6.3 Public exhibition

Hawkesbury City Council placed the Draft Flood Study Report on public exhibition for 60 days, from 2 December 2024 to 30 January 2025, to gather feedback from the community. Property owners and local residents were invited to participate by attending a public meeting and submitting formal comments for consideration. The following sections outline the details of the public meeting and the key takeaways from the community submissions.

6.3.1 Public Meeting

A public meeting was held by the Council on the evening of Wednesday, 11 December 2024, providing an opportunity for community members to ask questions about the flood study and share their experiences with flooding in the Redbank Creek catchment. A total of 34 community members attended the session. Feedback from attendees highlighted concerns about the impact of urban development on the creek's hydrology, with residents attributing increased erosion, property damage, and habitat disruption to stormwater runoff from the Redbank estate. Additional concerns included debris accumulation, a lack of flood markers, stormwater infrastructure failures, and reports of sewer system overflows during flood events.

6.3.2 Community submissions

Residents were also encouraged to submit formal feedback to the Council. A total of seven formal submissions were received. Three submissions provided anecdotal accounts, photos, and videos of the March 2022 flood event, which were instrumental in validating the flood model. Four submissions emphasised the need for further flood risk management studies and planning to mitigate flood risks in the catchment.

The Redbank Creek Flood Study has been conducted in accordance with the NSW State Government's Flood Prone Land Policy, focusing on data collection and flood behaviour analysis under the existing catchment conditions. This study forms the foundation for future flood risk management planning but does not include an impact assessment of specific developments. The results will inform future planning efforts, ensuring that community concerns and flood risks are addressed in the broader flood risk management framework.

7 Hydrologic analysis

Hydrologic modelling consists of determining the volume of water and the flows generated in a catchment based on various parameters including rainfall, catchment area, percentage of the ground that is pervious (such as grass or bare earth for example) or impervious (such as concrete or roads) and the typical lag coefficient (which defines the time the flood water takes to travel through the catchment).

7.1 Model selection

The hydrological model selected for this study is WBNM (version 2017). This version of the model was developed to include the 2016 Intensity-Frequency-Duration (IFD) diagrams that are part of the ARR 2019 guideline requirements.

7.2 Model setup

7.2.1 Catchment delineation

Redbank Creek catchment extends from Grose Vale Road in the south and west, Bells Line of Road and the western extent of Kurmond Road in the north, down to the Hawkesbury River in the southeast and some natural high ground between Kurmond Road and the Hawkesbury River in the east. The sub-catchments were delineated using CatchmentSIM version 3.6 covering the area of approximately 27 km^2. This software was specifically developed to identify how sub-catchments are connected and determine the surface characteristics of each sub-catchment such as area and percentage impervious. The catchment was divided into 170 sub-catchments, delineated based on a 5 m DEM developed from the available 2019 LiDAR dataset shown on **Figure 7.1.**

7.2.2 Model parameters

Parameters required by the WBNM model include sub-catchment area and linkage, pervious and impervious percentage, runoff lag factor, stream routing lag factor, rainfall input, initial losses and continuing losses. Key parameters are described in the following sections.

7.2.2.1 Impervious areas

Impervious areas were derived by adopting impervious percentages for various land cover developed by Geoscape Australia in December 2022 obtained from the Department of Climate Change, Energy, the Environment and Water (DCCEEW). The land cover map with resolution of 2 m were utilised in the present study. Based on land cover areas, a weighted average was calculated for each sub-catchment. The building footprints, roadway corridors and water bodies / basins were assumed to be 100% impervious while the rest of rural areas were assumed to be pervious. The impervious fraction for urban areas also considered the increased imperviousness associated with driveways, sheds, and other paved areas. **Table 7.1** summarises the percentage imperviousness used for each sub-catchment.

Table 7.1 Adopted percentage impervious for each sub-catchment

Sub-catchment	Area (ha)	% Impervious	Sub-catchment	Area (ha)	% Impervious	Sub-catchment	Area (ha)	% Impervious
1	11.0	2.5	58	15.1	4.2	115	21.5	5.0
2	21.2	5.9	59	16.1	5.4	116	19.7	51.8
3	15.2	9.6	60	27.8	17.0	117	15.0	9.8
4	18.2	0.8	61	15.2	11.7	118	22.5	55.7
5	15.8	22.3	62	15.4	1.0	119	15.1	8.1
6	15.1	8.1	63	16.8	8.4	120	16.0	48.7
7	15.1	3.1	64	15.1	6.7	121	18.3	22.0
8	15.1	5.0	65	15.2	7.8	122	15.3	41.9
9	15.3	4.5	66	16.0	7.8	123	15.0	54.5
10	20.0	2.0	67	14.9	7.8	124	15.1	13.1
11	17.5	10.9	68	15.6	6.8	125	2.9	7.5
12	17.3	4.5	69	16.1	4.7	126	8.3	4.5
13	15.6	5.8	70	16.9	13.9	127	16.9	21.2
14	15.0	2.7	71	17.5	4.7	128	15.2	4.7
15	15.1	0.0	72	19.3	4.3	129	16.1	14.9
16	15.4	1.8	73	15.6	3.6	130	15.3	9.9
17	15.8	4.1	74	17.9	7.4	131	15.0	5.5
18	15.4	4.4	75	17.9	26.7	132	21.2	6.5
19	15.1	5.7	76	15.9	8.4	133	15.0	28.9
20	20.0	8.9	77	15.2	5.8	134	17.4	5.9
21	17.8	10.3	78	14.9	12.2	135	15.4	6.8
22	25.5	6.0	79	15.1	6.2	136	16.1	18.0
23	14.9	5.6	80	23.5	7.5	137	8.7	5.2
24	17.9	12.6	81	15.3	31.2	138	15.2	5.1
25	12.1	13.5	82	15.5	5.4	139	15.0	11.5
26	14.9	10.2	83	16.1	3.5	140	15.1	8.9
27	15.4	1.0	84	19.3	7.6	141	24.7	5.1
28	15.5	10.7	85	15.0	2.3	142	25.9	7.3
29	17.3	3.5	86	15.0	14.1	143	15.2	8.3
30	15.3	2.8	87	17.6	10.4	144	16.5	5.1
31	15.1	6.4	88	22.6	24.1	145	14.9	23.6

