is located downstream of North Richmond WPS gauge.

The July 2022 flood event was a more typical single peak event. The Hawkesbury-Nepean River water level reached a peak of 14.85 m AHD at 3:00 am on 4th of July with an approximate likelihood of 1 in 10 chance per year (10% AEP event) at North Richmond WPS (212200) gauge.

3.7 NSW Coast Flood Summary February / March 2022 (Manly Hydraulics Laboratory, 2023)

The NSW Coast Flood Summary February / March 2022 (MHL2936) was prepared for the former NSW Department of Planning and Environment – Environment and Heritage Group by Manly Hydraulics Laboratory (MHL2936) in August 2023 to summarise the February/March 2022 flood event on the NSW coast (Manly Hydraulics Laboratory, 2023). This flood report (MHL2936) was conducted to provide a snapshot of the intensity of flooding experienced across the coast of NSW based on the river and rainfall data collected within 61 disaster-declared LGAs. This report presents a selected group of water level and rainfall hydrometric data collected between 15 February and 11 March 2022 along the coast of NSW. The peak observed water levels for the North Richmond were reported as 14.66 m AHD at 11:15 pm on 8th of March while the SES flood classification for North Richmond station was 4.3 m AHD, 8.4 m AHD, and 11 m AHD for minor, moderate, and major, respectively. The observed peak water levels for the Hawkesbury River and South Creek region between the period of 15 February to 11 March 2022 are listed in **Table 3.3**.

Table 3.3 Observed peak water level in the Hawkesbury River and South Creek region from 15 February to 11 March 2022

Station name	Station number	Owner	Peak level (m AHD)
Webbs Creek	212408	DPE BCD	5.18
Colo Junction	212407	DPE BCD	8.67
Sackville	212406	DPE BCD	10.68
Windsor	212426	DPE BCD	13.80
North Richmond	212200	WaterNSW	14.66
Penrith	212201	WaterNSW	22.46
Wallacia Weir	212202	WaterNSW	37.96

3.8 Hawkesbury-Nepean River Flood Study (Rhelm and Catchment Simulation Solutions, 2024)

The Hawkesbury-Nepean River Flood Study was prepared for the NSW Reconstruction Authority by Rhelm and Catchment Simulation Solutions in May 2024 to identify areas in the valley affected by flooding from the Hawkesbury-Nepean River (including backwater flooding up tributaries such as Redbank Creek) and assess the potential impacts of climate change on flooding (Rhelm and Catchment Simulation Solutions, 2024). An investigation of flood behaviour for the Hawkesbury-Nepean River between Bents Basin and Brooklyn, was undertaken and included WBNM hydrologic modelling, TUFLOW hydraulic modelling, Monte Carlo framework assessment, flood frequency analysis and Colo / Hawkesbury joint probability analysis.

The study accounted for flows from the entire 21,400 km^2 Hawkesbury-Nepean catchment, providing detailed flood information for the 190 km length of the Hawkesbury-Nepean River from Bents Basin near Wallacia through to Brooklyn. The study area falls mainly within the Penrith, Hawkesbury, Blacktown and The Hills LGAs. Other LGAs in this floodplain include Wollondilly, Liverpool, Hornsby and Central Coast.

A WBNM hydrologic model of the Hawkesbury-Nepean catchment was developed for WaterNSW, as described in (WMA Water, 2018). This model was calibrated to five streamflow gauges within the Warragamba Dam catchment, the Nepean River catchment and the Colo River catchment. The model was calibrated to eight separate historical flood events including, June 1964, June 1975, March 1978, August 1986, May 1988, August 1990, August 1998, and February 2020. An iterative approach in the hydrologic model calibration process was adopted to modify the model parameters including the initial and continuing losses for each storm event to best fit the overall flow gauge data. A summary of the median loss values for the calibrated catchments is provided in **Table 3.4**.

Table 3.4 Calibration Lag and Median Loss Values

Catchment	Lag parameter C	Initial Loss (mm)	Continuing Loss (mm/hr)
Nepean River – Upper catchment	1.00	70.0	2.0
Nepean River – Maldon to Camden	1.90	70.0	1.9
Nepean River – Camden to Wallacia	1.90	80.0	2.0
Grose River	1.36	50.0	0.9
South Creek	1.90	50.0	1.0
Colo River - Upper Colo	1.50	102.5	2.2
Macdonald River - Howes Valley	1.90	87.5	3.4
Macdonald River - St Albans	1.90	110.0	1.0

The TUFLOW Highly Parallelised Computer (HPC) software was used to develop the new hydraulic modelling within the study area. The TUFLOW model extends along the Nepean and Hawkesbury rivers from Cowpasture Bridge, Camden to West Head. A 15 m grid size was used with 5 m sub-grid sampling (SGS) across the full model domain, with 2-metre SGS across critical areas, to ensure a detailed representation of flood conveyance and storage across the full model area. The 2019 LiDAR did not cover the full hydraulic model area, so the 2017 and 2011 LiDAR data were added to ensure complete topographic coverage. Both 2011 and 2017 LiDAR datasets had comparable accuracy, but the 2017 data was prioritised for its more recent description of ground elevations. The roughness values were initially selected in the model based on values obtained in literature (e.g., Chow, 1959), but the values were refined during the model calibration process.

The simulated flows from the calibrated hydrologic model were routed through the hydraulic model to compare surveyed flood levels and/or water levels at stream gauge locations from each historical flood events including, November 1961, June 1964, June 1975, March 1978, August 1986, April / May 1988, August 1990, February 2020, March 2021, March 2022 and July 2022. The March 2021 flood was the highest flood at Penrith since 1925 at 24.1 m AHD and the highest at Windsor since 1990 at 12.9 m AHD and several metres higher than the February 2020 calibration event.

Design flood modelling was undertaken from frequent to extreme events including the 20%, 10%, 5%, 2%, 1%, 1 in 200, 1 in 500, 1 in 1,000, 1 in 2,000, 1 in 5,000 AEP events, and PMF. The results of simulated peak flood levels at several locations were documented in **Table 3.5**. The outputs from each of the design flood simulations were processed and the output types included peak flood levels, depths and velocities, flood extents, flood hazard categories, flood function categories, and information to support emergency services and evacuation.

