PORT MACQUARIE HASTINGS COUNCILCUSTOMER NAME

Camden Haven River and Lakes System Flood Study Update

Draft Report

March 2025

rp311015-00481jc_crt250324-Camden Haven FS Update_DRAFT.docx

This page is intentionally blank

Port Macquarie-Hastings Council
PO Box 84 NSW 2444
council@pmhc.nsw.gov.au
(02) 6581 8111

Disclaimer

Rev	Description	Author	Reviewer	Approved	Approval Date
A	Draft report – Issued for client review	JC J Cain	CRT C Thomas	Chris Thomas	24-03-2025

This page is intentionally blank

Table of Contents

List of Tables

List of Figures

Appendices

1. Introduction

A hydrologic model of the Camden Haven River catchment, including the catchments of Herons and Stewarts Creeks, and a two-dimensional RMA-2 flood model of the floodplain below the tidal limit, were developed as part of work undertaken for Port Macquarie-Hastings Council (Council) for the *'Camden Haver River & Lakes System Flood Study'*. The study was prepared by WorleyParsons (now Worley Consulting) and was published in 2013 (**the 2013 Flood Study**).

Since then, the RMA-2 flood model has been updated to include additional and more detailed topographic data in areas where new data became available as a function of development proposals and infrastructure projects. This included upgrades to the flood model to incorporate topographic data for projects such as the Stingray Creek Bridge Replacement Project at North Haven (2015) and the Dunbogan Flood Access Road Upgrade Project (2018).

More recently, the Camden Haven River catchment experienced widespread flooding during the March 2021 Weather Event which extended from 18 to 22 March 2021. The March 2021 Weather Event generated substantial volumes of rainfall across the upper and central valleys of the catchment and led to the most severe flooding in the region in over 50 years. It caused severe erosion along many of the tributaries upstream of Kendall and significant inundation of the floodplain and property damage in downstream areas including low lying areas of Laurieton, West Haven, North Haven and Dunbogan.

In the aftermath of the event, a range of rainfall, flood extent and peak height data was compiled by Port Macquarie-Hastings Council (**PMHC**), the NSW State Emergency Services (**SES**), consultants and the insurance industry. Due to the severity of the March 2021 event and the associated impact on the community, PMHC decided to use the compiled data to better validate the flood models that were developed as part of the 2013 Flood Study, and in so doing, improve the contemporary understanding of flood risk in the valley.

The objectives were to:

1. define flood characteristics such as peak level and hazard in areas of the floodplains of the Camden Haven River system upstream of the limits of the flood modelling undertaken for the 2013 Flood Study; and to,
2. take advantage of the extensive data that has been gathered during and since the March 2021 event, so that the flood models can be validated and used to more reliably predict flood characteristics for use in land use planning, environmental assessment and the design of infrastructure.

This report documents the findings from these investigations and serves as an update to the 2013 Flood Study. It should be viewed as the contemporary government funded flood study for the Camden Haven River and Lakes catchment.

2. Data Collection and Review

2.1 Introduction

The March 2021 Weather Event showed that although flooding of the lower reaches of the Camden Haven River below Kendall was well understood, there was a dearth of reliable flood data for smaller communities located along the banks of the upstream tributaries. Therefore, new data was obtained and used to develop a TUFLOW hydraulic model for the purpose of simulating flooding in the upper reaches of the catchment above the areas covered by the RMA-2 flood model that was developed for the 2013 Flood Study. The following sections document this data and that which was used to create and calibrate the TUFLOW model.

2.2 Topographic and Infrastructure Survey Data

2.2.1 LiDAR

Topographic Digital Elevation Models (DEMs) as derived from triangulation of Light Detection and Ranging (LiDAR) survey of the study area were sourced from the online ELVIS portal made available by Geoscience Australia. The primary LiDAR data sets were the NSW Spatial Services 1 metre LiDAR DEMs for:

- Camden-Haven (2012-2017),
- Kempsey (2012); and,
- Wingham (2012-2017).

These were merged and adopted as the primary topographic data set for use in development of the TUFLOW model. The topography of the Camden Haven River catchment as derived from these data sets is presented in **Figure 2-1**.

2.2.2 Bathymetric Survey

A number of data sets were obtained containing hydrographic surveys of the tributaries that drain the catchment and for the estuarine lakes. These data sets are predominantly the same as those that were used in the RMA-2 flood model that was developed for the 2013 Flood Study.

