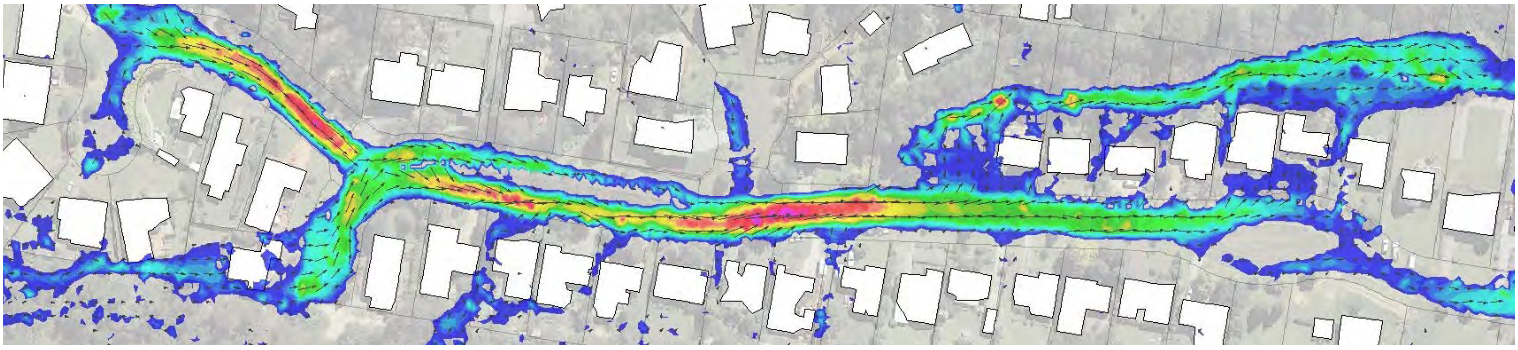


HAZELBROOK AND WOODFORD CATCHMENTS MAINSTREAM AND OVERLAND FLOW FLOOD STUDY

STAGE 4 – DRAFT FLOOD STUDY REPORT

Report MHL2174-3
May 2013

Prepared for
Blue Mountains City Council

Hazelbrook and Woodford Catchments Mainstream and Overland Flow Flood Study

Stage 4 – Draft Flood Study Report

Progress Report MHL2174-3
May 2013

Bronson McPherson
NSW Public Works
Manly Hydraulics Laboratory
Assistant Principal Engineer
110b King Street
Manly Vale NSW 2093
T: 02 9949 0200
F: 02 9948 6185
E: Bronson.McPherson@mhl.nsw.gov.au
W: www.mhl.nsw.gov.au

Document Control

Issue/ Revision	Author	Reviewer	Approved for Issue	
			Name	Date
Draft Flood Study	L Collins, MHL	B McPherson, MHL Ted Rigby, Rienco	B McPherson, MHL	23/05/2013

Progress Report MHL2174-3
PW Report No. 12093
MHL File No. FH-00131
First published May 2013

Manly Hydraulics Laboratory is Quality System Certified to AS/NZS ISO 9001:2008.

Foreword

This detailed flood study for the Hazelbrook and Woodford catchments has been prepared in accordance with the New South Wales Government's Floodplain Development Manual (2005). The manual guides implementation of the NSW Government's Flood Prone Land Policy (2005), which aims to reduce the impacts of flooding on communities and existing development, and to ensure that future development is compatible with flood risk.

Under the policy, primary responsibility for floodplain risk management rests with local government. Financial and technical assistance is provided to councils by the NSW Government's Office of Environment and Heritage (OEH).

The Floodplain Development Manual (NSW Government 2005) defines the following steps in the Floodplain Risk Management Process:

- Formation of a Floodplain Risk Management Committee
- Data Collection
- Flood Study Preparation
- Floodplain Risk Management Study Preparation
- Floodplain Risk Management Plan Preparation
- Floodplain Risk Management Plan Implementation.

Blue Mountains City Council has formed a Floodplain Risk Management Committee in order to complete a comprehensive Floodplain Risk Management Plan for the Hazelbrook and Woodford catchments. The Hazelbrook and Woodford Catchments Mainstream and Overland Flow Flood Study constitutes the first phase in the process and aims to define existing flood behaviour within the study area. The outcomes of the study will provide the basis for the subsequent preparation of a Floodplain Risk Management Study and Plan.

Contents

APPENDICES

TABLES

FIGURES

APPENDIX FIGURES

1. Introduction

1.1 Preamble

NSW Public Works (NSW PW) was engaged by Blue Mountains City Council (Council) to undertake the Hazelbrook and Woodford Catchments Mainstream and Overland Flow Flood Study. The aim of the study was to define flood behaviour within the study area under existing conditions.

The study provides a holistic assessment of flooding within the study area, including integrated investigation of overland and mainstream flood flows. The potential influence of climate change on flood impacts has also been considered.

The study has been prepared to meet the objectives of the NSW Government Flood Prone Land Policy and has received financial assistance from the NSW Office of Environment and Heritage (OEH) under the NSW Floodplain Management Program. The models and results produced in this study are intended to form the basis for a subsequent Floodplain Risk Management Study and Plan.

A staged approach to this study has been adopted as outlined below:

- Stage 1 – Data Collection, Assessment and Community Consultation
- Stage 2 – Model Calibration and Validation
- Stage 3 – Design Flood Estimation and Mapping
- Stage 4 – Draft Flood Study Report and Review
- Stage 5 – Final Flood Study Report

This report constitutes the Stage 4 – Draft Flood Study Report and details the methodology and outcomes of all work undertaken during the project. This report will undergo an exhibition and review period, after which comments will be collated and the Final Flood Study Report prepared.

1.2 Study Location

The Blue Mountains Local Government Area (LGA) is located in the west of the Greater Sydney Region, with a large percentage of the LGA being incorporated into the World Heritage Blue Mountains National Park. Hazelbrook is located approximately 93 km west of Sydney and 17 km east of Katoomba at an elevation of approximately 670 m AHD. The town of Woodford is located immediately to the south-east of Hazelbrook along the Great Western Highway.

The Hazelbrook and Woodford Catchments study area encompasses those areas of the towns of Hazelbrook and Woodford that lie to the north of a ridgeline coinciding largely with the alignment of the Great Western Highway, as shown in Figure 1.1.

1.3 Study Background

Council's flood records indicate that the Hazelbrook and Woodford catchments have had the most significant flood-related issues within the Blue Mountains LGA. A significant amount of flood damage was reported across Hazelbrook following a storm in February 2010, and again in February 2012.

No previous flood studies have been undertaken within the study area, and there is currently no specific flood policy. Recent flood events have increased pressure to undertake investigation of flooding issues.

This detailed flood study was requested by Council in order to define flooding behaviour within the study area, and will form the basis for a subsequent Floodplain Risk Management Study and Plan. The Floodplain Risk Management Study and Plan will identify options to minimise danger to personal safety, reduce flood damage to property, and ensure that future development is compatible with the flood risk.

Council has acknowledged that it wishes to adopt a holistic approach to future floodplain risk management activities. Various aspects of any proposed flood mitigation measures will be assessed, including potential environmental and ecological impacts, and the application of water sensitive urban design principles.

1.4 Study Objectives

In summary, the flood study objectives were to:

- define flood behaviour under historic and existing catchment conditions in the study area including mainstream and overland flooding
- determine flood conditions for the 20%, 10%, 2%, 1% and 0.5% AEP and Probable Maximum Flood (PMF) design events
- provide information on :
  - flood levels, extents, velocities, flows and preliminary flood planning levels and areas
  - hydraulic categories, provisional hazard categories, flood emergency response classification and preliminary true hazard categories
- undertake sensitivity analysis to assess the possible impacts of:
  - variation in hydrologic and hydraulic model parameters
  - changes in rainfall due to climate change
- contribute toward subsequent stages of the floodplain risk management process including provision of a computer model that can be used to assess flood mitigation options.

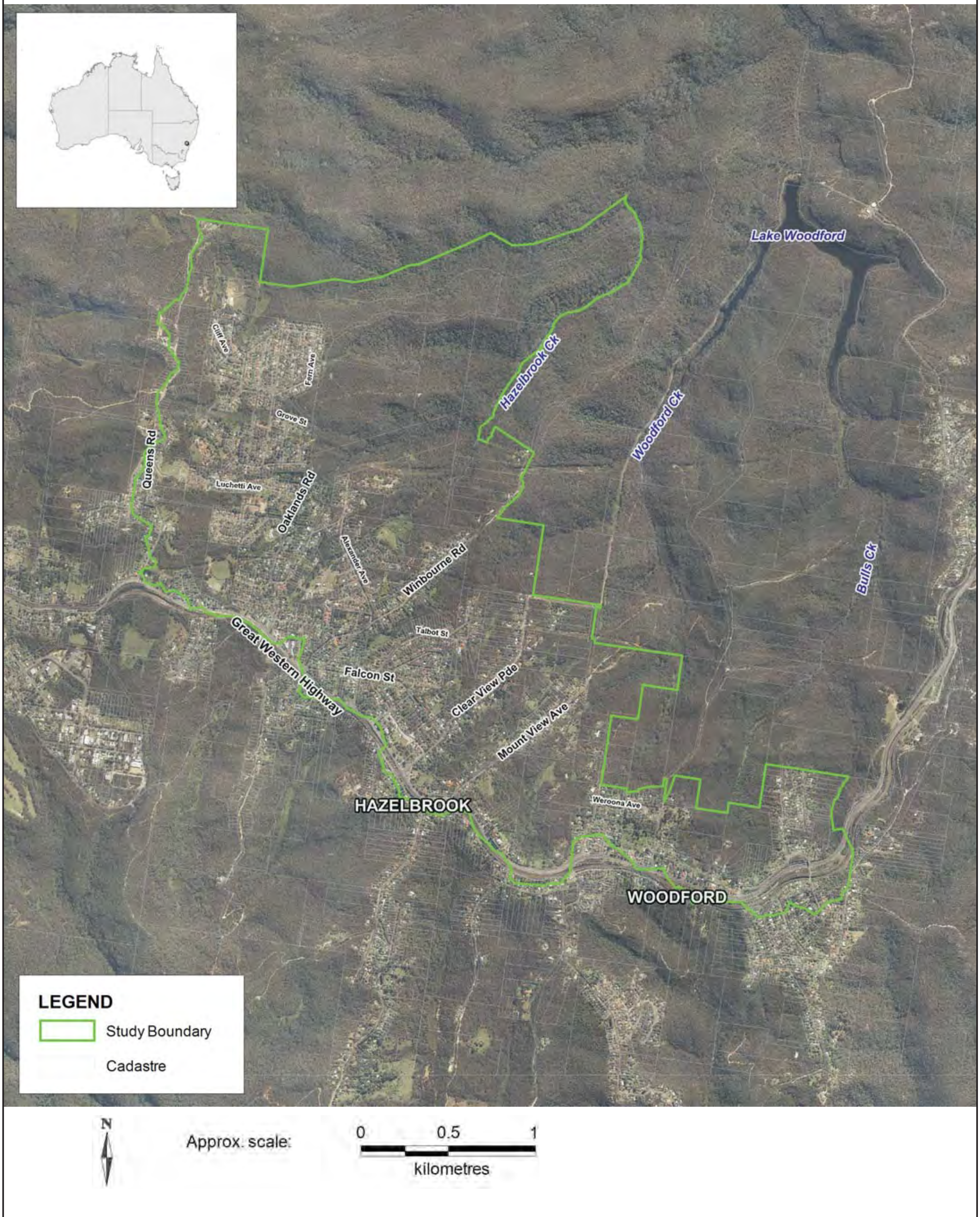
1.5 Study Methodology

The methodology employed in undertaking this study can be summarised as follows:

- site reconnaissance, compilation and review of available information
- identification of additional required data
- community consultation to collect information on historical flood behaviour, identify local flooding concerns and ensure community engagement through the floodplain management process
- set-up of hydrologic and hydraulic models
- calibration, verification and sensitivity testing of historic flood events
- modelling of design events for current conditions
- assessment of flooding impacts
- mapping, reporting and documentation of results.

To date the following tasks have been completed:

- site reconnaissance, compilation and review of available information
- acquisition of additional Airborne Laser Scanning (ALS) data
- community consultation
- set-up of hydrologic and hydraulic models
- model calibration and verification
- modelling of design events for current conditions
- floodplain mapping and reporting.



Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
STUDY AREA

MHL Report 2174

Figure 1.1

DRAWING 2174-01-01.cdr

2. Site Description

The study area includes a number of sub-catchments with a combined area of approximately 7.6 km^2, located on the northern side of a ridge line coinciding largely with the alignment of the Great Western Highway (see Figure 1.1). The sub-catchments drain north and north-east into the upper reaches and tributaries of Hazelbrook, Woodford and Bulls creeks. Woodford and Bulls creeks flow into Lake Woodford before merging with Hazelbrook Creek which finally joins into the Grose River.

Land use within the study area is primarily residential, along with a significant amount of bushland. Other land uses include recreational open space and small commercial zonings. The Great Western Highway and a railway corridor pass through the south of the study area. Recent developments such as the Great Western Highway upgrade, Hazelbrook Shopping Centre and the Log Bridge Place residential development have been identified by residents as potential contributors to flooding downstream.

The study area consists of a series of ridges and steep valleys; whilst primarily located upon the ridges, development has also occurred within the upper parts of the valleys. Runoff from the various sub-catchments drains toward the valleys to form several intermittent creeks, some of which contain 'hanging swamp' in their upper reaches. While drainage easements have been allocated in many such areas, residential development has encroached upon and altered a number of natural creek lines, parts of which have been converted into concrete channels. An extensive system of pits and pipes also discharges into the natural drainage lines, with culvert systems in place to allow passage of stormwater flows beneath intersecting roads. An apparent increase in siltation and growth of introduced plant species in areas of hanging swamp is perceived by residents to have contributed toward the severity of recent flood events.

The presence of hanging swamps, along with shallow bedrock (as evidenced by numerous rock outcrops), is likely to be an influence on hydrology and runoff generation in the study area (Hawkesbury-Nepean CMA 2008). During wetter periods, such as occur during La Niña events, water is retained by the slow draining soils of the hanging swamps and the groundwater table can remain elevated for some time. When these conditions persist, further rainfall is rapidly transformed into runoff. Conversely, following prolonged dry periods, such as may occur during El Niño events, the sandy soils of the hanging swamps can become comparatively dry, allowing significant infiltration and attenuation of rainfall.

Hanging swamps are highly sensitive to changes in natural flow volume and water quality due to their highly erodible, low-nutrient soils. Increases in the volume and velocity of stormwater flowing through a swamp can result in severe erosion, while associated increased nutrient inflows can result in proliferation of weed species (Hawkesbury-Nepean CMA 2008).

Location of culvert crossing on Oaklands Road, Hazelbrook

Hanging Swamp to the north of Grove Street, Hazelbrook

3. Data Collection

3.1 Topographic Data

NSW PW was initially provided a raw topographic data set for the study area captured via Airborne Laser Scanning (ALS) in 1999. This data was used to create a high resolution (1 m grid) digital elevation model (DEM) which, upon review, highlighted significant 'noise' in the ALS data. Further investigation revealed large discrepancies in elevation between neighbouring data points from overlapping ALS runs. This data set was considered unsuitable for flood modelling purposes and its use would have cast uncertainty over the flood study outcomes.

A second ALS data set was captured by Photomapping Services on 18 June 2012. The ALS survey covered the study area plus a buffer zone with an average point spacing of 0.7 m. The raw ALS data was post-processed by Photomapping Services to remove non-ground features, such as buildings and trees, and was verified against 17 surveyed ground control points. Verification found that the ALS data complied with the requested statistical vertical accuracy of 0.1 m at one standard deviation on clear ground.

NSW PW carried out an independent verification of the data against 55 surveyed ground points comprised of Permanent Marks, State Survey Marks and Photomapping Services' ground control points. This independent verification indicated a slightly lower vertical accuracy than that reported by Photomapping Services, however, a number of the ground points included in the analysis were located in vegetated areas where a lower ALS point density is achieved and a lower accuracy is expected. The recaptured ALS data was found to meet the level of coverage and accuracy required to achieve quality representation of terrain for the purposes of flood modelling, and was adopted for use in the Hazelbrook and Woodford Creeks Catchments Flood Study.

A high resolution DEM (1 m grid) was derived from the 2012 ALS data, as presented in Figure 3.1. Elevation in the study area ranges from approximately 470 m AHD at the downstream extent of Hazelbrook Creek to approximately 730 m AHD along the ridge forming the western study boundary. The majority of the development in the towns of Hazelbrook and Woodford lies between elevations of approximately 580 and 670 m AHD.

In addition to the ALS data, a number of measurements were made on site to ensure that features such as open channels are properly represented in the DEM.

3.2 Council Data

3.2.1 Geographic Information

A selection of digitally available information was provided by Council in the form of GIS data sets. The data was provided on DVD on 11 April 2012 and assumed to be current at this date.

The following Council GIS data have been utilised in the study:

- Cadastre
- 2007 Aerial Photography
- LEP Zoning
- Study Boundary
- Vegetation Communities
- Stormwater Drainage Pipes
- Stormwater Drainage Pits.

3.2.2 Stormwater Drainage Network

It was noted by Council that the locations of pits and pipes in the provided Stormwater Drainage Pits and Stormwater Drainage Pipes GIS layers are approximate due to the method of data capture. In a number of instances NSW PW made minor adjustments to the locations of pits and pipes to conform with aerial photography, topographic information and site observations. Modelled pit depths were also adjusted in some instances to ensure connecting pipes were sloped in the correct direction.

3.3 Rainfall Data

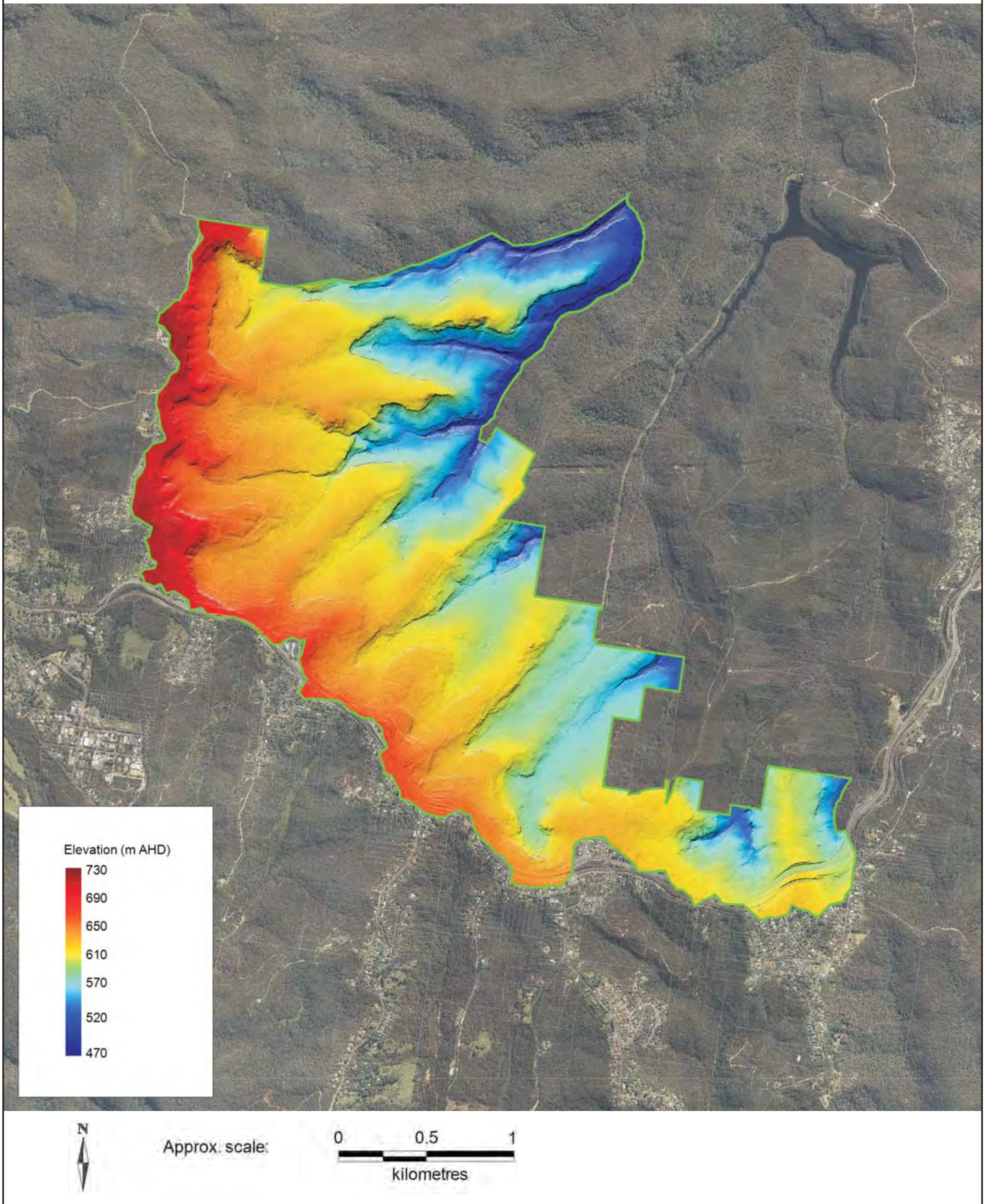
Through consultation with various agencies one continuous rainfall gauge (pluviometer), operated by Sydney Water, was identified within the study area and another identified within the lower Woodford Creek catchment, operated by Sydney Catchment Authority (SCA). The locations of these gauges are shown in Figure 3.2. Data from a pluviometer at Wentworth Falls, approximately 9 km west of the study area, was also reviewed. Metadata for each pluviometer is presented in Table 3.1.

Table 3.1 Pluviometer Metadata

Station Code	Station Name	Agency	Start/End Date	Data Type
563065	Hazelbrook STP	Sydney Water	1982–present	Continuous
563070	Linden (Woodford Creek Dam)	SCA	1986–present	Continuous
563061	Wentworth Falls (Bodington)	SCA	1990–present	Continuous

In addition to these pluviometers, a number of nearby daily rainfall stations operated by the Bureau of Meteorology (BoM) were identified. Data from these stations was acquired, however, given the availability of reliable continuous rainfall data at locations of greater relevance to the study, this has not been used.

The presence of a water level gauge at Lake Woodford was also investigated, however the operator, SCA, was unable to provide this data.



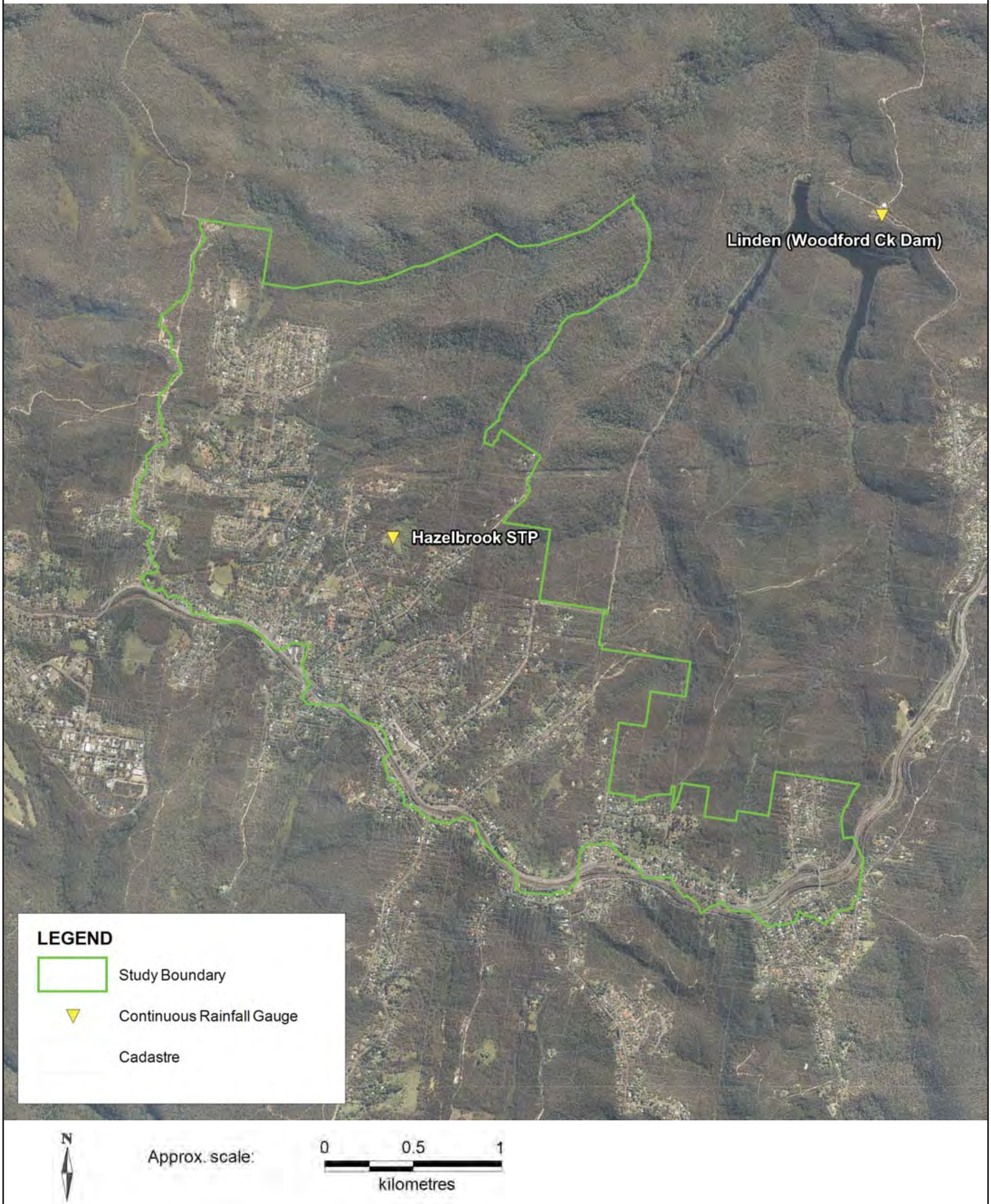
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
TOPOGRAPHY

MHL Report 2174

Figure 3.1

DRAWING 2174-03-01.cdr



Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
RAINFALL GAUGES

MHL Report 2174

Figure 3.2

DRAWING 2174-03-02.cdr

4. Community Consultation

4.1 Community Consultation Program

A major part of the success of the floodplain management process lies in the effective engagement of the community in its development. Community consultation during this phase of the process has aimed to inform the community about the flood study and to garner information regarding historical flooding events, flooding concerns and ideas on potential floodplain management measures.

The primary components of the consultation process for this study have included:

- newspaper article informing the community of the study
- provision of information on Council's website
- distribution and collation of a Community Survey.

4.2 Community Flood Survey

4.2.1 Overview

In August 2012 a community survey form and supporting information was distributed by Council to land owners, residents and businesses within the study area, and was also made available online. The survey sought information regarding historical flooding events that may be useful in the calibration and validation of flood models, and also provided an opportunity for the community to contribute their concerns and ideas regarding the management of flooding issues. A copy of the survey form is included in Appendix C.

A total of 152 responses to the survey were received by Council and forwarded to NSW PW along with accompanying flood photography and video. Information regarding community flood experience derived from the completed surveys is summarised in Table 4.1.

Table 4.1 Summary of Community Survey Responses

Number of Responses Received	Experienced Property Flooding		
	No	Yes	House Flooded
152	31	121	25

A number of residents reported significant flooding of their property, of which 25 reported above-floor flooding of their home. The most prominent flood events identified in the survey responses occurred on 11 February 2012 and 6 February 2010.

4.2.2 Community Concerns and Suggestions

Flooding concerns raised by the community and their suggestions for resolving flooding problems are summarised in Table 4.2 and Table 4.3 respectively.

Table 4.2 Flooding Concerns Raised by the Community

Issue or Concern Raised	Number of Times Raised
Lack of kerb and guttering	21
Increased runoff from upslope development	17
Blockage of drains and gutters	12
Damage to road surfaces	8
Erosion of creek banks, flowpaths and hanging swamps	6
Blockage, excessive vegetation and siltation in drainage easements	5
Structural maintenance of drainage system needed	4
Flooding of grass areas adjacent to roads	4
Infilling of natural creeks	2
Flooding of pedestrian access to Woodford Station	2
Lack of drainage easement locations	1
Continuous flow from hanging swamp	1
Presence of natural spring on property	1

Table 4.3 Community Suggestions to Address Flood Problems

Suggested Management Option	Number of Times Raised
Upgrade the existing drainage system	31
Install kerb and guttering	28
Regular clearing of drain and gutter blockages	13
Clear drainage easements including excess vegetation and silt	12
Install footpaths and/or raise nature strip	5
Maintenance and/or upgrade of road	5
Maintenance of damaged drainage assets	4
Upgrade natural creek or easement to concrete channel or pipes	2
Maintain vegetated areas and prevent increase in impervious areas	1
Reinstate natural creek lines	1

The most commonly raised issues regarding the perceived causes of flooding include:

- a lack of kerb and guttering
- increased runoff as a result of development upslope
- blockage of drains and gutters.

Common community suggestions to address flooding problems include:

- upgrade the existing drainage system – this includes suggestions such as increased pit and pipe sizes, installation of additional pits and pipes, raising of existing gutter levels and upgrading of existing stormwater channels
- install kerb and guttering
- regular clearing of drain and gutter blockages
- maintenance of drainage easements, including removal of excess vegetation and silt.

Possible flood mitigation options are to be assessed in later stages of the floodplain risk management process.

4.2.3 Consideration of Data for Model Calibration

Limited information appropriate for the purposes of flood model calibration was identified from the survey responses. Flood level information was generally adopted for calibration purposes only where specific dates were provided and levels could be substantiated by photographic evidence or inspection of flood marks.

Flood level information derived from the survey responses and adopted for use in model calibration is further discussed in Section 6.

5. Numerical Model Development

5.1 Modelling Approach

Numerical computer models have been adopted as the primary means of investigating flood behaviour throughout the Hazelbrook and Woodford catchments study area. When used carefully, modern computer models allow simulation of flood behaviour over large areas in a cost efficient and reliable manner.

For this study, the TUFLOW 2D/1D hydraulic modelling software package was selected. TUFLOW was considered suitable to replicate the complex 2D nature of overland flow patterns in the urban study catchments, due to its ability to allow:

- accurate representation of all overland flow paths in 2D
- accurate representation of stormwater drainage components in 1D and link these to the 2D model domain
- direct application of rainfall over the study area to simulate development of overland flows (as opposed to applying mainstream flows only)
- production of high quality, GIS compatible flood mapping outputs.

While hydrologic rainfall-runoff processes have been represented within TUFLOW using the direct rainfall method, a separate hydrologic model has also been developed using the WBNM software. This model provided further verification of the TUFLOW flood model operation and assisted in determining critical design storm duration.

5.2 Hydraulic Model

5.2.1 Model Extent and Layout

The 2D/1D hydraulic TUFLOW model developed covers all areas of the Hazelbrook Creek, Woodford Creek and Bulls Creek catchments that may influence flood behaviour within the study area. This includes a sufficient distance downstream of the study area such that boundary conditions have little influence on flood behaviour within the study area, and all sub-catchment areas contributing to flows at the downstream model extents.

The model extent generally covers the study area as provided by Council. The study area boundary was, however, based on sub-catchment boundaries defined using the 1999 ALS data set. Works associated with the Great Western Highway upgrade have since altered the catchment boundary along the south-west of the study area. This is evident from the 2012 ALS data and the model boundary has been adjusted to reflect this.

The model consists of both a 2D domain and a dynamically linked 1D domain. The 2D domain models flows over the catchment topography using a square grid, while the 1D domain has been used to model drainage pits, pipes and culverts.

The adopted model layout is shown in Figure 5.1.

5.2.2 2D Model Domain and Topography

The 2D hydraulic model domain covers an area of 1143 hectares with a 2 m square grid size selected, resulting in approximately 2,858,200 computational grid cells.

Each square grid cell contains information on ground surface elevation, hydraulic roughness and rainfall loss rates (see Section 5.2.4). The ground surface elevation is sampled at the centre, mid-sides and corners of each cell from a specified DEM. For a 2 m grid this results in DEM elevations being sampled every 1 m. This resolution was selected in order to accurately represent overland flow paths and open channels in 2D.

The DEM used to sample model topography was derived from ALS data acquired in 2012. While this data is of a high quality, a lower ALS data point density is achieved in heavily vegetated areas. In such areas DEM values may be interpolated across distances in excess of the TUFLOW grid size, potentially resulting in less accurate representation of smaller scale topographic features. Where topographic features likely to influence overland flow patterns (such as open channels and embankments) were identified within areas of sparser ALS coverage, 2D TUFLOW z-shapes were used to ensure that only relevant ALS data points were used to interpolate model ground elevations at the feature.