Sub-catchment	Area (ha)	% Impervious	Sub-catchment	Area (ha)	% Impervious	Sub-catchment	Area (ha)	% Impervious
32	15.1	9.1	89	15.1	8.8	146	16.4	7.5
33	15.3	5.2	90	15.0	21.1	147	15.1	2.7
34	15.1	3.8	91	14.9	4.1	148	15.2	3.8
35	21.4	5.9	92	15.5	17.7	149	5.2	0.5
36	24.3	5.6	93	15.2	10.3	150	19.3	8.0
37	20.8	1.9	94	15.1	6.4	151	15.0	7.5
38	7.9	8.3	95	15.3	6.3	152	15.0	7.5
39	20.5	6.1	96	17.8	8.5	153	19.9	3.8
40	15.2	4.9	97	15.9	0.5	154	16.0	1.3
41	15.1	8.1	98	17.0	7.8	155	16.1	8.6
42	15.0	6.0	99	21.8	11.9	156	15.7	2.9
43	19.4	6.5	100	15.5	8.7	157	20.6	5.0
44	19.5	5.5	101	16.6	51.3	158	15.3	2.6
45	15.2	2.4	102	15.2	48.8	159	6.0	16.6
46	15.3	1.7	103	17.7	5.2	160	4.8	2.5
47	15.6	6.6	104	17.9	63.9	161	2.9	7.0
48	6.7	2.3	105	15.9	49.0	162	3.2	10.7
49	15.2	3.4	106	23.4	5.9	163	11.5	7.9
50	24.9	2.4	107	17.9	49.3	164	9.9	13.2
51	15.1	2.3	108	15.0	5.6	165	7.6	7.4
52	15.7	8.9	109	15.7	4.5	166	6.4	44.3
53	16.3	7.5	110	15.1	9.1	167	4.2	24.5
54	24.3	5.3	111	15.1	9.5	168	9.9	11.1
55	16.1	5.6	112	15.2	3.2	169	6.3	5.1
56	15.1	3.1	113	15.7	60.8	170	8.5	11.2
57	17.4	9.2	114	19.4	5.8	-	-	-

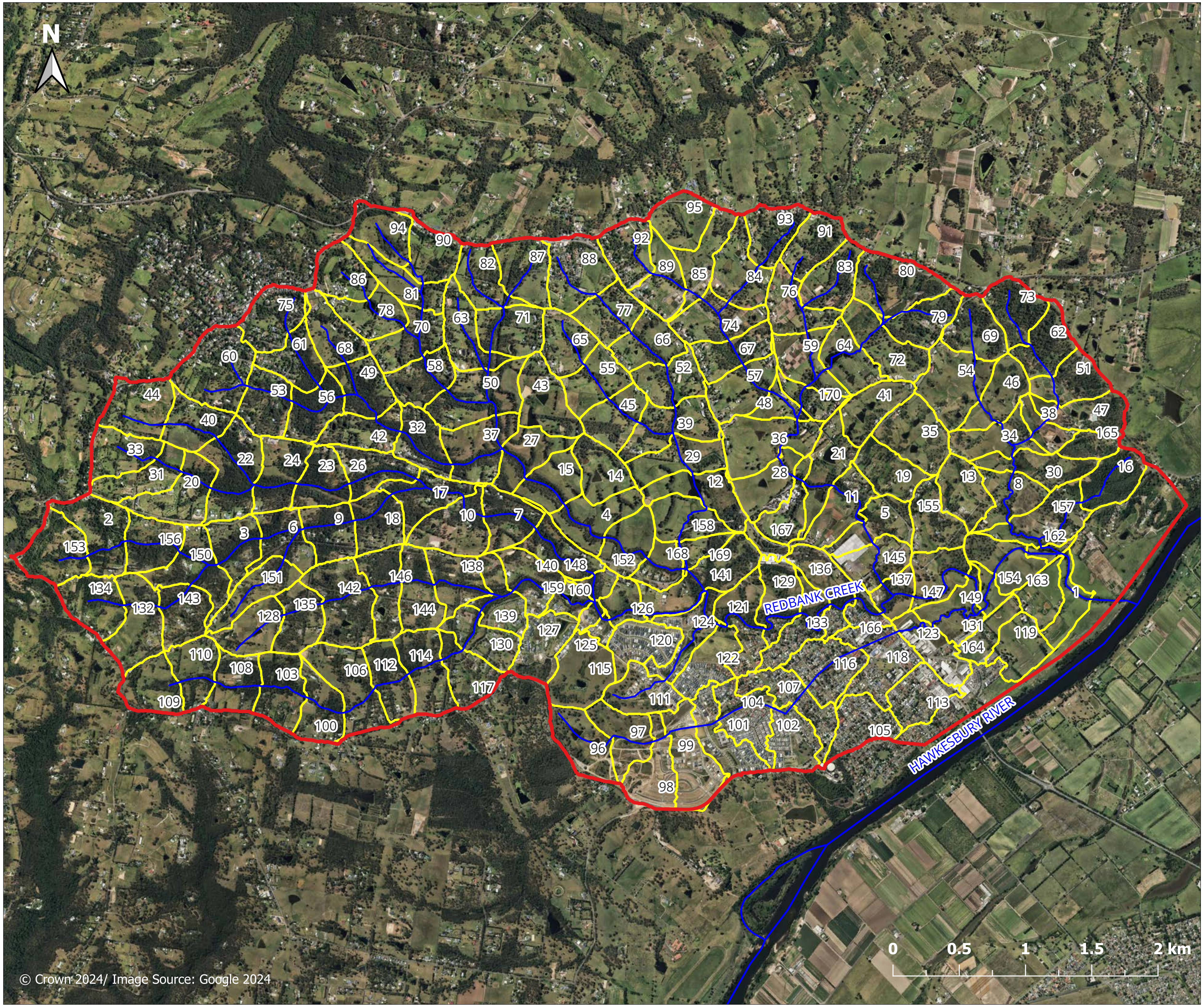

Figure 7.1

Hydrologic model catchment delineation

Legend

- Study area
- Subcatchment boundary
- Watercourses

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7.2.2.2 Rainfall losses

In compliance with the Floodplain Risk Management Guide Incorporating 2016 Australian Rainfall and Runoff in studies (OEH, 2019), a hierarchical method was implemented to ascertain rainfall losses and pre-burst estimation. This approach prioritises utilising the average calibration losses from the specific catchment if available, yet due to the absence of gauges within the current study area, this option was not feasible. Consequently, following the hierarchical method, the second preferred approach involved employing the average calibration losses from other studies in the catchment, if available and appropriate for the study. As a result, rainfall losses were sourced from the Hawkesbury-Nepean River Flood Study Technical Volume 7 (Rhelm and Catchment Simulation Solutions, 2024).