These hydrosurveys were undertaken as part of flood mitigation investigations in 1979 by the former Public Works Department. They include single beam bathymetry survey conducted by the former NSW Office of Environment and Heritage (OEH) (now the Department of Planning & Environment) which was obtained from the online Australian Ocean Data Network system.

Additional cross sections of Camden Haven River were also obtained from flood mitigation surveys carried out by the Department of Public Works and Services in 1990. These cross-sections provide hydrographic detail of the Camden Haven River between Watson Taylors Lake and Kendall.

Survey data gathered by Hopkins Consulting in 2009 was also compiled. This survey data was specifically gathered for the 2013 Flood Study and includes 13 cross sections of the Camden Haven River between the Kendall Road Bridge and Manly Hydraulics Laboratory's (MHL) river level gauge, and a further 8 cross-sections of Herons Creek between Queens Lake and the Pacific Highway Bridge crossing.

It should be noted that many of these surveys were completed years ago. However, they are still regarded as providing a suitable representation of the channel and associated lakes for the purpose of flood modelling.

2.2.3 Infrastructure Data

Asset data was provided by Council in the form of several GIS layers which includes details of bridges and major culverts across the Camden Haven River catchment.

The data pertaining to bridges typically includes details regarding the bridge deck and soffit levels, waterway opening widths and spans between piers.

The culvert network data typically includes culvert dimensions and layout information.

The data has been compiled and has been incorporated into the TUFLOW hydraulic model where appropriate.

2.3 Recorded Rainfall and Flood Level Data

Rainfall and river level gauges in the catchment were identified and their locations are shown in **Figure 2-2**. Most of these gauges are the same gauges as were identified as part of the 2013 Flood Study. These gauges are listed in **Table 2-1** and **Table 2-2**.

Available rainfall and river level data was obtained for significant events that led to flooding in the central and lower reaches of the study area. This involved collating rainfall and historical flood data for the two most significant events over the last 40 years which occurred in February 2013 and March 2021.

Cumulative rainfall plots for each of the available rain gauges are presented in **Figure 2-3** and **Figure 2-4** for the February 2013 and March 2021 events, respectively. Recorded water levels for gauges located along the Camden Haven River are shown in **Figure 2-5** and **Figure 2-6**, for the February 2013 and March 2021 events, respectively. This data will be used to re-calibrate the RMA-2 flood model and to calibrate the new TUFLOW flood model of the upper reaches of the river.