Table 3.5 Peak Flood Levels at Key Reporting Locations (m AHD)

Design event	North Richmond Bridge (gauge) (m AHD)	Windsor Bridge (gauge) (m AHD)
50% AEP	6.7	5.5
20% AEP	12.3	9.7
10% AEP	14.5	11.7
5% AEP	15.6	13.8
2% AEP	16.3	15.9
1% AEP	17.5	17.3
1 in 200 AEP	18.6	18.5
1 in 500 AEP	20.2	20.2
1 in 1,000 AEP	21.4	21.3
1 in 2,000 AEP	22.8	22.8
1 in 5,000 AEP	24.4	24.4
PMF	30.6	30.6

Building on the comprehensive Monte Carlo framework generating thousands of potential events to replicate the variability of actual floods in the Hawkesbury-Nepean River Valley as part of Hawkesbury-Nepean River Flood Study (Rhelm and Catchment Simulation Solutions, 2024), and following the hierarchical method outlined in the Floodplain Risk Management Guide Incorporating 2016 Australian Rainfall and Runoff in studies (OEH, 2019), the present study adopted the initial and continuing losses as specified in **Section 7.2.2.2**.

In the present study, the tailwater level in the Hawkesbury River for design events have been derived from the simulated water level at the North Richmond Bridge reported in the Hawkesbury - Nepean Valley River Flood Study, as noted in **Section 8.2.4.2**. The downstream reaches of the Redbank Creek catchment have been assessed to understand areas where Redbank Creek flooding predominates and where the Hawkesbury River flooding predominates to determine the most appropriate study to adopt for flood planning level definition. . Additionally, flood maps derived from this study provide extensive coverage of direct flooding from the Hawkesbury River, highlighting areas impacted by riverine flooding in the present report, refer to **Section 10.2.2**.

4 Data collection and review

4.1 Water level and rainfall data

MHL manages two water level gauges and one rainfall station in the vicinity of the study area (Castlereagh 212404, Freemans Reach 212410 and Sackville Downstream 212438). Additionally, WaterNSW manages a water level gauge at North Richmond on the Hawkesbury River. However, it is noted that none of the above-mentioned gauges fall within the boundaries of the present study area.

The only gauge within the study area (North Richmond STP 563069) is a near-real-time rainfall monitoring station owned by Sydney Water and maintained by the Bureau of Meteorology (BoM). An overview of the monitoring gauges is provided in **Table 4.1** while their respective locations are depicted in **Figure 4.1**. **Figure 4.2** presents daily rainfall data recorded at North Richmond Station (563069). This station is the only rainfall station located within Redbank Creek study area; therefore, it is the most representative rainfall station to replicate the rainfall events.

Table 4.1 Water level and rainfall stations in vicinity of the study area

Station Name	Station Number	Owner	Latitude	Longitude	Start Date	End Date
Water level						
Hawkesbury River North Richmond	212200	WaterNSW	-33.589	150.714	30/04/1988	Ongoing
Freemans Reach	212410	DCCEEW	-33.570	150.781	03/04/1980	Ongoing
Castlereagh	212404	DCCEEW	-33.634	150.677	11/11/1981	Ongoing
Daily rainfall						
North Richmond STP	563069	Sydney Water	-33.570	150.720	28/06/1997	Ongoing
Richmond - UWS Hawkesbury	67021	BoM	-33.616	150.747	01/01/1881	Ongoing
Richmond RAAF	67105	BoM	-33.600	150.776	01/09/1993	Ongoing
Sackville Downstream	212438	DCCEEW	-33.497	150.877	06/01/1999	Ongoing
Kurrajong Height	063043	BoM	-33.535	150.634	01/01/1866	Ongoing

