdotal Evidence

2.6.1 Historical Events

As part of this study, Council has provided a summary of historical flood event dates, with the key information outline below in Table 2-1. Council have obtained this information from previous flood studies, a community questionnaire, site visits, community engagement as well as news sources and community photos.

Information provided by council indicate that the 1973 event caused the greatest impact across the catchment. However, due the significant time has elapsed since this event occurred and with significant changes to the catchment made since this date, it has been agreed with council that the May 2018 event was to be used for validation of the hydraulic model.

Table 2-1 Historical Flooding Events of the Margate Rivulet catchment

Event	Information	Evidence (if any)
6-7th June 1954*	This event is referenced in the flood questionnaire provided by Council.	
22-23rd April 1960*	This event is referenced in the flood questionnaire provided by Council.	
May 1973	This event was referenced as an event of concern to a particular community member in the 2006 study (SKM). However, it has been reported that that only 55mm of rainfall was recorded within 24 hours. Community engagement was undertaken with the owner of a property on Sandfly Road, who identified that this event was the largest experienced for their property. For flooding that occurred at the property in question, the flooding reached the second row of fruit trees as shown in the first image on the right, with approximately 400mm deep flood waters experienced at the first row of fruit trees as seen in the second image. A significant flow path was experienced through their property with flood waters sheeting down the hill shown in the third image. Debris was washed up approximately halfway up this hill, with the flood waters being approximately half way up the large hill next to the town shown in the fourth image. "In the 1973 flood, the water level reached to where the main limbs branch out from the butt…The 1973 flood did not come down the main Margate Rivulet tributary, but a smaller minor tributary, which roughly runs parallel to the last part of Old Bernies Road…" – Owner of a property on Sandfly Road Upstream at the top of the catchment near Old Bernies Rd "the flood piled logs on the bridge and his property and then continued on scouring trees and vegetation from both sides of the rivulet. (This can be seen in the aerial photo of 1974). Some logs are still there" – Owner of property on Sandfly Road	 Image 1: Flood debris at a property on Sandlfy Road, at the plum fruit trees (Site Visit location 29l)

Image 2: Flood debris a property on Sandlfy Road, at the apple fruit trees (Site Visit location 29a and 29b)

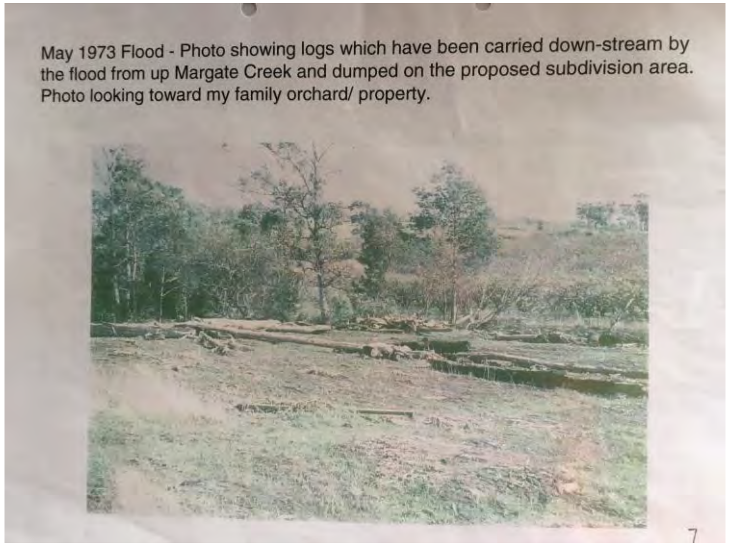
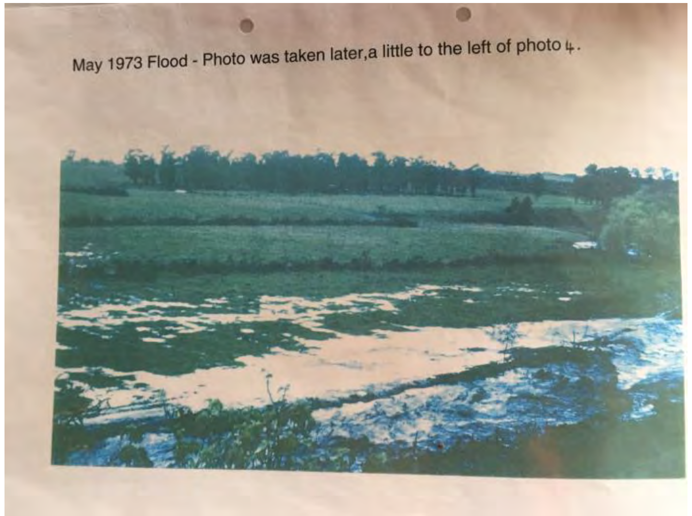


Image 3: Flood debris at a property on Sandlfy Road (across between Site Visit location 29b and 29k)

		 Image 4: Taken from the bank of a property on Sandfly Road looking downstream (between Site Visit location 29b and 29k)  Image 5: Taken from the bank of a property on Sandfly Road looking upstream (between Site Visit location 29b and 29k)

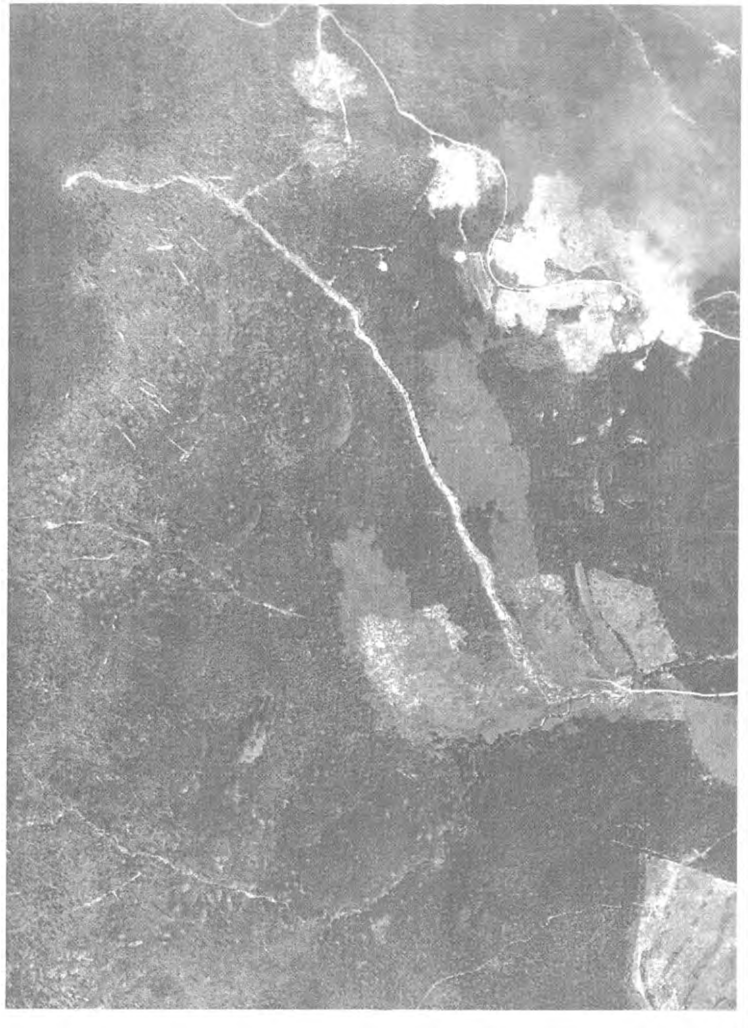


Image 6: Aerial image of 1973 flood event of catchment

		
22-23rd March 1983*	This event is referenced in the flood questionnaire provided by Council.	
18-19th December 1995*	This event is referenced in the flood questionnaire provided by Council. “There were also two floods in the 1990's, which reached a similar level (as 2018 event) about half way between Nierinna creek and old pear trees” – Owner of a property on Sandfly Road	
8-9th February 1996*	This event is referenced in the flood questionnaire provided by Council. “There were also two floods in the 1990's, which reached a similar level (as 2018 event) about half way between Nierinna creek and old pear trees” – Owner of a property on Sandfly Road	
August 2004	A rainfall intensity of 17mm/h, corresponding to a 1-in-20-year event is documented in the 2006 Flood Study Report. Rainfall recorded at the Margate (Sunnyside) rainfall station for this event (likely from the 9th-15th) was 88.2mm.	

3rd February 2005	This event is referenced in the flood questionnaire provided by Council. This flood event is documented in the 2006 Flood Study Report, stating that the 1-in-100-year rate was exceeded for between 2 to 6 hours (at the Cades Drive Gauge). The report states that the observed flood levels are approximate to the 1-in-100-year levels produced by the study. The report further states that the event did not overtop the Rivulet which contradicts a community member statement at Sandfly Road: “the maximum depth of flooding above ground was observed as being approximately 4 metres, over the top bank of the Rivulet on the southern side”. Based on the rainfall recorded at the Margate (Sunnyside) station, it is likely the event occurred between the 2nd to the 4th of February 2005 with a total rainfall of 118.4mm. Photos taken along Sandfly Road have been provided for the event looking both upstream and downstream in Images 1 and 2 respectively. According to the flood questionnaire, community members along Van Morey Road and Day Spring Drive identified the February 2005 flood event as greater in magnitude than the May 2018 event.	 Image 1: Taken from the bank of a property along Sandfly Road looking downstream (between Site Visit location 29b and 29k)  Image 2: Taken from the bank of a property along Sandfly Road looking upstream (between Site Visit location 29b and 29k)
11-12th August 2010*	This event is referenced in the flood questionnaire provided by Council. Two residents along Day Spring Drive indicated that the event in August 2010 exceeded the May 2018 event.	

13th April 2011	This event likely occurred between the 10th to the 16th of April 2011 with a total rainfall of 127.8mm at Margate (Sunnyside) rainfall station. Residents at along Day Spring Drive indicated that the event in April 2011 exceeded the May 2018 event. Photos taken from a resident of Morey Road have been provided for the event as per Image 1.	 Image 1: Taken from the bank of a property along Van Morey Road looking upstream
13-14th January 2015	This event is referenced in the flood questionnaire provided by Council. There was a significant rainfall event on 13th and 14th January 2015 resulting from a complex low-pressure system bringing tropical moisture to Tasmania. The highest daily rainfall was 153.4mm at Mount Wellington on the 14th January. Residents along Nierinna Road indicated the January 2015 flood exceeded the May 2018 event.	

9-12th May 2018	This event is referenced in the flood questionnaire provided by Council. According to ABC news sources (2018), an extreme rainfall event likely occurred within the study area between the 9th to the 12th of May 2018 with a total rainfall of 210.4mm. It was reported that chest-deep water flowed through the downstairs level of a Margate restaurant, located at on the Channel Highway. This is shown in Image 1 which was uploaded to ABC Hobart social media on the 10th of May 2018. It must be noted that the restaurant is located within the area likely to be influenced by flooding from the North West Bay River. As the North West Bay River is not within this scope of works, this location may not be fully verified. Images 2, 3 and 4 provided by the owner of properties along Sandfly Road and Nierinna Road. Flood extents are typically demarked by debris.	 Image 1: Flood waters in the restaurant with levels seen approximately ¾ up the wall (ABC, 2018).  Image 2: Flood Debris at Channel Highway Culvert May 2018

Image 3: Flood Extent (Debris) at a property along Sandfly Road near Nierinna Creek

Image 3: Flood Extent (Debris) at a property along Nierinna Road at Margate Rivulet

5th November 2018*	This event is referenced in the flood questionnaire provided by Council. A community member has recorded a maximum flood depth of 1.65m at a shed on a property along the Channel Highway. Aerial imagery shows a vast number of sheds on the property no photo evidence was provided. Additionally, this is located within the area likely to be influenced by flooding from the North West Bay River. As the North West Bay River is not within this scope of works, this location may not be fully verified.	

* While the respondent identified the event as the 5th of November 2018, no rainfall was recoded as occurring on this date, and therefore is it highly likely that this corresponds to a different event (likely the May 2018 event)"

2.6.2 Community Engagement

Council has previously undertaken community engagement as part of their internal investigations into flooding of the Margate Rivulet catchment and have provide responses to Cardno for inclusion in this study. The engagement was carried out as a questionnaire and asked local community members to provide comments on the impacts of the most recent 2018 event in the Margate Rivulet catchment. The survey also asked for information on the relative comparisons to other historical events. The outputs of this questionnaire are summarised in Table 2-2.

Table 2-2 Community Engagement Responses from the Kingborough Council's questionnaire of the 2018 event

Location*	Flooding Observations	Requested Action by Community Member
Dayspring Drive	Flooding 20cm depth, 1m within house and directly in front of property at intersections for less than 1 hour. Flooding less than 50mm in centre of street. The open drain that traverses the property, servicing Van Morey and Merediths Road overflows (sometimes) with sudden downpours onto downstream property.	Open council drain unable to cope with stormwater deluge (this has occurred prior). Drain upgrade.
Dayspring Drive	Less than 50mm flooding at centre of the road. Flooding from street into driveway, within separate unit and surrounding house (not within) (2-4hrs). Suspect the flooding was due to blocked drain at the end of our Driveway.	Drainage maintenance
Dayspring Drive	Flooding up to house highest at slab (2-4hrs). The water didn't run away as the drainage system was not effectively cleaned out and was unable to cope with amount of stormwater.	Drainage maintenance
Van Morey Road	Overflowing culverts (4-8hrs) eroding road away (100-200mm in centre of road) and between 50-100m down the street (inaccessible 2-4hrs)	A bigger drain which runs off and under the bend above the property Inadequate and ineffective road/drainage works along Van Morey Road [to be resolved.]
Van Morey Road	13th April 2011: It was reported that the top of the driveway to the standing water level = 2m change in flood level in photo for this date in Table 2-1. Flooding was caused by the ephemeral stream. A metal 'agi drain' style culvert runs beneath the road.	
Van Morey Road	Road was flooded and river was building up across the road, so it was unsafe to drive and residents had to stay home. Gutters were blocked with leaves as they are not maintained by Council (meant to be but it only occurs ~once a year).	Gutter maintenance and cleaning.
Crimson Drive	Flooding directly in front of the house but not in the road (1-2hrs) and ponding surrounding the house (4-8hrs). Outside of the house the door of the under-floor storage door had a mark about 80cm high.	
Nierinna Road	Water flowed down driveways of properties opposite and overflowed Nierinna Road drains cascading into the property at three points**	
Sandfly Road	3rd February 2005: The maximum depth of flooding above ground was observed as being approximately 4 metres, over the top bank of the Rivulet on the southern side.	
Worsley Drive	Less than 50mm flooding (24hrs) in interior of the house by overflowing gutters.	

*Full address details have been withheld to maintain privacy of residents comments

**No events were selected from the questionnaire events so cannot assign to a specific date

2.6.3 Site Visit Community Engagement

During the site visit for this project, a local community member who owns a property on Meredith's Road at Site 6a (See 2.7) discussed flooding behaviour around their property. It was stated that the open channel that runs alongside the rural properties does not fully contain flood waters when it has been raining for more than a day and flood extents are typically 1.5m beyond the centreline of the channel.

Additionally, an owner of a property on Sandfly Road (also the owner of a property at the top of the catchment on Old Bernies Road) guided Cardno on a walkthrough of their property. This provided additional context for evidence supplied for this study and has been used in the model result verification process. It should also be noted that the owner also provided Cardno with information relating to the flows experienced in the Margate Rivulet on the day of the site visit (24/03/2021). No significant flows were experienced down the Margate Rivulet after 2mm rain was observed at the Sunnyside gauge.

Figure 2-1 Upstream Margate Rivulet Crossing on Old Bernies Road (Cardno, 2021)

2.7 Margate Rivulet Site Visit

On Wednesday the 24th of March 2021, Cardno undertook a site visit to the Margate Rivulet catchment as part of this stage of the Project works. This site visit was undertaken to:

> Determine expected flooding behaviour throughout the catchment;
> Understand catchment characteristics such as vegetation, erosion and development;
> Assess regions of flooding identified based on preliminary model results; and
> Collect data on 'Missing Pipe and Pits' throughout the catchment.

The locations at which data was collected is shown in Figure 2-2 and summarised in Table 2-3. Photographs obtained during the Site Visit have been provided to Council electronically. The site observations have been summarised below:

> The catchment is predominantly cleared rural open space with several structures such as farm houses, sheds and animal shelters.
> The urban township of Margate is located at a localised highpoint and there is minimal urban development elsewhere.
> The forested regions are heavily vegetated with dense eucalypt trees, abundant mid-story cover and heavy grass ground cover.
> The topography of the catchment features a high degree of slope with private dams (storages) being typically located in the areas where slopes decline, and flow paths generally being steep (approximately greater than 5%).
> Private dams (storages) are the only systems which currently retain flows in the catchment with other formalised/constructed stormwater assets observed to treat and maintain waterways. A single outlet was observed directly outletting into the Margate Rivulet while it is assumed that several other assets discharge into the main channels at various points along the reach.
> There are areas within the forested regions that feature exposed and degraded soil due to erosion and sedimentation. This is predominantly along flow paths surrounding unsealed roads and in areas where the forest has been cleared.
> Both Margate Rivulet and Nierinna Creek have varying degrees of vegetation within the channel, with a large proportion of the main reach incised within natural bedrock.
> Both Margate Rivulet and Nierinna Creek typically feature undulating topographies such that there are shallow pools followed by an incised section, which is then again followed by more shallow pools.
> Dispersive clay soils were observed throughout the catchment which leads to sedimentation and erosion likely to be a significant risk for the catchment.
> There are notable signs of erosion on the upper side of banks in the main channel, however, this is likely due to the dispersivity of soils in the region and will only arise as a potential issue in significantly large flood events (approximately greater than 2% AEP).
> Several sites featured assets that were blocked by either vegetation or sediment, and large proportion of the assets were determined to be old with capacities likely to be inadequate to deal with moderate flows (10% AEP through to 20% AEP events).
> Several sites featured recently upgraded assets that were determined to be appropriate to deal with moderate flows based on their relative size to the older assets present.

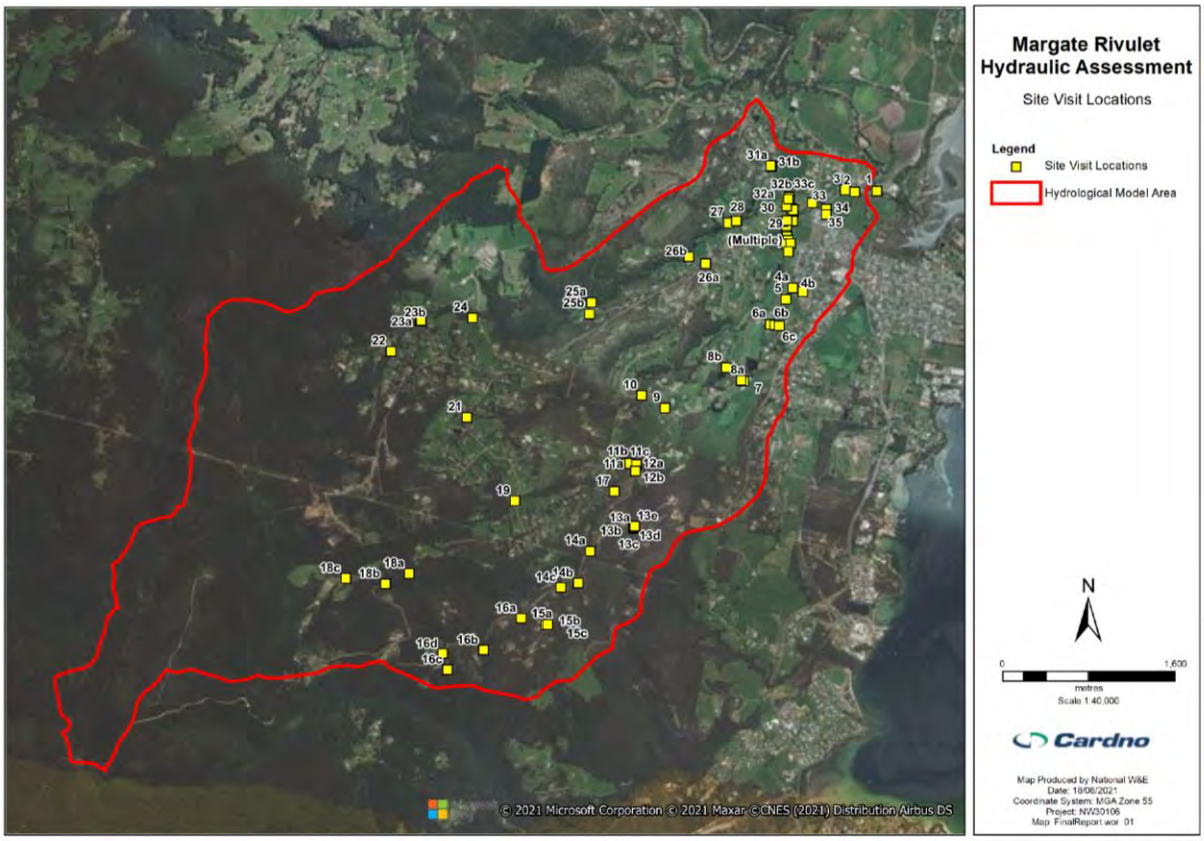


Figure 2-2 Site Visit Locations

Informal community engagement occurred as part of the site visit to understand flooding characteristics of the catchment. This was limited to engagement with two residents within the Margate Rivulet catchment and is further detailed in above Section 2.6.3.

Table 2-3 Site Observations recorded on 24/03/2021 by Cardno of Margate Rivulet catchment characteristics

ID	Description	Type	Data	Comments
1	Bridge	Pier	2 Piers - 12m x 0.8m, Approx 5.8m from bottom of Piers to Deck Bottom (L1)	Anecdotal evidence of flooding up to bottom of deck - Construction workers
2	Crossing	Culvert	2x1200	Right culvert partially covered by vegetation when looking DS (looking southward)
3	Chute, GPT and Crossing	Culvert	600	Roadside drainage 300 links up. Outlet not identified. Can be assumed based on open channel.
4a	Crossing	Culvert	600	1200 measured on upstream, 600 estimated on downstream. Potential chokepoint. 300 pipe from road outlets to upstream - 4b.
4b	Roadside	Culvert	450	Under driveway and then turns alongside property boundary and outlets at 1200 - 4a.
5	Crossing	Culvert	1200	Not accessed as private driveway. 1200 assumed based on Site 4 and 6 culverts.
6a	Crossing	Culvert	1200	Owner of Cat Hotel anecdotally stated that when flooding occurs the culvert can't convey all flow and her neighbour to the east experiences flooding across her front yard.

ID	Description	Type	Data	Comments
				When there is enough rain the extent is approx 1m either side of culvert.
6b	Overland	N/A	N/A	No defined flowpath. Small Channel.
6c	Open Channel	N/A	N/A	No cross or road drainage. No defined flow path for water to be conveyed across road. Likely overland
7	Crossing	Culvert	1200	Heavily vegetated on upstream side
8a	Crossing	Culvert	300	N/A
8b	Open Channel	N/A	N/A	No defined flowpath. Small Channel.
9	Crossing	Culvert	300	Half submerged on downstream side. Pooling at outlet. Channel on downstream side.
10	Bridge	Clear span	N/A	No vegetation in channel. Bedrock.
11a	Bridge	Clear span	N/A	Vegetation on downstream side. No vegetation on upstream side. Upstream similar to Site 10.
11b	Crossing	Culvert	450 & 600	600 is closer to Margate Rivulet side and 450 closer to road and other 450. More than half blocked with sediment on downstream side
11c	Roadside	Culvert	450	Outlets at 11b, inlet is approx 5m. Another 450 midway to main road under a driveway.
12a	Crossing	Culvert	450	Sediment present but not blocking culvert.
12b	Crossing	Culvert	2x600	When looking upstream, right culvert is blocked more than half. Left not blocked. Significant sediment downstream of culvert. Soiled channel downstream. Upstream not blocked.
13a	Crossing	Culvert	300	Under Driveway
13b	Crossing	Culvert	300	Under Driveway
13c	Crossing	Culvert	300	Under Driveway
13d	Open Channel	N/A	N/A	Eroded channel
13e	Crossing	Culvert	300	Assumed based on other culverts
14a	Crossing	Culvert	400	Unusual sizing. Size was frequently found in catchment. Upstream rocky channel.
14b	Crossing	Culvert	450	New Upgrade
14c	Crossing	Culvert	300	Smaller than other culverts
15a	Roadside	Culvert	450	Into closed pit.
15b	Pit	SEP	N/A	375 according to GIS, however right side is a 450.
15c	Open Channel	N/A	N/A	Very small open channel. Essentially soil and rocks. No vegetation.
16a	Crossing	Culvert	600	New upgrade. Eroded slightly downstream.

ID	Description	Type	Data	Comments
16b	Crossing	Culvert	400	Upstream old culvert and downstream upgraded with what measured to be a 350. 400 assumption is okay. Upstream vegetated flow path.
16c	Crossing	Culvert	600	Sediment present in culvert
16d	Open Channel	N/A	N/A	Heavily Vegetated
17	Bridge	Clear span	N/A	Bedrock channel.
18a	Crossing	Culvert	300	Small black pipe coming into culvert from private property.
18b	Crossing	Culvert	450	New upgrade.
18c	Bridge	Clear span	N/A	Bedrock Upstream with Downstream mainly rocks and vegetation is some parts.
19	Crossing	Culvert	2x1200	Vegetated Upstream. Erosion alongside road. Rock lined drain for roadside drain from either side entering the DS side.
20	Crossing	Culvert	300	Significant erosion and sediment runoff. Minor culvert.
21	Crossing	Culvert	3x450	Cleared upstream for rural properties.
22	Bridge	Clear span	N/A	Vegetated Upstream and regular rocky downstream. Roadside was partially eroded but had vegetation.
23a	Crossing	Culvert	900	Half Submerged with vegetation on upstream side.
23b	Crossing	Culvert	900	Heavily vegetated on downstream side
24	Bridge	Clear span	N/A	Vegetated on upstream and downstream side
25a	Crossing	Culvert	1500	Regular channel with minimal vegetation on both upstream and downstream.
25b	Crossing	Culvert	500	Eroded channel alongside driveway down to Nierinna Creek
26a	Pit Chamber	Closed	N/A	300 under road
26b	Bridge	Clear span	N/A	Height only about 300. however this has likely replaced an old crossing. A 300 is blocked at the bottom of the original crossing.
27	Bridge	Clear span	N/A	Rocks on downstream and upstream with minimal vegetation.
28	Bridge	Clear span	N/A	Rocks on downstream and upstream with minimal vegetation.
29a	Anecdotal Evidence	Flood Level	400mm up to base of tree	1973 flood event
29b	Anecdotal Evidence	Flood Level	Extent between second row of trees	1973 flood event
29c	Anecdotal Evidence	Flood Level	Extent at bottom of hill prior to trees along bank.	1990s and 2018 events. A small flow path along side the rivulet comes down and enters at this location.

ID	Description	Type	Data	Comments
29d	Anecdotal Evidence	Flood Extent	Up to just below the bank on northern side	1990s and 2018
29e	Anecdotal Evidence	Flood Extent	Foot path (previously an illegal levee implemented by developers) was covered up to the bushes on the other side	1973 flood event
29f	Anecdotal Evidence	Flood Extent	Bottom of foundations for the pump station shack	1973 flood event
29g	Anecdotal Evidence	Rain Gauge	Sunnyside Station (BoM)	Operational
29h	Anecdotal Evidence	Rain Gauge	Manual Recordings (Hand Records)	Non-Operational
29i	Anecdotal Evidence	Observation	Natural Spring which keeps pools of water full	No flow received from upstream on 24/3/201. Only 2mm of rain in catchment (BoM recorded rainfall checked)
29j	Anecdotal Evidence	Observation	Stormwater Outlet from new development	Flowing into Rivulet.
29k	Anecdotal Evidence	Observation	Dry rivulet	No flow received from upstream on 24/3/201. Only 2mm of rain in catchment (BoM recorded rainfall checked)
29l	Anecdotal Evidence	Flood Extent	Flood waters sheet down this area into the Rivulet	1973 flood event
29m	Anecdotal Evidence	Flood Extent	Flood waters reached bank	1973 flood event
29n	Anecdotal Evidence	Observation	Vegetation clearing in this area after 1973 event	Erosion on banks due to vegetation removal. Significant banks have been displaced.
29o	Rivulet	N/A	N/A	Pools and minimal vegetation. Bedrock.
30	Bridge	Clear span	N/A	Square clear span (i.e width not as large as channel)
31a	Crossing	Culvert	750	Blocked on upstream side.
31b	Crossing	Culvert	500	Half Blocked
32a	Crossing	Culvert	2x450	Brand new for which appears to be specifically for development on site. Rock chute structure upstream alongside road.
32b	Crossing	Culvert	900	Heavily vegetated upstream. Half blocked.
33c	Crossing	Culvert	600	Outlets to behind childcare
33	Crossing	Culvert	N/A	Couldn't measure as area was heavily vegetated and couldn't see the inlet.
34	Bridge	Pier	2 Piers - 25m x 0.5m, 2m height	Actually 3 clear spans with what appears to be a 1.2m box on the northern side (too vegetated to assess box culvert - likely to be high flow). Heavily vegetated.
35	Open Channel	N/A	N/A	Minor flows on 24/3/2021. Runoff into channel through reserve. Pits not containing flows from upstream. No GIS for upstream.

Figure 2-3 Upstream Margate Rivulet (Cardno, 2021)

3 Hydrological Model Setup

The hydrological modelling software RORB (version 6.45) was utilised for this flood mapping project. 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 hydrological model that has been used within the Australian Rainfall and Runoff 2019 (ARR2019) Guidelines and more widely in previous studies undertaken by Cardno.

The base hydrological model was created in GIS, utilising the MapInfo plug-in, MiRORB. MiRORB assists in calculating hydrological components such as catchment areas, slopes and other geometries required for implementation in the hydrological model itself. The methodology implemented in MiRORB is outlined in Sections 3.1, 3.2, 3.3 and 3.4 while the RORB modelling methodology has been outlined in Sections 4.1, 5 and 5.4.

3.1 Catchment / Sub-Catchment Delineation

An indicative catchment was obtained from The List as part of the Conservation of Freshwater Ecosystem Values (CVEV) state-wide catchment dataset. This catchment was reviewed and refined based on initial high level 2D only model results, topographic data, property information (where applicable) and Council drainage asset data.

Topography and drainage asset information was used to ensure that all areas which have the potential to contribute flow in the 1% AEP storm were included in the catchment, regardless of the flow mechanism (pipe or overland). Occasionally topographical flow paths contradict pipe flow directions and therefore, topographic flow paths were preferenced for catchment delineation. Following the derivation of the catchment, it was matched to the edge of property boundaries using property GIS information where applicable.

As with catchment delineation, sub-catchments were also delineated using the topographic and drainage asset information. Unlike the catchment boundary, the sub-catchments were not necessarily edge matched to property boundary information when applicable, but rather were edge matched to planning data. The catchment and subarea boundaries are illustrated in Figure 3-1.

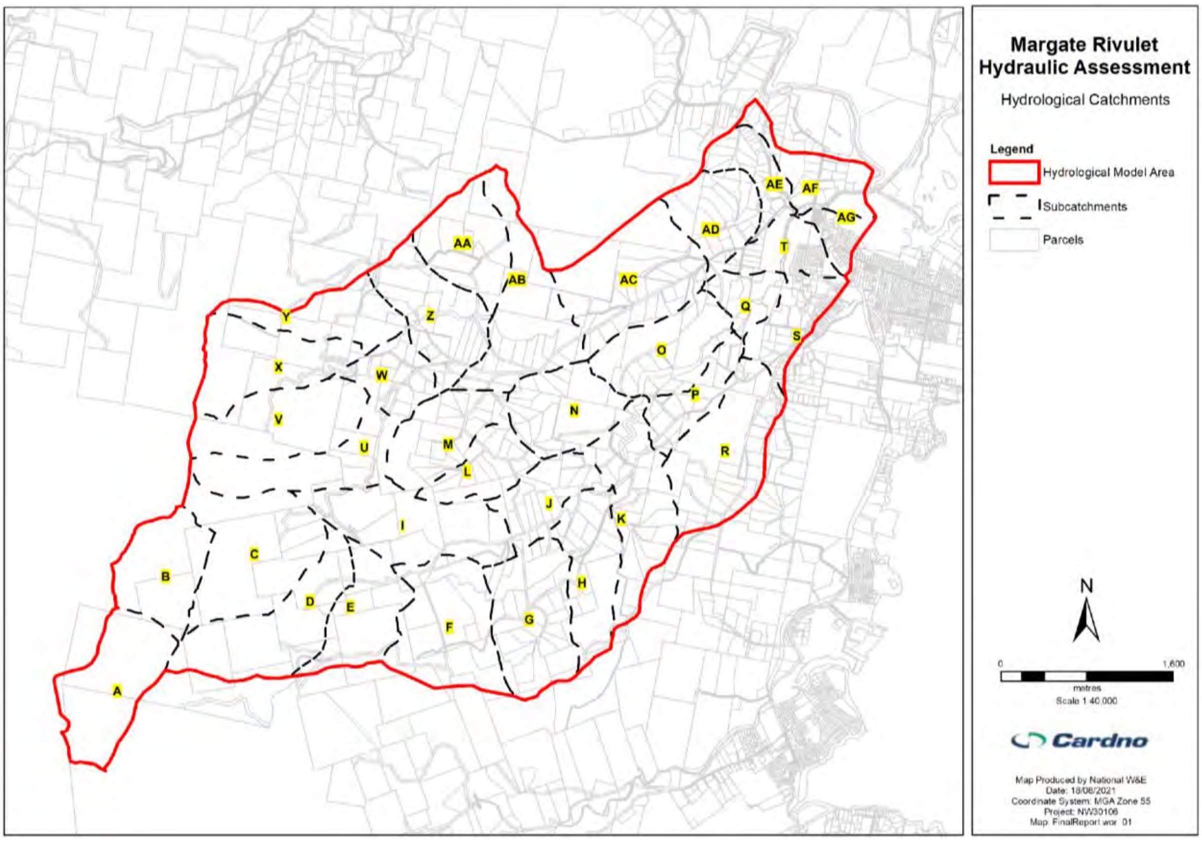


Figure 3-1 Hydrological Catchment and sub catchments

3.2 Nodes and Reaches

Nodes were located as required at centroids of subareas, at the downstream end of each subarea and at any confluence which was considered as a critical location. The nodes were placed so that they made some allowance for the time taken for subarea flows to reach the main channel, while flow routing from sub-catchments used control codes appropriate to the flow routing required.

Reach types were selected to represent the likely routing properties of the subareas. The majority of the reaches used in the hydrological model were reach type 1 (natural channel) and were adopted to represent the natural areas. Reach type 2 (excavated but unlined) was adopted to represent the urban areas within the catchment. It must be noted that while reach type 3 (lined channel or pipe) can be used to represent urban areas, experience suggests that this over estimates routing with under attenuation of flows.

Figure 3-2 of Appendix A illustrates the sub-catchments, nodes, reaches and storage locations.

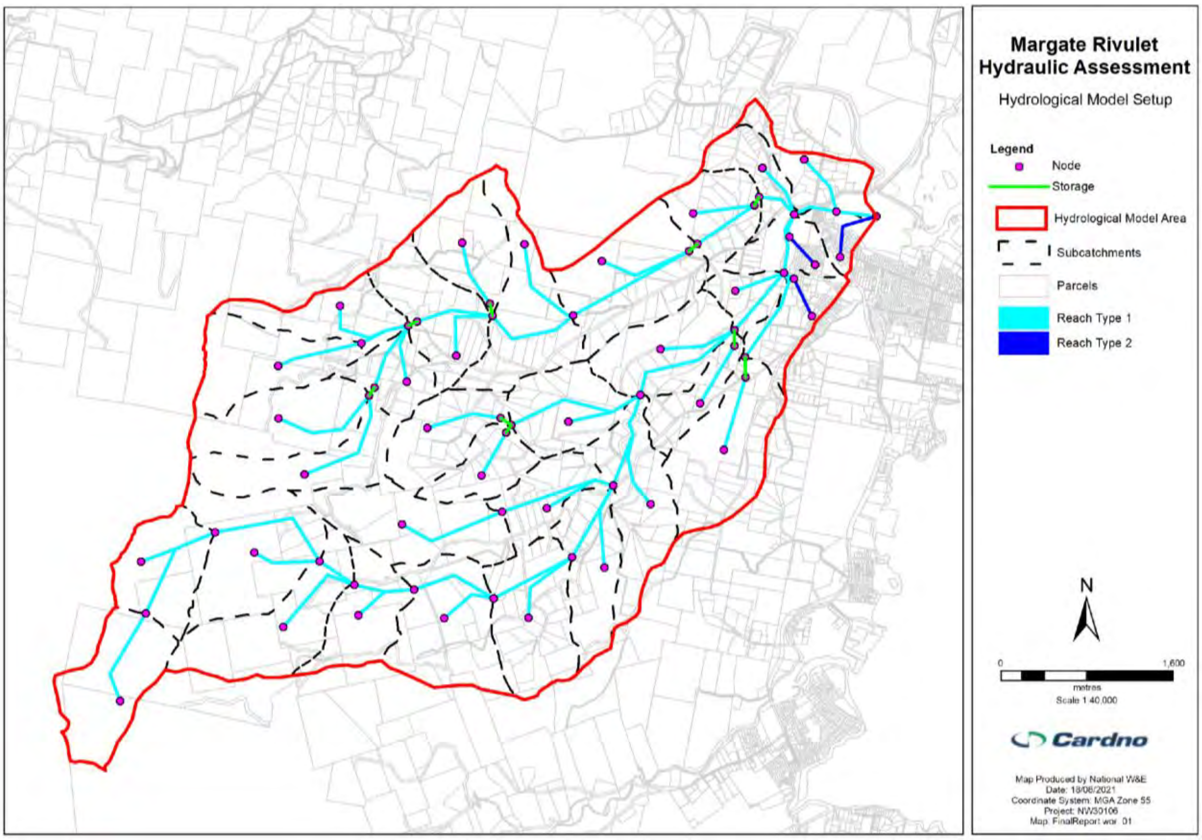


Figure 3-2 Hydrological Model Setup

3.3 Storages

Formal and informal storages that were determined to be critical to the retention of flows in the system were identified in the Data Review Report (dated 26/02/21). It must be noted that other storages were considered for inclusion, however, it was determined that these would not influence the critical flows within the catchment.

16 distinct informal storages were identified for inclusion in the hydrological model so that a critical duration can be estimated within RORB. The full effects of storages have been considered in the hydraulic model. Given some storages were in a linear orientation along major flow paths, some of these were combined to reduce model complexity.

Storage parameters for RORB were estimated using stage-storage relationships obtained from LiDAR with each storage individually assessed for spillway characteristics. It must be noted that it is likely that some of these storages have a pipe outlet, although as these are privately owned, no data was able to be provided by Council for this Project.

3.4 Effective Impervious Area Estimation

ARR 2019 (Book 5, Chapter 3) advises the loss model estimations are made of two aspects:

> Effective Impervious Areas (EIA)
  - Directly Connected Impervious Areas (DCIA) – impervious areas (e.g. roads, roofs and paved areas) which are directly connected to the drainage system (or where rainfall is directly connected to the drainage network)
  - Indirectly Connected Impervious Areas (ICIA) – impervious areas which are not directly connected, runoff from which flows over pervious surfaces before reaching the drainage system (e.g. a driveway that discharges onto a lawn) or pervious areas that interact with Indirectly Connected Impervious Areas (e.g. nature strips, garden areas next to paved patios, etc.) where some continuing losses occur

> Pervious Areas (PA) can be identified as regions in the catchment that features vegetation that is not directly and/or indirectly connected to drainage infrastructure. Typically, this is defined by untouched heavily wooded areas. However, this can also include farmland, parklands and cleared regions. The defining feature of PA is that generated runoff is conveyed through the defined PA as surface and/or ground water once the soil has been saturated without actively interacting with any impervious areas.

The following formula is typically used when estimating EIA for a sub-catchment:

$$EIA = DCIA + ICIA$$

As noted above, ARR 2019 outlines that the definition of a pervious area is untouched heavily wooded land (i.e. areas that largely remain unchanged from in their natural state). It has been assumed that the majority of areas that have been modified from their natural state in some way and therefore will flow to a designated drainage asset (be it an underground pipe, irrigation channel, constructed waterway, etc.).

ARR 2019 discusses that using GIS techniques to identify directly connected impervious areas (identifying road, roof and driveway areas) show that the Effective Impervious Area (EIA) is typically between 70% and 80% of the Total Impervious Area (TIA). However, this may trend to 100% as the catchment EIA increases to 100%. When measured at a catchment scale, without considering connectedness, the EIA is approximately 55-65% of the TIA (Phillips et al, 2014).

For this assessment, Cardno have adopted individual DCIA and ICIA values specified in Melbourne Water's Technical Specification (MW 2019) in GIS for each land use type. This method is current best practice and aligns with other industry guidance documents.

Specifically, the following methodology was adopted for estimating the EIA for the Margate Rivulet catchment:

> The areas in GIS were contextually assigned a 'DCIA' factor value according to the aerial imagery and corresponding planning data to reflect land use. This estimated whether the planning zone and corresponding parcel was impervious and how much of it was directly connected. A value of 1 would reflect an impervious area that conveys all runoff flows to the drainage network while a value of 0 would reflect either a completely pervious area or an impervious area that doesn't convey flows to the drainage network.

> The areas in GIS were then assigned an 'ICIA' factor value according to the parcel's proximity to drainage assets and its general direction of flow to determine the indirectly runoff connectiveness as specified in ARR 2019. A value of 1 would reflect an impervious area or pervious area which indirectly convey all its runoff to drainage infrastructure while a value of 0 would reflect a parcel that will not convey runoff directly into the drainage infrastructure.

> An area weighted average for each sub-catchment was then calculated using GIS queries for both the DCIA and ICIA values which were directly implemented into RORB to represent the EIA.

> RORB automatically determined the PA (Pervious Area) based on the EIA using the formula below:

$$PA = 1 - EIA$$

Appendix B summarises the sub-catchment DCIA, ICIA and PA that have been implemented into the RORB model and Table 3-1 summarises the range of DCIA, ICIA and PA values adopted according each planning zone.

Table 3-1 Planning Zone and values adopted for individual parcels to estimate Effective Impervious Area

Zone	DCIA	ICIA	PA	Rationale
12.0 Low Density Residential	Varying (0.05 – 0.7)	Varying (0.05 – 0.35)	Varying (0.15 – 0.875)	It is estimated that the majority of runoff from these impervious areas will enter directly into the pipe system through roof drainage. It must be noted that some of these areas are not fully developed or are similar to rural living, therefore lower values have been assigned to reflect this based on aerial imagery.
13.0 Rural Living	Varying (0 – 0.7)	Varying (0.025 – 0.15)	Varying (0.15 – 0.975)	Generally similar to low density residential areas (above) but with less impervious areas and less directly connected areas. Some sections feature significant impervious areas such as roads, however, this region largely represents cleared landscapes.
14.0 Environmental Living	Varying (0 – 0.7)	Varying (0.025 – 0.15)	Varying (0.15 – 0.975)	Similar to Rural Living with large areas of undeveloped and largely untouched regions. Some areas have developed sections with a high imperviousness and connectiveness.
17.0 Community Purpose	Varying (0.05 – 0.7)	Varying (0.05 – 0.3)	Varying (0.15 – 0.9)	Developed area with highly impervious regions that will have runoff directly into the pipe system through roof drainage. Some areas feature low lying cleared vegetation.
18.0 Recreation	0.5	0.25	0.25	A majority of the area has hard surfaces and there is some degree of connection to drainage in these areas.
19.0 Open Space	Varying (0 – 0.05)	Varying (0.025 – 0.1)	Varying (0.9 – 0.975)	Predominantly untouched regions with various types of low-lying vegetation.
20.0 Local Business	Varying (0.075 – 0.7)	Varying (0.05 – 0.4)	Varying (0.15 – 0.875)	Similar to Community Purpose areas with a high imperviousness and high degree of connectiveness to the drainage network.
26.0 Rural Resource	Varying (0 – 0.05)	Varying (0.025 – 0.5)	Varying (0.9 – 0.975)	Undeveloped area with minimal imperviousness and connections to the drainage infrastructure
28.0 Utilities	0.7	0.15	0.15	Significant hardstand areas with a high degree of connectiveness to the drainage network.
29.0 Environmental Management	Varying (0 – 0.05)	Varying (0.25 – 0.1)	Varying (0.9 – 0.975)	Predominantly untouched bushland with unsealed tracks and roads.
32.0 Particular Purpose	0.075	0.075	0.85	Similar to Rural Resource with largely undeveloped areas with minimal imperviousness and connections to the drainage infrastructure.

The weighted sub-catchment EIA derived from using the above DCIA and ICIA values is shown in Figure 3-3.

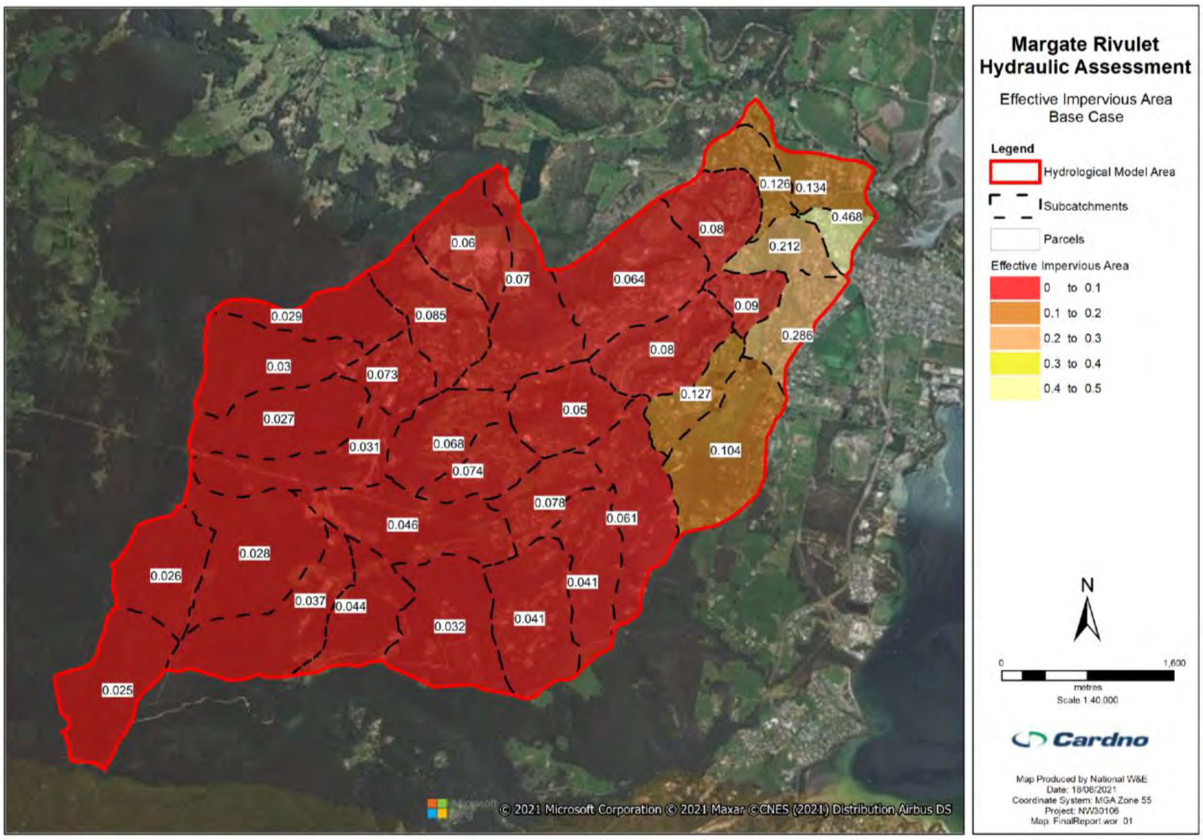


Figure 3-3 Effective Impervious Area – Base Case

3.4.2 Future Development Scenarios

As part of this study, Cardno hydrologically modelled two future development scenarios for the Margate Rivulet catchment. These scenarios have modelled an estimated EIA increase throughout the catchment, when compared to its current development conditions to reflect an indicative worst-case and best-case output. It should be noted that the boundaries do not relate to Kingborough Council's urban growth boundaries

Under current conditions (base case), the Margate township consists of low to medium density urban development with regions outside of the immediate township area consisting of rural to low density urban development as shown above in Figure 3-3. Therefore, for the worst-case scenario, the following changes have been made to the base case values:

> Margate township urban regions have had the assigned imperviousness (directly and/or indirectly connected areas) increased to reflect medium density urban development;

> All unsealed roads have had the assigned imperviousness (directly and/or indirectly connected areas) increased to reflect sealed roads; and

> Rural regions within close proximity to the Margate township have had the assigned imperviousness (directly and/or indirectly connected areas) increased to reflect a low-density urban development.

For the best-case scenario, the following changes have been made to the base case values:

> All unsealed roads have had the assigned imperviousness (directly and/or indirectly connected areas) increased to reflect sealed roads; and

> Rural regions within close proximity to the Margate township have had the assigned imperviousness (directly and/or indirectly connected areas) increased to values that match base case Margate township urban regions.

Figure 3-4 shows the proposed changes to the base case for the worst case developed scenario, while Figure 3-5 shows the proposed changes to the base case scenario for the best case developed scenario.