As part of the Hawkesbury-Nepean River Flood Study Technical Volume 7 (Rhelm and Catchment Simulation Solutions, 2024), WMA water was commissioned to carry out a Monte Carlo framework generating thousands of potential events to replicate the variability of actual floods in the Hawkesbury-Nepean Valley. **Table 7.2** summarises the initial and continuing loss values applied in the study. According to the Floodplain Risk Management Guide Incorporating 2016 Australian Rainfall and Runoff in studies (OEH, 2019), it is recommended to utilise the probability neutral burst initial loss values from the ARR data Hub for catchments in NSW unless a detailed Monte Carlo assessment of pre-burst and losses has been conducted. The initial loss value of 30 mm was a median value drawn from a standardised ARR loss distribution curve. The continuing loss values were derived from a calibration parameter. A summary of the adopted rainfall losses on pervious surfaces is provided in **Table 7.2**. Additionally, initial and continuing losses of 1.0 mm and 0.0 mm/hr, respectively, were adopted on impervious surfaces for all events excluding the PMF event. No losses were attributed to impervious or permanently wet areas for the PMF.

Table 7.2 Adopted rainfall losses on pervious surfaces obtained from Hawkesbury-Nepean River Flood Study Technical Volume 7 (Rhelm and Catchment Simulation Solutions, 2024)

Event	Pervious surfaces	
	Initial loss (mm)	Continuing loss (mm/hr)
20% AEP	30	1.2
10% AEP		1.5
5% AEP		2.4
2% AEP		2.7
1% AEP		2.7
1 in 200 AEP		2.2
1 in 500 AEP		*2.2**
1 in 1,000 AEP		*2.2**
1 in 2,000 AEP		*2.2**
1 in 5,000 AEP		*2.2**
PMF	0	0.1

* *Note: The continuing loss value for rainfall was adopted based on the continuing loss of the 1 in 200 AEP event reported in Hawkesbury-Nepean River Flood Study Technical Volume 7* (Rhelm and Catchment Simulation Solutions, 2024).

7.2.2.3 Lag and routing

A lag parameter (C) of 1.6 was adopted for the WBNM model. WBNM recommends lag parameter values ranging between 1.3 and 1.8 with an average value of 1.6. It is also, the recommended value for use on ungauged catchments for NSW (Boyd and Bodhinayake 2006). The Lag parameter value was determined for several catchments across Queensland, NSW, Victoria, and South Australia, showing that it remains independent of factors such as catchment area, stream slope, and storm characteristics.

A stream lag routing Type R with a value of 1 was adopted. This is the recommended natural channel routing value. The flow paths, which are influenced by the presence of vegetation substantially reduce flow velocity and extend travel time, thereby supporting the decision to adopt this routing value.

7.3 Design events

The design events modelled in this study include:

- Frequent events: 20% and 10% AEPs;
- Rare events: 5%, 2% and 1% AEPs;
- Very rare events: 1 in 200, 1 in 500, 1 in 1,000 and 1 in 2,000 AEPs; and
- Extreme events: 1 in 5,000 AEP and Probable Maximum Flood (PMF).

The terminology of these events is defined as per the ARR 2019 guidelines presented in **Table 7.3.** All events (except the 1 in 5,000 AEP and PMF) use spatial and temporal patterns provided by the ARR 2019 Data Hub. The 1 in 5,000 AEP and PMF use a combination of other temporal and areal patterns as described in the following **Section 7.4**.

7.4 Probable Maximum Flood event

The Probable Maximum Flood (PMF) is the largest conceivable flood event resulting from the Probable Maximum Precipitation (PMP). The PMP rainfall depth has been estimated using the ARR 2019 guidelines. According to the PMP method zones diagram (Bureau of Meteorology, 2003), Redbank Creek catchment falls within the GSAM Coastal Zone. Therefore, durations of up to 6-hours have been considered for the PMP in accordance with the Generalised Short Duration Method (GSDM) derived by the Bureau of Meteorology (BoM) (Bureau of Meteorology, 2003) and durations of 24 hours or longer have been estimated using the Generalised Southeast Australia Method (GSAM) (Bureau of Meteorology., 2006). Intermediary durations (i.e., 9 hr, 12 hr and 18 hr) have been estimated using the best fit of PMP values of both methods. A summary of the GSDM and GSAM results was provided in **Table 7.4** and **Table 7.5**, respectively.

Table 7.3 Design Event Terminology as per ARR 2019

Frequency Descriptor	EY	AEP (%)	AEP (1 in x)	ARI
Very Frequent	12			
	6	99.75	1.002	0.17
	4	98.17	1.02	0.25
	3	95.02	1.05	0.33
	2	86.47	1.16	0.5
	1	63.21	1.58	1
Frequent	0.69	50	2	1.44
	0.5	39.35	2.54	2
	0.22	20	5	4.48
	0.2	18.13	5.52	5
	0.11	10	10	9.49
Rare	0.05	5	20	19.5
	0.02	2	50	49.5
	0.01	1	100	99.5
Very Rare	0.005	0.5	200	199.5
	0.002	0.2	500	499.5
	0.001	0.1	1000	999.5
	0.0005	0.05	2000	1999.5
Extreme	0.0002	0.02	5000	4999.5
			↓	
			PMP/ PMP Flood	

Table 7.4 GSDM summary for Redbank Creek catchment

LOCATION INFORMATION					
Catchment Name:	Redbank Creek Catchment		State:	NSW	
Duration Limit:	6 hours	(3 - 6) hours	Area:	27	km^2
Approx. Centroid	Latitude		Longitude		
	Easting	285917.4672	Northing	6283354.258	
Portion of Area Considered:					
Smooth, **S** =	0.00	(0.0 - 1.0)	Rough, **R** =	1.00	(0.0 - 1.0)
ELEVATION ADJUSTMENT FACTOR (EAF)					
Mean Elevation:	74.95	m required if greater than 1500 m			
Adjustment for Elevat	0.00	- 0.05 per 300 m above 1500 m			
EAF =	1.00	(0.85 - 1.00)			
GSDM MOISTURE ADJUSTMENT FACTOR (MAF)					
$EPW_{chatchment}$ =	72.92	**GSDM MAF = $EPW_{catchment}$ / 104.5**	0.70		
	OR				
Read directly off GSDM Moisture Adjustment Factor chart at centroid					
GSDM MAF =	0.70	(0.46 - 1.19)			

Summer PMP values (mm)			Autumn PMP values (mm)		
Duration (hours)	**Initial Depth (D_{summer})**	**PMP Estimate (D_s×TAF×MAF_s)**	**Duration (hours)**	**Initial Depth (D_{autumn})**	**PMP Estimate (D_a×TAF×MAF_a)**
24		0.00	**24**		0.00
36		0.00	**36**		0.00
48		0.00	**48**		0.00
72		0.00	**72**		0.00
96		0.00	**96**		0.00