Table 2-1 Rainfall gauges around the catchment

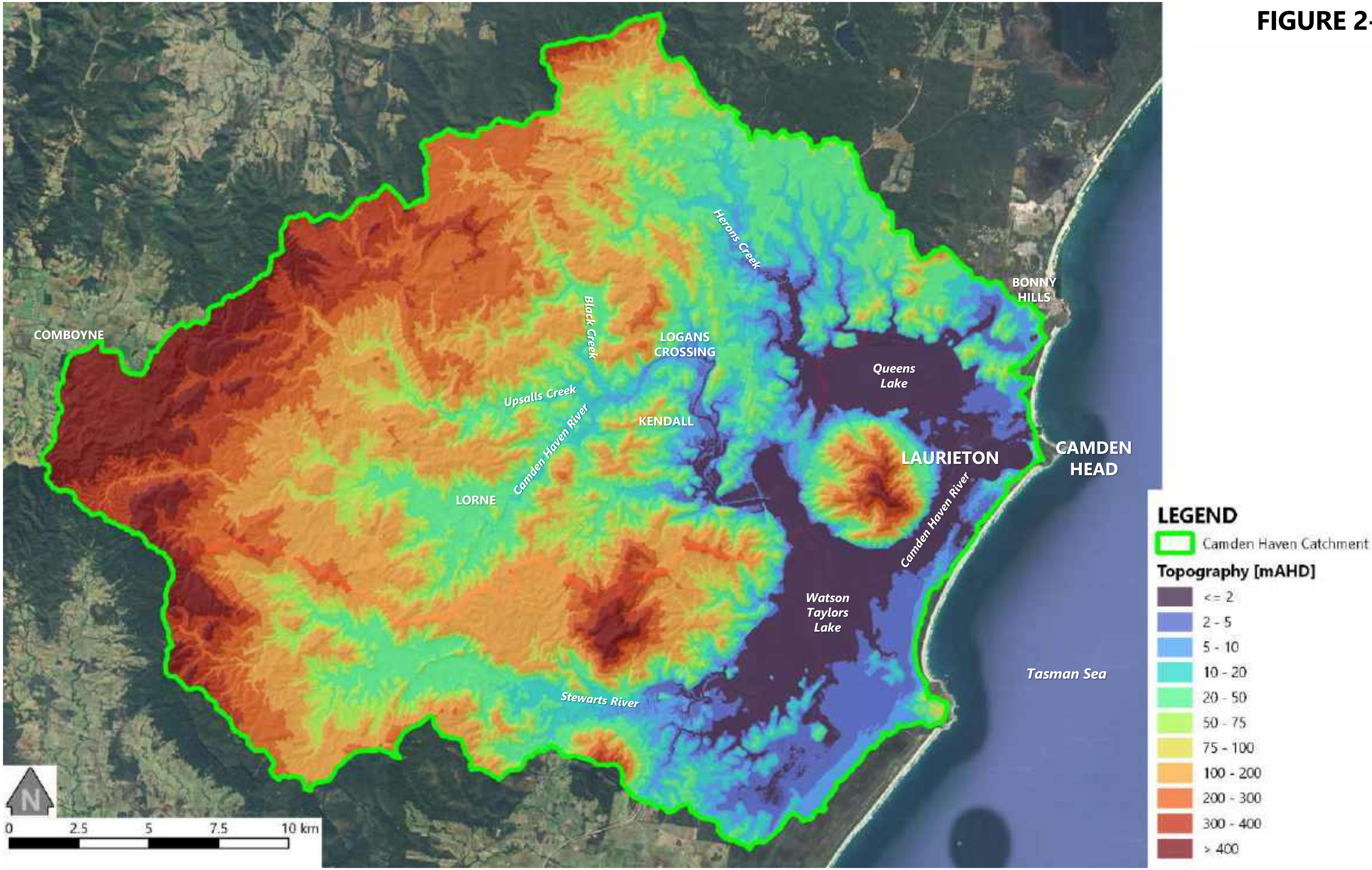
Gauge No.	Rainfall Gauge Name	Gauge Type	Gauge Owner	Duration of Record Available
60017	Hannam Vale	Daily	BoM	1926 – present
60022	Laurieton (Elouera Street)	Daily	BoM	1885 – 2019
60027	Lorne Road	Daily	BoM	1938 – 2016
60147	Killabakh	Daily	BoM	2003 – present
60160	Harrington (Crown St)	Daily	BoM	2009 – 2013
60161	Comboyne Public School	Daily	BoM	2012 – present
60165	Mooral Creek (The Den)	Daily	BoM	2012 – present
560012	Red Oaks (Stewarts River)	Pluvio	DCCEEW	
560017	Logans Crossing	Pluvio	PMHC/DCCEEW	1989 – present

560018	Laurieton (Mill St)	Pluvio	PMHC/DCCEEW
560019	Lake Cathie	Pluvio	PMHC
560021	Kerewong (Broken Bago)	Pluvio	PMHC
560023	Kendall (Delward)	Pluvio	PMHC
560024	Comboyne (Thone River)	Pluvio	PMHC

Table 2-2 Water level gauges within the catchment

Gauge No	Water Level Gauge Name	Owner	Duration of Record
207008	Stewarts River at Stewarts	DCCEEW	1969 – present
207475	Queens Lake at Lakewood	DCCEEW	2001 – present
207480	Watson Taylor Lake	DCCEEW	2001 – present
560010	Upsalls Creek	PMHC	
560017	Logans Crossing	PMHC/DCCEEW	1970 – present
560018	Laurieton	PMHC/DCCEEW	1990 – present
560022	Herons Creek Bridge (Pacific Hwy)	PMHC	
560025	Lorne Bridge	PMHC	
560045	North Haven	DCCEEW	1986 – present
560047	West Haven (Stingray Creek)	DCCEEW	1986 – present