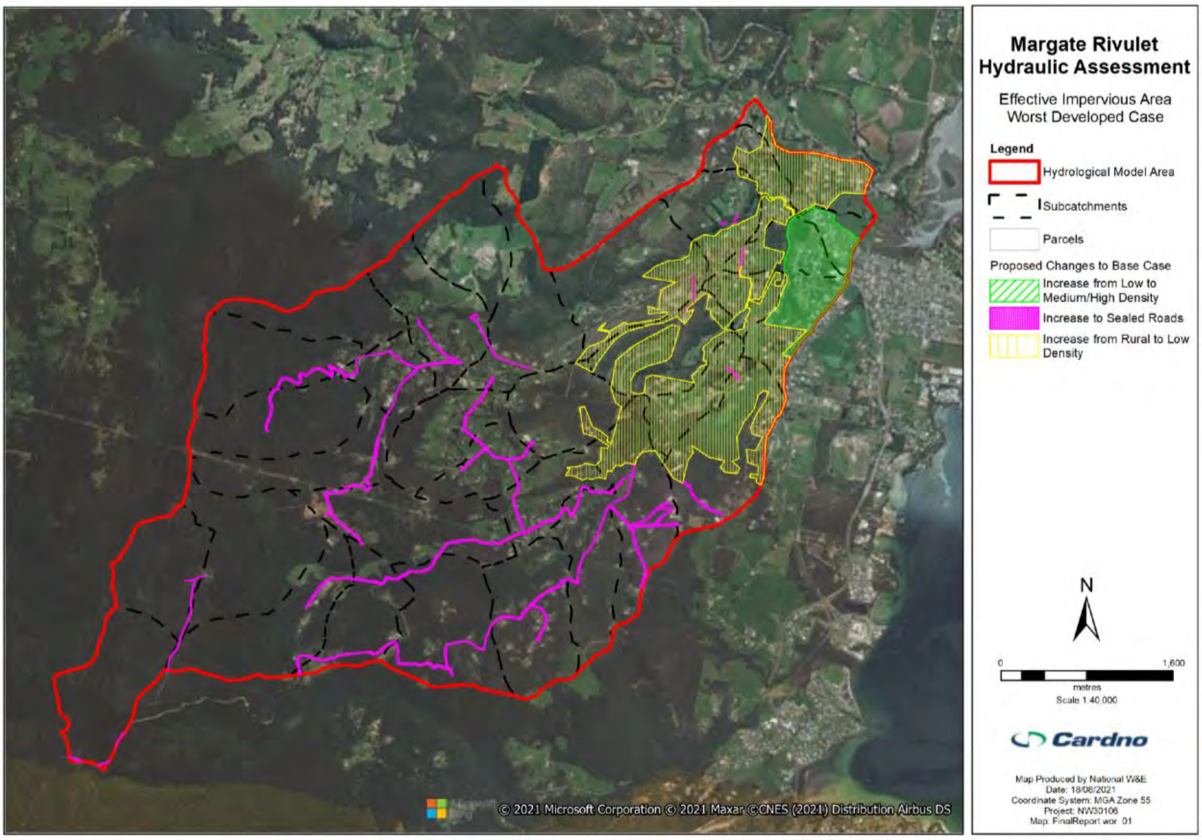


Figure 3-4 Proposed Effective Impervious Area Changes for Worst Case Development

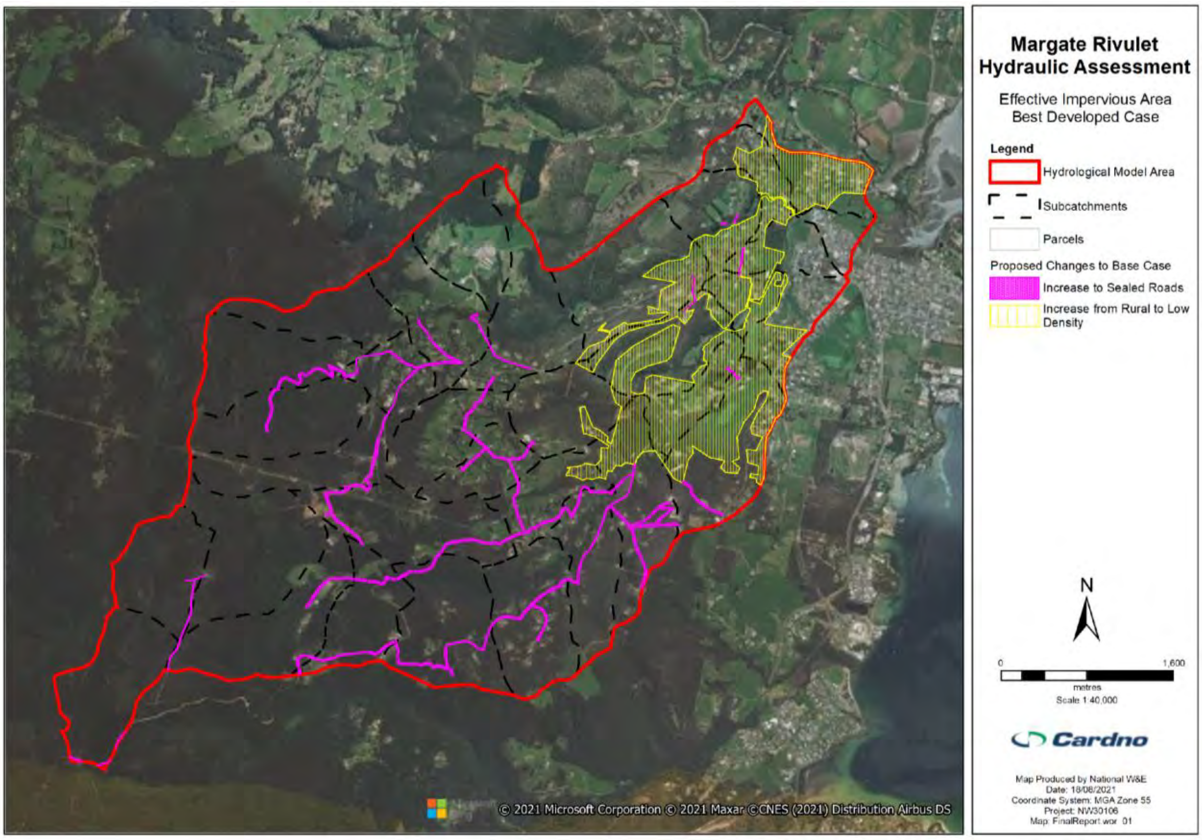


Figure 3-5 Proposed Effective Impervious Area Changes for Best Case Development

4 Hydrological Model Parameters

4.1 RORB Parameters

4.1.1 ARR Text File

The ARR Text File for the centroid of the catchment was downloaded from the ARR data hub. This file is typically used to specify the coefficients for the Areal Reduction Factor (ARF) formula and determine the estimate of regional losses. However, as the hydrological model is run at a sub-catchment scale, this information has been refined to suit the sub-catchment modelling approach. Further details of the adopted ARF are outlined in Section 4.1.4, while further details of the adopted losses are outlined in Section 4.1.5. The adopted ARR Text file is provided in Appendix C.

4.1.2 Temporal Patterns

An ensemble of 10 temporal patterns was downloaded from the ARR data hub. Given that the catchment area is not larger than 75 km^2, aerial temporal patterns are not required. No adjustments have been made to this information and these have been directly adopted into the model.

It should be noted that for temporal patterns that have an AEP rarer than the burst as a whole, the embedded bursts have been removed via the built-in RORB filtering technique that has been developed by *Scorah et al.* (2019). This has been adopted to ensure no skewed (also known as erroneous) temporal patterns are included in model results. While this feature is built-in, Cardno acknowledges that there may be potential for the erroneous temporal patterns to influence model results, and therefore Cardno has undertaken a visual inspection of results to ensure that this has not occurred once the models have been run.

4.1.3 BoM Intensity Frequency Duration (IFD) Depths

All required ARR 2019 Intensity Frequency Duration (IFDs) relationships for base case modelling have been downloaded from the Bureau of Meteorology (BoM) website for all design events. This included obtaining the standard and non-standard durations ranging from 10 minutes to 168 hours.

4.1.3.1 Rainfall Spatial Variance

As the total catchment size is greater than 20 km^2, an analysis of the spatial variance of rainfall was required. This was undertaken using multiple IFDs sampled from different locations throughout the catchment as shown in Figure 4-1. The four locations were chosen as they covered the spatial variance across the catchment and included:

> Centroid: -43.0377, 147.2342

> Margate Rivulet Outlet: -43.0234, 147.2626

> Top of Margate Rivulet: -43.0635, 147.1774

> Top of Catchment: -43.0560, 147.2227

The spatial variance of the four IFDs were analysed against one another in order to calculate a coefficient of variance (CV). A catchment is determined to have significant rainfall variance when the CV between the relevant rainfall intensities are equal to or greater than 5%. Results for the assessment shown in Table 4-1 demonstrated all storm events longer than 2hrs experience a spatial variation of rainfall.

A weighted IFD for the catchment was generated from rainfall depth ASCIIs that were obtained from BoM in order to capture this spatial variance. This utilises a point sampling method based on the centroid of each sub-catchment with rainfall depths statically processed to a median value for each AEP and duration. The weighted IFD is provided in Appendix D.

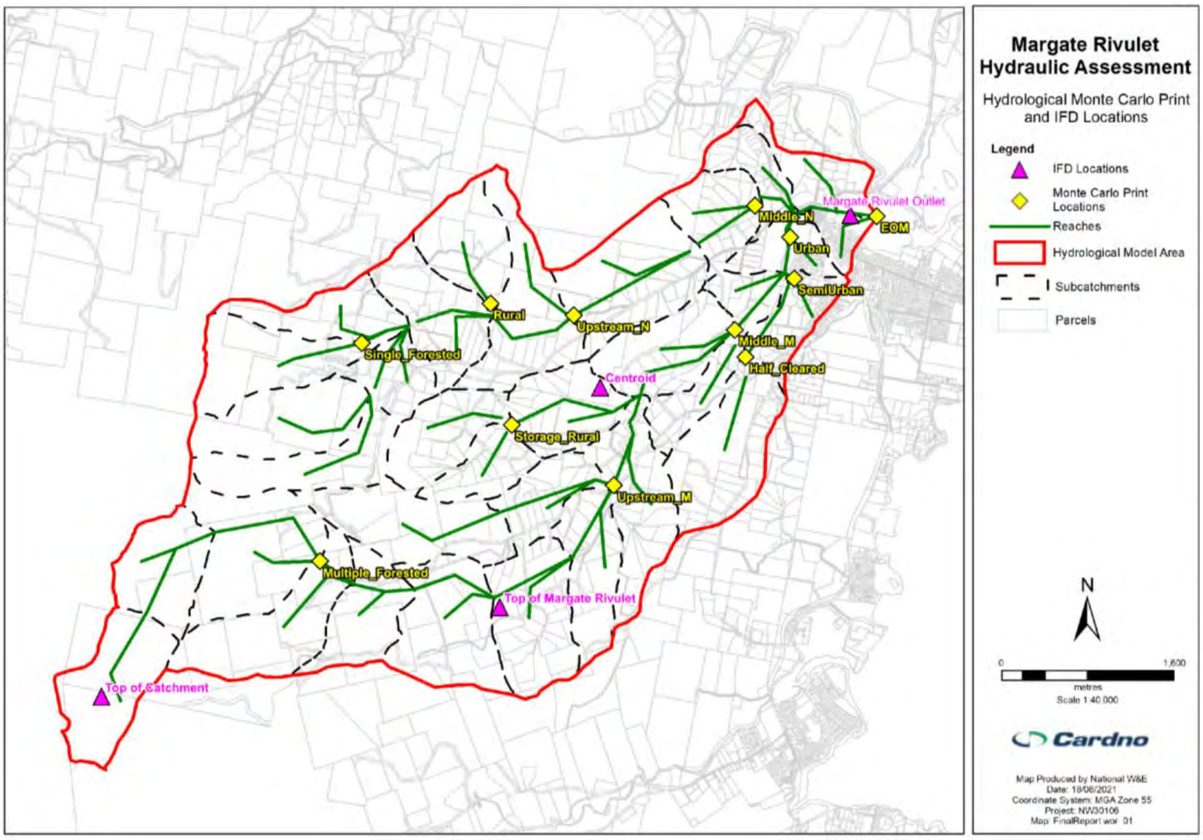


Figure 4-1 Assessed IFD Locations

Table 4-1 Coefficient of Variance Assessment for Four Key Locations throughout the Margate Rivulet Catchment

Duration	AEP							
	63.20%	50%	20%	10%	5%	2%	1%	0.50%
10 min	3%	3%	3%	3%	3%	3%	3%	4%
15 min	3%	3%	3%	3%	3%	3%	3%	4%
20 min	3%	3%	3%	3%	3%	3%	3%	3%
25 min	3%	3%	3%	3%	3%	3%	3%	4%
30 min	3%	3%	3%	3%	3%	3%	3%	3%
45 min	3%	3%	3%	3%	3%	3%	3%	4%
1 hour	3%	3%	3%	3%	4%	4%	3%	4%
1.5 hour	4%	4%	4%	4%	4%	4%	4%	4%
2 hour	5%	5%	5%	5%	5%	5%	4%	5%
3 hour	7%	7%	6%	6%	6%	6%	5%	6%
4.5 hour	9%	9%	8%	8%	7%	7%	7%	7%
6 hour	10%	10%	9%	9%	9%	8%	8%	9%
9 hour	13%	12%	12%	11%	11%	10%	10%	11%

Duration	AEP							
	63.20%	50%	20%	10%	5%	2%	1%	0.50%
12 hour	14%	14%	13%	13%	12%	12%	12%	12%
18 hour	17%	16%	15%	15%	15%	15%	15%	15%
24 hour	18%	18%	17%	17%	17%	16%	17%	17%
30 hour	19%	19%	18%	18%	18%	18%	18%	19%
36 hour	19%	19%	19%	19%	19%	19%	19%	20%
48 hour	20%	20%	20%	21%	21%	21%	21%	22%

4.1.3.2 Climate Change

A Climate Change IFD was developed to represent a predicted 2100 scenario based on the Climate Change document provided to Cardno by Kingborough Council (See Data Review Report date 23/02/2021). The values contained within the document identify expected changes relative to the 1961-1990 baseline period for the RCP8.5 emissions scenario for rainfall.

The Climate Change IFD was generated using the weighted IFD for the catchment (discussed in Section 4.1.3.1 above) as a basis. The conservative increased percentage from the *Climate Change Information for Decision Making* (Kingborough Council, 2021) of 12.9% for rainfall extremes across all events and durations has been adopted for this study, based on the assumption that that 2020 is taken as the current conditions. It must be noted that the previously completed Kingston Beach Flood Study adopted both a 10% and 30% increase in rainfall.

The Climate Change IFD has also been provided in Appendix D.

4.1.3.3 Pre-Burst Rainfalls

Median preburst data was downloaded from the ARR 2019 Data Hub for the centroid of the study area and has been implemented into RORB. This has been applied in a single increment prior to the design storm as per the process outlined in ARR 2019 which details using the in-built functionality of RORB. Given that preburst ratios for durations of less than one hour are not available from the ARR 2019 Data Hub, ratios for the one-hour duration have been adopted for all durations of less than one hour as per existing best practice.

The median preburst values have been adopted as they are the most defendable values without any additional guidance currently available in literature. Each of the time increments have been manually set to be compatible with the imported temporal pattern increments from the ARR 2019 Data Hub. The proposed median preburst data is shown in Table 4-2 below. It should be noted that the preburst values vary across the four locations, however, the values which occurred at a majority of the locations were selected.

Table 4-2 Infilled Preburst Ratios implemented into RORB for the Margate Rivulet catchment

Duration	AEP							
	63.20%	50%	20%	10%	5%	2%	1%	0.50%
10 min	0	37.5	33	30.8	29.1	19.3	13.8	0
15 min	0	37.5	33	30.8	29.1	19.3	13.8	0
20 min	0	37.5	33	30.8	29.1	19.3	13.8	0
25 min	0	37.5	33	30.8	29.1	19.3	13.8	0

Duration	AEP							
	63.20%	50%	20%	10%	5%	2%	1%	0.50%
30 min	0	37.5	33	30.8	29.1	19.3	13.8	0
45 min	0	37.5	33	30.8	29.1	19.3	13.8	0
1 hour	0	37.5	33	30.8	29.1	19.3	13.8	0
1.5 hour	0	23.6	19.8	18.1	16.9	17.6	17.9	0
2 hour	0	29.4	24.6	22.6	21.1	14.2	10.3	0
3 hour	0	33.7	25.9	22.7	20.4	31.1	37.1	0
4.5 hour	0	16.5	18.9	19.9	20.5	25.5	28.4	0
6 hour	0	16.5	18.9	19.9	20.5	25.5	28.4	0
9 hour	0	7.6	9.7	10.4	10.8	8.1	6.5	0
12 hour	0	7.6	9.7	10.4	10.8	8.1	6.5	0
18 hour	0	1.8	5.1	6.4	7.2	9.2	10.3	0
24 hour	0	0.7	5.4	7.1	8.2	6.6	5.7	0
30 hour	0	0.3	0.7	0.9	1	6.9	10	0
36 hour	0	0.3	0.7	0.9	1	6.9	10	0
48 hour	0	0	1.7	2.2	2.6	4.1	4.8	0
72 hour	0	0	0.7	1	1.2	0.6	0.3	0
96 hour	0	0	0	0	0	0	0	0
120 hour	0	0	0	0	0	0	0	0
144 hour	0	0	0	0	0	0	0	0
168 hour	0	0	0	0	0	0	0	0

4.1.4 Areal Reduction Factors (ARFs)

The total area of the Margate Rivulet catchment is 23.11km^2, however, the average contributing size of each sub-catchment delineated in the hydrological model is less than 1km^2. As the hydrological model has been developed with inclusion of accurate sub-catchments, water has been applied to the hydraulic model on a sub-catchment basis.

With respect to ARF application, using an ARF of 23.11km^2 would under-represent the actual volume of water generated, while adopting an ARF of 1km^2 would reflect a slightly conservative approach. As such, the RORB model was run with two different ARF values:

1. An ARF of 23.11km^2 – This has been adopted to check for critical durations at the catchment outlet and used for validation of the hydrological model (See Section 5); and
2. An ARF of 1 km^2 – This has been adopted to generate the required inflows for each sub-catchment within the hydraulic model boundary and the expectation that flows along the main drainage trunk lines will generate slightly conservative results.

It must be noted that when the ARF of 23.11km^2 is adopted, the ARR Data Hub coefficients have been utilised. However, when the ARF of 1km^2 has been adopted the ARR Data Hub coefficients are not utilised. These coefficients are presented in Table 4-3 and this approach is in alignment with ARR 2019 Guidelines (Book 2, Chapter 4, Table 2.4.1.)

Table 4-3 ARR 2019 Tasmania ARF Parameters

Parameter	Value
A	0.0605
B	0.347
C	0.2
D	0.283
E	0.00076
F	0.347
G	0.0877
H	0.012
I	-0.00033

4.1.5 Initial and Continuing Loss

The Margate Rivulet catchment was modelled as an Initial Loss (IL) / Continuing Loss (CL) model. ARR 2019 recommends that the IL and CL values vary according to the three different types of areas i.e. DCIA, ICIA and PA (previously defined in Section 3.4) represented in the model.

ARR2019 recommends that the loss rates for these areas are as follows:

> DCIA: IL = 1-2 mm, CL = 0mm/h

> ICIA: IL = 60-80% of adopted pervious loss, CL = 1-3 mm/h.

> PA: IL & CL = Rural loss rates provided in the ARR Data Hub Text File

As such, the regional rural loss estimates for the four locations assessed for Rainfall Spatial Variance (See Section 4.1.3.1) were downloaded from the ARR 2019 Data Hub for the Margate Rivulet catchment. The initial losses for all four locations were the same. For continuing losses, the centroid, the outlet and the south east were identical, while the north west differed by 0.2mm/h.

As three of the four locations specified have identical IL and CL, these values were considered reasonable to represent the entire catchment. Specifically, these were estimated as:

> Storm Initial Losses = 28.0mm

> Storm Continuing Losses = 3.4mm/h

Based on recommendations from ARR2019, the following loss rates have been adopted for use in this study:

> DCIA: IL = 1mm, CL = 0mm/h

> ICIA: IL = 19.6mm (70% of adopted pervious loss), CL = 2 mm/h.

> PA: IL = 28.0mm, CL = 3.4mm/h

It must be noted that these are the values recommended when no calibration and/or validation of the models can be undertaken. However, Cardno has determined that the hydrological model can be validated with supplied data from Kingborough Council (See Data Review Report dated 23/02/2021).

4.1.6 Model Time Step

The continuing loss has not been adjusted for the model time step. This is not required as the data used to generate the loss values is based on rainfall data recorded at 6 minute intervals and as such the loss rates are compatible with the RORB model minimum timestep.

4.1.7 Routing Parameters

The *m* routing parameter has been set to 0.8 which is typically the value assigned to RORB models. An *m* value of 1.0 would imply that discharge and storage increase at the same rate. Therefore, this value implies that flood magnitude discharge increases more rapidly than storage (ARR 2019).

5 Hydrological Model Results

5.1 Modelling Scenarios

The following scenarios were hydrologically modelled:

> A range of critical durations and associated temporal patterns for the 5%, 1% and 0.5% AEP base case events;
> A range of critical durations and associated temporal patterns for the 1% AEP climate change event; and
> A range of critical durations and associated temporal patterns for the 1% AEP event best and worst development scenarios.

5.2 Identification of Design Flow Events

5.2.1 RORB Monte Carlo Module

A probabilistic (Monte Carlo) assessment has been completed in order to determine the design flow events using the inbuilt RORB Monte Carlo module. The RORB Monte Carlo module automates the process to include:

> Undertaking multiple runs, using parameters, while sampling from the defined temporal patterns
> Undertaking 2,000 runs for each duration storm
> Extracting the average or median design event for each duration and locations, using statistics to derive the appropriate flood frequency curve
> Specifying the critical duration at strategically chosen locations

This methodology is a more efficient, more defensible and robust approach for deriving the appropriate flood frequency curve (and hence appropriate design events) for the catchment. It is also reproducible, as the sampling size is suitably large to reduce the uncertainty in the derived flood frequency curve.

The Monte Carlo assessment has been run using the MC analysis module in RORB. The module divides the rainfall distribution into 50 discretised intervals and runs 40 samples from each interval. This results in a total of 2,000 runs per storm duration as noted above. The flood frequency curve is then derived using exceedance probability calculations based on the total probability theorem.

An example of the outputs from the runs undertaken for a set of rainfall is shown in Table 5-1. This shows a wide range of flood hydrographs at a specific location depending on the parameters adopted including rainfall temporal pattern selected and/or loss rates. From this sample, a distribution of likely hydrograph peaks can be assessed and an expected peak flow rate assigned to the flood probability. This is shown as the red distribution in Figure 5-1. It should be noted that in this analysis, only the rainfall temporal patterns are varied as outlined above.

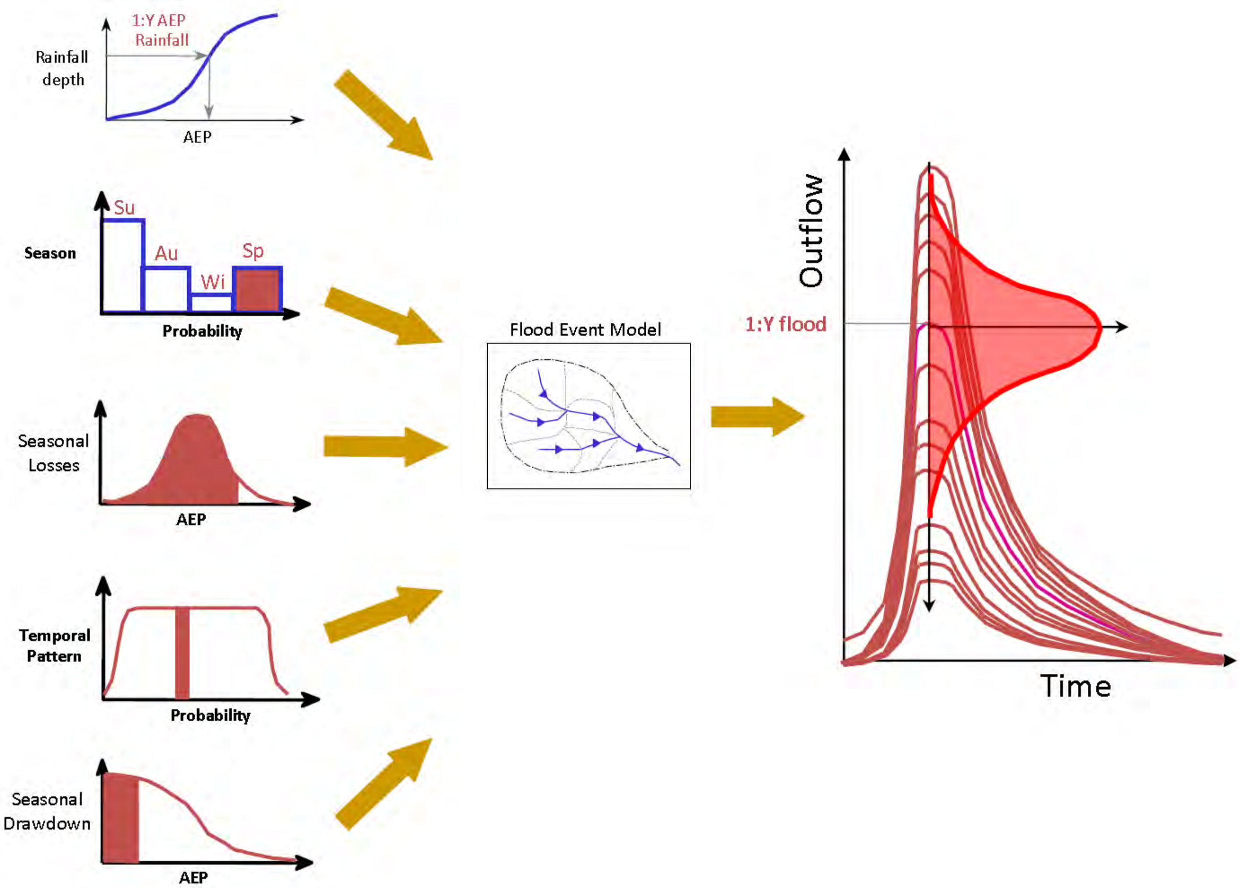


Figure 5-1 Example Monte Carlo Input Sampling (HARC, 2016)

The example above shows the assessment for a given location and expected rainfall probability. This approach can be extended across the full range of the rainfall frequency curve by breaking the curve down into intervals (in this case 50 intervals) and sampling a number of times from each interval. This result is an estimate of the distribution of the peak flow for each rainfall interval. Taking the expected peak flow for each interval yields the flood frequency curve. This curve can then be used to derive the appropriate selection of design flood events to represent the expected behaviour of the system. Figure 5-2 shows the flood frequency derivation process.

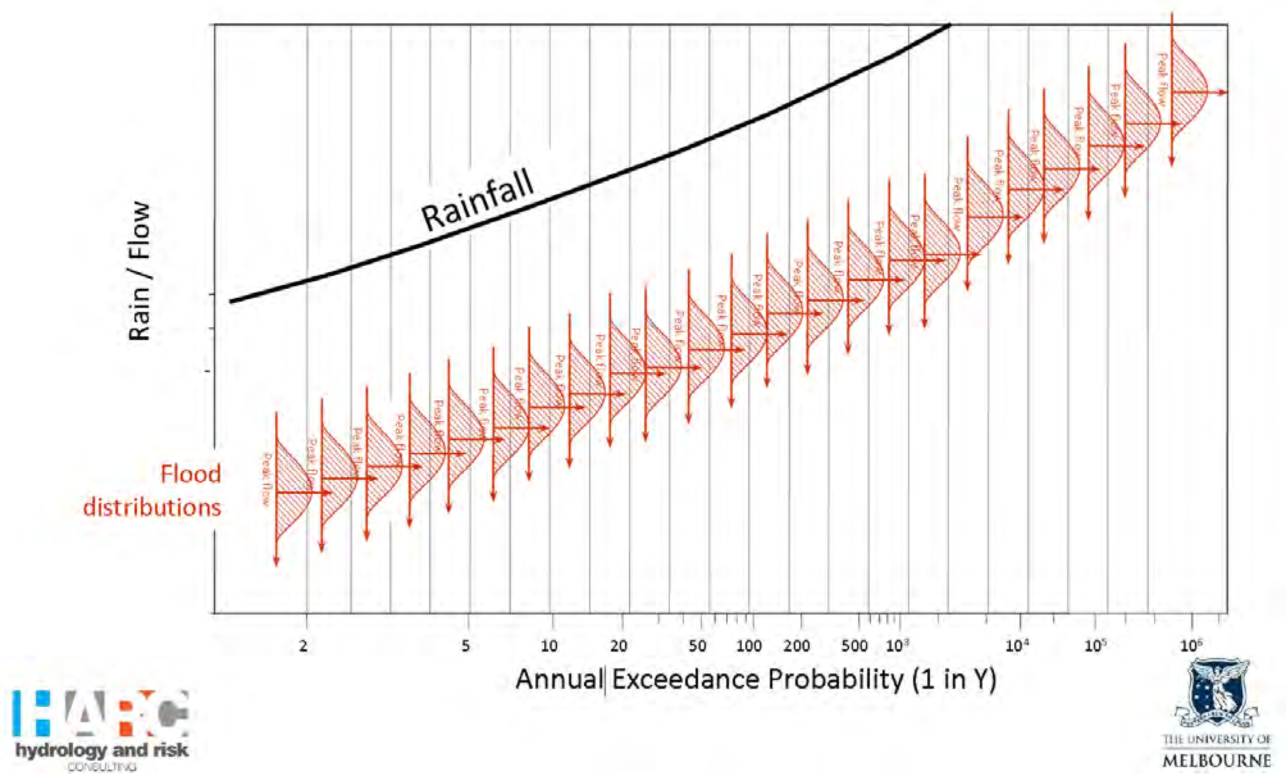


Figure 5-2 Deriving the Flood Frequency Curve (HARC, 2016)

5.2.2 K_c Analysis

K_c is a RORB input that defines the lag parameter in the catchment model and can be compared with other runoff-routing models and their parameters such as C, B and β used in WBNM, RAFTS and URBS respectively. RORB features a range of regional relationships that are listed in the known publications and involve a single catchment variable (area in km^2). This is because area has been found to be the dominant variable (ARR 2019).

It is for this reason, that Cardno assessed a range of K_c values that are appropriate for the Margate Rivulet based on catchment characteristics to determine a single K_c value that best represents the overall catchment. This is determined by undertaking a Monte Carlo simulation for the hydrological model with results generated at each print location compared to the median and mean flows. The K_c value that generates flows closest to the median (and mean) has been adopted. This adopted value, in conjunction with the loss values, generates outputs from the hydrological model for input into the hydraulic model.

Figure 5-3 and Figure 5-4 show the results of the Monte Carlo analysis for various K_c values. As the default equation for determining the K_c value in RORB results in a Kc significantly higher value than the other methods appropriate for the Margate Rivulet catchment, it is considered to be an outlier. Therefore, this value has not been included when calculating both the mean and median for the K_c values. The West Tasmanian method for determining the K_c generates flows closest to the median (and mean) and therefore has been adopted for the design events. The West Tasmanian method has a K_c value of 5.15 for the catchment.

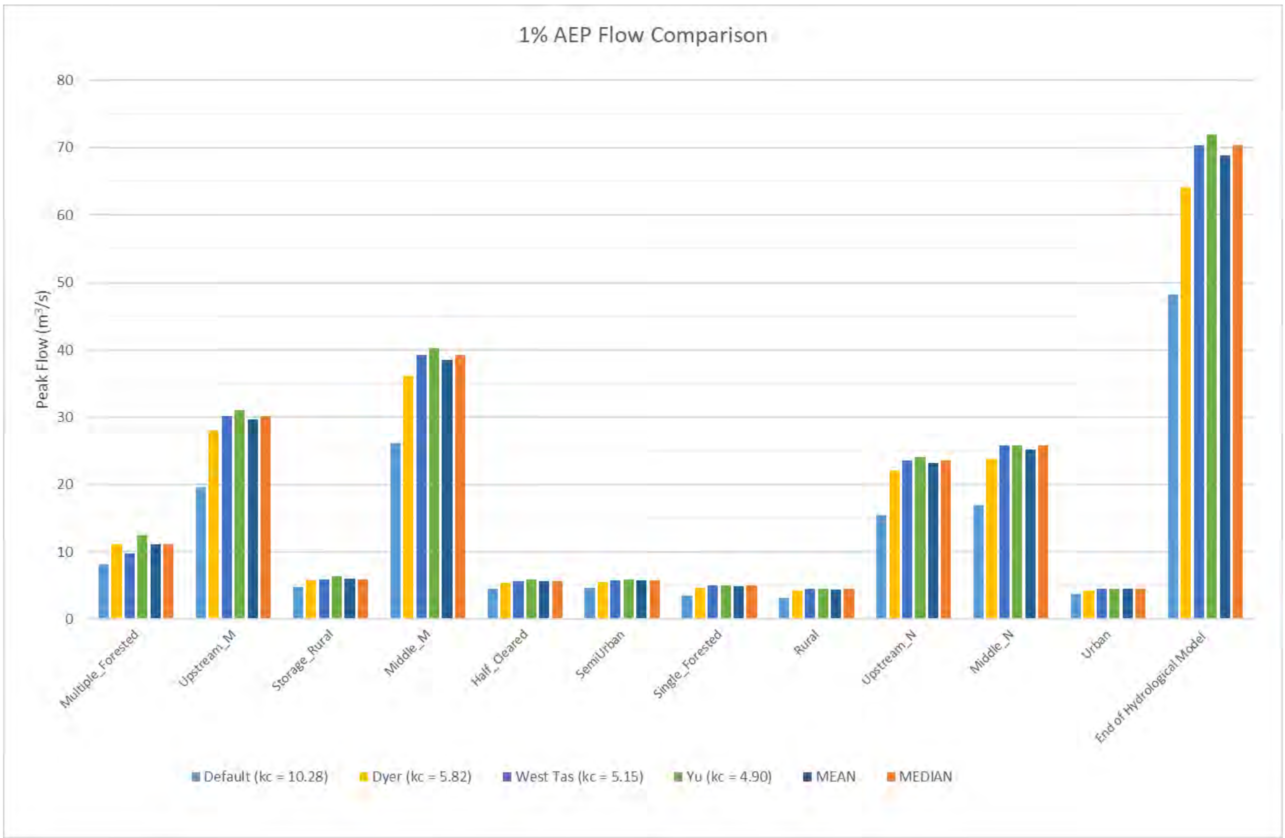


Figure 5-3 1% AEP Flow Comparison

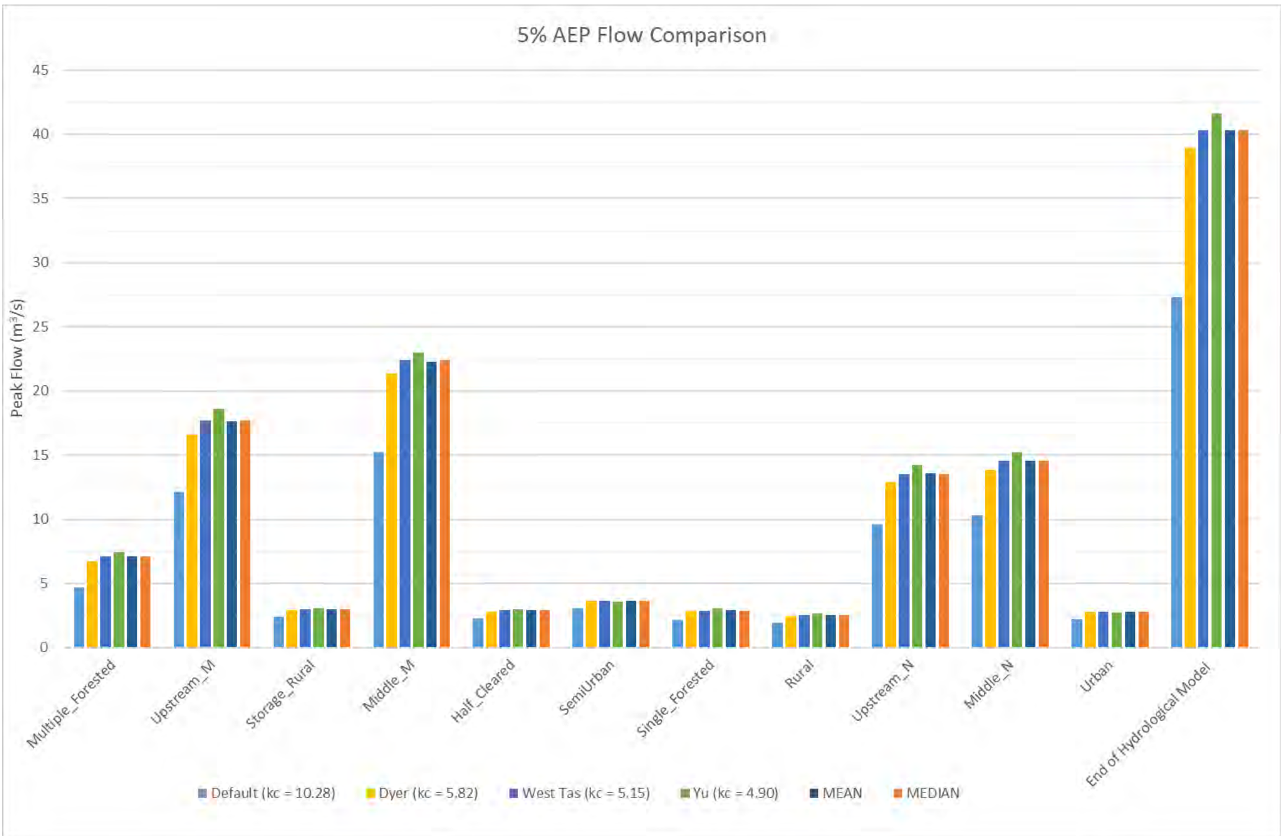


Figure 5-4 5% AEP Flow Comparison

5.2.3 RORB Ensemble and Design Modules

The Monte Carlo assessment process described in Section 5.2.1 above has been undertaken for 12 strategically chosen locations throughout the catchment as shown in Figure 5-5. These locations were strategically chosen throughout the catchment in order to capture sub-area variances. It was especially important to select a wide range of locations, representing upper areas (likely to have shorter critical durations) and main branch flow areas, as well as areas of differing fraction imperviousness.

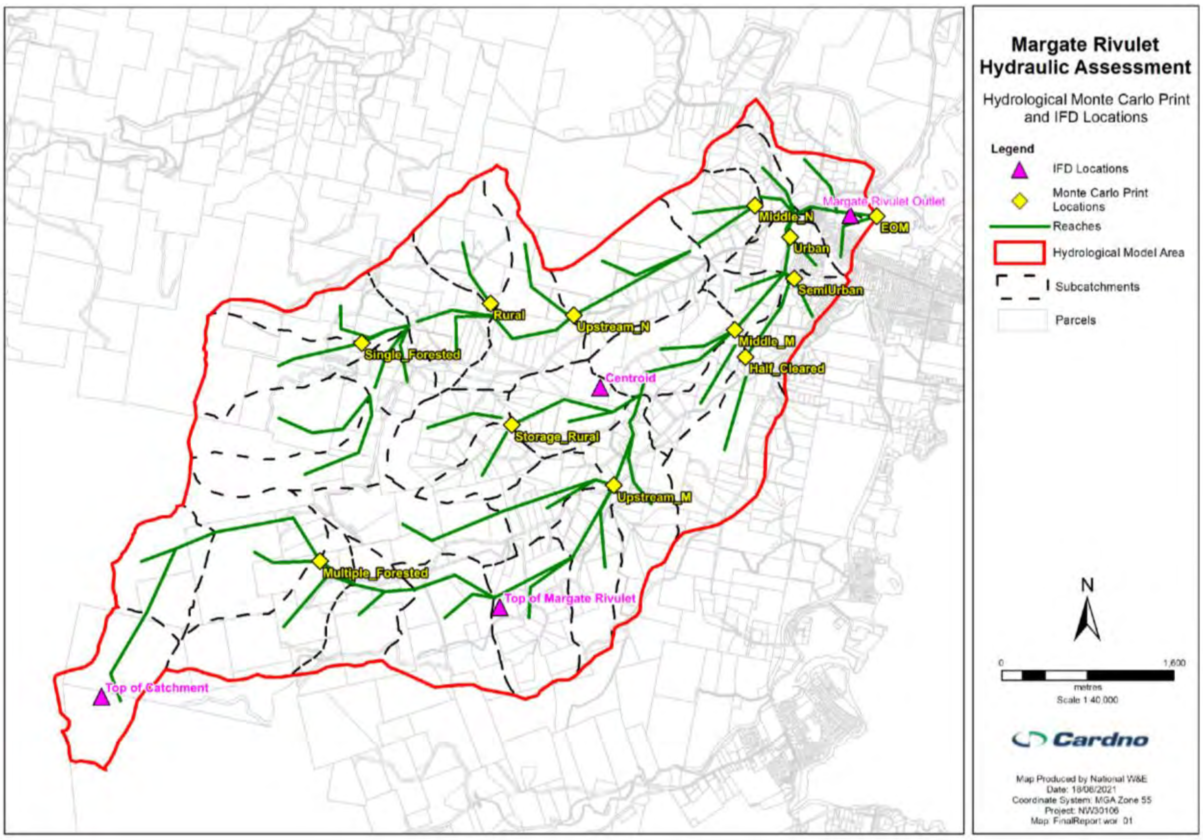


Figure 5-5 Assessed Monte Carlo Print Locations

The critical storm (duration) selection methodology has been undertaken using the following steps:

- ARR parameters were downloaded from the Data Hub including, temporal patterns, aerial reduction factors and rainfall pre-burst information
- BoM IFD parameters (2019 version) were also downloaded
- A RORB Monte Carlo analysis was run by varying the rainfall temporal pattern (using the files downloaded from the Datahub) while keeping losses, m and k_c fixed as derived using the methodology in Sections 4.1.5, 4.1.7 and 5.2.2

It should be noted that the RORB Monte Carlo analysis has been undertaken using a single ARF value ($1km^2$) for simplicity. Varying ARF values are not required as the ARF only applies a single scaling factor to the rainfall depths and so does not impact the selection of the median event.

Once the critical storm durations have been identified using the RORB Monte Carlo assessment, associated critical temporal patterns for each duration are selected by running a full suite of ensemble events through the RORB ensemble module. The temporal pattern which most closely matches the peak flowrate (at each of the analysis locations) for each critical duration from the RORB Monte Carlo output is then selected. In some cases, multiple temporal patterns are adopted for a single duration where they are producing similar peak flowrates as compared to the Monte Carlo outputs.

5.2.4 Selection of Critical Storm Events and Associated Temporal Patterns

The resultant critical storm events (and associated temporal patterns) are outlined in Table 5-1. In order to assess the impacts of changes in the level of development within the catchment and climate change, the same temporal patterns have been adopted with updated model inputs (Effectives Impervious Areas, IFD's etc.). By adopting the same temporal patterns, the impacts of both development and climate change are able to be determined without the effects of changes in temporal patterns influencing the results.

Table 5-1 Design Events

AEP	Duration	RORB Temporal Pattern
5% AEP	45 Minutes	14
	60 Minutes	17
	90 Minutes	15
	120 Minutes	16,17
	360 Minutes	12, 14, 16, 20
	540 Minutes	15
	720 Minutes	15
1% AEP	45 Minutes	22
	60 Minutes	30
	90 Minutes	26
	120 Minutes	28
	270 Minutes	29
	360 Minutes	23, 25, 26, 28
	540 Minutes	27
	720 Minutes	21
0.5% AEP	45 Minutes	22
	60 Minutes	30
	90 Minutes	23
	120 Minutes	28
	270 Minutes	29
	360 Minutes	24, 25, 26, 27, 29
	540 Minutes	24
	720 Minutes	25

5.3 Hydrological Model Validation

5.3.1 Flow Gauge Analysis

As no stream flow gauge is located within the Margate Rivulet catchment, the hydrological model is unable to be calibrated to recorded data.

5.3.2 Previous Flood Study Works

5.3.2.1 Margate Rivulet Flood Plain Study

The previous Margate Rivulet Flood Plain Study undertaken by Sinclair Knight Merz (SKM, 2006) used gauged flows from Snug River to 'calibrate' an XP-Rafts Snug River model in accordance with ARR1987. The loss values from this 'calibration' were then adopted for the XP-Rafts Margate Rivulet model to generate flows. This was undertaken to determine flooding for the previous Brookside Devmar Development Area directly adjacent to the Margate Rivulet near the Channel Highway.

Key adopted parameters from the 2006 study include:

> Initial Loss = 15mm

> Continuing Loss = 8mm/h

> Peak 1% AEP Flow Rate at the Channel Highway Culvert = 58.3 m^3/s

5.3.2.2 Snug River Flood Study

The Snug River Flood Study undertaken by Council (Kingborough Council, 2019) utilised the streamflow gauge which is approximately 2.8km upstream of the outlet on the Snug River. The hydrological and hydraulic models were developed using XPSWMM with ARR2016 guidance and three events were selected for event calibration. This was undertaken to map the flood behaviour for a range of coincidental storm events under both existing and future climate conditions in the Snug River catchment. It must be noted that this was undertaken for Snug River flooding only and did not explicitly consider flooding from stormwater within the Snug Township.

Key adopted parameters from the 2006 study include:

> Initial Loss = 10mm

> Continuing Loss = 3.2mm/h

> Modelled Peak Flows from Council's Snug River Model as shown below in Figure 5-6.

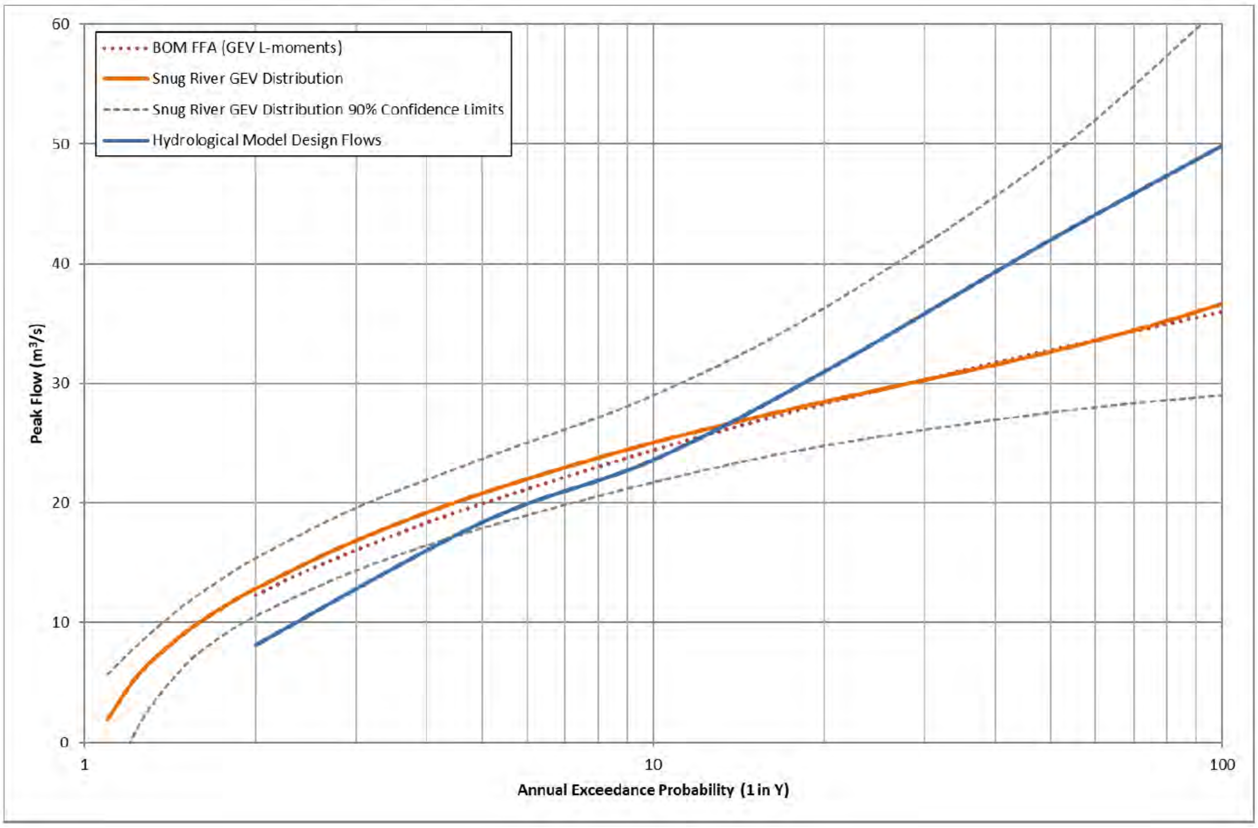


Figure 5-6 Snug River Flood Frequency Analysis compared with Council's XPSWWM Modelled Peak Flows (Kingborough Council, 2019)

5.3.3 Regional Flood Frequency Estimation (RFFE)

A Regional Flood Frequency Estimation (RFFE) has been obtained from the ARR Data Hub for the Margate Rivulet catchment and is shown below in Figure 5-7.

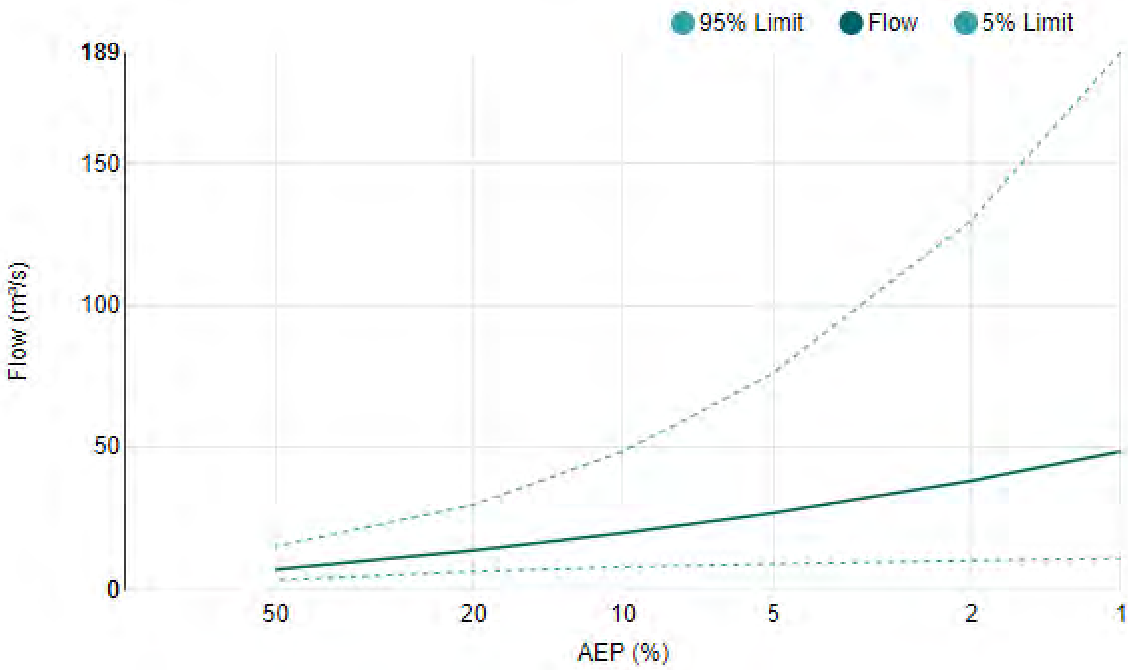


Figure 5-7 Margate Rivulet Regional Flood Frequency Estimation obtained from ARR Data Hub

5.3.4 Nikolaou/Vont Steen Equation

The Nikolaou/Vont Steen equations were developed by Nick Nikolaou and Roel Von't Steen for the Department of Natural Resources and Environment (Victoria) in 1997, based on both flood studies and large historical events, with the results shown in Figure 5-8.