5.2.3 Boundary Conditions

The model boundary conditions consist of the following:

- direct rainfall application over the 2D model domain
- normal-depth calculations at the downstream boundaries.

The locations of the three normal-depth downstream boundaries are shown in Figure 5.1. These boundaries calculate water levels based on inflow rates, hydraulic roughness and bed slope. The boundaries have been placed at distances of 300 m to 750 m downstream of the study area so that any backwater influences are limited. Preliminary sensitivity testing showed that model results are not sensitive to the bed slope applied at the boundaries. This is not surprising considering their distance downstream of the study area and the steep nature of the catchments.

5.2.4 Hydraulic Roughness

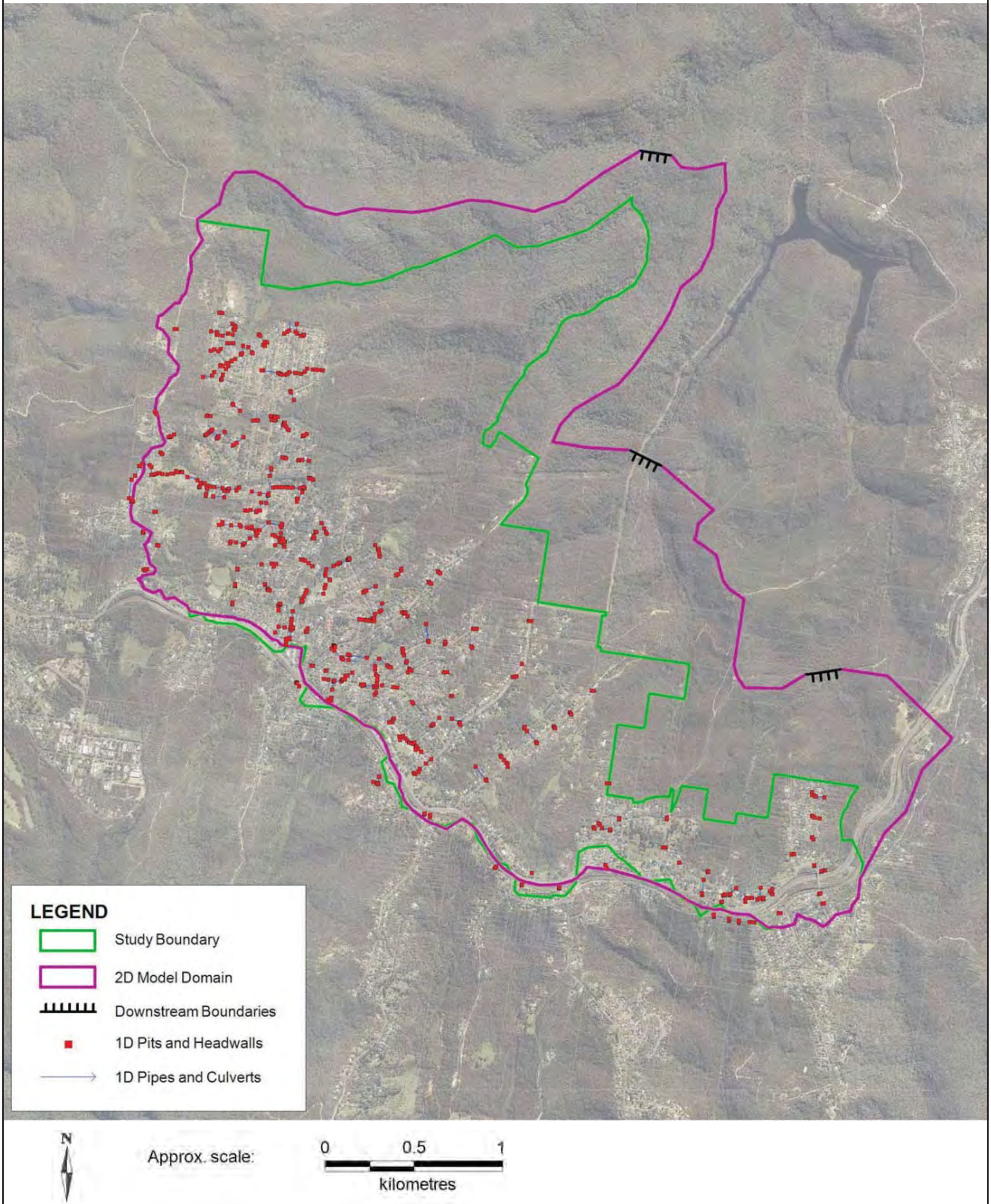
Hydraulic roughness coefficients (Manning's 'n') are used to represent the resistance to flow of different surface materials. Hydraulic roughness has a major influence on flow behaviour and is one of the primary parameters in hydraulic model calibration.

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, cadastral data, vegetation communities, aerial photography and site observations. 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 fences and garden beds. Manning's 'n' values assigned to each zone were determined based on site observations, with reference to standard values recommended by Chow (1959). The effect of buildings on flow behaviour has been represented in the model by applying a high Manning's 'n' value across building footprints to impede flow. 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 have been adopted for this study.

The delineation of hydraulic roughness zones applied in the TUFLOW model is shown in Figure 5.2, and associated Manning's 'n' roughness coefficients provided in Table 5.1. The higher Manning's values are applied at depths below the specified depth range of variable roughness, and the lower Manning's values applied at depths above the specified depth range. At flow depths within the range of variable roughness, applied Manning's values are determined by linear interpolation. Buildings have been modelled as zones of depth-varying roughness, with low hydraulic roughness at shallow depths to represent rapid runoff from roofs, and high hydraulic roughness at higher depths to represent obstruction to flow.

Table 5.1 Adopted Manning's 'n' Hydraulic Roughness Coefficients

Material	Depth range of variable roughness (m)	Manning's 'n'
Open Space	0.15–0.75	0.07–0.04
Vegetation – medium density	1.0–2.5	0.1–0.075
Vegetation – high density	1.0–5.0	0.2–0.1
Residential – low density	0.2–1.0	0.1–0.04
Residential – medium density	0.4–2.0	0.15–0.08
Residential – high density	0.4–2.0	0.2–0.1
Commercial	0.2–1.0	0.1–0.04
Creeks	0.3–1.5	0.08–0.06
Open Channel – concrete	0.2–1.0	0.035–0.02
Open Channel – unlined	0.15–0.75	0.1–0.05
Hanging Swamp	0.5–2.0	0.12–0.06
Roads	0.2–1.0	0.03–0.02
Rail Corridor	0.3–1.5	0.2–0.07
Buildings	0.03–0.1	0.1–10



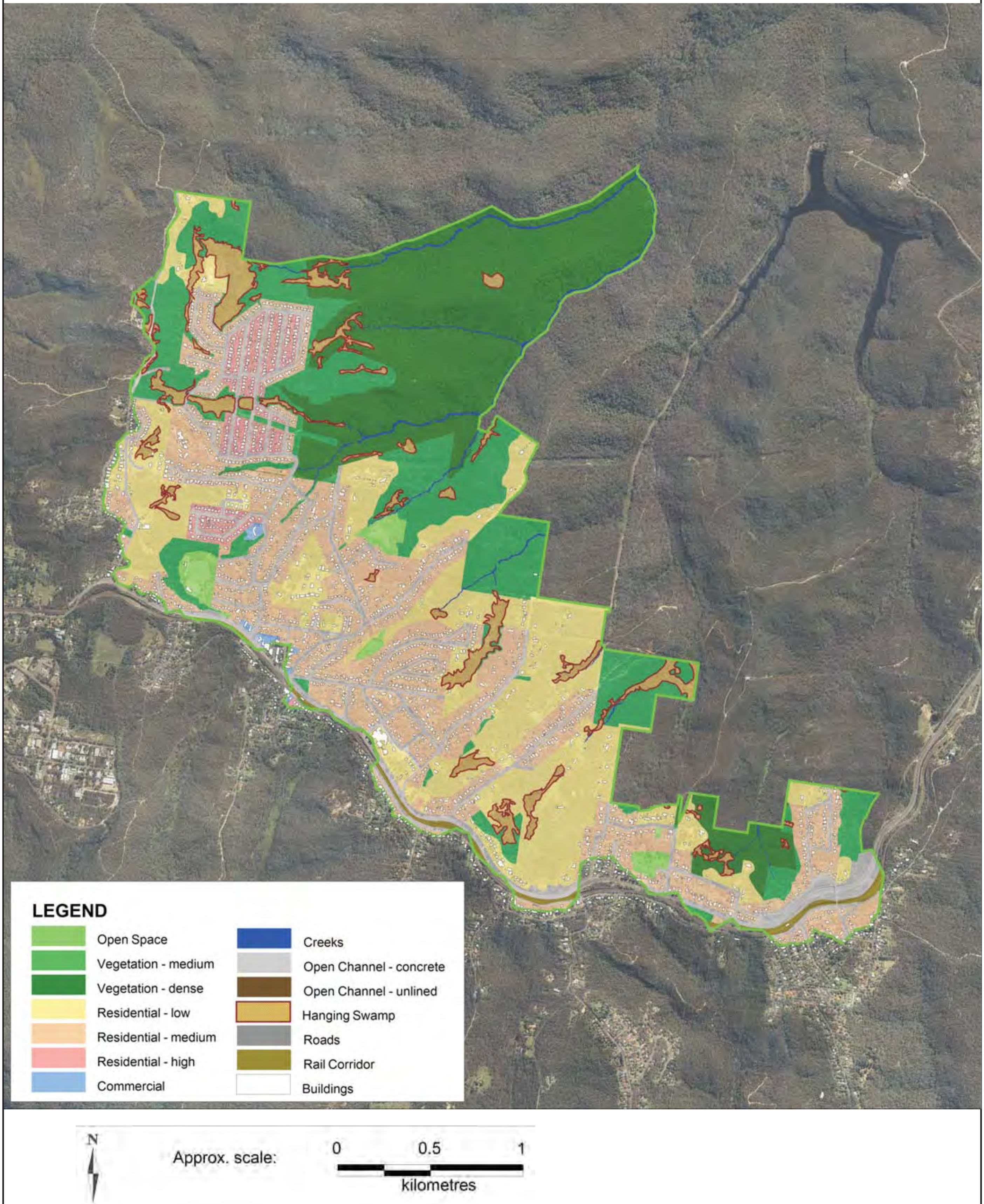
NSW GOVERNMENT Public Works Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
TUFLOW MODEL LAYOUT

MHL Report 2174

Figure 5.1

DRAWING 2174-05-01.cdr



Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
HYDRAULIC ROUGHNESS ZONES

MHL Report 2174

Figure 5.2

DRAWING 2174-05-02.cdr

6. Model Calibration and Validation

6.1 Methodology and Event Selection

Model calibration is an essential step in the flood modelling process to confirm that the model can adequately simulate historical flood events.

In order to carry out model calibration it is necessary to have available suitable recorded data sets against which to evaluate model results. Generally, recorded depth and flow data are not available to allow rigorous calibration and validation of overland flow flood models. Information gathered through the community consultation process, together with recorded rainfall data, therefore acts as the primary basis for model calibration. The reliability of peak flood depth data collected through community consultation can be highly variable. Flood level information was, therefore, adopted for model calibration only where specific dates were provided and levels could be substantiated by photographic evidence or inspection of flood marks.

While several flood events were prominent in the community survey responses, only the February 2012 event garnered information of a level of detail and reliability considered sufficient for use in model calibration. The February 2012 event was, therefore, adopted as the primary calibration event.

As little data is available against which to validate the model, NSW PW has undertaken additional model verification through comparison of flow hydrographs computed by TUFLOW with those produced by an alternative WBNM hydrologic model.

6.2 Model Calibration - February 2012

6.2.1 Rainfall Data

The rainfall leading to flooding in Hazelbrook and Woodford on 11 February 2012 fell over a duration of less than 1 hour. Continuous rainfall data was therefore required in order to capture rainfall intensity and duration information for the event and drive the model flood simulation.

One continuous read gauge (pluviometer) was active within the study area on 11 February 2012, with two further gauges located in the surrounding area. The cumulative rainfall recorded at these gauges during the period from 1 February 2012 to 15 February 2012 is shown in Figure 6.1.

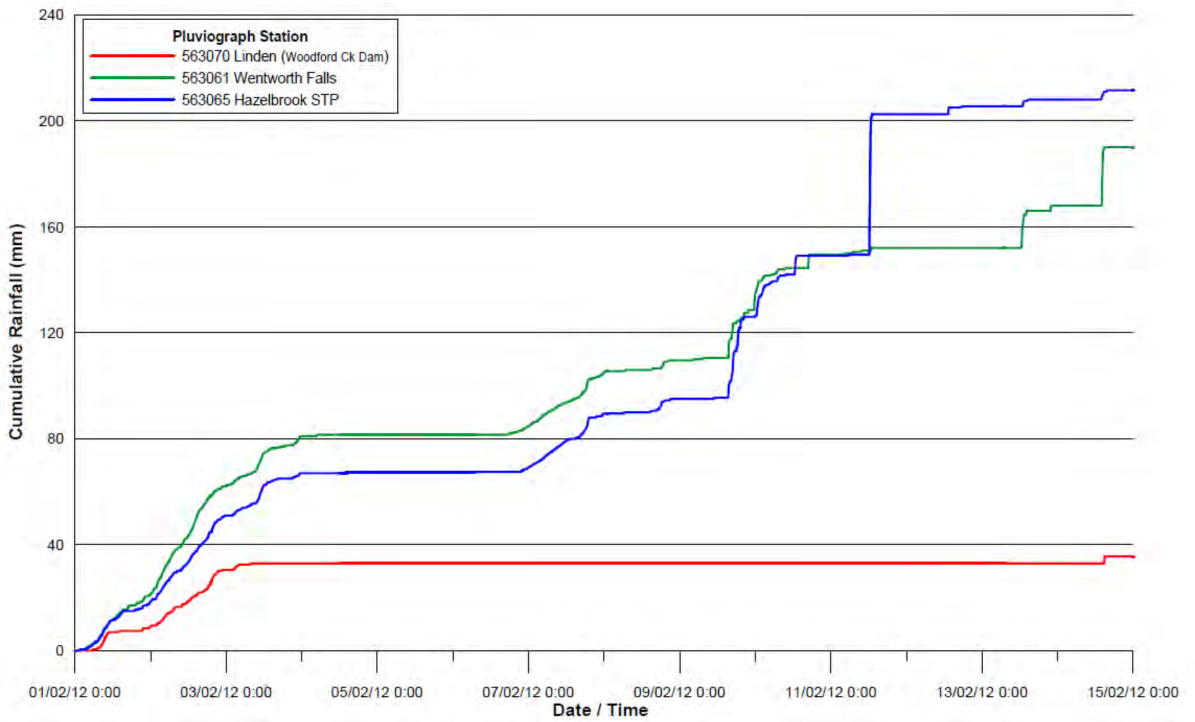


Figure 6.1 February 2012 Cumulative Rainfall

Significant differences are evident in the rainfall records at each site. Cumulative rainfall at Linden was seen to flatline from 3 February to 14 February 2012. Further investigation revealed that the tipping bucket pluviometer at this site was installed in January 2012 and replaced for testing on 13 February 2012 due to discrepancies with surrounding sites. This data has therefore been excluded from use in model calibration. Differences between the Hazelbrook and Wentworth Falls sites are likely to be a result of real spatial rainfall variability. Discussions with residents also indicate that intense rainfall and hail during the storm of 11 February 2012 was highly localised to the Hazelbrook area, with little rainfall observed in various surrounding suburbs.

Data from the Hazelbrook pluviograph station has been adopted for model calibration due to its central location within the study area. Furthermore, the timing of rainfall recorded at the Hazelbrook site on 11 February correlates strongly with the timing of observed flooding. The rainfall hyetograph recorded at Hazelbrook on 11 February 2012 is shown in Figure 6.2. The majority of recorded rainfall fell over a 36-minute period from 12:12pm to 12:48pm Australian Eastern Standard Time (AEST). A BoM Doppler radar image indicating the spatial distribution of rainfall intensity at 12:24pm AEST is shown in Figure 6.3. A pocket of ‘heavy’ rainfall is evident in the Hazelbrook area to the east of Katoomba.

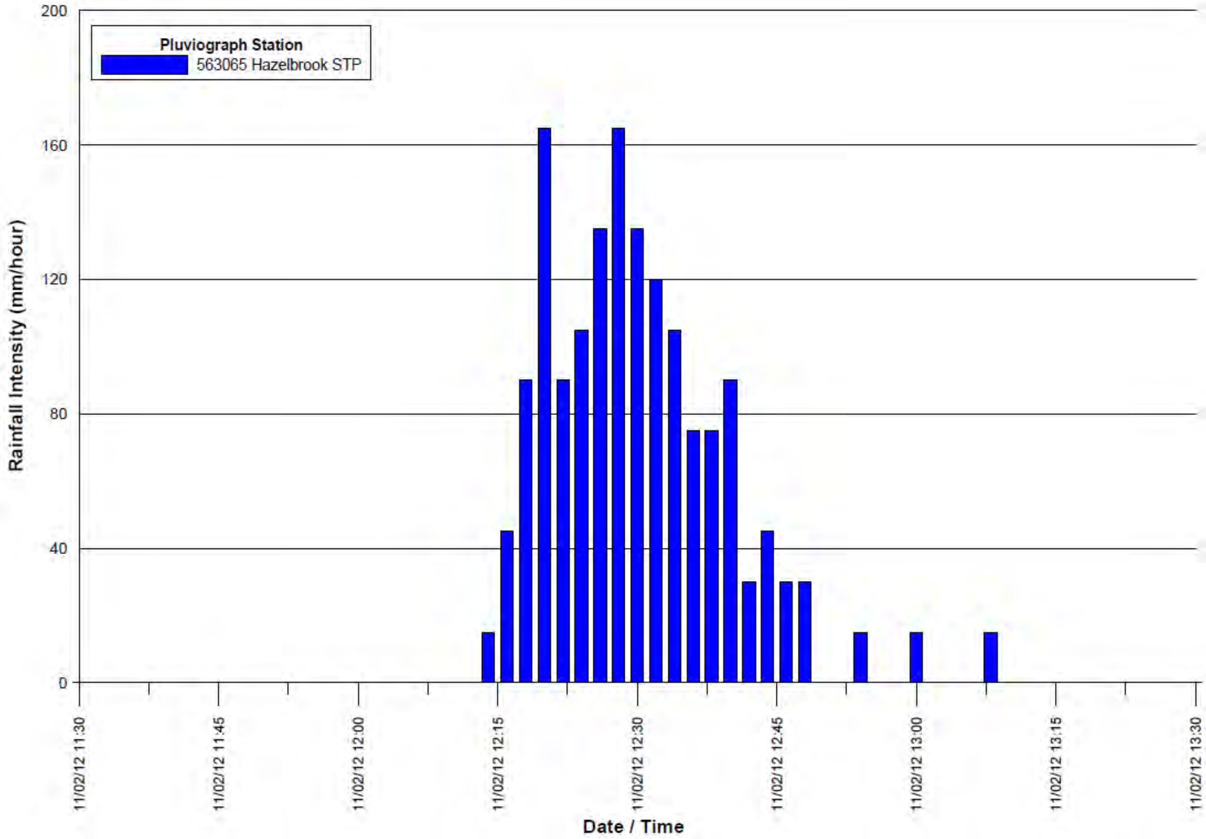


Figure 6.2 February 2012 Rainfall Hyetograph

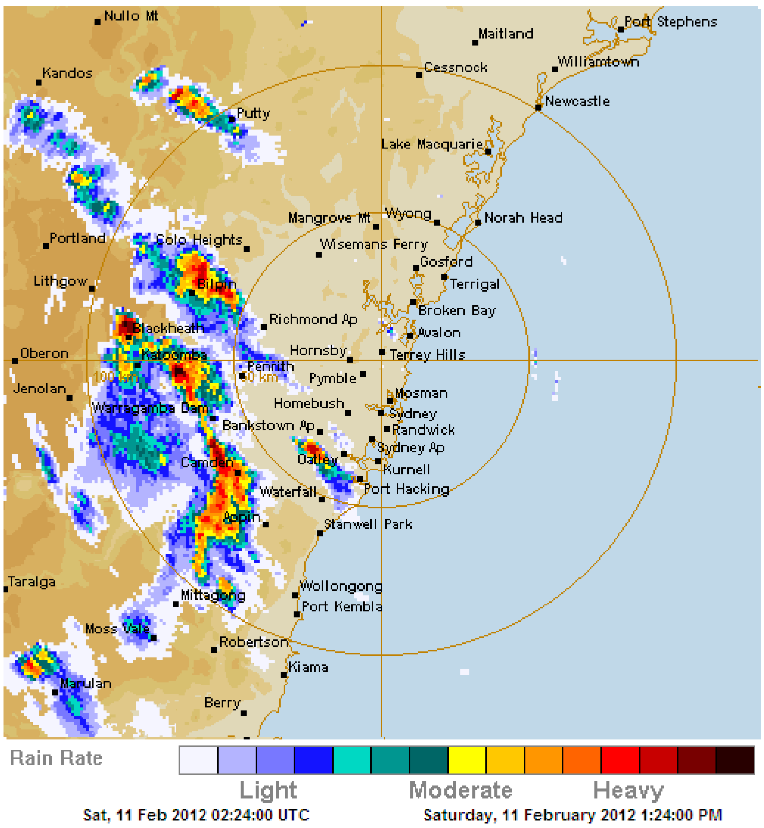


Figure 6.3 February 2012 Radar Image

(Source: BoM)

6.2.2 Intensity-Frequency-Duration Analysis

In order to provide relative context to the intensity of the February 2012 rainfall event, the maximum rainfall depth recorded over a given duration has been compared with design Intensity-Frequency-Duration (IFD) data for Hazelbrook, as shown in Figure 6.4. The February 2012 event was found to exceed the 2% AEP (50-year ARI) design rainfall curve for durations between approximately 15 minutes and 38 minutes. Tabulated comparisons to design rainfall depths are also presented in Table 6.1.

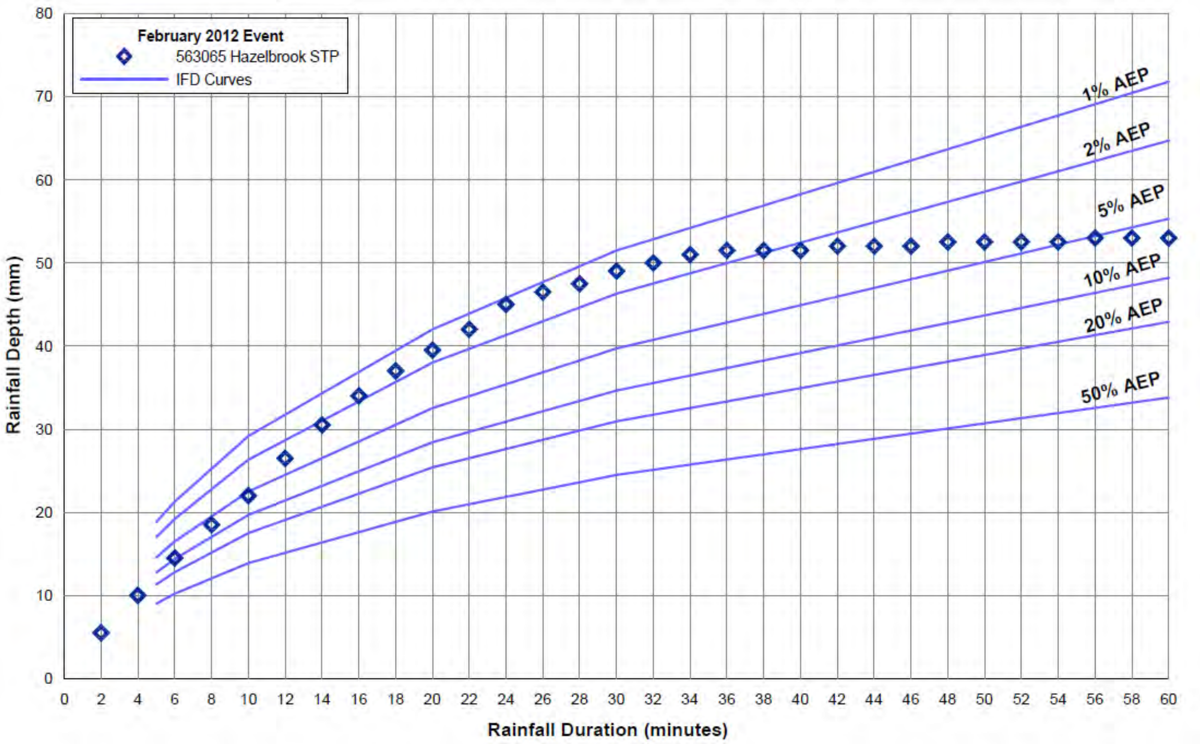


Figure 6.4 February 2012 IFD Comparison

Table 6.1 February 2012 Design Rainfall Comparison

Duration (minutes)	Hazelbrook STP Recorded Rainfall Depth (mm)	10% AEP Design Rainfall Depth (mm)	5% AEP Design Rainfall Depth (mm)	2% AEP Design Rainfall Depth (mm)	1% AEP Design Rainfall Depth (mm)
10	**22**	19.7	22.5	26.3	29.2
20	**39.5**	28.4	32.5	38	42
30	**49**	34.7	39.7	46.3	51.5
60	**53**	48.2	55.3	64.7	71.8

Recorded rainfall exceeds design rainfall depth

6.2.3 Rainfall Loss Parameters

The translation of rainfall into runoff is directly influenced by the antecedent soil moisture conditions throughout the catchment. Rainfall losses are applied in hydrologic modelling to represent the amount of rainfall that does not contribute to runoff as a result of infiltration processes. The initial loss-continuing loss approach is widely accepted and was adopted in this study.

As shown in Figure 6.1, approximately 150 mm of rain had fallen in Hazelbrook during February leading up to the 11 February 2012 event. Considering this, and the slow draining nature of the study catchments, no initial losses were applied in the TUFLOW model. A standard continuing loss value of 2.5 mm/hr was adopted for pervious areas, as recommended for eastern NSW in Australian Rainfall and Runoff (AR&R, Institution of Engineers Australia, 1987). No losses were applied to impervious areas.

6.2.4 Model Calibration Results

6.2.4.1 Comparison with Observed Flood Depth Information

As discussed previously, flood depth information gathered through the community consultation process served as the primary calibration data set. Comparisons between model depth results and substantiated observations of flood depth for the February 2012 event are presented in Table 6.2.

Table 6.2 February 2012 Calibration Results

ID	Location	Observed Flood Depth (m)	Peak Modelled Flood Depth (m)	Difference (m)
1	Grove Street	0.4–0.5	0.44	0.0–0.06
2	Grove Street	0.25	0.38	0.13
3	Oaklands Road	0.3–0.4	0.31	0.0–0.09
4	Oaklands Road	0.3–0.4	0.41	0.01–0.11
5	Luchetti Avenue	Up to 0.5	0.5	0.0
6	Luchetti Avenue	Up to 1.5	1.43	0.0–0.07
7	Talbot Road	0.5–0.6	0.41	0.09–0.19
8	Talbot Road	0.3–0.4	0.33	0.0–0.07

The results in Table 6.2 indicate a high level of correlation between model results and observed flood depths, providing confidence in the model parameters and assumptions made.

Structures such as fences are likely to play a role in a number of the local differences between observed and modelled flood depths. It is, however, unfeasible to model all fences throughout the study area in any level of detail, and their effects would be expected to be fairly localised. The effects of fences on broader scale flow patterns have been allowed for in determining Manning's roughness values for areas of residential land use. A further complication in the model calibration is the likely occurrence of spatially variable rainfall intensity across the study area during the February 2012 event. The actual spatial variation could not be determined from available rainfall data sets.

In addition to the above results, the modelled extent of flood inundation was found to compare well with observed inundation extents and flood photography in several locations.

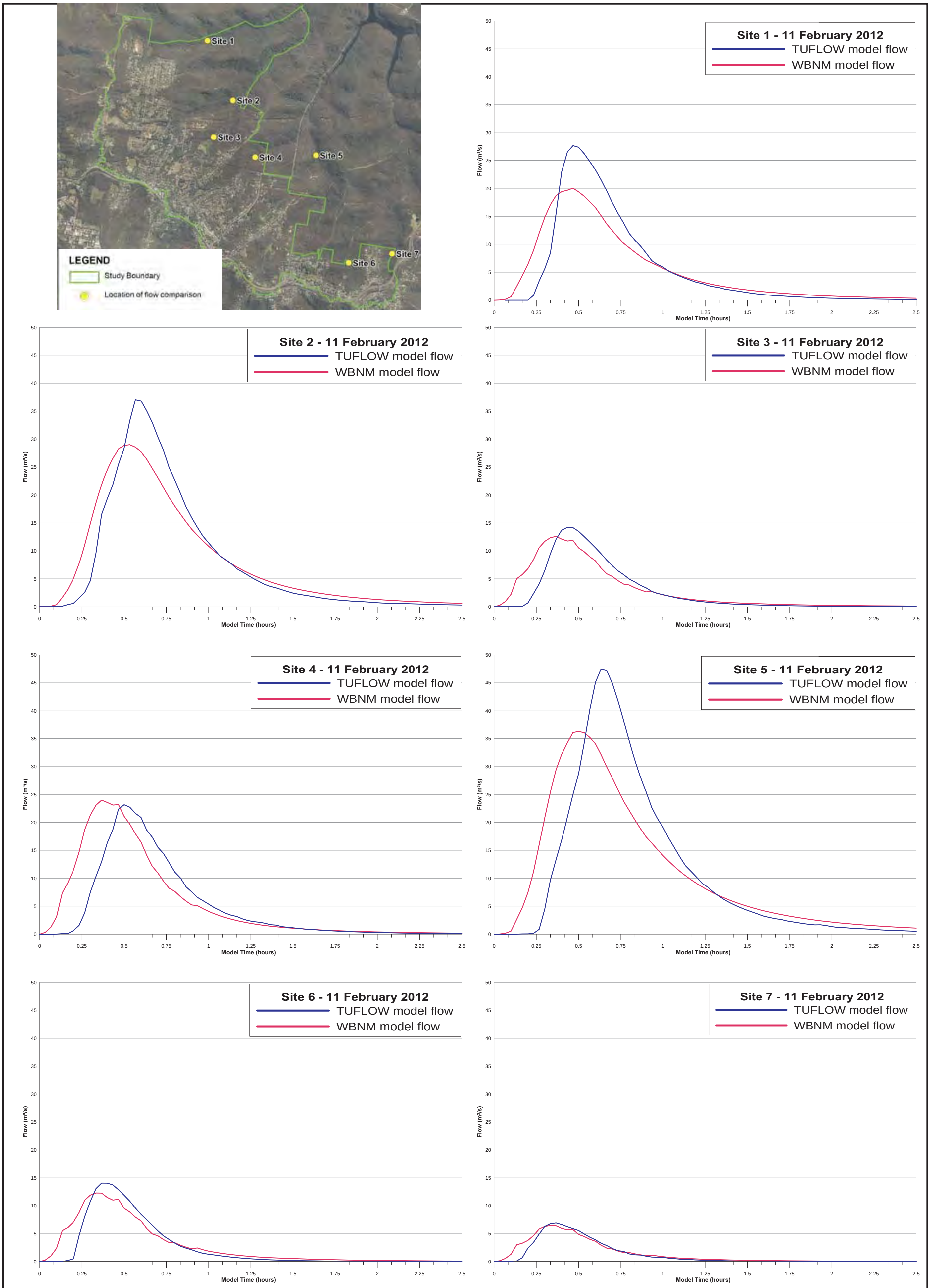
6.2.4.2 Comparison of TUFLOW and WBNM Flow Hydrographs

As no recorded flow data was available in the study area, NSW PW undertook additional model verification through comparison of flow hydrographs computed by TUFLOW with those computed by a traditional WBNM hydrologic model. This provided both an additional means of calibrating model parameters, and a check on the proper operation of the direct rainfall method. A comparison of the resulting flow hydrographs at several locations is shown in Figure 6.5.