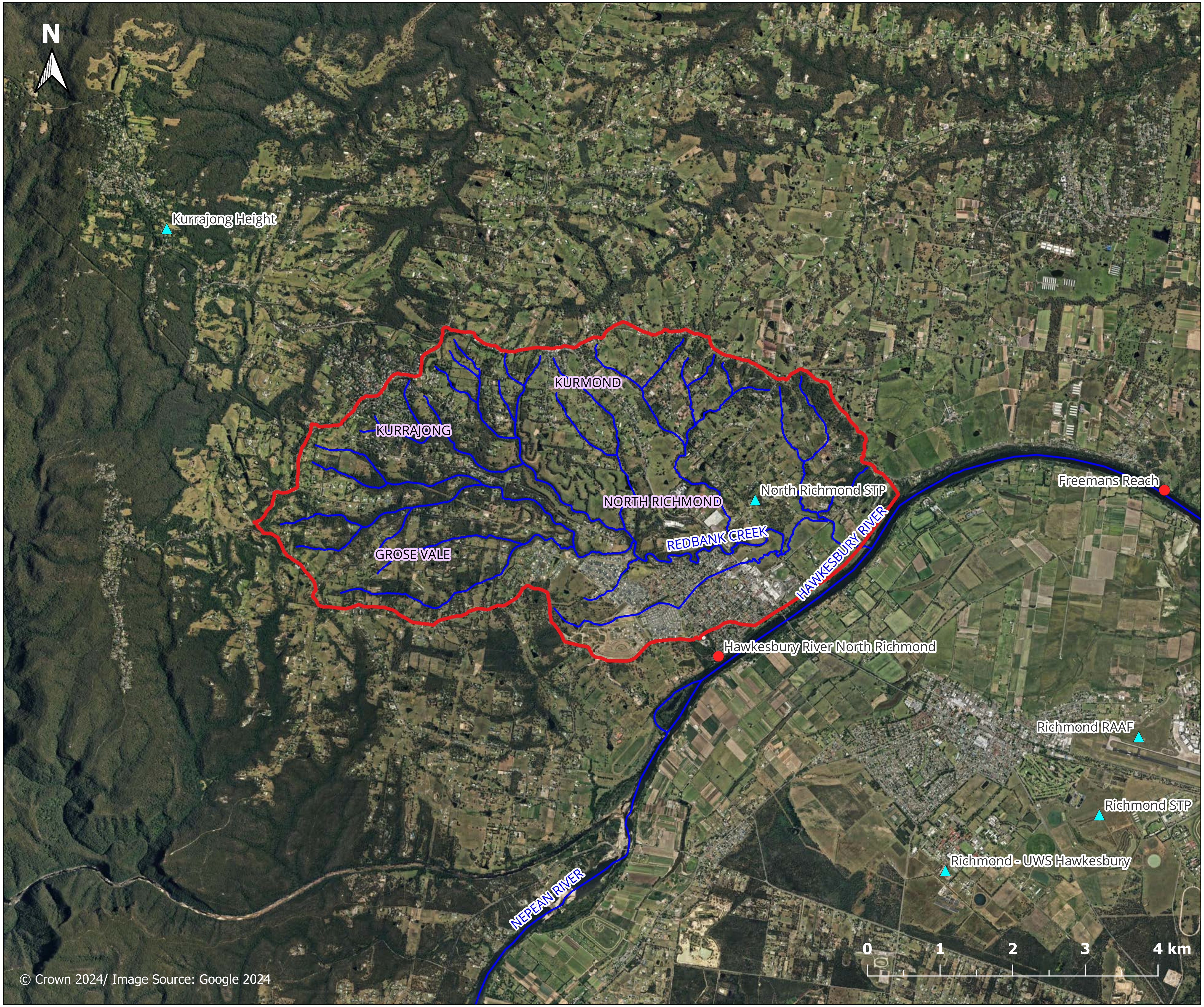

Figure 4.1

Water level and rainfall stations

Legend

Study area

Watercourses

Monitoring stations

Rainfall

Water level

Report MHL3008

Redbank Creek Flood Study

NSW GOVERNMENT

Manly Hydraulics Laboratory

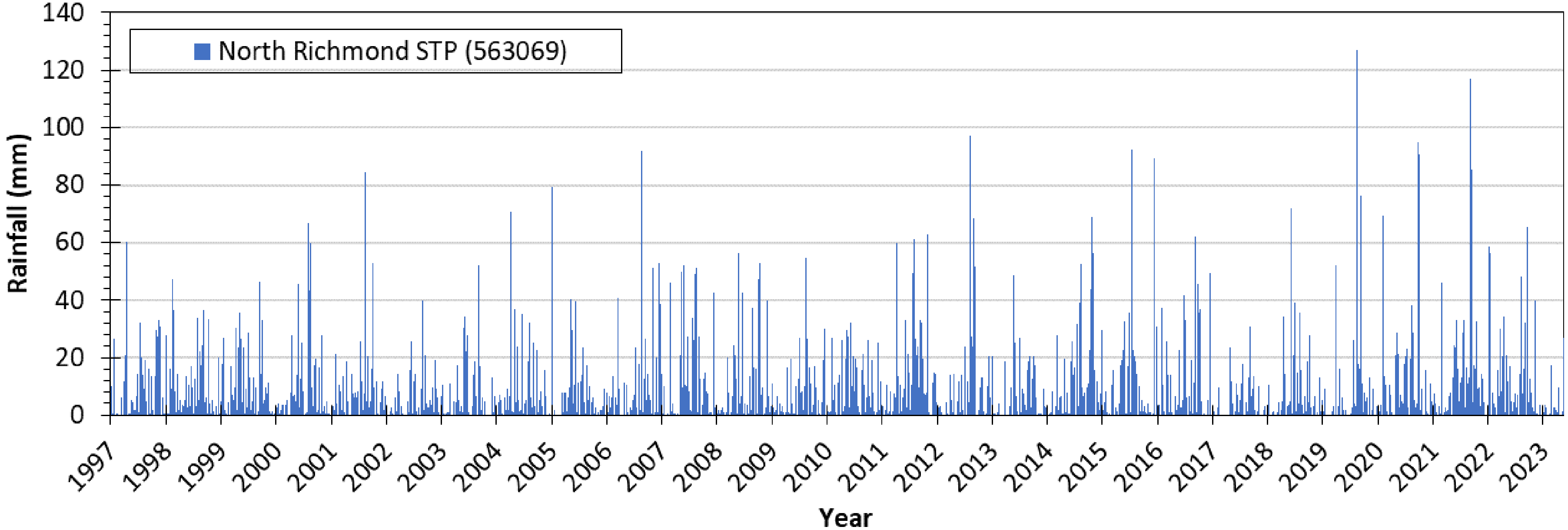

Figure 4.2 Daily rainfall data recorded at North Richmond STP 563069

4.2 Topographic data

Light Detection and Ranging (LiDAR) is an advanced aerial surveying technique that provides a comprehensive topographic representation of the Earth's surface. For this study, LiDAR survey data covering the study area and its immediate surroundings was sourced from the Elevation Information System (ELVIS) (https://elevation.fsdf.org.au/). One-metre resolution LiDAR data from the 'Penrith' datasets (NSW Spatial Services 2011, 2017 and 2019) were available for the Redbank Creek catchment. The horizontal accuracy of these datasets is 0.8 m at 95% confidence interval, while the vertical accuracy is 0.3 m at 95% confidence interval.

A comparative assessment of LiDAR datasets from February 2011, February 2017, and April 2019 were undertaken and presented in **Figure 4.3** and **Figure 4.4.** It is noted that the 1 m resolution 2017 LiDAR dataset only covers the lower half of the study area. While the difference between the various datasets appears significant in a number of locations, this is primarily due to slight horizontal shifts leading to major vertical differences along steep slopes and it can be noted that the various datasets are more consistent in flat areas (e.g., in North Richmond township). Such horizontal shift would have negligible impact on the flood behaviour in the hydraulic model. It is also important to note that the accuracy of the ground information obtained from LiDAR survey can be adversely affected by the nature and density of vegetation, the presence of varying terrain, the vicinity of buildings and / or the presence of water. Considering the recent developments and changes in the area's topography, the most current dataset from 2019 was selected for this study. The terrain topography is illustrated in **Figure 4.5**.

As part of the data review, a comparison of 2019 LiDAR and survey marks was undertaken to check the accuracy of the LiDAR data. These survey marks were obtained from Sixmaps – the Survey Control Information Management System (SCIMS) database developed by the NSW Government's Spatial Services. Under the S&SI Reg 2017, only marks that have a vertical class of L2A, LA, LB, LC, LD, 2A, A or B should be used for the adoption of AHD. Therefore, survey marks were filtered to exclude the following:

- Survey marks that were either damaged or not found; and
- Survey marks that had class of "U" defined as Unknown or unreliable surveys.