For urban catchments the Nikolaou/Vont Steen equation is $Q_{1\%\ AEP} = 4.67A^{0.763}$

For rural catchments the Nikolaou/Vont Steen equation is $Q_{1\%\ AEP} = 10.29A^{0.71}$

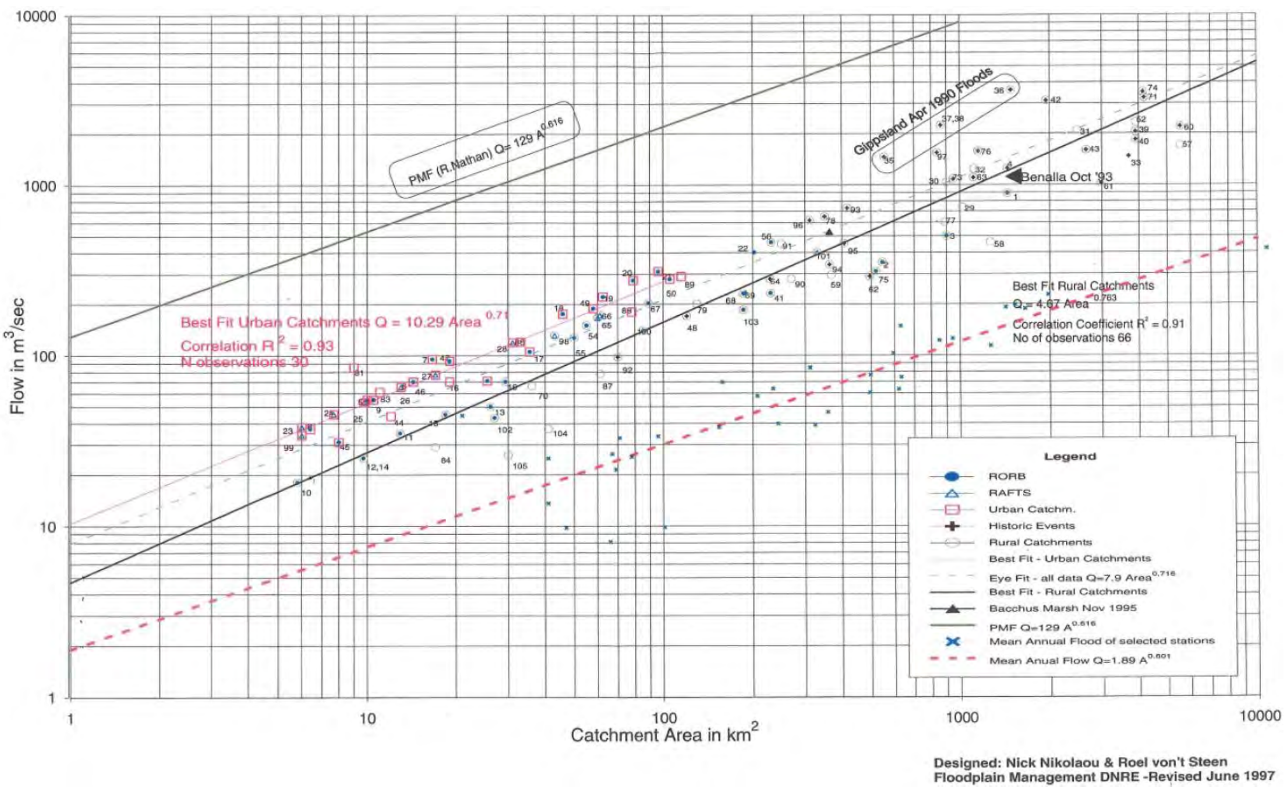


Figure 5-8 Nikolaou/Vont Steen Equation

5.3.5 Rules of Thumb

According to the Melbourne Water Technical Specifications and Smith & Smith 2015, a 'typical' small urban catchment will generate approximately $10m^3/s$ of runoff per 100ha (100ha = $1km^2$), while a rural catchment will generate $3m^3/s$ approximately per 100ha.

5.4 Validation of the Hydrological Results

The results of the Monte Carlo analysis for adopted k_c value (5.2.2) have been validated against the four comparative methodologies outlined above in section 5.3. The results outlined in Table 5-2, show that the adopted 1% AEP flow for this study fits within the expected range as per the comparative methodologies.

Table 5-2 Results of the RORB Model Validation

Method	Peak 1% AEP Flow Rate
Margate Rivulet Flood Plain Study	58.3m^3/s (result from Sinclair Knight Merz model, 2006)
Snug River Flood Study	50 m^3/s
RFFE	48.4 m^3/s
Vont Steen Rural	51 m^3/s
Vont Steen Urban	96 m^3/s
Melbourne Water Rural Rule of Thumb	69 m^3/s
Melbourne Water Urban Rule of Thumb	230 m^3/s
Adopted Kc Value	70.3 m^3/s (5% AEP = 40.3 m^3/s)

The 2006 Margate Rivulet Flood Study was undertaken in line with ARR1987 with a predicted 1% AEP flow rate of 58.3 m^3/s. As this study has been undertaken in line with ARR2019, it would be expected that the 1% AEP peak flow rate would be different due changes in model parameters such as, losses, IFD data and the way fraction impervious is calculated.

As part of the Snug River Flood Study, the hydrological model was calibrated to the stream flow gauge located within the catchment. This calibration resulted in a peak 1% AEP flow rate of 50 m^3/s. While both the Snug River catchment and the Margate Rivulet Catchment are approximately the same size (21.9 km^2 vs. 23.1 km^2), it is not considered appropriate to directly use the calibration results from one catchment to apply them to a completely different catchment. However, as the Snug River catchment generally has the same shape, size and topographical characteristics, the results can be used to assist in understanding the likely magnitude of expected flowrates.

While the RFFE indicates a peak 1% AEP flow rate of 48.4 m^3/s for the Margate Rivulet Catchment, the 70.3 m^3/s identified as part of the Monte Carlo analysis is within the expected error bounds as shown in Figure 5-7

While the Margate Rivulet catchment is predominantly rural there are areas of urbanisation in the lower reaches. Comparing the 1% AEP peak flow rates from both the Vont Steen equation and the Melbourne Water rules of thumb, shows that the adopted 1% AEP peak flow rate as predicted by the Monte Carlo analysis falls between the rural and urban results for both methods as would be expected.

6 Hydraulic Model Setup

A 1D/2D hydraulic model has been developed for the Margate Rivulet catchment. This type of model allows for dynamic links between the overland flow and pipe components based on the capacity of the drainage system. As such, once the drainage system is exceeded, the resultant overland flow patterns are determined by the two-dimensional hydraulic model.

Cardno has utilised the TUFLOW 2D HPC (Heavily Parallelised Computing) and 1D ESTRY solvers (version 2020-10-AA\TUFLOW_iDP_w64) to undertaken the hydraulic modelling. The individual components of the model and their setup are detailed in the following Sections.

6.1 Digital Elevation Model

LiDAR used to construct the Digital Terrain Model (DTM) has been obtained from ELVIS (Elevation Information System) at a grid cell resolution of 3m.

6.1.1 LiDAR

As no single LiDAR dataset covered the entire study area, the DTM has been constructed from five separate datasets as outlined below:

> Wellington Range 1m LiDAR - Tasmanian Flood Recovery Project from 2019

> Greater Hobart 1m LiDAR - Tas Coastal Project from 2013

> Mt Wellington 1m LiDAR - Forestry Tasmania Project from 2011

> Derwent 1m LiDAR - Climate Futures Project from 2008

> Geoscience Australia 5m LiDAR – National Resampled Project from a collection of datasets

As each of the datasets have been captured at different times/resolutions they have been combined to ensure the newer datasets are take preference over older, historical datasets.

6.1.2 Topographic Modifications

As the hydraulic model is being run at resolution of 3m, topographic modifications are required to ensure key features are captured within the DTM.

In order to ensure that the inverts for both the Margate Rivulet and Nierinna Creek channels are properly captured within the DTM, gully lines have been used. The channel inverts for both waterways has been set based on the 1m LiDAR supplied for this study.

Inversely, ridge lines have been used to ensure the crest levels of key features such as dam walls and the levee located along Sandfly Road are adequately captured within the DTM

Where the DTM does not accurately represent a key topographic feature such as a bridge due to issues within the underlying LiDAR, z-shapes have been used.

Figure 6-1 shows the final model DTM and the location of all topographical modifications.

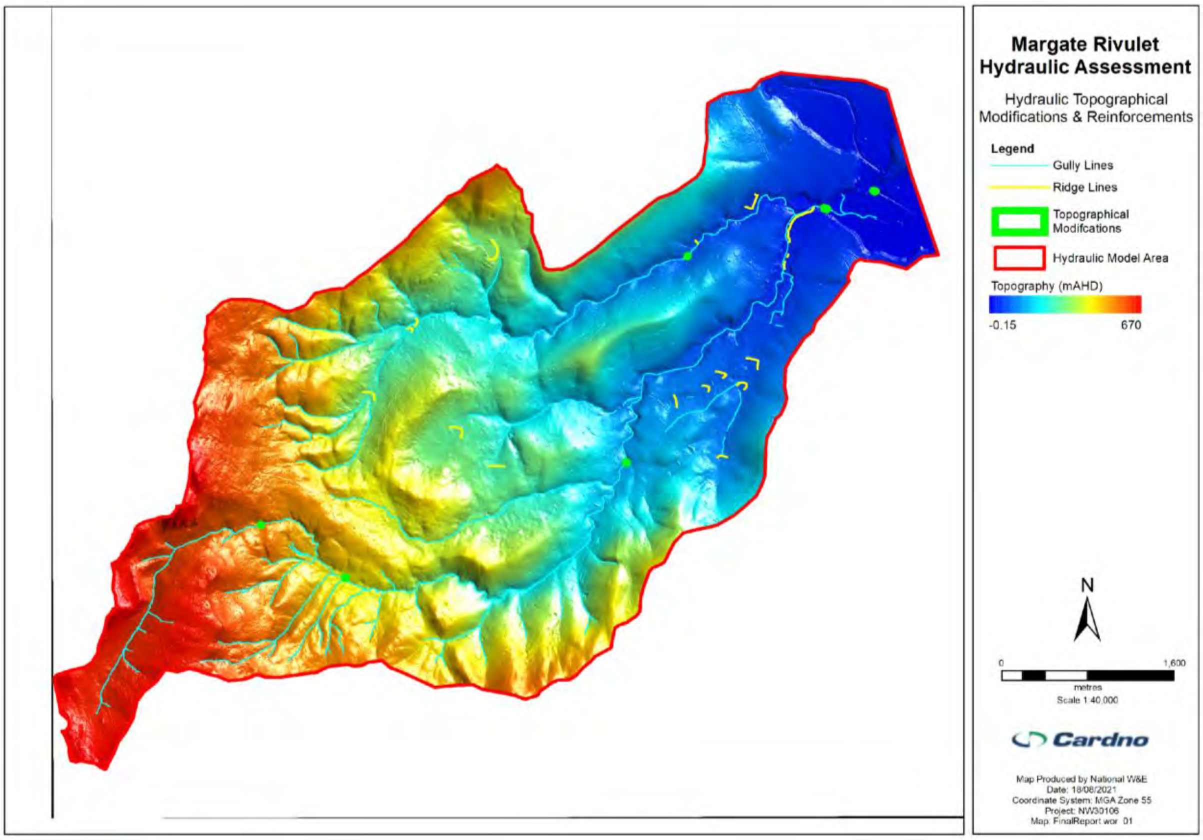


Figure 6-1 Final DTM and Topographic Modifications

6.2 Roughness Manning’s ‘n’

Water flows in the 2D elements of the model, according to the hydraulic properties of the land surface, as defined by the DTM and the hydraulic roughness.

The 2D hydraulic roughness was determined using property data, planning zones and aerial photography, with the Manning’s ‘n’ values being consistent with industry guidelines and previous studies in the area. Manning's 'n' or hydraulic roughness is a co-efficient which corresponds to the roughness (friction) of the ground surface. The adopted roughness categories and associated values are detailed below in Table 6-1 and shown in Figure 6-2.

Table 6-1 Land Use and associated Manning’s ‘n’ Values

Land Use	Manning’s ‘n’ Value
Residential High Density Urban | Combined Parcel and Building	0.300
Residential Lower Density Rural | Combined Parcel and Building	0.100
Building	0.500
Industrial / Cemetery	0.300
Commercial	0.300
Open Pervious Areas | Minimal Grassed Vegetation	0.040
Open Pervious Areas | Moderate Shrubbed Vegetation	0.060
Open Pervious Areas | Thick Treed Vegetation	0.100
Waterways / Channels | Minimal Vegetation / Rock/Earth Lined	0.030
Waterways / Channels | Moderate Vegetation	0.060
Waterways / Channels | Heavy Vegetation	0.090
Paved Roads / Driveways	0.020
Lakes | No Emergent Vegetation	0.020
Wetlands | Emergent Vegetation	0.060
Estuaries / Oceans	0.030
Gravelled Surface | Rural Road	0.050
Artificial Turf / Handstand Sporting Surface	0.015
Agriculture / Farmland	0.050
Carparks	0.022
Education	0.2
Agriculture / Farmland with Buildings Combined	0.1

6.2.2 Vegetation Assessment Scenario

In order to assess the sensitivity of the catchment to changes in levels of vegetation along waterways, the following changes were made to hydraulic model roughness values for these modelled scenarios.

- Regions designated as “Waterways / Channels | Minimal Vegetation / Rock/Earth Lined” (0.030) have been maintained as is.
- Regions designated as “Waterways / Channels | Moderate Vegetation” (0.060) have been changed to “Waterways / Channels | Minimal Vegetation / Rock/Earth Lined” (0.030); and
- Regions designated as “Waterways / Channels | Heavy Vegetation” (0.090) have been changed to “Waterways / Channels | Moderate Vegetation” (0.060).

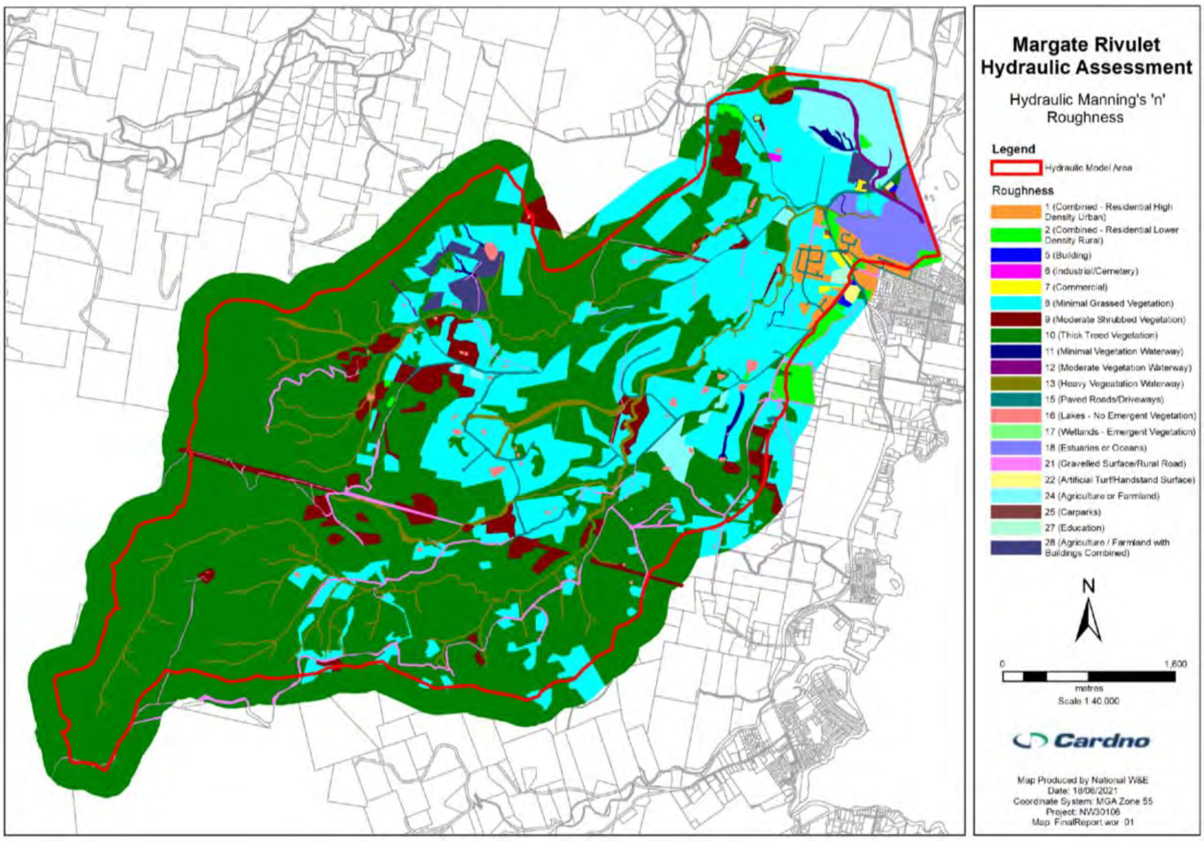


Figure 6-2 Assigned Roughness (Manning's 'n') for the Margate Rivulet Catchment

6.3 Pipe Infilling

As outlined in the Data Review Report (dated 11/11/19), a significant number of the received pipe data had missing inverts and diameters. These diameters and inverts were therefore required to be estimated based on the available information. Additionally, some inverts provided in the dataset were altered to facilitate model running, as these appeared to be incorrectly input into the GIS dataset due to typographical errors.

Further areas of discrepancy were also detected between pipe inverts and surface levels, particularly in areas that have recently changed due to development. Despite pipe inverts potentially being correct, they needed some degree of altering to ensure that they do not break the surface as the model will not run if pipes are found to do this.

Pipes which were originally supplied without inverts or sizes were primarily infilled from design plans that were received from council. Where council were not able to provide design plans, engineering judgment was used. Unknown diameters were infilled based on surrounding diameters and the location of the pipe. Unknown inverts were estimated by subtracting the diameter and an assumed 600mm cover from ground surface levels. They were then matched in with surrounding pipe inverts to ensure a realistic pipe network with all pipes able to flow downhill.

6.4 Pit Sizing

Pits were located in the model according to Council data, as outlined in the Data Review Report (dated 11/11/19). Additional pits were added where connections should be, but were not present in the data received. This was usually the case in newly developed areas and where there were missing pipes in the dataset. In some instances, the pipe was split and a junction pit added to enable a connection.

The following assumptions have been made regarding the modelled pits:

> Pits were assumed to be rectangular (R), with height and width per LGAT standard drawings (provided to Cardno after Data Review Report)

> Height and Width determined to be 1.2 by 1.2m. This was an assumption given the largest pipe in a network was 0.6m. The LGAT drawing TSD-SW05-01 shows the typical width of the concrete pit is 150mm, totalling 0.3m. Therefore, using the schematic, it was assumed internal width was 0.9 x0.9.

> Pit inverts were assumed to be the bottom of the pipe invert

> All Pits have been modelled as 2D SX connections except where the provided pit layer was used to identify manholes and house connections. These were set to nodes.

> Entry and exit losses are set to 0.5 and 1 respectively

> Each pit is connected to two additional 2D cells. As no “junction pits” have been labelled in the Kingborough Dataset, it has been assumed that pits labelled as “manholes” are actually junction pits.

6.5 Layered Flow Constriction Shapes

Based on Cardno’s experience of modelling urban pipe networks, Cardno typically includes bridges and some large culverts within the 2d domain as layered flow constriction shapes (lfcsh). The main reason for this is that Cardno has found that they are less prone to causing instabilities and erroneous flow values than their 1d counterparts. In order to use lfsch files, various blockage and flow constriction factors are required for each layer (i.e. below the soffit, the bridge deck itself and railings above the bridge deck). These values were all estimated using the following (depending on availability):

> Design drawings

> Measurements from the site visit

> Site visit photos

> Aerial photos

> Google Street View photos

Furthermore, all flow constriction factor values were calculated using the methodologies outlined in Hydraulics of Bridge Waterways (1978) with the various bridge types considered according to those shown in Figure 6-3.

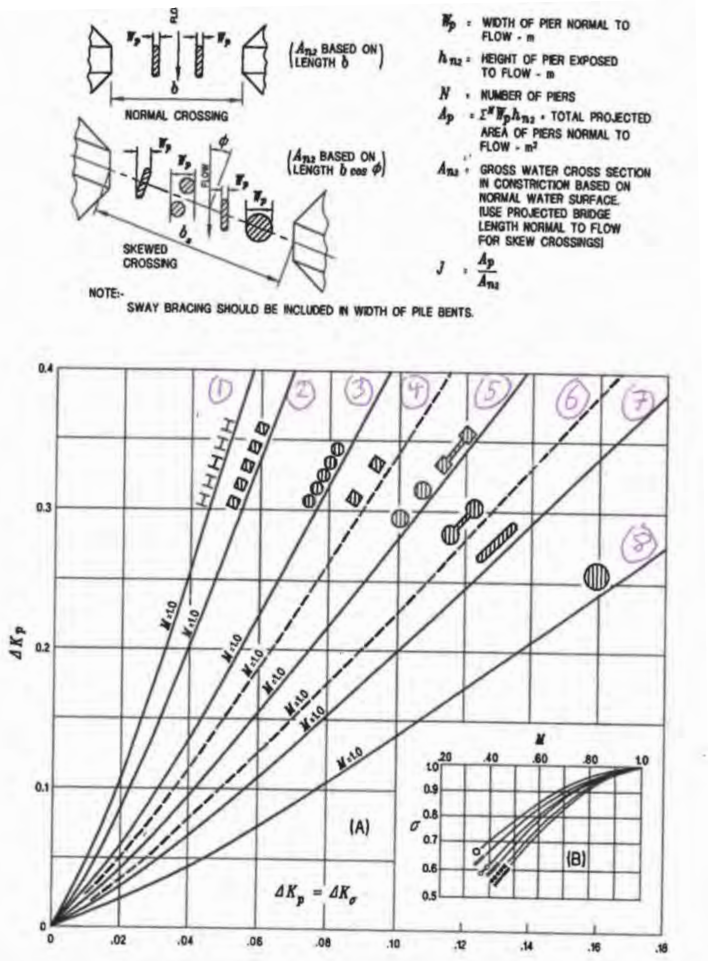


Figure 4 Incremental Backwater Coefficient for Piers (Hydraulics of Bridge and Waterways, 1978)

Figure 6-3 Bridge Types – source: Hydraulics of Bridge Waterways (1978) and TUFLOW Manual

All attributes used in the estimation of blockage and flow constriction factors are summarised in Table 6-2, with the locations of these bridges (Layered Flow Constriction Shapes) shown in Figure 6-4. Based on the observations from the site visit, all but two bridges were designated as clear single span bridges and therefore no blockage was associated with this bridge opening. For the two bridges which have piers, the blockage applied to the bridge opening was determined by the ratio of the width of the piers to the width of the bridge opening.

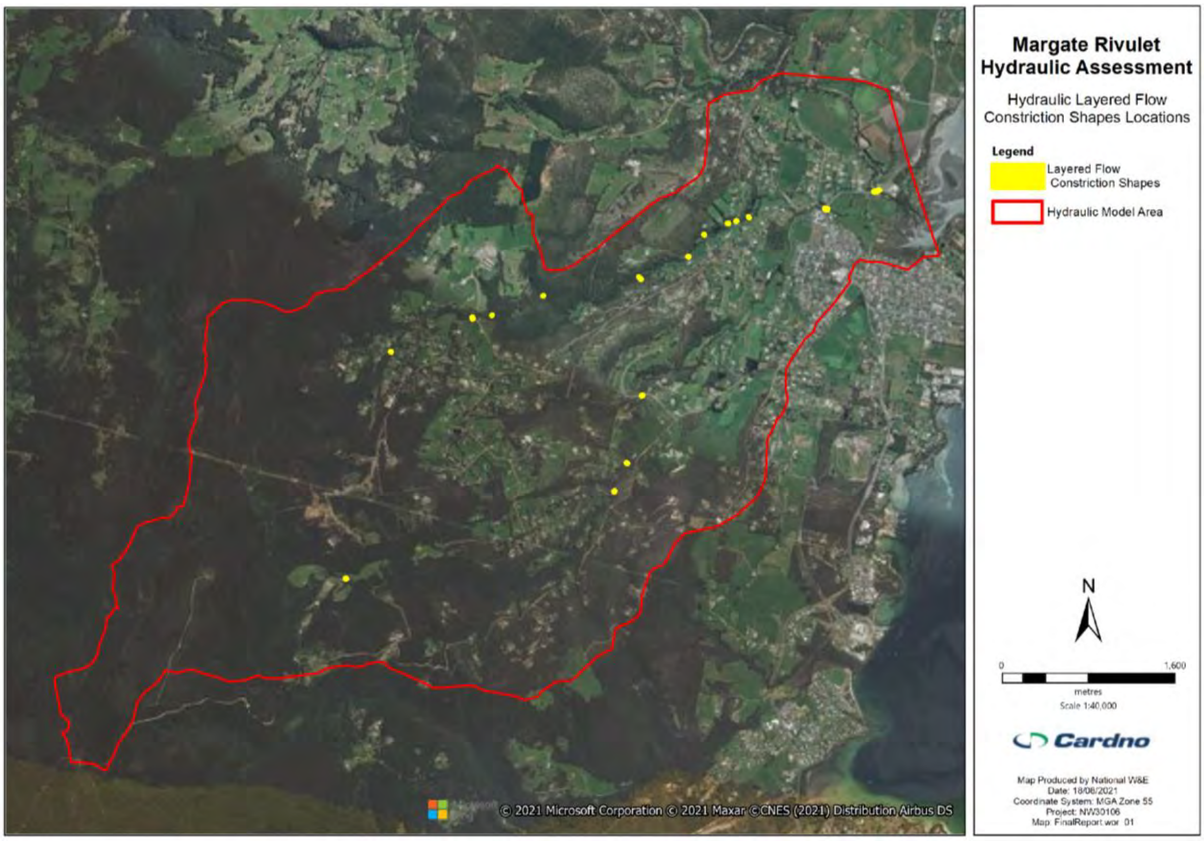


Figure 6-4 Bridge (Layered Flow Constriction Shapes) Locations

Table 6-2 Layered Flow Constriction Shapes Summary

ID	Invert	Bridge Obvert (mAHD)	L1* Blockage (%)	L1 LFC	Deck Width (m)	L2** Blockage (%)	L2 LFC	Railing Height (m)	L3*** Blockage (%)	L3 FLC
M1	-99999	5.90	3.17	0.008	1.00	100	0.106	0.75	30	0.006
M2	-99999	6.05	8.59	0.012	1.65	100	0.064	1.1	75	0.006
M3	-99999	14.41	0.00	0.000	1.00	100	0.149	0.5	45	0.006
M3a	-99999	24.21	0.00	0.000	0.30	100	0.172	0.5	40	0.006
M4	-99999	28.40	0.00	0.000	0.50	100	0.142	0.3	75	0.006
M5	-99999	31.43	0.00	0.000	0.50	100	0.119	0.3	75	0.006
M5a	-99999	35.80	0.00	0.000	0.30	100	0.159	0.5	40	0.006
M6	-99999	43.70	0.00	0.000	0.50	100	0.146	0	0	0.006
M6a	-99999	59.70	0.00	0.000	0.30	100	0.159	0.5	40	0.006
M7	-99999	143.80	0.00	0.000	0.50	100	0.071	0.5	45	0.006
M7a	-99999	124.70	0.00	0.000	0.30	100	0.310	0.5	40	0.006
M7b	-99999	131.01	0.00	0.000	0.30	100	0.310	0.5	40	0.006
M8	-99999	167.60	0.00	0.000	0.50	100	0.104	0.6	45	0.006
M9	-99999	65.10	0.00	0.000	0.30	100	0.044	0.6	45	0.006
M10	-99999	85.93	0.00	0.000	1.00	100	0.214	1.3	25	0.006
M11	-99999	97.55	0.00	0.000	0.60	100	0.126	0.6	60	0.006
M12	-99999	263.60	0.00	0.000	0.60	100	0.153	0.3	95	0.006

*L1 = bridge piers

**L2 = bridge deck

**L3 = bridge railings

6.6 Rainfall Application

Rainfall has been applied to the hydraulic model via 2d_sa (all) layers in the hydraulic model extent via excess rainfall hydrographs. The excess rainfall hydrographs have been derived from the RORB model, and evenly distributed over the relevant sub catchment.

6.7 Downstream Boundary Conditions

For the downstream boundary of the hydraulic model, the 5% AEP level within North West Bay of 1.47 mAHD has been adopted based on the analysis outlined below.

Due to the topography along Beach Road, there is a pipe which directs overland flow into the neighbouring catchment to the south. A 1d_bc has been applied to this pipe where it leaves the catchment, with the level set as the pipe obvert.

6.7.1 Influence of the North West River

As the North West River discharges into North West Bay in the direct vicinity of the Margate Rivulet, an assessment has been undertaken in order to determine how it influences results within the study area as shown in Figure 1-2.

The North West River has an upstream catchment of approximately 96 sq. km, with a stream flow gauge (5201-1 North West bay Rivulet @ Margate WS INT) located approximately 3.9 km upstream of the river mouth, just upstream of Miandetta Drive (between Allens Rivulet and Blue Gate Creek). This gauge has been active since 1965.

6.7.1.1 North West River Flood Frequency Analysis

In order to understand the expected likely peak flow rates of the North West River, and their influence on the Margate Rivulet catchment, a Flood Frequency Analysis (FFA) has been undertaken at the gauge location. As apart for the FFA, the quality and quantity of the recorded data was reviewed, with grade codes 11 (F-Issues) and 21 (E-Unknown) removed from the sampled dataset. This has resulted in 30 years of stream flow data being included within the FFA, with the largest maximum yearly flow rate of 207.5 m^3/s being recorded in 1986 and the lowest maximum yearly flow rate of 4.7 m^3/s being recorded in 2017. As shown in Figure 6-5, the FFA estimates the 1% AEP flow rate at the gauge in the North West River to be 330 m^3/s, which is significantly higher than the 249 m^3/s predicted by the RFFE of the same catchment.

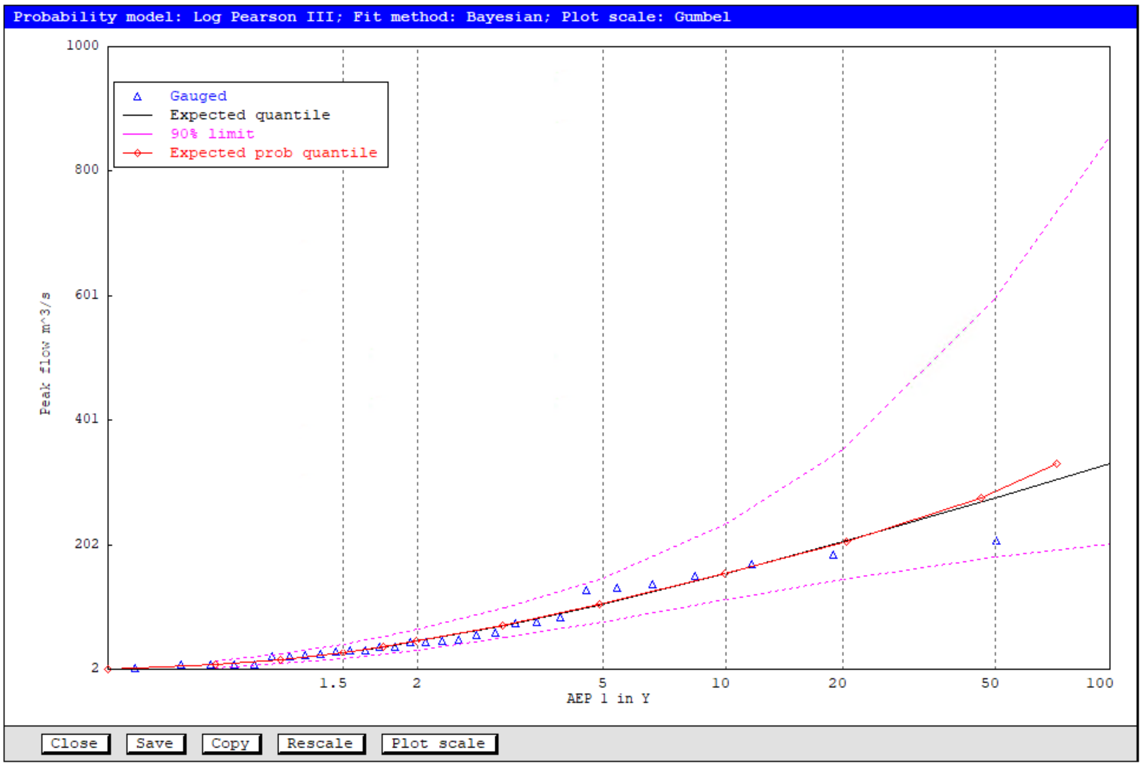


Figure 6-5 North West River Flood Frequency Analysis

6.7.1.2 Flooding in the Lower Reaches of the North West River

In order to determine the influence that the 1% AEP flood event (see section 6.7.1.1) has on flooding within the Margate Rivulet study area, a simple 2D hydraulic model was developed for the lower reaches of the North West River. This model applied an inflow of the peak 1% AEP inflow of 330 m^3/s (as per the FFA), with the hydraulic roughness being consistent with the Margate Rivulet hydraulic model and downstream boundary level of 1.47 mAHD.

It is expected that based on the assessment outlined above, for the 1% AEP event along the North West River, overland flows are generally contained within the waterway, with the overland flows backing up behind the Channel Highway and inundating the escarpment to the west of the river. As shown in Figure 6-6 there is likely to be overtopping of the Channel highway due to flows from the North West River. However, as they do no propagate up into the Margate Rivulet study area, it has been assessed that flooding in the North West River does therefore not impact on the modelled flood levels within the Margate Rivulet catchment.

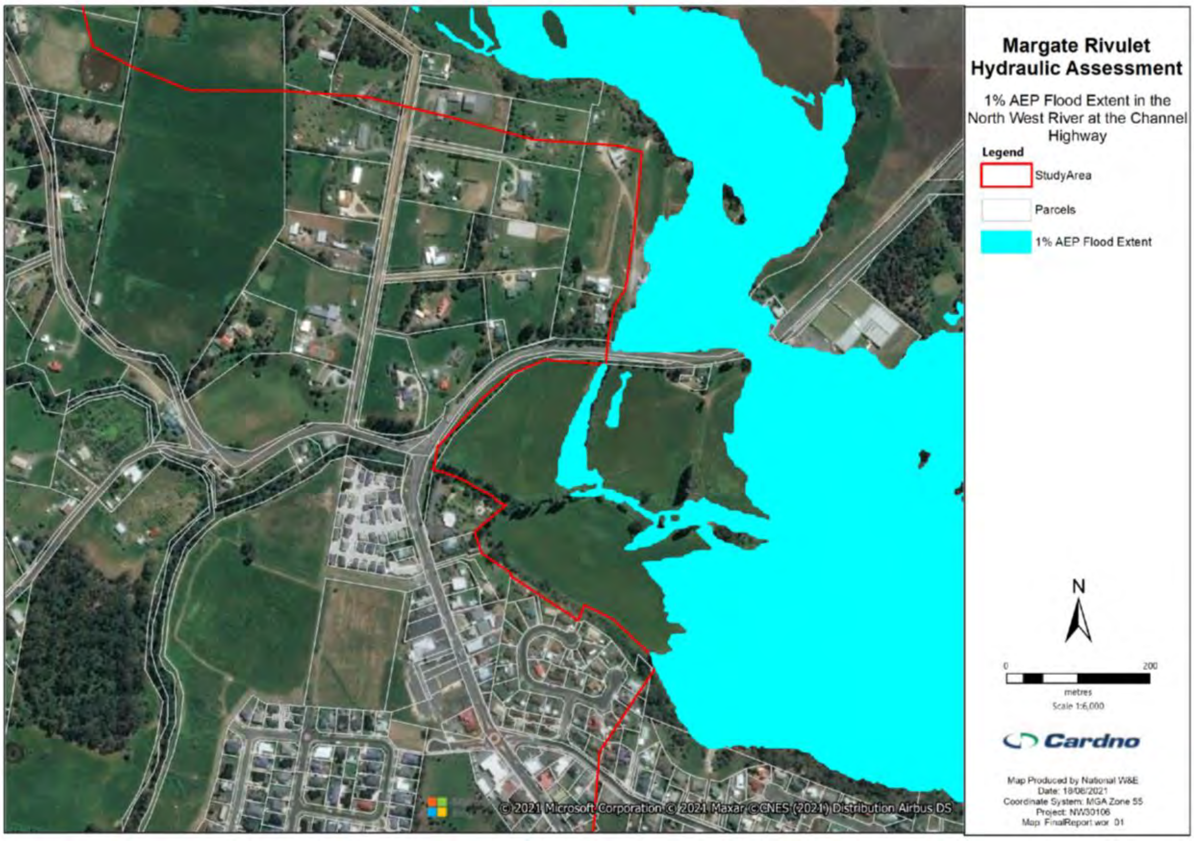


Figure 6-6 1% AEP Flood Extent in the North West River at the Channel Highway

6.7.2 Coincidental Storm Surge and Tidal Data

In order to determine the appropriate downstream water level within North West Bay, an assessment utilising peak Nearshore Water Levels, as determined by the Water Research Laboratory of UNSW (2017), has been undertaken in order to quantify the impacts of different Tailwater levels on the flood levels within the study area. This assessment has been undertaken on both the 5% AEP and 1% AEP Peak Nearshore Water Levels of 1.47 mAHD and 1.57 mAHD (as well as their climate change equivalents) as shown in Figure 6-7.

Year	ARI	Sea Level Rise (m)	Tide at Peak (m AHD)	Anomaly at Peak (m)	Local Wind Setup at Peak (m)	Wave Setup at Peak (m) (Shoreline)	Peak Nearshore Water Level (m AHD)
Present Day	1	0	0.53	0.44	0	0.1	1.07
	10		0.53	0.68	0	0.16	1.37
	20		0.53	0.75	0	0.19	1.47
	50		0.53	0.84	0	0.13	1.5
	100		0.53	0.91	0	0.13	1.57
2050	1	0.3	0.53	0.44	0	0.1	1.37
	10		0.53	0.68	0	0.16	1.67
	20		0.43	0.75	0	0.19	1.67
	50		0.53	0.84	0	0.13	1.8
	100		0.53	0.91	0	0.13	1.87
2100	1	1	0.53	0.44	0	0.1	2.07
	10		0.53	0.68	0	0.16	2.37
	20		0.53	0.75	0	0.19	2.47
	50		0.53	0.84	0	0.13	2.5
	100		0.53	0.91	0	0.13	2.57

Figure 6-7 Water Levels in North West Bay

Due to the topography of the lower reaches of the study area, neither the 5% AEP nor the 1% AEP Peak Nearshore Water Levels in North West Bay (Present Day or Climate Change) propagate up into the study area as shown in Figure 6-8. As neither Peak Nearshore Water Levels propagate up into the study area, the 5% AEP level has been adopted in order to be consistent with the previous Snug Bay study, with the 5% AEP climate change level adopted for the climate change scenarios.

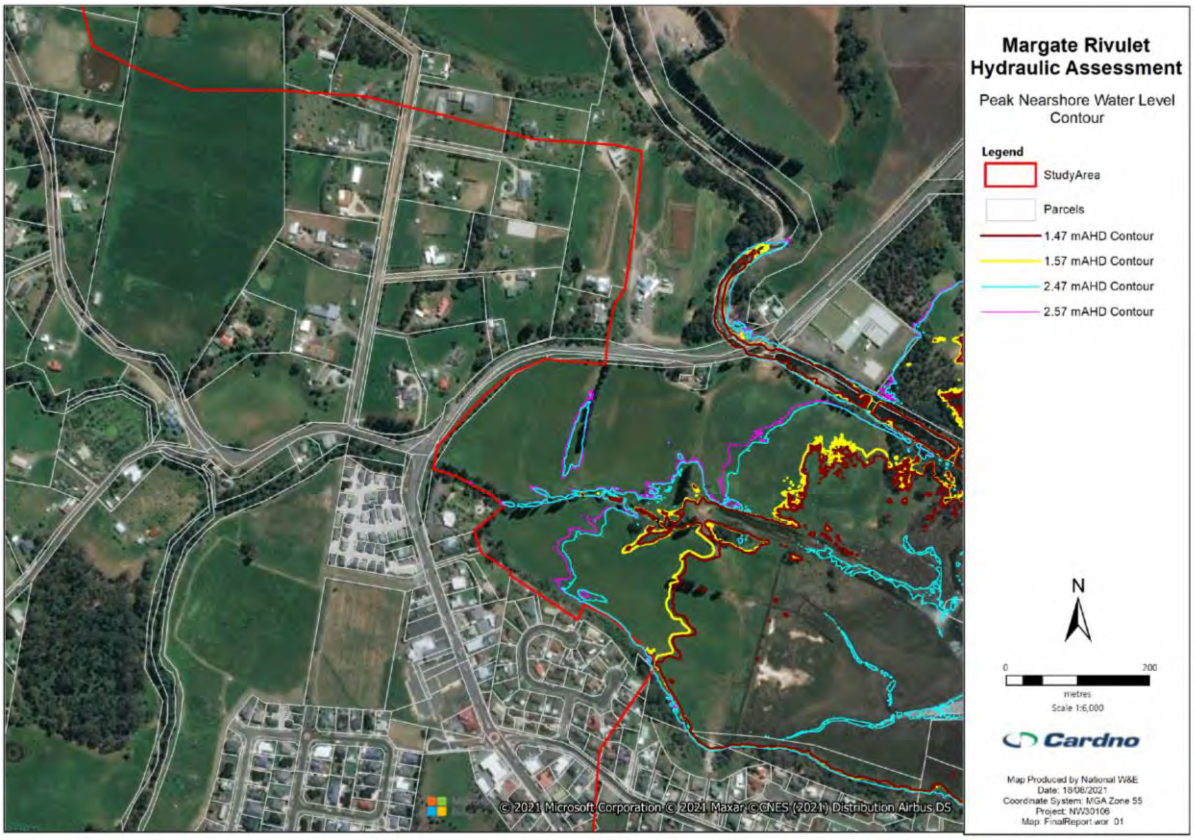


Figure 6-8 Peak Nearshore Water Level Contour

7 Hydraulic Model Parameters

The TUFLOW model has been run with the following key parameters:

> ESTRY Control File (1D)
  - Start Time == 0
  - Timestep (s) == 0.2
  - Output Interval (s) == 300
> TUFLOW Control File (2D)
  - Solution Scheme == HPC
  - Model TUFLOW Build == 2020-10-AA-isP-w64
  - Hardware == GPU
  - Timestep == Variable
  - Cell Wet/Dry Depth == 0.0002
  - Map Output Data Types == hVqdZAMIEdt
  - Start Map Output == 0
  - Map Output Format == GRID XMDF
  - Grid format == ASC
  - Grid Output Cell Size == 3
  - Map Output Interval == 300
  - Time Series Output Interval == 300
  - Maximums and Minimums Only For Grids == ON
  - Store Maximums and Minimums == ON MAXIMUMS ONLY
> TUFLOW Geometry Control
  - Origin == 514000,5231000
  - Orientation == 514000,5231000
  - Grid Size (X,Y) == 9000, 9000
  - Cell Size == 3

8 Hydraulic Model Results

8.1 Modelling Scenarios

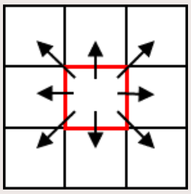
The following events have been hydraulically modelled:

- 5%, 1% and 0.5% AEP base case events;
- 1% AEP climate change event with the climate change tidal levels;
- 1% AEP event best and worst development cases; and
- 1% AEP event decreased vegetation (lowered Roughness Manning's 'n' values)

8.2 Results Processing

Raw outputs from each of the events assessed within the hydraulic model have been combined into a single set of results using an in-house Cardno tool, which essentially mimics TUFLOW's asc_to_asc tool by sampling the results at each grid cell and selecting the critical value. As the critical events have been identified as part of the hydrological modelling stage of the project (see section 5.2), the critical value selected is the maximum value from all the hydraulically modelled durations and temporal patterns for each event. Once the results have been combined into a single set of results based on the event, they have been filtered in order to produce a smoothed flood extent, using the process outlined in Table 8-1.

Table 8-1 Result Processing Methodology

Process	Description
Depth filtering	Results are filtered to remove any cells where the depth of flooding (D) is less than 0.05m
Area filtering	An area filter has been applied to remove isolated 'wet puddles' or 'dry islands' from the flood extent and provide a more cohesive shape. The area threshold adopted is $100m^2$. In assessing the area of wet puddles or dry islands, it is assumed that diagonal connections constituted a connection. The schematic below shows all cells considered as neighbours and includes diagonal connections. 
Smoothing	To remove the staircase effect from the edge of the flood extent, the shape is then smoothed using a process developed by Cardno as mentioned above. This is the final step in the generation of the flood extent.
Provide grid results of the flood extent	The grid cells, which remain within the smoothed flood extent, are extracted to provide a dataset of flood modelling results.

8.3 Flood Maps

Flood maps have been included in Appendix A for the 5% AEP, 1% AEP and 0.5% AEP events.

Flood maps have been created for:

> Flood Level
> Flood Depth
> Flood Velocity
> Flood Hazard

8.4 Verification of Results

In order to verify the hydraulic model, a two-step process has been adopted as outlined below and discussed in the following Sections.

> Step 1 – Verify the results to an historical event
> Step 2 – Compare council hot spots to the design event model results

8.4.1 Historical Flooding Event

In order to verify that the hydraulic model is producing results in line with historical events, the May 2018 event has been hydraulically modelled. During this event, the Sunnyside rainfall gauge recorded 151mm of rainfall over a 24-hour period.

As the Sunnyside rainfall gauge only records daily rainfall and not pluviograph (sub-daily rainfall) data, the temporal patterns of this storm has been obtained from the Blackmans Bay Treatment Plant pluviograph station. As the total rainfall recorded by the Blackmans Bay station slightly varied from the Sunnyside station, the total rainfall recorded at Blackmans Bay has been scaled to match that recorded by the Sunnyside. As such, the rainfall temporal pattern has been adopted from the Blackmans Bay Treatment Plant location using the total rainfall recorded within the most relevant gauge.

Once the total rainfall and temporal pattern for the May 2018 had been determined, the excess rainfall hydrograph was calculated using RORB, with the same parameters (i.e. losses, EIA, KC value etc.) selected as for the design events adopted.

As shown in Figure 8-1 the hydraulic model generally corresponds to the reported council hotspots relating to the May 2018 event (see Table 2-2).

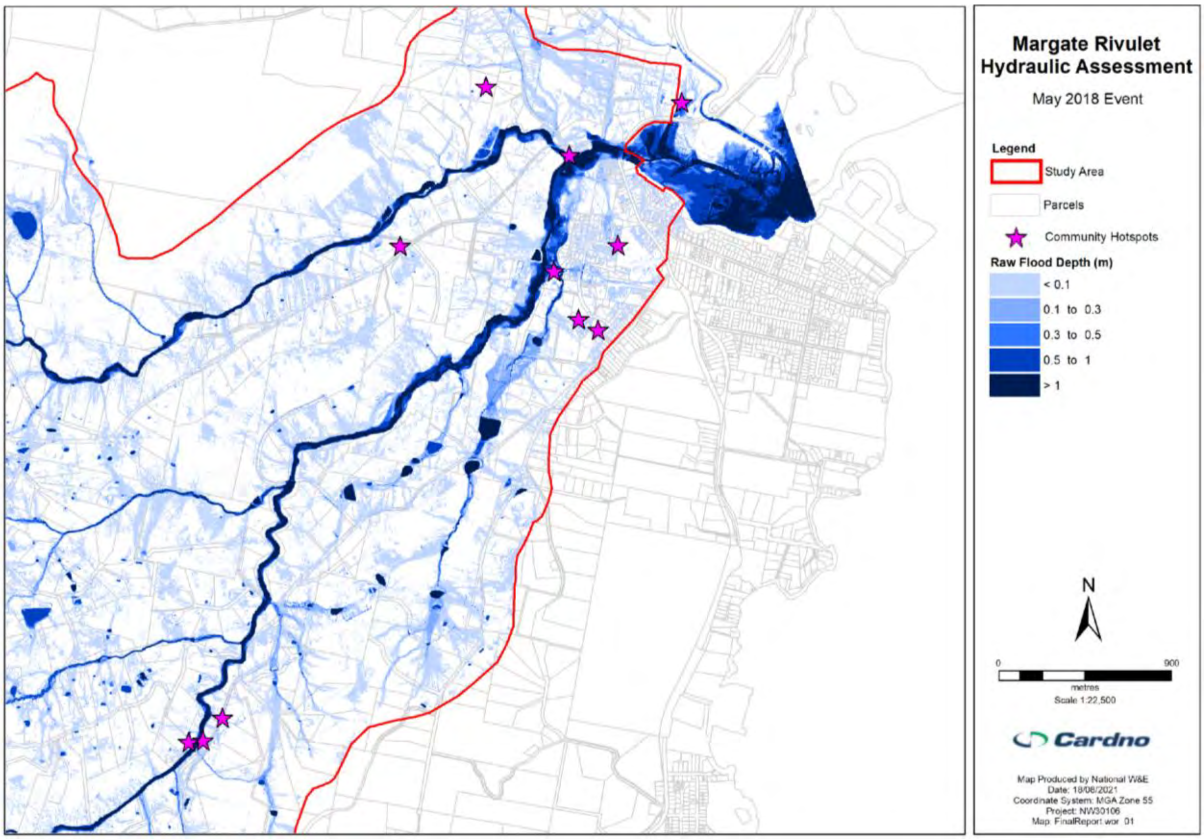


Figure 8-1 May 2018 Event Maximum Flood Depths and Recorded Hotspots

8.4.2 Base Case

In order to verify the design events, the model results have been cross checked against anecdotal flooding issues as outlined in Table 2-2 (community engagement survey) and Table 2-3 (site visit community engagement). Table 8-2 highlights where the filtered results from the hydraulic model indicate flooding in the vicinity of the anecdotal evidence and shows that for all identified locations, the hydraulic model accurately indicates flooding does occur.

Several of the reported locations (Dayspring Drive, Van Morey Road, Nierinna Road and Sandfly Road and Merediths Road) contain properties in the vicinity of the flooding which directly border onto the Rivulet.

Table 8-2 Highlights the locations where

Location	5% AEP	1% AEP	0.5% AEP
Dayspring Drive (community engagement survey)	√	√	√
Van Morey Road (community engagement survey)	√	√	√
Crimson Drive (community engagement survey)	√	√	√
Nierinna Road (community engagement survey)	√	√	√
Sandfly Road (community engagement survey and Site Visit Community Engagement)	√	√	√
Worsley Drive (community engagement survey)	√	√	√
Merediths Road (Site Visit Community Engagement)	√	√	√

8.5 Flood Risk Identification

The flood risk of the catchment has been undertaken in line with the ARR2019 Hazard categories H1-H6, where H1 is considered to the safest category and H6 the most unsafe, as shown in Figure 8-2.

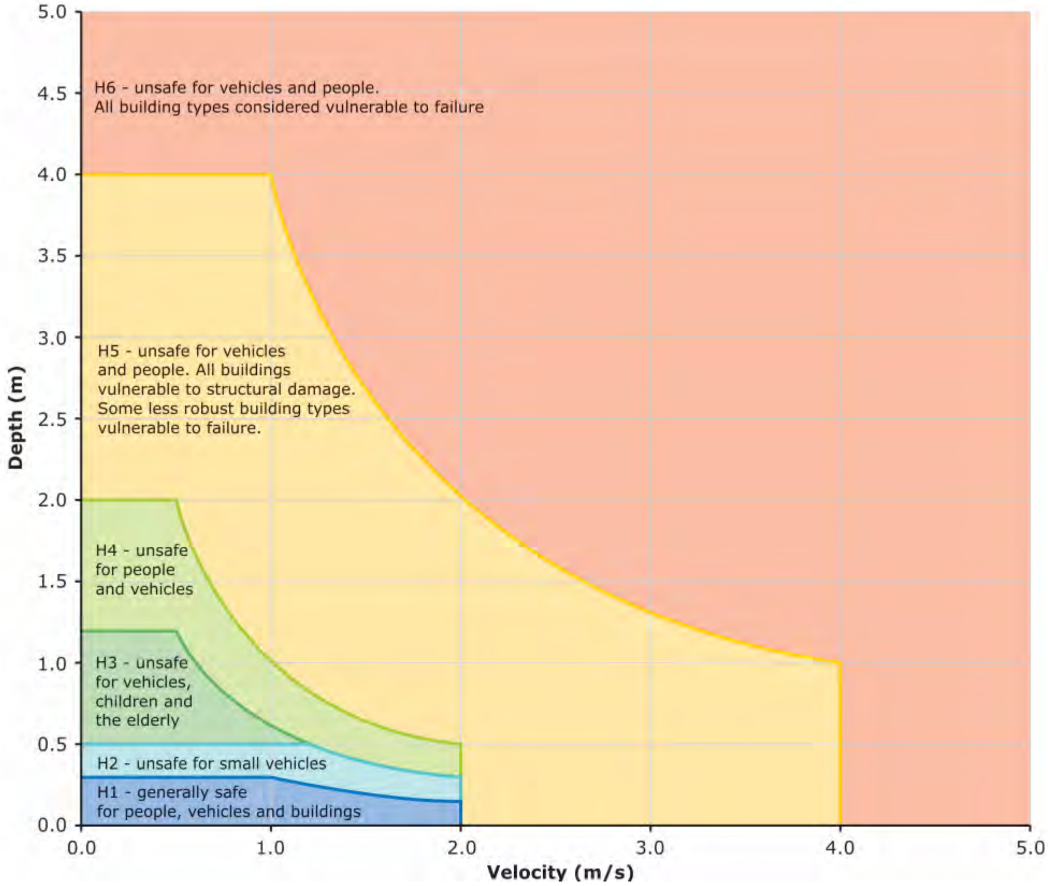


Figure 8-2 ARR2019 Hazard Classes

In the 1% AEP event, flooding within the rivulet is unsafe where it is classed predominantly as H5 and H6, due to both the high velocities and depth of the flooding. Outside of the rivulets, farm dams are generally classified as H3 and H4 due to the depth of flooding. In the urban areas in the 1% AEP event, flooding is generally very shallow, which results in this flooding being classed as H1. Figure 8-3 shows the location of areas of high flood risk within the Margate Rivulet catchment, with the Table 8-3 outlining these locations.