The flow hydrographs simulated using TUFLOW and WBNM demonstrate a satisfactory level of agreement with regard to:

- **Total volume.** While minor differences are evident, total volumes are generally in good agreement. Volume differences may be related to storage losses represented in TUFLOW that have not been specifically modelled in WBNM, and possible differences in delineation of sub-catchment areas. The results indicate that volume is being conserved within the rainfall on the grid method.
- **Hydrograph shape.** The TUFLOW hydrographs show greater initial attenuation than those computed by WBNM, and also exhibit a lag in peak flow in comparison to WBNM. This may be related primarily to hydraulic controls and other features which have not been specifically detailed in WBNM. As no recorded stream data is available for calibration, there is also uncertainty regarding suitable parameter values for routing flow through the steep creeks draining the lower study area where flow comparisons have been made. While some adjustment of hydraulic roughness parameters was undertaken in TUFLOW to better fit the WBNM hydrographs, both models rely on a number of underlying assumptions, and further modification to match the less detailed WBNM model was not considered warranted.
- **Peak flow.** In a number of cases peak flows computed by TUFLOW were higher than those from WBNM, while at other locations a strong agreement was shown. The larger differences in peak flows were observed within the steep creek valleys lower in the catchment. These differences are therefore likely to be related primarily to differences in the routing of flows within these steep creeks. While higher peak flows simulated by TUFLOW may result in more conservative flood levels in lower creek reaches, these areas occur within steep valleys well downstream of existing development and this is not, therefore, of concern.

While differences are evident, the results of inter-model comparisons indicate that the different principles of operation in each model are converging on a common result. This provides additional confidence in the catchment runoff response of the TUFLOW model developed, and shows that volume is being conserved within the rainfall on the grid method.



Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
COMPARISON OF MODEL FLOW HYRDOGRAPHS
11 FEBRUARY 2012 EVENT

MHL Report 2174

Figure 6.5

DRAWING 2174-06-05.cdr

7. Design Flood Estimation

7.1 Design Flood Events

Design flood conditions are estimated from hypothetical design rainfall events that have a statistical probability of occurrence. The probability of a design event occurring can be expressed in terms of percentage Annual Exceedance Probability (AEP), and provides a measure of the relative frequency and magnitude of the flood event.

Flood conditions for the 20%, 10%, 2%, 1% and 0.5% AEP and Probable Maximum Flood (PMF) design events have been investigated in this study.

7.2 Design Rainfall

7.2.1 Design Rainfall Intensities

Design rainfall depths for the 20% to 1% AEP events have been derived from standard procedures defined in AR&R (1987) for durations from 10 minutes to 6 hours.

The Probable Maximum Precipitation (PMP), used to derive the PMF conditions, has been estimated based upon the Generalised Short Duration Method (GSDM) as defined by BoM (2003).

Rainfall depths for the 0.5% AEP event has been derived by interpolation between the 1% AEP and PMP rainfall depths using techniques described in AR&R (1987).

The derived average design rainfall intensities are presented in Table 7.1.

Table 7.1 Average Design Rainfall Intensities

Duration (mins)	Design Event Average Rainfall Intensity (mm/hr)					
	20% AEP	10% AEP	2% AEP	1% AEP	0.5% AEP	PMF
10	104.7	117.3	156.3	173.2	190.3	-
20	76.4	85.6	114.2	126.6	139.2	-
30	62.2	69.7	93.0	103.1	113.4	-
60	42.4	47.6	63.7	70.6	77.7	-
90	34.7	39.1	52.6	58.5	64.6	-
120	30.0	33.9	45.9	51.1	56.5	224.7
180	24.4	27.6	37.7	42.1	46.7	-
270	19.8	22.5	31.0	34.7	38.5	-
360	17.0	19.5	26.9	30.2	33.6	-

7.2.2 Temporal Rainfall Patterns

Temporal patterns are required to define the distribution of design rainfall over time throughout the duration of a design event. For the 20% to 0.5% AEP design flood events temporal rainfall patterns from AR&R (1987) were adopted. For the PMF, the GSDM temporal pattern (BoM 2003) was adopted.

7.2.3 Design Rainfall Losses

The initial loss-continuing loss approach was adopted in this study to represent infiltration in rainfall-runoff process.

Zero initial losses have been applied in design modelling. This value has been determined in consideration of the following:

- Traditionally adopted initial loss values incorporate losses due to infiltration, initial storage and other processes. When using the direct rainfall approach with a high resolution DEM, as adopted in this study, losses associated with initial storage are well represented in the 2D domain. Research has shown that such losses can be of the same order as traditionally adopted initial loss values (Taaffe et al. 2011). Initial losses should therefore be lower in a direct rainfall model when compared with a traditional hydrological model (Institution of Engineers Australia 2012).
- The design rainfalls applied are representative of intense bursts of rainfall. Such bursts generally occur within longer storm events (Institution of Engineers Australia 1987) and therefore it is likely that initial losses will have occurred prior to the start of the design storm burst.

Adopted continuing loss values of between 0 and 2.5 mm/hr were applied in design modelling depending on the imperviousness of delineated TUFLOW hydraulic roughness zones. These values are consistent with standard recommended values for eastern NSW in AR&R (1987).

7.2.4 Critical Duration

In order to determine critical storm durations for the study area a series of model runs were undertaken. The WBNM hydrologic model was run for the 1% AEP event for durations between 10 minutes and 6 hours. The critical storm duration required to produce maximum stream flows throughout the catchment was typically found to be 120 minutes, with 90 minutes critical in some areas. When investigating overland flow flooding, higher peak water levels may occur locally as the result of shorter storm durations, typically between 10 and 30 minutes.

The 1% AEP design event was run in TUFLOW for durations of 10, 30, 90 and 120 minutes to determine the critical durations causing peak flood levels throughout the catchment. Critical durations throughout the study area for the 1% AEP design event are mapped in Figure 7.1.

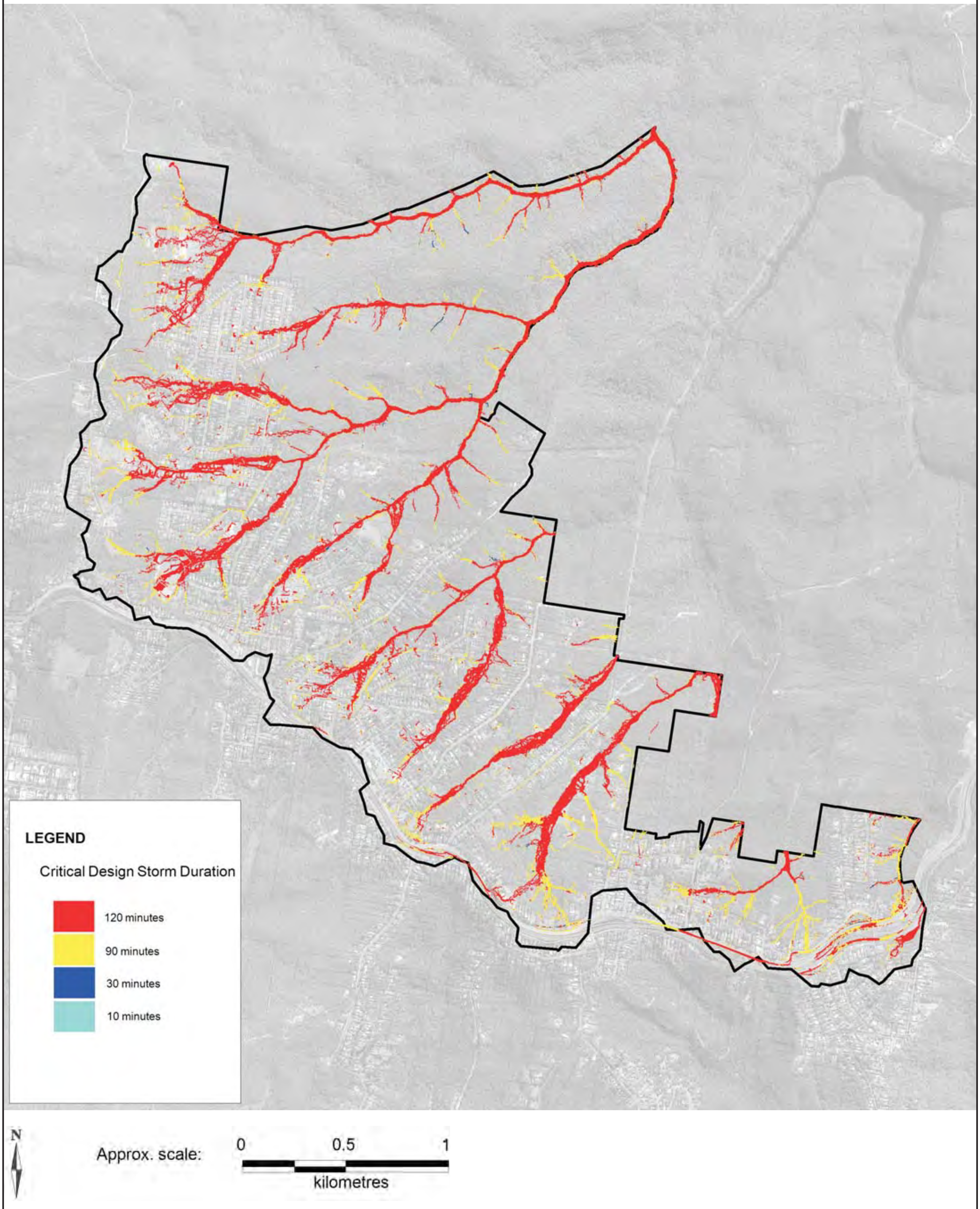
For the 1% AEP, a design storm duration of 120 minutes was found to be critical throughout the majority of the study area. A 90-minute storm duration was critical in a number of upper catchment areas with relatively small contributing catchment areas. A 30-minute storm duration was critical in a few minor localised areas, while a 10-minute event was not critical over any significant area.

Differences in peak flood level between the maximum ‘envelope’ of all modelled storm durations, and the 120-minute duration event are presented in Figure 7.2. It can be seen that areas with differences of 0.02 m or more are very minor on a catchment scale. The 120-minute storm duration was found to be critical for over 91% of the model domain, while the area over which another duration had a peak flood level greater than 0.02 m higher than the 120-minute event accounted for only 0.04% of the model domain. A duration of 120 minutes was therefore determined to be critical for the study area, and other design events were simulated for this duration.

7.3 Design Catchment Conditions

Design modelling has been undertaken for the following catchment conditions:

- ‘present’ levels of development as per aerial photography provided by Council in 2012
- topography as per 2012 ALS data
- hydraulic roughness as per that developed for the February 2012 calibration event
- drainage infrastructure as per GIS data layers provided by Council in 2012
- drainage lines assumed clear
- retarding basins assumed empty at start of design events.



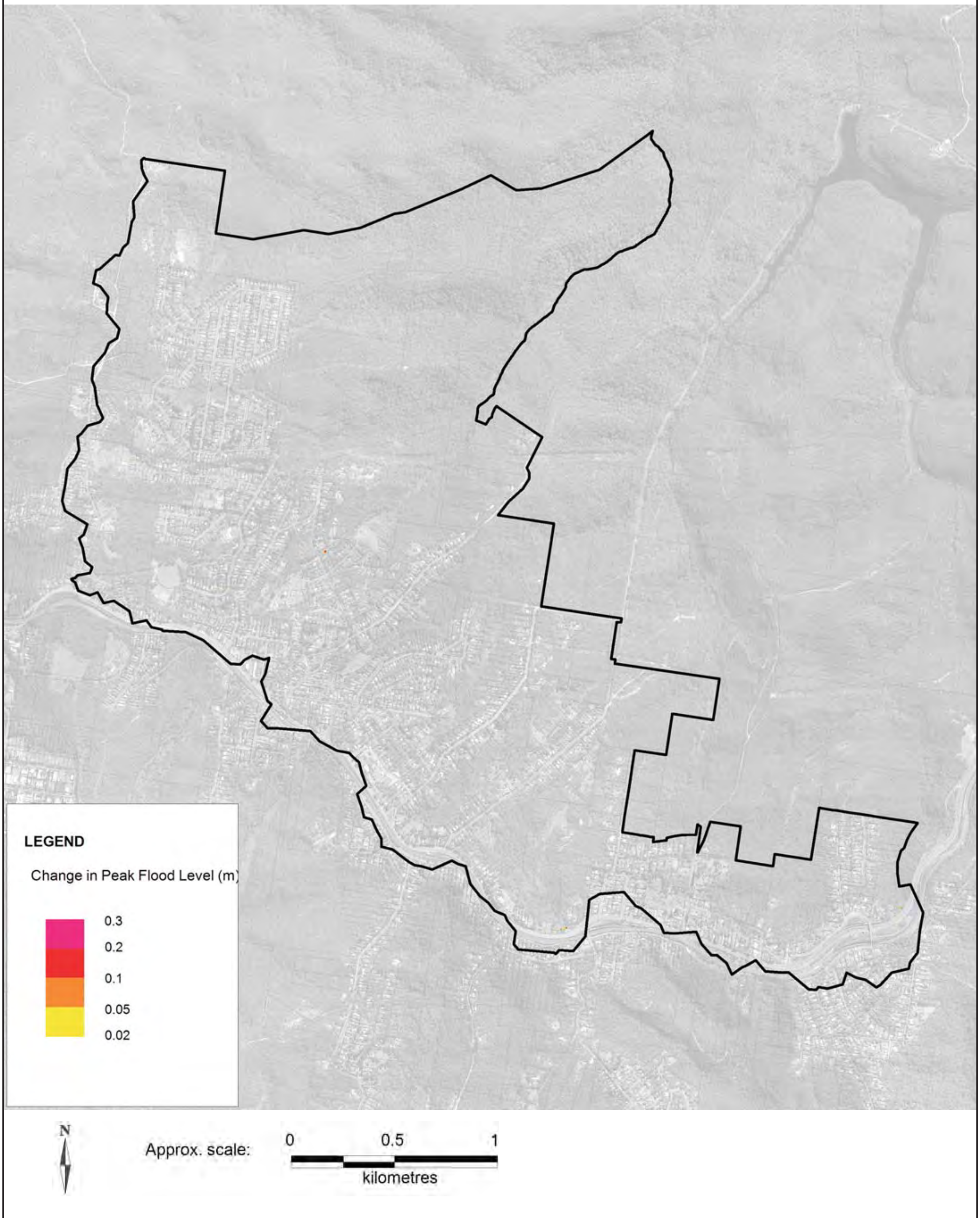
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
1% AEP CRITICAL DURATION

MHL Report 2174

Figure 7.1

DRAWING 2174-07-01.cdr



Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
DIFFERENCE IN PEAK FLOOD LEVEL BETWEEN
MAXIMUM OF ALL DURATIONS AND 120-MINUTE DURATION

MHL Report 2174

Figure 7.2

DRAWING 2174-07-02.cdr

8. Design Flood Results and Mapping

8.1 Flood Mapping Approach

The use of the direct rainfall method in TUFLOW results in all active model cells being 'wet'. Directly mapping all flood model results therefore produces a flood extent covering the entire model domain. To improve the presentation and interpretability of results the mapped flood extents for the design events were determined using the following filtering methodology:

- PMF Design Event
  - The maximum extent of areas affected by the PMF event, even to a minor degree, was determined including areas where: Depth ≥ 0.03 m AND Velocity x Depth ≥ 0.01 m^2/s, OR Depth ≥ 0.1 m. Within this extent, isolated 'islands' of flooding were nullified. As such 'islands' of flooding were not linked to significant overland flowpaths even by shallow flows during an extreme event such as the PMF, they were considered to be caused by local ponding or sheet flow only.
  - Areas of erroneous high depth can occur when mapping model flood depths in steep areas as the flood level is interpolated between neighbouring cells of significantly different elevation. In order to reduce the inclusion of erroneous depths along steep features such as cliff lines, results were nullified where: Slope > 25^o AND Velocity < 0.2 m/s, OR Slope > 25^o AND Velocity x Depth < 0.05 m^2/s.
  - The 'Flood Mapping Filter' as described in Table 8.1 was applied to remaining flood results.
- 0.5% AEP Design Event
  - Areas outside the mapped flood extent for the PMF event were nullified
  - The 'Flood Mapping Filter' was applied to remaining flood results.
- 1% AEP Design Event
  - Areas outside the mapped flood extent for the PMF event were nullified
  - The 'Flood Mapping Filter' was applied to remaining flood results.
  - Resulting small isolated islands of flooding with an area of less than 50 m^2 were nullified.
- 20%, 10% and 2% AEP Design Events
  - Areas outside the mapped flood extent for the 1% AEP event were nullified
  - The 'Flood Mapping Filter' was applied to remaining flood results.

Table 8.1 Flood Mapping Filter

Criteria for Inclusion in Flood Mapping	Description
Depth ≥ 0.3 m	Includes areas with significant depths of flooding (≥0.3 m) in mapping
Depth ≥ 0.1 m AND Velocity x Depth ≥ 0.01 m^2/s	Includes depths between 0.1 m and 0.3 m but only where these have some flow component. This reduces the inclusion of small areas of still ponding
Depth ≥ 0.05 m AND Velocity x Depth ≥ 0.025 m^2/s	Includes shallower flows with some conveyance that may link overland flowpaths with areas of flooding sourced from them. Small 'islands' of flooding displayed in mapping are thus likely to be the result of local ponding only

8.2 Design Flood Peaks

Results of design flood modelling are presented in a series of flood maps in Appendix A. This includes maps of peak flood level, depth, and velocity for the 20% AEP, 10% AEP, 2% AEP, 1% AEP, 0.5% AEP and PMF design events.

8.3 Hydraulic Categories

Hydraulic categorisation is a useful tool in assessing the suitability of land use and development in flood-prone areas. The Floodplain Development Manual (NSW Government, 2005) describes the following three hydraulic categories of flood-prone land:

- **Floodway** – Areas that convey a significant portion of the flow. These are areas that, even if partially blocked, would cause a significant increase in flood levels or a significant redistribution of flood flows, which may adversely affect other areas.
- **Flood Storage** – Areas that are important in the temporary storage of the floodwater during the passage of the flood. If the area is substantially removed by levees or fill it will result in elevated water levels and/or elevated discharges. Flood storage areas, if completely blocked, would cause peak flood levels to increase by 0.1 m and/or would cause the peak discharge to increase by more than 10%.
- **Flood Fringe** – Remaining area of flood-prone land, after floodway and flood storage areas have been defined. Blockage or filling of this area will not have any significant impact on the flood pattern of flood levels.

These qualitative descriptions do not prescribe specific thresholds for determining the hydraulic categories in terms of model outputs, and such definitions may vary between floodplains depending on flood behaviour and associated impacts.

For the purposes of the Hazelbrook and Woodford Creeks Mainstream and Overland Flow Flood Study, hydraulic categories have been defined as per the criteria in Table 8.2. These criteria have been derived from Howell et al. (2003). The addition of a minimum depth criteria of 0.1 m for floodway definition has been added to differentiate between areas of significant conveyance and shallower high velocity flows that often develop on roads.

Table 8.2 Hydraulic Category Criteria

Hydraulic Category	Criteria	Description
Floodway	Velocity x Depth > 0.25 m^2/s AND Velocity > 0.25 m/s, OR Velocity > 1 m/s AND Depth > 0.1 m	Flowpaths and channels where a significant proportion of flood flows are conveyed
Flood Storage	Depth > 0.2 m, Not Floodway	Areas that temporarily store floodwaters and attenuate flood flows
Flood Fringe	Depth > 0.05 m, Not Floodway or Flood Storage	Generally shallow, low velocity areas within the floodplain that have little influence on flood behaviour

Hydraulic category mapping for the 1% AEP, 0.5% AEP and PMF design events is presented in Appendix A.

8.4 Flood Hazard Categories

8.4.1 Provisional Hazard Categories

Flood hazard is a measure of the potential risk to life, limb and property posed by a flood. Flood hazard categories are defined in the Floodplain Development Manual (NSW Government 2005) as follows:

- **High hazard** – possible danger to personal safety; evacuation by trucks difficult; able-bodied adults would have difficulty in wading to safety; potential for significant structural damage to buildings.
- **Low hazard** – should it be necessary, trucks could evacuate people and their possessions; able-bodied adults would have little difficulty in wading to safety.

Provisional flood hazard categories for flood-prone land are generally determined based on relationships between simulated flood depths and velocities. These relationships are defined in Figures L1 and L2 in the Floodplain Development Manual (NSW Government 2005), as presented in Figure 8.1.

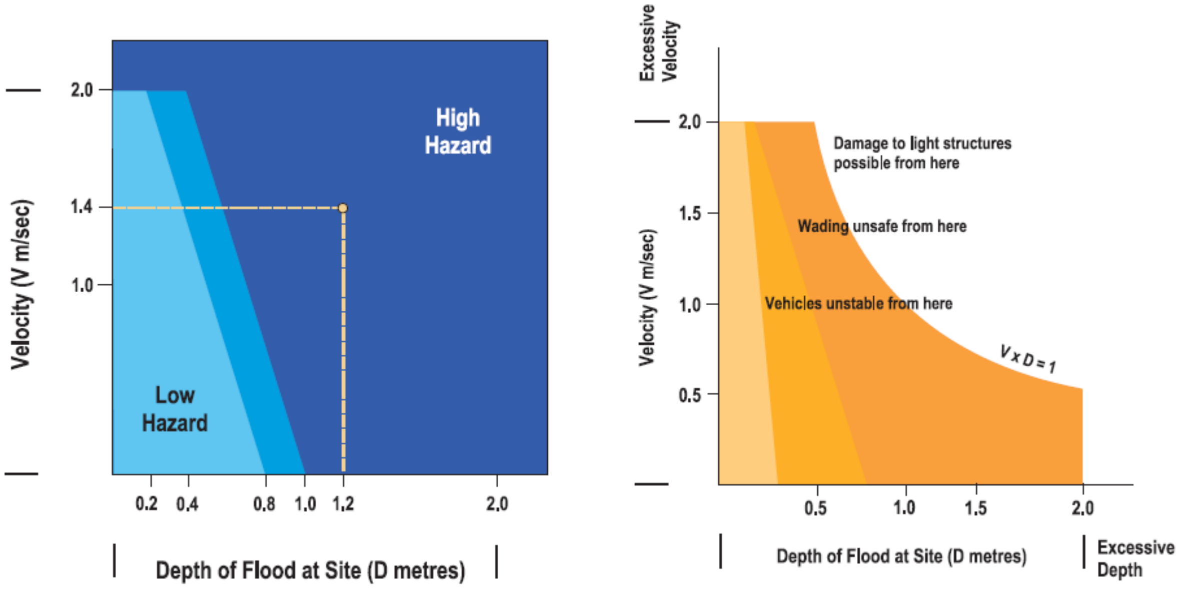


Figure 8.1 Velocity-Depth Relationships for Provisional Hazard Categories

(Source: NSW Government, 2005)

Provisional hazard categories have been determined for the 1% AEP, 0.5% AEP and PMF design events and are presented in Appendix A. The 'transition zone' between high and low hazard is often assigned a high hazard category, but this should be determined based on review of factors such as those discussed in Section 8.4.2 below.

8.4.2 Preliminary True Hazard Categories

True hazard categorisation requires the consideration of various factors in addition to provisional hazard categories including:

- effective warning time
- flood readiness
- rate of rise of floodwaters
- duration of flooding
- evacuation problems
- effective flood access, and
- type of development.

Preliminary true hazard categories for the 1% AEP, 0.5% AEP and PMF design events are presented in Appendix A, Figures A26 to A28. Areas identified as 'transition zone' in the provisional hazard categorisation have been assigned a high preliminary true hazard in consideration of the rapid rise of floodwaters and limited effective warning time available.

8.5 Preliminary Flood Emergency Response Classification

Flood emergency response classification provides an indication of firstly whether homes in a community are flood-affected, and if so what emergency response measures may be required.

Preliminary flood emergency response classification has been determined with reference to the floodplain risk management guideline 'Flood Emergency Response Planning Classification of Communities' (DECC 2007) and is presented in Appendix A, Figure A25. The study area has been delineated into the following Preliminary Flood Emergency Response Planning Classifications:

- **Not Flood Affected** – land not significantly impacted by the PMF.
- **High Trapped Perimeter Area** – land not significantly impacted by the PMF, but to which vehicle evacuation / emergency service access routes may be cut by flood waters.
- **High Flood Island** – land that is not significantly impacted by the PMF, but is surrounded by flood waters. Evacuation can only be completed before routes become cut.
- **Rising Road Access Area** – land inundated by the PMF but to which continuous vehicle evacuation / emergency access is possible as flood waters advance on residential properties.
- **Area with Overland Escape Route** – land inundated by the PMF where vehicle evacuation / emergency service access routes may also be cut by flood waters. People can reach safety by walking overland to areas above the PMF.

As no habitable floor level survey data was available for use in this study, flood-affected land has been defined as those areas subject to 'high hazard' or an inundation depth of greater than 0.3 m under peak PMF design event conditions. Homes on affected properties may or may not, therefore, be subject to flooding. Roads have been deemed to be 'cut' where a portion of the road is subject to high hazard under PMF conditions that may prevent vehicular evacuation or access by emergency services.

An indication of emergency response measures that may be required for each emergency response classification is presented in Table 8.3. Given the catchment behaviour with respect to duration of flooding, it is unlikely that resupply would be required.

Table 8.3 Emergency Response Required
(Adapted from Flood Emergency Response Planning Classification of Communities, DECC 2007)

Classification	Response Required		
	Resupply	Rescue/Medivac	Evacuation
Not Flood Affected	No	No	No
High Trapped Perimeter Area	Possibly	Possibly	Possibly
High Flood Island	Possibly	Possibly	Possibly
Rising Road Access Area	No	Possibly	Yes
Area with Overland Escape Route	No	Possibly	Yes

During an actual flood event there may be considerable uncertainty over what is the safest action to take. For example, in some cases it may be best to leave the area that is, or is about to be, inundated while in other situations it may be more dangerous to evacuate than to shelter in place. Further investigation of personal safety, evacuation, and emergency response issues is required as part of the Floodplain Risk Management Study.

8.6 Preliminary Flood Planning Area

Flood planning areas and levels are an important practical tool in the management of floodplain risk through the application of development controls. These concepts are defined in the NSW Floodplain Development Manual (NSW Government 2005) as below:

- **Flood planning levels (FPLs)** - FPLs are the combinations of flood levels (derived from significant historical flood events or floods of specific ARIs) and freeboards selected for floodplain risk management purposes, as determined in risk management studies and incorporated in risk management plans.
- **Flood planning area** - the area of land below the FPL and thus subject to flood-related development controls.

Traditionally, flood planning areas have often been determined by applying a freeboard of 0.5 m to the 1% AEP flood extent and extending this surface laterally until it intersects the surrounding topography. This method has generally been applied to land bordering lakes, rivers and creeks where flooding is confined to, or sourced from, a water body at an elevation below the surrounding land. When determining flood planning areas based on overland flows, however, this method should not be applied blindly and its appropriateness should be carefully considered on a site specific basis (e.g. see Figure 8.2).

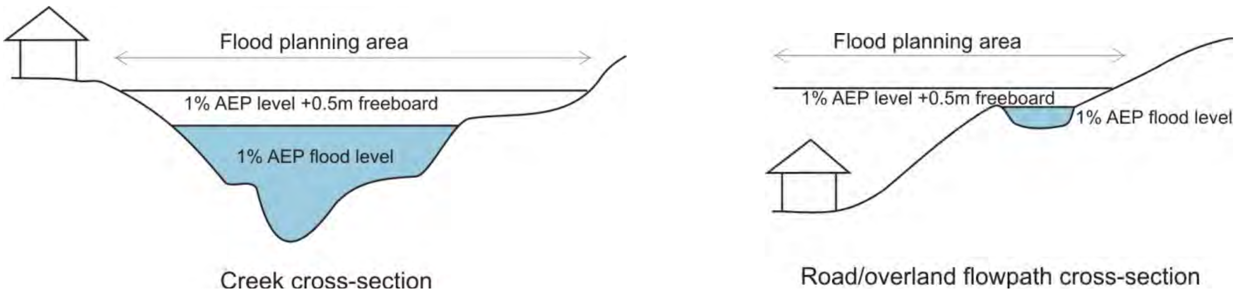


Figure 8.2 Considering Application of Freeboard to Creek Flow vs. Overland Flow

The methodology used to derive the flood planning level and area should be technically sound and readily justifiable to the community. Consideration of multiple factors should therefore be made in determining an appropriate freeboard to be applied to the 1% AEP overland flow flood surface, and whether this should be extended laterally. These include:

- results of sensitivity analysis for the 1% AEP design flood
- flood hazard within the resulting flood planning area
- logic of resulting flood planning area based on ground truthing
- type of development (e.g. different freeboards may be applicable to garages, habitable floors and industrial buildings).

Results of sensitivity testing (see Section 8.7) and climate change analysis (see Section 9) for the 1% AEP design event show that even for a 30% increase in rainfall, simulated increases in peak flood level in proximity to existing residential areas were generally less than 0.2 m. Increases in flood level under this scenario became larger (up to around 0.75 m) moving lower in the catchment, where the additional runoff becomes concentrated into creeks. Increases in flood level when comparing the 0.5% AEP event to the 1% AEP event were generally less than 0.2 m even in the lower catchment. These results suggest that a freeboard of 0.2 to 0.3 m would appropriately allow for factors such as model accuracy, afflux due to blockages, and increased rainfall intensity due to climate change in the developed upper catchment. Application of a 0.5 m freeboard to the 1% AEP flood level in these areas may be over-conservative as even PMF conditions do not reach such levels except in the lower creek valleys.

The following methodology has been adopted to derive a preliminary flood planning area and associated flood planning levels:

- **Preliminary Flood Planning Area** – The flood extent for the 1% AEP 120-minute design event with a 30% increase in rainfall intensity was taken as the maximum flood planning area extent. Small ‘islands’ of flooding (areas less than 250 m^2) with a low flood hazard and likely to be caused by local ponding or sheet flow, have been removed from the planning area. This provides a simple, logical and scientifically justifiable means of determining the lateral extent of the flood planning area.
- **Preliminary Flood Planning Level** – Preliminary flood planning levels within the preliminary flood planning area have been determined by taking the maximum of levels determined using the following two methods:
  - Peak flood levels from the 1% AEP 120-minute design event with a 30% increase in rainfall intensity. These levels are more conservative in the lower catchment creeks.
  - Application of a freeboard of 0.3 m to the 1% AEP design event level (for current conditions) within the preliminary flood planning area. These levels are more conservative in the vicinity of existing development in the upper catchment.

The resulting Preliminary Flood Planning Area is presented in Appendix A, Figure A29. It is noted that there may be a number of appropriate methods of determining the flood planning area and level and that this should be given further consideration during the subsequent Floodplain Risk Management Study stage including logical ground truthing.

8.7 Sensitivity Analysis

8.7.1 Blockage of Hydraulic Structures

Flood flows may transport with them various debris which have the potential to cause blockage of the hydraulic structures they encounter. Blockages reduce the flow capacity of hydraulic structures and may result in an increase in flood levels upstream of the structure (afflux) and/or diversion of flows into alternative flow paths.

Australian Rainfall and Runoff Revision Project 11: Blockage of Hydraulic Structures (Institution of Engineers Australia 2013) provides guidance on the consideration of blockages in determining design flood levels. Following the *Assessment Procedure for an AEP Neutral Blockage Level – Scheme A*, assessment of debris availability, debris characteristics and catchment characteristics indicated a medium to high debris potential, and a 90th percentile debris length of 0.9 m was assumed. The resulting 'most likely' blockage levels for differing levels of debris potential are presented in Table 8.4.

Table 8.4 Most Likely Blockage Levels
(Institution of Engineers Australia, 2013)

Control Dimension	At-Site Debris Potential		
	High (Adopted)	Medium	Low
W < 0.9 m	100%	50%	25%
W ≥ 0.9 m	20%	10%	0%
W > 2.7 m	10%	0%	0%

In order to test the sensitivity of design flood results to a more conservative blockage scenario, the blockage levels for a 'high' debris potential were adopted. Sensitivity testing of the potential impact of structure blockages was thus undertaken for the 1% AEP critical duration design event using the following blockage assumptions:

- 100% blockage of structures with opening width less than 0.9 m
- 20% blockage of structures with opening width 0.9 m and greater
- 10% blockage of structures with opening greater than 2.7 m.

Changes in peak flood levels under assumed blockage conditions are presented in Appendix B and summarised in Table 8.4. The locations of data presented in Tables 8.5 and 8.6 are shown in Figure 8.3.