FIGURE 2-1



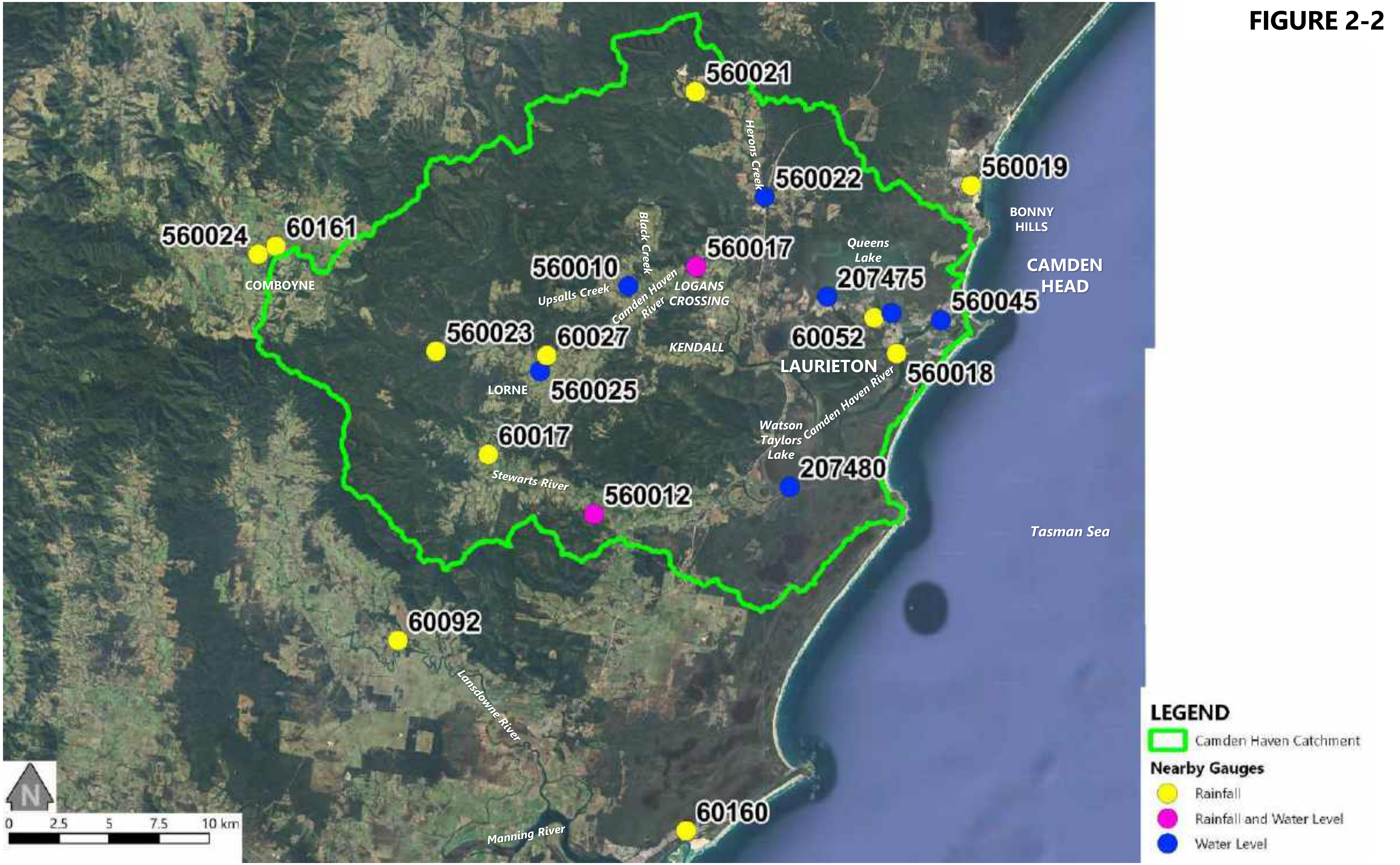
PORT MACQUARIE HASTINGS

Prepared by: worley consulting

250205_QGIS_CamdenHaven_Figures.qgs
fg311015-00481_250205_CamdenHaven_A4L_P1.pdf

TOPOGRAPHY OF THE
CAMDEN HAVEN RIVER CATCHMENT