Table 8-3 Flood Risk Identification

ID	Location	Flood Risk
1	**The walking track along Margate Rivulet**	Directly upstream of the Channel Highway along the west side of Margate Rivulet, in the 1% AEP event the flooding along the Margate Rivulet Track is classified as H5, which is unsafe.
2	**Van Morey Road**	Along Van Morey Road the access for several properties is via bridges/culverts across Margate Rivulet. In the 1% AEP event the rivulet is classified at being subject to H5 and H6 flooding which is unsafe.
3	**The walking track along Nierinna Creek**	Upstream of Burnaby Drive, flooding along the Nierinna Creek Walking Track is classified as H5 and H6 which is unsafe, the Track crosses the rivulet several times.

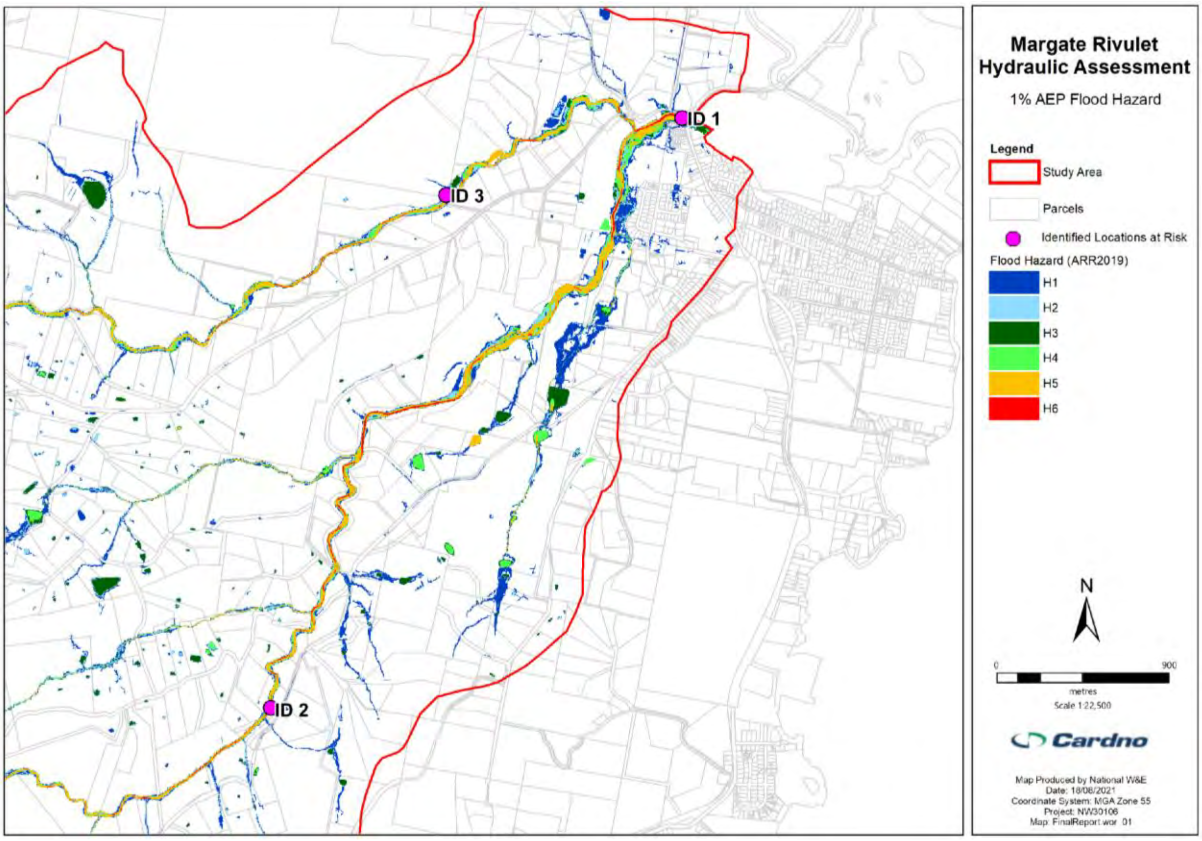


Figure 8-3 1% AEP Flood Hazard

9 Further Analysis

9.1 High-Level Erosion Assessment

Due to the mountainous nature of the Margate Rivulet catchment, slopes of over 60% are fairly common in the upper reaches. Further downstream, in the more residential areas towards the bottom of the catchment, the slope is normally less than 10%, except along the rivulets themselves. Due to the high slopes throughout the catchment velocities are generally very high, with velocities within topographically defined flow paths usually in excess of 2 m/s.

During the site visit undertaken on the 24th of March 2021 (Section 2.7), the following observations were made:

> There are areas within the forested regions that feature exposed and degraded soil due to erosion and sedimentation. This is predominantly along flow paths surrounding unsealed roads and in areas where the forest has been cleared.

> Both Margate Rivulet and Nierinna Creek have varying degrees of vegetation within the channel, with a large proportion of the main reach incised within natural bedrock.

> Both Margate Rivulet and Nierinna Creek typically feature undulating topographies such that there are shallow pools followed by an incised section, which is then again followed by shallow pools.

> Dispersive clay soils were observed throughout the catchment which leads to sedimentation and erosion likely to be a significant risk for the catchment.

> There are notable signs of erosion on the upper side of banks in the main channel, however, this is likely due to the dispersivity of soils in the region and will only arise as a potential issue in significantly large flood events (greater than 2% AEP).

Figure 9-1 shows significant signs of erosion that was observed during the site visit as per the comments above.

Figure 9-1 Examples of Erosion Observed During the Site Visit

Grass is generally able to provide erosion protection from velocities of only up to 1.2 m^2/s. Figure 9-2 highlights the areas within the catchment where in the modelled 1% AEP flood velocities are greater than 1.2m^2/s. Depending to the soil structure, presence of bedrock and level of vegetation, it is likely that erosion may be present in these areas.

Depending on the location and scale of erosion, there are several potential ways to control/limit these impacts, including:

> Sealing of gravel roads

> Increasing the level of vegetation in order to slow velocities, and help bind soils together

> Installation of protective rock work to absorb/dissipate the erosive energy of the water

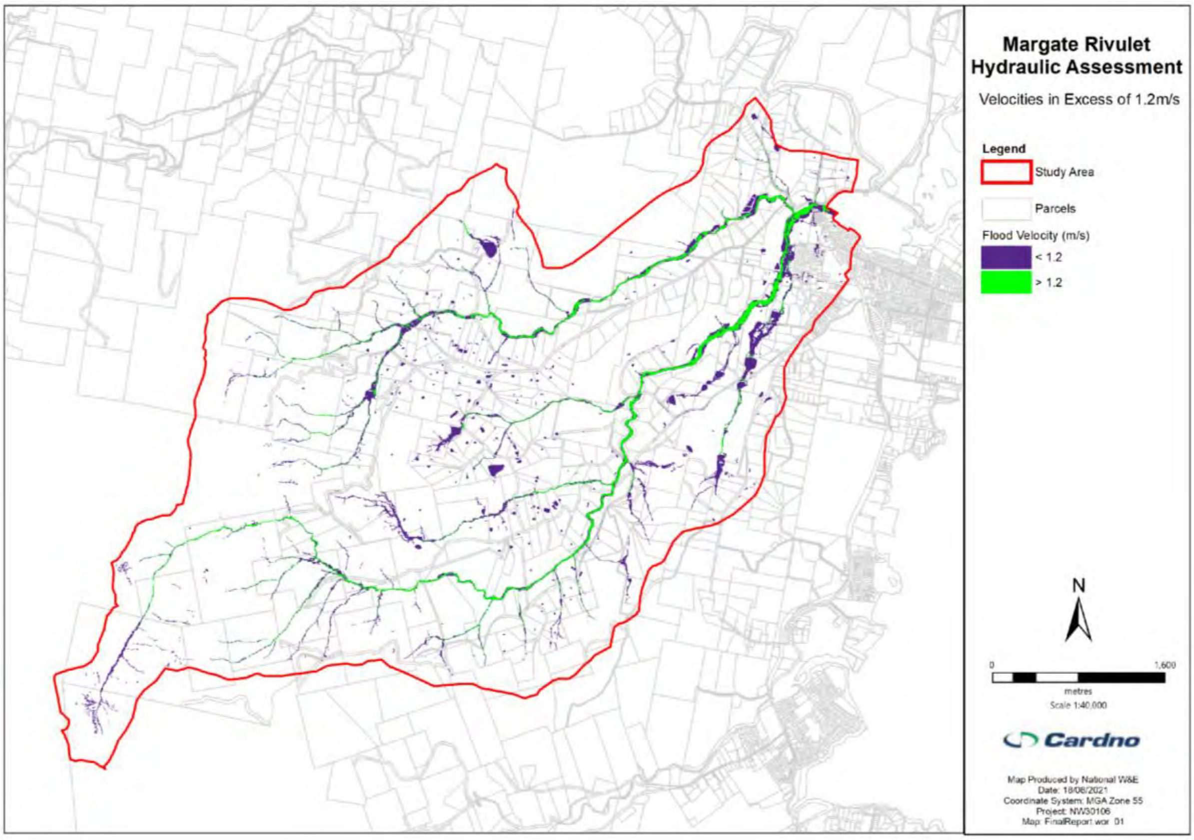


Figure 9-2 Velocities in excess of 1.2m/s

9.2 High-Level Vegetation Assessment

In order to help Council determine the potential impact of vegetation clearing along the Rivulet, an assessment has been undertaken with a reduced hydraulic roughness along the Rivulet to simulate partial clearing of vegetation.

For this assessment the following changes to the hydraulic roughness have been made:

> Regions designated as “Waterways / Channels | Minimal Vegetation / Rock/Earth Lined” remained as is

> Regions designated as “Waterways / Channels | Moderate Vegetation” were changed to “Waterways /Channels | Minimal Vegetation / Rock/Earth Lined”

> Regions designated as “Waterways / Channels | Heavy Vegetation” were changed to “Waterways /Channels | Moderate Vegetation”

As shown in Figure 9-3, clearing of vegetation along rivulets will likely result in a decrease in flood levels from the top of the catchment to the outlet in North West Bay. Due to an increase in flow conveyance in the upstream reaches of the Rivulet, a small number of limited/isolated areas witness small increases in flood levels of up to 0.1m

If the Council wish to undertake clearing of vegetation along the Rivulet, it is recommended that this process is started at the downstream reaches before moving into the upstream areas. This is to ensure that any increases in the flow capacity of the Rivulet due to the vegetation clearing does not result an increase in flood levels in the lower reaches where the capacity of the rivulet is maintained.

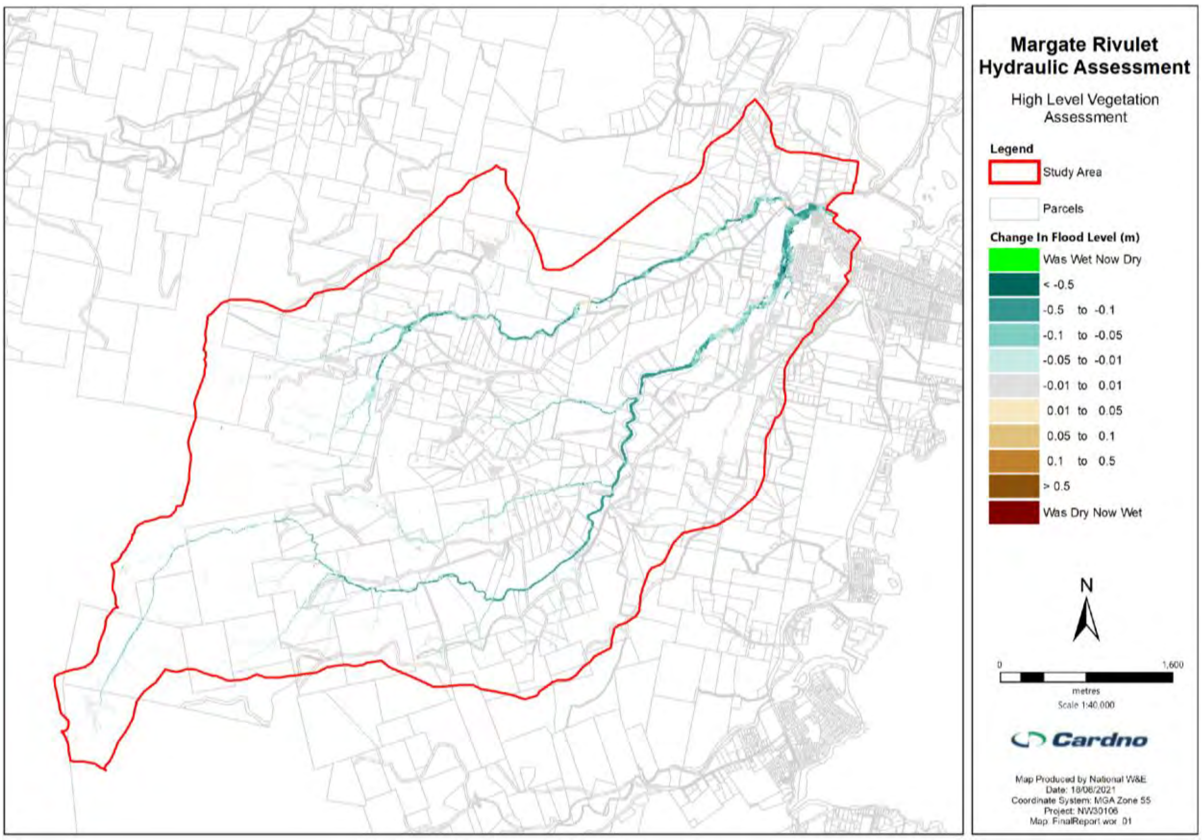


Figure 9-3 High Level Vegetation Assessment

9.3 Flood Mitigation Multi Criteria Analysis (MCA)

Based on both the outcomes of the community engagement and results of the hydraulic model, five potential mitigation options have been identified. Due to the topography of the catchment, flooding is predominantly limited to the rivulets. Furthermore, due to the relatively low level of current development within the catchment, there is limited impacts due flooding within the rivulets themselves.

Potential flood mitigation options have been identified by two key approaches:

- Mitigation Strategy
  - Proactive approach to mitigate flood risk
  - Quantification of structural measures
  - Qualification of non-structural measures
- Residual Risk Strategy
  - Reactive approach to flood risk response
  - Qualification of risk response measures

Table 9-1 presents relative levels of costs, constructability and potential flood reductions for each mitigation option. The following methodology has been used in defining these aspects:

- **Expected Cost** is mainly based on ease of construction. For example, if a major drainage alignment is required, it is expected to be relatively high cost compared to other options.
- **Constructability** is mostly linked to cost, such that high cost projects are typically difficult to construct and would therefore have low constructability.
- **Flood Reduction** has been based on the general potential for the reduction in flood affected properties with the introduction of the mitigation option.

Table 9-1 Identified Mitigation Measures

ID (S- structural, NS – non-structural, C – combined)	Mitigation Name	Description	Expected Cost ($, $$, $$$)	Constructability (Easy, Average, Difficult)	Flood Reduction (Good, Medium, Limited)
1 (NS)	Preventive Maintenance	As part of the community engagement survey, several responders identified blocked drainage infrastructure as being the cause of flooding. A preventative maintenance programme would include a list and schedule of where key drainage infrastructure is to be regularly inspected and any blockages cleared.	$	Easy	Limited
2 (NS)	Planning Controls	Planning controls would allow for development in flood prone areas to be undertaken sympathetically to any flooding issues. Planning controls would ensure (among other aspects) that any development does not increase the flood risk to neighbouring properties, all floor levels are constructed above the relevant flood level and there is safe access/egress to the site during a flood event.	$	Easy	Good
3 (S)	Channel Highway Bridge Upgrade	Due to limited conveyance capacity, flooding currently backs-up behind the Channel Highway Bridge in the 5% AEP event and impacts private property. Increasing the conveyance capacity of the bridge should help to reduce flood levels within private property upstream of the bridge. The Channel Highway Bridge is owned by the Department of State Growth and not by Kingston Council and therefore any works undertaken to the bridge would need to be undertaken in conjunction with this Department.	$$$	Difficult	Good
4 (S)	Nierinna Road	Due to the limited conveyance capacity of various culverts, flows overtop Nierinna Road in the 1% AEP event. Increasing the capacity of these culverts should help to reduce the amount of overtopping which occurs.	$$	Average	Good
5 (S)	Crimson Drive	In the 5% AEP event, there is ponding of water within the block bounded by Crimson Drive and Dayspring Drive. This is due to the location being a trapped low point and there being insufficient capacity in the downstream drainage. By upgrading the drainage from the trapped low point to the undeveloped areas, downstream flood levels should be able to be reduced along Crimson Drive.	$	Average	Good
6 (S)	Tarragon Drive	Flooding from the undeveloped land to the rear of the properties located along Tarragon Drive extends into private property in the 5% AEP event. Further sculpting of the land with either cut within the flooding plain or fill within the private properties should limit the amount of inundation within these private property.	$	Easy	Medium

ID (S- structural, NS – non-structural, C – combined)	Mitigation Name	Description	Expected Cost ($, $$, $$$)	Constructability (Easy, Average, Difficult)	Flood Reduction (Good, Medium, Limited)
7 (S)	Levee System Upstream of Channel Highway	Several properties are affected by flooding upstream of the Channel Highway Bridge in events as lower the 5% AEP event. Through the construction of a levee system, an increase in flood immunity may be able to be offered to properties protected. However, due to the construction of a levee system there may be increases to flood levels within the Rivulet which may reduce the flood immunity to other properties.	$$$	Difficult	Medium
8 (S)	Minor Roads	There are 12 minor roads which are overtopped in events as low as the 5% AEP. By increasing the conveyance capacity of the culverts located below these minor roads, or by raising the road level, it should be possible to increase the level of immunity offered by the roads. As these roads are only minor roads and the flooding generally doesn't affect residential dwellings, it would be expected that upgrading these roads should not be a priority for council (at least from a flood impact perspective). However, if council is already planning on undertaking significant works to these roads in the vicinity of existing culverts, then the impacts of flooding should be considered during the design process.	$$$ (Depending on number selected)	Average	Good

9.4 Stormwater Management Assessment and Stormwater Development Controls

9.4.1 Level of Service of Underground Drainage Assets

A stormwater management assessment has been undertaken in order to determine the level of service provided by the current stormwater network based on the AEP in which the pipes first run full. As can be seen in Figure 9-4, the majority of the pipes in the catchment are reported as having a greater then 200yr level of service, which is highly unlikely to be the case. As is clearly visible in the flood maps in Appendix A, no overland flow is shown as being located above the majority of the pipes and as such the hydraulic model is unable to transfer water from the 2D surface (as there are no overland flows) into the 1D pipes. However, the pipes which are not located within any of the flood extents still provide a vital role within the catchment. Due to the steepness of the area, the minor topographic features which these asset service are typically not captured within the 3m grid cells resolution of the hydraulic model extent.

Within the Margate township, the trunk drains are identified as having less than a 5% AEP capacity (which is the smallest event modelled). This level of service is typical in urban areas. This is further verified using the maximum flood depth results, which show that there are only two areas where there is ponding occurring where drainage is present in the 5% AEP event. Given urban drainage networks are typically designed for events less than the 5% AEP event, the existing drainage network within the Margate Township would be generally considered to be appropriately servicing the urban portion of the Margate catchment.

Within the Margate Township catchment there are 6 locations where piped flows discharge into the Rivulet, the maximum piped discharge in each of these locations are identified in Table 9-2.

Table 9-2 Existing Piped Discharge from the Margate Township

ID	Location	5% AEP Event	1% AEP Event	0.5% AEP Event
1	Between Merediths Road and Dayspring Road - Piped	0.04 m^3/s	0.05 m^3/s	0.06 m^3/s
2	The walking track along Margate Rivulet at Dayspring Drive - Piped	0.05 m^3/s	0.07 m^3/s	0.09 m^3/s
3	Between Margate Rivulet Track and Tarragon Drive - Piped	0.47 m^3/s	0.62 m^3/s	0.64 m^3/s
	Between Margate Rivulet Track and Tarragon Drive - Overland	0.00 m^2/s	0.048 m^3/s	0.385 m^3/s
4	Citrus Drive - Piped	0.21 m^3/s	0.26 m^3/s	0.35 m^3/s
5	Channel Highway - Piped	0.04 m^3/s	0.05 m^3/s	0.07 m^3/s
6	Riverdowns Drive North - Piped	0.04 m^3/s	0.05 m^3/s	0.06 m^3/s
7	Riverdowns Drive South - Piped	0.1 m^3/s	0.12 m^3/s	0.13 m^3/s
8	Crimson Drive North - Overland	0.00 m^2/s	0.32 m^3/s	0.51 m^3/s

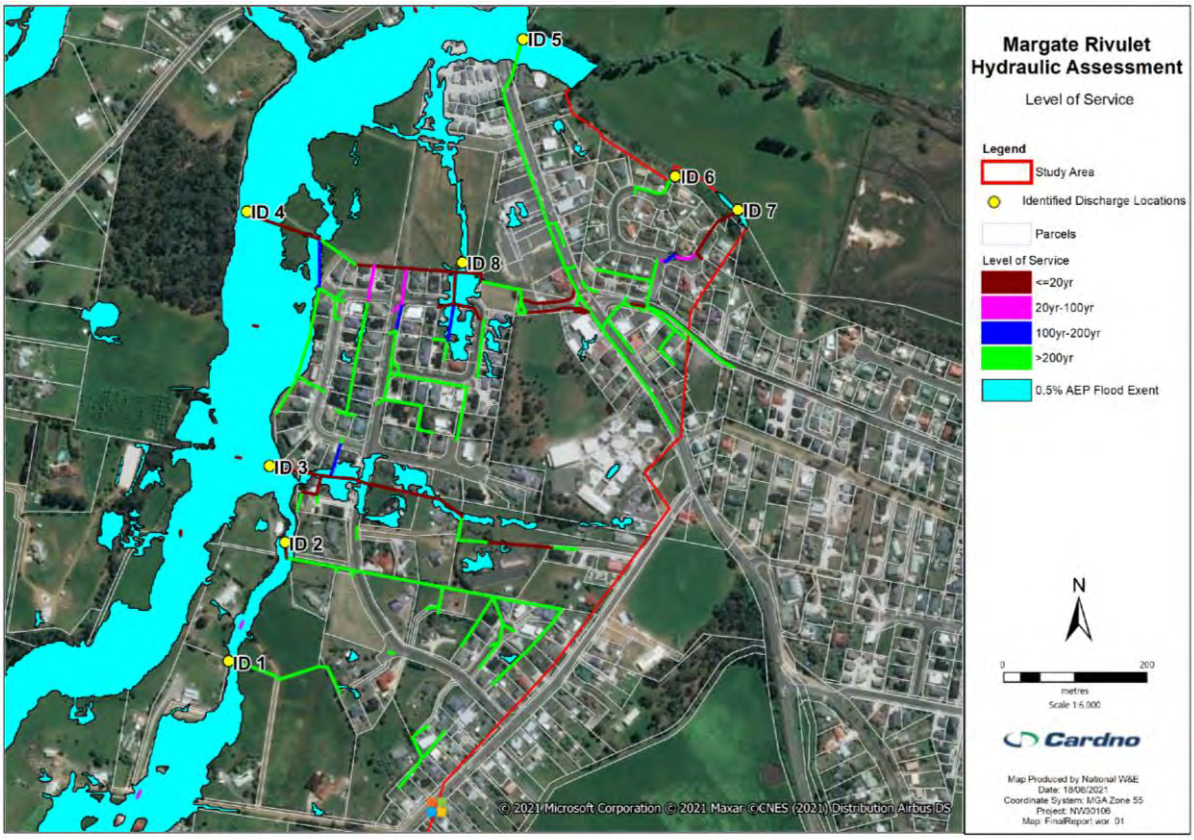


Figure 9-4 Stormwater Level of Service

9.4.2 Assessment of Increased Development Scenarios

An assessment of the increased development scenarios has been undertaken based on an increase to the effective impervious areas as outlined in Section 3.4.2, to represent potential future development within the catchment.

Flooding within the Margate Rivulet is driven by flooding within the upper reaches of the catchment, and therefore as shown in both Figure 9-5 and Figure 9-6, increases to the level of development in the lower reaches of the catchment do not result in large increases to flood levels.

While the increased levels of development do not lead to large increases in flood levels, this does not mean that future developments should not be required to meet best practise guidelines in terms of both controlling runoff volumes from the site/s and meeting water quality targets.

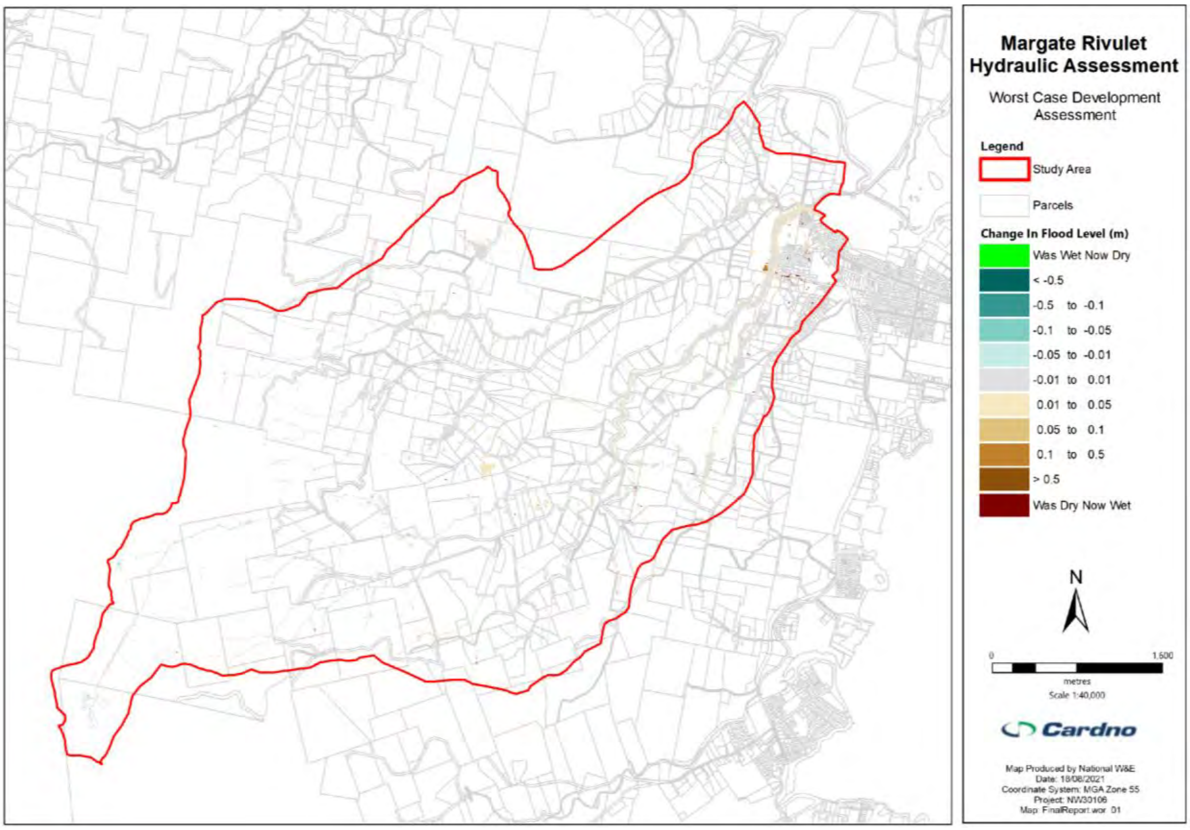


Figure 9-5 Worst Case Development Assessment

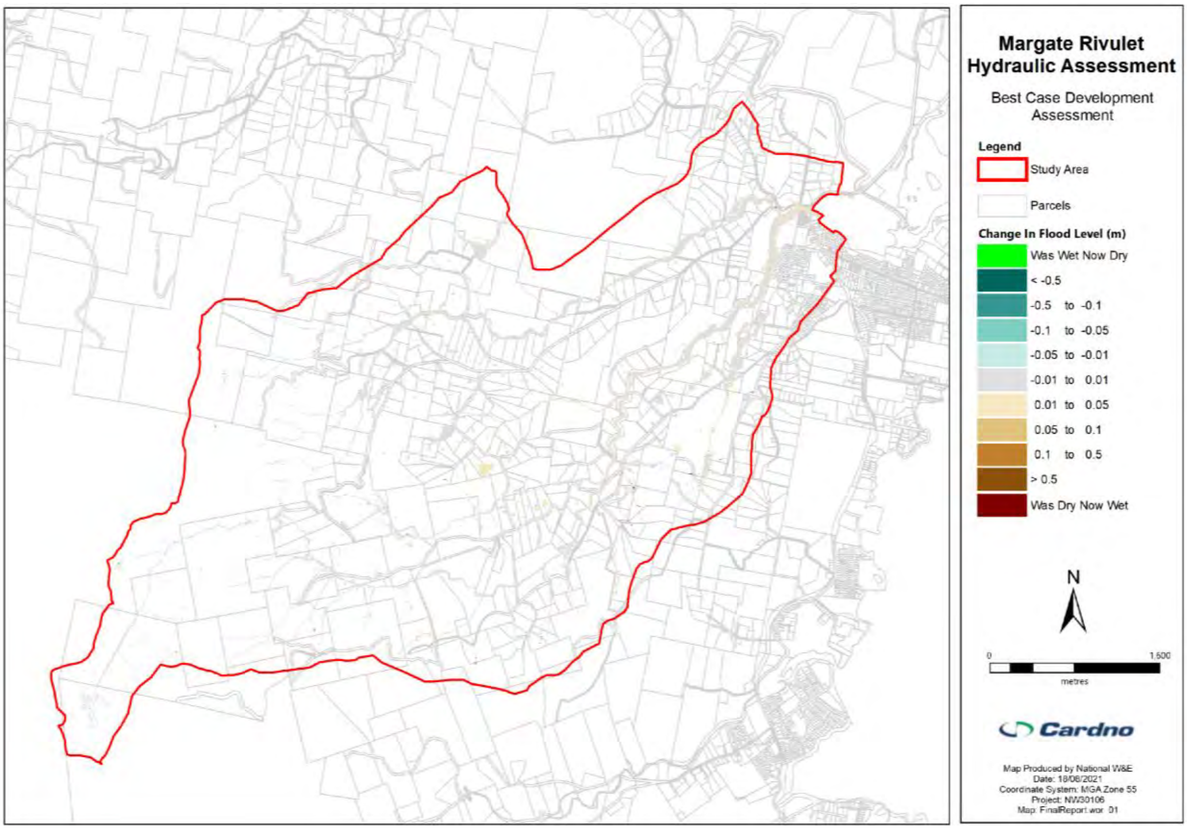


Figure 9-6 Best Case Development Assessment

10 Conclusions and Recommendations

The Margate Rivulet Flood Study provides an improved understanding of the flood behaviour throughout the Margate catchment and identifies a number of potential structural and non-structural mitigation measures which can improve the flood protection for both residents and visitors to the catchment.

As there is no pluviograph rainfall station located within the catchment and no verified flood levels along the rivulet, the hydrological model has been verified via four separate methods, with the hydraulic model verified to both the May 2018 event and the outcomes of the community engagement survey.

A series of design flood events have been modelled providing important intelligence in regards to the impact of flooding within the Margate Rivulet. A set of high-level options for potential flood mitigation have been identified for council to consider in order to reduce the overall flood risk of the catchment.

10.1 Recommendations

It is recommended that:

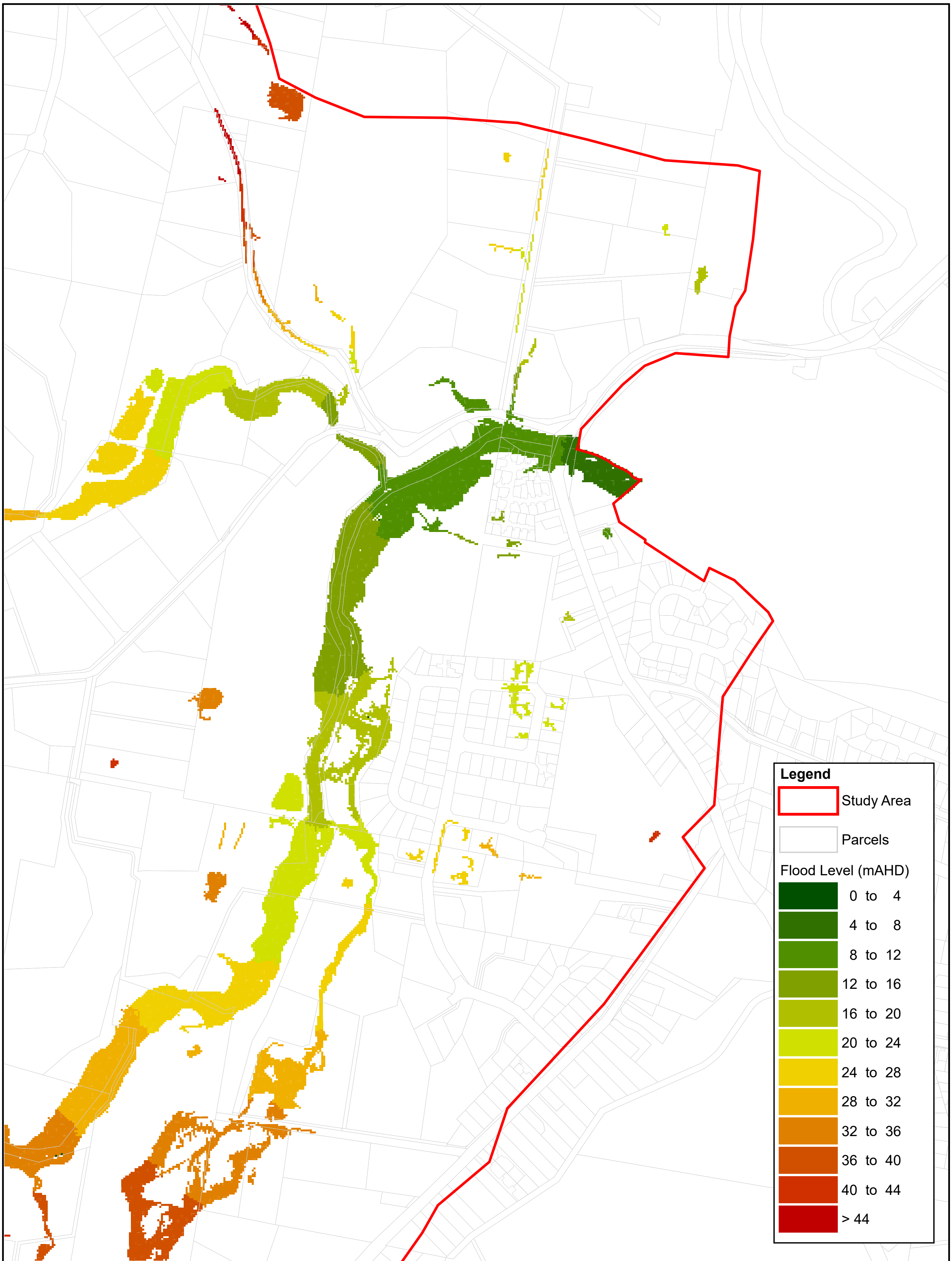
> Council make available the results of the flood study for the greater Margate catchment

> Council consider the potential mitigation options presented in this report to improve the overall flood risk of the catchment and control the impact of future development within the catchment

APPENDIX

A

FIGURES



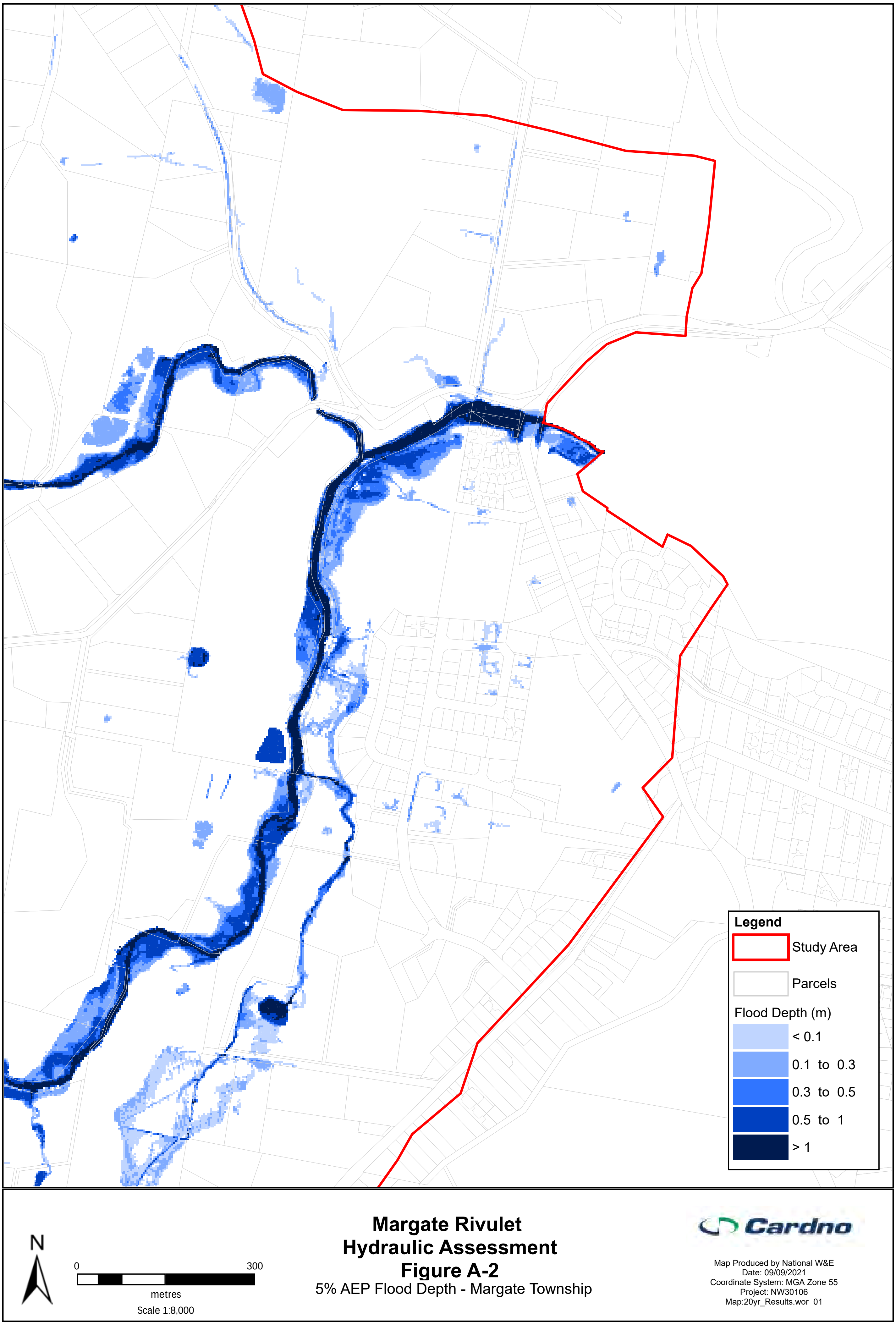
N

0 300
metres
Scale 1:8,000

Margate Rivulet
Hydraulic Assessment
Figure A-1
5% AEP Flood Level - Margate Township

Cardno

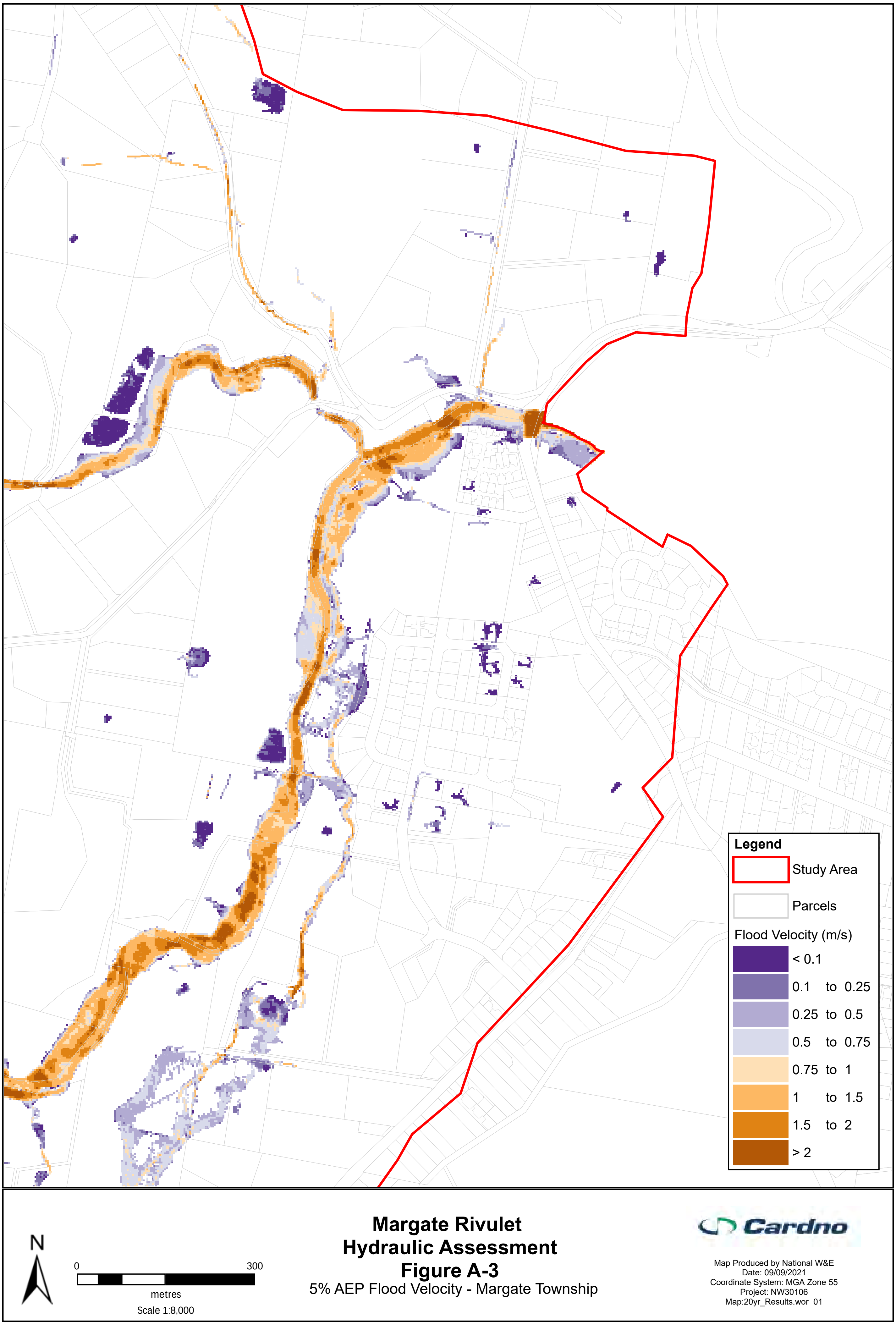
Map Produced by National W&E
Date: 09/09/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map:20yr_Results.wor 01



Margate Rivulet
Hydraulic Assessment
Figure A-2
5% AEP Flood Depth - Margate Township

Cardno

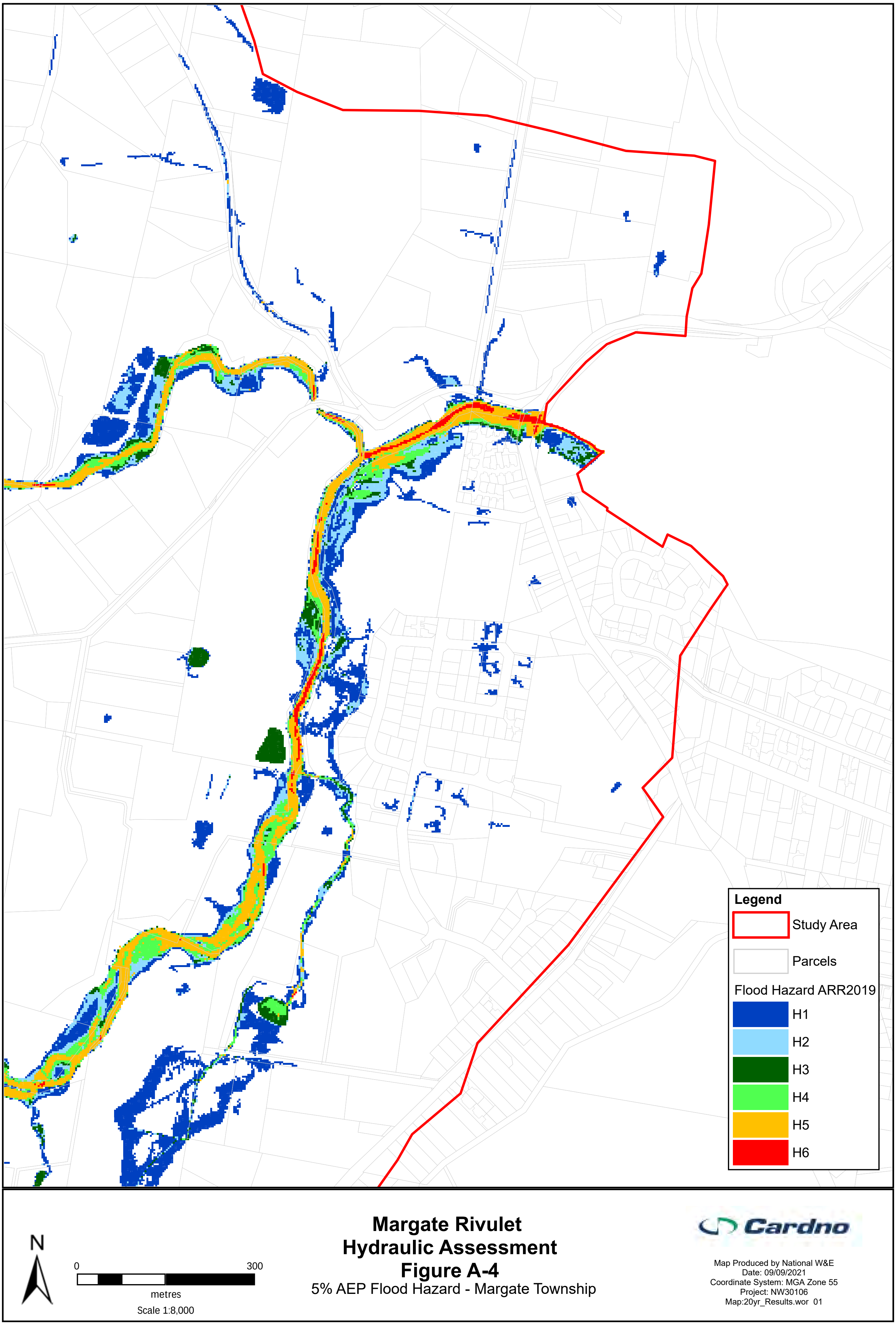
Map Produced by National W&E
Date: 09/09/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map:20yr_Results.wor 01



Margate Rivulet
Hydraulic Assessment
Figure A-3
5% AEP Flood Velocity - Margate Township

Cardno

Map Produced by National W&E
Date: 09/09/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map:20yr_Results.wor 01



Margate Rivulet
Hydraulic Assessment
Figure A-4
5% AEP Flood Hazard - Margate Township