Table 8.5 1% AEP Peak Flood Level Sensitivity - Structure Blockage

Location		Design Conditions		Blockage Scenario	
No.	Description	Flood Peak (m AHD)	Peak Depth (m)	Flood Peak (m AHD)	Difference (m)
1	Grove Street 1	626.62	0.39	626.63	0.01
2	Grove Street 2	620.74	1.05	620.73	-0.01
3	Luchetti Avenue 1	639.35	0.22	639.36	0.01
4	Luchetti Avenue 2	631.05	1.23	631.05	0
5	Oaklands Road 1	626.54	1.31	626.54	0
6	Oaklands Road 2	619.78	0.38	619.79	0.01
7	Oaklands Road 3	630.96	1.13	630.96	0
8	Oaklands Road 4	629.03	0.25	629.02	-0.01
9	Oaklands to Origma 1	626.26	1.88	626.24	-0.03
10	Oaklands to Origma 2	620.78	1.9	620.83	0.06
11	Alexander Avenue 1	616.2	0.64	616.24	0.04
12	Alexander Avenue 2	613.98	0.22	613.99	0.01
13	Alexander Avenue 3	608.33	1.2	608.33	0
14	Hazel Avenue	603.01	0.28	603.02	0
15	Talbot Road	615.44	0.63	615.43	-0.01
16	Cunningham Street	627.07	0.29	627.12	0.05
17	North of Mount View Avenue	576.22	0.55	576.22	0
18	South of Mount View Avenue	568.15	0.53	568.15	0

Under the blockage scenario tested, simulated increases in peak flood level were quite localised and were generally less than 0.2 m. In general, blockages did not result in significant diversion of flows onto alternative flow paths, however some minor instances of flow diversion were observed that may affect a small number of additional properties. Flood levels also rose on a number of properties already affected under 1% AEP design flood conditions.

8.7.2 Hydraulic Roughness

The sensitivity of model results to hydraulic roughness was investigated by applying a 20% decrease and a 20% increase to adopted Manning's 'n' values for the 1% AEP critical duration design event. Results of the sensitivity testing are presented in Appendix B and summarised in Table 8.6.

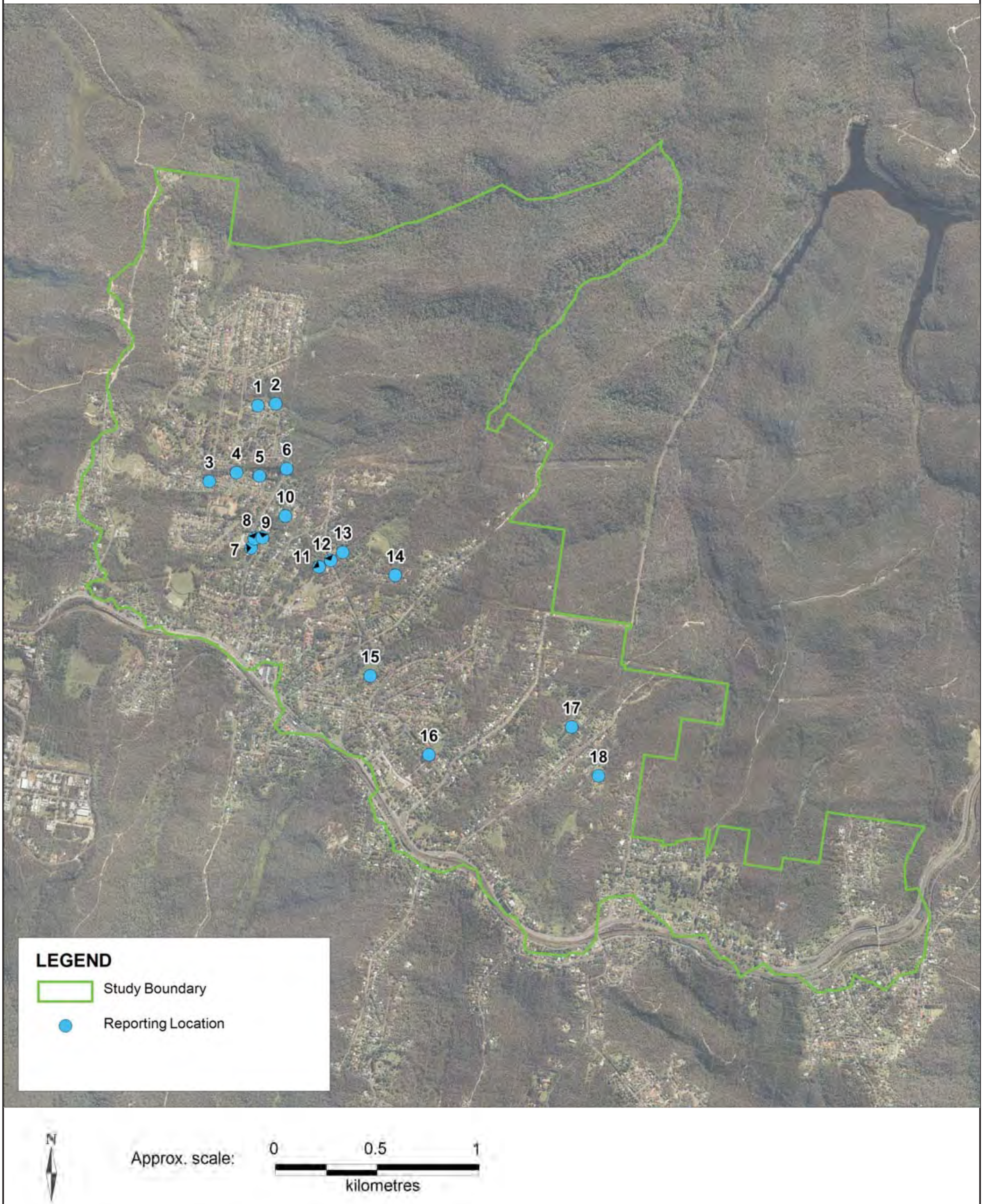
Table 8.6 1% AEP Peak Flood Level Sensitivity - Hydraulic Roughness

Location		Design Conditions		20% Decrease		20% Increase	
No.	Description	Flood Peak (m AHD)	Peak Depth (m)	Flood Peak (m AHD)	Difference (m)	Flood Peak (m AHD)	Difference (m)
1	Grove Street 1	626.62	0.39	626.63	0.01	626.61	-0.01
2	Grove Street 2	620.74	1.05	620.66	-0.08	620.78	0.05
3	Luchetti Avenue 1	639.35	0.22	639.34	-0.01	639.35	0
4	Luchetti Avenue 2	631.05	1.23	631	-0.04	631.07	0.03
5	Oaklands Road 1	626.54	1.31	626.52	-0.02	626.55	0.01
6	Oaklands Road 2	619.78	0.38	619.79	0.01	619.77	-0.01
7	Oaklands Road 3	630.96	1.13	630.92	-0.04	630.99	0.03
8	Oaklands Road 4	629.03	0.25	629.02	-0.01	629.03	0
9	Oaklands to Origma 1	626.26	1.88	626.23	-0.03	626.27	0.01
10	Oaklands to Origma 2	620.78	1.9	620.76	-0.02	620.78	0
11	Alexander Avenue 1	616.2	0.64	616.17	-0.03	616.23	0.02
12	Alexander Avenue 2	613.98	0.22	613.97	-0.01	613.99	0.01
13	Alexander Avenue 3	608.33	1.2	608.33	0	608.34	0.01
14	Hazel Avenue	603.01	0.28	603	-0.01	603.03	0.01
15	Talbot Road	615.44	0.63	615.41	-0.03	615.46	0.03
16	Cunningham Street	627.07	0.29	627.07	0	627.08	0
17	North of Mount View Avenue	576.22	0.55	576.18	-0.03	576.24	0.03
18	South of Mount View Avenue	568.15	0.53	568.11	-0.04	568.18	0.03

Peak flood levels for the 1% AEP design event were not found to be greatly sensitive to a 20% increase or decrease in hydraulic roughness, with changes throughout the study area generally less than 0.05 m.

A 20% decrease in hydraulic roughness resulted in decreases in peak flood levels of 0.02 to 0.05 m along most flowpaths and creeks, with localised decreases of up to 0.2 m. Highly localised increases of up to 0.1 m were also observed.

A 20% increase in hydraulic roughness resulted in increases in peak flood levels of 0.02 to 0.05 m along most flowpaths and creeks, with localised increases of up to 0.1 m. Localised decreases of up to 0.1 m were also observed.



Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
TABULAR DATA REPORTING LOCATIONS

MHL Report 2174

Figure 8.3

DRAWING 2174-08-03.cdr

9. Climate Change Analysis

9.1 Potential Climate Change Impacts

Climate change is expected to alter flood behaviour as a result of increased rainfall intensity and sea level rise. Investigation of potential climate change impacts in the study area involved sensitivity analysis of the 1% AEP design event to increased rainfall intensity. Based on current projections for the year 2100, sea level rise will not affect the study area.

The Floodplain Risk Management Guideline on Practical Consideration of Climate Change (DECC 2007) recommends that sensitivity analyses are undertaken for increases in rainfall intensity and volume of up to 30%. Sensitivity analysis of the 1% AEP critical duration design event to 20% and 30% increases in rainfall intensity due to climate change has therefore been undertaken. Comparison of the 1% AEP and 0.5% AEP events has also been undertaken, representing a 10% increase in rainfall (actual rainfall increase of 10.49%).

9.2 Climate Change Results

Mapping of modelled climate change impacts on peak flood levels and flood extents are presented in Appendix B. A summary of peak flood levels for the increased rainfall climate change scenarios is presented in Table 9.1. The selected reporting locations have been presented previously in Table 8.3. In general, flood level increases due to increased rainfall intensities were comparatively small in the upper catchment and became greater moving lower into the catchment where the increased runoff volumes are concentrated in creeks.

For a 10% increase in rainfall, overland flow flood levels in the developed upper catchment generally increased by less than 0.05 m. Mainstream flood levels in the upper catchment generally increased by less than 0.1 m, while in the lower catchment increases of up to 0.4 m were observed.

For a 20% increase in rainfall, overland flow flood levels in the developed upper catchment generally increased by less than 0.05 m. Mainstream flood levels in the upper catchment generally increased by less than 0.2 m, while in the lower catchment increases of up to 0.6 m were observed.

For a 30% increase in rainfall, overland flow flood levels in the developed upper catchment generally increased by less than 0.1 m. Mainstream flood levels in the upper catchment generally increased by less than 0.2 m, while in the lower catchment increases of up to 0.75 m were observed.

Table 9.1 1% AEP Peak Flood Levels for Climate Change Scenarios

Location		Current Conditions		10% Rainfall Increase		20% Rainfall Increase		30% Rainfall Increase	
No.	Description	Flood Peak (m AHD)	Peak Depth (m)	Flood Peak (m AHD)	Difference (m)	Flood Peak (m AHD)	Difference (m)	Flood Peak (m AHD)	Difference (m)
1	Grove Street 1	626.62	0.39	626.63	0.01	626.64	0.02	626.65	0.03
2	Grove Street 2	620.74	1.05	620.79	0.06	620.84	0.1	620.88	0.14
3	Luchetti Avenue 1	639.35	0.22	639.37	0.02	639.39	0.03	639.4	0.04
4	Luchetti Avenue 2	631.05	1.23	631.08	0.03	631.08	0.03	631.11	0.06
5	Oaklands Road 1	626.54	1.31	626.55	0.01	626.57	0.03	626.58	0.04
6	Oaklands Road 2	619.78	0.38	619.79	0.01	619.82	0.04	619.85	0.07
7	Oaklands Road 3	630.96	1.13	630.99	0.03	631.02	0.06	631.04	0.08
8	Oaklands Road 4	629.03	0.25	629.04	0.01	629.06	0.03	629.08	0.05
9	Oaklands to Origma 1	626.26	1.88	626.33	0.07	626.38	0.12	626.43	0.17
10	Oaklands to Origma 2	620.78	1.9	620.84	0.06	620.88	0.1	620.93	0.15
11	Alexander Avenue 1	616.2	0.64	616.23	0.03	616.26	0.06	616.29	0.08
12	Alexander Avenue 2	613.98	0.22	613.99	0.01	614.01	0.03	614.02	0.04
13	Alexander Avenue 3	608.33	1.2	608.38	0.05	608.43	0.1	608.47	0.14
14	Hazel Avenue	603.01	0.28	603.04	0.02	603.06	0.04	603.08	0.06
15	Talbot Road	615.44	0.63	615.47	0.03	615.49	0.06	615.52	0.09
16	Cunningham Street	627.07	0.29	627.09	0.01	627.1	0.02	627.1	0.03
17	North of Mount View Avenue	576.22	0.55	576.24	0.02	576.26	0.04	576.28	0.07
18	South of Mount View Avenue	568.15	0.53	568.17	0.02	568.19	0.04	568.21	0.06

10. Conclusions and Qualifications

The primary objective of this study has been to define flood behaviour in the Hazelbrook and Woodford catchments under existing conditions and to address possible future variations due to climate change. These objectives have been achieved through completion of the following activities:

- compilation and review of available information
- acquisition of additional data
- community consultation to identify local flooding concerns and obtain information on flood behaviour
- development and calibration of a detailed flood model
- model simulation and mapping of flood conditions for 20% AEP, 10% AEP, 2% AEP, 1% AEP, 0.5% AEP and PMF design events
- sensitivity analysis of flood model results to variation in hydraulic roughness and structural blockages
- sensitivity of flood impacts to 10%, 20% and 30% increases in rainfall intensity due to climate change.

This report provides a full description of the works undertaken in completing the Hazelbrook and Woodford Catchments Mainstream and Overland Flow Flood Study and presents key study outputs including a full suite of flood mapping. Study outcomes have helped to define flood behaviour in the Hazelbrook and Woodford catchments and have established a basis for the subsequent preparation of a Floodplain Risk Management Study and Plan.

Important findings of the study for consideration in future floodplain risk management activities include:

- Relatively short durations (90 to 120 minutes) of intense rainfall cause critical flood conditions throughout the study area.
- Design flood simulations indicate that flood levels rise rapidly in response to rainfall. The February 2012 calibration flood event, where the majority of rainfall occurred within a 30-minute period, provides an example of this catchment flood behaviour. The potential for rapid inundation of properties and access roads in response to short durations of rainfall has implications for flood warning and emergency response.
- Overland flowpaths and creek lines in the study area are quite well defined. Increases in flood severity (in terms of % AEP) generally did not result in major increases in flood extent, but resulted in higher depths, velocities and hydraulic hazard within flooded areas.

- A number of existing properties within the study area are exposed to flood risk, however, dwellings are generally located within areas of low hydraulic hazard as defined by the NSW Floodplain Development Manual (NSW Government 2005). Flooding of properties is caused by overland flows through properties, overflows from roadways into properties, and rising water levels in creeks and open channels adjacent to properties.
- Significant flood flows that may pose threats to vehicle stability and safety can occur along or across a number of roads in the study area. These include Grove Street, Red Gum Avenue, Luchetti Avenue, Oaklands Road (two locations), Origma Avenue, Park Road, Alexander Avenue, Log Bridge Place and Hazel Avenue.
- Climate change sensitivity analysis shows that even if rainfall intensity were to increase by 30%, the 1 % AEP flood extent would not be expected to increase significantly. Flood depth and hazard within the current 1 % AEP flood extent would, however, increase.
- Council has acknowledged that it wishes to adopt an ecologically positive approach in considering future floodplain risk management measures. This includes the use of water sensitive urban design principles, and a desire to preserve natural creek lines and Hanging Swamp. Introduction of additional stormwater flows across Hanging Swamps can lead to significant degradation through erosion and proliferation of weeds (Hawkesbury-Nepean Catchment Management Authority 2008).

While all due effort has been made to ensure the reliability of flood model results, all models have limitations (e.g. Institution of Engineers 2012). The accuracy of any model is a function of the quality of the data used in the model development including topographical data, drainage structure data, and calibration data. Modelling is by nature a simplification of very complex systems, and results of flood model simulations should be considered as a best estimate only. There is, therefore, an unknown level of uncertainty associated with all model results that should be considered when utilising the outputs from this study.

Results of sensitivity testing for the 1% AEP design event showed that changes in peak flood level resulting from variation in hydraulic roughness and structure blockage were generally less than 0.2 m. Greater variations were observed due to increases in rainfall intensity. These results provide an indication of the model accuracy.

11. References

Bureau of Meteorology 2003, *The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method*, June 2003

Department of Environment and Climate Change, NSW Government 2007, *Floodplain Risk Management Guideline – Floodway Definition*

Department of Environment and Climate Change, NSW Government 2007, *Floodplain Risk Management Guideline – Flood Emergency Response Planning Classification of Communities*

Department of Environment and Climate Change, NSW Government 2007, *Floodplain Risk Management Guideline – Practical Consideration of Climate Change*

NSW Government 2005, *Floodplain Development Manual*

Hawkesbury-Nepean Catchment Management Authority 2008, *Hanging Swamps Fact Sheet*, 12 February 2008

Howells L, McLuckie D., Collings G., Lawson N. (2003), *Defining the Floodway – Can One Size Fit All?, 43rd Annual NSW Floodplain Management Association Conference*

Institution of Engineers Australia 1987, *Australian Rainfall and Runoff – Volume 1*

Institution of Engineers Australia 2012, *Australian Rainfall and Runoff Revision Project 15: Two Dimensional Modelling in Urban and Rural Flood Plains, Stage 1 and 2 Draft Report,* November 2012

Institution of Engineers Australia 2013, *Australian Rainfall and Runoff Revision Project 11: Blockage of Hydraulic Structures – Stage 2 Report*

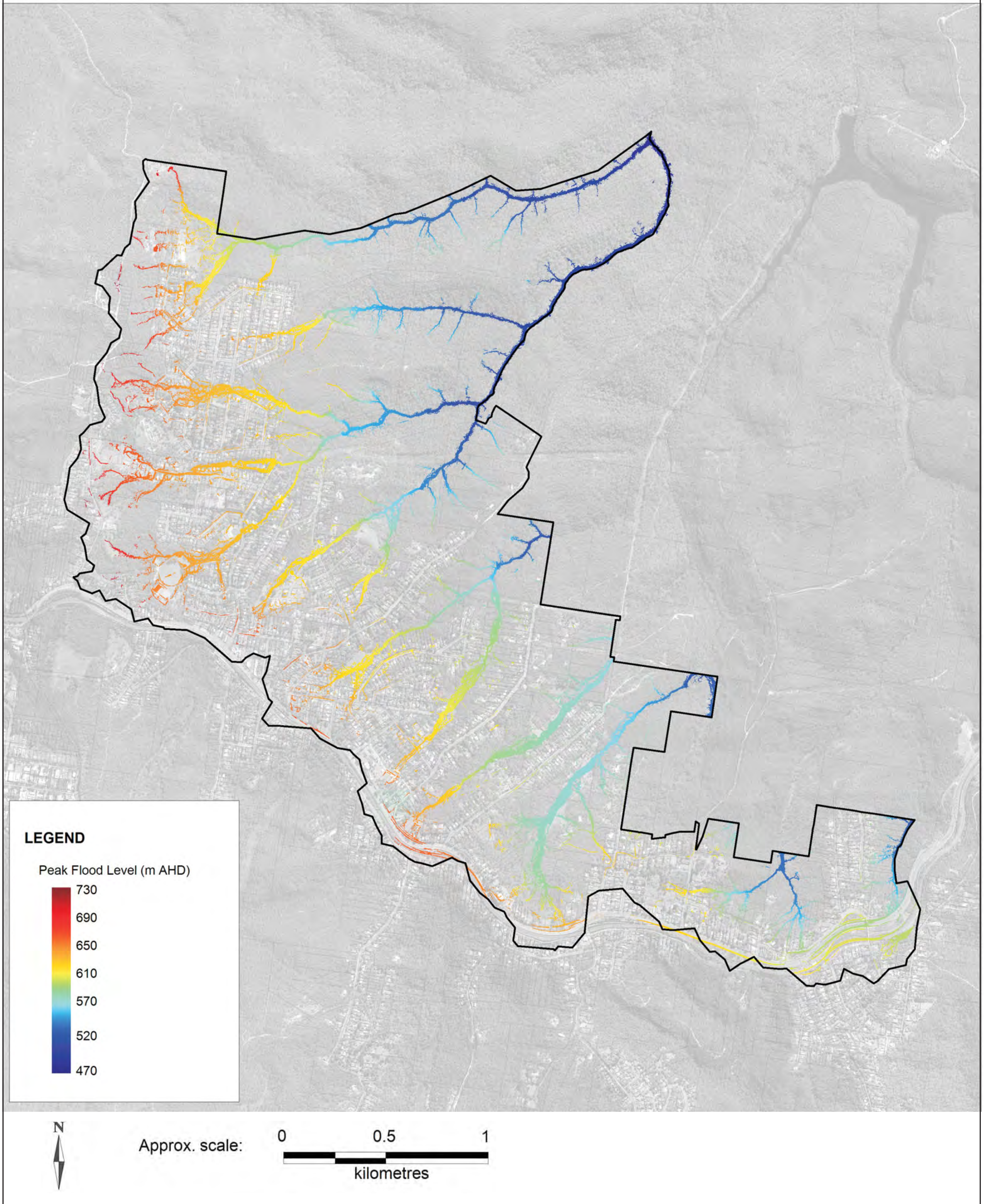
Manly Hydraulics Laboratory 2004, *DIPNR Brisbane Water Estuary Tidal Data Collection February-May 2004, Report MHL1319*

Manly Hydraulics Laboratory 2012, *OEH Tidal planes Analysis 1990-2010 Harmonic Analysis, Report MHL2053*

Taaffe, Gray, Sharma and Babister, 2011, *The Ineptitude of Traditional Loss Paradigms in a 2D Direct Rainfall Model, 34th IAHR World Congress – Balance and Uncertainty, 33rd Hydrology & Water Resources Symposium, 10th Hydraulics Conference, Brisbane, Australia, 26 June – 1 July 2011*

Appendix A

Design Flood Mapping



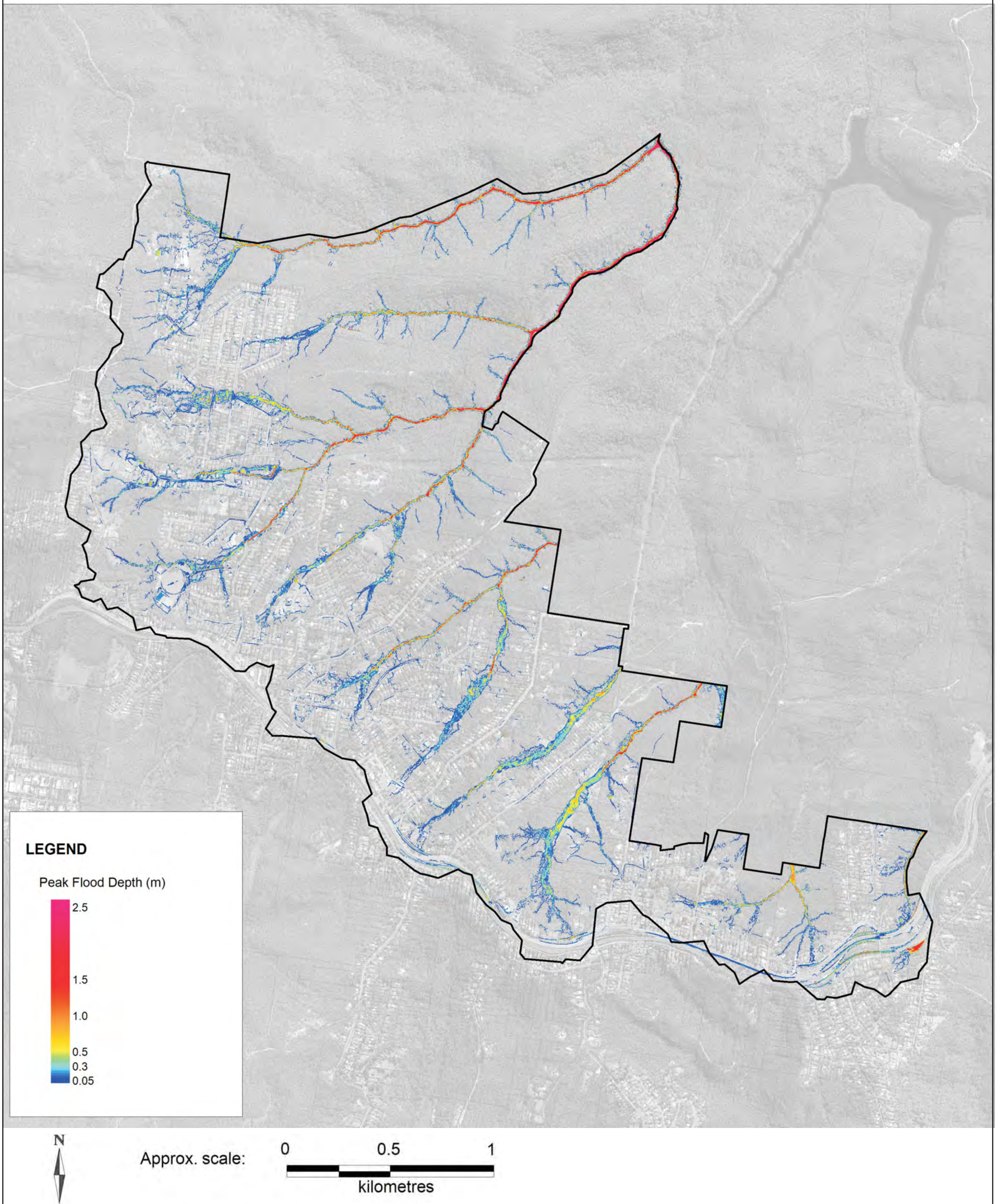
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
20% AEP PEAK FLOOD LEVEL

MHL
Report 2174

Figure
A1

DRAWING 2174-A01.cdr



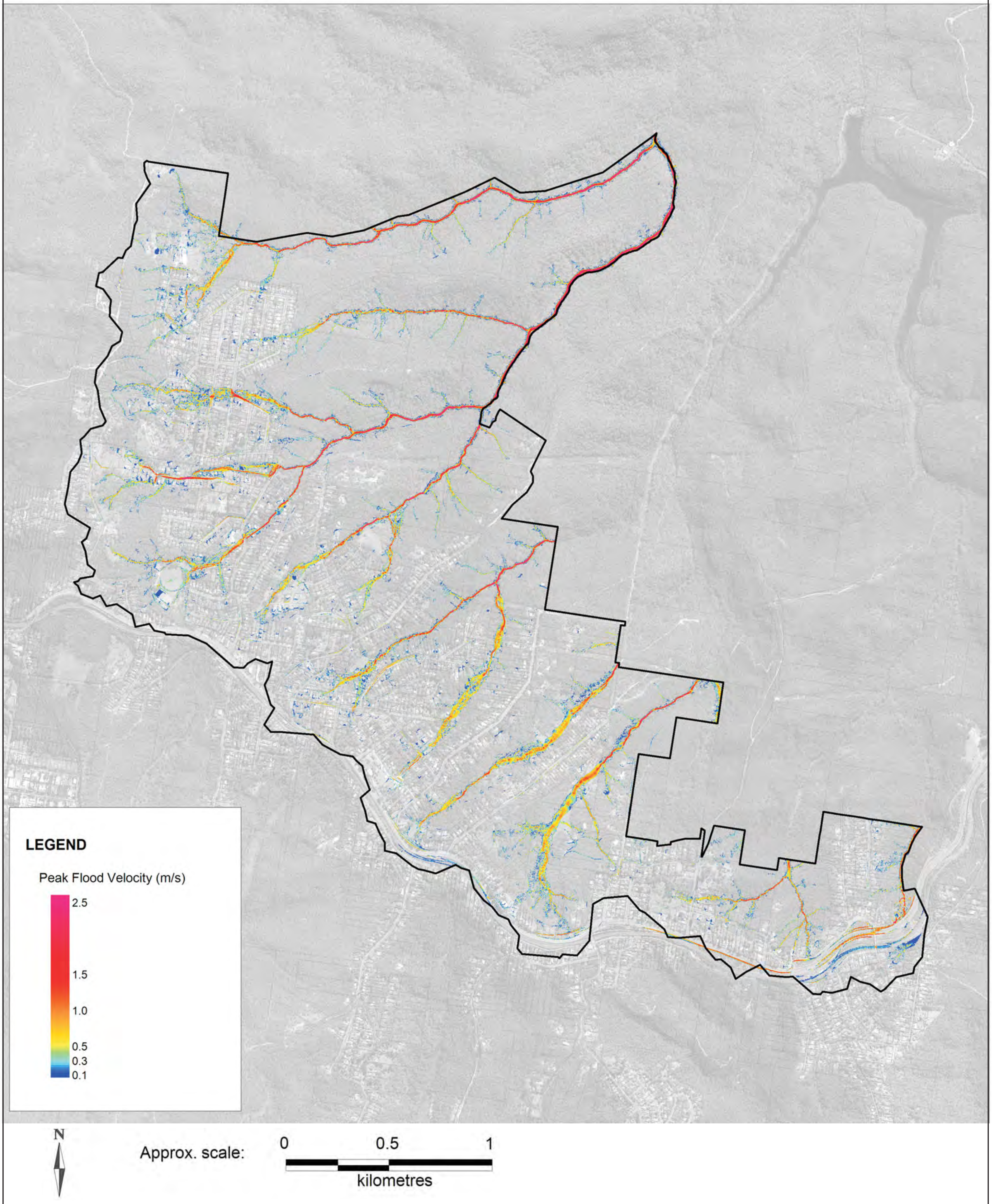
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
20% AEP PEAK FLOOD DEPTH

MHL Report 2174

Figure A2

DRAWING 2174-A02.cdr



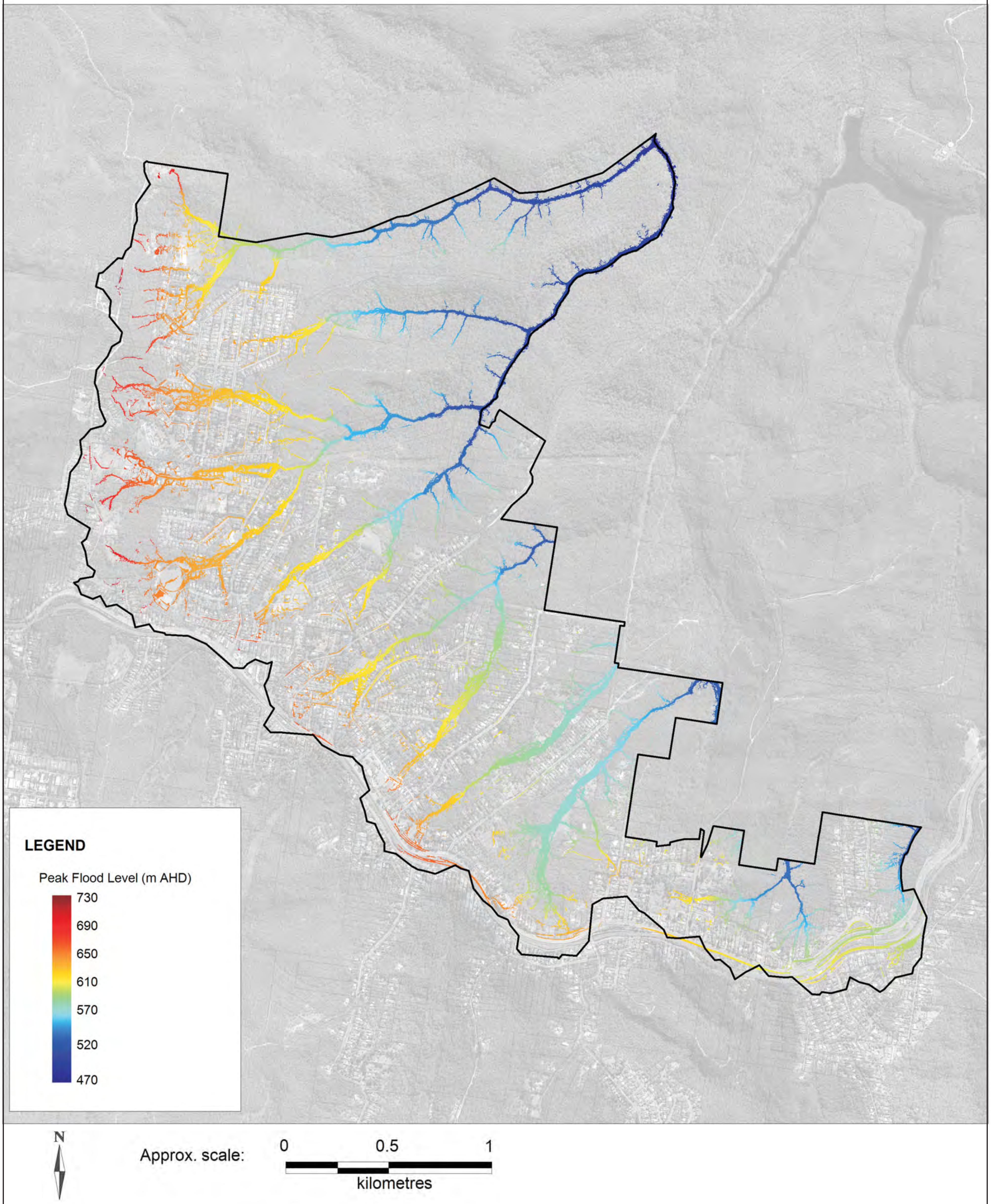
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
20% AEP PEAK FLOOD VELOCITY