FIGURE 2-2

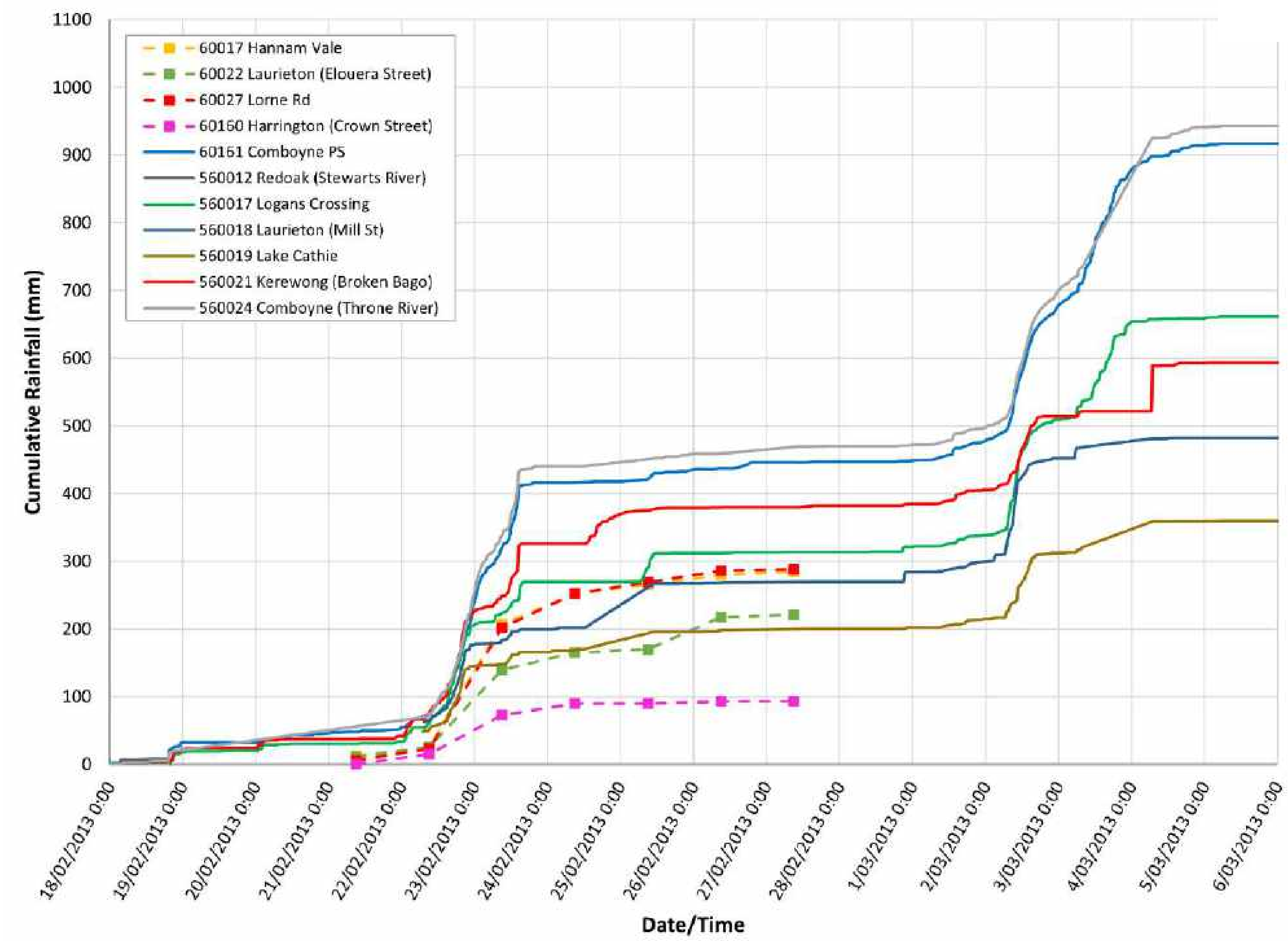


Prepared by: worley consulting

250205_QGIS_CamdenHaven_Figures.qgs
fg311015-00481_250205_CamdenHaven_A4L_P1.pdf

LOCATION OF RAINFALL AND RIVER LEVEL GAUGES IN THE VICNITY OF THE CATCHMENT