Map Produced by National W&E
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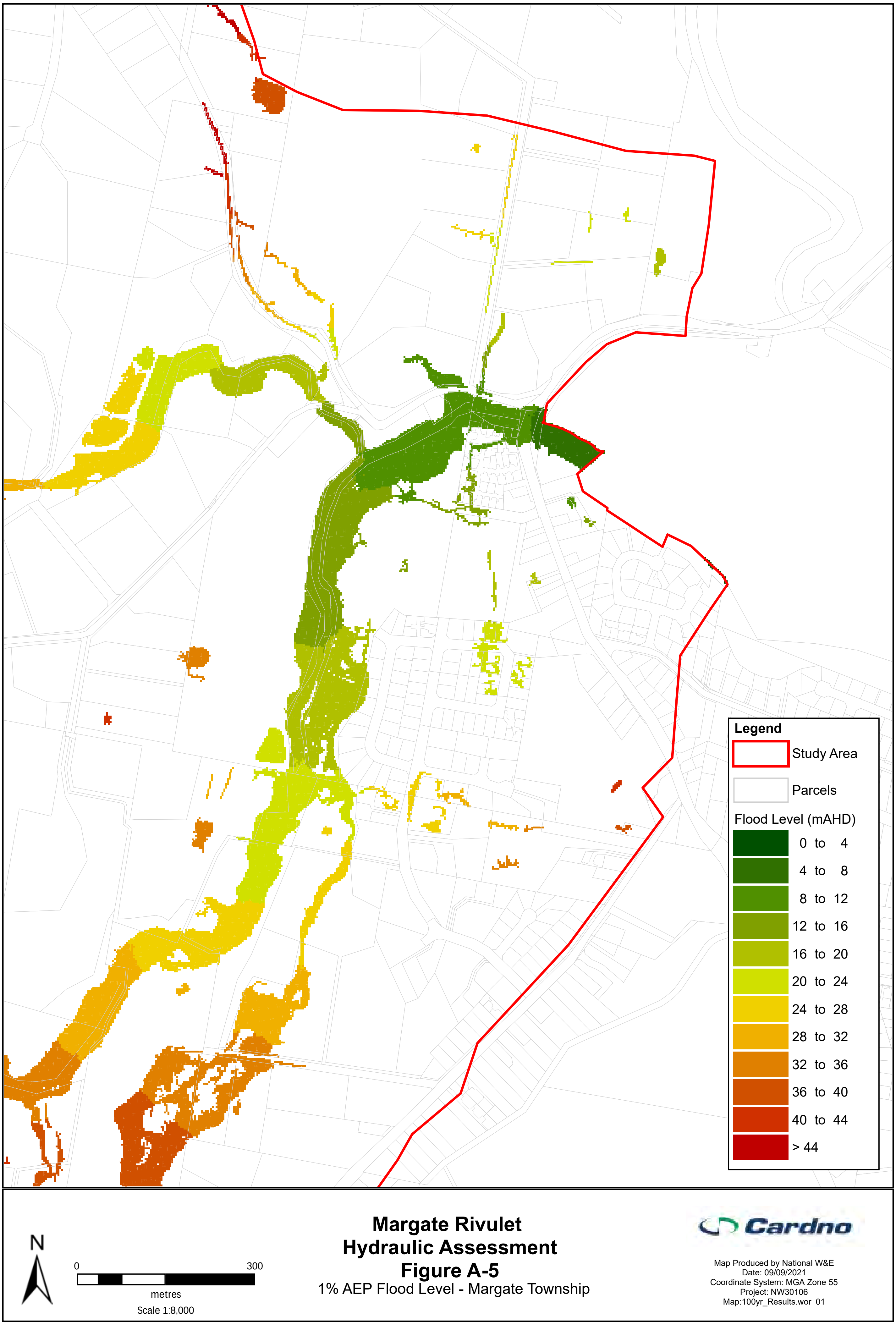
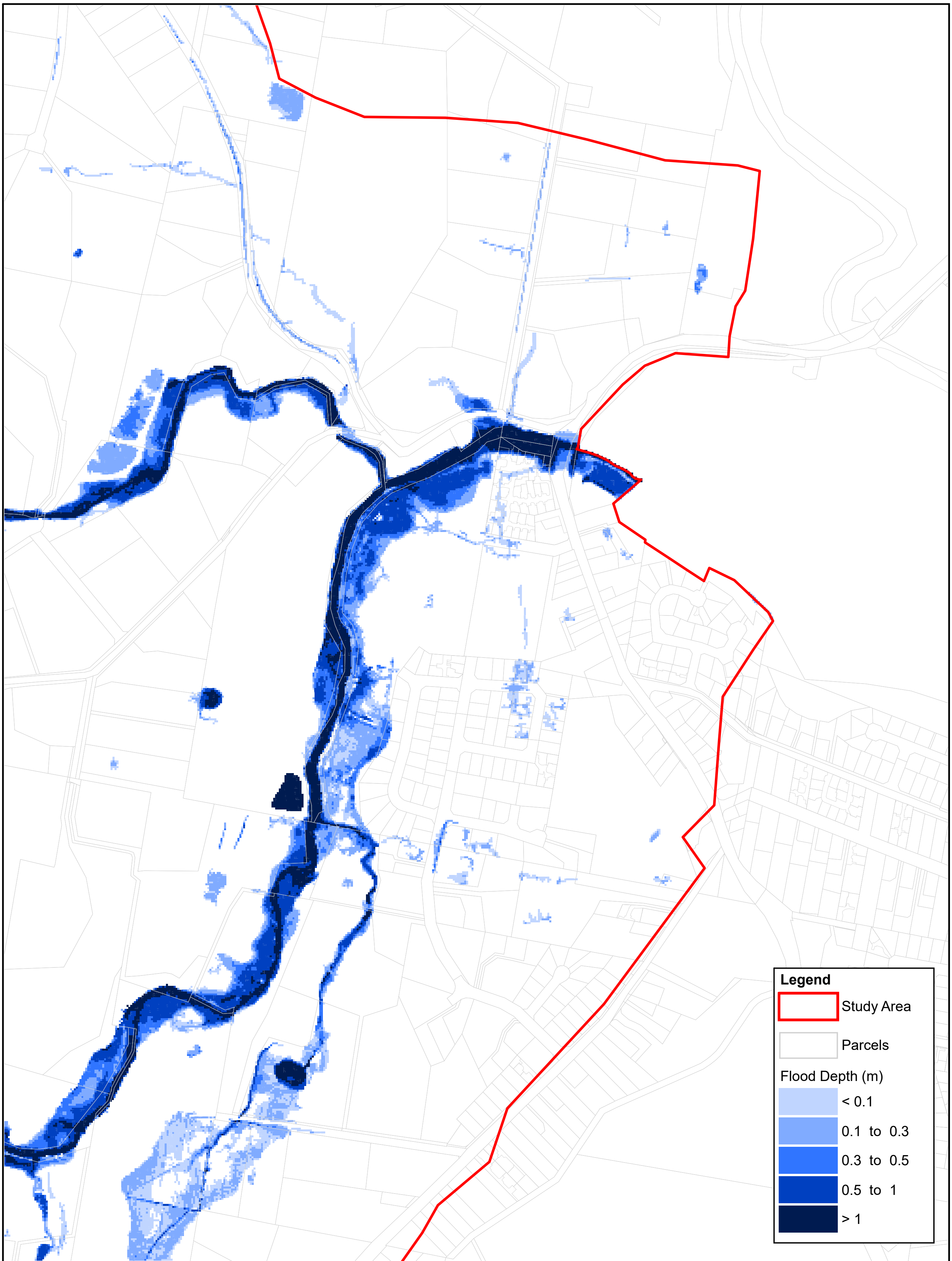
Coordinate System: MGA Zone 55
Project: NW30106
Map:20yr_Results.wor 01



Margate Rivulet
Hydraulic Assessment
Figure A-5
1% AEP Flood Level - Margate Township

Cardno

Map Produced by National W&E
Date: 09/09/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map:100yr_Results.wor 01



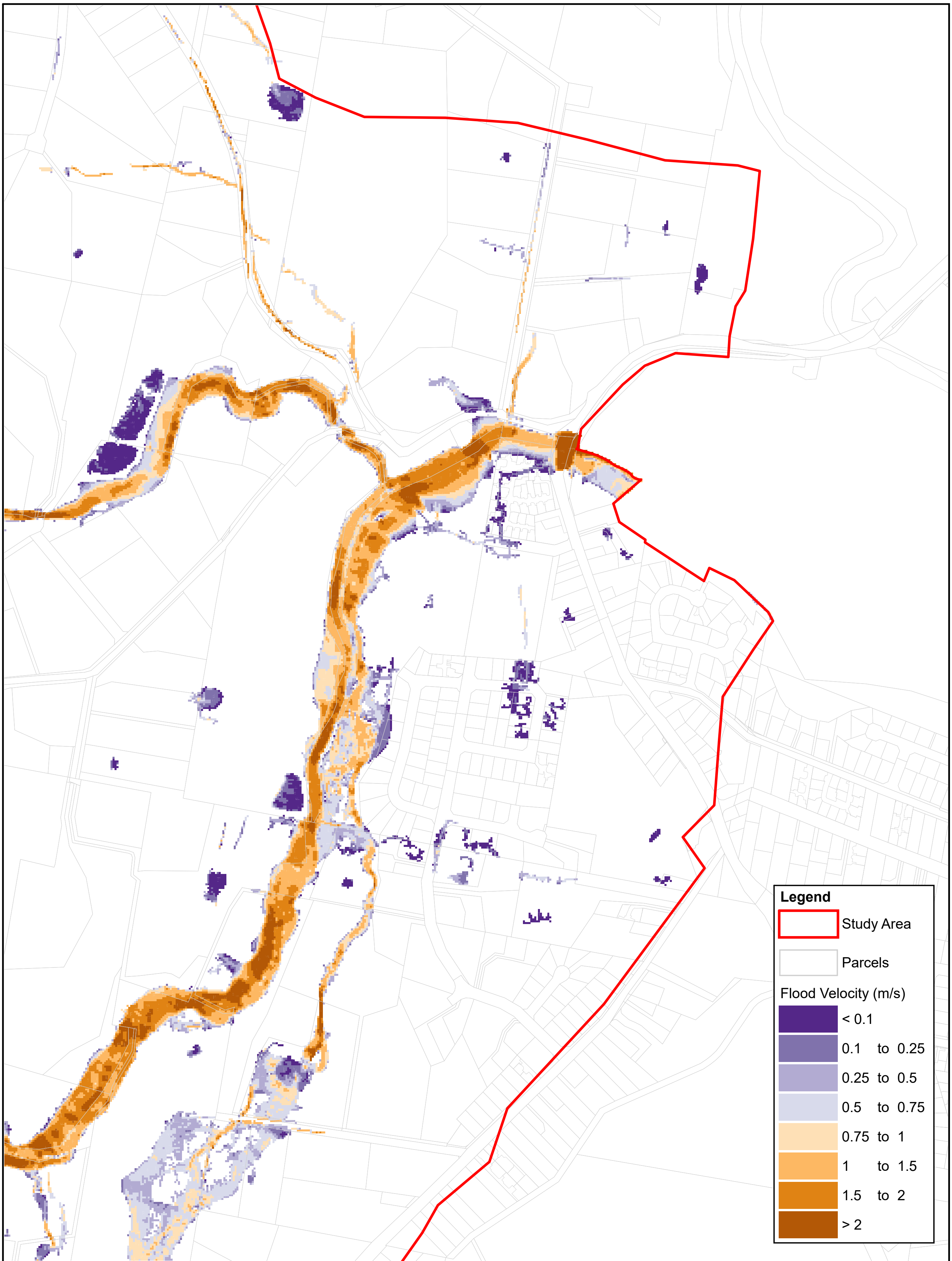
N

0 300
metres
Scale 1:8,000

Margate Rivulet Hydraulic Assessment
Figure A-6
1% AEP Flood Depth - Margate Township

Cardno

Map Produced by National W&E
Date: 09/09/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map:100yr_Results.wor 01



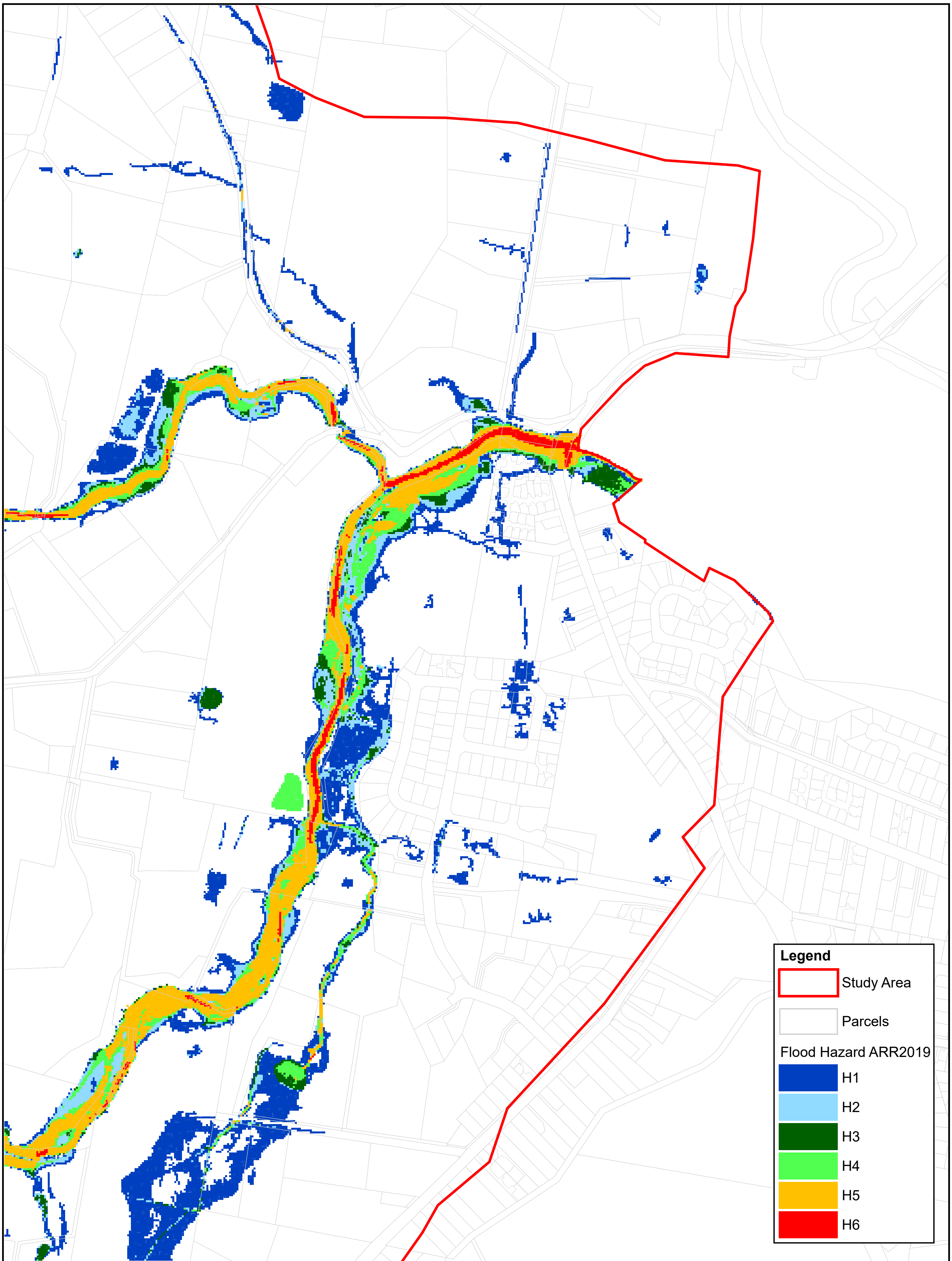
N

0 300
metres
Scale 1:8,000

Margate Rivulet Hydraulic Assessment
Figure A-7
1% AEP Flood Velocity - Margate Township

Cardno

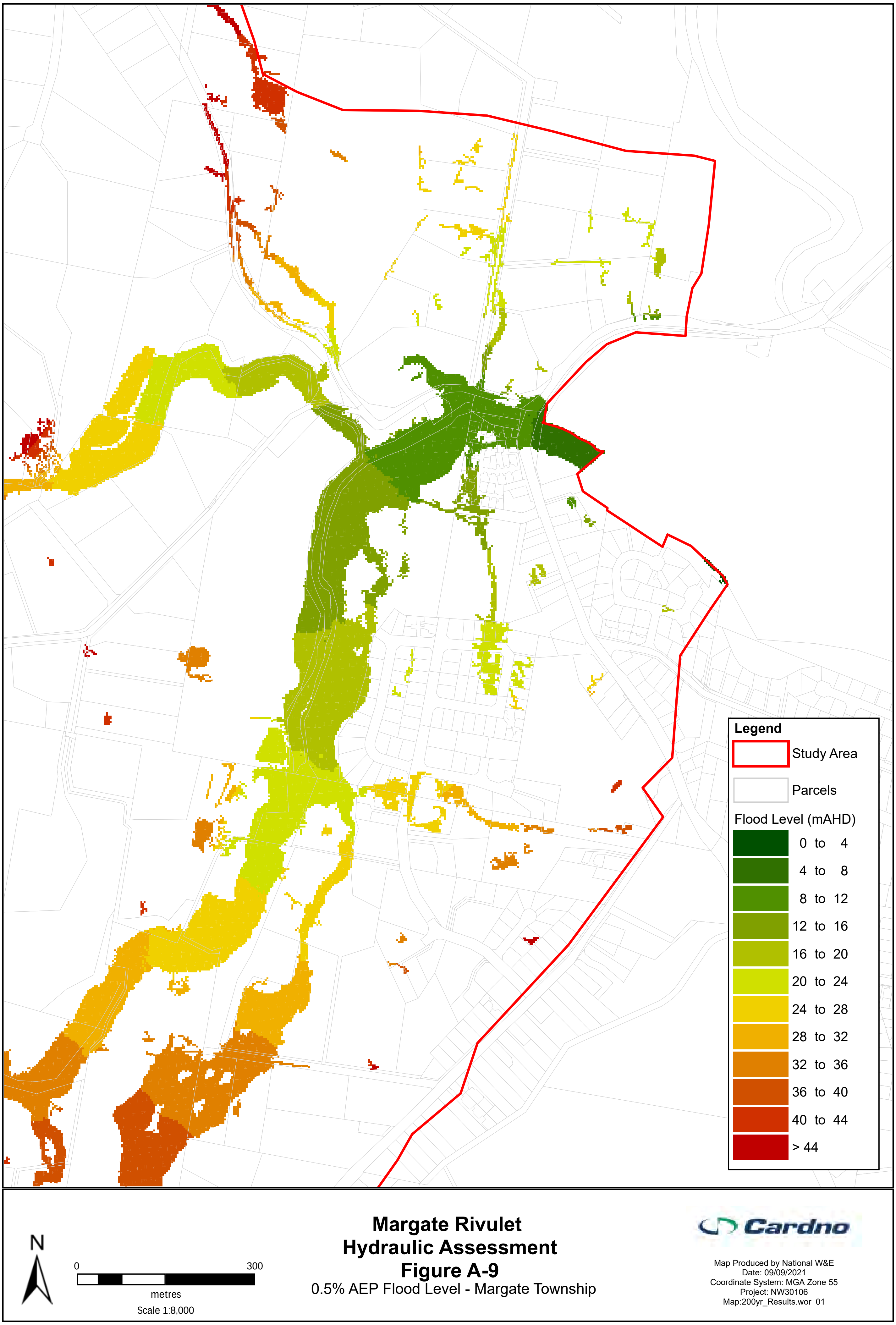
Map Produced by National W&E
Date: 09/09/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map:100yr_Results.wor 01



Margate Rivulet
Hydraulic Assessment
Figure A-8
1% AEP Flood Hazard - Margate Township

Cardno

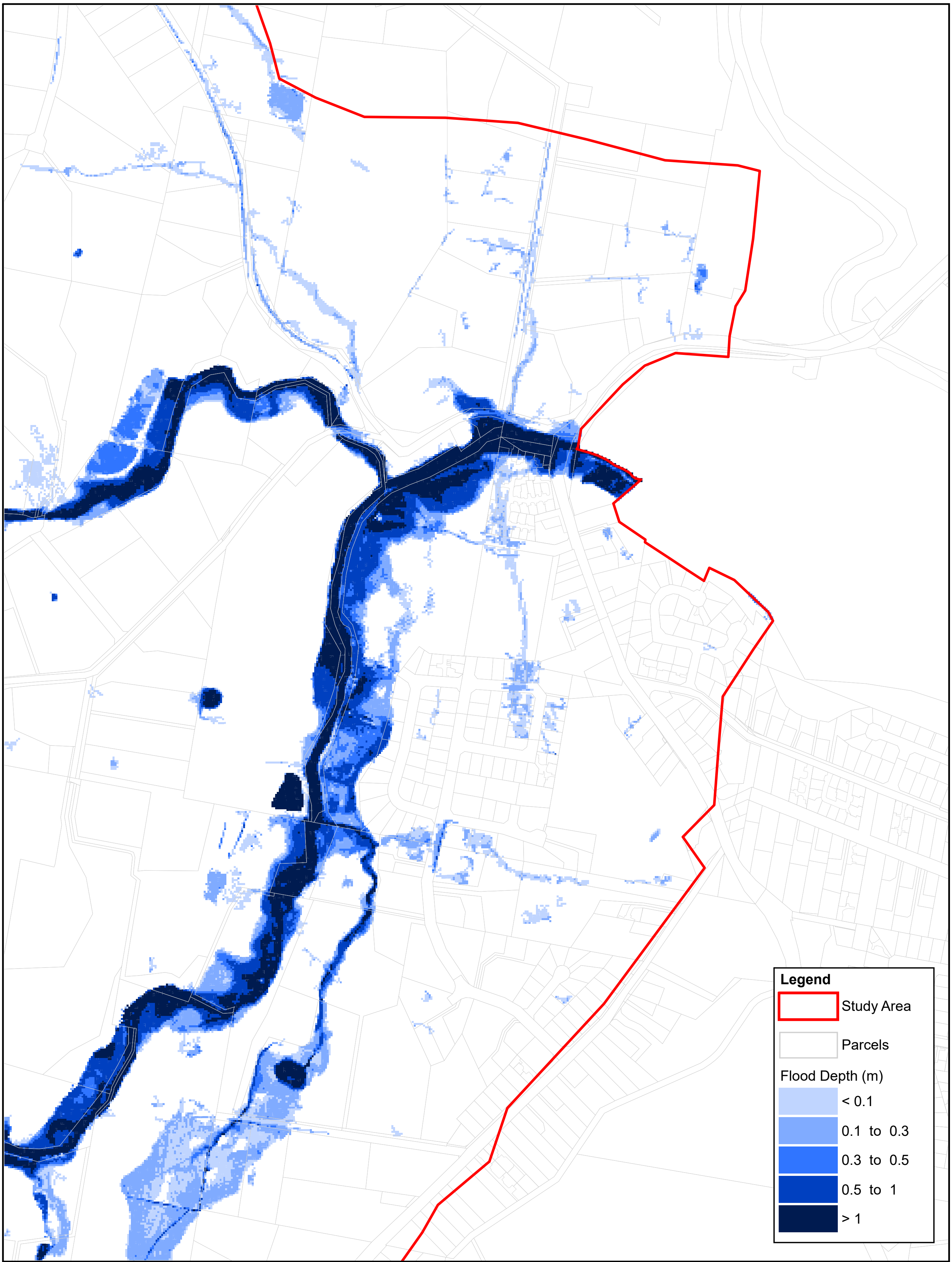
Map Produced by National W&E
Date: 09/09/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map:100yr_Results.wor 01



Margate Rivulet
Hydraulic Assessment
Figure A-9
0.5% AEP Flood Level - Margate Township

Cardno

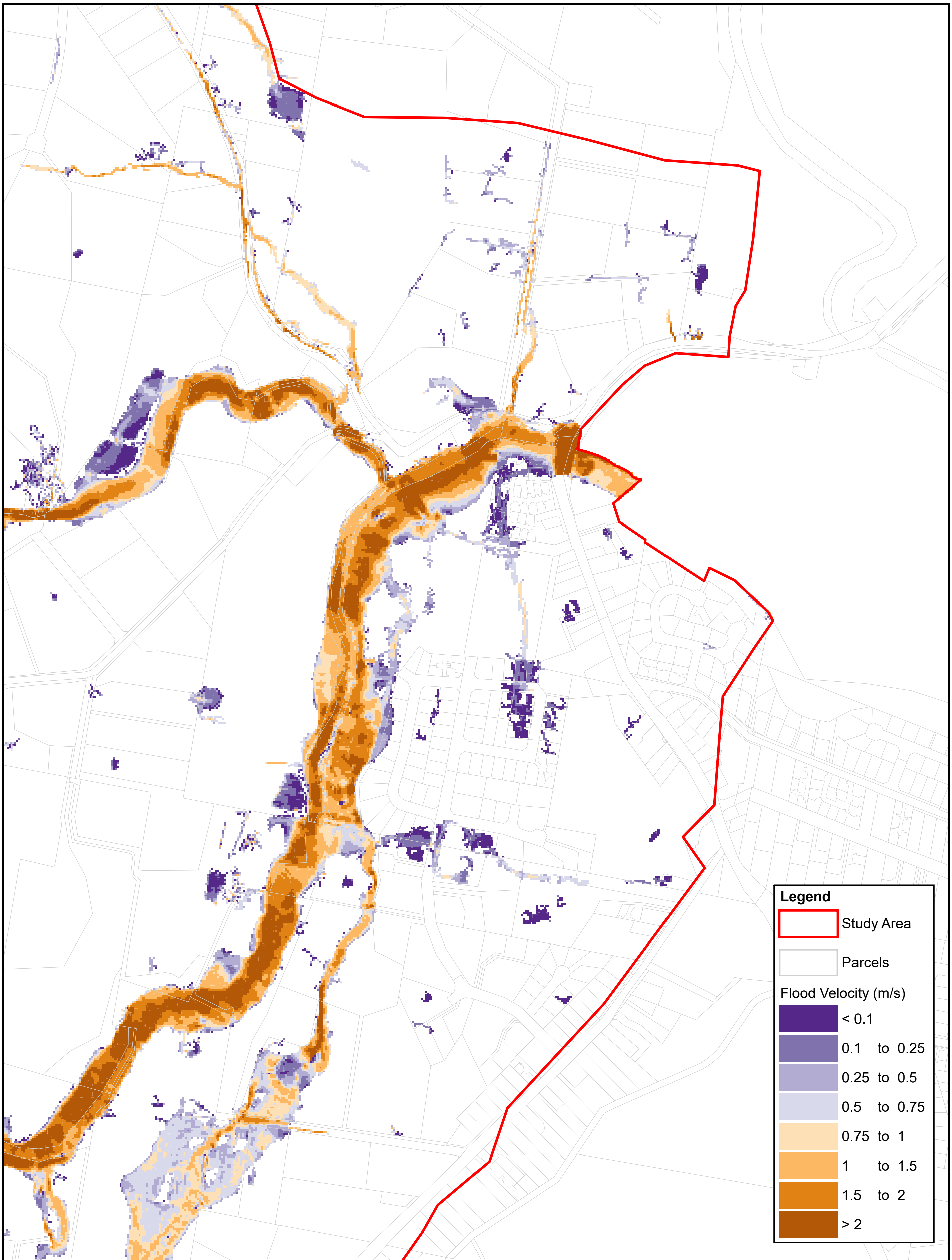
Map Produced by National W&E
Date: 09/09/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map:200yr_Results.wor 01



Margate Rivulet
Hydraulic Assessment
Figure A-10
0.5% AEP Flood Depth - Margate Township

Cardno

Map Produced by National W&E
Date: 09/09/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map:200yr_Results.wor 01

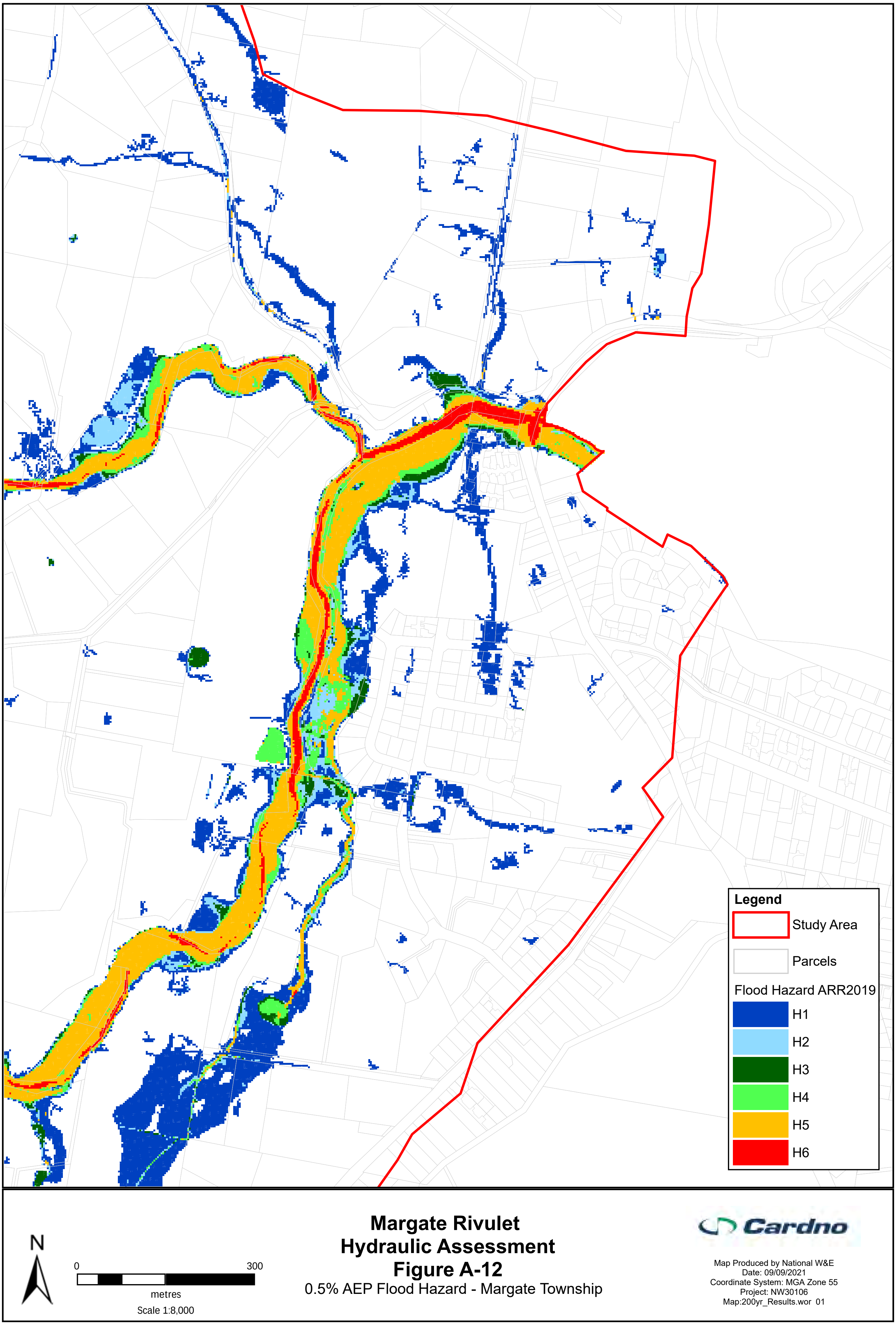


N

0 300
metres
Scale 1:8,000

Margate Rivulet
Hydraulic Assessment
Figure A-11
0.5% AEP Flood Velocity - Margate Township

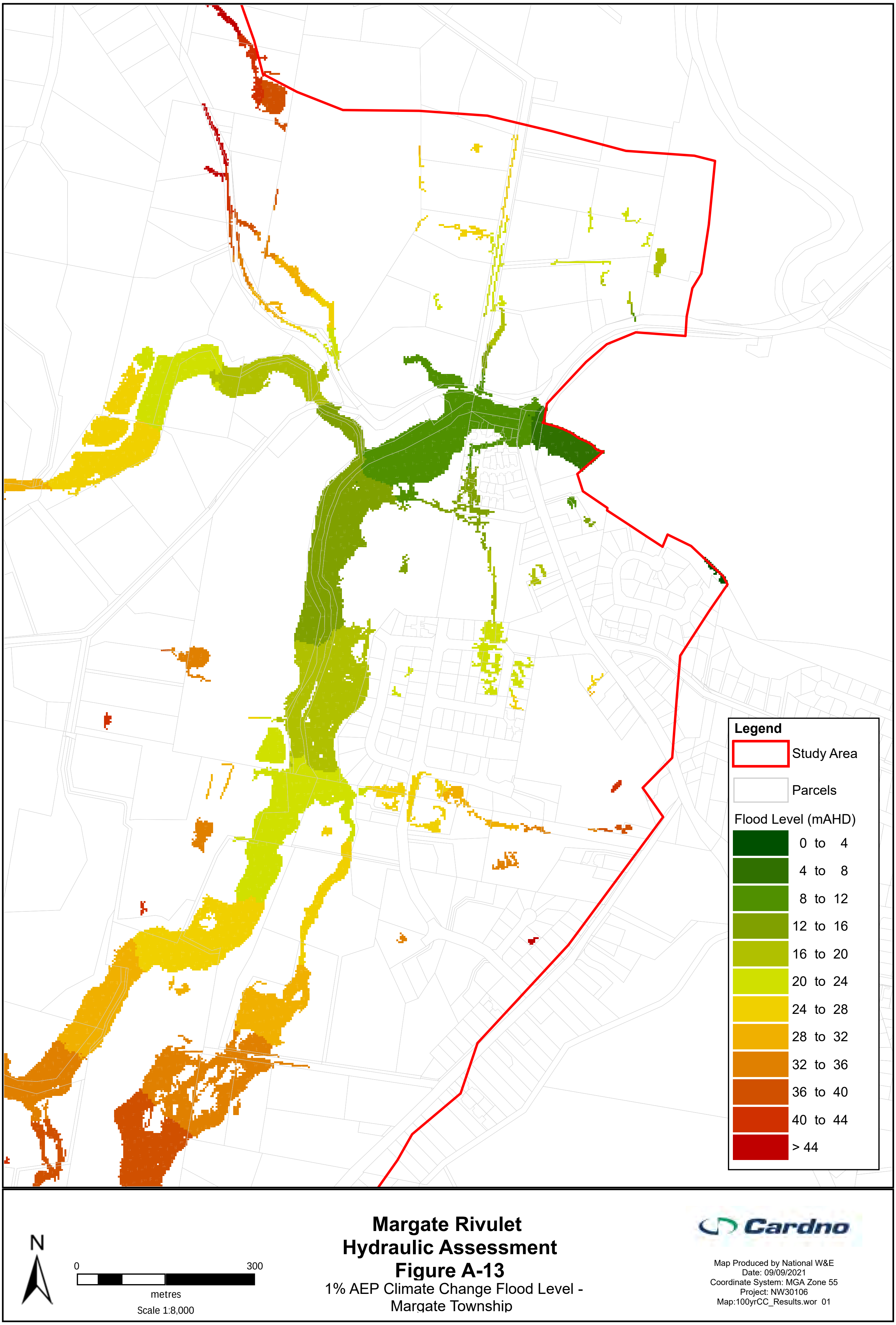
Map Produced by National W&E
Date: 09/09/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map:200yr_Results.wor 01



Margate Rivulet
Hydraulic Assessment
Figure A-12
0.5% AEP Flood Hazard - Margate Township

Cardno

Map Produced by National W&E
Date: 09/09/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map:200yr_Results.wor 01



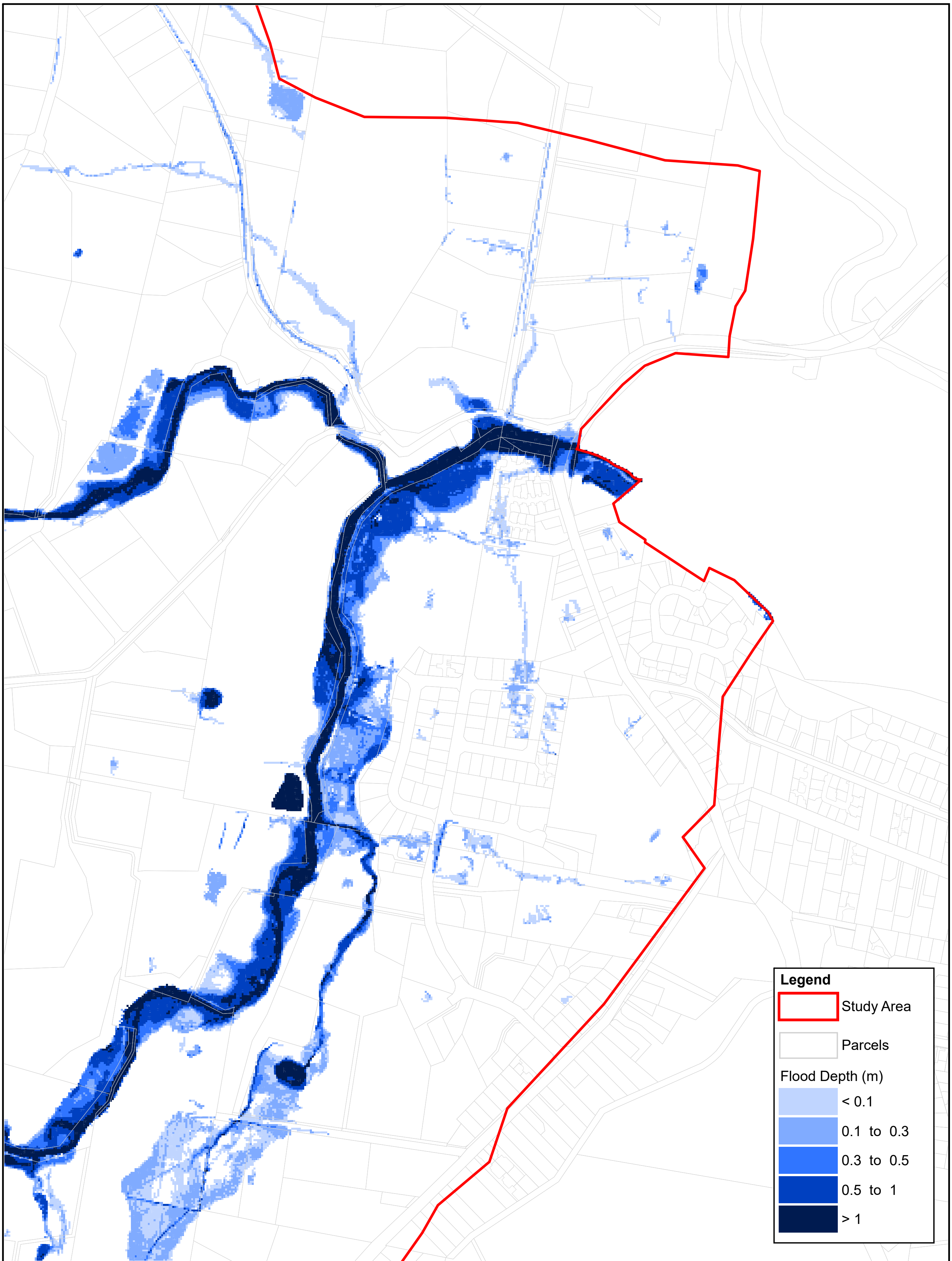
Margate Rivulet Hydraulic Assessment

Figure A-13

1% AEP Climate Change Flood Level - Margate Township

Cardno

Map Produced by National W&E
Date: 09/09/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map:100yrCC_Results.wor 01



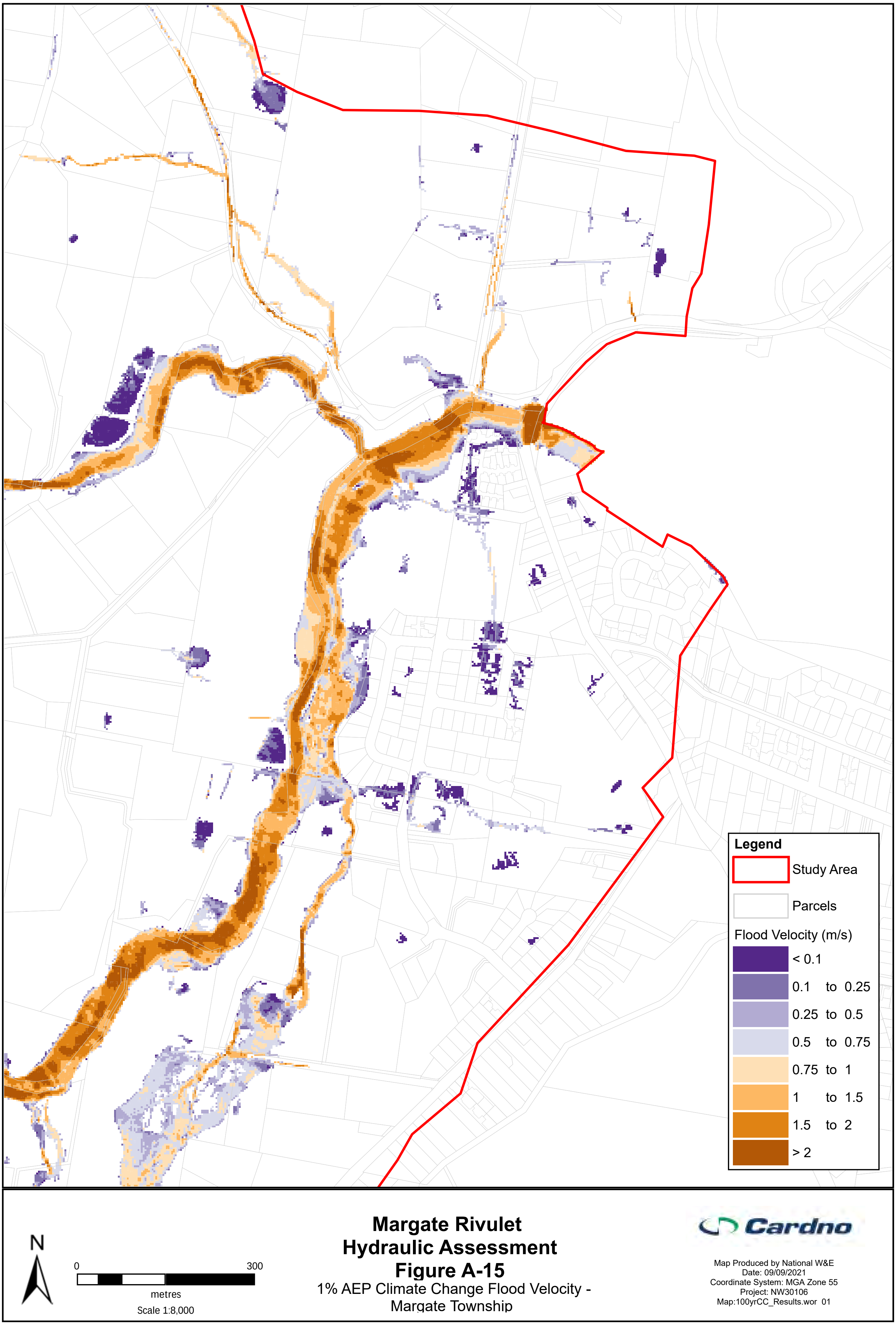
N

0 300
metres
Scale 1:8,000

Margate Rivulet
Hydraulic Assessment
Figure A-14
1% AEP Climate Change Flood Depth -
Margate Township

Cardno

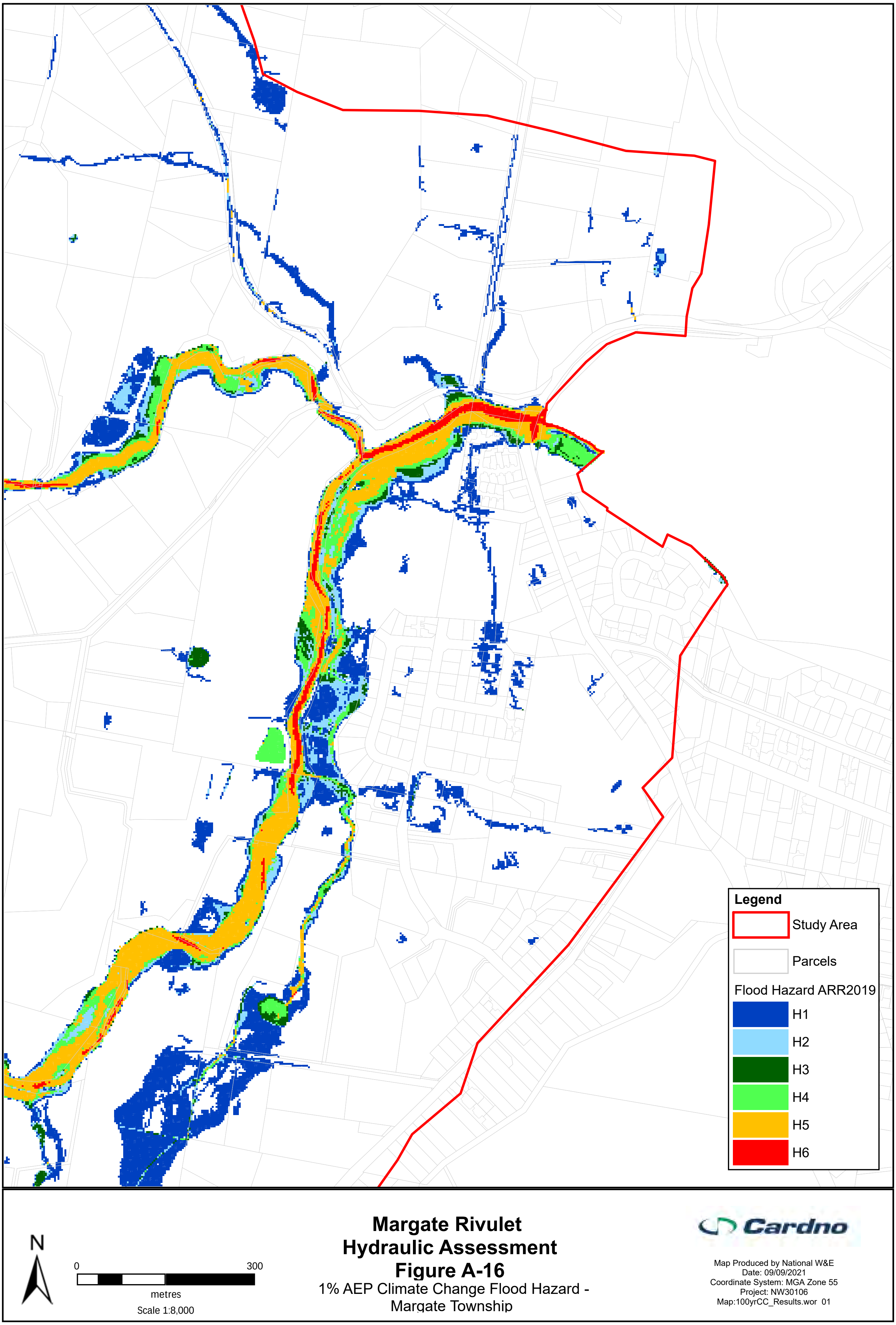
Map Produced by National W&E
Date: 09/09/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map:100yrCC_Results.wor 01



Margate Rivulet
Hydraulic Assessment
Figure A-15
1% AEP Climate Change Flood Velocity -
Margate Township

Cardno

Map Produced by National W&E
Date: 09/09/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map:100yrCC_Results.wor 01



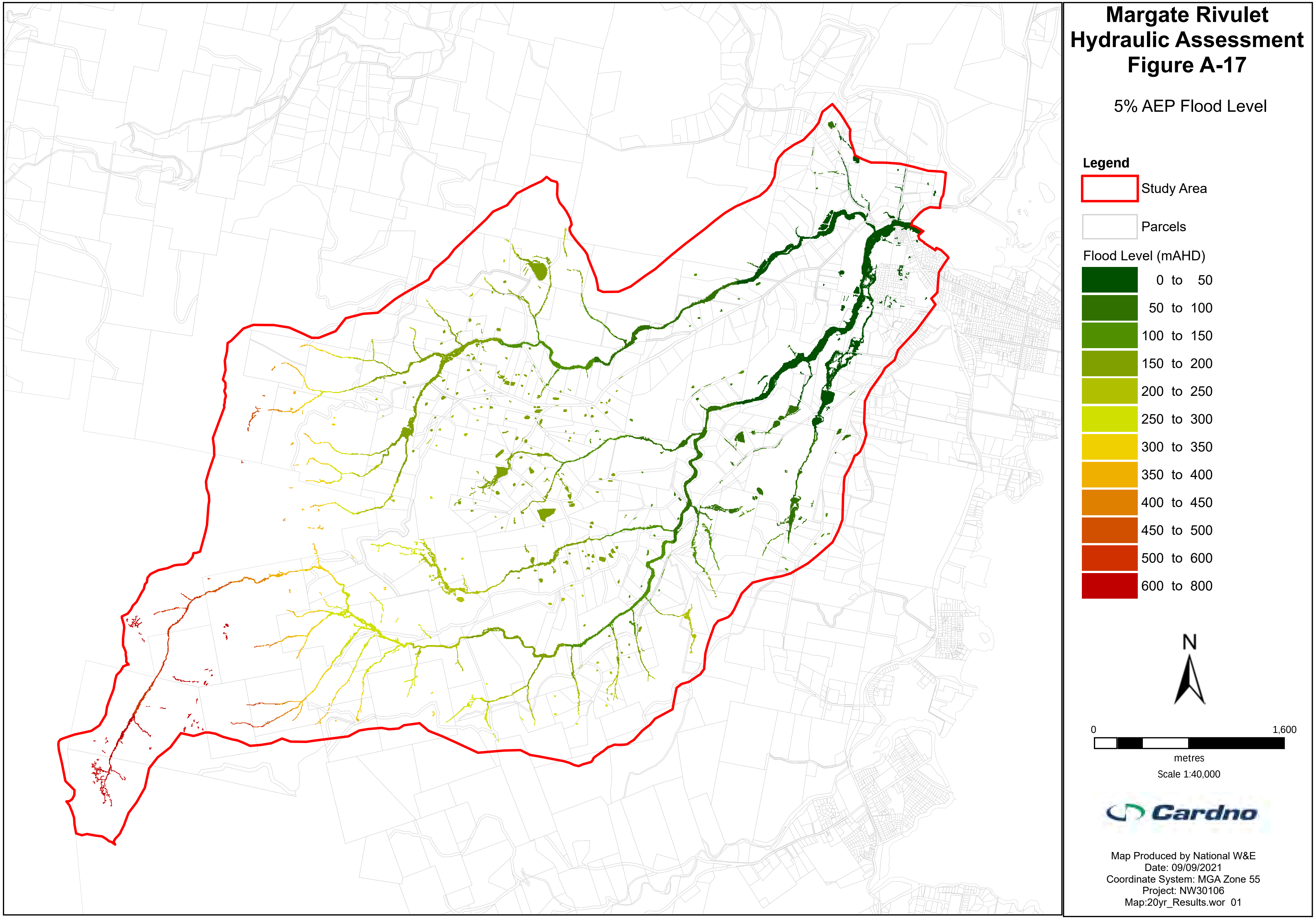
Margate Rivulet Hydraulic Assessment

Figure A-16

1% AEP Climate Change Flood Hazard - Margate Township

Cardno

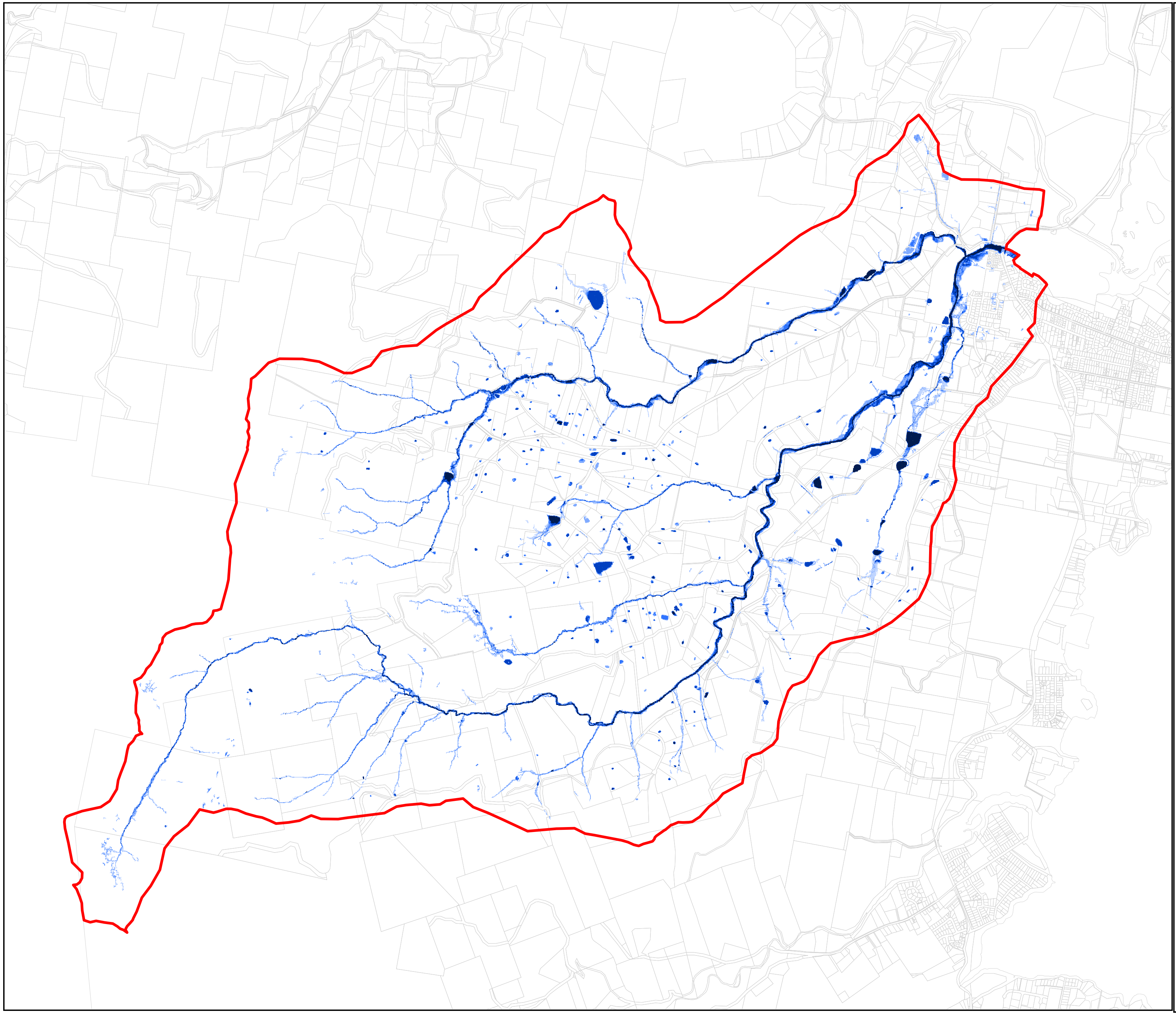
Map Produced by National W&E
Date: 09/09/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map:100yrCC_Results.wor 01