Details of the survey marks including name, coordinates, elevation from SCIMS database, corresponding elevation extracted from 2019 LiDAR data and difference in levels are presented in **Appendix A** . The difference between the 2019 LiDAR dataset and the elevation of the survey marks were calculated and are presented in **Figure 4.5**. It was observed that this difference ranges from -0.5 to 0.5 m with the majority of elevation differences falling between -0.2 to 0.2 m which is consistent with the vertical accuracy of the dataset. Marks with differences exceeding ± 0.3 m were inspected; many were near vegetation, fences, road signs, or resurfaced areas, contributing to observed discrepancies.

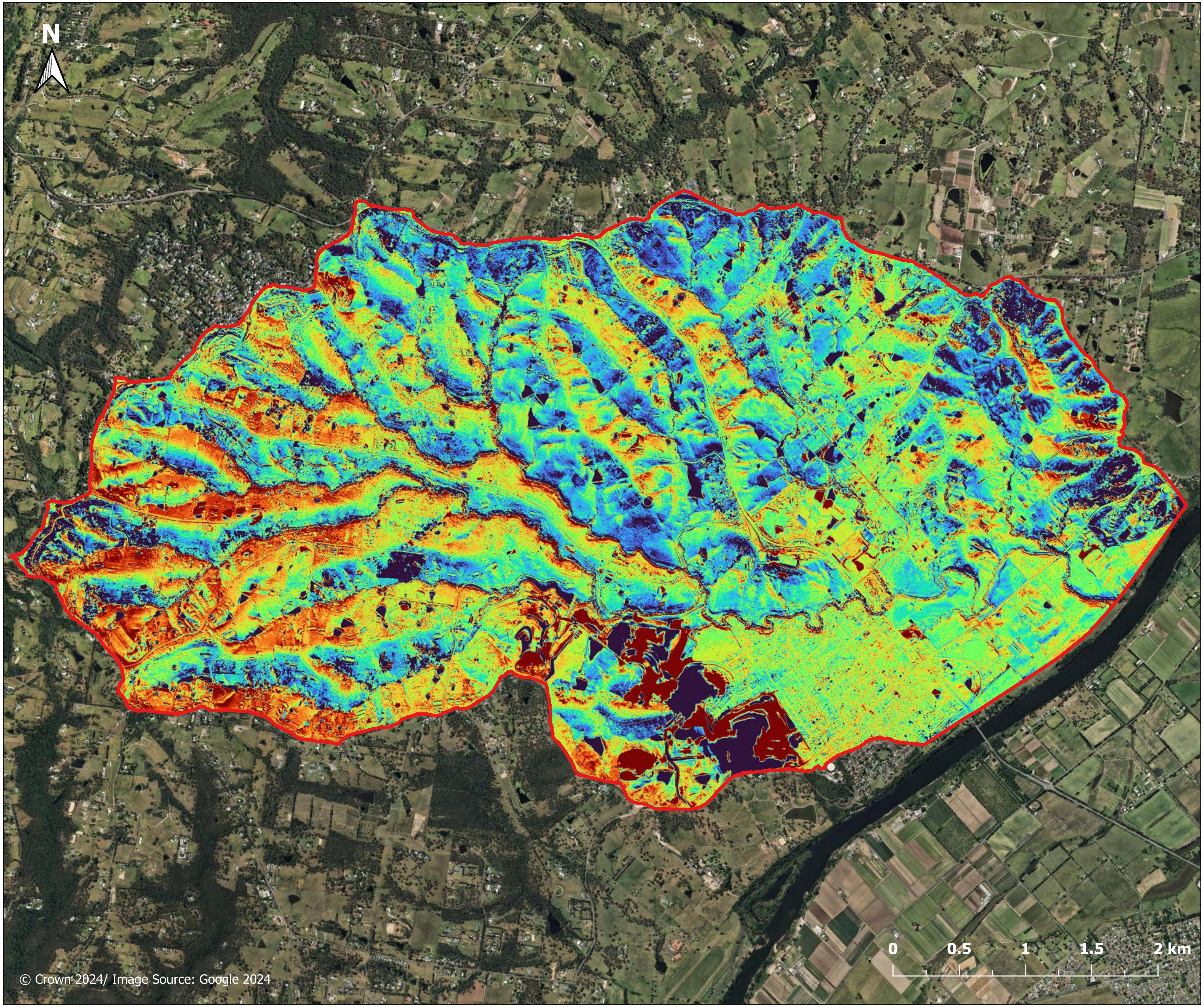

Figure 4.3

Comparison of 1 m resolution LiDAR datasets (2019 LiDAR minus 2011 LiDAR)

Legend

Study area

2019 LiDAR minus 2011 LiDAR

- <= -0.40
- -0.40 - -0.30
- -0.30 - -0.20
- -0.20 - -0.10
- -0.10 - 0.00
- 0.00 - 0.10
- 0.10 - 0.20
- 0.20 - 0.30
- 0.30 - 0.40
- > 0.40