MHL Report 2174

Figure A3

DRAWING 2174-A03.cdr



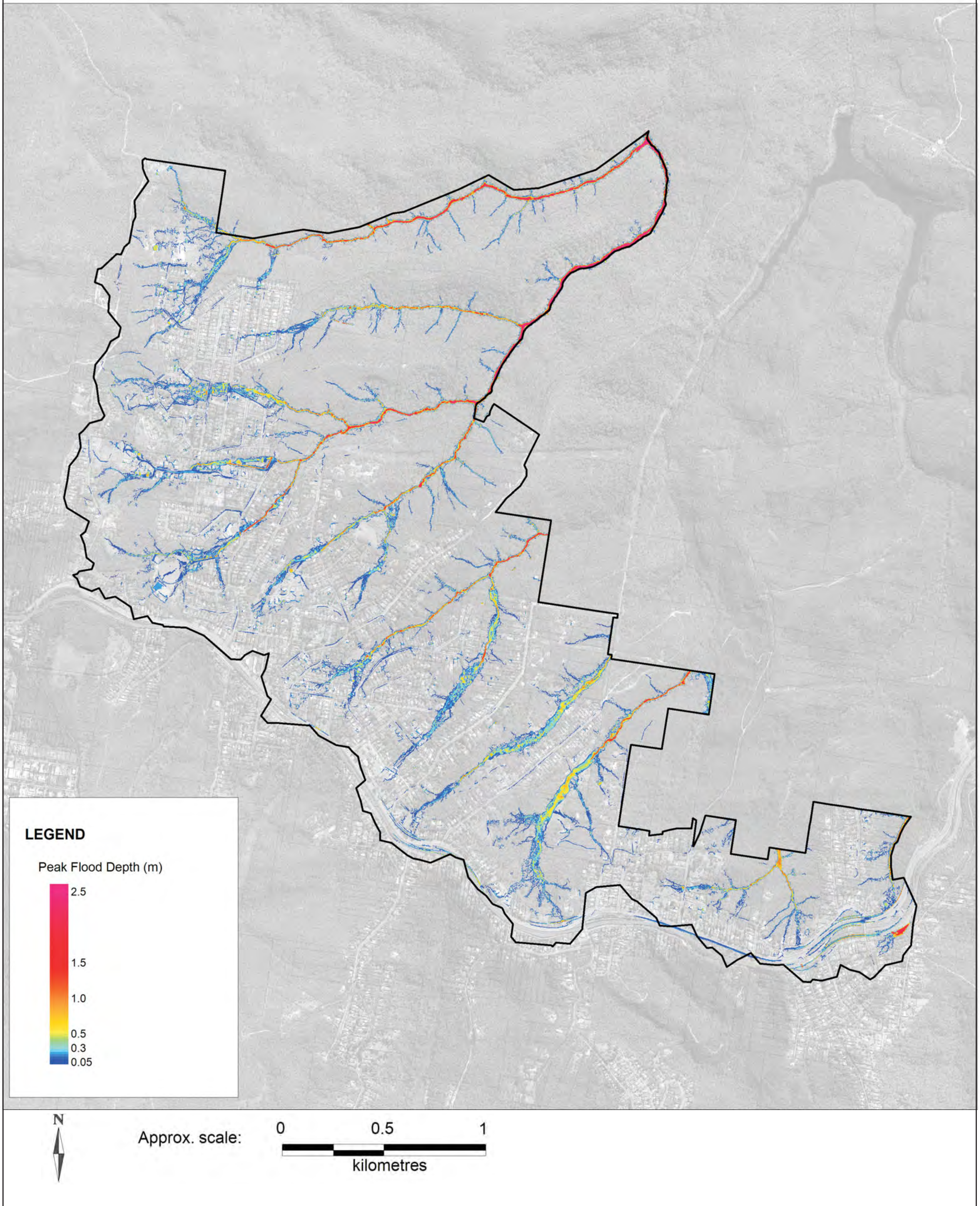
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
10% AEP PEAK FLOOD LEVEL

MHL Report 2174

Figure A4

DRAWING 2174-A4.cdr



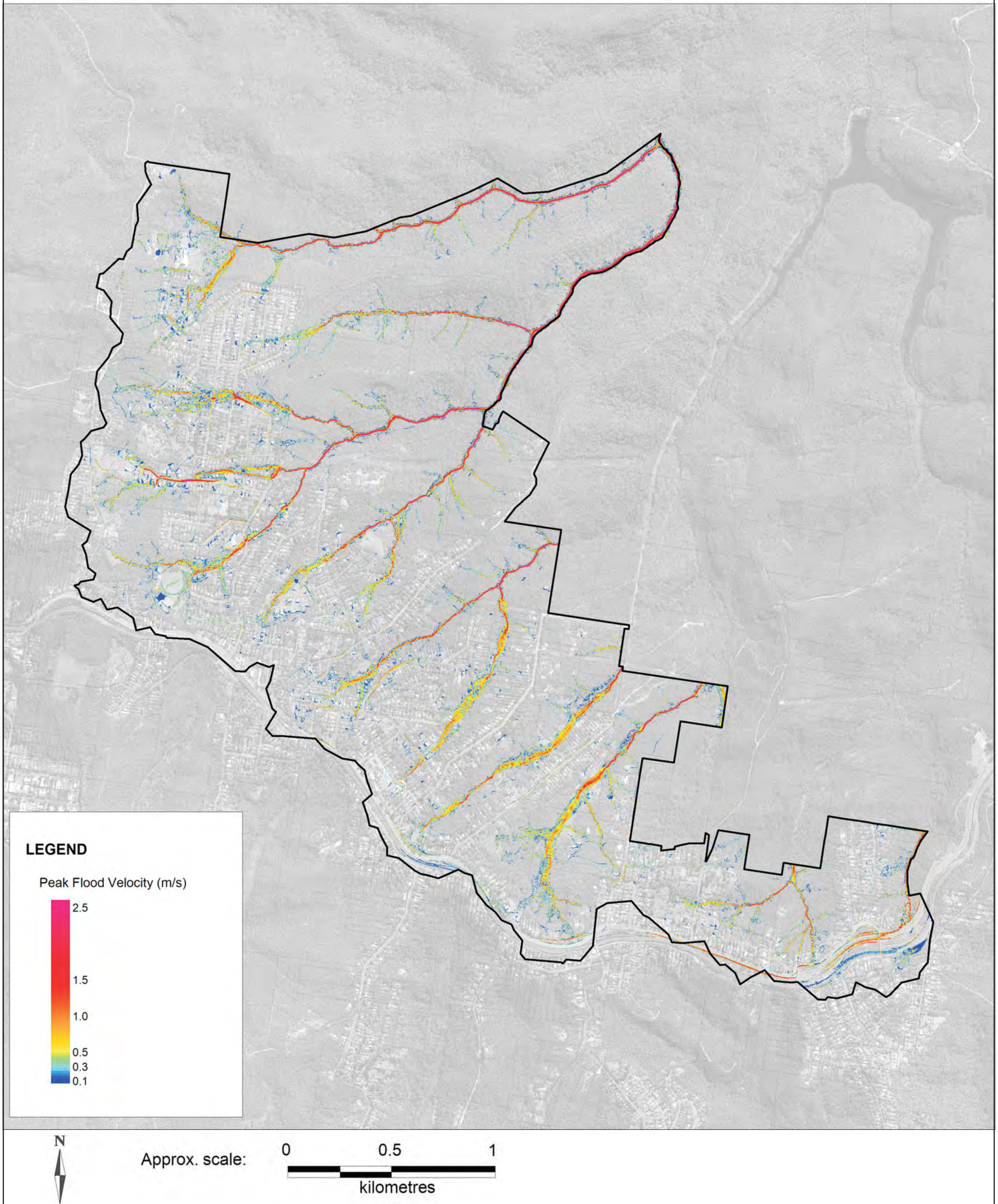
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
10% AEP PEAK FLOOD DEPTH

MHL Report 2174

Figure A5

DRAWING 2174-A05.cdr



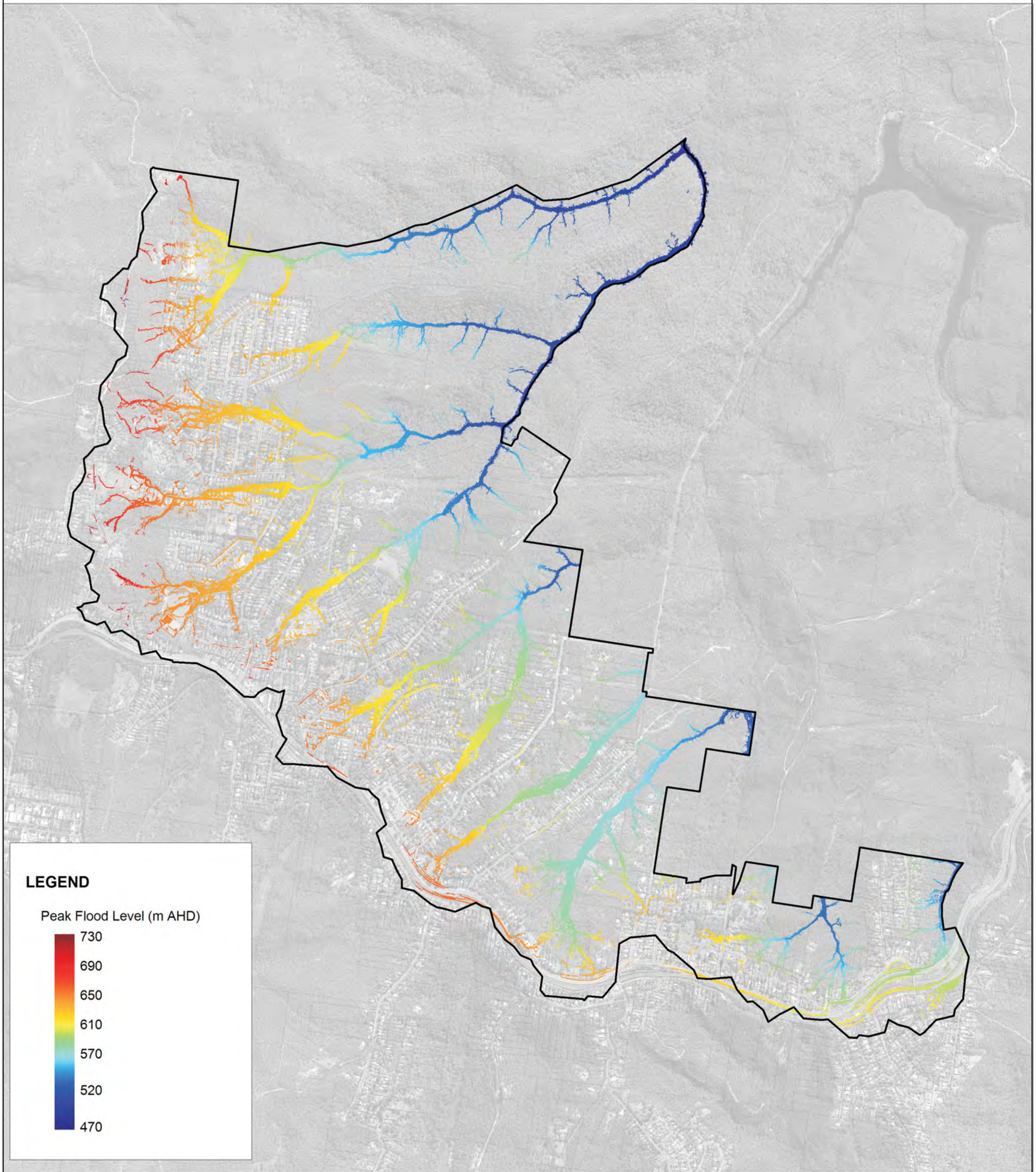
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
10% AEP PEAK FLOOD VELOCITY

MHL
Report 2174

Figure
A6

DRAWING 2174-A06.cdr



N
Approx. scale: 0 0.5 1
kilometres

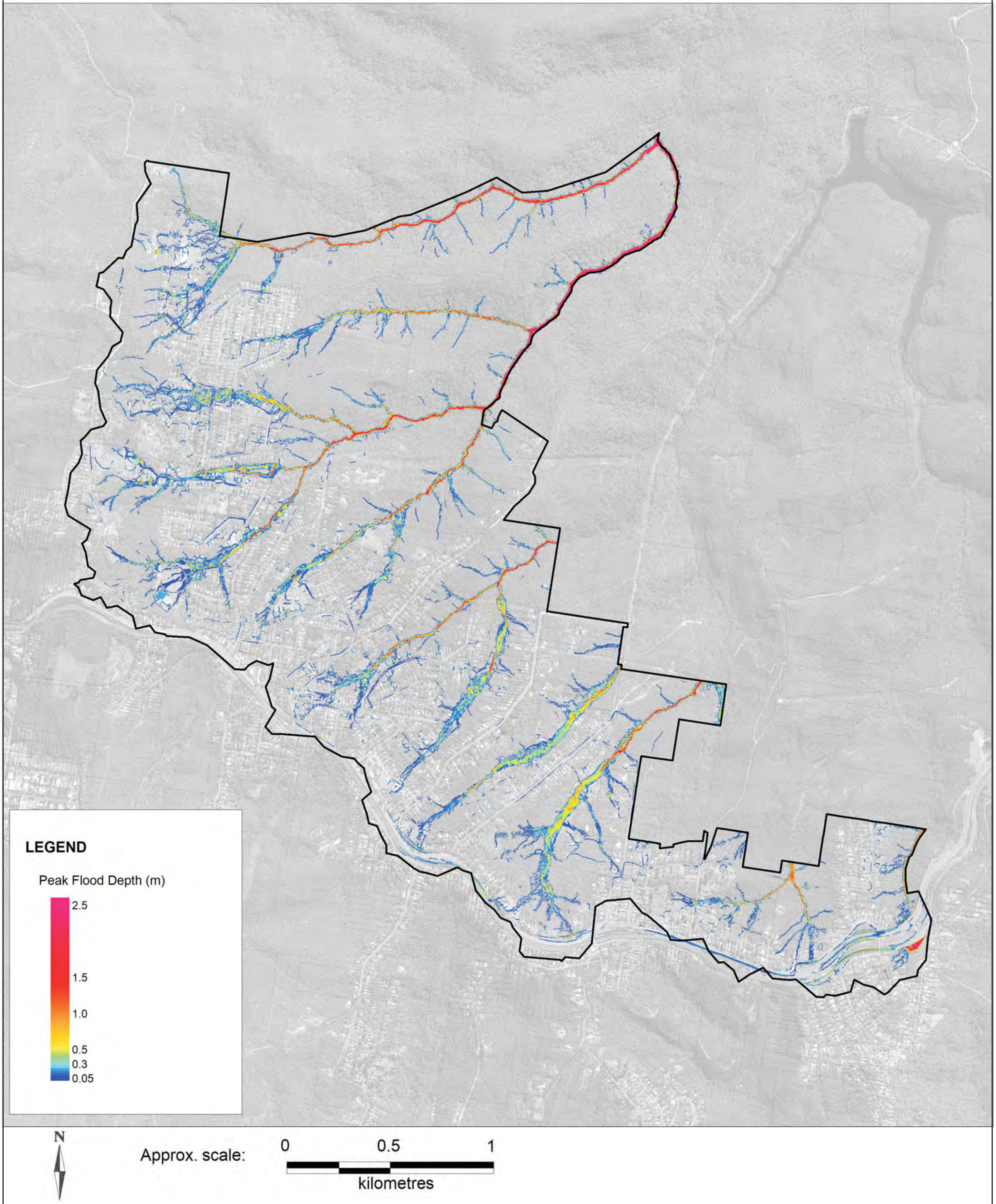
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
2% AEP PEAK FLOOD LEVEL

MHL Report 2174

Figure A7

DRAWING 2174-A07.cdr



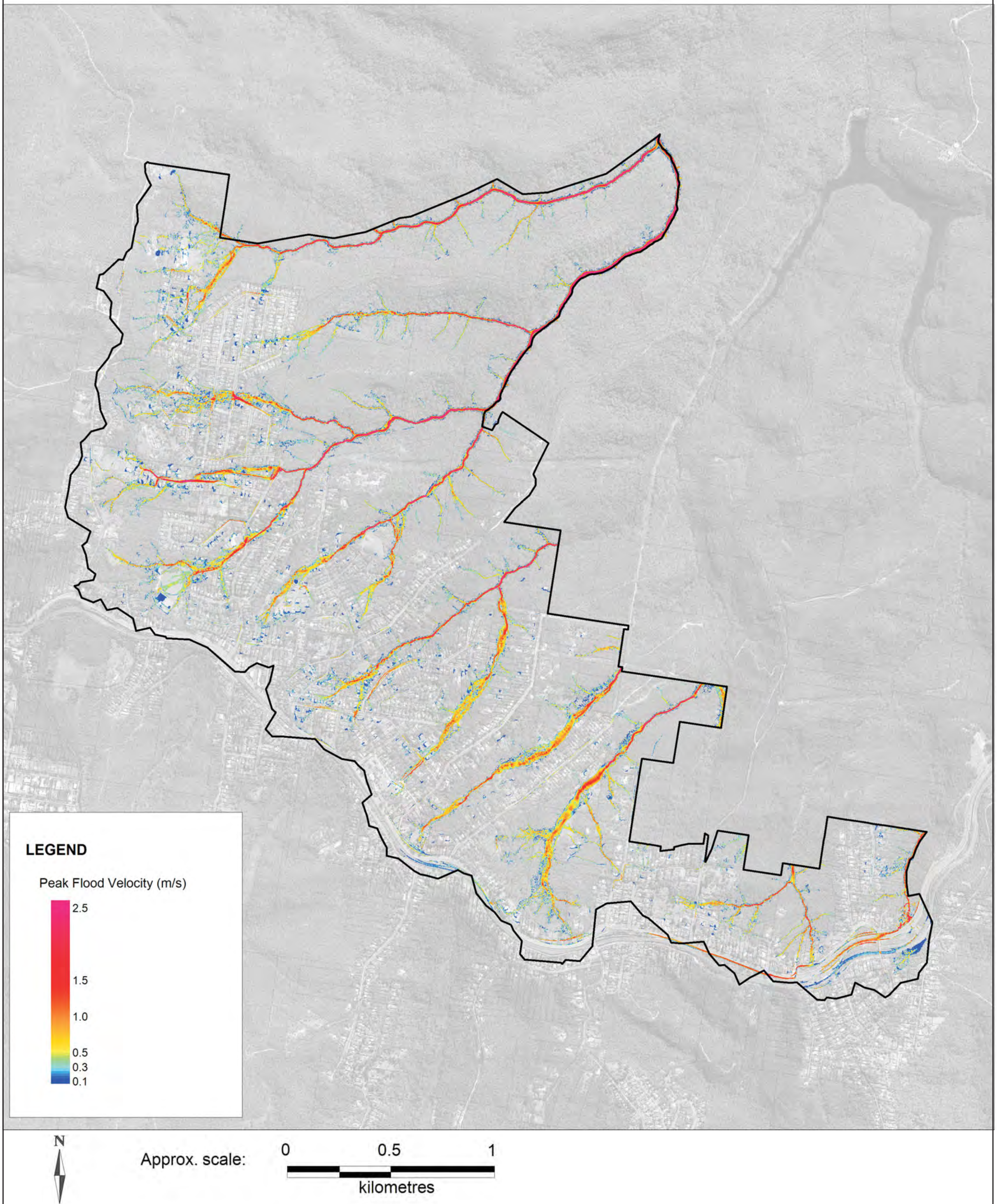
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
2% AEP PEAK FLOOD DEPTH

MHL Report 2174

Figure A8

DRAWING 2174-A08.cdr



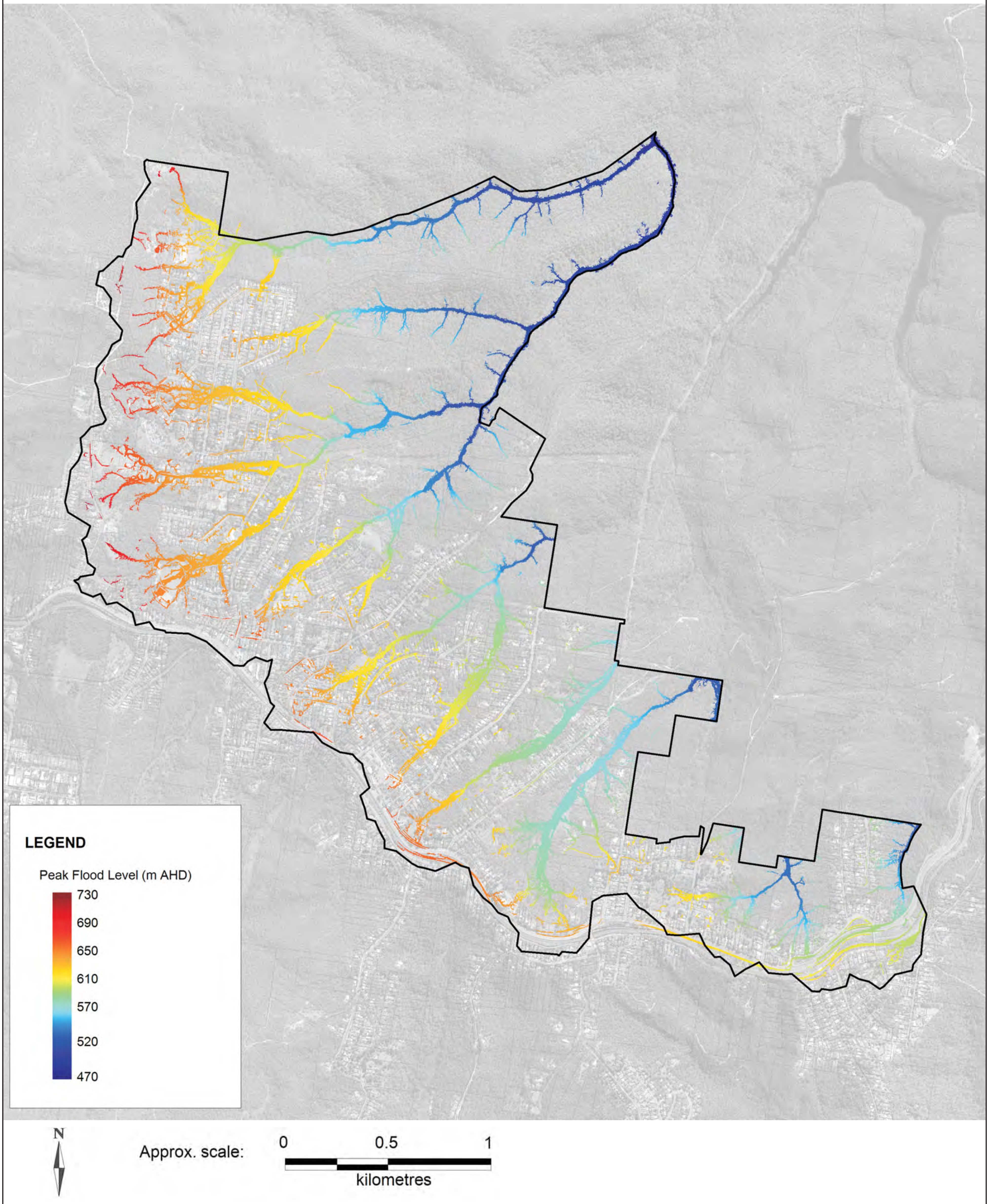
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
2% AEP PEAK FLOOD VELOCITY

MHL Report 2174

Figure A9

DRAWING 2174-A09.cdr



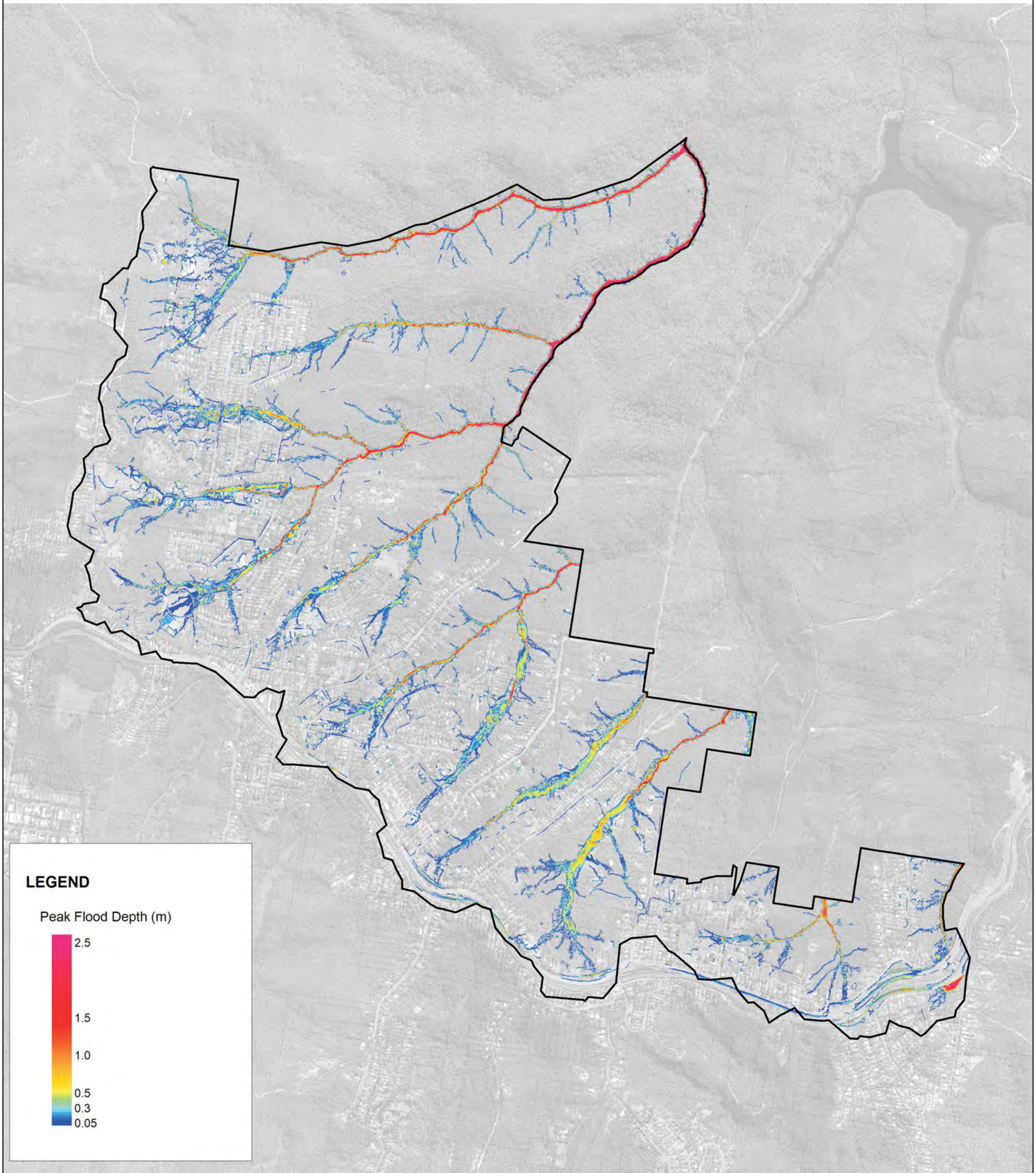
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
1% AEP PEAK FLOOD LEVEL

MHL Report 2174

Figure A10

DRAWING 2174-A10.cdr



N

Approx. scale: 0 0.5 1 kilometres

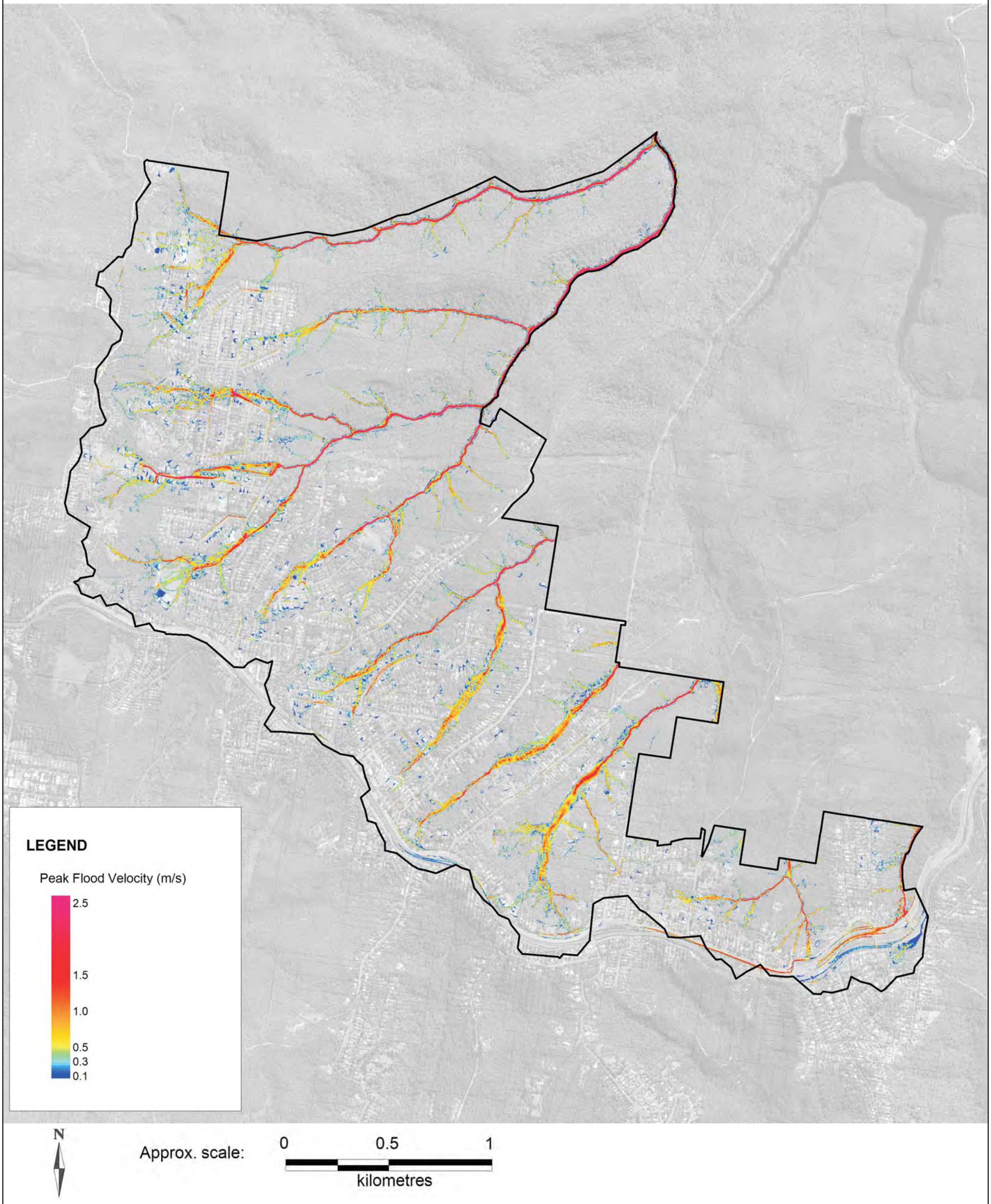
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
1% AEP PEAK FLOOD DEPTH