Margate Rivulet Hydraulic Assessment Figure A-17

5% AEP Flood Level

Map Produced by National W&E
Date: 09/09/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map:20yr_Results.wor 01



Margate Rivulet Hydraulic Assessment
Figure A-18

5% AEP Flood Depth

Legend

Study Area

Parcels

Flood Depth (m)

< 0.1

0.1 to 0.3

0.3 to 0.5

0.5 to 1

> 1

N

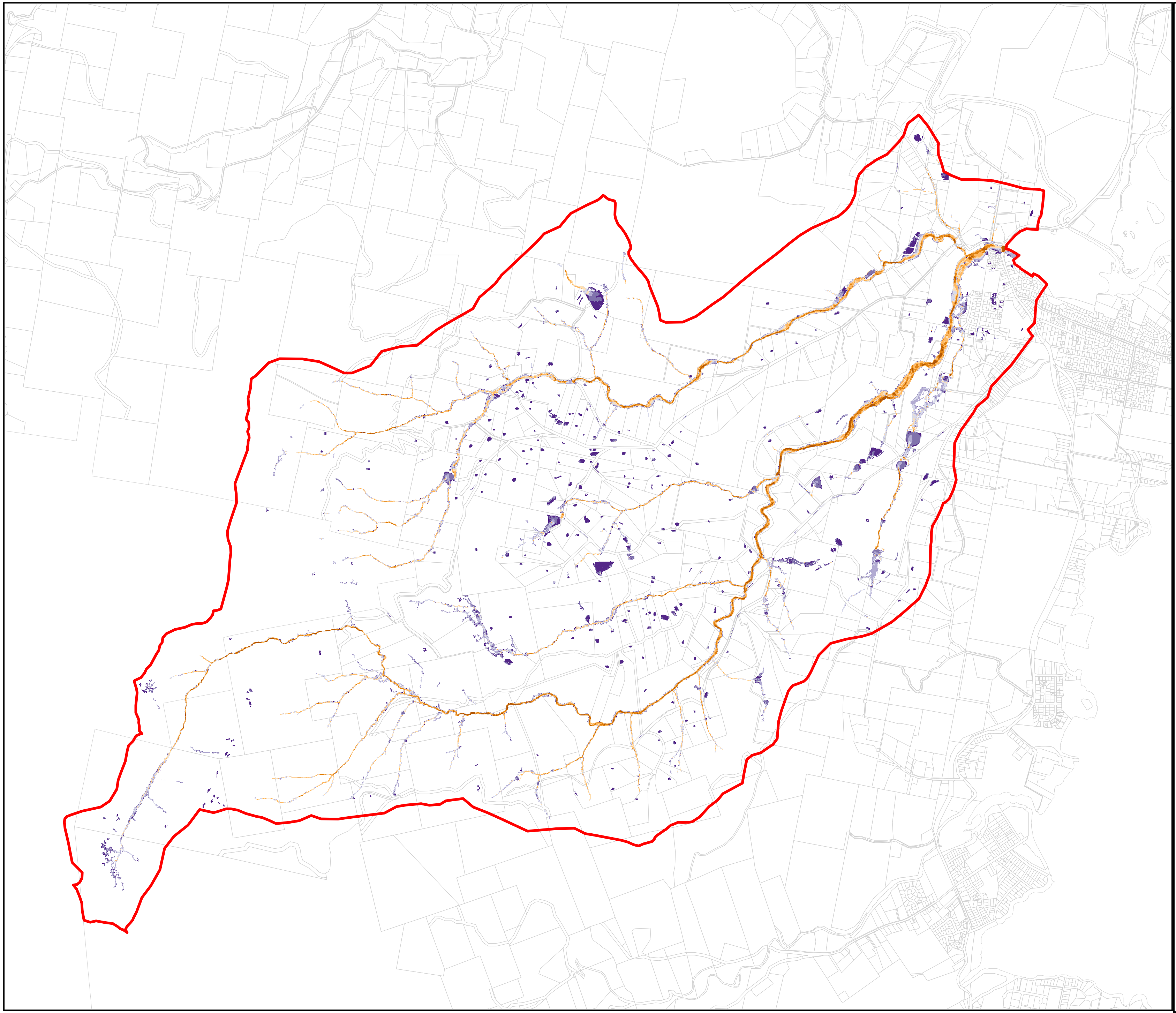
0 1,600

metres

Scale 1:40,000

Cardno

Map Produced by National W&E
Date: 09/09/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map:20yr_Results.wor 01



Margate Rivulet Hydraulic Assessment Figure A-19

5% AEP Flood Velocity

Legend

Study Area

Parcels

Flood Velocity (m/s)

- < 0.1
- 0.1 to 0.25
- 0.25 to 0.5
- 0.5 to 0.75
- 0.75 to 1
- 1 to 1.5
- 1.5 to 2
- > 2

N

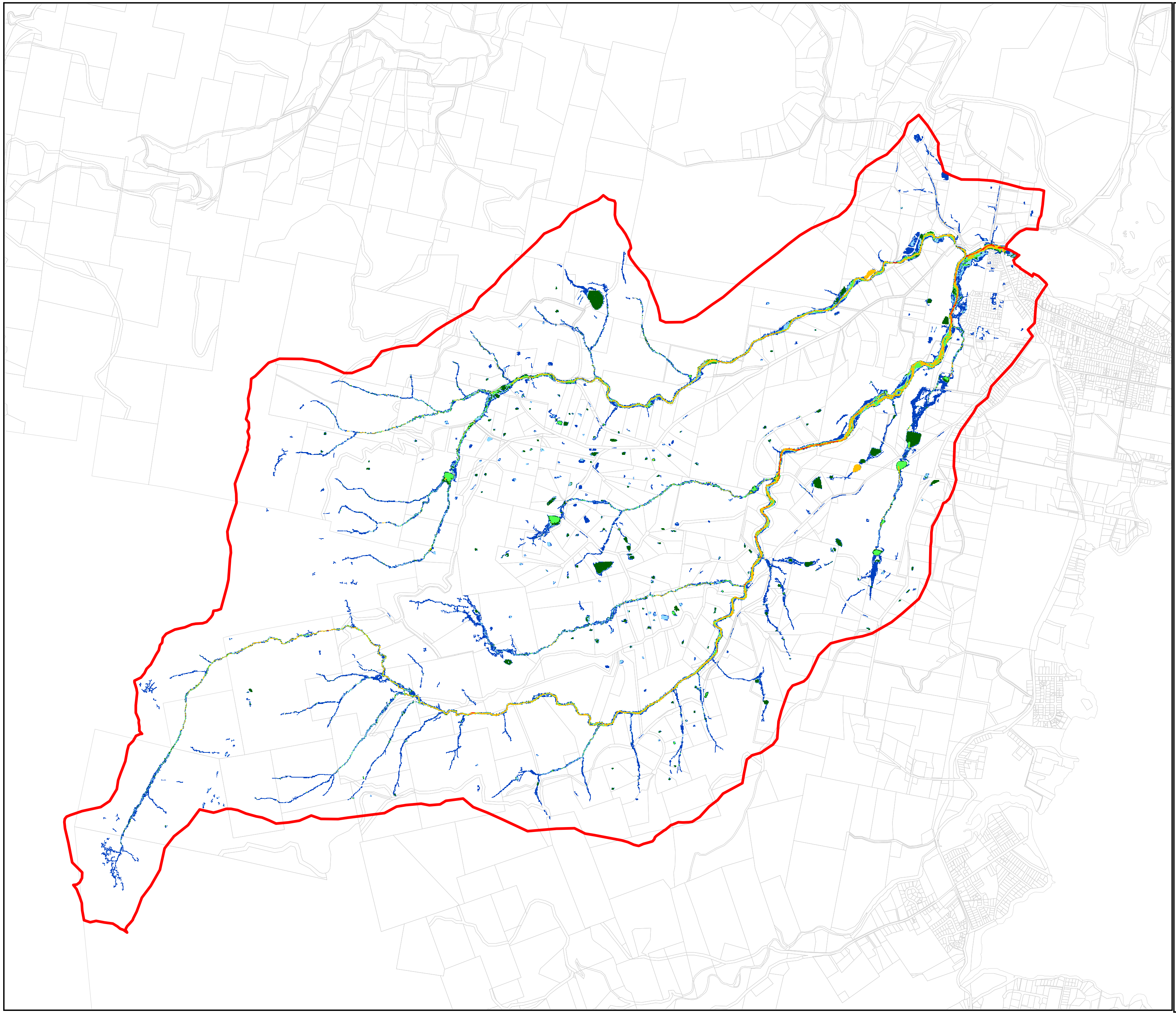
0 1,600

metres

Scale 1:40,000

Cardno

Map Produced by National W&E
Date: 09/09/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map:20yr_Results.wor 01



Margate Rivulet Hydraulic Assessment
Figure A-20

5% AEP Flood Hazard

Legend

Study Area

Parcels

Flood Hazard (ARR2019)

H1

H2

H3

H4

H5

H6

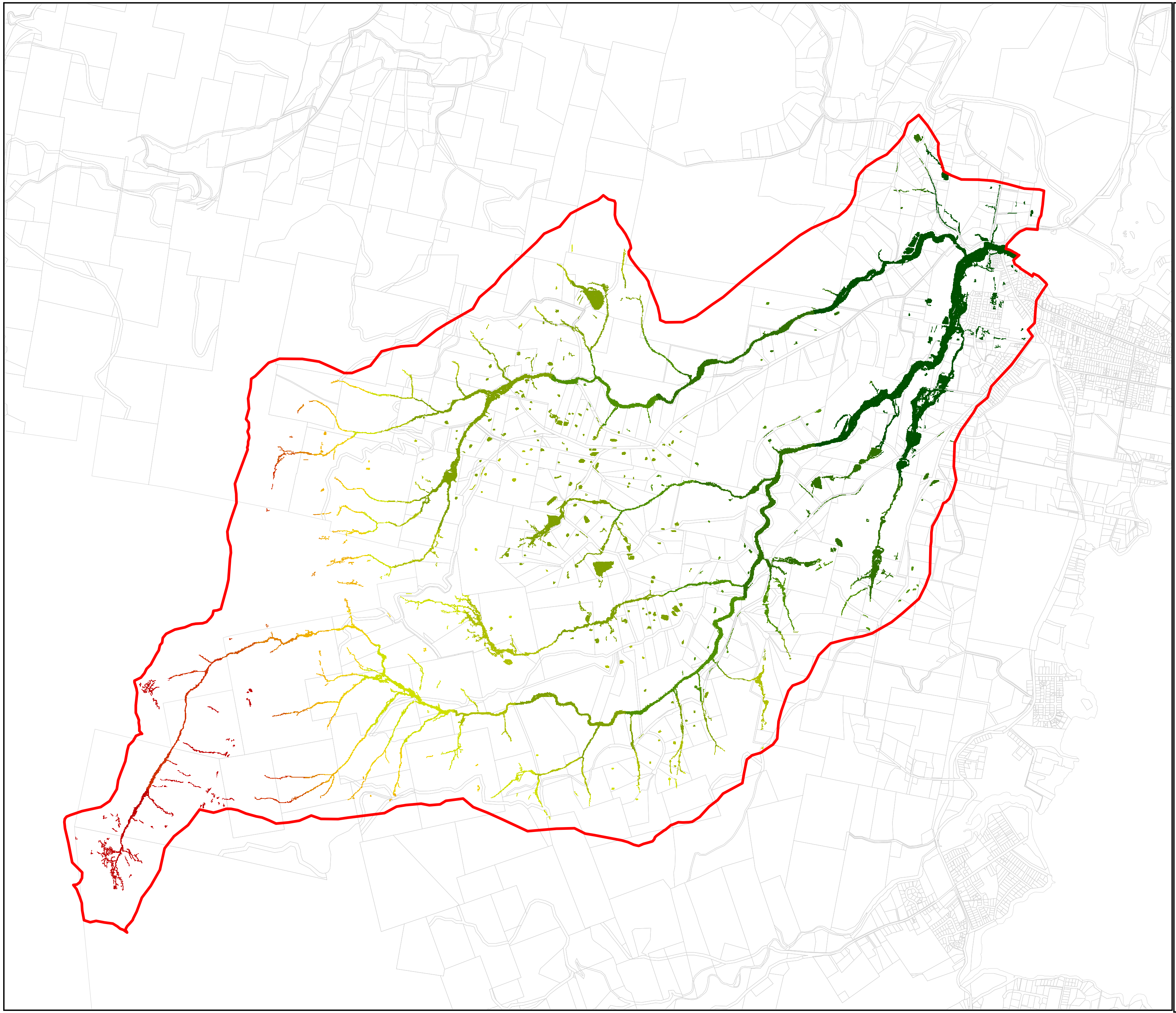
N

0 1,600

metres

Scale 1:40,000

Map Produced by National W&E
Date: 09/09/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map:20yr_Results.wor 01



Margate Rivulet Hydraulic Assessment Figure A-21

1% AEP Flood Level

Legend

Study Area

Parcels

Flood Level (mAHD)

Flood Level (mAHD)
0 to 50
50 to 100
100 to 150
150 to 200
200 to 250
250 to 300
300 to 350
350 to 400
400 to 450
450 to 500
500 to 600
600 to 800

N

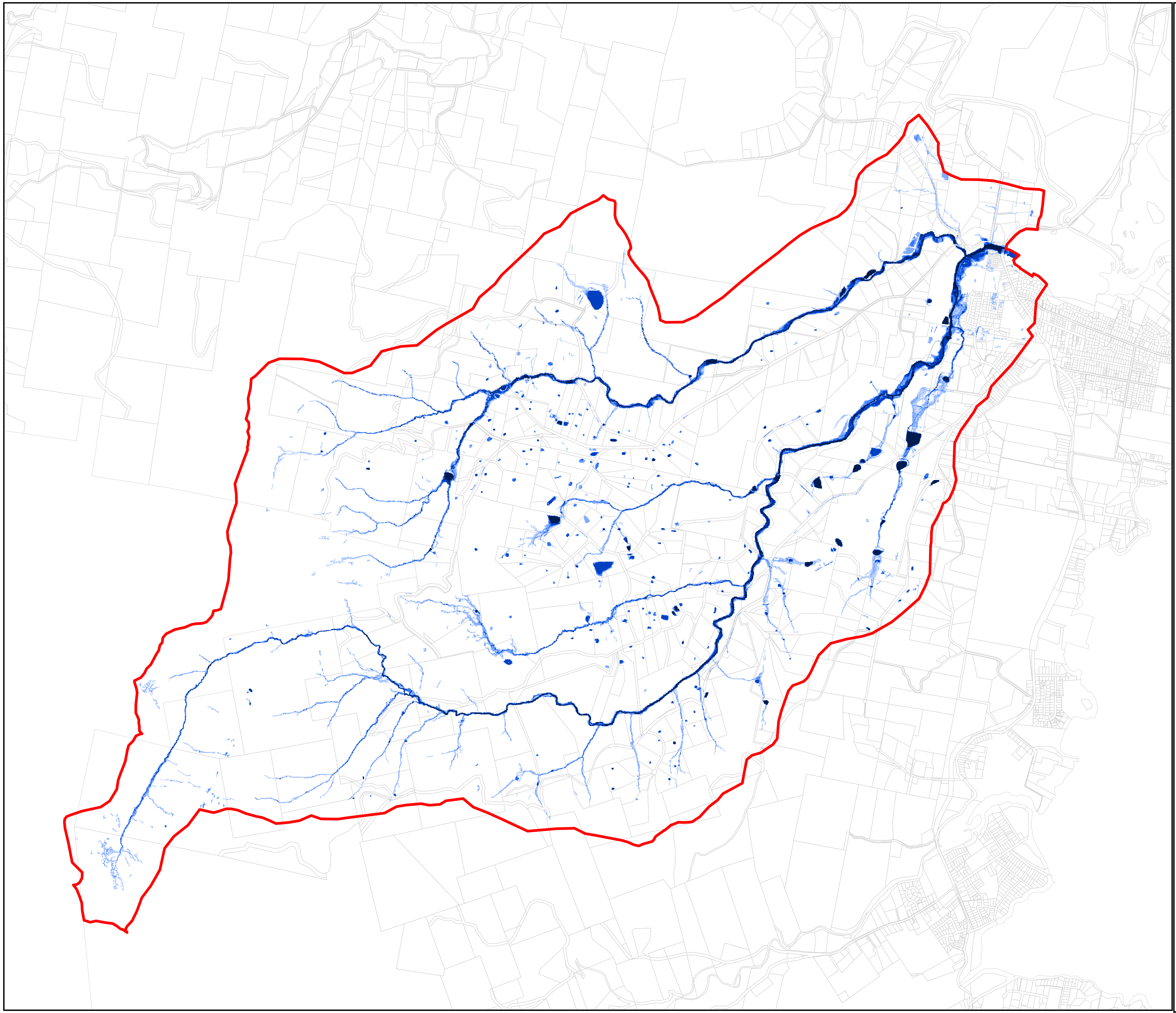
0 1,600

metres

Scale 1:40,000

Cardno

Map Produced by National W&E
Date: 09/09/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map:100yr_Results.wor 01



Margate Rivulet Hydraulic Assessment Figure A-22

1% AEP Flood Depth

Legend

Study Area

Parcels

Flood Depth (m)

< 0.1

0.1 to 0.3

0.3 to 0.5

0.5 to 1

> 1

N

0 1,600

metres

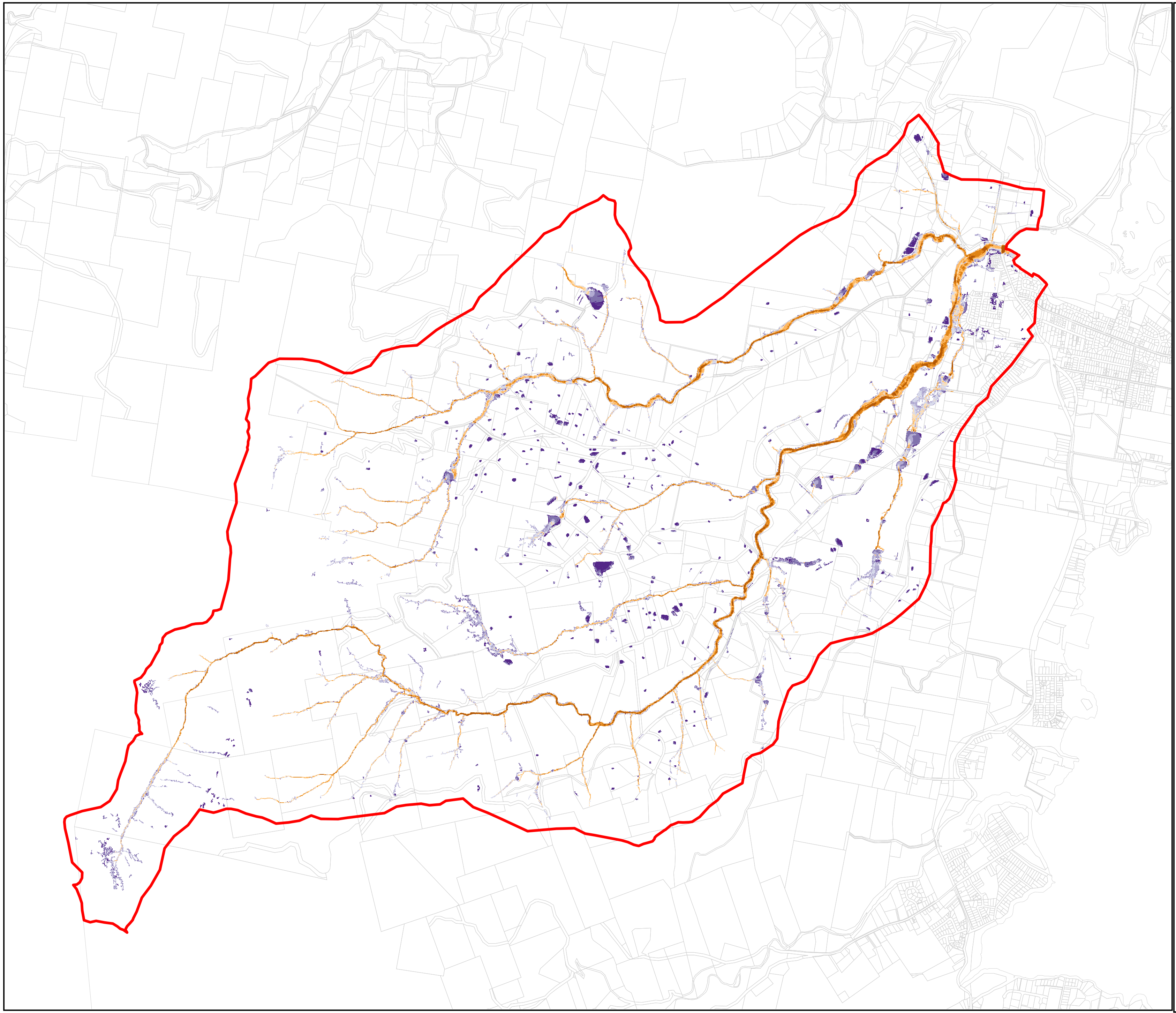
Scale 1:40,000

Cardno

Map Produced by National W&E
Date: 09/09/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map:100yr_Results.wor 01

Margate Rivulet Hydraulic Assessment Figure A-23

1% AEP Flood Velocity



Legend

Study Area

Parcels

Flood Velocity (m/s)

< 0.1

0.1 to 0.25

0.25 to 0.5

0.5 to 0.75

0.75 to 1

1 to 1.5

1.5 to 2

> 2

N

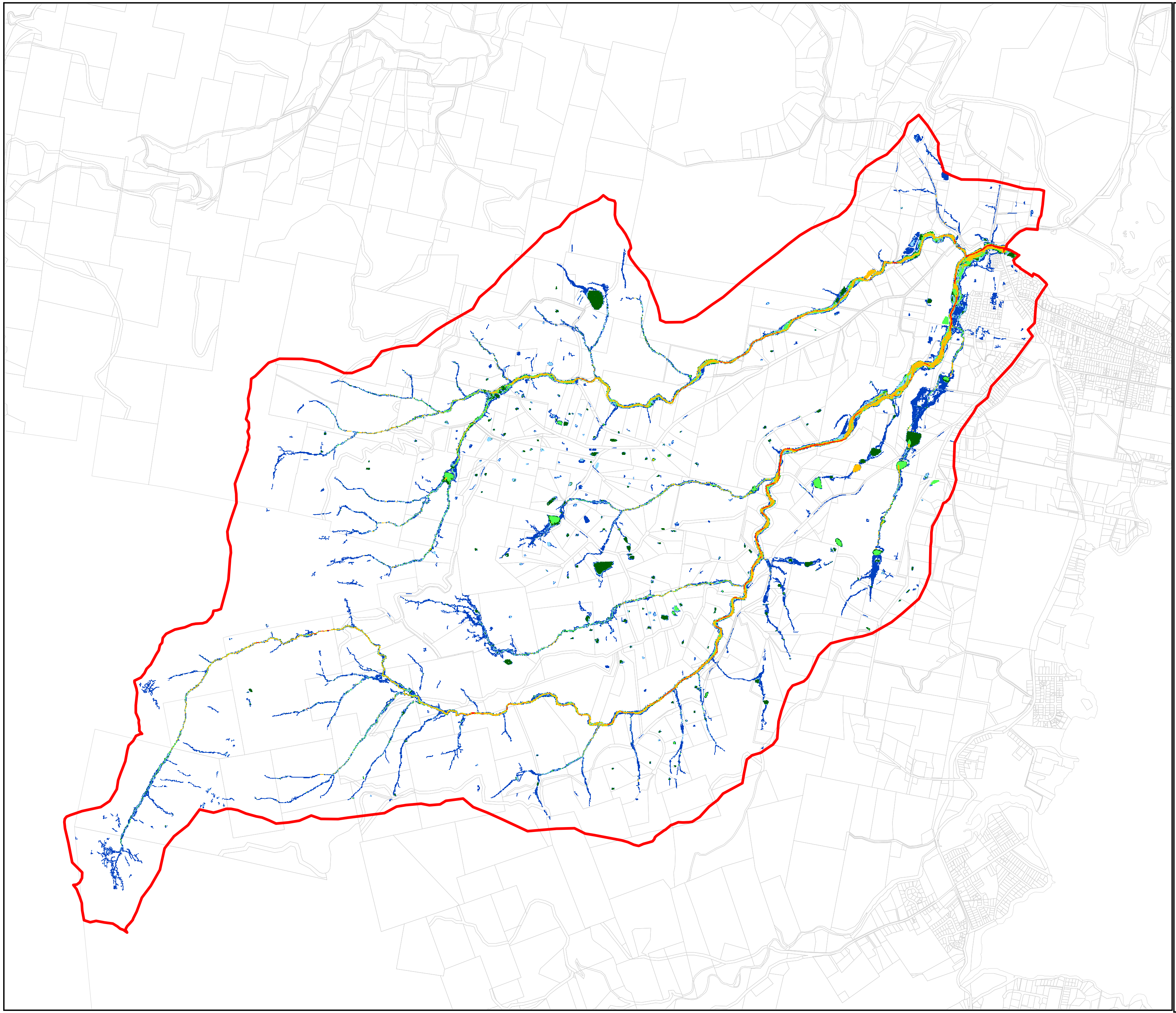
0 1,600
metres
Scale 1:40,000

Cardno

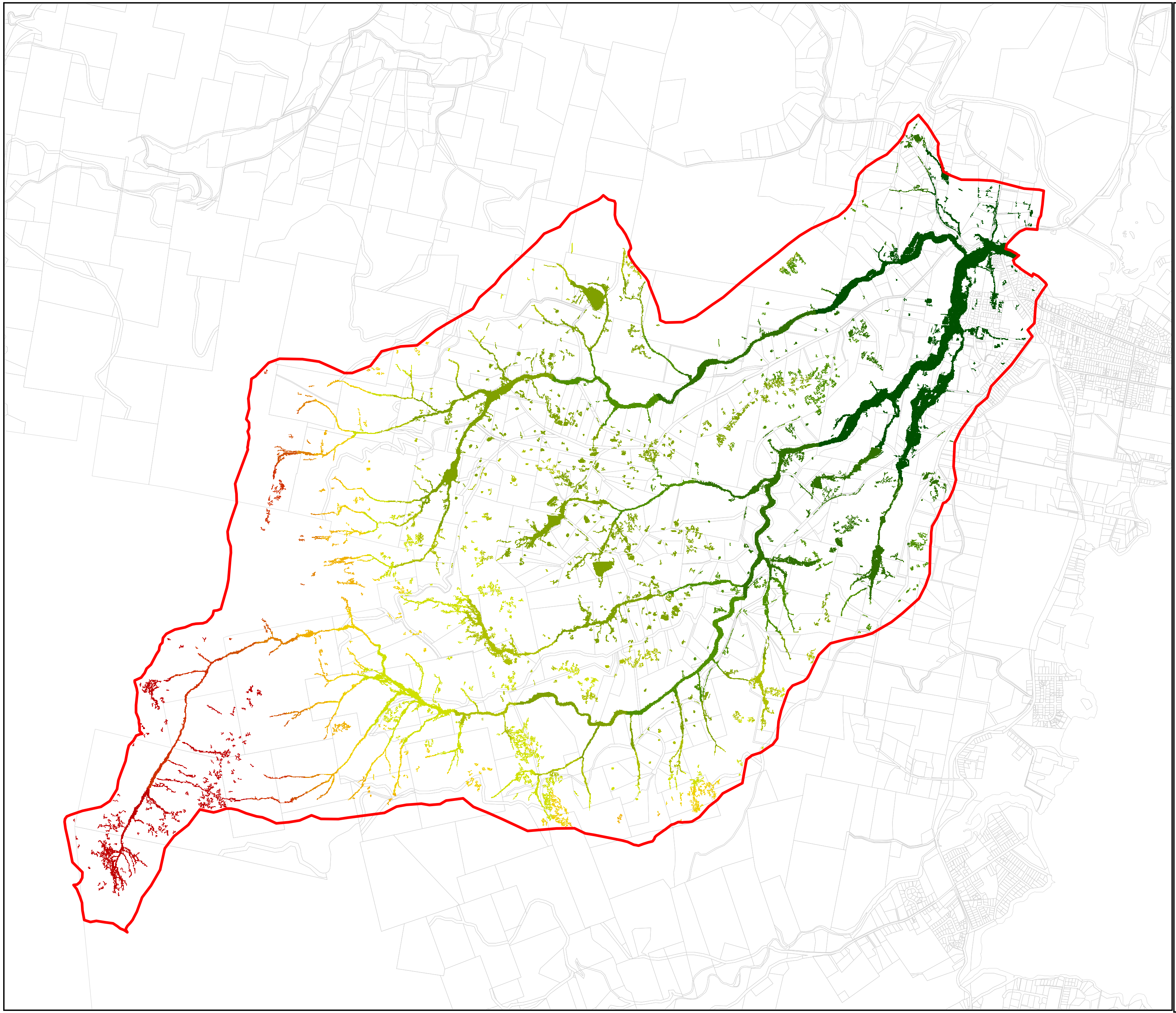
Map Produced by National W&E
Date: 09/09/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map:100yr_Results.wor 01

Margate Rivulet Hydraulic Assessment Figure A-24

1% AEP Flood Hazard



Map Produced by National W&E
Date: 09/09/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map:100yr_Results.wor 01



Margate Rivulet Hydraulic Assessment Figure A-25

0.5% AEP Flood Level

Legend

Study Area

Parcels

Flood Level (mAHD)

Flood Level (mAHD)
0 to 50
50 to 100
100 to 150
150 to 200
200 to 250
250 to 300
300 to 350
350 to 400
400 to 450
450 to 500
500 to 600
600 to 800

N

0 1,600

metres

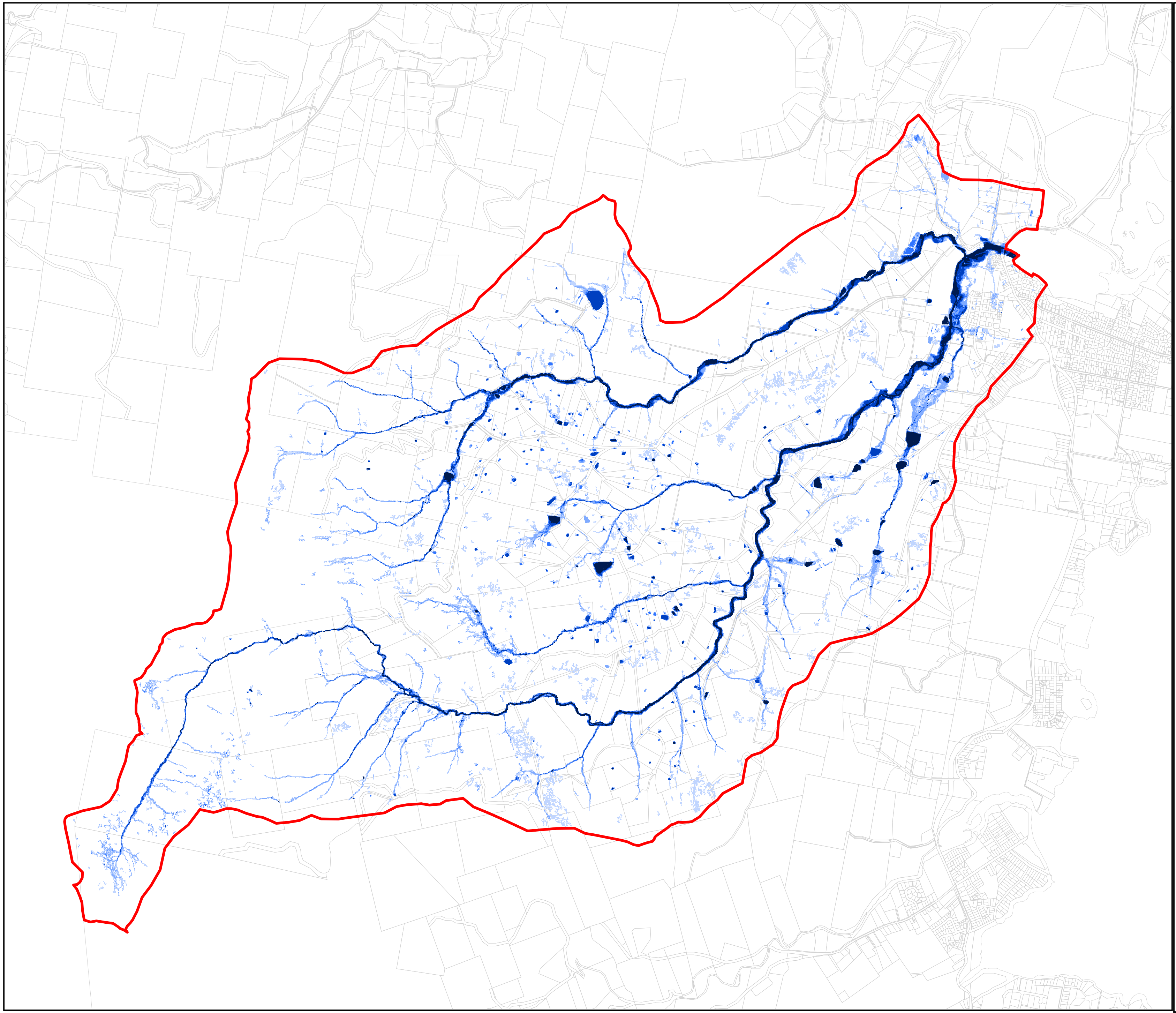
Scale 1:40,000

Cardno

Map Produced by National W&E
Date: 09/09/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map:200yr_Results.wor 01

Margate Rivulet Hydraulic Assessment Figure A-26

0.5% AEP Flood Depth



Legend

Study Area

Parcels

Flood Depth (m)

< 0.1

0.1 to 0.3

0.3 to 0.5

0.5 to 1

> 1

N

0 1,600

metres

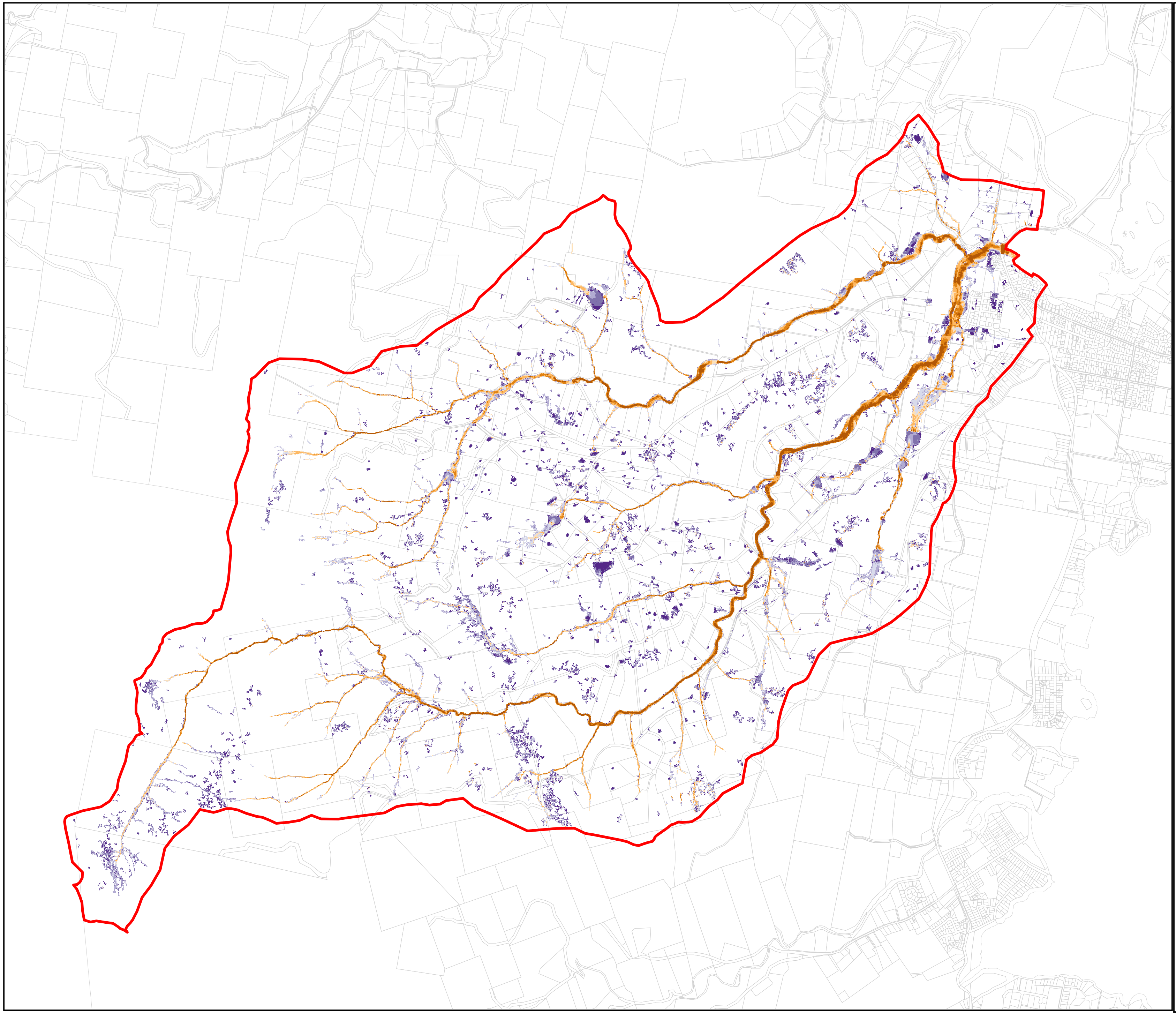
Scale 1:40,000

Cardno

Map Produced by National W&E
Date: 09/09/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map:200yr_Results.wor 01

Margate Rivulet Hydraulic Assessment Figure A-27

0.5% AEP Flood Velocity



Legend

Study Area

Parcels

Flood Velocity (m/s)

< 0.1

0.1 to 0.25

0.25 to 0.5

0.5 to 0.75

0.75 to 1

1 to 1.5

1.5 to 2

> 2

N

0 1,600

metres

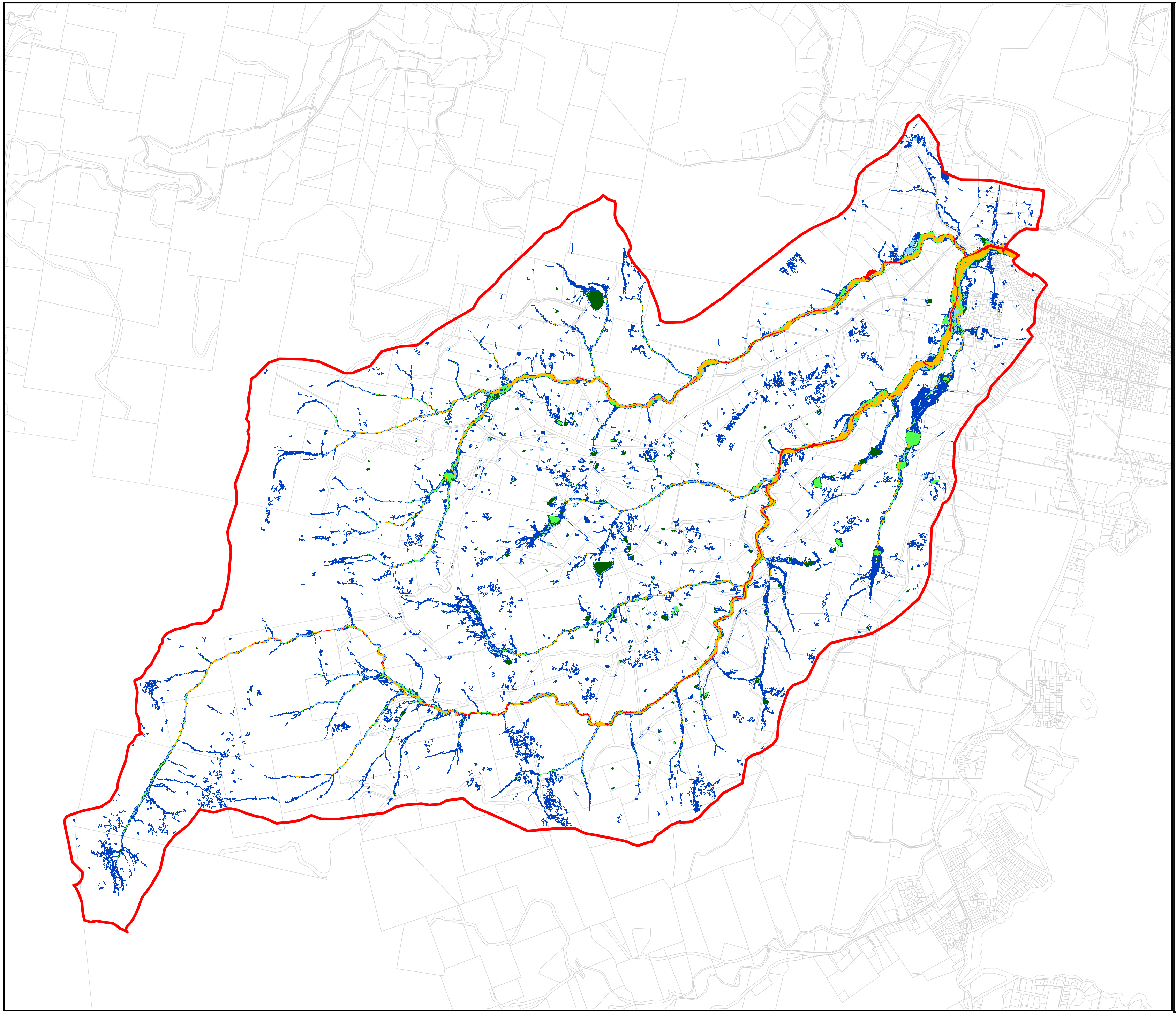
Scale 1:40,000

Cardno

Map Produced by National W&E
Date: 09/09/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map:200yr_Results.wor 01

Margate Rivulet Hydraulic Assessment Figure A-28

0.5% AEP Flood Hazard



Legend

Study Area

Parcels

Flood Hazard (ARR2019)

H1

H2

H3

H4

H5

H6

N

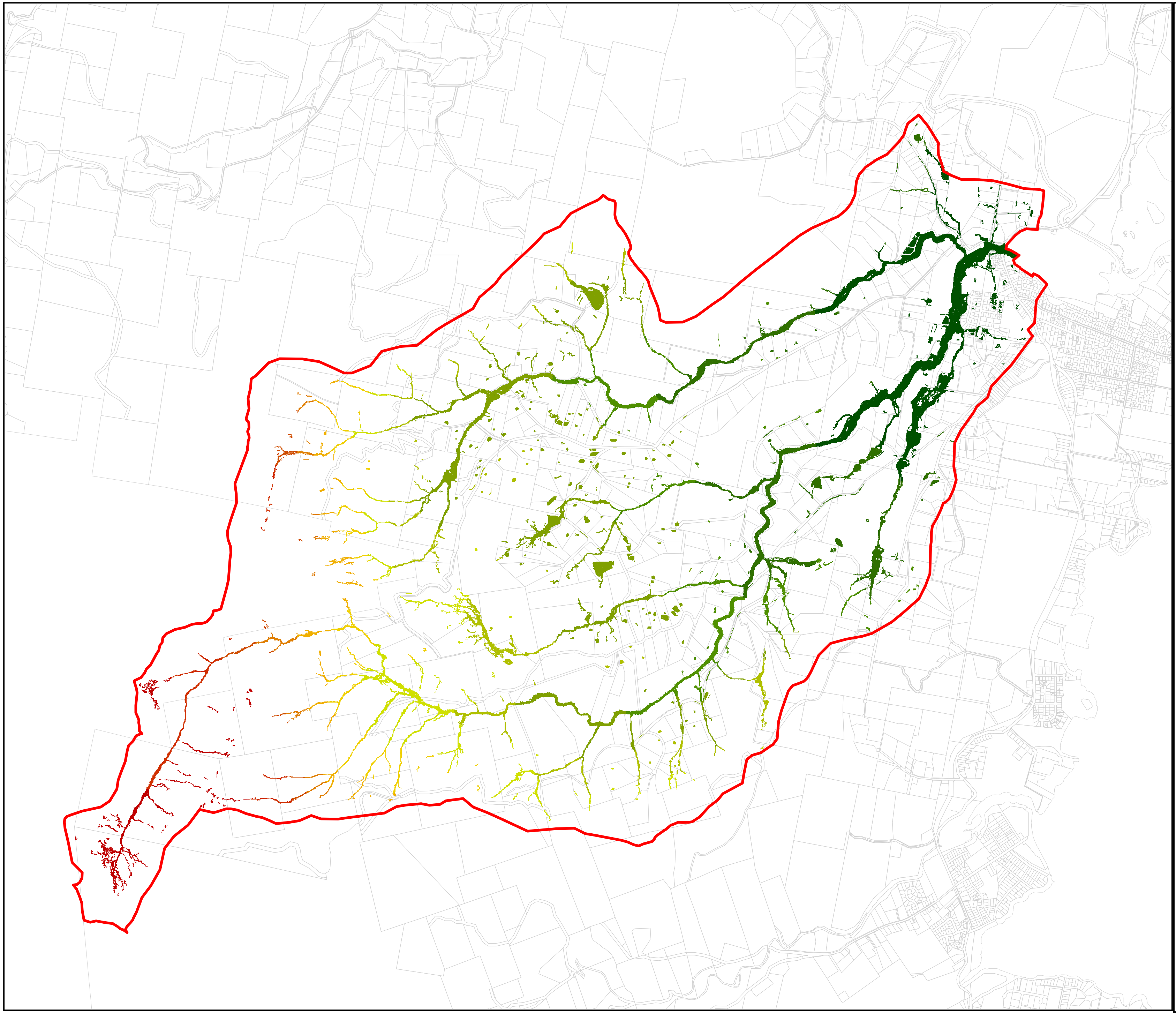
0 1,600

metres

Scale 1:40,000

Cardno

Map Produced by National W&E
Date: 09/09/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map:200yr_Results.wor 01



Margate Rivulet Hydraulic Assessment Figure A-29

1% AEP Climate Change Flood Level

Legend

Study Area

Parcels

Flood Level (mAHD)

Flood Level (mAHD)
0 to 50
50 to 100
100 to 150
150 to 200
200 to 250
250 to 300
300 to 350
350 to 400
400 to 450
450 to 500
500 to 600
600 to 800

N

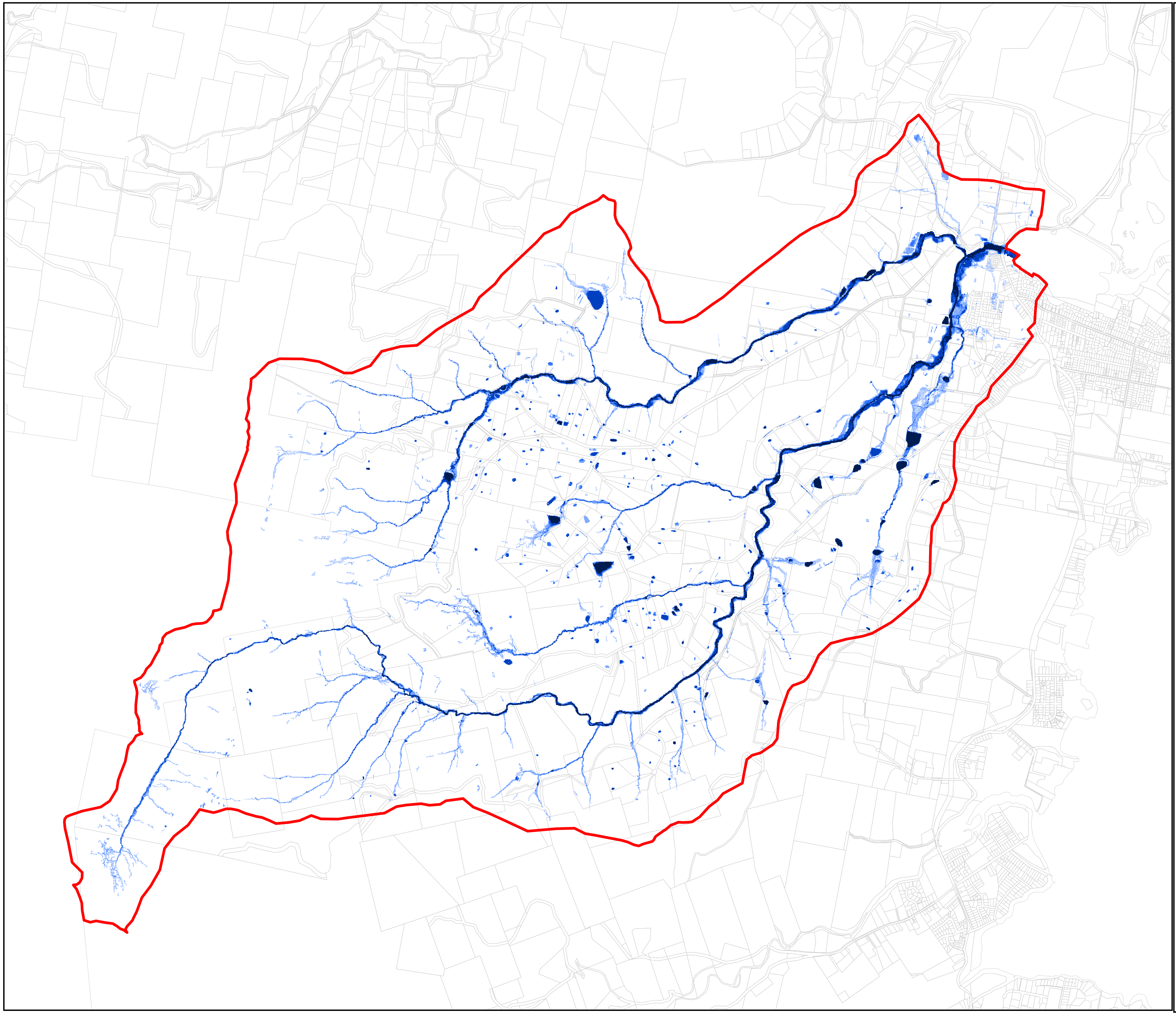
0 1,600

metres

Scale 1:40,000

Cardno

Map Produced by National W&E
Date: 09/09/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map:100yrCC_Results.wor 01