Report MHL3008

Redbank Creek Flood Study

NSW GOVERNMENT

Manly Hydraulics Laboratory

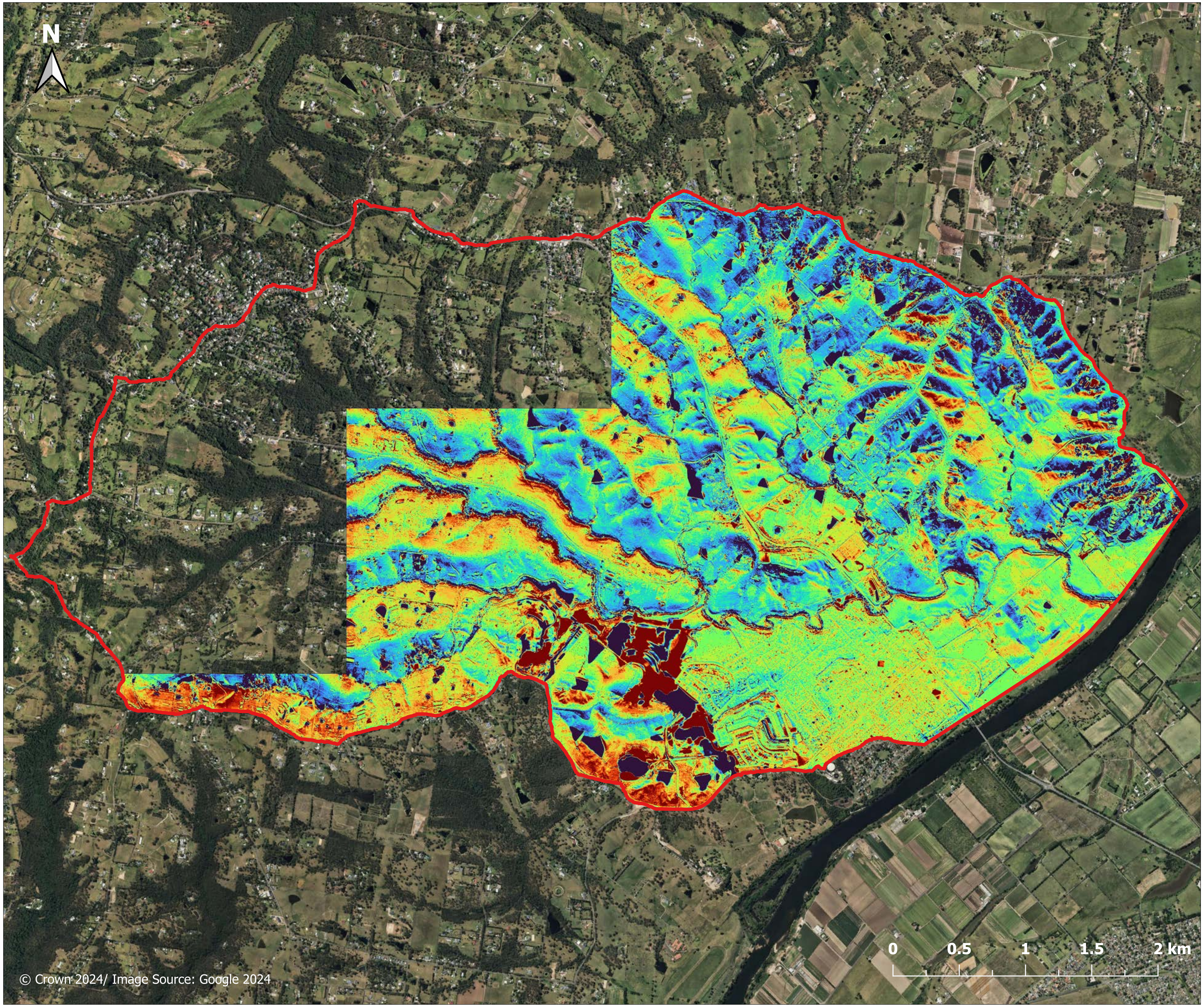

Figure 4.4

Comparison of 1 m resolution LiDAR datasets (2019 LiDAR minus 2017 LiDAR)

Legend

Study area

2019 LiDAR minus 2017 LiDAR

- <= -0.40
- -0.40 - -0.30
- -0.30 - -0.20
- -0.20 - -0.10
- -0.10 - 0.00
- 0.00 - 0.10
- 0.10 - 0.20
- 0.20 - 0.30
- 0.30 - 0.40
- > 0.40

Report MHL3008

Redbank Creek Flood Study

NSW GOVERNMENT

Manly Hydraulics Laboratory

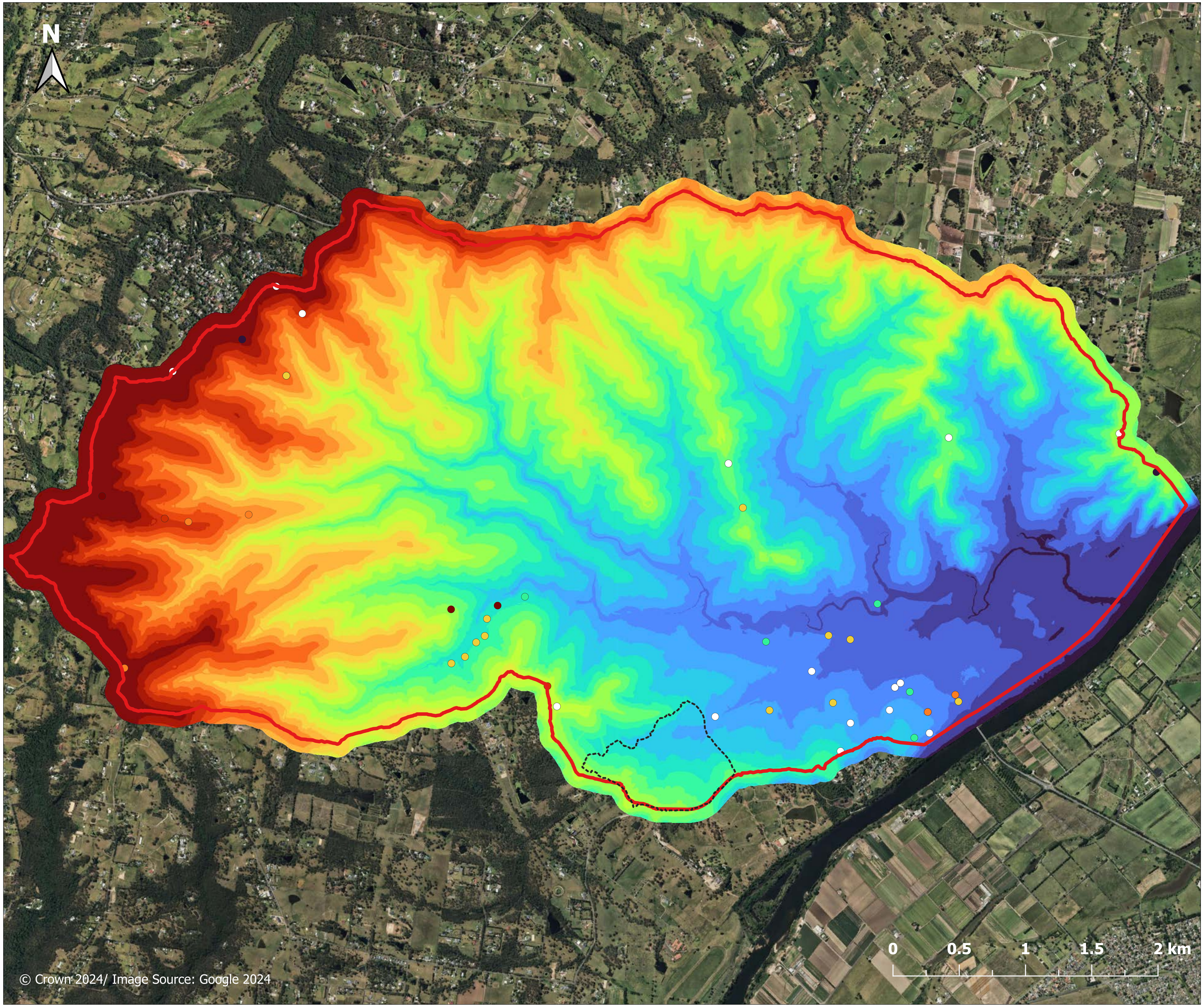

Figure 4.5

Topographic data

Legend

Study area

New development extent

2019 LiDAR minus survey mark elevation (m)

- -0.5 - -0.4
- -0.4 - -0.3
- -0.3 - -0.2
- -0.2 - -0.1
- -0.1 - 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5