PMP Values (mm)				
Duration (hours)	**Initial Depth - Smooth (D_s)**	**Initial Depth - Rough (D_R)**	**PMP Estimate = (D_s×S+D_R×R)×MAF×EAF**	**Final PMP Estimate (from envelope)**
0.25	195	195	137	140
0.5	287	287	201	200
0.75	366	366	256	260
1	432	432	302	300
1.5	494	554	388	390
2	554	645	452	450
2.5	590	716	501	500
3	619	778	545	550
4	689	887	621	620
5	432	975	683	680
6	554	1040	728	730

Table 7.5 GSAM summary for Redbank Creek catchment

LOCATION INFORMATION					
Catchment Name:	Redbank Creek Catchment		State:	NSW	
GSAM Zone:	Coastal		Area:	27	km^2
CATCHMENT FACTORS					
Topographical Adjustment Factor			**TAF =**	1.67	(1.0 - 2.0)
Annual Moisture Adjustment Factor			**MAF = EPW** $_{\text{seasonal catchment average}}$ **/ EPW** $_{\text{seasonal standard}}$		
Season	**EPW** $_{\text{seasonal catchment average}}$	**EPW** $_{\text{seasonal standard}}$	**MAF**		
Summer (Annual)	72.92	80.8	0.90	(0.60 - 1.05)	
Autumn	59.59	71	0.84	(0.56 - 0.91)	
Summer PMP values (mm)			**Autumn PMP values (mm)**		
Duration (hours)	**Initial Depth (D_{summer})**	**PMP Estimate (D_s×TAF×MAF_s)**	**Duration (hours)**	**Initial Depth (D_{autumn})**	**PMP Estimate (D_a×TAF×MAF_a)**
24	848	1274.55	**24**	564	788.24
36	948	1425.50	**36**	695	971.00
48	1000	1503.57	**48**	816	1141.32
72	1046	1572.32	**72**	1032	1443.18
96	1082	1625.72	**96**	1105	1545.29

Final GSAM PMP Estimates			
Duration (hours)	**Maximum of the Seasonal Depths**	**Preliminary PMP Estimate (nearest 10 mm)**	**Final PMP Estimate (from envelope)**
1		300	300
2	Where applicable,	450	450
3	calculate GSDM depths	550	550
4	(Bureau of Meteorology,	620	620
5	2003)	680	680
6		730	730
9	(no preliminary estimates available)		880
12	(no preliminary estimates available)		100
18	(no preliminary estimates available)		1160
24	1275	1280	1280
36	1425	1430	1430
48	1504	1500	1500
72	1572	1570	1570
96	1626	1630	1630

The temporal patterns used to derive the PMF should be selected from an ensemble of patterns appropriate for use with the Generalised PMP.

At present, the best source of ensemble temporal patterns for use with short duration PMF events are those derived by (Jordan, Nathan, & Mittiga, 2005) for durations up to 6 hours. The procedure suggested to derive the design temporal distribution of GSAM patterns for duration of 24 hours or longer were described in the revised edition of Australian Rainfall and Runoff, Book IV, ARR (Nathan and Weinmann, 1999) using the Average Variability Method (AVM) of

Pilgrim et al., (1969) (Bureau of Meteorology., 2006) and (Bureau of Meteorology, 2005). The GSDM and GSAM patterns were used for intermediary durations (i.e., 9 hr, 12 hr and 18 hr). The (Jordan, Nathan, & Mittiga, 2005) patterns were derived specifically from storms associated with thunderstorm or deeply convective events while the GSDM and GSAM patterns are defined in the associated guidelines. The ellipse approach from the GSDM was applied to define the areal pattern for the shorter duration events.

These patterns were therefore adopted in this study and applied to the calculated PMP rainfall depth. The critical pattern determined as per the typical ARR 2019 guidelines was applied to all other design events.

7.5 Model results and critical duration

For each design event, 23 different durations were modelled ranging from 10 minutes to 168 hours, except for the PMF which had twenty durations ranging from 15 minutes to 120 hours. Within each duration, 10 specific rainfall events were modelled (as recommended in ARR 2019) which varied the rainfall temporal pattern, though not the magnitude, over that period. This led to 230 individually modelled rainfall events per design event which were then analysed to pick the most appropriate events to use as design rainfall.

Critical durations were selected based on the methodology described in ARR 2019. This methodology consists of selecting, for each duration, the rainfall temporal pattern that is the closest to the average flow obtained from the 10 specific patterns provided in the ARR 2019 database. This provides an automated approach that can then be adjusted for consistency in durations between the various events.

Figure 7.2 presents the critical durations with the associated temporal pattern (TP) of each sub-catchment across the study area for the 1% AEP event. It is evident that in most sub-catchments, durations of 120 and 720 minutes corresponded to the highest peak flows, while a few sub-catchments exhibited critical durations of 20 and 45 minutes. As a result, these four durations were adopted as critical durations.

For the 20 and 45 minute events, temporal patterns 4404 and 4531 resulted in peak flows. However, the 120 and 720 minute events yielded multiple temporal patterns contributing to peak flows. A comparative analysis of these temporal patterns was conducted to identify the most representative temporal pattern. Notably, in the majority of sub-catchments with a critical duration of 120 minutes, temporal patterns 4611, 4614, 4615 and 4618 generated closely aligned peak flows. **Figure 7.3** demonstrates that these temporal patterns exhibit similar peak flow characteristics; therefore, given that temporal pattern 4614 was the most frequently occurring, it was selected as the critical duration / temporal pattern. A similar approach was employed for 720 minutes event, resulting in the selection of temporal pattern 4443.

A summary of the selected critical durations / temporal patterns for each design event was tabulated in **Table 7.6**. These critical durations / temporal patterns were incorporated to simulate direct rainfall for the development of the hydraulic model.