Margate Rivulet Hydraulic Assessment Figure A-30

1% AEP Climate Change Flood Depth

Legend

Study Area

Parcels

Flood Depth (m)

< 0.1

0.1 to 0.3

0.3 to 0.5

0.5 to 1

> 1

N

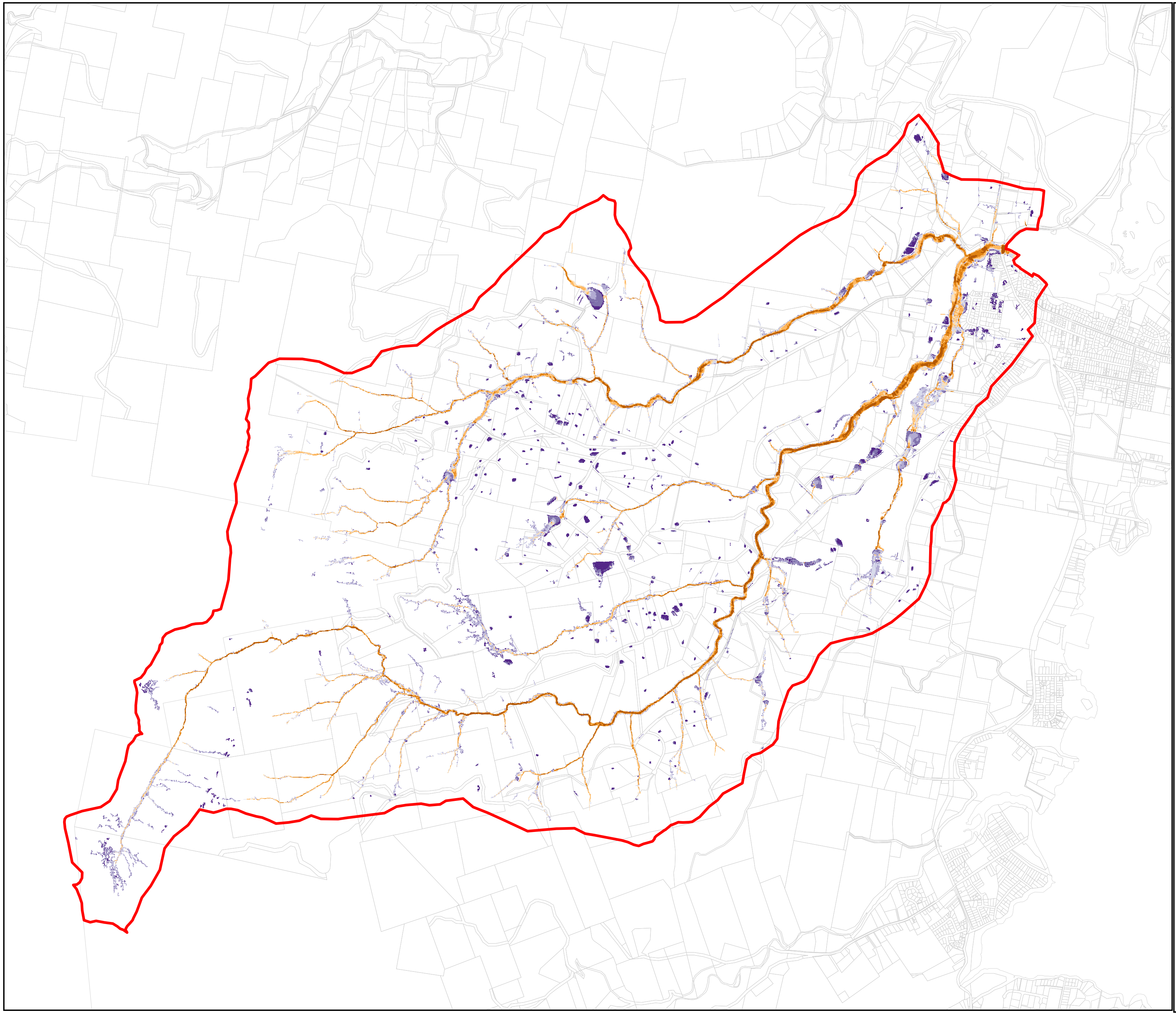
0 1,600

metres

Scale 1:40,000

Cardno

Map Produced by National W&E
Date: 09/09/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map:100yrCC_Results.wor 01



Margate Rivulet Hydraulic Assessment Figure A-31

1% AEP Climate Change Flood Velocity

Legend

Study Area

Parcels

Flood Velocity (m/s)

- < 0.1
- 0.1 to 0.25
- 0.25 to 0.5
- 0.5 to 0.75
- 0.75 to 1
- 1 to 1.5
- 1.5 to 2
- > 2

N

0 1,600

metres

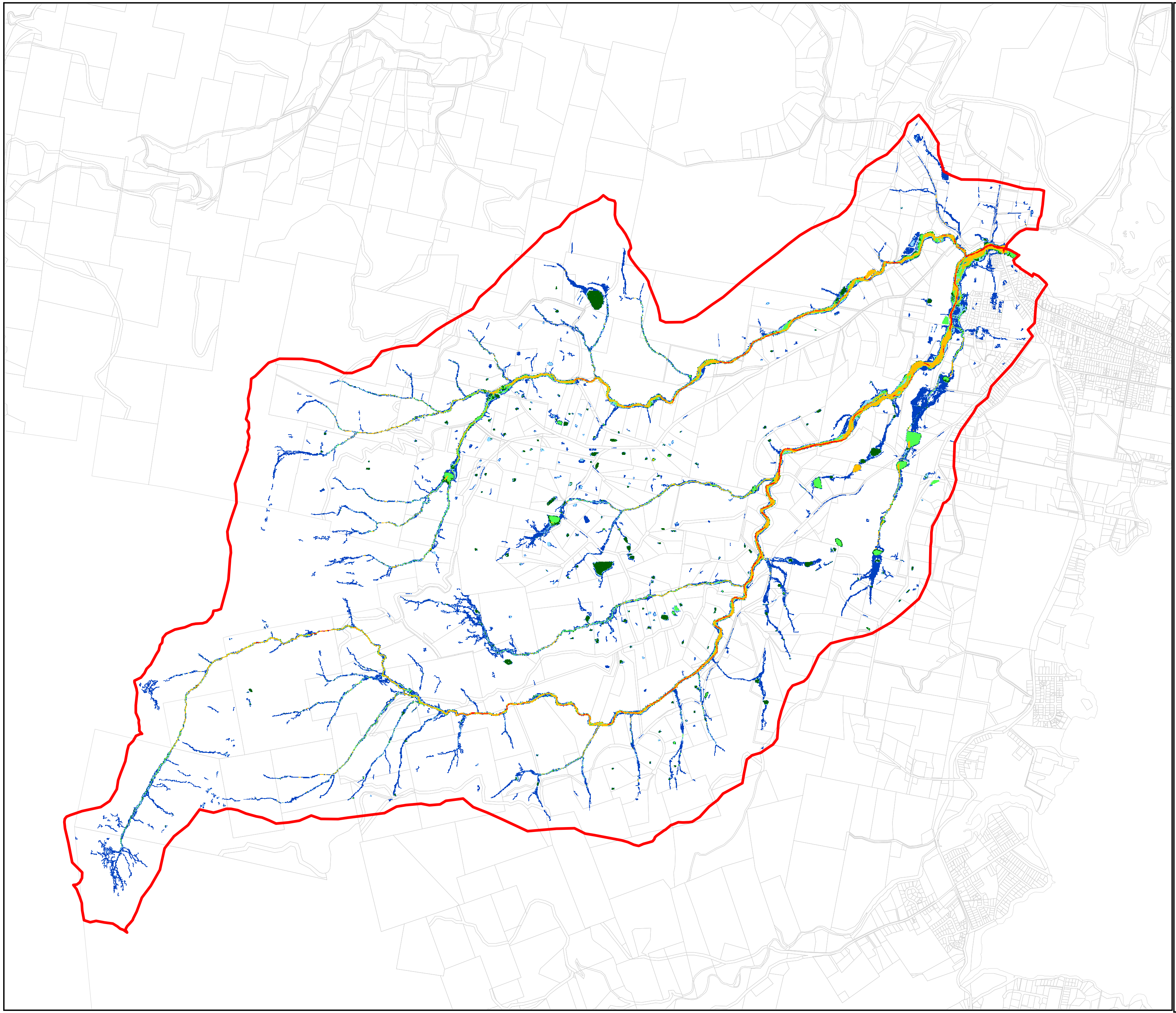
Scale 1:40,000

Cardno

Map Produced by National W&E
Date: 09/09/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map:100yrCC_Results.wor 01

Margate Rivulet Hydraulic Assessment Figure A-32

1% AEP Climate Change Flood Hazard



Legend

Study Area

Parcels

Flood Hazard (ARR2019)

H1

H2

H3

H4

H5

H6

N

0 1,600

metres

Scale 1:40,000

Cardno

Map Produced by National W&E
Date: 09/09/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map:100yrCC_Results.wor 01

APPENDIX

B

SUB-CATCHMENT CHARACTERISTICS

SubArea Number	SubArea ID	Area (m^2)	DCIA	ICIA	PA
1	A	0.904	0	0.025	0.975
2	B	0.718	0	0.026	0.974
3	C	1.176	0.002	0.026	0.972
4	D	1.002	0.007	0.03	0.963
5	E	0.633	0.011	0.033	0.956
6	F	1.022	0.003	0.029	0.968
7	G	0.933	0.009	0.032	0.959
8	H	0.7	0.009	0.032	0.959
9	I	0.986	0.012	0.034	0.954
10	J	0.484	0.034	0.044	0.922
11	K	0.894	0.023	0.038	0.939
12	L	0.432	0.03	0.044	0.926
13	M	0.647	0.028	0.04	0.932
14	N	0.684	0.017	0.033	0.95
15	O	0.759	0.04	0.04	0.92
16	P	0.386	0.075	0.052	0.873
17	Q	0.282	0.043	0.047	0.91
18	R	1.042	0.058	0.046	0.896
19	S	0.449	0.157	0.129	0.714
20	T	0.369	0.123	0.089	0.788
21	U	0.747	0.003	0.028	0.969
22	V	0.867	0.001	0.026	0.973
23	W	0.415	0.03	0.043	0.927
24	X	0.829	0.002	0.028	0.97
25	Y	0.581	0.003	0.026	0.971
26	Z	0.783	0.037	0.048	0.915
27	AA	0.676	0.029	0.031	0.94
28	AB	0.985	0.033	0.037	0.93
29	AC	1.126	0.028	0.036	0.936
30	AD	0.559	0.04	0.04	0.92
31	AE	0.369	0.076	0.05	0.874

32	AF	0.47	0.082	0.052	0.866
33	AG	0.203	0.268	0.2	0.532

APPENDIX

C

ARR DATAHUB TEXT FILE

```
Results - ARR Data Hub
[STARTTXT]

Input Data Information
[INPUTDATA]
Latitude,-43.037700
Longitude,147.234200
[END_INPUTDATA]

River Region
[RIVREG]
Division,Tasmania
River Number,5
River Name,Kingston Coast
[RIVREG_META]
Time Accessed,27 April 2021 09:53AM
Version,2016_v1
[END_RIVREG]

ARF Parameters
[LONGARF]
Zone,Tasmania
a,0.0605
b,0.347
c,0.2
d,0.283
e,0.00076
f,0.347
g,0.0877
h,0.012
i,-0.00033
[LONGARF_META]
Time Accessed,27 April 2021 09:53AM
Version,2016_v1
[END_LONGARF]

Storm Losses
[LOSSES]
ID,10530.0
Storm Initial Losses (mm),28.0
Storm Continuing Losses (mm/h),3.4
[LOSSES_META]
Time Accessed,27 April 2021 09:53AM
Version,2016_v1
[END_LOSSES]

Temporal Patterns
[TP]
code,SStas
Label,Southern Slopes (Tas)
[TP_META]
Time Accessed,27 April 2021 09:53AM
Version,2016_v2
[END_TP]

Areal Temporal Patterns
[ATP]
code,SStas
arealabel,Southern Slopes (Tas)
[ATP_META]
Time Accessed,27 April 2021 09:53AM
Version,2016_v2
[END_ATP]

Median Preburst Depths and Ratios
[PREBURST]
```

```
min (h)\AEP(%),50,20,10,5,2,1
60 (1.0),4.3 (0.346),6.0 (0.348),7.2 (0.345),8.2 (0.340),6.1 (0.209),4.5 (0.135)
90 (1.5),4.3 (0.285),4.7 (0.222),4.9 (0.195),5.1 (0.175),6.1 (0.176),6.8 (0.175)
120 (2.0),6.2 (0.352),6.4 (0.262),6.5 (0.225),6.7 (0.198),6.1 (0.154),5.7 (0.128)
180 (3.0),7.7 (0.352),8.7 (0.286),9.4 (0.259),10.0 (0.240),16.6 (0.339),21.6 (0.395)
360 (6.0),7.7 (0.243),11.1 (0.249),13.4 (0.250),15.6 (0.251),20.8 (0.284),24.7 (0.302)
720 (12.0),5.2 (0.116),8.5 (0.131),10.7 (0.136),12.8 (0.139),12.5 (0.114),12.3 (0.100)
1080 (18.0),5.0 (0.092),6.9 (0.088),8.2 (0.086),9.5 (0.085),11.7 (0.086),13.3 (0.087)
1440 (24.0),4.3 (0.071),6.0 (0.068),7.1 (0.066),8.1 (0.064),10.0 (0.066),11.5 (0.066)
2160 (36.0),2.8 (0.041),2.8 (0.028),2.7 (0.022),2.7 (0.019),11.6 (0.066),18.3 (0.091)
2880 (48.0),1.5 (0.021),3.8 (0.035),5.2 (0.040),6.7 (0.043),10.6 (0.056),13.5 (0.063)
4320 (72.0),0.0 (0.000),2.1 (0.018),3.4 (0.025),4.7 (0.029),2.9 (0.014),1.4 (0.006)
[PREBURST_META]
Time Accessed,27 April 2021 09:53AM
Version,2018_v1
Note,Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.
[END_PREBURST]From preburst class

10% Preburst Depths
[PREBURST10]
min (h)\AEP(%),50,20,10,5,2,1
60 (1.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000)
90 (1.5),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000)
120 (2.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000)
180 (3.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000)
360 (6.0),0.0 (0.000),0.1 (0.001),0.1 (0.002),0.1 (0.002),1.5 (0.020),2.5 (0.031)
720 (12.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),1.0 (0.009),1.8 (0.015)
1080 (18.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000)
1440 (24.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000)
2160 (36.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.1 (0.000)
2880 (48.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000)
4320 (72.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000)
[PREBURST10_META]
Time Accessed,27 April 2021 09:53AM
Version,2018_v1
Note,Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.
[END_PREBURST10]From preburst class

25% Preburst Depths
[PREBURST25]
min (h)\AEP(%),50,20,10,5,2,1
60 (1.0),0.8 (0.067),1.0 (0.055),1.0 (0.050),1.1 (0.046),1.0 (0.035),0.9 (0.028)
90 (1.5),0.7 (0.044),0.7 (0.035),0.8 (0.030),0.8 (0.027),0.8 (0.022),0.8 (0.019)
120 (2.0),1.0 (0.056),0.7 (0.029),0.5 (0.019),0.4 (0.011),0.3 (0.008),0.3 (0.007)
180 (3.0),0.4 (0.018),0.5 (0.015),0.5 (0.014),0.6 (0.013),2.9 (0.058),4.6 (0.084)
360 (6.0),0.6 (0.020),2.3 (0.050),3.3 (0.062),4.4 (0.070),6.3 (0.086),7.7 (0.094)
720 (12.0),0.1 (0.002),0.6 (0.010),1.0 (0.012),1.3 (0.014),3.2 (0.029),4.6 (0.037)
1080 (18.0),0.1 (0.002),0.3 (0.003),0.4 (0.004),0.5 (0.004),1.9 (0.014),3.0 (0.020)
1440 (24.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.1 (0.000),0.0 (0.000),0.0 (0.000)
2160 (36.0),0.0 (0.000),0.1 (0.001),0.1 (0.001),0.1 (0.001),0.5 (0.003),0.8 (0.004)
2880 (48.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.1 (0.001),0.2 (0.001)
4320 (72.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000)
[PREBURST25_META]
Time Accessed,27 April 2021 09:53AM
Version,2018_v1
Note,Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.
[END_PREBURST25]From preburst class

75% Preburst Depths
[PREBURST75]
min (h)\AEP(%),50,20,10,5,2,1
60 (1.0),18.5 (1.487),21.9 (1.268),24.2 (1.167),26.4 (1.088),27.3 (0.937),27.9 (0.847)
90 (1.5),18.1 (1.193),20.6 (0.980),22.3 (0.887),23.9 (0.818),28.8 (0.829),32.4 (0.832)
```

```
120 (2.0),20.4 (1.162),22.8 (0.934),24.4 (0.838),25.9 (0.768),31.6 (0.794),35.8 (0.805)
180 (3.0),23.4 (1.077),29.0 (0.956),32.7 (0.905),36.3 (0.869),43.3 (0.881),48.5 (0.886)
360 (6.0),26.1 (0.825),32.2 (0.718),36.2 (0.675),40.0 (0.645),41.0 (0.559),41.6 (0.509)
720 (12.0),21.8 (0.487),30.8 (0.475),36.7 (0.468),42.4 (0.462),43.2 (0.394),43.8 (0.355)
1080 (18.0),30.0 (0.557),37.3 (0.477),42.2 (0.443),46.8 (0.418),82.2 (0.609),108.7 (0.711)
1440 (24.0),27.6 (0.459),34.1 (0.388),38.4 (0.358),42.5 (0.336),83.2 (0.544),113.8 (0.654)
2160 (36.0),21.5 (0.315),26.3 (0.263),29.4 (0.241),32.4 (0.225),42.2 (0.240),49.5 (0.247)
2880 (48.0),15.1 (0.205),28.9 (0.270),38.1 (0.292),46.8 (0.303),46.6 (0.248),46.5 (0.217)
4320 (72.0),5.6 (0.070),22.2 (0.194),33.2 (0.239),43.8 (0.267),57.3 (0.289),67.5 (0.298)
[PREBURST75_META]
Time Accessed,27 April 2021 09:53AM
Version,2018_v1
Note,Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.
[END_PREBURST75]From preburst class

90% Preburst Depths
[PREBURST90]
min (h)\AEP(%),50,20,10,5,2,1
60 (1.0),38.9 (3.130),50.0 (2.893),57.3 (2.764),64.3 (2.653),58.5 (2.010),54.1 (1.640)
90 (1.5),37.5 (2.478),46.7 (2.219),52.7 (2.098),58.5 (2.004),59.8 (1.725),60.8 (1.561)
120 (2.0),64.1 (3.652),58.3 (2.392),54.5 (1.876),50.8 (1.510),61.3 (1.542),69.2 (1.555)
180 (3.0),65.0 (2.988),65.2 (2.148),65.4 (1.808),65.5 (1.568),70.9 (1.441),74.9 (1.367)
360 (6.0),75.6 (2.394),83.7 (1.868),89.0 (1.660),94.1 (1.515),89.6 (1.223),86.3 (1.055)
720 (12.0),66.6 (1.485),83.1 (1.281),94.0 (1.199),104.5 (1.140),114.9 (1.049),122.7 (0.995)
1080 (18.0),64.4 (1.199),89.0 (1.137),105.3 (1.106),120.9 (1.080),152.7 (1.132),176.5 (1.155)
1440 (24.0),59.3 (0.987),84.0 (0.958),100.4 (0.938),116.1 (0.919),145.7 (0.953),167.9 (0.965)
2160 (36.0),66.9 (0.976),73.0 (0.731),77.1 (0.632),81.0 (0.561),83.5 (0.476),85.4 (0.426)
2880 (48.0),53.2 (0.720),86.5 (0.808),108.5 (0.831),129.7 (0.840),112.0 (0.597),98.8 (0.460)
4320 (72.0),42.7 (0.532),73.7 (0.643),94.2 (0.677),113.8 (0.695),141.6 (0.714),162.4 (0.718)
[PREBURST90_META]
Time Accessed,27 April 2021 09:53AM
Version,2018_v1
Note,Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.
[END_PREBURST90]From preburst class

Interim Climate Change Factors
[CCF]
,RCP 4.5,RCP6,RCP 8.5
2030,0.648 (3.2%),0.687 (3.4%),0.811 (4.0%)
2040,0.878 (4.4%),0.827 (4.1%),1.084 (5.4%)
2050,1.081 (5.4%),1.013 (5.1%),1.446 (7.3%)
2060,1.251 (6.3%),1.229 (6.2%),1.862 (9.5%)
2070,1.381 (7.0%),1.460 (7.4%),2.298 (11.9%)
2080,1.465 (7.4%),1.691 (8.6%),2.719 (14.2%)
2090,1.496 (7.6%),1.906 (9.7%),3.090 (16.3%)

[CCF_META]
Time Accessed,27 April 2021 09:53AM
Version,2019_v1
Note,ARR recommends the use of RCP4.5 and RCP 8.5 values. These have been updated to the values that can be found on the climate change in Australia website.
[END_CCF]



Baseflow Factors
[BASEFLOW]
```

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Downstream,0
Area (km2),440.214336
Catchment Number,11527
Volume Factor,0.123618
Peak Factor,0.032059
[BASEFLOW_META]
Time Accessed,27 April 2021 09:53AM
Version,2016_v1
[END_BASEFLOW]