MHL Report 2174

Figure A11

DRAWING 2174-A11.cdr



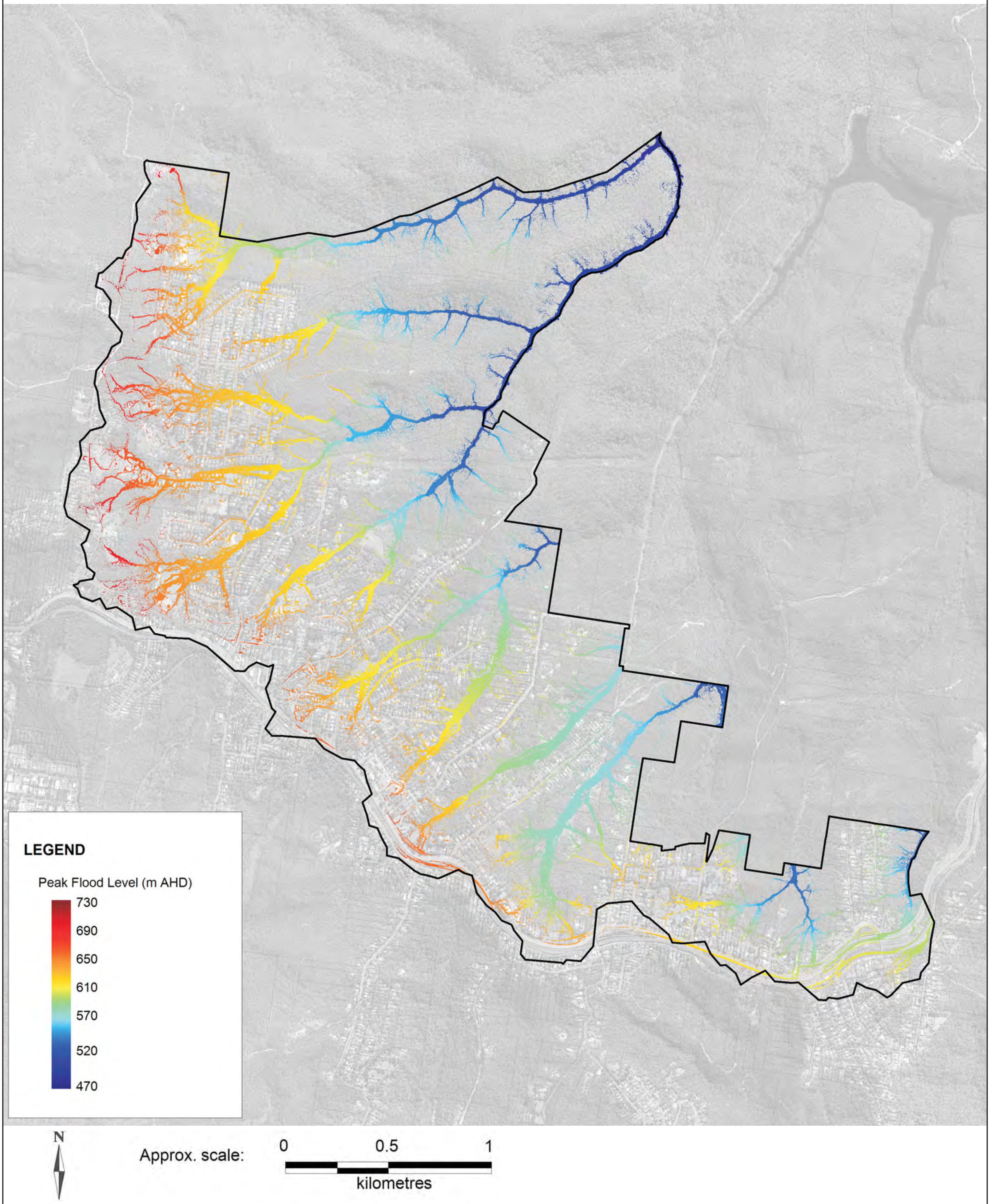
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
1% AEP PEAK FLOOD VELOCITY

MHL Report 2174

Figure A12

DRAWING 2174-A12.cdr



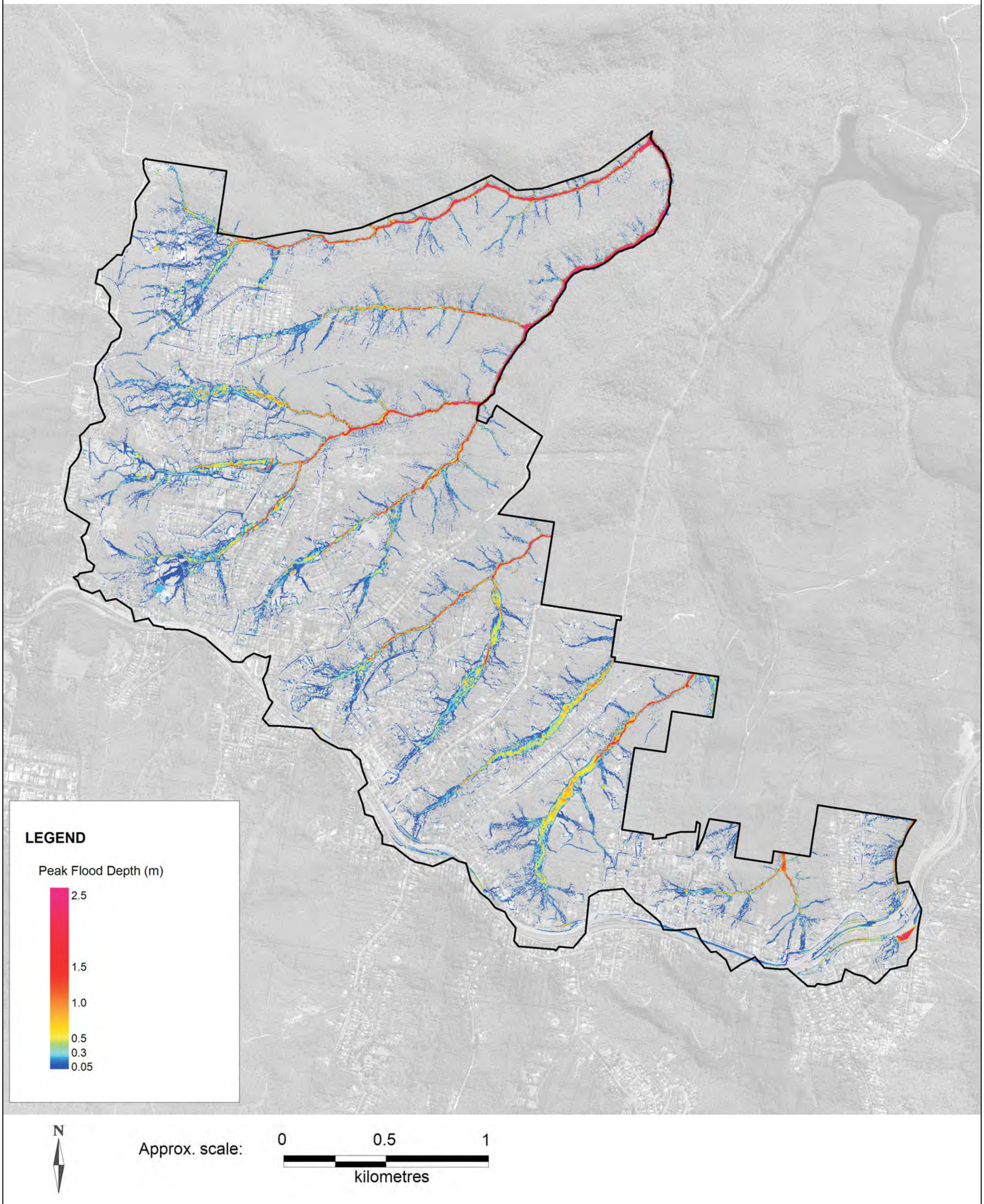
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
0.5% AEP PEAK FLOOD LEVEL

MHL Report 2174

Figure A13

DRAWING 2174-A13.cdr



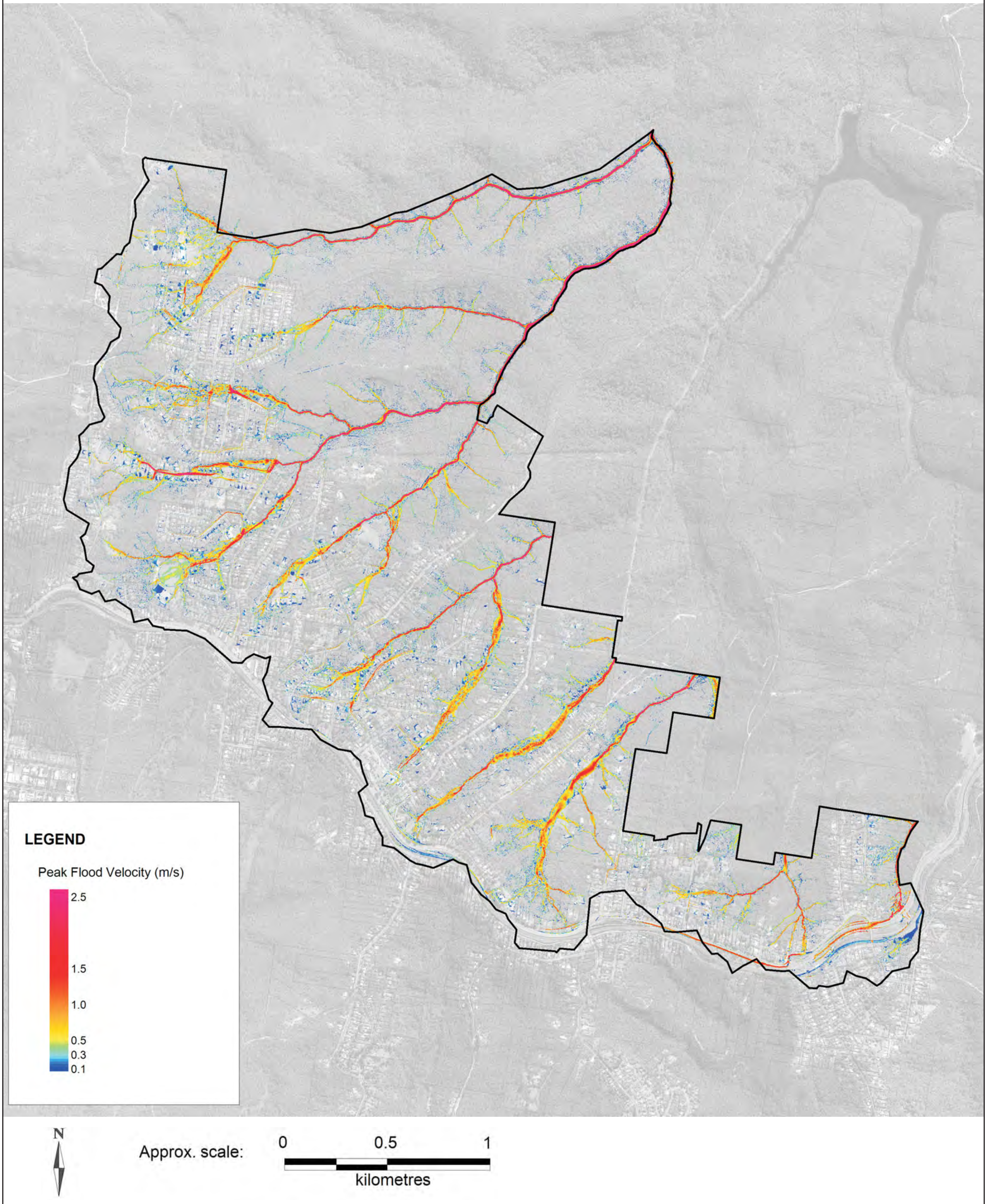
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
0.5% AEP PEAK FLOOD DEPTH

MHL Report 2174

Figure A14

DRAWING 2174-A14.cdr



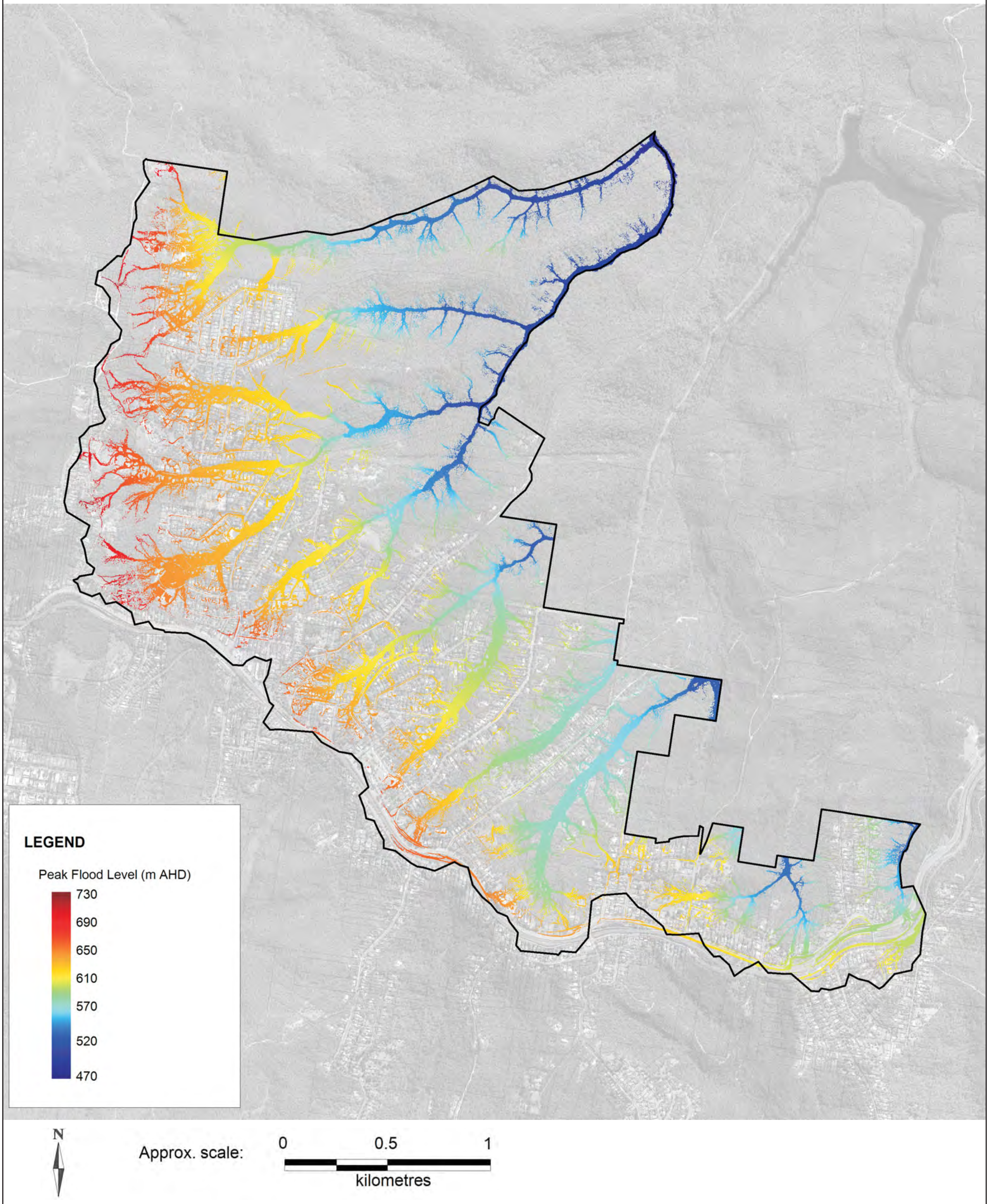
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
0.5% AEP PEAK FLOOD VELOCITY

MHL Report 2174

Figure A15

DRAWING 2174-A15.cdr



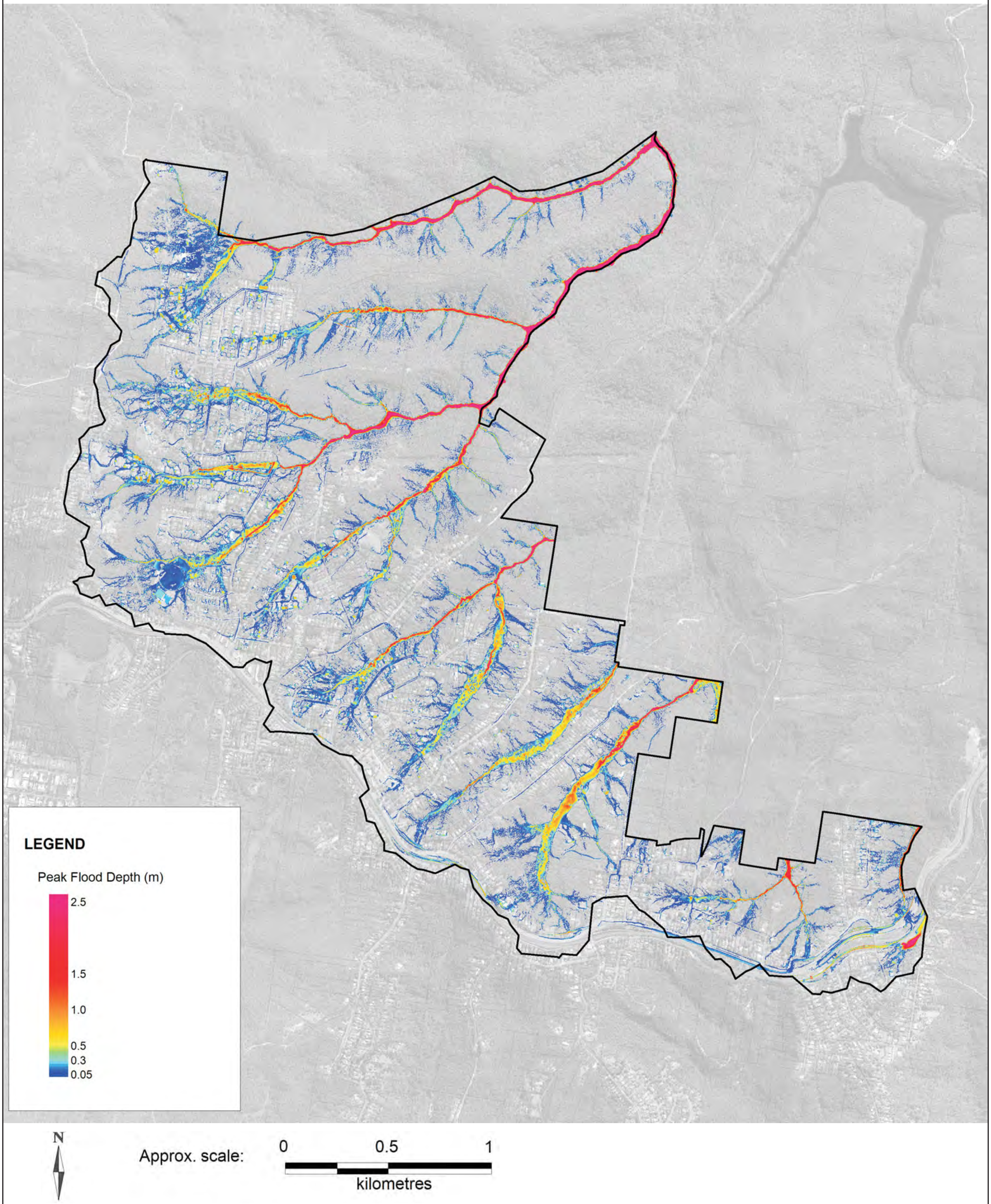
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
PMF PEAK FLOOD LEVEL

MHL Report 2174

Figure A16

DRAWING 2174-A16.cdr



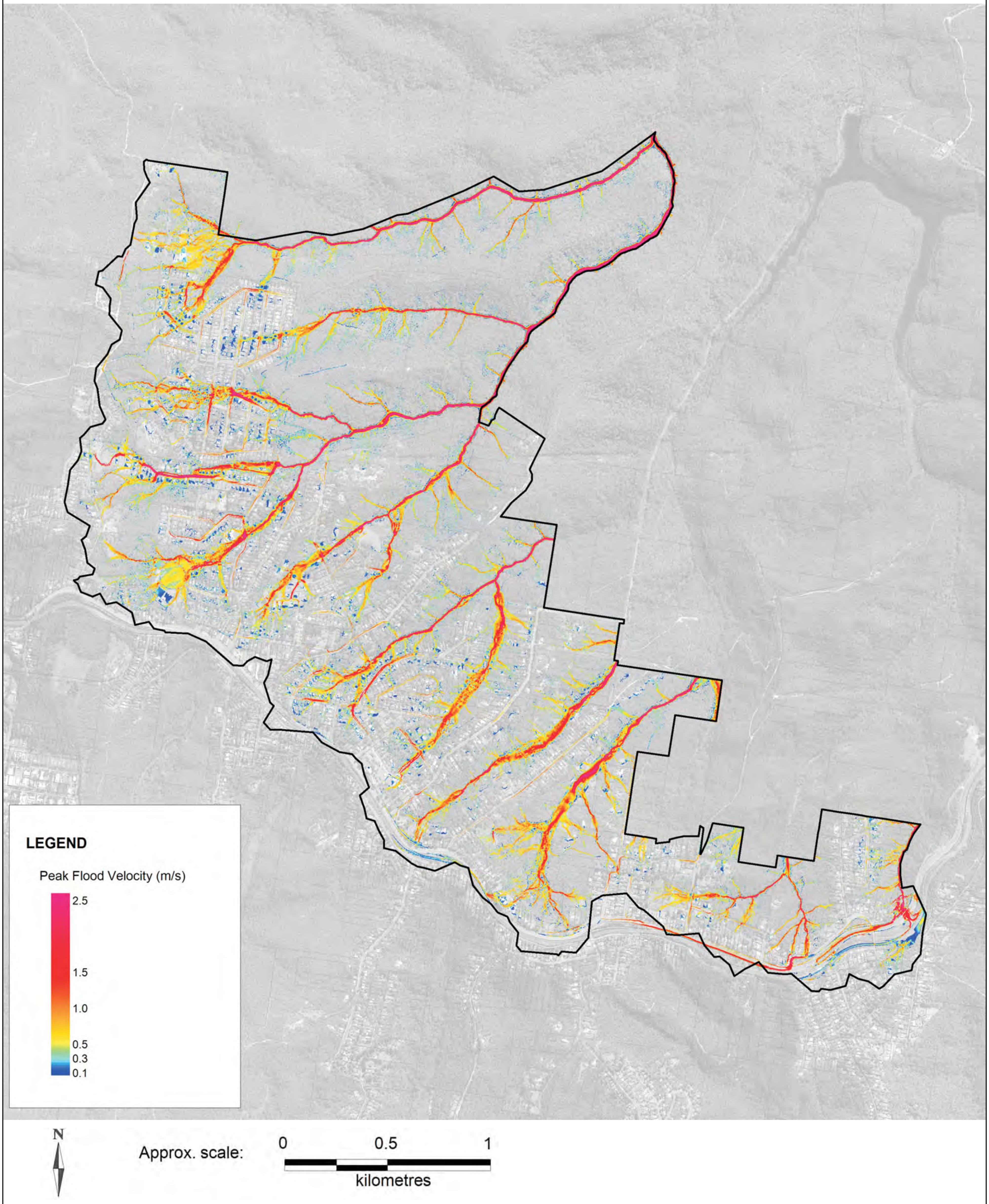
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
PMF PEAK FLOOD DEPTH

MHL Report 2174

Figure A17

DRAWING 2174-A17.cdr



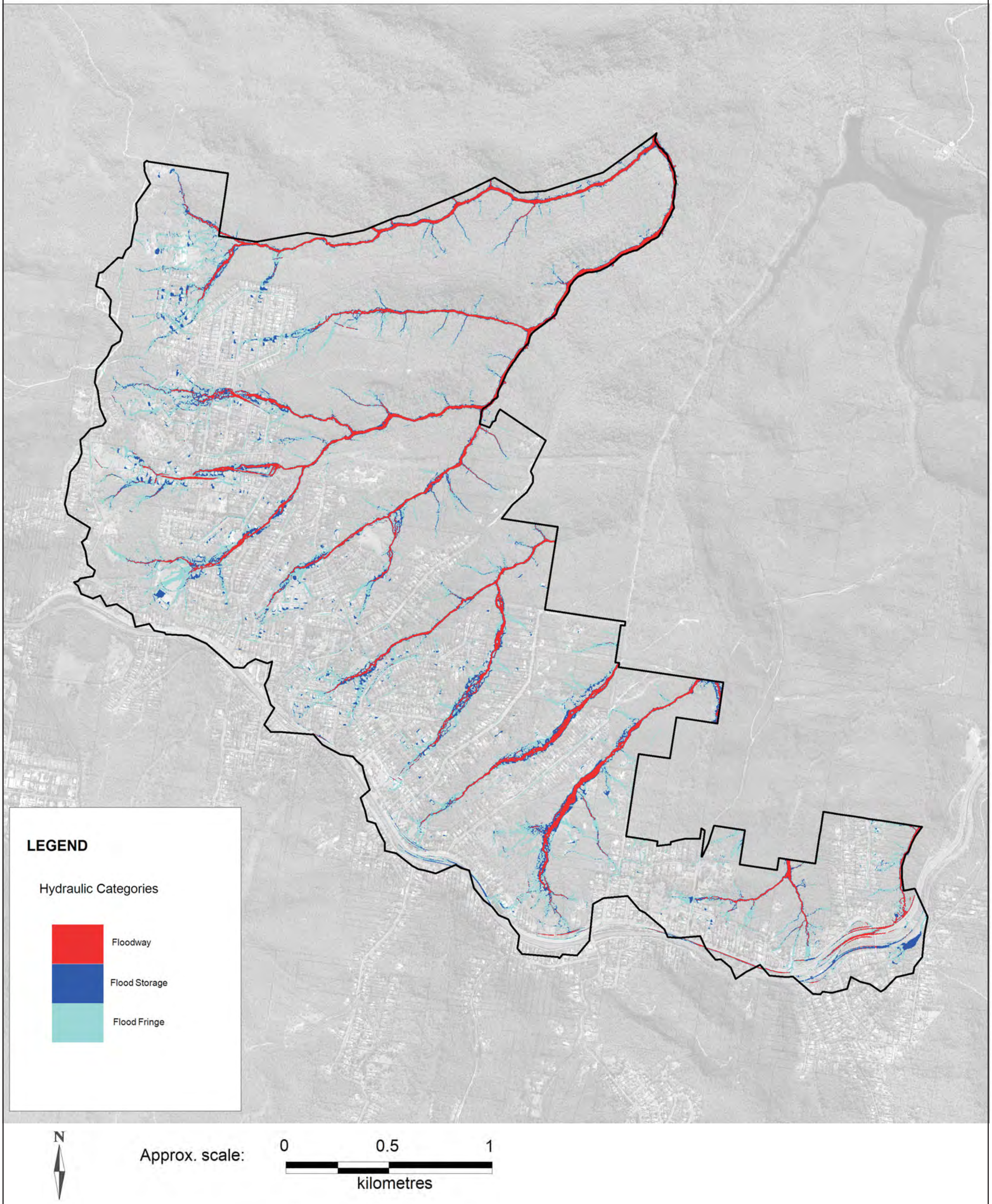
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
PMF PEAK FLOOD VELOCITY

MHL Report 2174

Figure A18

DRAWING 2174-A18.cdr



Public Works
Manly Hydraulics Laboratory

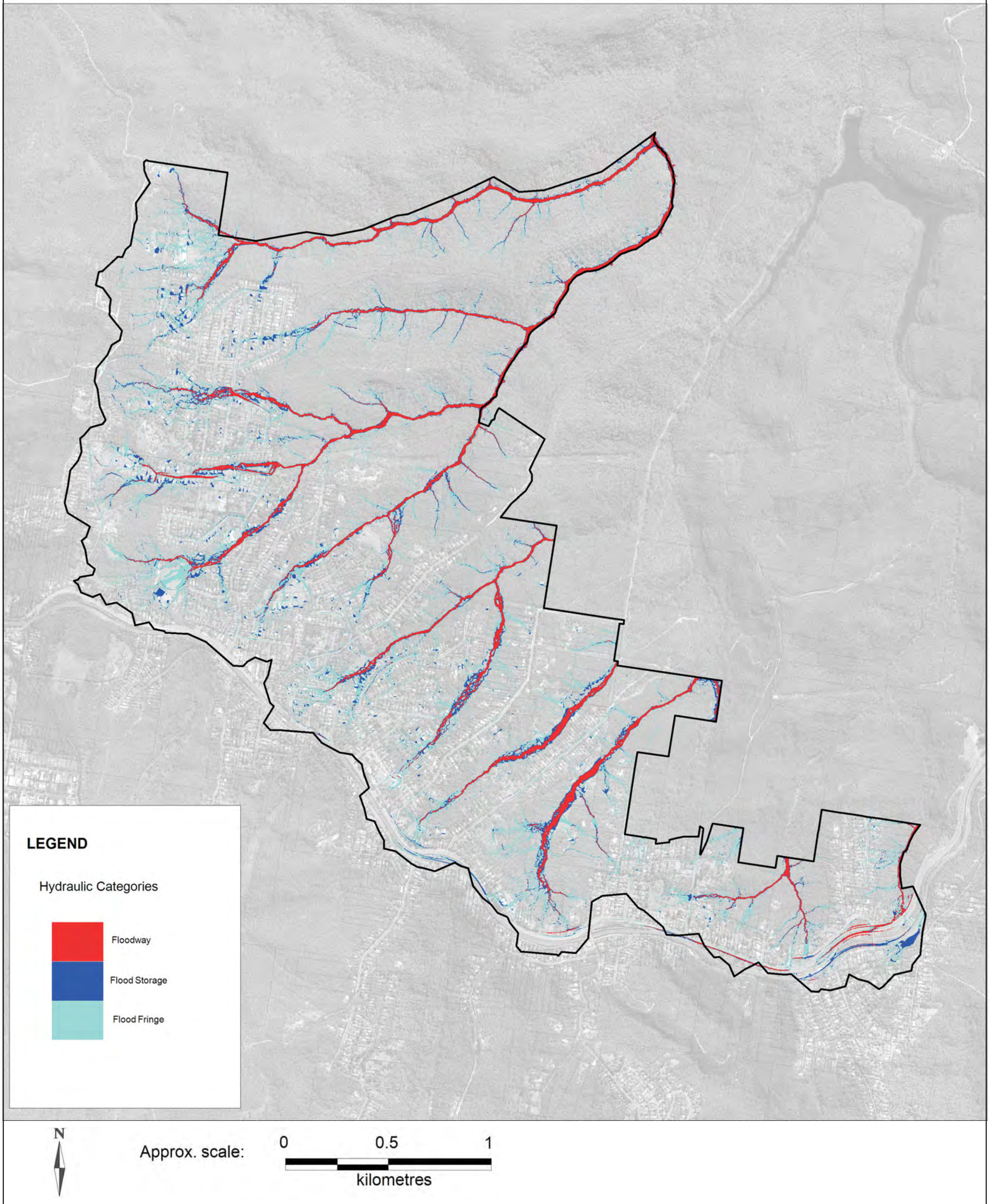
NSW GOVERNMENT

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
1% AEP HYDRAULIC CATEGORIES

MHL Report 2174

Figure A19

DRAWING 2174-A19.cdr



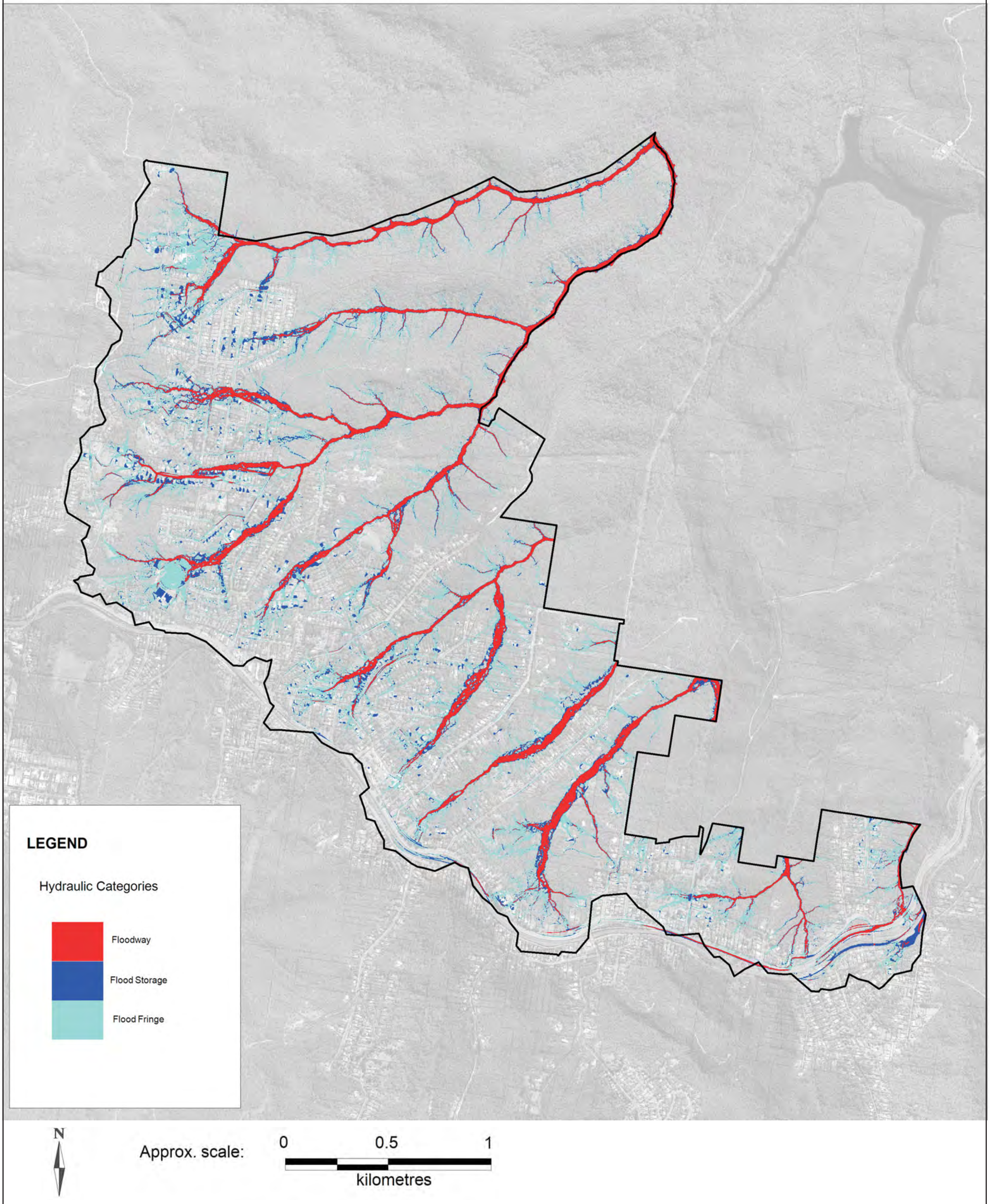
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
0.5% AEP HYDRAULIC CATEGORIES