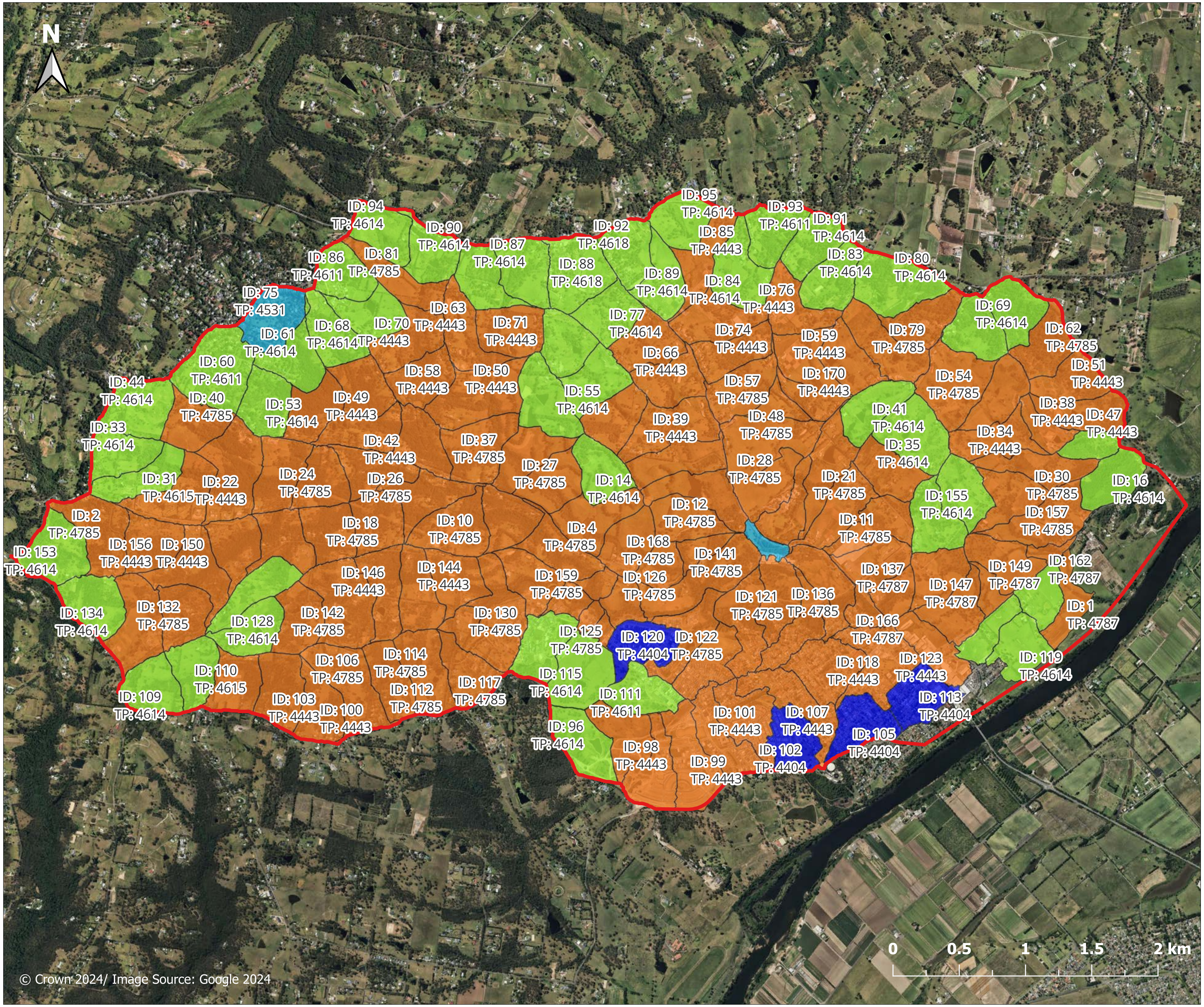

Figure 7.2

Critical duration 1% AEP event

Legend

Study area

Critical duration (min)

- 20
- 45
- 120
- 720

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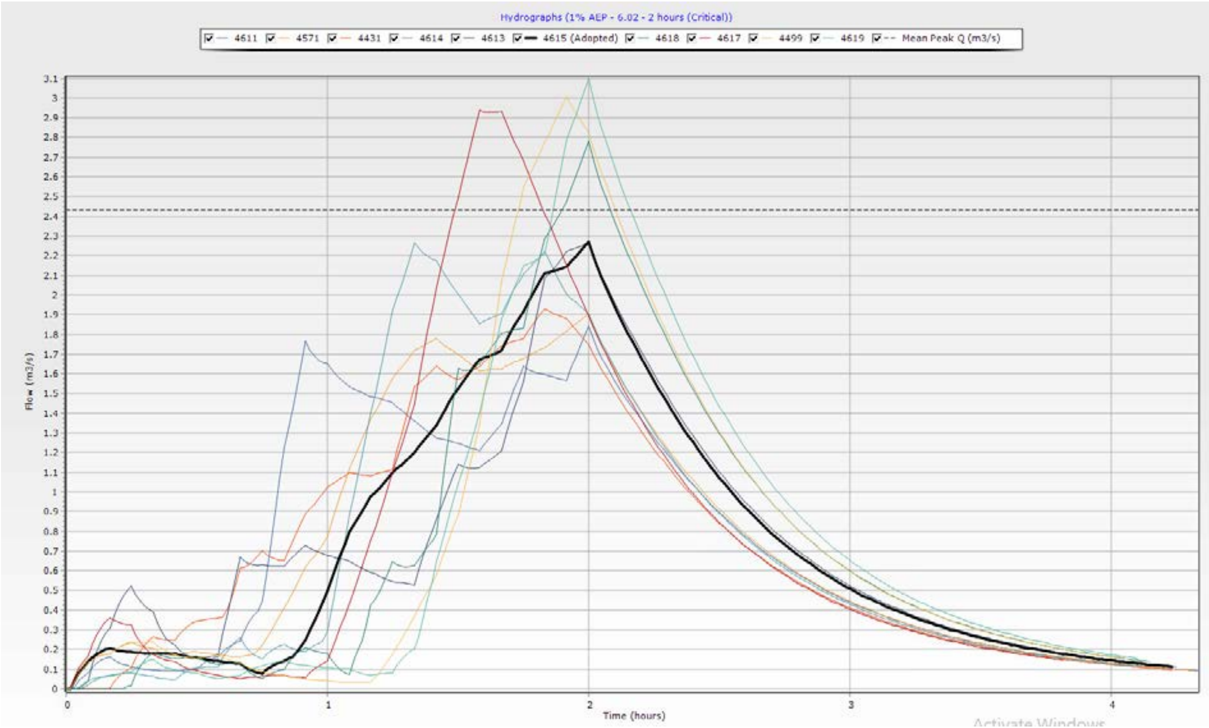


Figure 7.3 Example of hydrographs of 10 temporal patterns for 2 hours rainfall event for the 1% AEP event (sub-catchment 110)