Elevation (m AHD) 2019 Penrith LiDAR

- <= 8
- 8 - 16
- 16 - 24
- 24 - 32
- 32 - 40
- 40 - 48
- 48 - 56
- 56 - 64
- 64 - 72
- 72 - 80
- 80 - 88
- 88 - 96
- 96 - 104
- 104 - 112
- 112 - 120
- 120 - 128
- 128 - 136
- 136 - 144
- 144 - 152
- > 152

Report MHL3008

Redbank Creek Flood Study

NSW GOVERNMENT

Manly Hydraulics Laboratory

4.3 Aerial photography

The most recent available aerial imagery was obtained from Google Earth (www.googleearth.com), captured in 2023 to observe current features within the study area. Some high-resolution (0.075 m resolution) aerial imagery from 2 November 2023 was also available from Nearmap for the township of North Richmond.

4.4 Council's drainage network

Council's drainage network GIS layers were reviewed to determine the adequacy of the data for flood modelling purposes. A map of the drainage network within the study area is shown in **Figure 4.6**.The review identified some missing data required for modelling the stormwater network and the main observations are summarised as follows:

- Pipe / culvert data including approximate locations and sizing were available for the majority of the catchment, but no invert level was provided.
- Information for several pipes was unknown along Shortland Close, Bells Line of Road, Yobarnie Avenue and between Elizabeth Street and Pecks Road. Most of the missing pipes with unknown diameter were inspected to obtain basic dimensions during the site visit (except for the area nearest to the Hawkesbury River where no flooding was observed in our preliminary model).
- Drainage network in the senior housing development located directly east of Yobarnie Ave and the residential development are north of Grose Vale Road was not included in Council's drainage network data; however, PDFs of the Work as Executed have been provided for these locations to facilitate the estimation of the pits and pipes.
- Locations of pits were mostly available; however, the provided data did not include invert levels or pit sizes. The inlets and outlets of the drainage system were checked to ensure alignment with the available elevation data and aerial imagery (e.g., confirming that headwalls are not positioned just outside of a dish drain). Consequently, the positions of several pits were adjusted to properly align with the stormwater lines.

It is noted that for the purpose of flood modelling, a minimum pipe diameter of 0.3 m was included in the hydraulic model. A minimum cover depth of 300 mm was assumed for all provided pits using standard pipe grading as a guide to ensure hydraulic continuity. All kerb-type pits were assumed to be 1800 mm wide and 100 mm high.

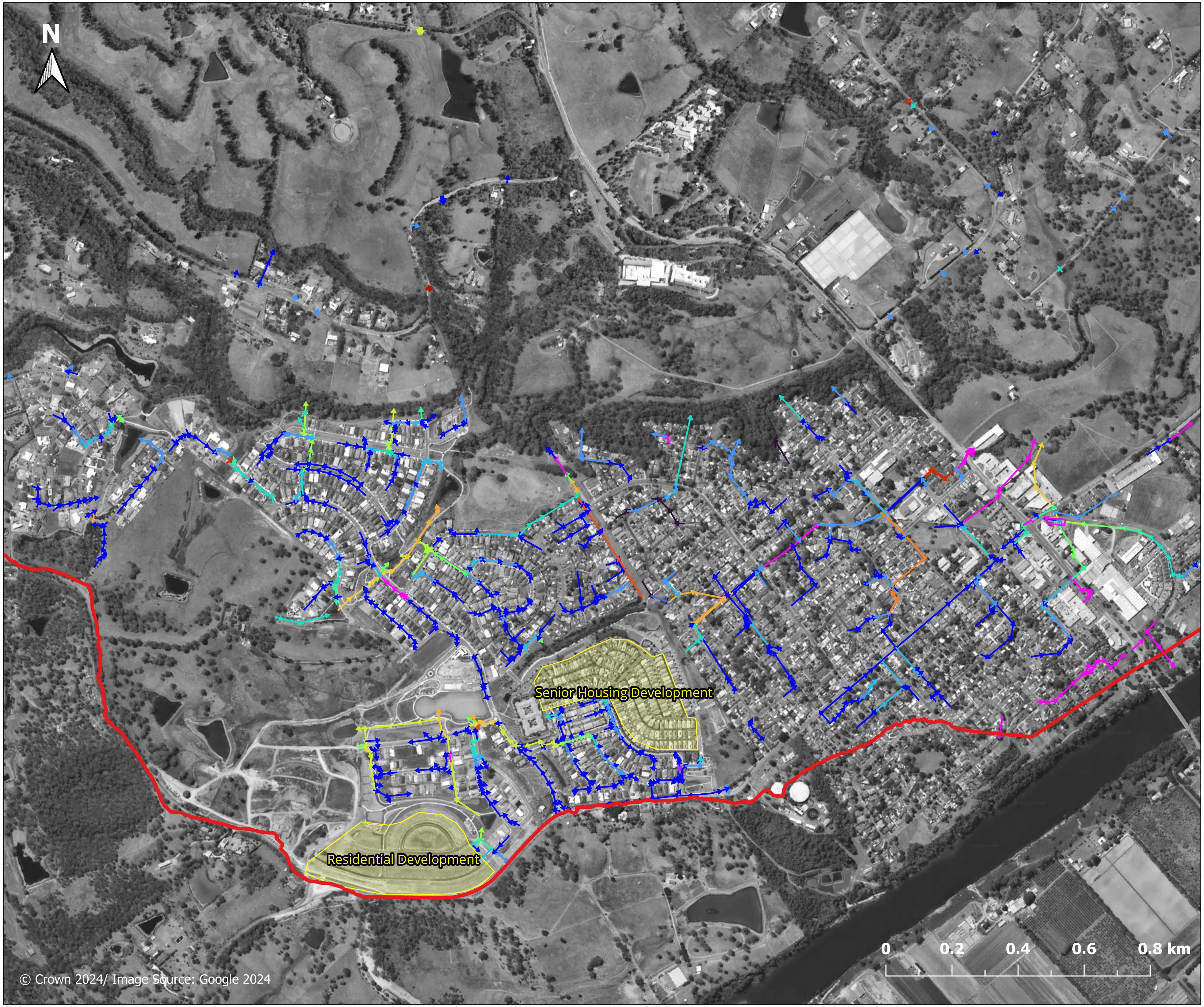

Figure 4.6

Drawing network

Legend

Study area

Pipe diameter (mm) from Council's stormwater drainage network dataset

- 300
- 375
- 400
- 450
- 525
- 600
- 675
- 750
- 825
- 900
- 1050
- 1200
- 1350
- 1500
- 1800
- 3000
- Unknown Dimension