MHL Report 2174

Figure A20

DRAWING 2174-A20.cdr



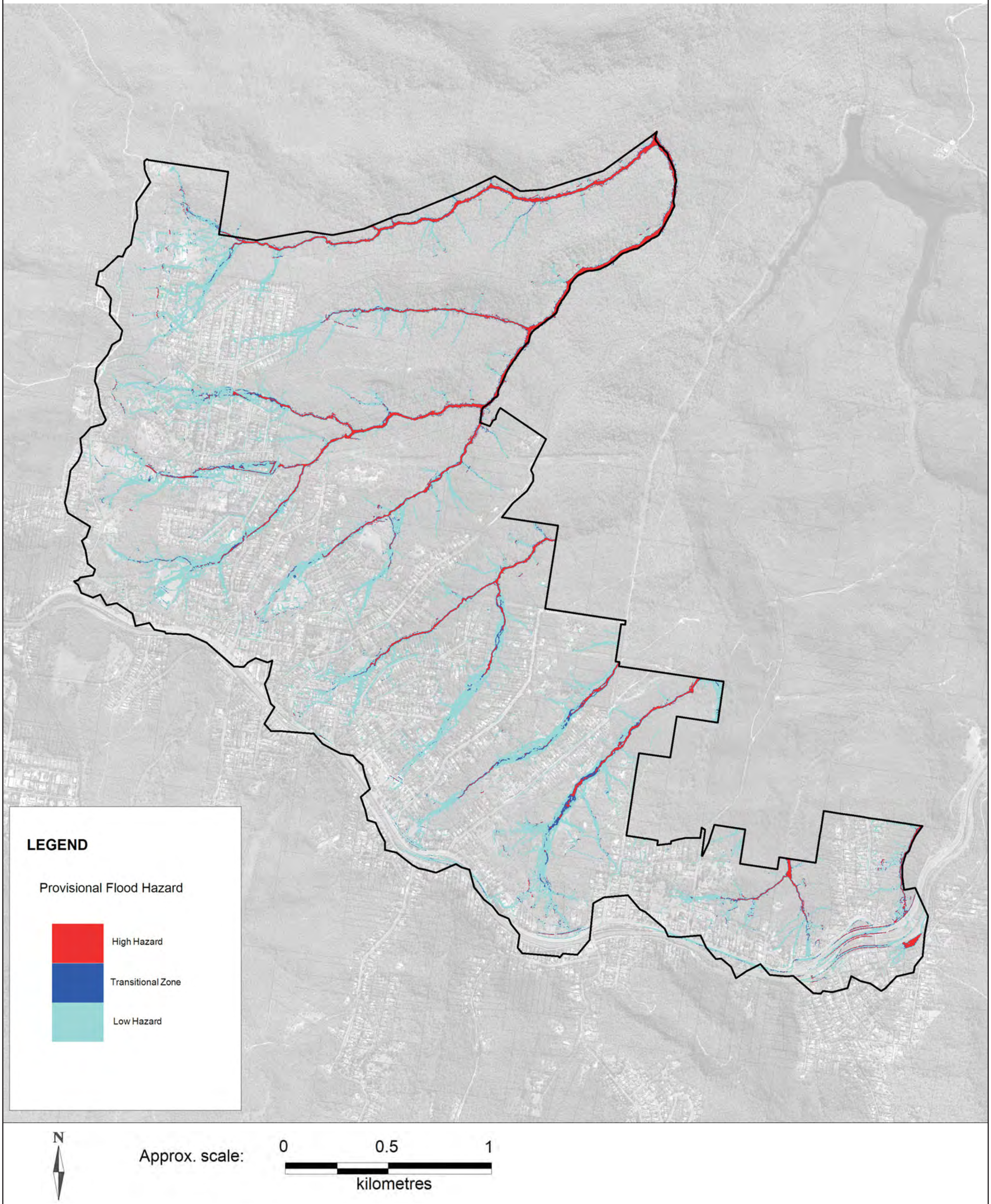
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
PMF HYDRAULIC CATEGORIES

MHL Report 2174

Figure A21

DRAWING 2174-A21.cdr



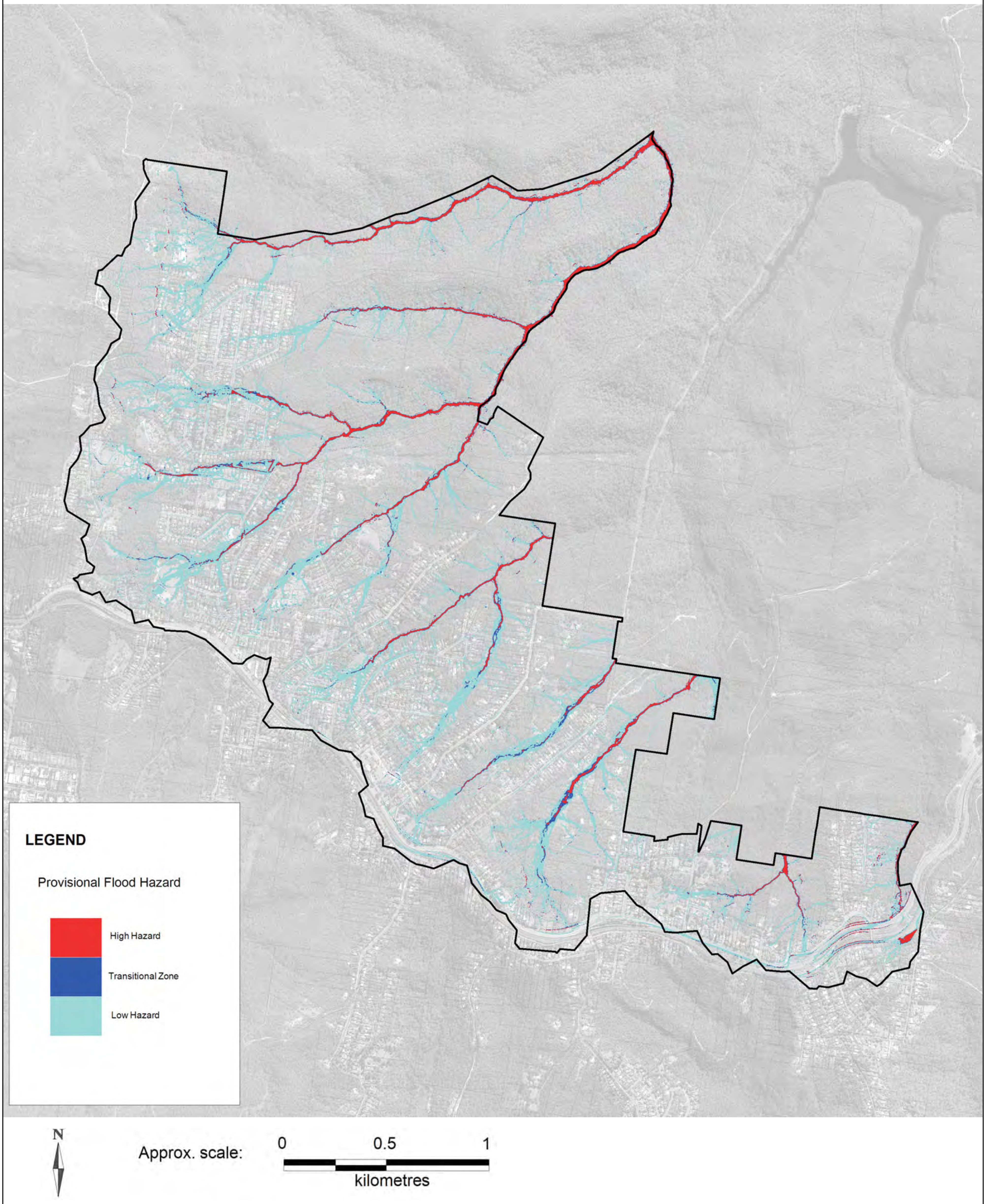
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
1% AEP PROVISIONAL HAZARD

MHL Report 2174

Figure A22

DRAWING 2174-A22.cdr



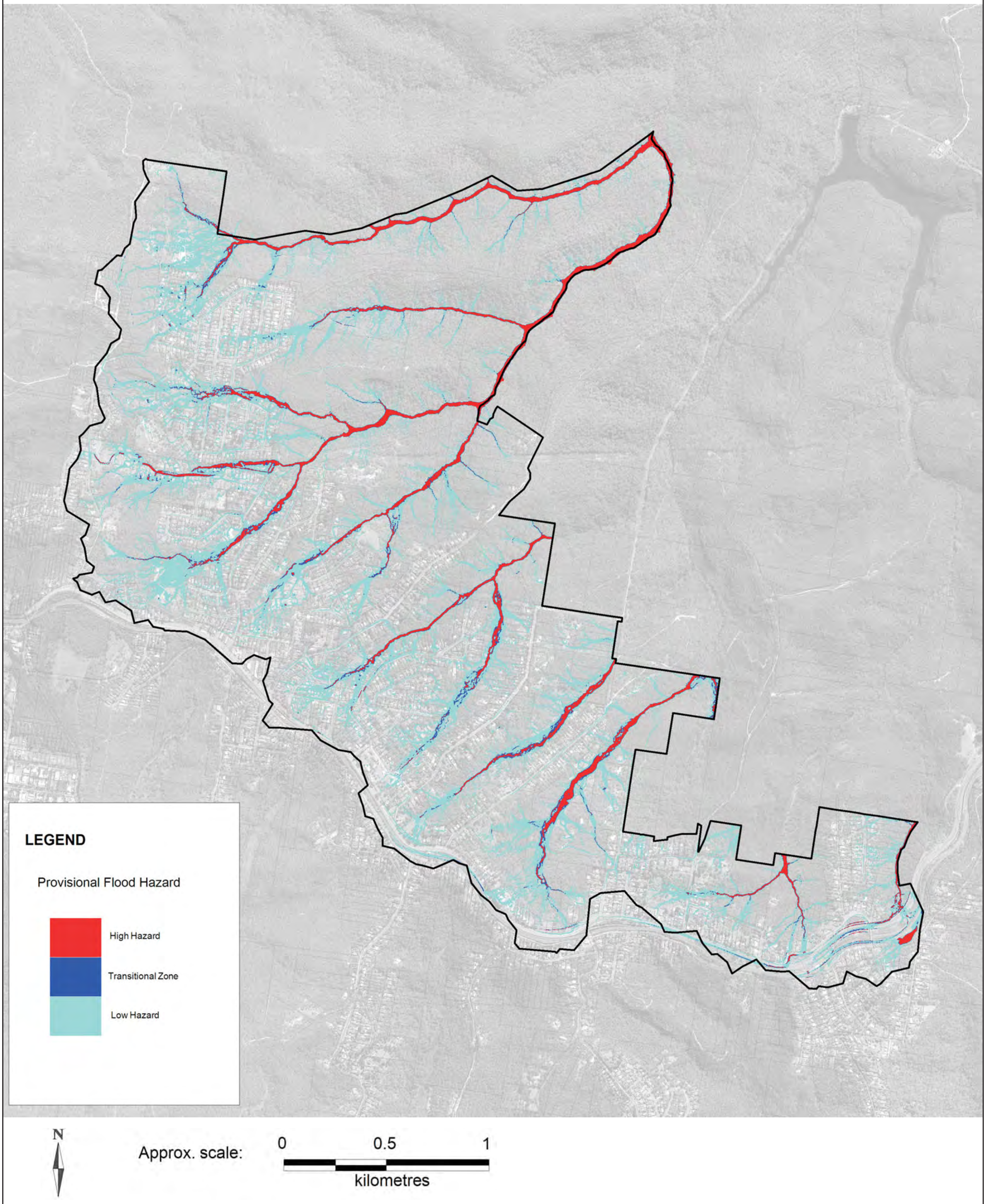
NSW GOVERNMENT
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
0.5% AEP PROVISIONAL HAZARD

MHL Report 2174

Figure A23

DRAWING 2174-A23.cdr



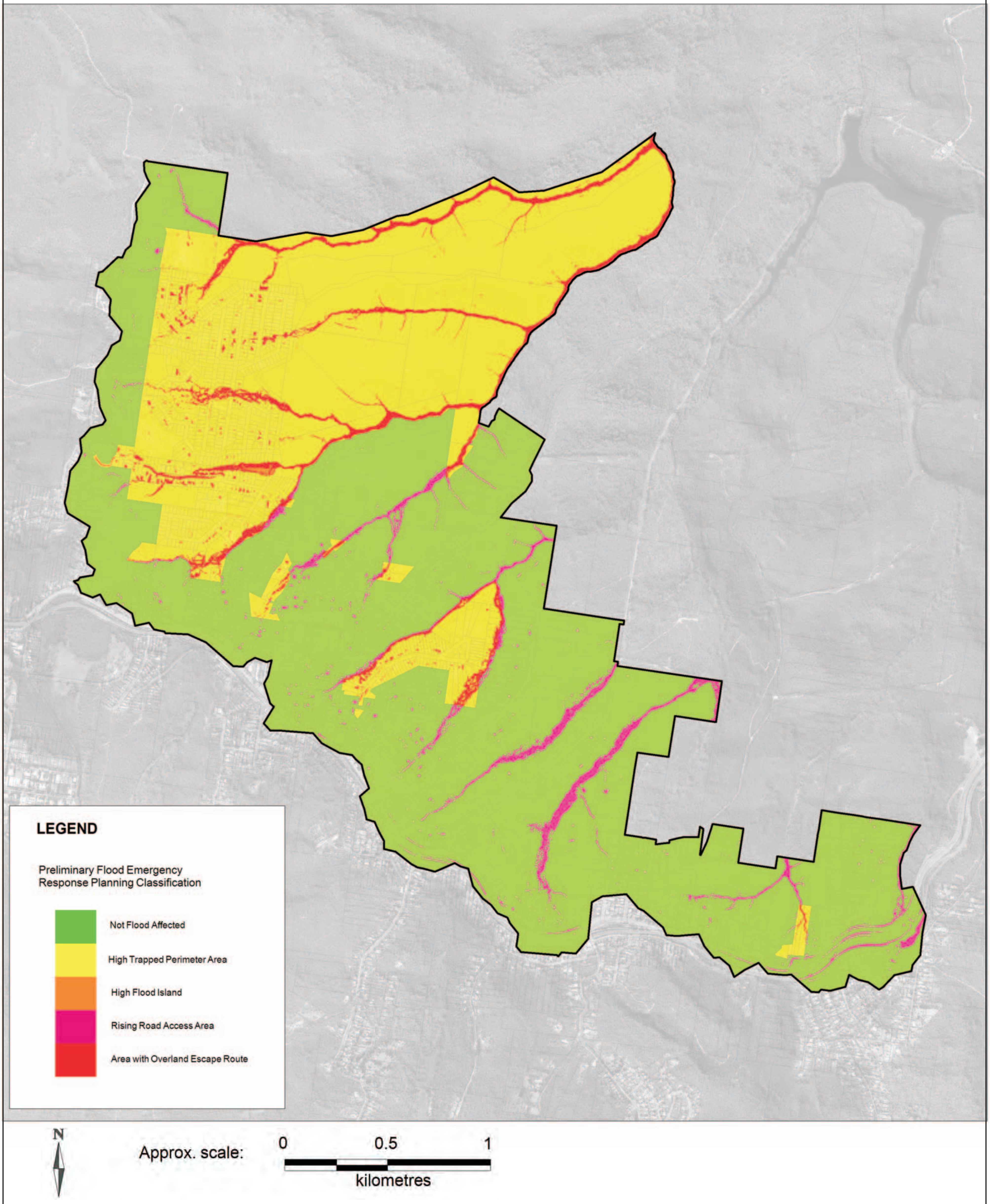
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
PMF PROVISIONAL HAZARD

MHL Report 2174

Figure A24

DRAWING 2174-A24.cdr



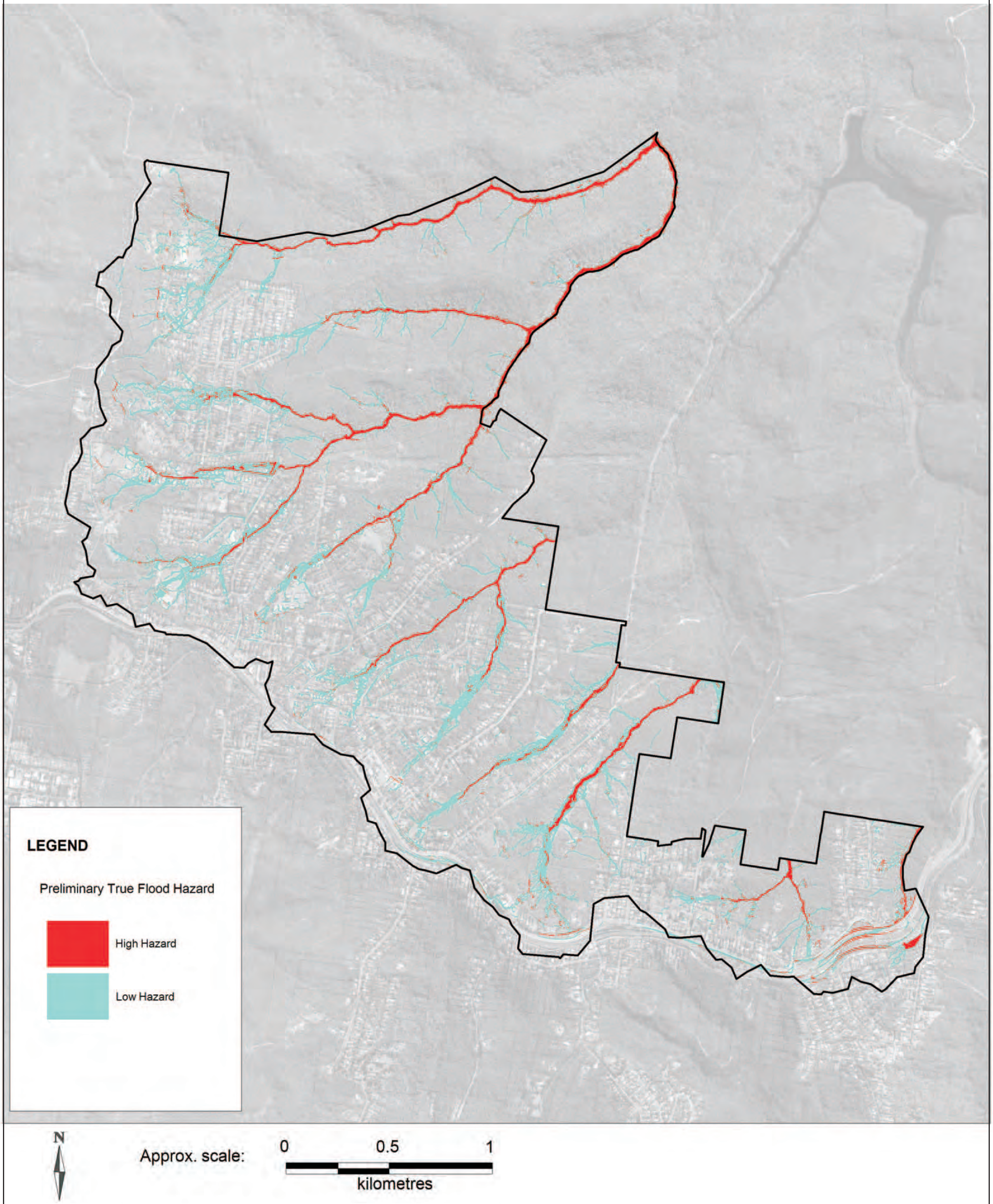
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
PRELIMINARY EMERGENCY RESPONSE CLASSIFICATION

MHL Report 2174

Figure A25

DRAWING 2174-A25.cdr



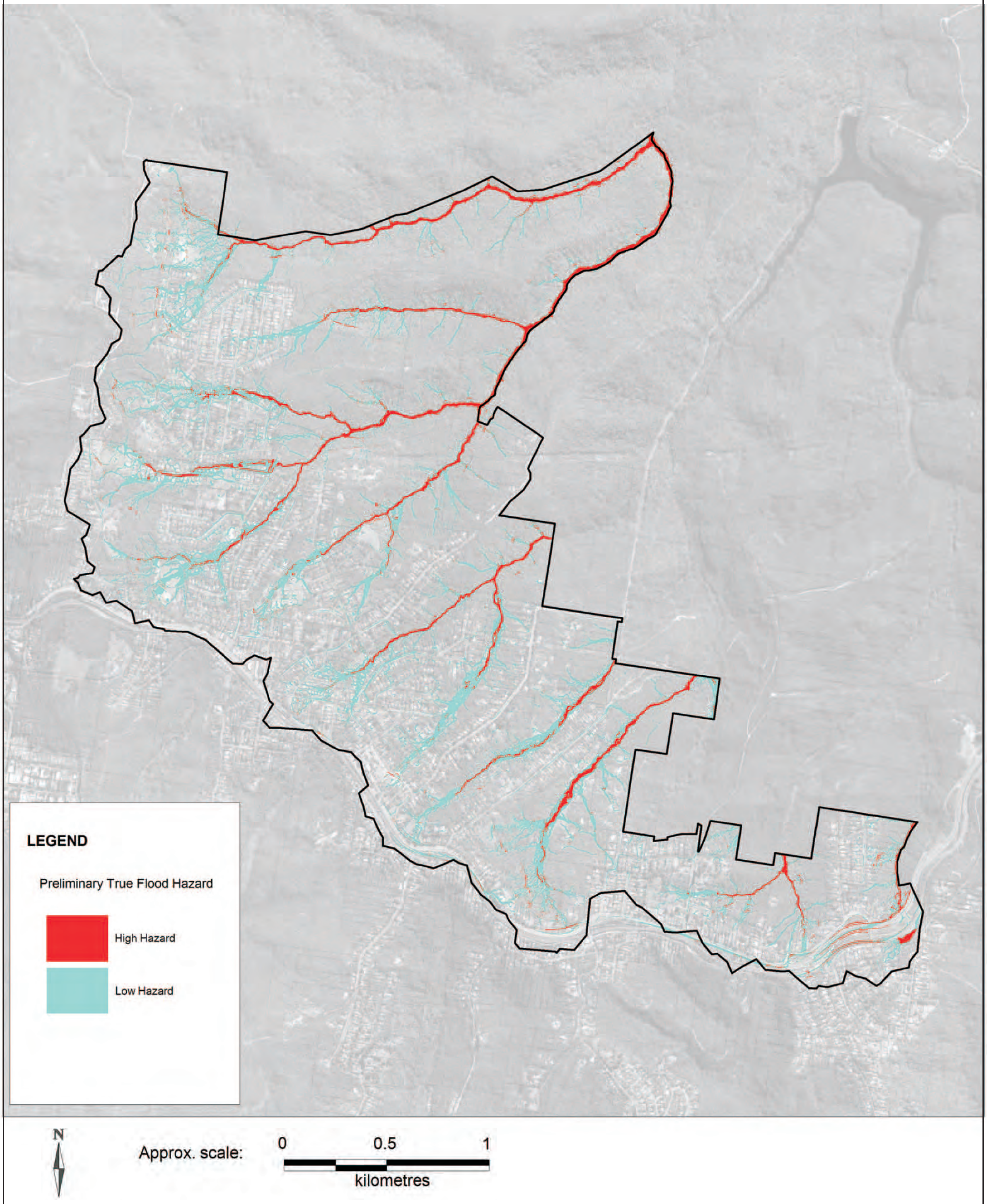
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
1% AEP PRELIMINARY TRUE HAZARD CATEGORIES

MHL Report 2174

Figure A26

DRAWING 2174-A26.cdr



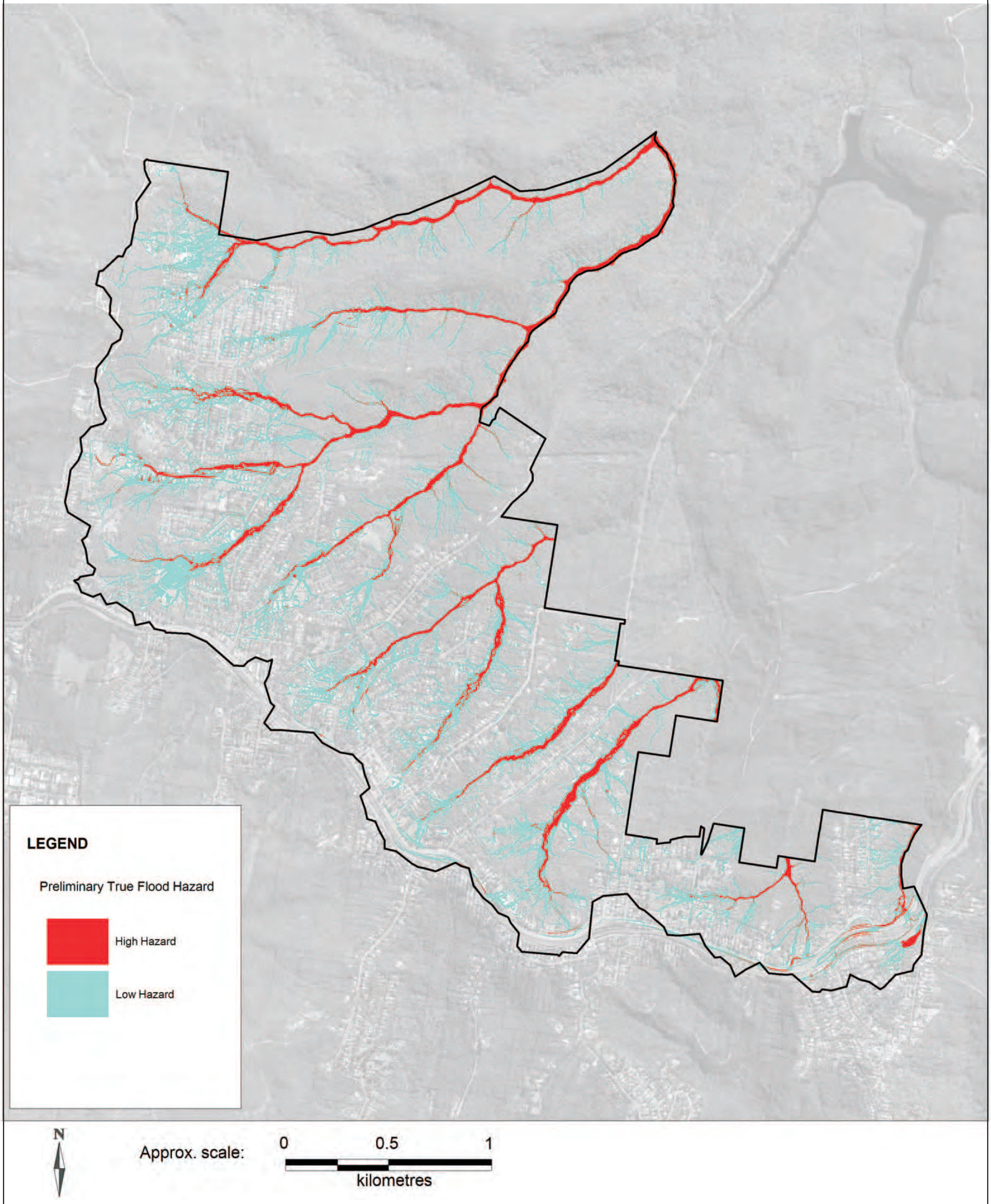
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
0.5% AEP PRELIMINARY TRUE HAZARD CATEGORIES

MHL Report 2174

Figure A27

DRAWING 2174-A27.cdr



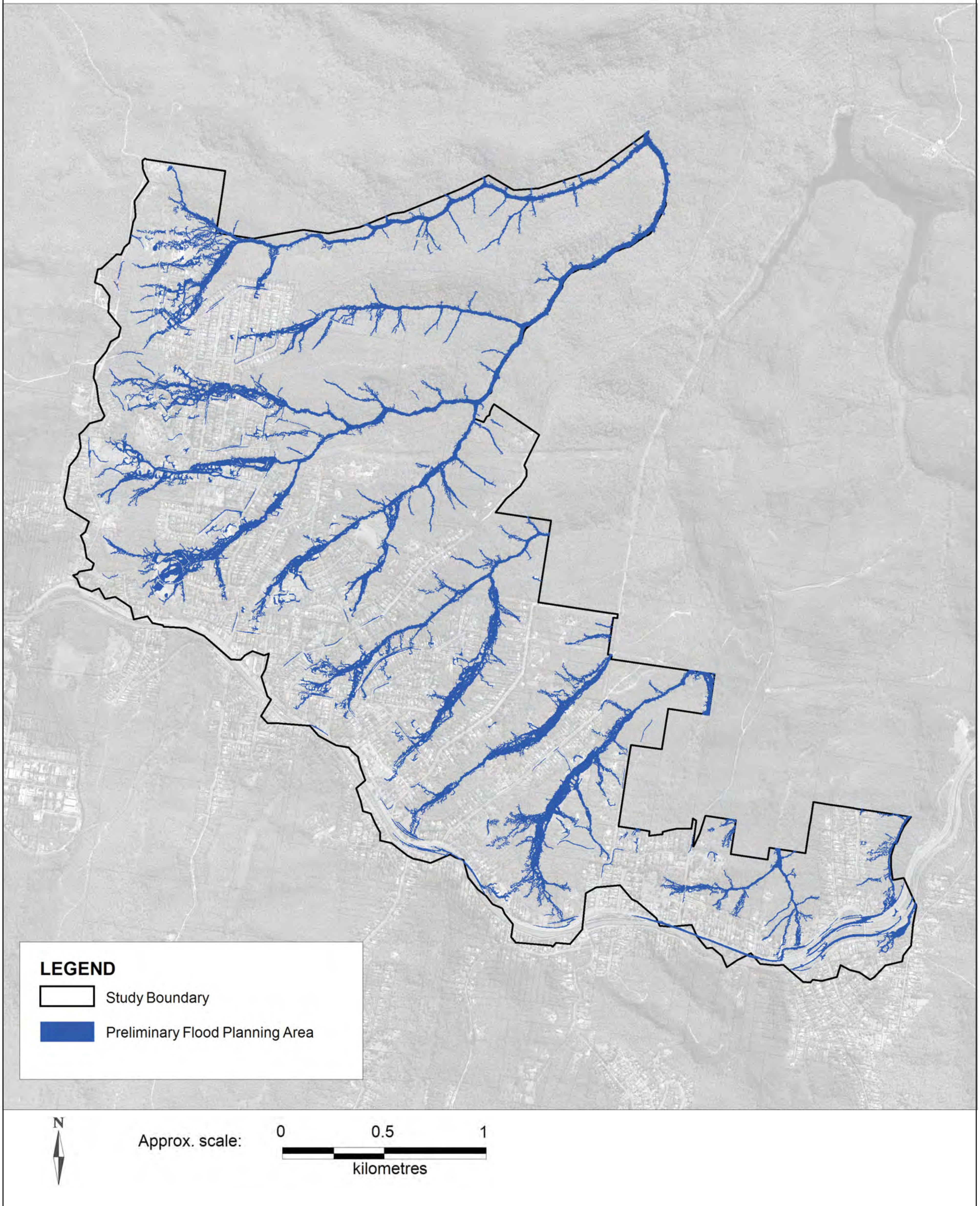
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
PMF PRELIMINARY TRUE HAZARD CATEGORIES