Table 7.6 Adopted critical duration and temporal pattern for each design event

Event	Adopted critical duration (min)	Adopted temporal pattern from ARR 2019 Data Hub
20% AEP	20 45 60 120 540 720	4440 4540 4569 4630 4764 4793
10% AEP	20 45 60 120 540 720	4440 4540 4569 4630 4764 4793
5% AEP	20 45 60 120 540 720	4440 4540 4569 4630 4764 4793
2% AEP	20 45 120 720	4404 4531 4614 4443

Event	Adopted critical duration (min)	Adopted temporal pattern from ARR 2019 Data Hub
1% AEP	20 45 120 720	4404 4531 4614 4443
1 in 200 AEP	20 45 120 720	4404 4531 4614 4443
1 in 500 AEP	20 45 120 720	4404 4531 4614 4443
1 in 1,000 AEP	20 45 120 720	4404 4531 4614 4443
1 in 2,000 AEP	20 45 120 720	4404 4531 4614 4443
1 in 5,000 AEP	30 45 120 720	4 1 4 1
PMF	30 45 120 720	4 1 4 1

7.6 Regional Flood Frequency Estimation Model

Regional Flood Frequency Estimation (RFFE) is a method used to estimate flood characteristics for ungauged locations by leveraging data from gauged catchments within a specific region. The approach involves two key steps:

1. Formation of Regions: Identifying geographical areas where flood data from existing gauging stations can be combined (pooled) for analysis.

2. Development of Regional Estimation Equations: Creating prediction equations from the pooled data to estimate design floods at ungauged locations.

RFFE relies on Flood Frequency Analysis (FFA) to derive the necessary data, and various techniques are available to transfer relevant flood information to ungauged sites within the defined region.

In this study, the geographical data of the catchment area was imported into the Regional Flood Frequency Analysis (RFFE) software, which is available on the Australian Rainfall and Runoff website (https://rffe.arr-software.org/). This software was used to model flood discharge based on the regional flood frequency analysis approach. The discharge results obtained from the RFFE model were then compared to those generated by the hydraulic model, with the results presented in **Figure 7.4**. The comparison shows that the discharge values of hydraulic model fall within the confidence limits provided by the RFFE model. The figure highlights the reliability of the hydraulic model in capturing the flood discharge characteristics within the established confidence range.

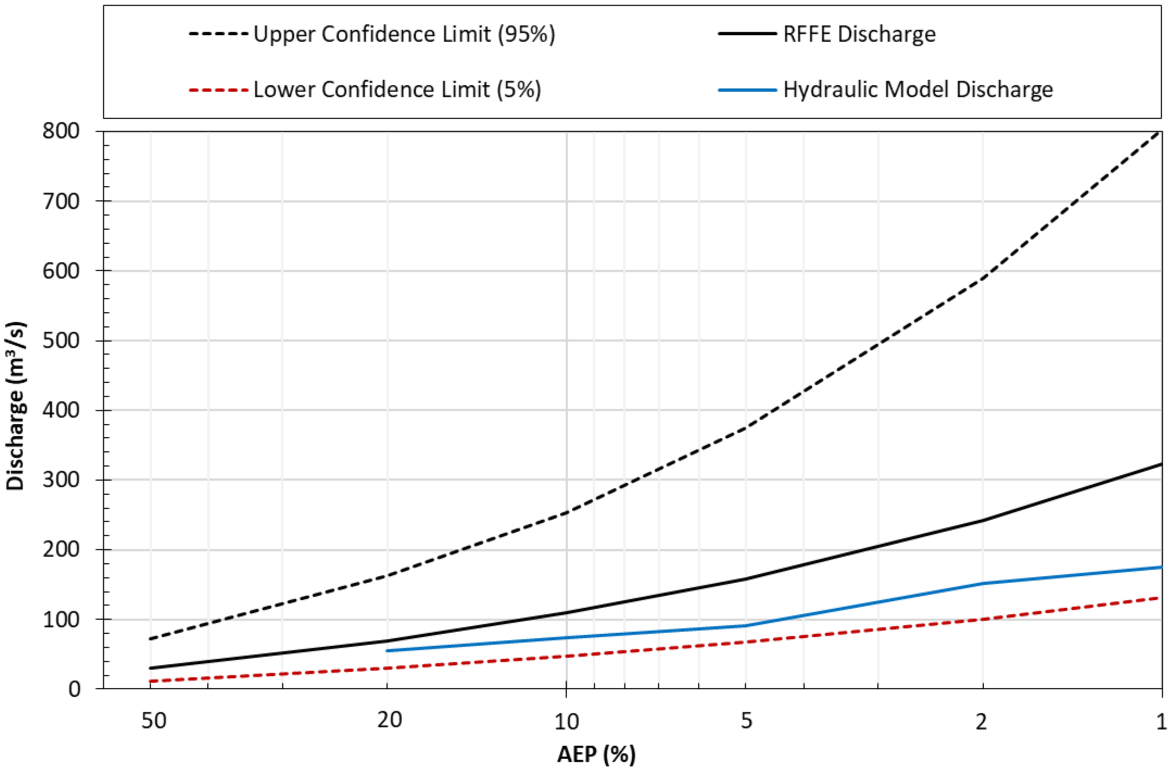


Figure 7.4 Comparison of RFFE discharge versus hydraulic model

8 Hydraulic modelling

Hydraulic modelling consists of understanding the physical properties of the flood water such as depth and velocity. This can be completed in various ways including:

- One-dimensional (1D) modelling, which consists of representing a creek or river with flood information provided at regular interval cross-sections along a stream as well as pipe systems and drainage networks;
- Two-dimensional (2D) modelling, which consists of representing a floodplain as a grid or mesh with flood information provided at each cell allowing the model to define flowpaths; and
- 1D/2D modelling, which can be completed as a combination of the above.

8.1 Model selection

A 1D / 2D TUFLOW Heavily Parallelised Compute (HPC) hydraulic model was developed to simulate flood behaviour across the study area. The use of a TUFLOW model allows integrated investigation of local overland flooding, mainstream creek flooding, foreshore flooding and tidal influences, and the inclusion of stormwater drainage infrastructure.

The GIS data layers, and control files used to drive the model can be easily modified for use in any future options assessment, including modelling the impact of mitigation measures, or impact assessment to support development applications. MHL flood modelling processes follow guidance provided in ARR 2019.

The dynamically linked 1D/2D model requires a number of GIS data layers to represent the study area. These include:

- 1D Domain
    - Pits and headwalls GIS layer;
    - Pipe network GIS layer;
    - Culverts GIS layer;
- 2D Domain
    - 2D grid / digital elevation model (DEM);
    - Topographic modifications and break lines (e.g., to incorporate embankments);
    - Materials layer (specifies surface roughness and infiltration);
    - Rainfall on the grid;
    - Layered flow constrictions layer for 2D bridges; and
    - Initial water level polygons.