[ENDTXT]
```

APPENDIX

D

WEIGHTED IFDS

All Design Rainfall Depth (mm)
Issued: 26-Apr-21
Location Label:
Requested Latitude -43.0377 Longitude 147.2342
Nearest gri Latitude 43.0375 (S) Longitude 147.2375 (E)

		Exceedanc	Annual Exceedance Probability (AEP)						
Duration	Duration in	50%	20%	10%	5%	2%	1%	0.50%	0.20%
10 min	10	6.17	7.86	9.59	11.4	14.07	16.27	18.6	21.68
15 min	15	7.46	9.51	11.6	13.83	17.07	19.8	22.61	26.36
20 min	20	8.49	10.78	13.14	15.66	19.3	22.27	25.49	29.67
25 min	25	9.38	11.9	14.46	17.18	21.06	24.3	27.74	32.32
30 min	30	10.18	12.88	15.59	18.51	22.58	25.96	29.66	34.53
45 min	45	12.25	15.38	18.56	21.84	26.39	30.1	34.32	39.97
1 hour	60	14.06	17.65	21.15	24.75	29.63	33.54	38.28	44.57
1.5 hour	90	17.27	21.54	25.71	29.86	35.42	39.74	45.34	52.84
2 hour	120	20.09	25.09	29.89	34.58	40.75	45.49	51.94	60.49
3 hour	180	25.19	31.53	37.43	43.15	50.66	56.33	64.31	74.9
4.5 hour	270	31.69	39.92	47.49	54.71	64.22	71.35	81.62	95.02
6 hour	360	37.32	47.32	56.42	65.15	76.64	85.3	97.61	113.44
9 hour	540	46.68	59.85	71.74	83.18	98.48	110.33	126.11	146.97
12 hour	720	54.2	70.08	84.39	98.28	117.35	131.52	150.65	175.85
18 hour	1080	65.74	85.71	103.92	122.09	146.53	165.8	190.02	221.47
24 hour	1440	74.06	96.99	118.05	139.21	168.3	191.43	218.66	254.74
30 hour	1800	80.33	105.33	128.8	152.28	184.66	210.22	241.73	281.63
36 hour	2160	85.19	111.74	136.7	161.78	196.88	224.91	257.47	300
48 hour	2880	92.14	120.64	147.93	175.13	213.02	243.68	276.74	322.5
72 hour	4320	100.77	130.59	159.21	188.69	228.45	260.42	293.35	341.64
96 hour	5760	106.32	135.92	164.97	194.83	234.4	266.5	299.51	348.79
120 hour	7200	110.63	140.2	169.07	198.55	237.61	269.06	303.22	352.28
144 hour	8640	114.74	144.33	173.11	201.67	240.89	271.29	305.54	354.96
168 hour	10080	119.42	149.18	177.58	205.55	244.12	274.75	308.17	357.9

All Design Rainfall Depth (mm) - Inclusive of Climate Change
Issued: 26-Apr-21
Location Label:
Requested Latitude -43.0377 Longitude 147.2342
Nearest gri Latitude 43.0375 (S) Longitude 147.2375 (E)

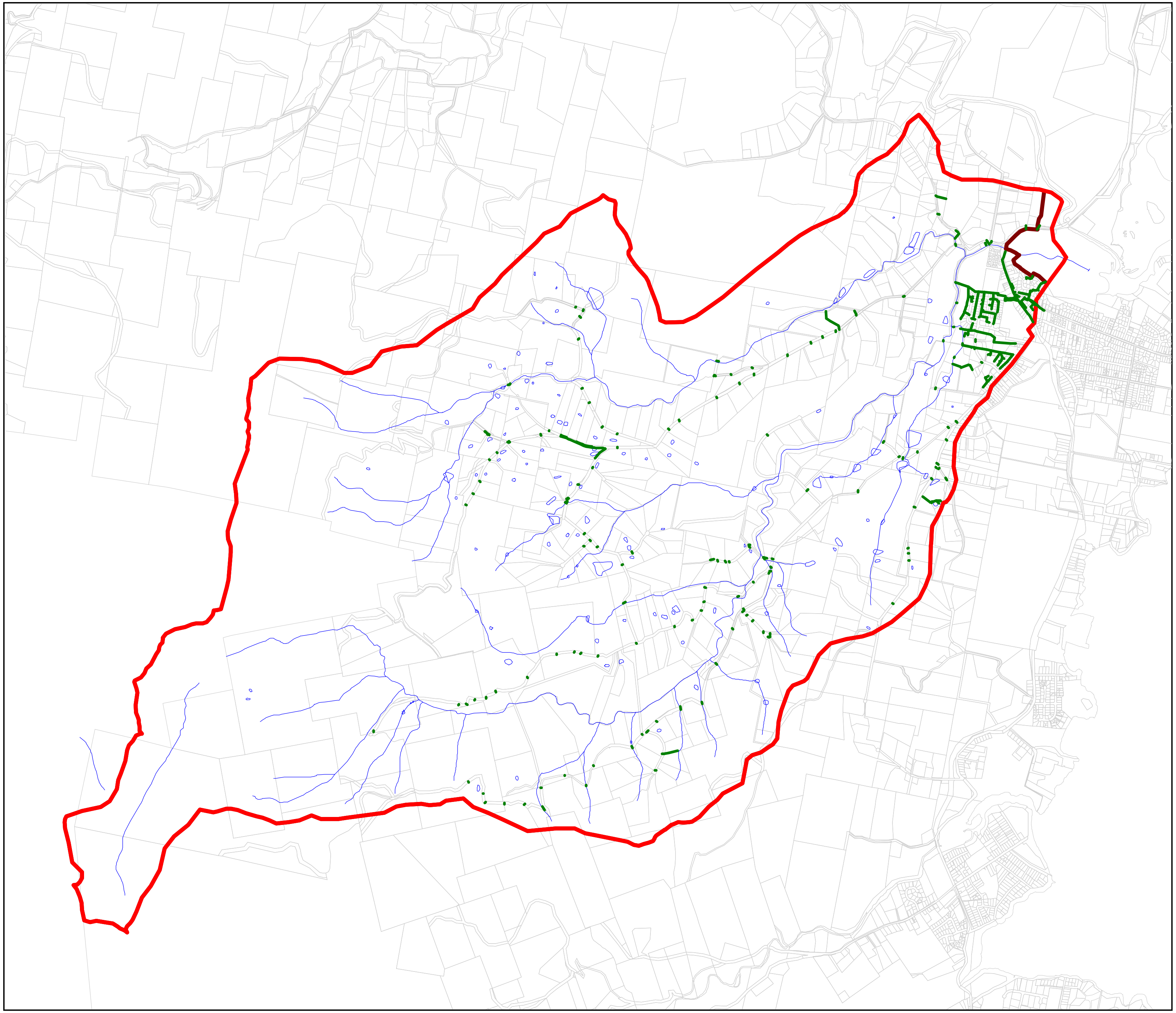
		Exceedanc	Annual Exceedance Probability (AEP)						
Duration	Duration in	50%	20%	10%	5%	2%	1%	0.50%	0.20%
10 min	10	6.96593	8.87394	10.82711	12.8706	15.88503	18.36883	20.9994	24.47672
15 min	15	8.42234	10.73679	13.0964	15.61407	19.27203	22.3542	25.52669	29.76044
20 min	20	9.58521	12.17062	14.83506	17.68014	21.7897	25.14283	28.77821	33.49743
25 min	25	10.59002	13.4351	16.32534	19.39622	23.77674	27.4347	31.31846	36.48928
30 min	30	11.49322	14.54152	17.60111	20.89779	25.49282	29.30884	33.48614	38.98437
45 min	45	13.83025	17.36402	20.95424	24.65736	29.79431	33.9829	38.74728	45.12613
1 hour	60	15.87374	19.92685	23.87835	27.94275	33.45227	37.86666	43.21812	50.31953
1.5 hour	90	19.49783	24.31866	29.02659	33.71194	39.98918	44.86646	51.18886	59.65636
2 hour	120	22.68161	28.32661	33.74581	39.04082	46.00675	51.35821	58.64026	68.29321
3 hour	180	28.43951	35.59737	42.25847	48.71635	57.19514	63.59657	72.60599	84.5621
4.5 hour	270	35.77801	45.06968	53.61621	61.76759	72.50438	80.55415	92.14898	107.2776
6 hour	360	42.13428	53.42428	63.69818	73.55435	86.52656	96.3037	110.2017	128.0738
9 hour	540	52.70172	67.57065	80.99446	93.91022	111.1839	124.5626	142.3782	165.9291
12 hour	720	61.1918	79.12032	95.27631	110.9581	132.4882	148.4861	170.0839	198.5347
18 hour	1080	74.22046	96.76659	117.3257	137.8396	165.4324	187.1882	214.5326	250.0396
24 hour	1440	83.61374	109.5017	133.2785	157.1681	190.0107	216.1245	246.8671	287.6015
30 hour	1800	90.69257	118.9176	145.4152	171.9241	208.4811	237.3384	272.9132	317.9603
36 hour	2160	96.17951	126.1545	154.3343	182.6496	222.2775	253.9234	290.6836	338.7
48 hour	2880	104.0261	136.2026	167.013	197.7218	240.4996	275.1147	312.4395	364.1025
72 hour	4320	113.7693	147.4361	179.7481	213.031	257.9201	294.0142	331.1922	385.7116
96 hour	5760	120.0353	153.4537	186.2511	219.9631	264.6376	300.8785	338.1468	393.7839
120 hour	7200	124.9013	158.2858	190.88	224.163	268.2617	303.7687	342.3354	397.7241
144 hour	8640	129.5415	162.9486	195.4412	227.6854	271.9648	306.2864	344.9547	400.7498
168 hour	10080	134.8252	168.4242	200.4878	232.066	275.6115	310.1928	347.9239	404.0691

APPENDIX

E

HIGH QUALITY REPORT FIGURES

Cardno



Margate Rivulet Hydraulic Assessment

Study Area
Figure 1-2

Legend

Council Pipes

Water Courses/Bodies

Study Area

Hydrological Model Area

Parcels

N

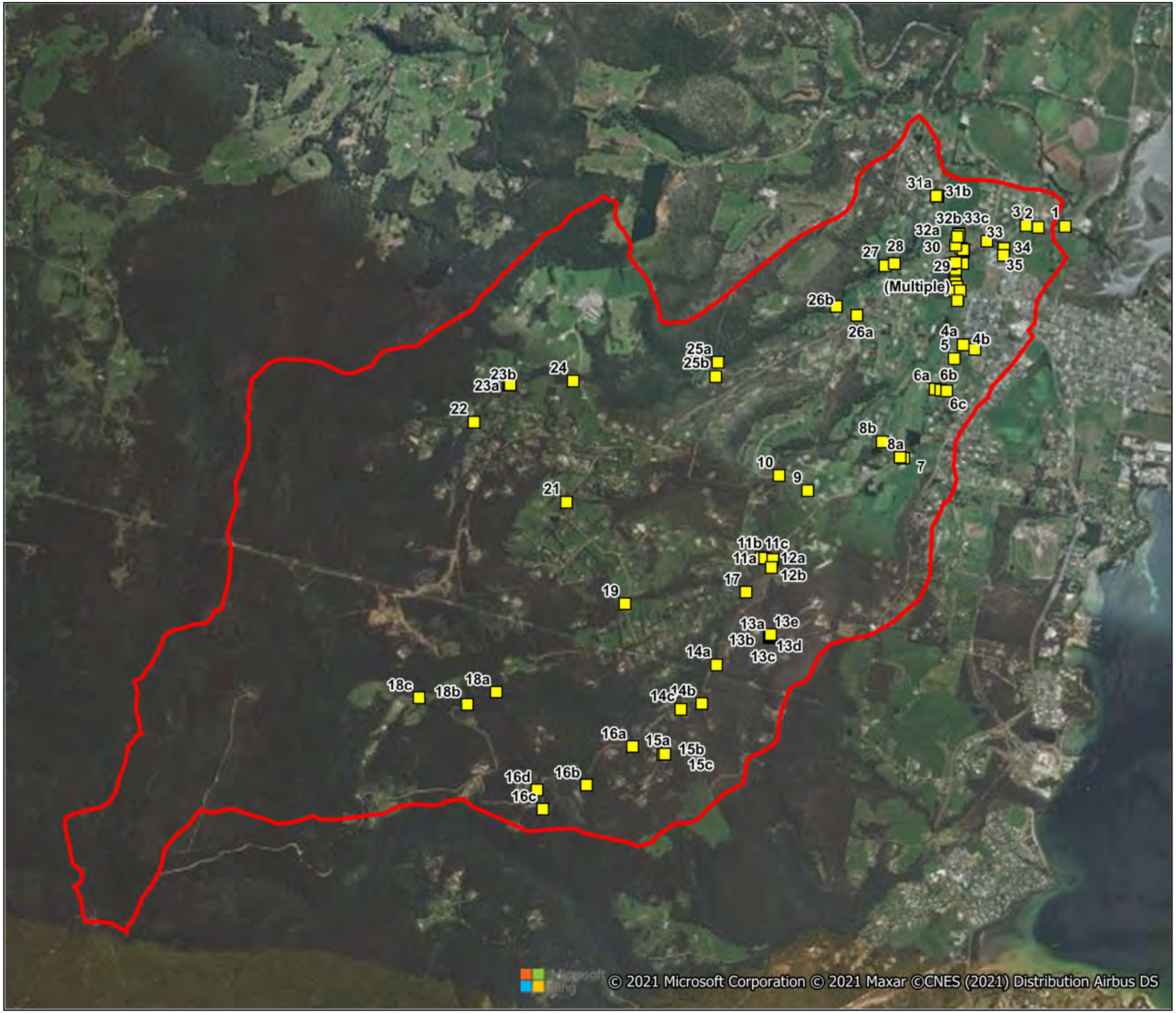
0 1,600

metres

Scale 1:40,000

Cardno

Map Produced by National W&E
Date: 18/08/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map: FinalReport.wor 01



Margate Rivulet Hydraulic Assessment

Site Visit Locations
Figure 2-2

Legend

Site Visit Locations

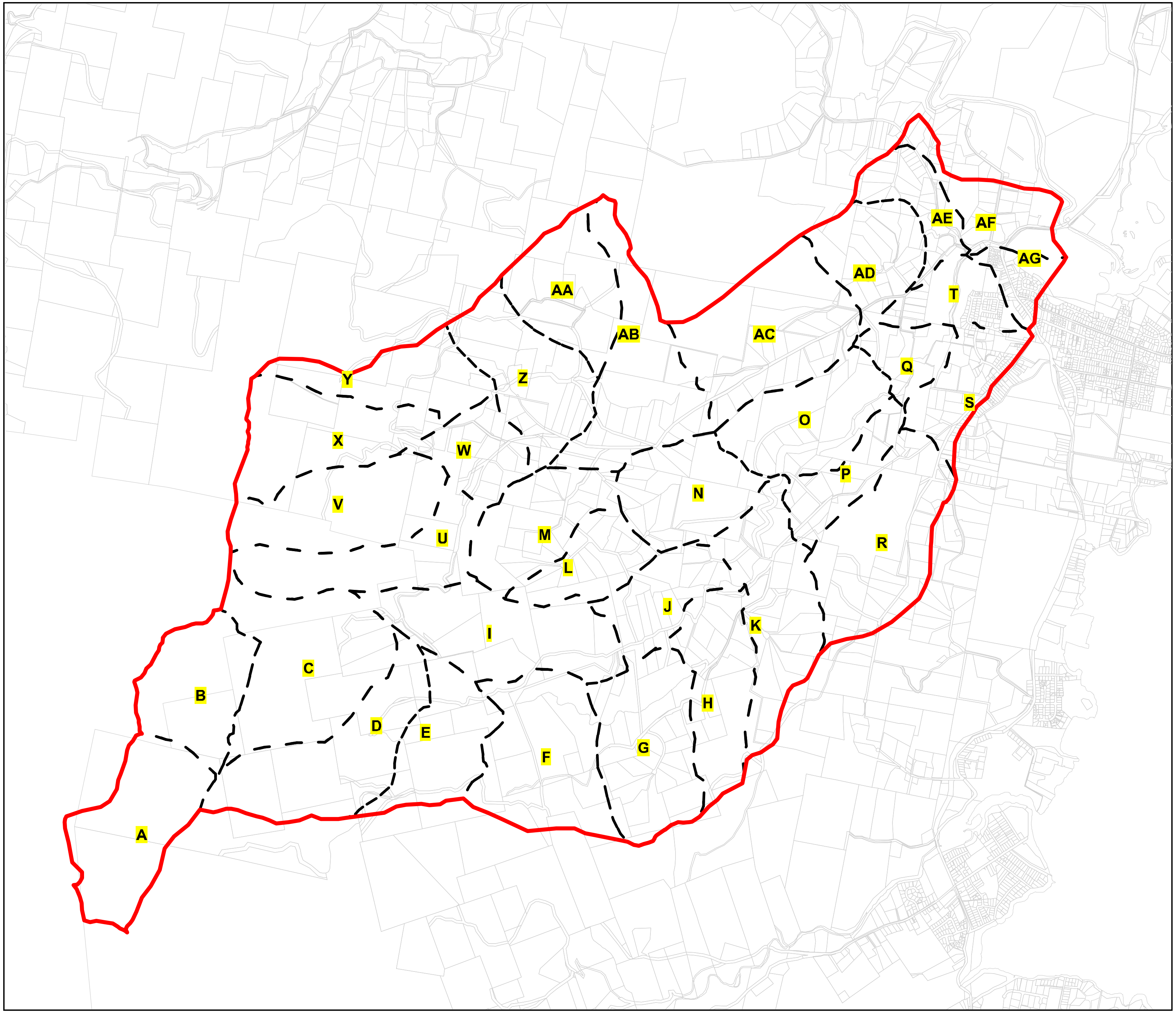
Hydrological Model Area

N

0 1,600
metres
Scale 1:40,000

Cardno

Map Produced by National W&E
Date: 18/08/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map: FinalReport.wor 01



Margate Rivulet Hydraulic Assessment

Hydrological Catchments
Figure 3-1

Legend

Hydrological Model Area

Subcatchments

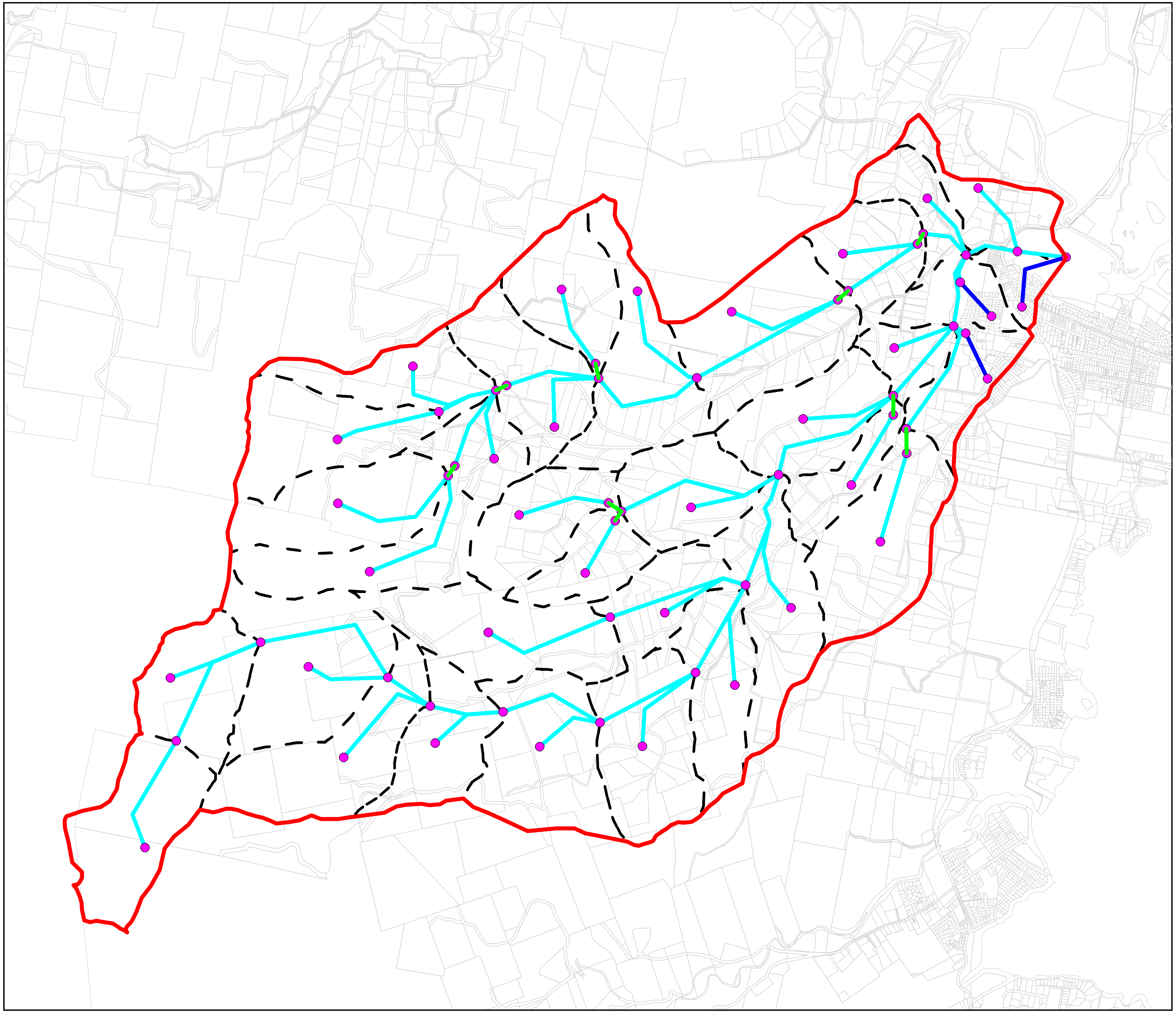
Parcels

N

0 1,600
metres
Scale 1:40,000

Cardno

Map Produced by National W&E
Date: 18/08/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map: FinalReport.wor 01



Margate Rivulet Hydraulic Assessment

Hydrological Model Setup
Figure 3-2

Legend

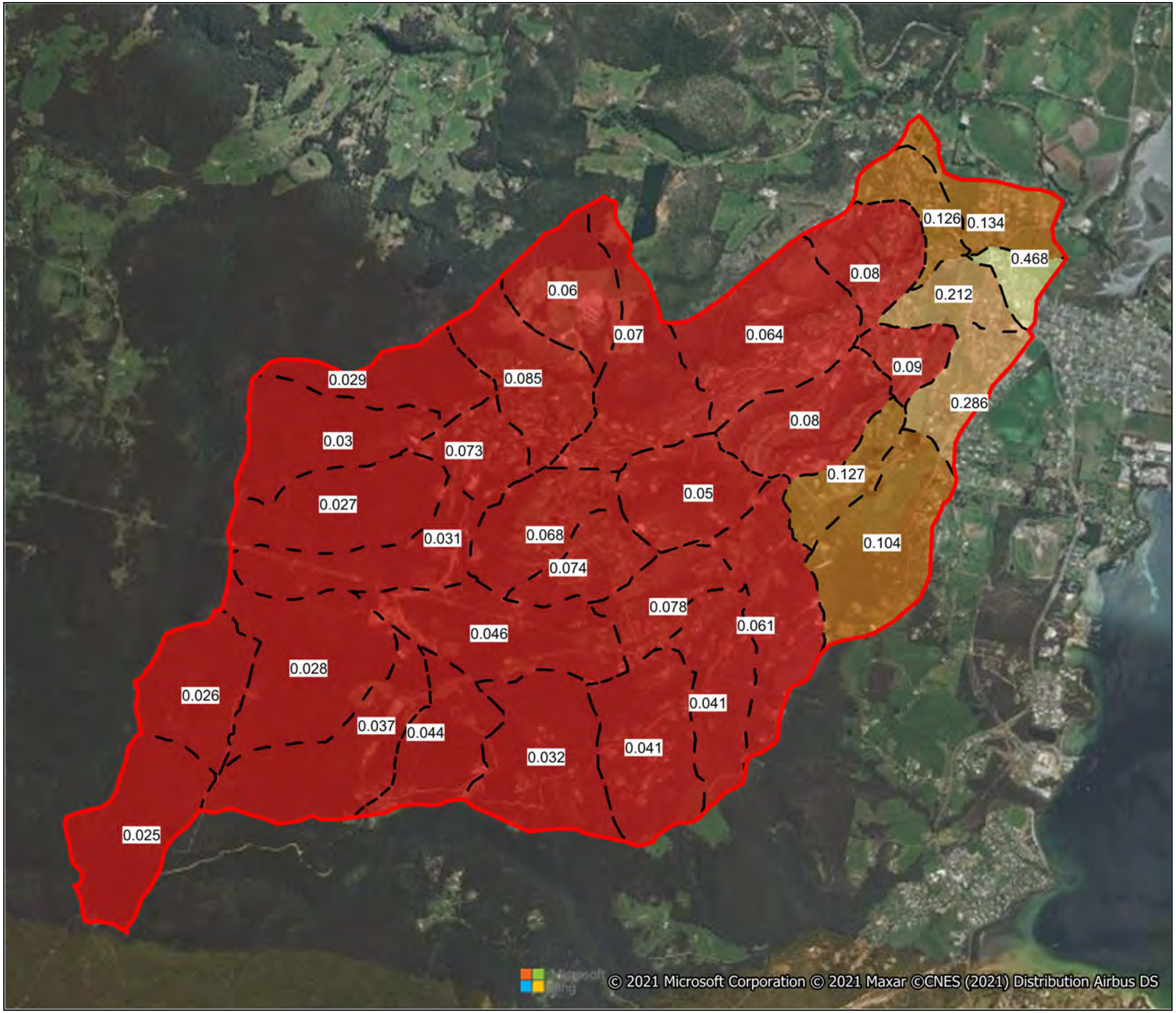
- Node
- Storage
- Hydrological Model Area
- Subcatchments
- Parcels
- Reach Type 1
- Reach Type 2

N

0 1,600
metres
Scale 1:40,000

Cardno

Map Produced by National W&E
Date: 18/08/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map: FinalReport.wor 01



Margate Rivulet Hydraulic Assessment

Effective Impervious Area
Base Case
Figure 3-3

Legend

Hydrological Model Area

Subcatchments

Parcels

Effective Impervious Area

0 to 0.1

0.1 to 0.2

0.2 to 0.3

0.3 to 0.4

0.4 to 0.5

N

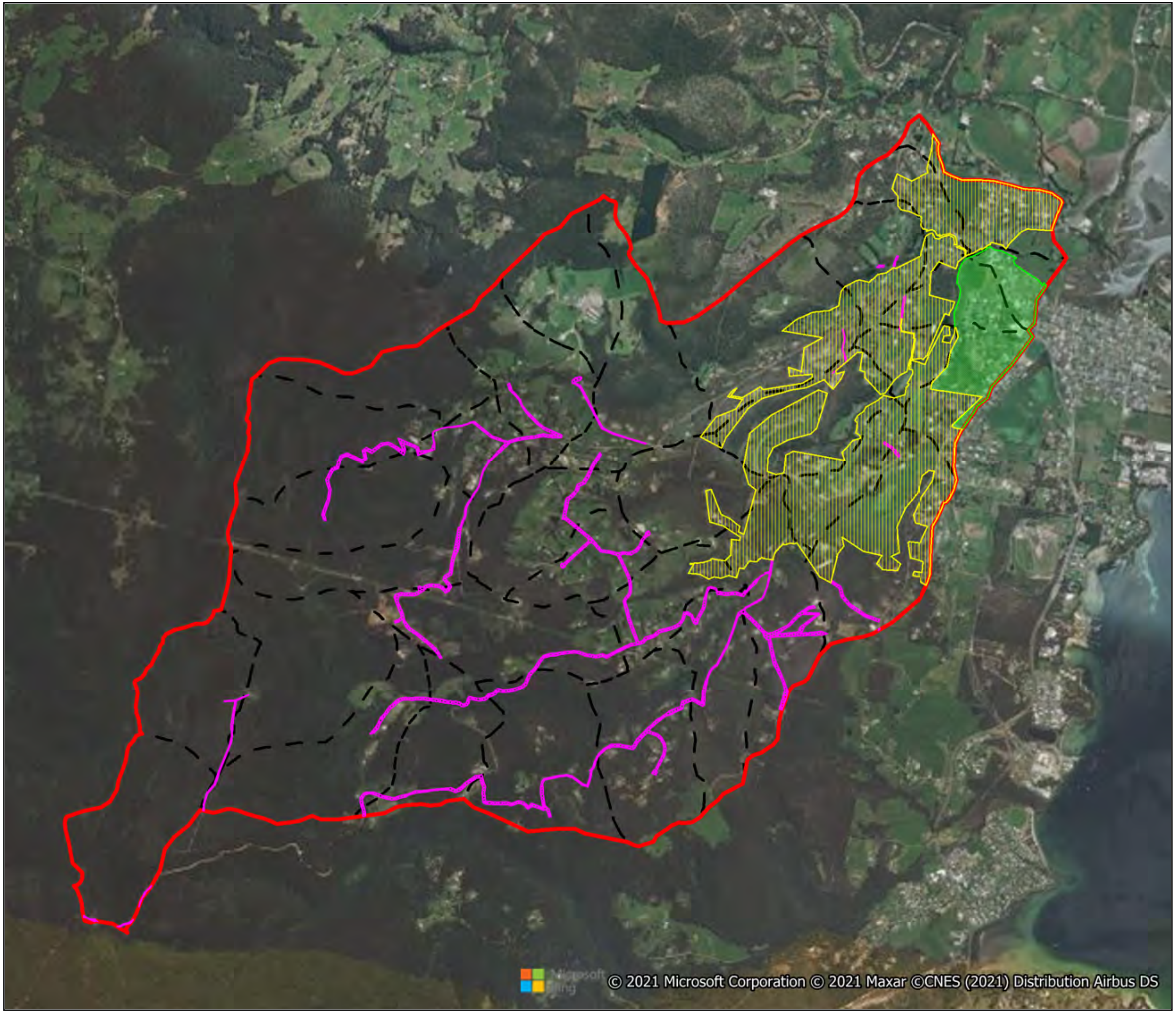
0 1,600

metres

Scale 1:40,000

Cardno

Map Produced by National W&E
Date: 18/08/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map: FinalReport.wor 01



Margate Rivulet Hydraulic Assessment

Effective Impervious Area
Worst Developed Case
Figure 3-4

Legend

- Hydrological Model Area
- Subcatchments
- Parcels

Proposed Changes to Base Case

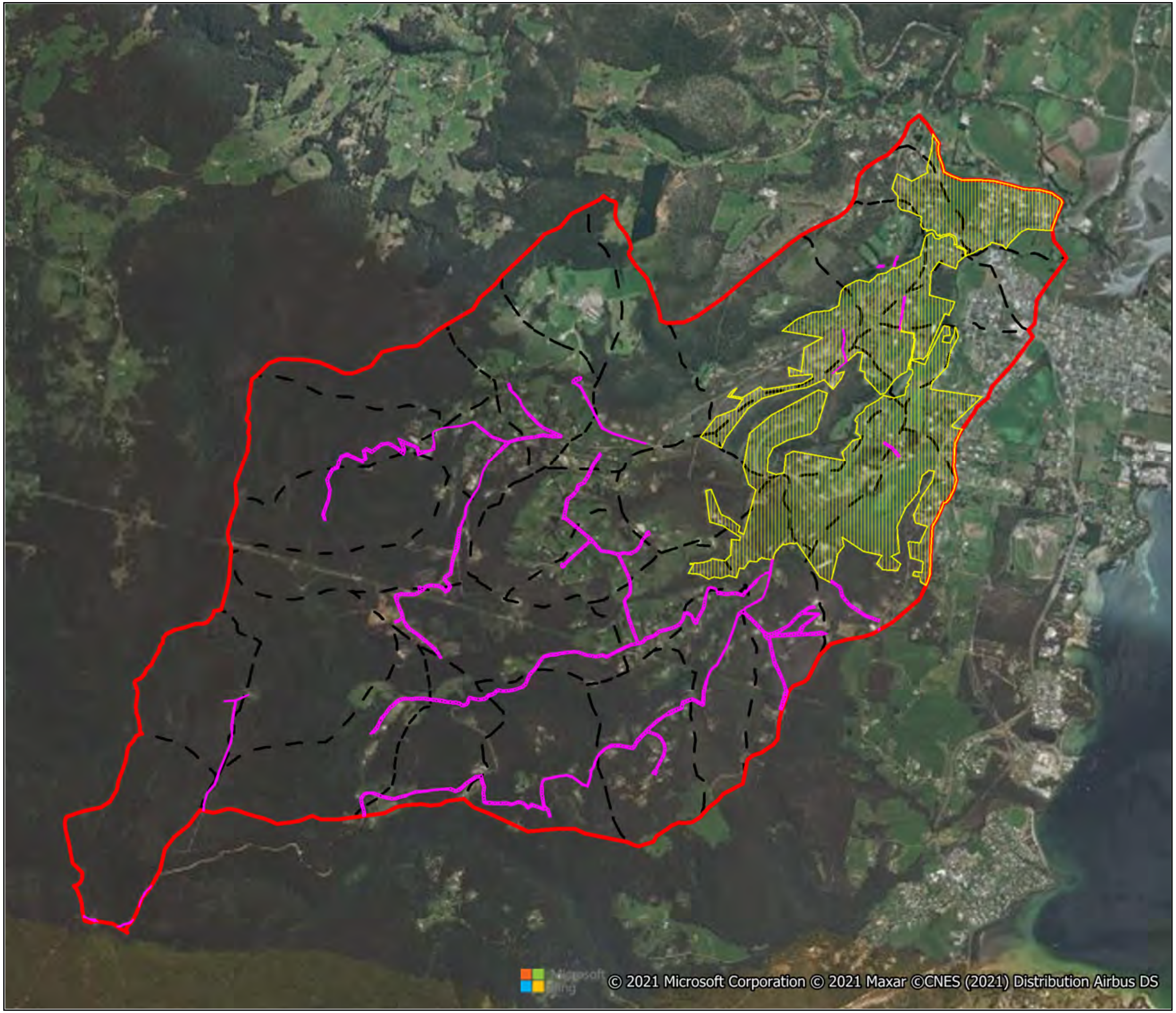
- Increase from Low to Medium/High Density
- Increase to Sealed Roads
- Increase from Rural to Low Density

N

0 1,600
metres
Scale 1:40,000

Cardno

Map Produced by National W&E
Date: 18/08/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map: FinalReport.wor 01



Margate Rivulet Hydraulic Assessment

Effective Impervious Area
Best Developed Case
Figure 3-5

Legend

Hydrological Model Area

Subcatchments

Parcels

Proposed Changes to Base Case

Increase to Sealed Roads

Increase from Rural to Low Density

N

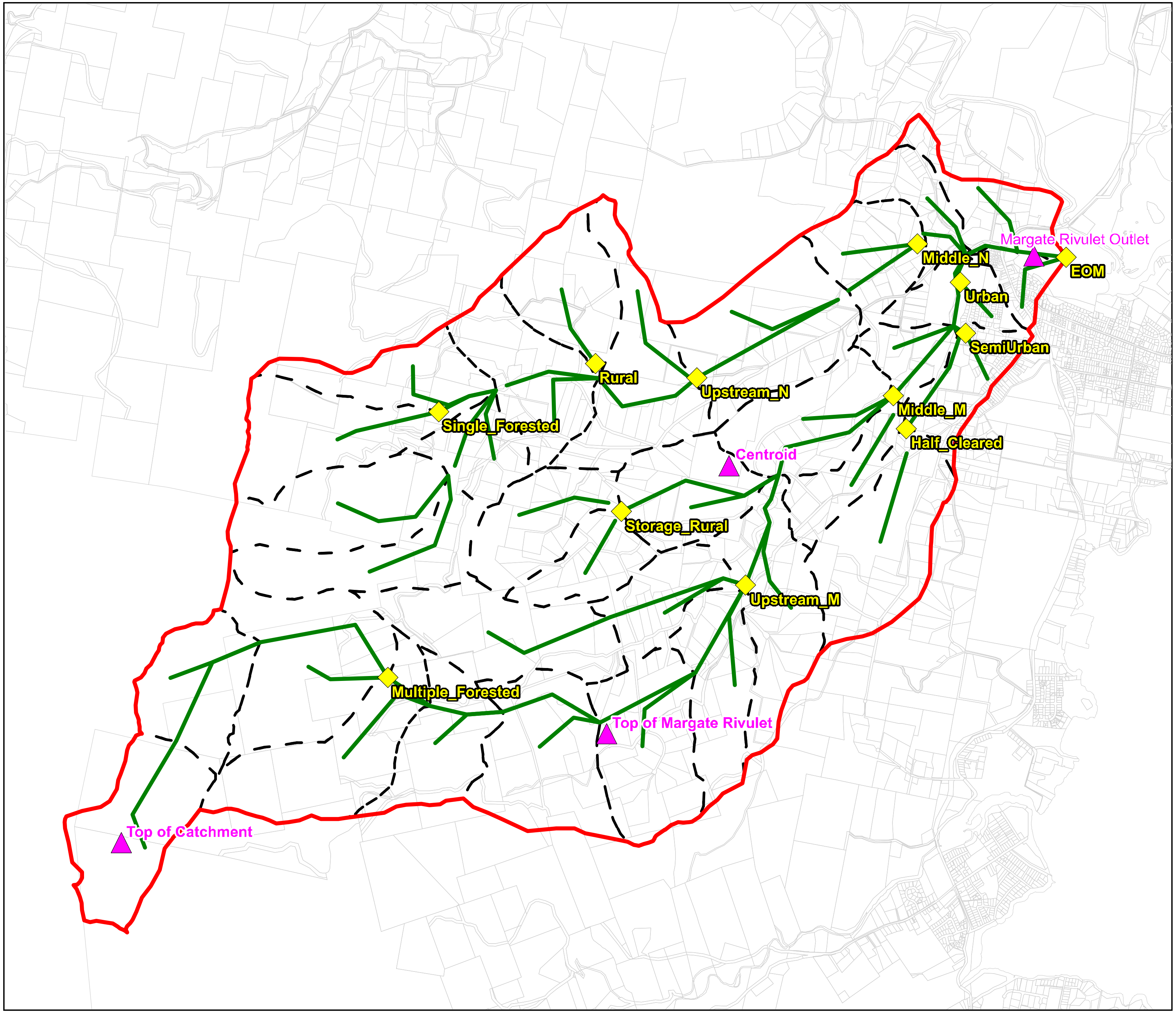
0 1,600

metres

Scale 1:40,000

Cardno

Map Produced by National W&E
Date: 18/08/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map: FinalReport.wor 01



Margate Rivulet Hydraulic Assessment

Hydrological Monte Carlo Print and IFD Locations
Figure 4-1 & 5-5

Legend

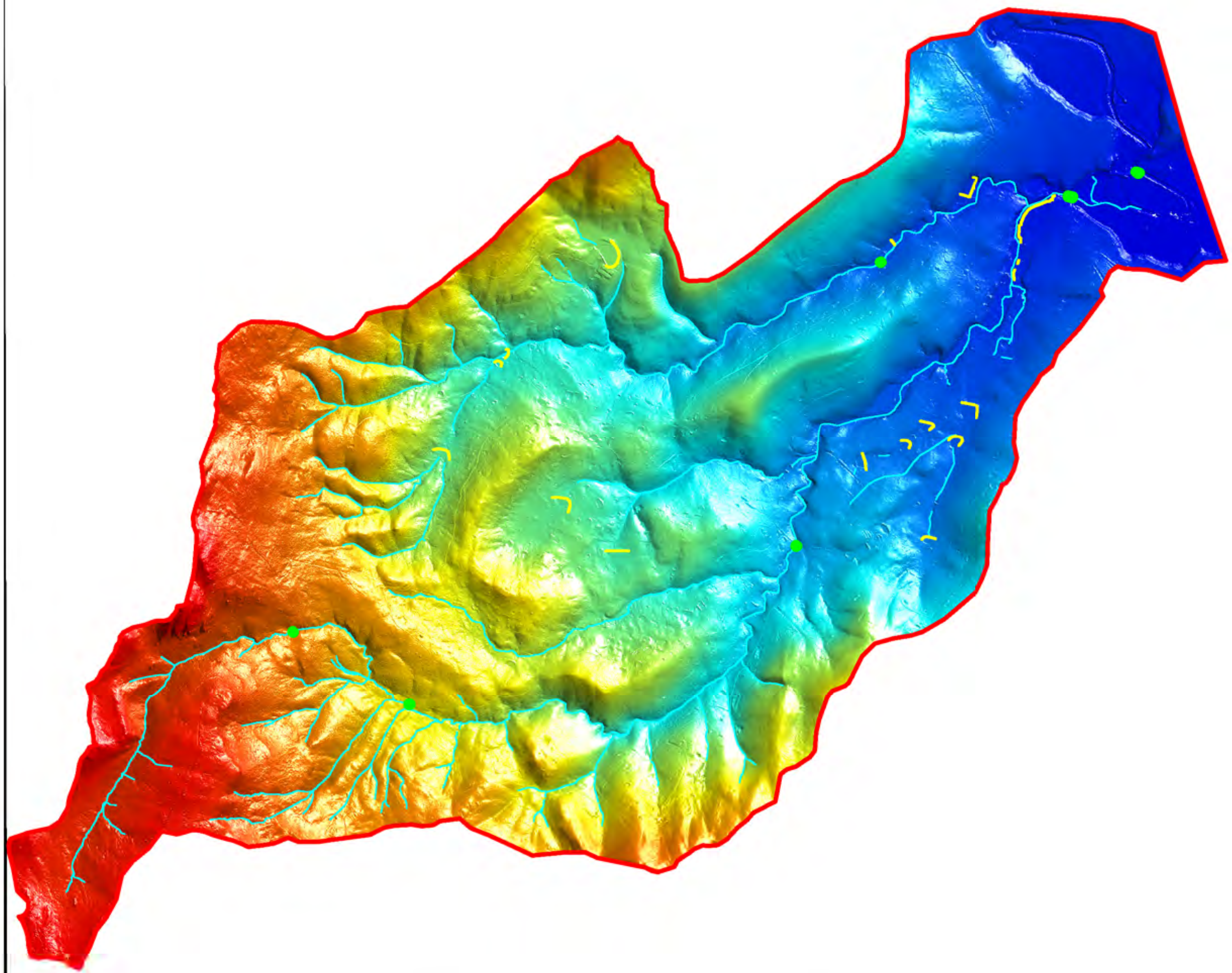
- IFD Locations
- Monte Carlo Print Locations
- Reaches
- Hydrological Model Area
- Subcatchments
- Parcels

N

0 1,600
metres
Scale 1:40,000

Cardno

Map Produced by National W&E
Date: 18/08/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map: FinalReport.wor 01



Margate Rivulet Hydraulic Assessment

Hydraulic Topographical Modifications & Reinforcements
Figure 6-1

Legend

Gully Lines
Ridge Lines
Topographical Modifcations
Hydraulic Model Area

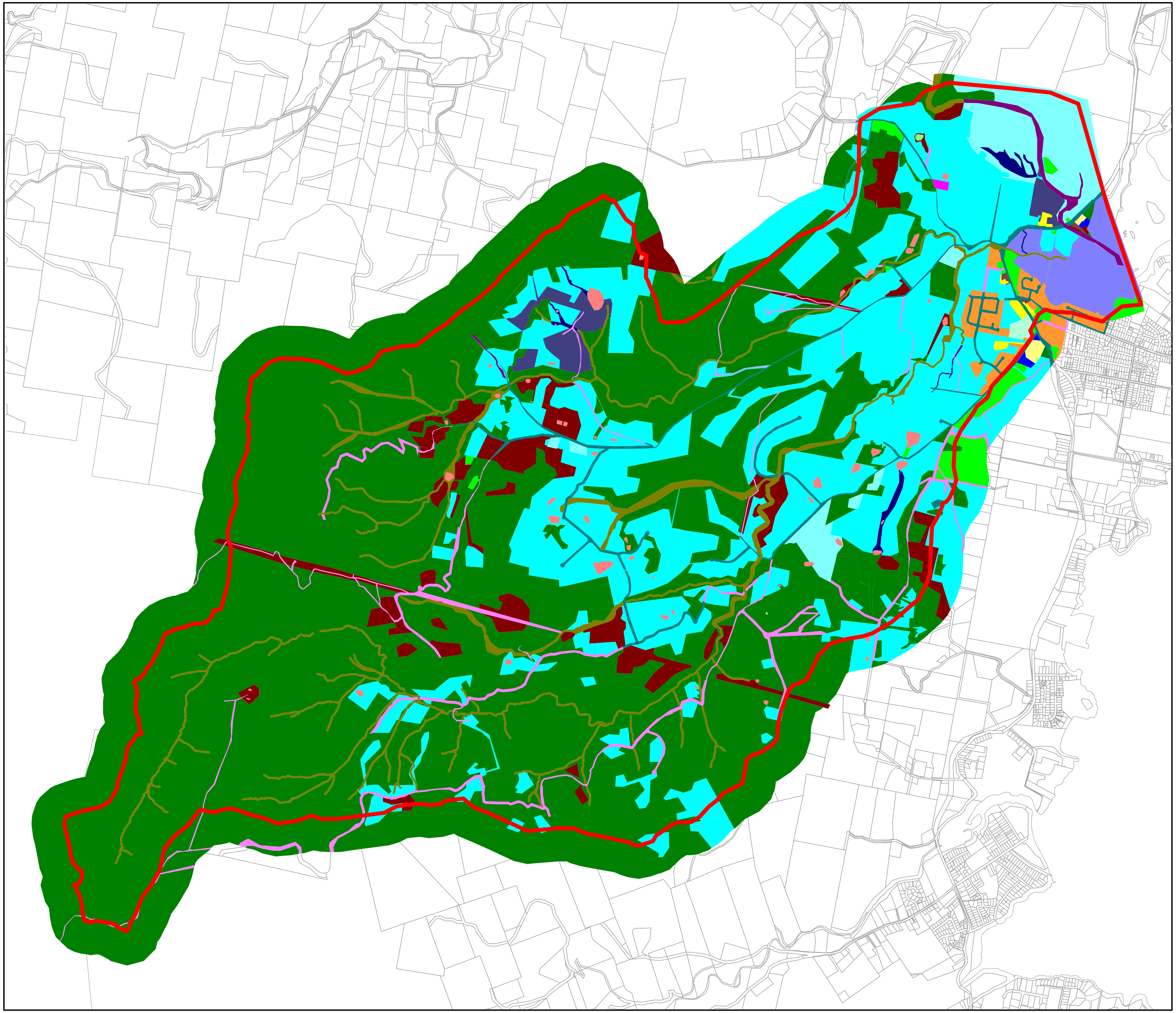
Topography (mAHD)
-0.15 665.6

N

0 1,600
metres
Scale 1:40,000

Cardno

Map Produced by National W&E
Date: 18/08/2021
Coordinate System: MGA Zone 55
Project: NW30106
Map: FinalReport.wor 01



Margate Rivulet Hydraulic Assessment

Hydraulic Manning's 'n' Roughness
Figure 6-2

Legend

Hydraulic Model Area

Roughness

- 1 (Combined - Residential High Density Urban)
- 2 (Combined - Residential Lower Density Rural)
- 5 (Building)
- 6 (Industrial/Cemetery)
- 7 (Commercial)
- 8 (Minimal Grassed Vegetation)
- 9 (Moderate Shrubbed Vegetation)
- 10 (Thick Treed Vegetation)
- 11 (Minimal Vegetation Waterway)
- 12 (Moderate Vegetation Waterway)
- 13 (Heavy Vegeatation Waterway)
- 15 (Paved Roads/Driveways)
- 16 (Lakes - No Emergent Vegetation)
- 17 (Wetlands - Emergent Vegetation)
- 18 (Estuaries or Oceans)
- 21 (Gravelled Surface/Rural Road)
- 22 (Artificial Turf/Handstand Surface)
- 24 (Agriculture or Farmland)
- 25 (Carparks)
- 27 (Education)
- 28 (Agriculture / Farmland with Buildings Combined)

N

0 1,600
metres
Scale 1:40,000

Cardno

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Margate Rivulet Hydraulic Assessment

Hydraulic Layered Flow Constriction Shapes Locations
Figure 6-4

Legend

- Layered Flow Constriction Shapes
- Hydraulic Model Area

N

0 — 1,600 metres

Scale 1:40,000

Cardno

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Margate Rivulet Hydraulic Assessment

1% AEP Flood Extent in the North West River at the Channel Highway
Figure 6-6

Legend

StudyArea

Parcels

1% AEP Flood Extent

N

0 200
metres
Scale 1:6,000

Cardno

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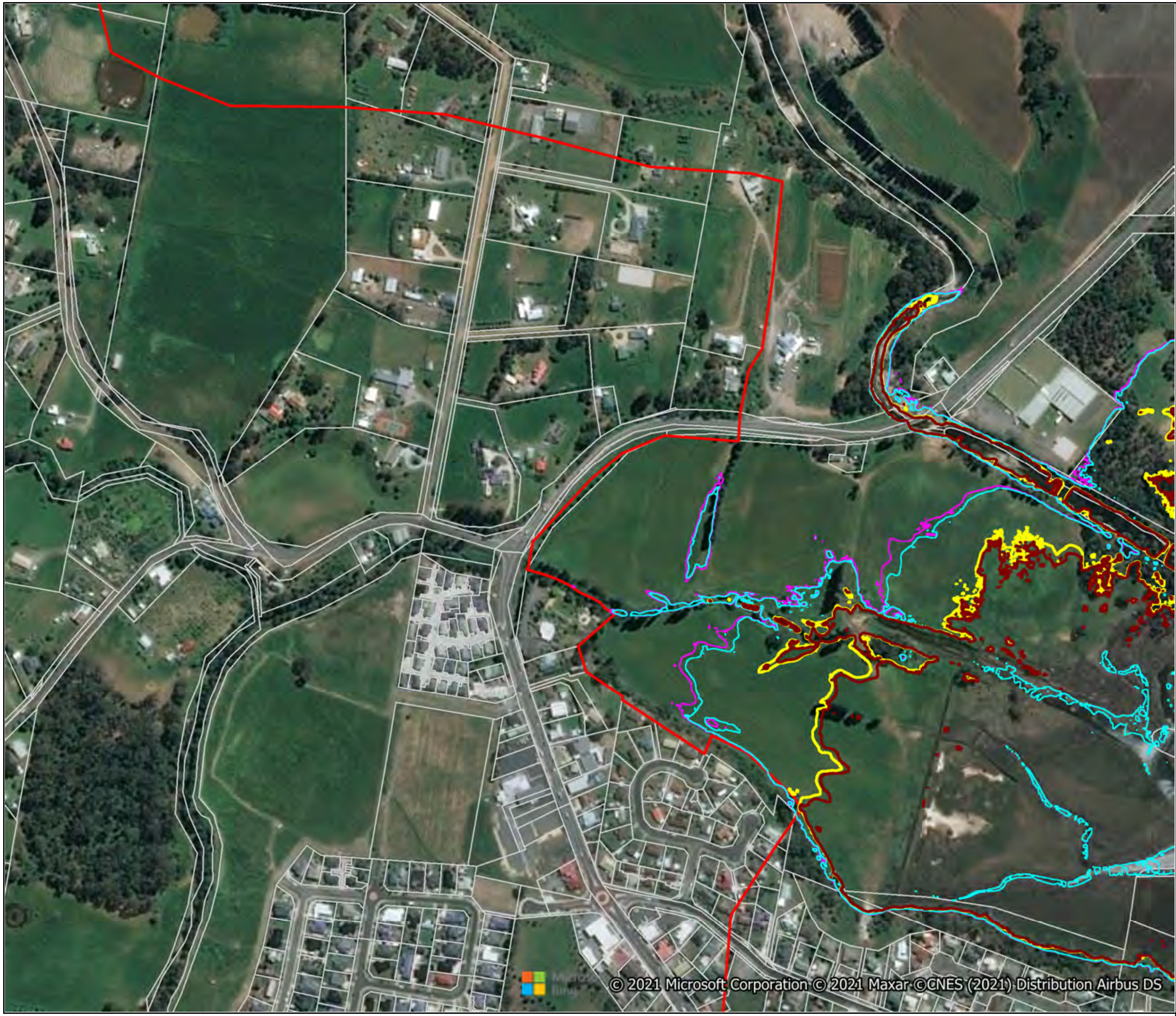

Margate Rivulet Hydraulic Assessment

Peak Nearshore Water Level Contour
Figure 6-8

Legend

StudyArea

Parcels

1.47 mAHD Contour

1.57 mAHD Contour

2.47 mAHD Contour

2.57 mAHD Contour

N

0 200
metres
Scale 1:6,000

Cardno

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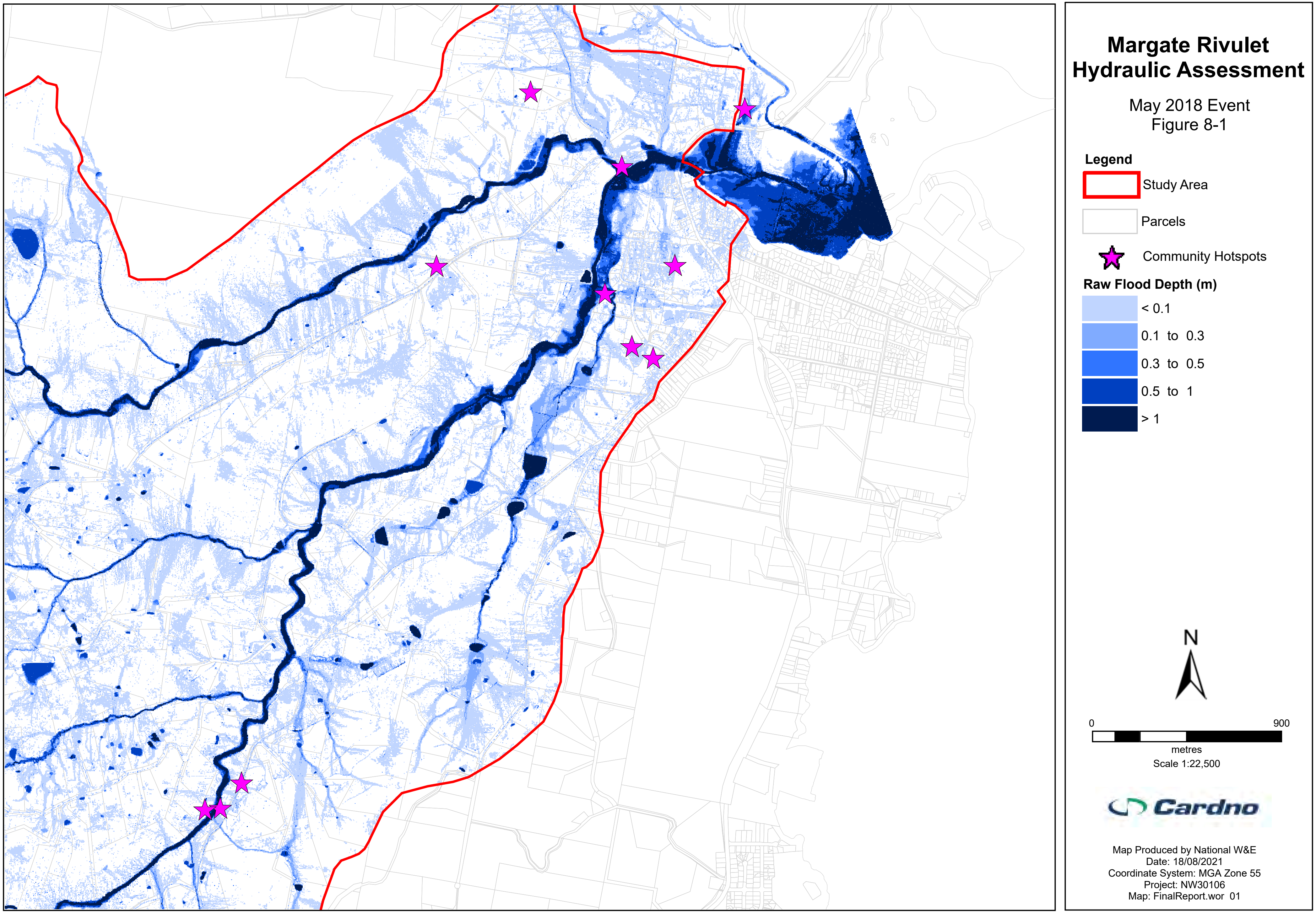
Margate Rivulet
Hydraulic Assessment
May 2018 Event
Figure 8-1
Legend
Study Area
Parcels
Community Hotspots
Raw Flood Depth (m)
< 0.1
0.1 to 0.3
0.3 to 0.5
0.5 to 1
> 1
N
0
900
metres
Scale 1:22,500
Cardno
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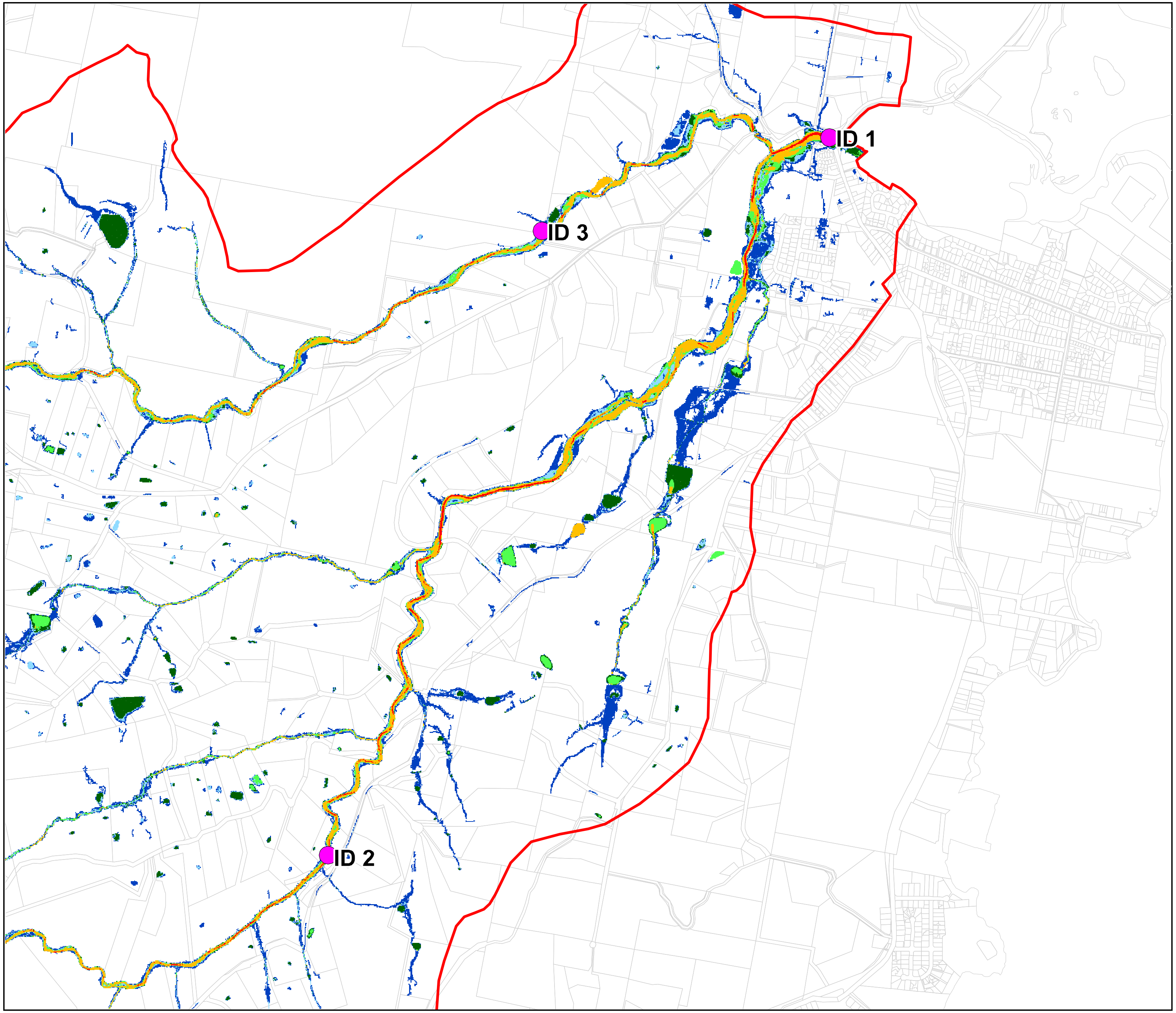

Margate Rivulet Hydraulic Assessment

1% AEP Flood Hazard
Figure 8-3

Legend

Study Area

Parcels

Identified Locations at Risk

Flood Hazard (ARR2019)

H1

H2

H3

H4

H5

H6

N

0 900

metres

Scale 1:22,500

Cardno

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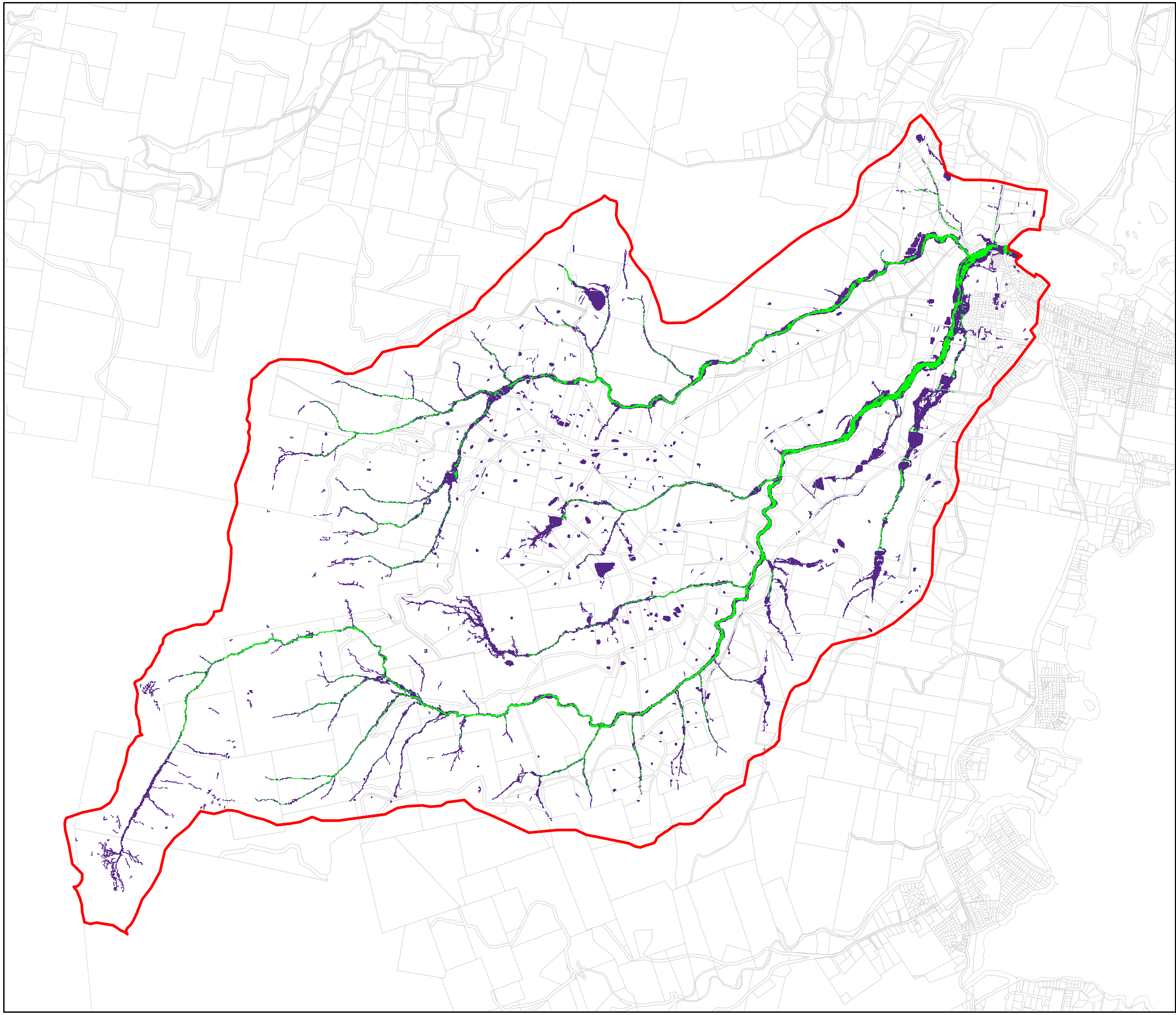

Margate Rivulet Hydraulic Assessment

Velocities in Excess of 1.2m/s
Figure 9-2

Legend

Study Area

Parcels

Flood Velocity (m/s)

< 1.2

> 1.2

N

0 1,600

metres

Scale 1:40,000

Cardno

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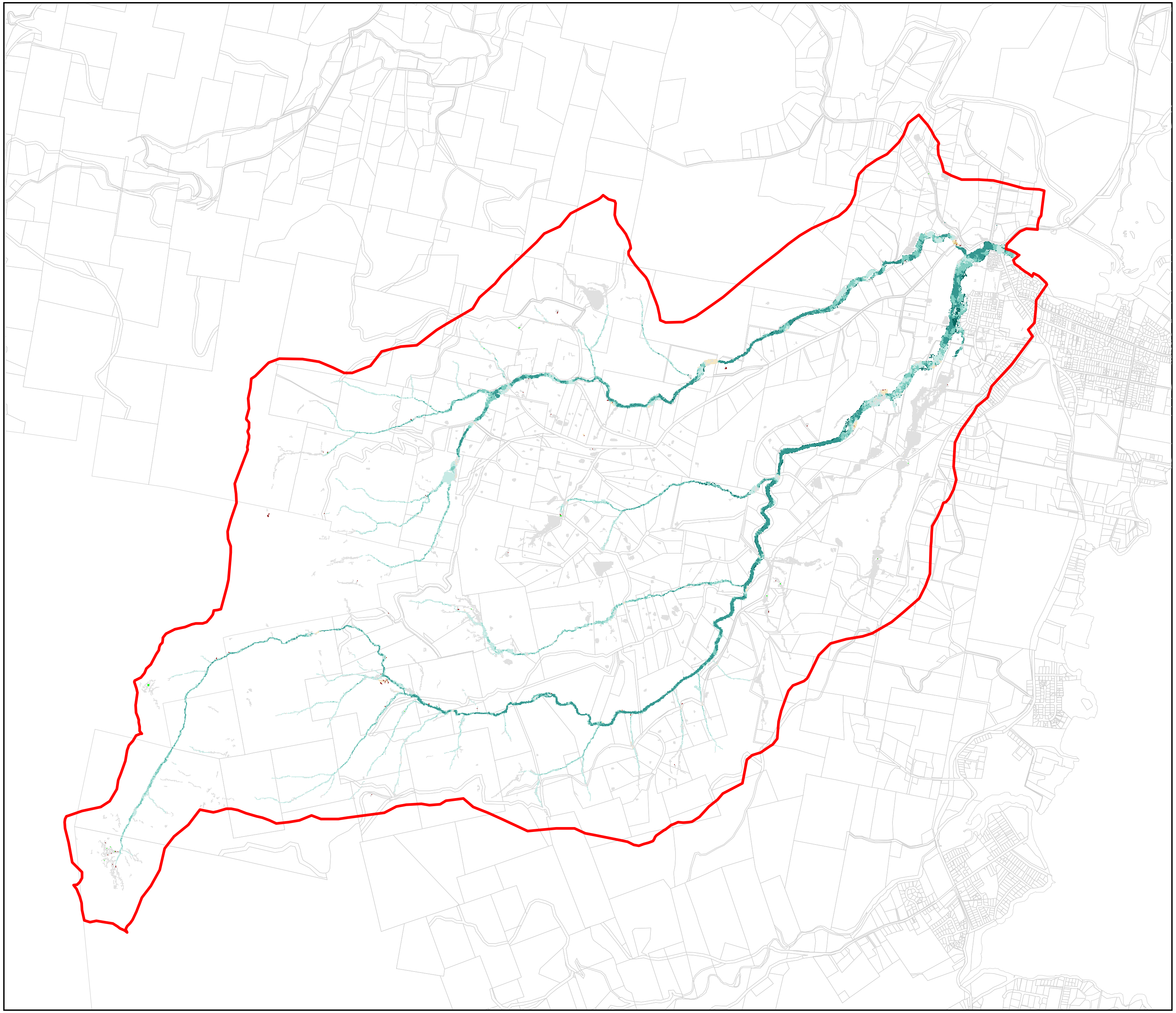

Margate Rivulet Hydraulic Assessment

High Level Vegetation Assessment
Figure 9-3

Legend

Study Area

Parcels

Change In Flood Level (m)

Was Wet Now Dry
< -0.5
-0.5 to -0.1
-0.1 to -0.05
-0.05 to -0.01
-0.01 to 0.01
0.01 to 0.05
0.05 to 0.1
0.1 to 0.5
> 0.5
Was Dry Now Wet

N

0 1,600
metres
Scale 1:40,000

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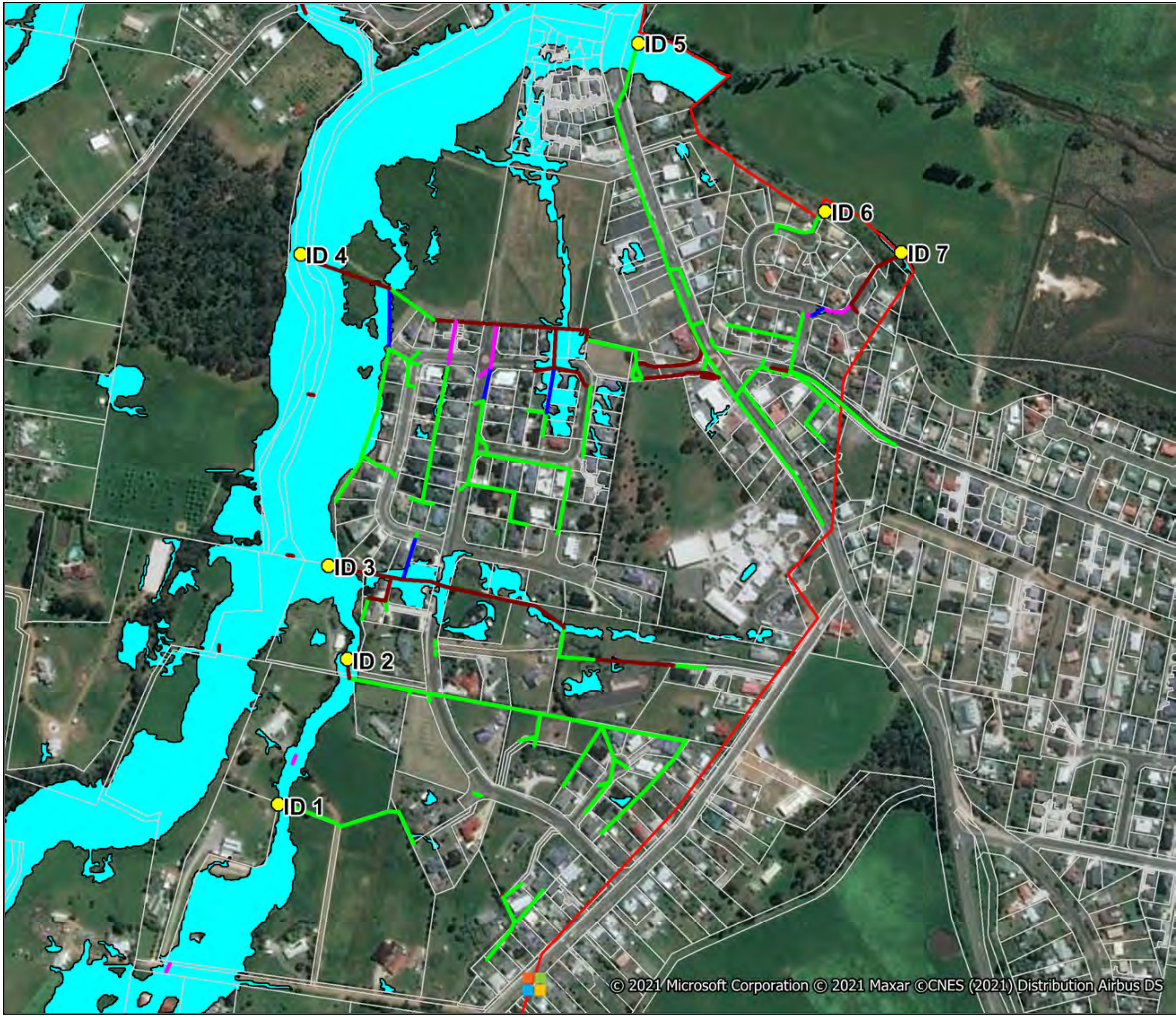

Margate Rivulet Hydraulic Assessment

Level of Service
Figure 9-4

Legend

- Study Area
- Identified Discharge Locations
- Parcels

Level of Service

- <=20yr
- 20yr-100yr
- 100yr-200yr
- >200yr
- 0.5% AEP Flood Extent

N

0 200
metres
Scale 1:6,000

Cardno

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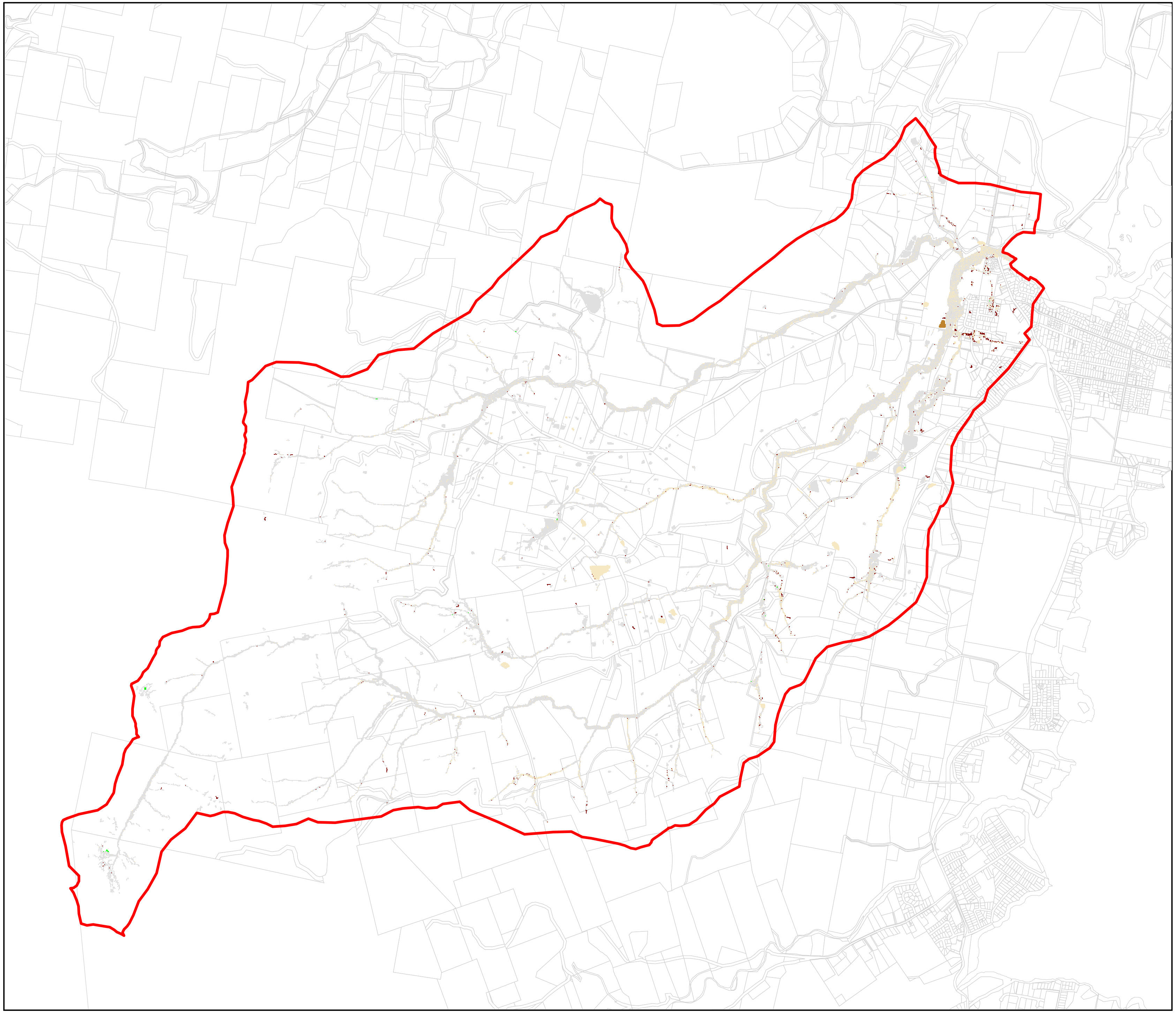

Margate Rivulet Hydraulic Assessment

Worst Case Development Assessment
Figure 9-5

Legend

Study Area

Parcels

Change In Flood Level (m)

Was Wet Now Dry
< -0.5
-0.5 to -0.1
-0.1 to -0.05
-0.05 to -0.01
-0.01 to 0.01
0.01 to 0.05
0.05 to 0.1
0.1 to 0.5
> 0.5
Was Dry Now Wet

N

0 1,600
metres
Scale 1:40,000

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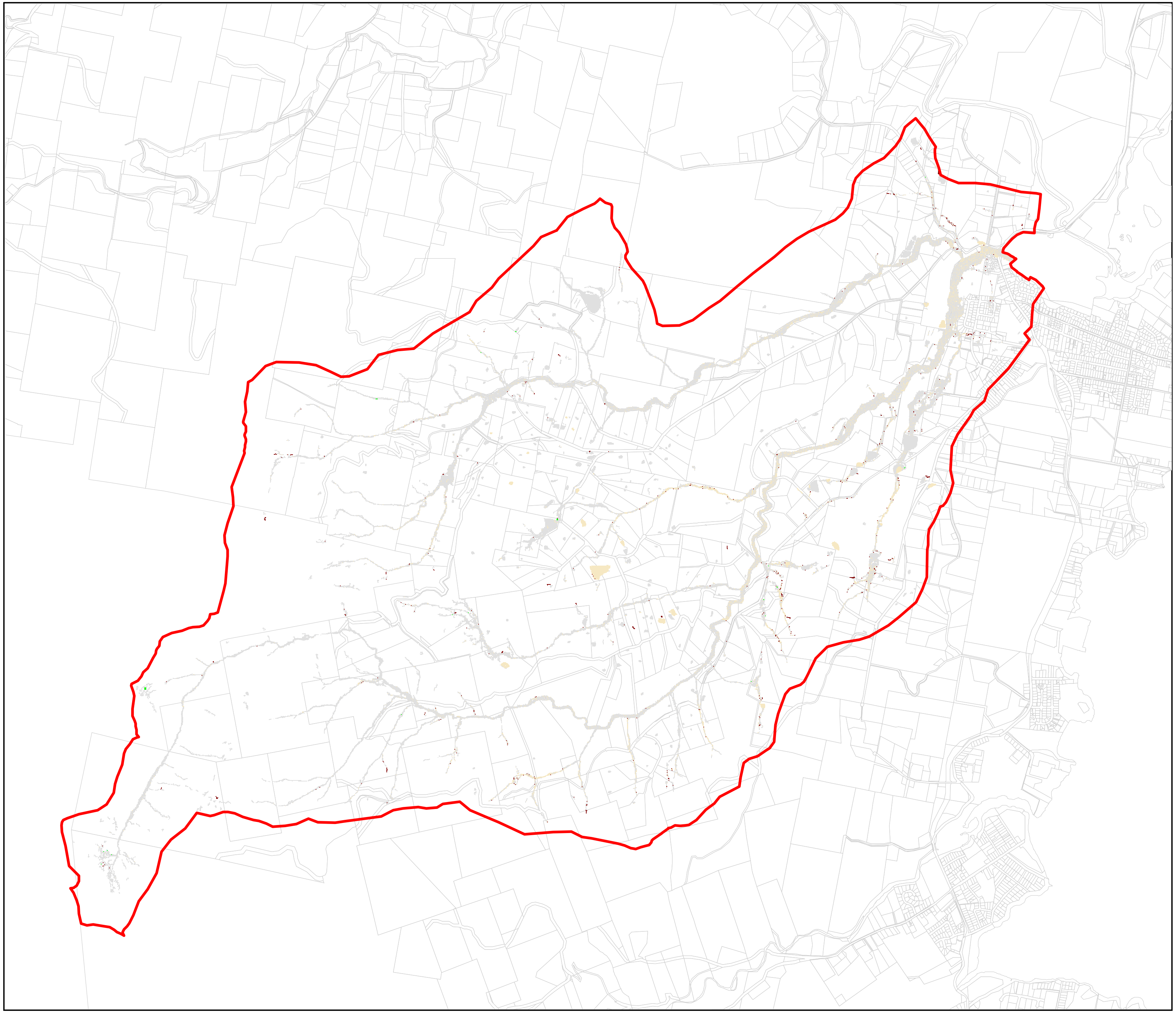

Margate Rivulet Hydraulic Assessment

Best Case Development Assessment
Figure 9-6

Legend

Study Area

Parcels

Change In Flood Level (m)

Was Wet Now Dry
< -0.5
-0.5 to -0.1
-0.1 to -0.05
-0.05 to -0.01
-0.01 to 0.01
0.01 to 0.05
0.05 to 0.1
0.1 to 0.5
> 0.5
Was Dry Now Wet

N

0 1,600
metres

Cardno

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Coordinate System: MGA Zone 55
Project: NW30106
Map: FinalReport.wor 01