Report MHL3008

Redbank Creek Flood Study

NSW GOVERNMENT

Manly Hydraulics Laboratory

5 Site inspection

A site inspection was carried out by the MHL project team on Thursday 2nd of November 2023. The purpose of this inspection was to gain an overall appreciation of the relevant characteristics of the area and to identify areas that either contributed to flood risk or that were subject to the greatest flood risk. A preliminary 1% AEP flood event was run prior to the site inspection to understand the main flow paths within the study area. A number of hydraulic structures including bridges, culverts, and pipes were then inspected within the study area. The goal was to assess the dimensions of these structures and gather information to fill any gaps in the data provided by the Council. During this inspection, the dimensions of key pipes / culverts along main flow paths were verified to confirm the accuracy of the barrel / pipe sizes as indicated in the Council's data. **Figure 5.1** and **Figure 5.2** present the various hydraulic structures that have been inspected during the site inspection. The following key observations were made:

- In the western part of North Richmond, new developments including residential constructions, have been initiated and are still in progress.
- The dimension of the majority of pipes appeared to be correctly recorded in Council's database.
- Some structures not included in Council's dataset were inspected during the site visit including:
  - Two pits and associated 375 mm diameter pipes at the intersection of Terrace Road and Bells Line of Road (items 24 and 25).
  - A large 900 mm pipe led to 2 × 750 mm diameter pipes within a sag pit in an open area between Williams Street and Bells Line of Road (item 30). It was noted that access to measure exact size was restricted and only the outer part of the pipes was measured and are therefore indicative.
  - A small 1.2 m tall weir was observed underneath a wooden bridge near Kuyper Christian School (item 41).
- It was also noted that the upstream catchment is subject to significant developments known as the Redbank development and therefore, the 2019 LiDAR data is not always representative of the current upper catchment conditions. Hence, further information was provided by the Council.
- Seven bridges were inspected including two along Terrace Road (items 1 and 2), one along Crooked Lane (item 3), a footbridge in the open area at the back of Monti Place (item 33), a footbridge in the open area near Tyne Crescent (item 37), a small timber bridge along a bush track near Redbank Road (item 41), and a large bridge along Bells Line of Road (item 39). The data collected during the inspection for bridges was length, width, railing height, and location and informed the flood modelling. Example of bridges photographs are shown in **Figure 5.3.**

- Seventeen culverts were inspected within the study area. The data collected during the inspection included the number of barrels, diameter or width / height, and location of each culvert. One of the culverts was found heavily blocked between Pecks Road and Elizabeth Street, as shown in **Figure 5.4**.