The latest version of TUFLOW at the time of the model construction was used for modelling (2023-03-AC).

8.2 Model setup

The following considerations were required to set up the TUFLOW model.

8.2.1 Model extent and grid size

A grid cell size of 2 m by 2 m was found to be suitable to represent flooding within the township and was also applied to represent embankment structures such as elevated roads (blue extent in **Figure 8.1**). The Quadtree capability was then used to transition to a 4 m cell size in the floodplain where rural properties are located and outside of the PMF extent.

The sub-grid sampling (SGS) capability of the TUFLOW model was also set to 1 m (i.e., the resolution of the available DEM). The SGS capability allows the use of sub-grid scale elevation data to enhance the hydraulic accuracy of the model (by providing an improved representation of flows in and out of each cell and the definition of the volume within each cell) while keeping reasonable run times.

This variable size grid complemented by the activation of the SGS allows an appropriate representation of the features of the local urban catchment while keeping the run time reasonable. Initial timesteps of 1.0 second for the 2D model and 0.5 second for the 1D model have been adopted as these are the recommended values for a 2 m cell size (being the smallest cell size in the model). TUFLOW HPC uses an adaptive timestep approach to maintain stability and varies this original value as required.

8.2.2 Modelling approach

MHL applied the following modelling approach to the development of a detailed and reliable 1D / 2D TUFLOW hydraulic model for the study area:

- Extent of the study area and 2D hydraulic model was determined based on the available elevation data;
- Direct rainfall method was adopted over the 2D model extent;
- Tailwater level was estimated at the downstream boundary condition located along Hawkesbury River based on the representative event water level in the Hawkesbury River modelled in the Hawkesbury-Nepean River Flood Study (Rhelm and Catchment Simulation Solutions, 2024) as reported in **Section 8.2.4;**
- Stormwater infrastructure: all pits, pipes, culverts and bridges were modelled as described in **Section 8.2.5**;
- Blockage: the blockage applied to the pits and pipes system has been established by following the method described in the blockage assessment form provided in ARR 2019 and ARR Project 11: Blockage of Hydraulic Structures; and

Hydraulic roughness: a materials layer was delineated based on Council LEP zoning, NSW Surface cover, cadastral data and aerial photography along with site observations. Initial material categories and associated depth-varying Manning's roughness coefficients were established for the present study (refer to **Section 8.2.3**).

8.2.3 Hydraulic roughness

Hydraulic roughness coefficients (Manning's n) are used to represent the resistance to flow of different surface materials. Hydraulic roughness has a major influence on flow behaviour and is one of the primary parameters in hydraulic model calibration.

Spatial variation in hydraulic roughness is represented in TUFLOW by delineating the catchment into zones of similar hydraulic properties. The hydraulic roughness zones adopted in this study have been delineated based on consideration of Council LEP zoning, NSW Surface cover, cadastral data and aerial photography. Factors affecting resistance to flow were of primary importance including surface material, vegetation type and density, and the presence and density of flow obstructions such as buildings and gross pollutant traps (GPTs). Manning's n values assigned to each zone were determined based on aerial imagery, with reference to standard values recommended by (Te Chow, 1959). As resistance to flow due to surface and form roughness varies with depth (e.g., Chow 1959, Institution of Engineers Australia 1987), variable depth-dependent hydraulic roughness values were adopted for this study to consider the typical sizes of vegetation/obstruction (i.e., typical grass or brush height). Once the obstruction is underwater, roughness reduces. **Figure 8.2** and **Table 8.1** summarise the Manning's n values used in the hydraulic model.

Table 8.1 Adopted Manning's n Hydraulic Roughness Coefficients

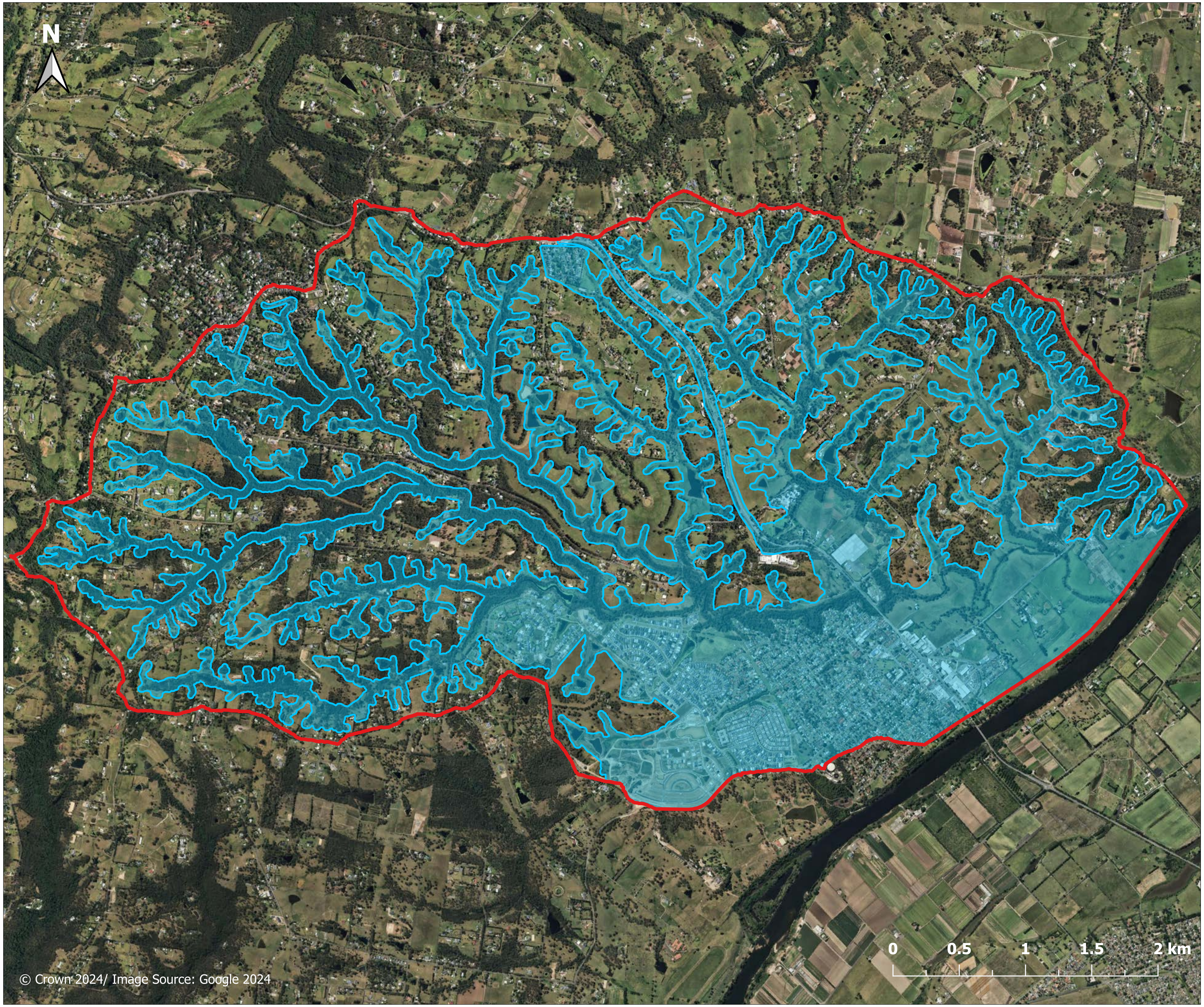
Material	Manning's n below each threshold	Threshold of depth variable roughness (m)
Waterbodies	0.03 / 0.013	0.1 / 0.5
Residential – Medium density	0.03 / 0.02	0.04 / 0.10
Open Space / Light vegetation	0.05 / 0.035	0.10 / 0.50
Vegetation – Medium density	0.075 / 0.40	0.10 / 0.50
Vegetation – high density	0.10 / 0.08	0.40 / 2.0
Roadways	0.03 / 0.02	0.04 / 0.10
Dry water courses / Vegetated channel	0.04 / 0.06	0.10 / 0.50
Building footprint	0.10 / 1.0*	0.03 / 0.10