MHL Report 2174

Figure A28

DRAWING 2174-A28.cdr



NSW GOVERNMENT
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
PRELIMINARY FLOOD PLANNING AREA

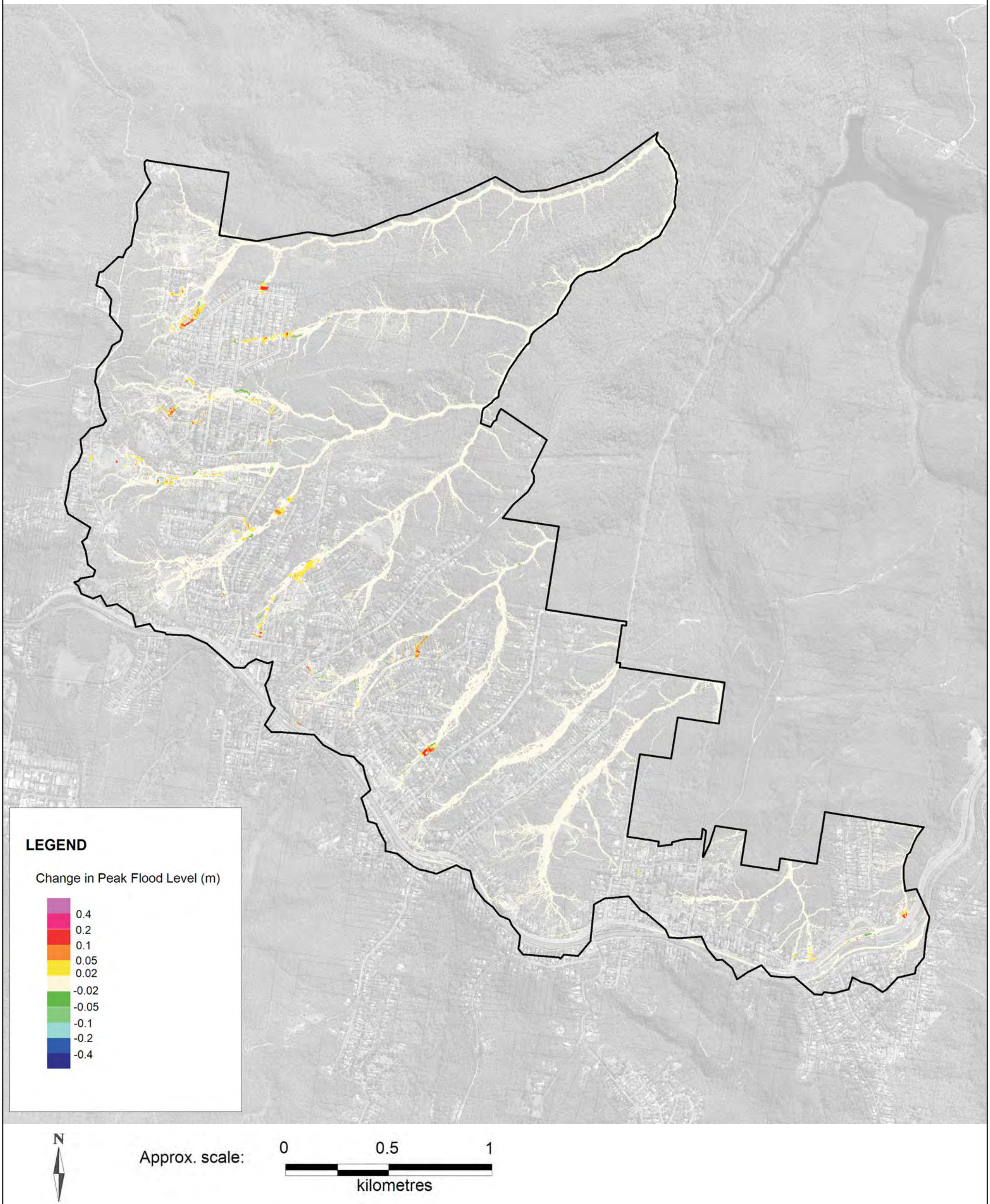
MHL Report 2174

Figure A29

DRAWING 2174-A29.cdr

Appendix B

Sensitivity and Climate Change Impact Mapping



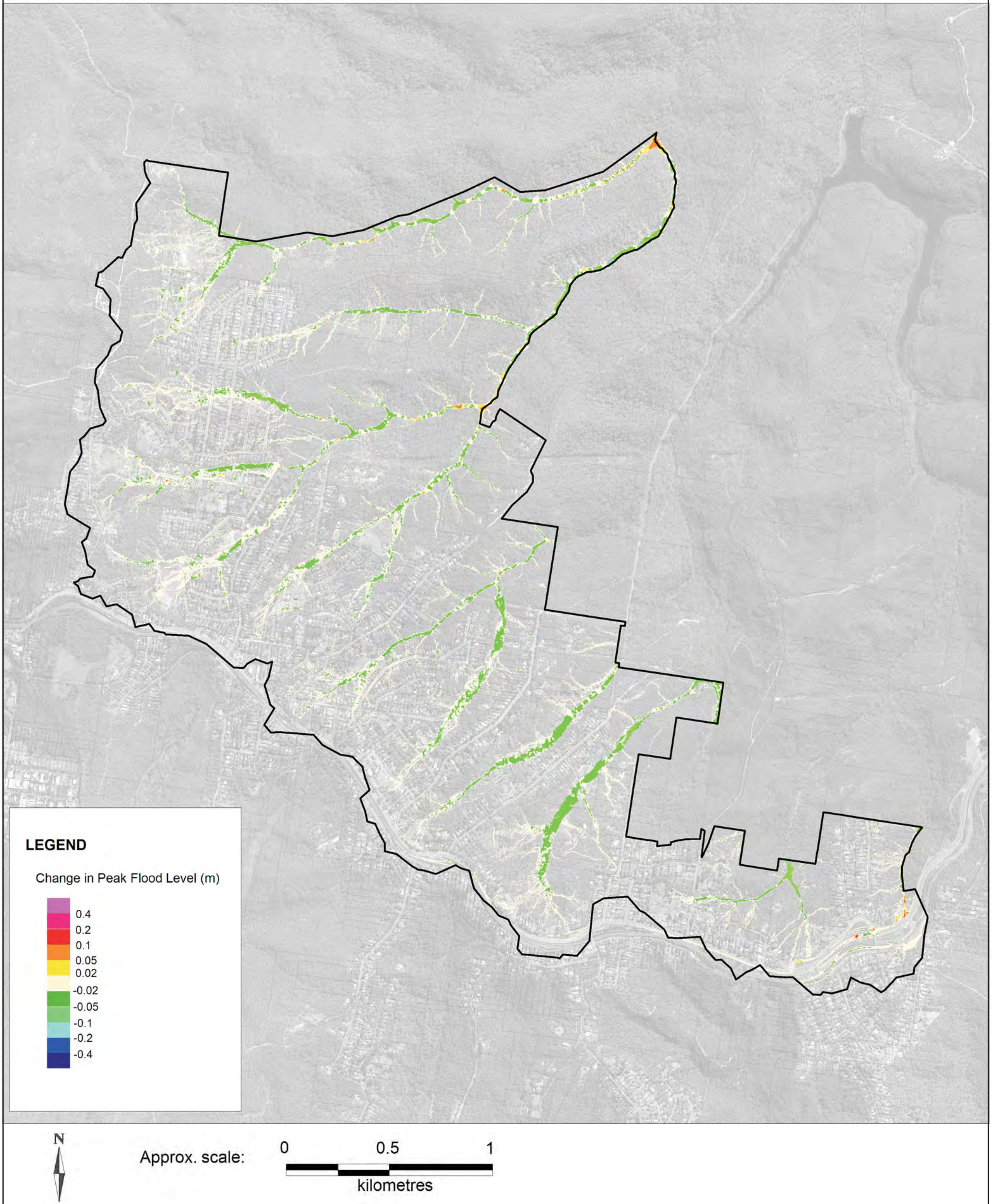
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
1% AEP STRUCTURAL BLOCKAGE SENSITIVITY

MHL Report 2174

Figure B1

DRAWING 2174-B1.cdr



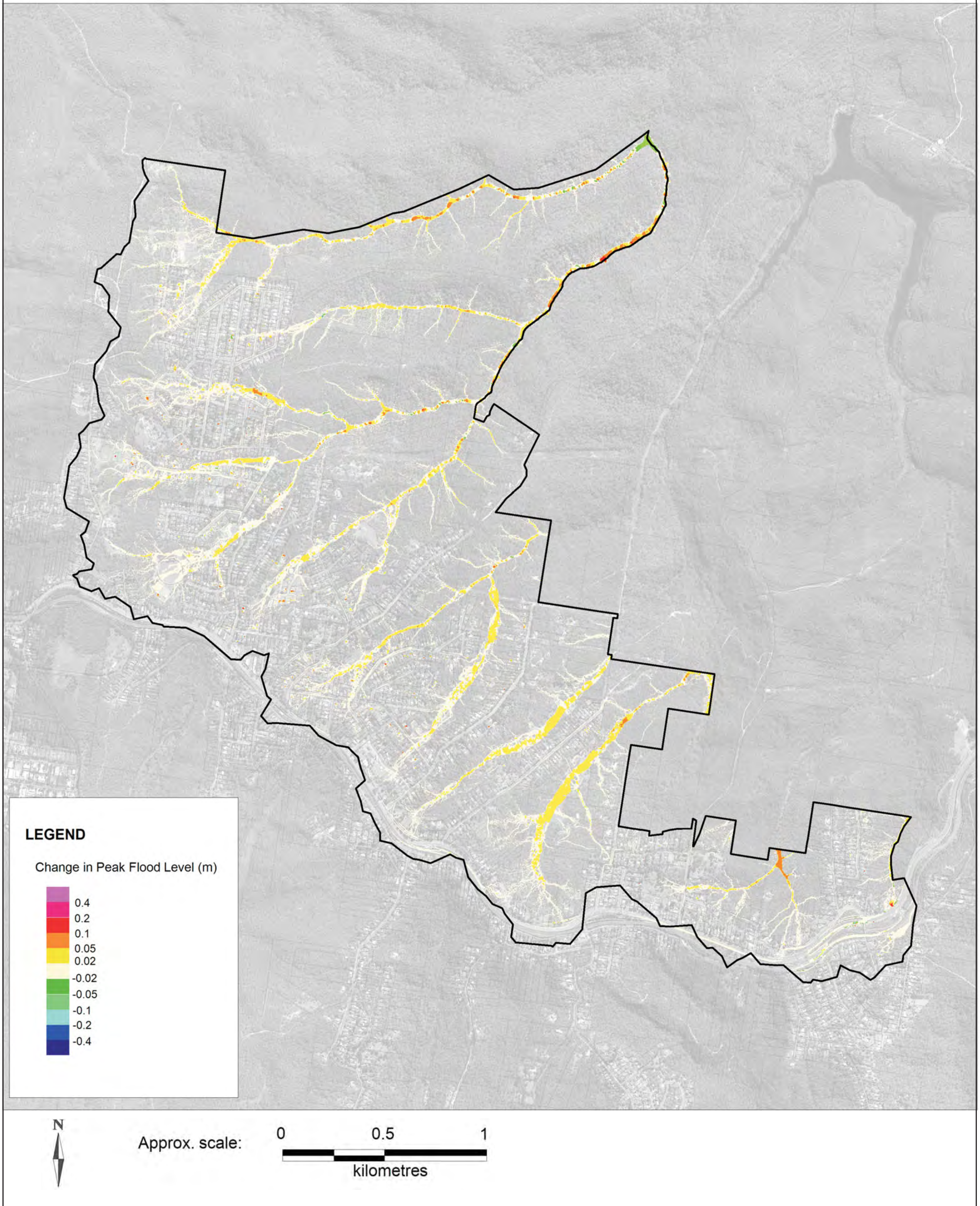
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
1% AEP 20% DECREASE IN HYDRAULIC ROUGHNESS

MHL Report 2174

Figure B2

DRAWING 2174-B2.cdr



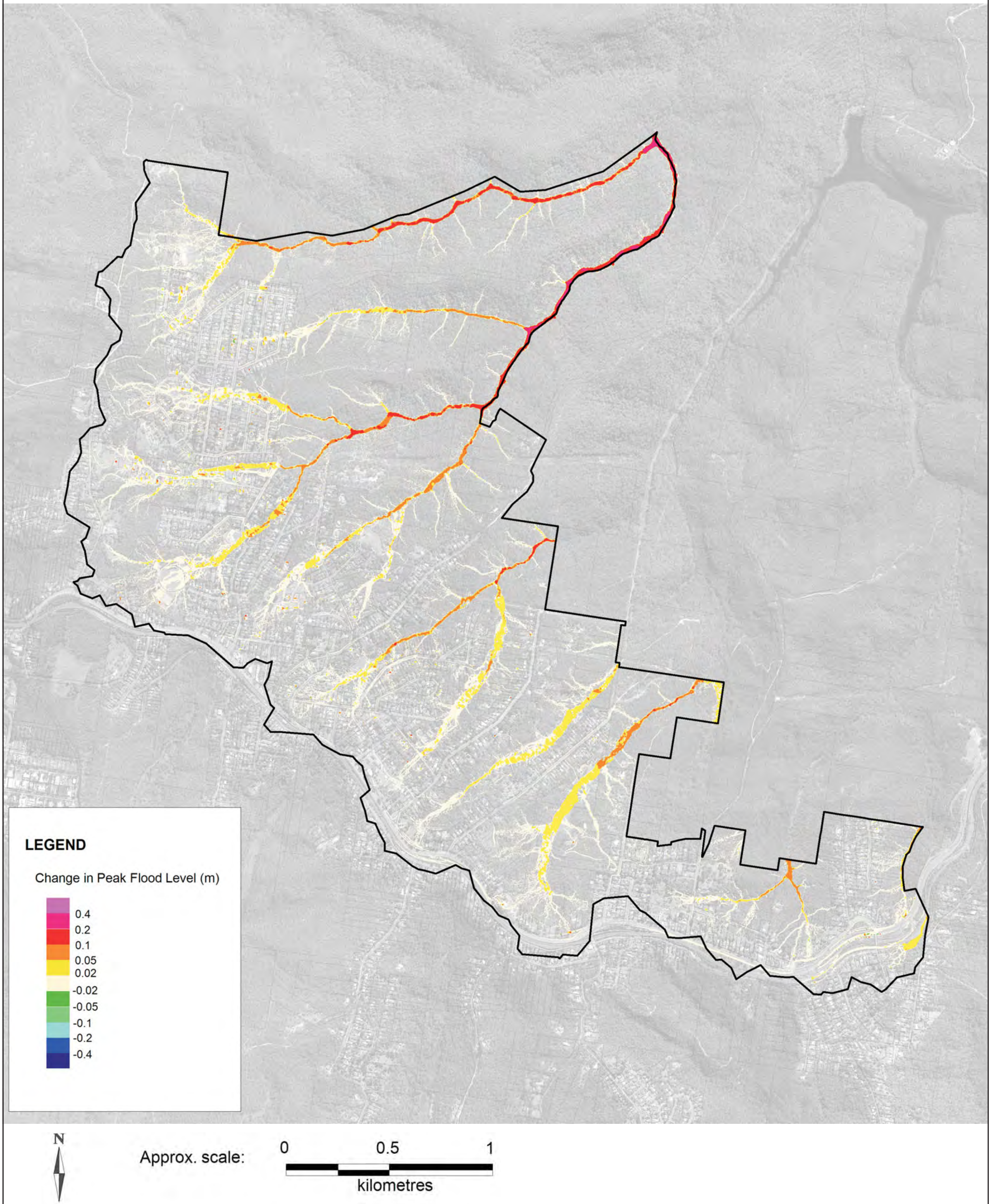
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
1% AEP 20% INCREASE IN HYDRAULIC ROUGHNESS

MHL Report 2174

Figure B3

DRAWING 2174-B3.cdr



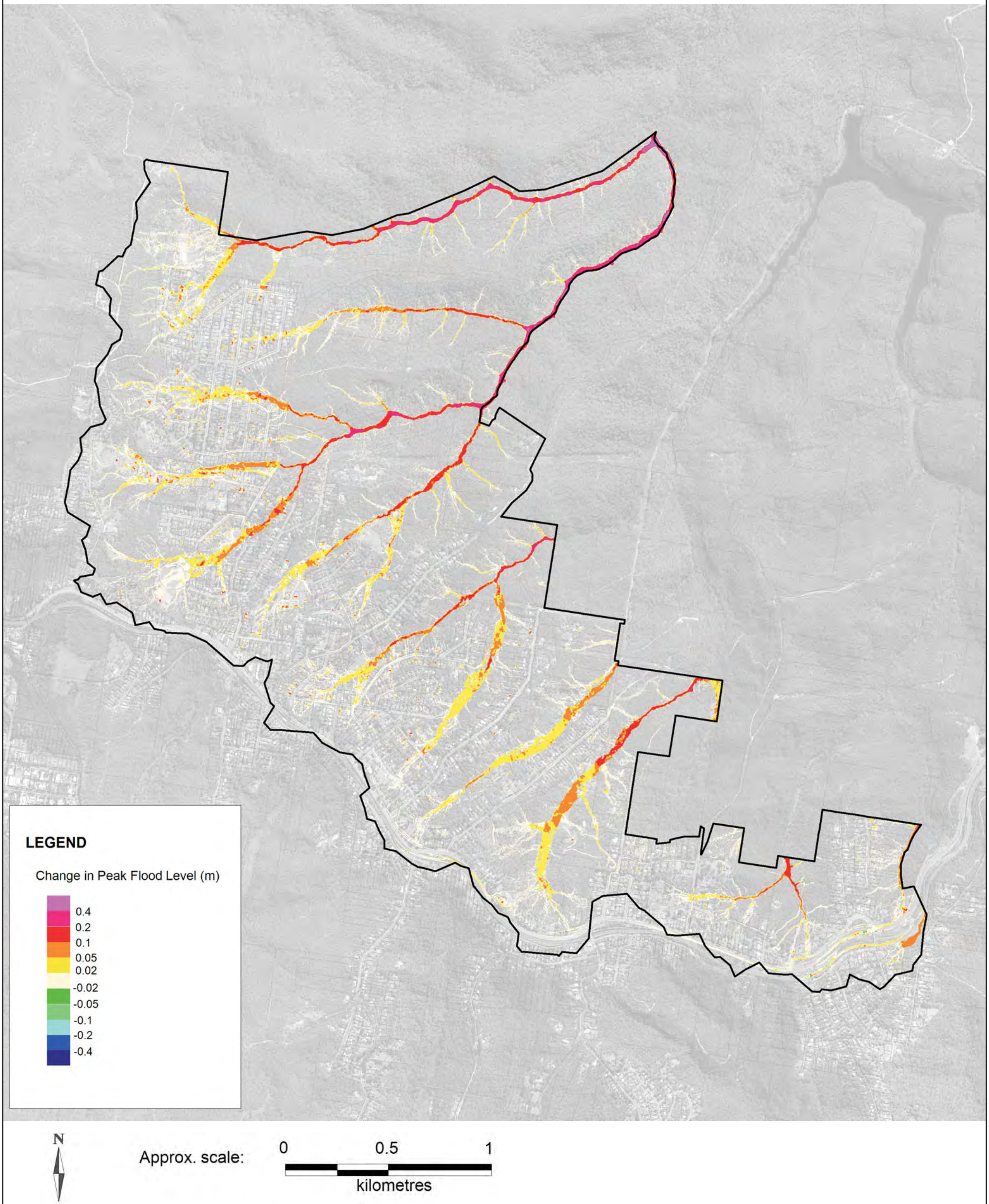
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
1% AEP 10% INCREASE IN RAINFALL INTENSITY

MHL Report 2174

Figure B4

DRAWING 2174-B4.cdr



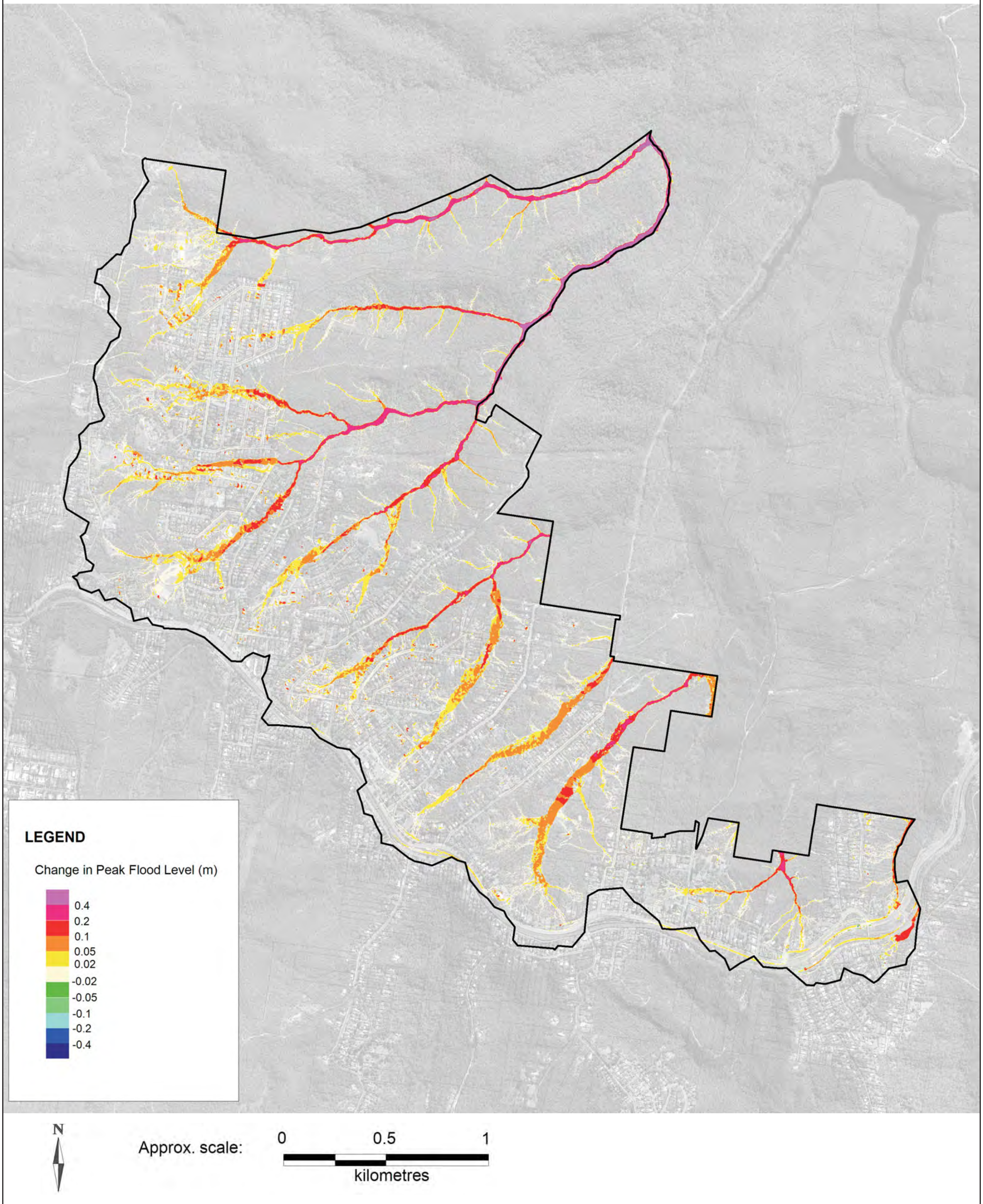
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
1% AEP 20% INCREASE IN RAINFALL INTENSITY

MHL Report 2174

Figure B5

DRAWING 2174-B5.cdr



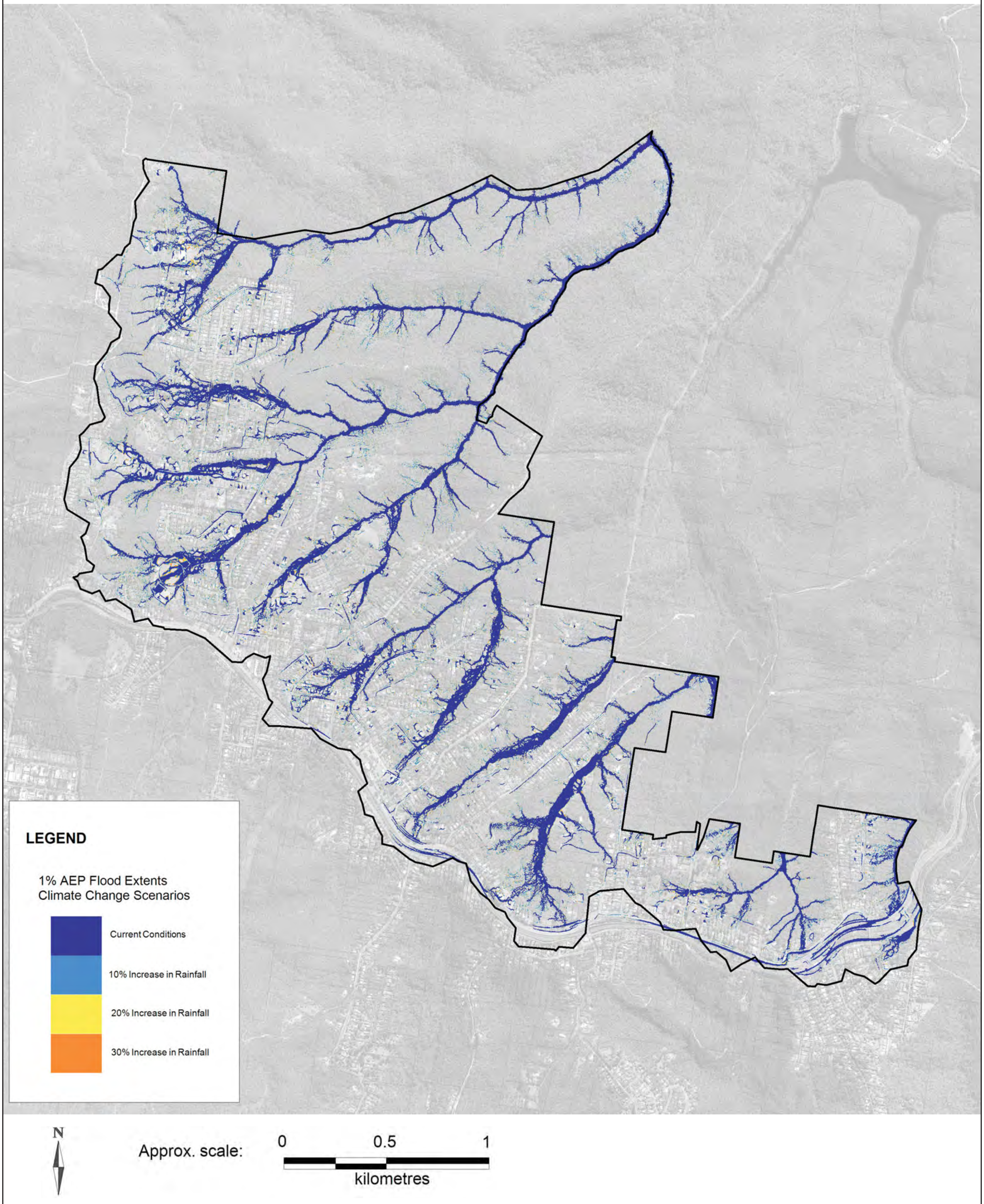
Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
1% AEP 30% INCREASE IN RAINFALL INTENSITY

MHL Report 2174

Figure B6

DRAWING 2174-B6.cdr



Public Works
Manly Hydraulics Laboratory

HAZELBROOK AND WOODFORD CATCHMENTS FLOOD STUDY
1% AEP CLIMATE CHANGE SCENARIO FLOOD EXTENTS

MHL Report 2174

Figure B7

DRAWING 2174-B7.cdr

Appendix C

Community Flood Survey Form

HAZELBROOK AND WOODFORD CREEKS CATCHMENTS
OVERLAND FLOW PATH STUDY (Flood Study)
COMMUNITY SURVEY

blue mountains City Council

Background Information

Under the NSW Government's Flood Prone Land Policy (2005), Council has a responsibility for floodplain risk management. Council has received a grant from the NSW Government, under the NSW Floodplain Management Program, to undertake a Flood Study of the **Hazelbrook and Woodford Creeks Catchments** within the Blue Mountains Local Government Area (LGA). Council has engaged a consultant, **NSW Public Works** to carry out the Flood Study.

The Hazelbrook and Woodford Creeks Catchments comprise an area of 7.6 km2, located in Ward 2 of the LGA at the Northern side of the Great Western Highway at Hazelbrook. For a map of the study area, see Council's website - www.bmcc.nsw.gov.au under 'H' in the A-Z section.

This Community Survey has been prepared to assist with the preparation of the Hazelbrook and Woodford Creeks Catchments Overland Flow Path Study (Flood Study). The information provided from this Survey will help the Consultant and Council identify any flooding problems within the Hazelbrook and Woodford Creeks Catchments.

Council invites residents to provide any historical flood information that could assist in the preparation of the Flood Study. The Community Survey results will be used to complete the flood study and will not be used for any other purpose. **This Community Survey is voluntary.**

****

COMMUNITY SURVEY FORM

To complete this Survey, please tick the appropriate boxes and make comments where required. **You may tick more than one box if applicable.** Please return the completed Survey to the following address by date

Hazelbrook and Woodford Creeks Catchments Overland Flow Path Study
Attention Mr Lee Lau - Project Coordinator
Blue Mountains City Council, Locked Bag 1005, KATOOMBA NSW 2780
or Fax to: (02) 4780 5555 Telephone (02) 4780 5000

CONTACT INFORMATION (This information will only be used to complete the Flood Study.)

Name:..

Address:..

Address of your Property in the Blue Mountains (if different from the address above)

....

Telephone:...Email: ....

1 What is the type of property? (please tick one)

☐ Residential ☐ Vacant land ☐ Industrial
☐ Commercial ☐ Farming/Rural ☐ Other (Please specify)..

2 If residential, what is the residential status of property? (please tick one)

☐ Owner occupied
☐ Leased to rental tenants
☐ Other (Please specify)..

3 If commercial, what is the status of property? (please tick one)

☐ Owner operated business
☐ Leased to tenants
☐ Other (Please specify)..

4 If owner occupied or owner operated business, how long have you lived or operated a business at this address?

0-5 years	6-10 years	10-20 years	More than 20 years

FLOOD HISTORY

5 **As far as you are aware, has your property ever been affected by flooding?**

☐ Yes (if you answered YES, please complete the table below)
☐ No (If you answered NO, please go to question 7)

Date/s your Property has been affected by floods, if known? (Date, Month, Year) (if more than one, please list all dates)				
What part/s of your property were affected by flooding (select more than one if appropriate) **1= Ground** **2 = Garage/Shed** **3 = Building** **4 = Other (please specify)**				
Depth of Flooding (in cms)				
Duration of Flooding (Hours/Days)				
What was the velocity of the flood waters at the peak/worst of the flooding? **Water velocity** **1 = Stationary** **2 = Walking Pace** **3 = Running Pace**				

6 (a) **Where was the water flowing from?**

☐ Creek (floodwaters rising in the creek)
☐ Water flowing through properties
☐ Water flowing down the roads
☐ Ponding of water within properties
☐ Ponding of water on roads
☐ Overflow from neighbouring properties
☐ Other (Please describe)..

....

(b) **Are there any flood marks on or near your property?**

☐ Yes ☐ No

If you answered Yes, do we have your permission for surveyors to access your property and will surveyors be able to do so?

☐ Yes ☐ No

7 **Do you have, or know of any photographs or records of these flood events?**

☐ Yes ☐ No

If Yes, would it be possible for Council to make copies of this data to contribute to the Flood Study?

☐ Yes ☐ No

If Yes, please indicate if the holder of this information is someone other than you.

....

COMMENTS

8 **Do you have any suggestions for resolving the flooding or drainage problems in your area or do you have any comments you wish to make in addition to the questions in the Survey?** Please attach additional pages for any further information, if needed.

....

....

....

....

Thank you for your time in completing this Community Survey.

Public Works
Manly Hydraulics Laboratory

110B King Street
Manly Vale NSW 2093
T 02 9949 0200
F 02 9948 6185
TTY 1300 301 181
www.mhl.nsw.gov.au