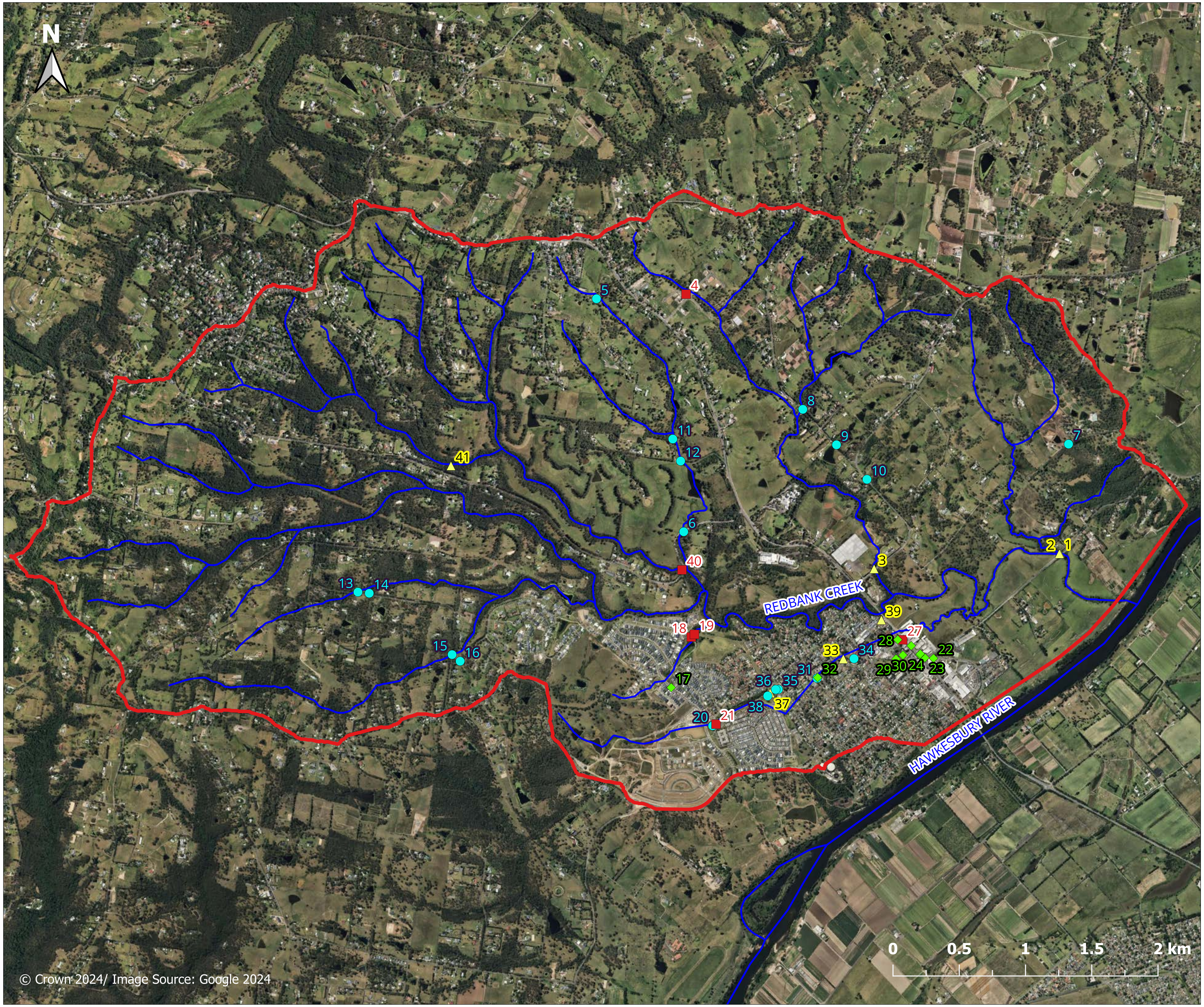

Figure 5.1

Inspected hydraulic structures within the study area

Legend

- Study area
- Watercourses

Inspected hydraulic structures

- Bridge
- Box culvert
- Circular culvert
- Pits and pipes

Report MHL3008

Redbank Creek Flood Study

NSW GOVERNMENT

Manly Hydraulics Laboratory

Figure 5.2

Inspected hydraulic structures at North Richmond

Legend

- Study area
- Watercourses

Inspected hydraulic structures

- Bridge
- Box culvert
- Circular culvert
- Pits and pipes

Report MHL3008

Redbank Creek Flood Study

NSW GOVERNMENT

Manly Hydraulics Laboratory

Figure 5.3 Example of photographs of inspected bridges within the study area

Figure 5.4 Photograph of inspected blocked culvert in the urbanised area (North Richmond)

6 Community consultation

6.1 Community questionnaire process

Consultation provides an opportunity for various stakeholders, including the community, to collaborate in providing information for Redbank Creek Flood Study. Engaging with the community throughout the process provides opportunities to both garner useful feedback on key areas of concern and ideas regarding future potential flood management measures and increase community acceptance of the flood study.

A project website was developed to provide information about the study, general flooding information, and a link to an online community questionnaire. A snapshot of the project website and a copy of the community questionnaire are presented in **Appendix B**.

6.2 Community questionnaire results

A total of seven responses were received from the online questionnaire. The approximate location of properties that participated in the questionnaire is also shown in **Appendix B.**

The following key observations were made based on the community questionnaire responses:

- All the seven responses indicated that the property is owner-occupied.
- Six responses specified the property type as residential, while one response indicated as other.
- Five residents have lived in the catchment for more than 20 years, one resident between 10 and 20 years, and one for less than five years.
- All of the respondents mentioned that only their property yards were affected by flooding.
- One of the respondents provided examples of flood events. The most commonly impacted part of the property included damage to trees and a wall in the yard.
- Observed flood depths were typically described as being over 3 m rise in the creek (three respondents).
- Flooding durations range between one day and 10 days (two respondents describing flooding as lasting for one day while one describes flooding as lasting for 10 days).
- The flood water was described as having a running pace by three respondents and as having a walking pace by three respondents.
- The main sources of flooding (six respondents) were described as the water flowing from Redbank Creek with floodwater rising in the Creek, Hawkesbury River inundation (one respondent), and overflow from neighbouring properties, followed by ponding of water within property.
- Two of the respondents reported that there are flood marks near the property.
- One of the respondents provided photographs as well as videos. Example of photographs are provided in **Figure 6.1** and **Figure 6.2**.

- The main concerns and suggestions from the respondents regarding flooding was the new development in the Redbank Creek catchment and the potential this development may have on increasing flooding. Respondents ask council to conduct studies to understand downstream impacts of these developments.

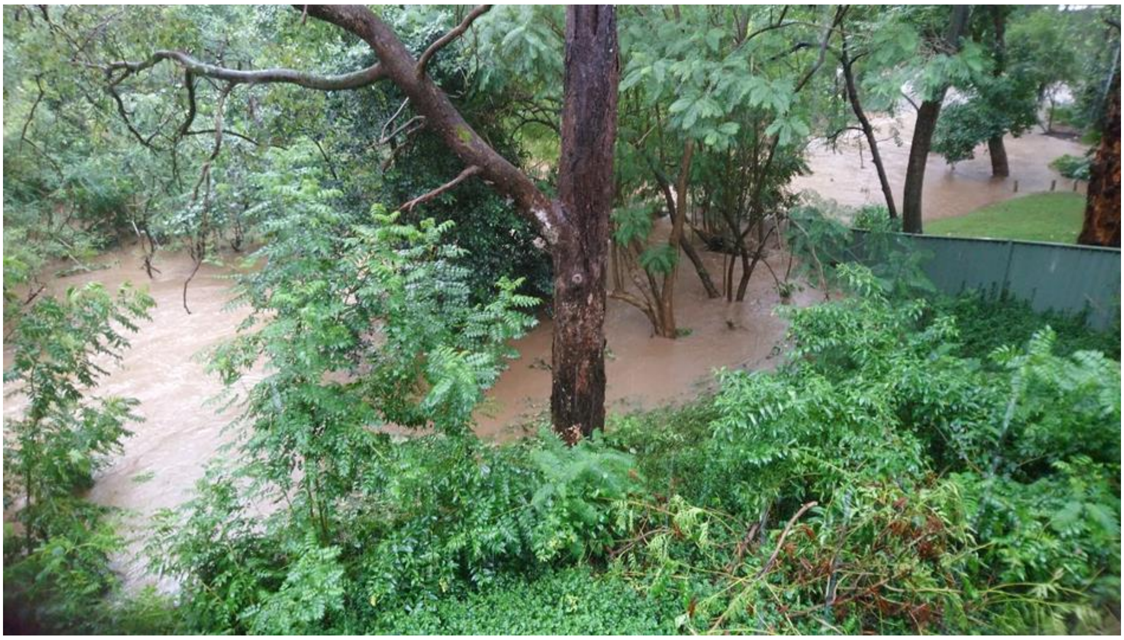

Figure 6.1 Flooding at the back of Susella Crescent on March 2022 (Courtesy of a community member)

Figure 6.2 Flooding in 2020 (location is unknown) (Courtesy of a community member)