N.B.: The Manning's n value is changing with depth and for example, for Open Space, the Manning's n value is 0.05 up to a depth of 0.1 m and then transitions down to 0.035 at a depth of 0.5 m or more.

* In the hydraulic model, which is based on direct rainfall, the roughness of the building footprint was represented using a depth-varying Manning's n value. This methodology facilitates the flow of shallow water across the roof, directing it into the gutter and downpipes. By accounting for the delay introduced by the drainage system, this approach prevents the formation of ponds on the roof surface.

Figure 8.1

TUFLOW model grid definition



Legend

Grid resolution

- 4 m
- 2 m

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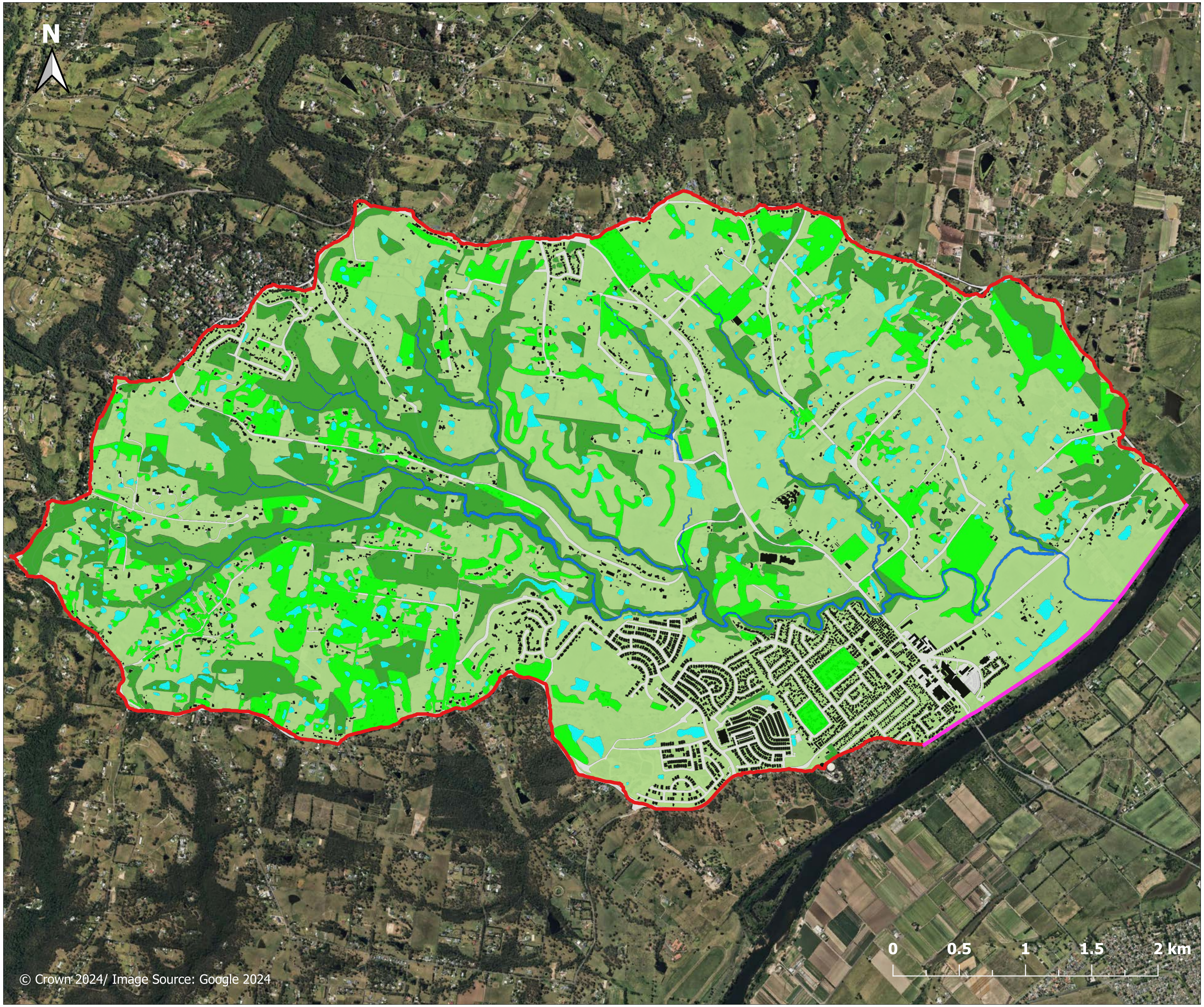

Figure 8.2

TUFLOW model Manning's n and boundary conditions

Legend

- Study area
- Building footprint
- Road corridor
- Thick vegetation
- Medium vegetation
- Light vegetation
- Dry watercourse
- Water body/Reservoir/ Lagoon

Boundary conditions

- Downstream tailwater

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