FIGURE 2-3



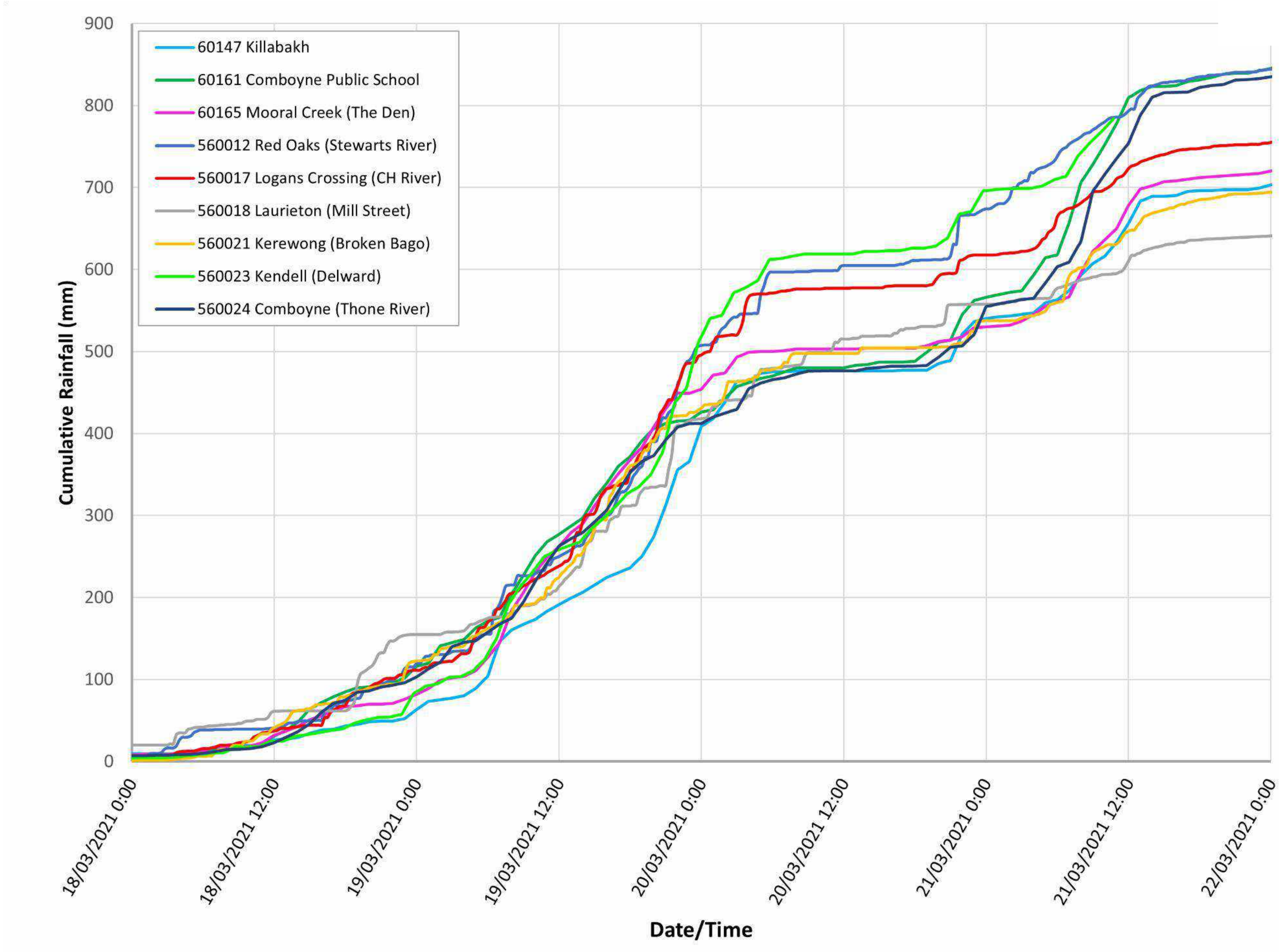
Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250205_CamdenHaven_A4L_P1.pdf

CUMULATIVE RAINFALL DATA FOR THE FEBRUARY 2013 EVENT

FIGURE 2-4



Prepared by:

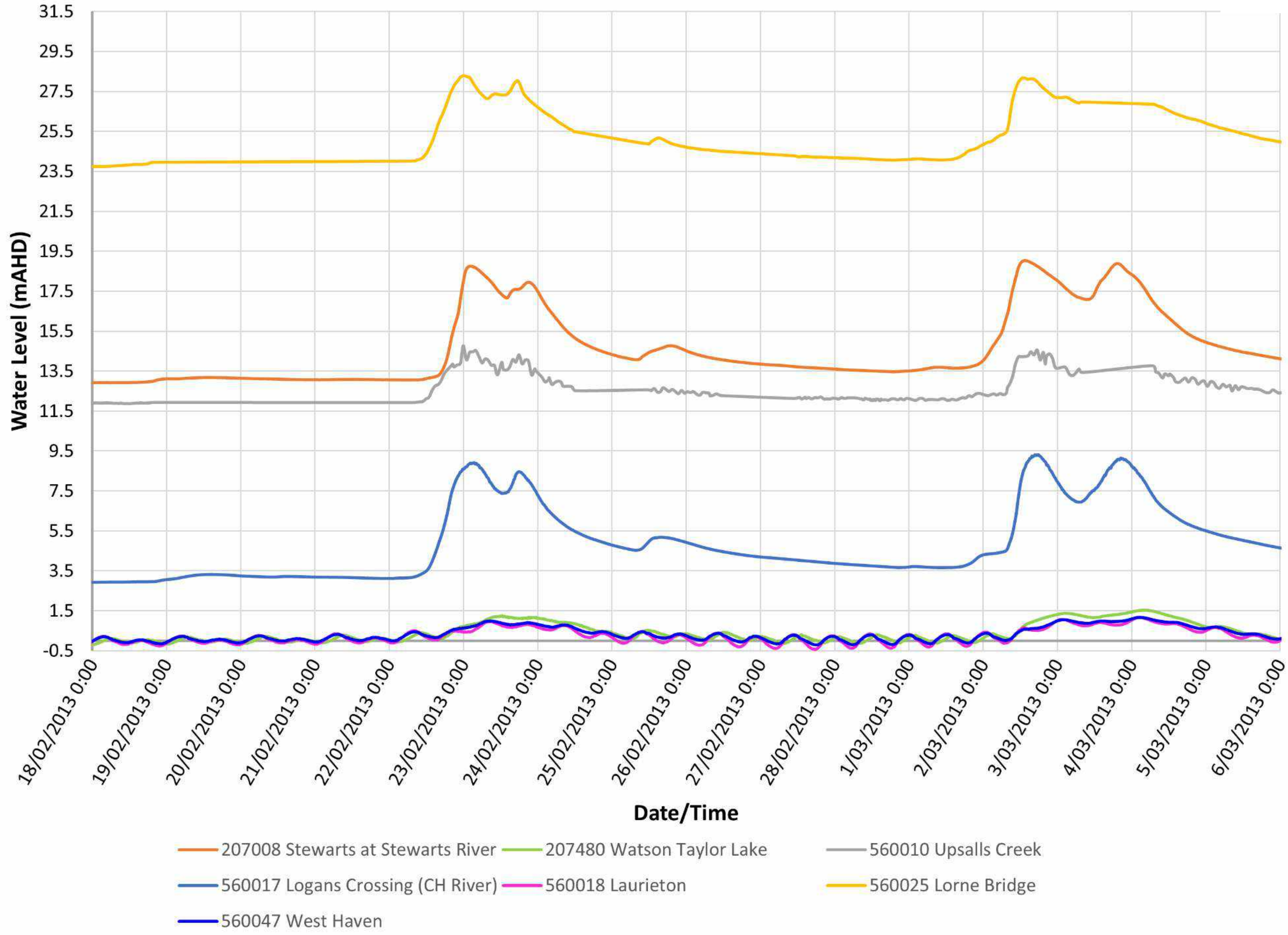
worley consulting

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250205_CamdenHaven_A4L_P1.pdf

CUMULATIVE RAINFALL DATA FOR THE MARCH 2021 EVENT

FIGURE 2-5



Prepared by:

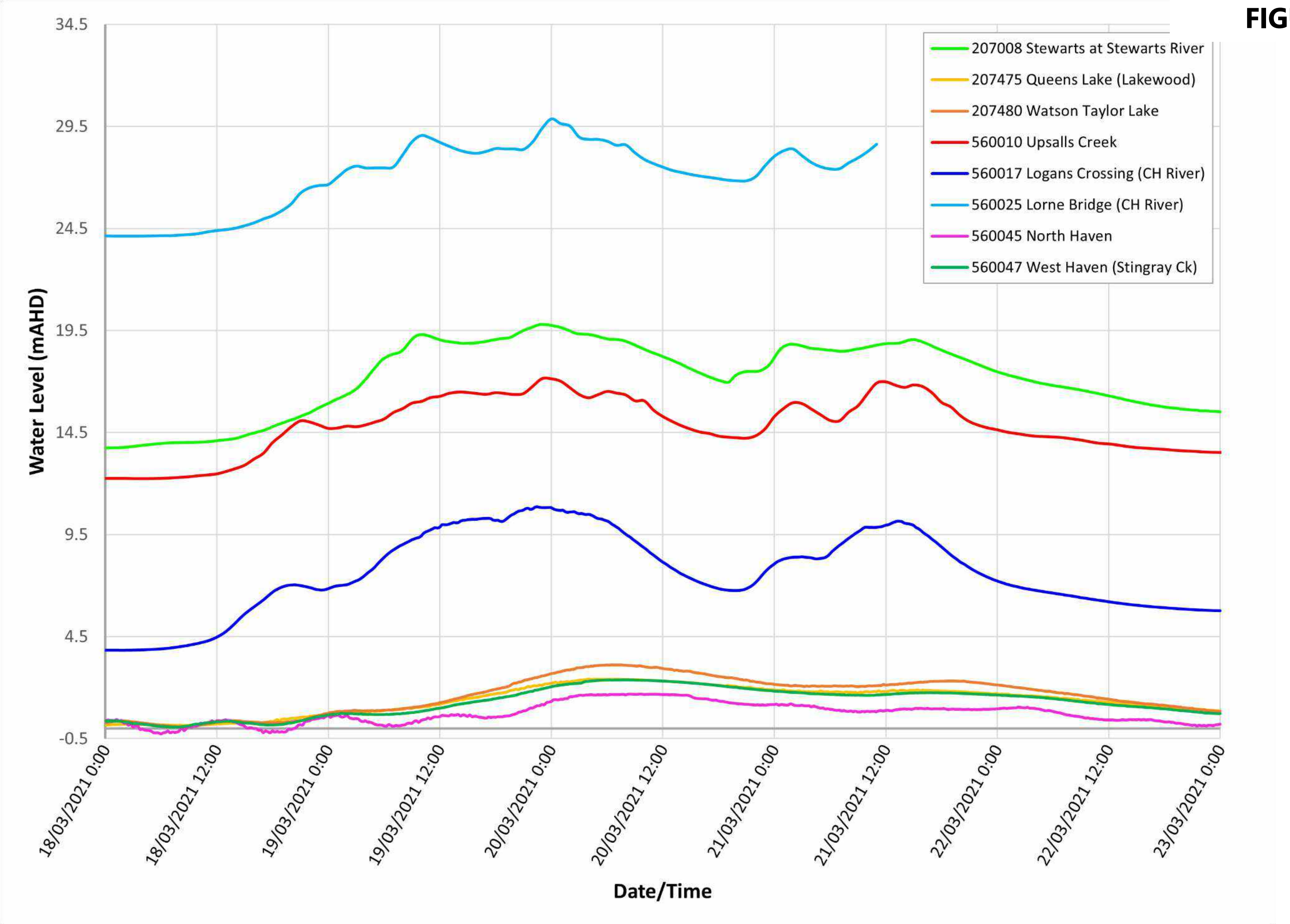
worley consulting

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250205_CamdenHaven_A4L_P1.pdf

RECORDED WATER LEVEL DATA FOR THE FEBRUARY 2013 EVENT

FIGURE 2-6



Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250205_CamdenHaven_A4L_P1.pdf

RECORDED WATER LEVEL DATA FOR THE MARCH 2021 EVENT

3. Flood Model Development

3.1 Flood Modelling Approach

As outlined in **Section 1**, the objective of this study is to extend Council's knowledge of expected flood characteristics higher into the Camden Haven River catchment, and to validate the existing flood model for the lower sections of the catchment to recorded flood data from the March 2021 event.

In order to achieve this, an approach has been implemented which utilises two separate hydraulic models as follows:

- The existing calibrated RMA-2 model has been adopted to define flood characteristics of the tidal reaches of the Camden Haven River estuary.
  - The RMA-2 model is considered an appropriate tool for this area as it has previously been successfully calibrated, and its flexible mesh allows for the model resolution to vary as appropriate to represent the various river and creek channels, lakes and lagoons, urban areas and undeveloped areas of the floodplain.
- A new TUFLOW model has been developed to define flood characteristics above the tidal limit along the Camden Haven River, Herons Creek and their tributaries.
  - TUFLOW is considered an appropriate tool for this area as it allows large areas to be efficiently and reliably modelled with tributaries and flowpaths identified based on the catchment topography rather than interpretation by the modeler.

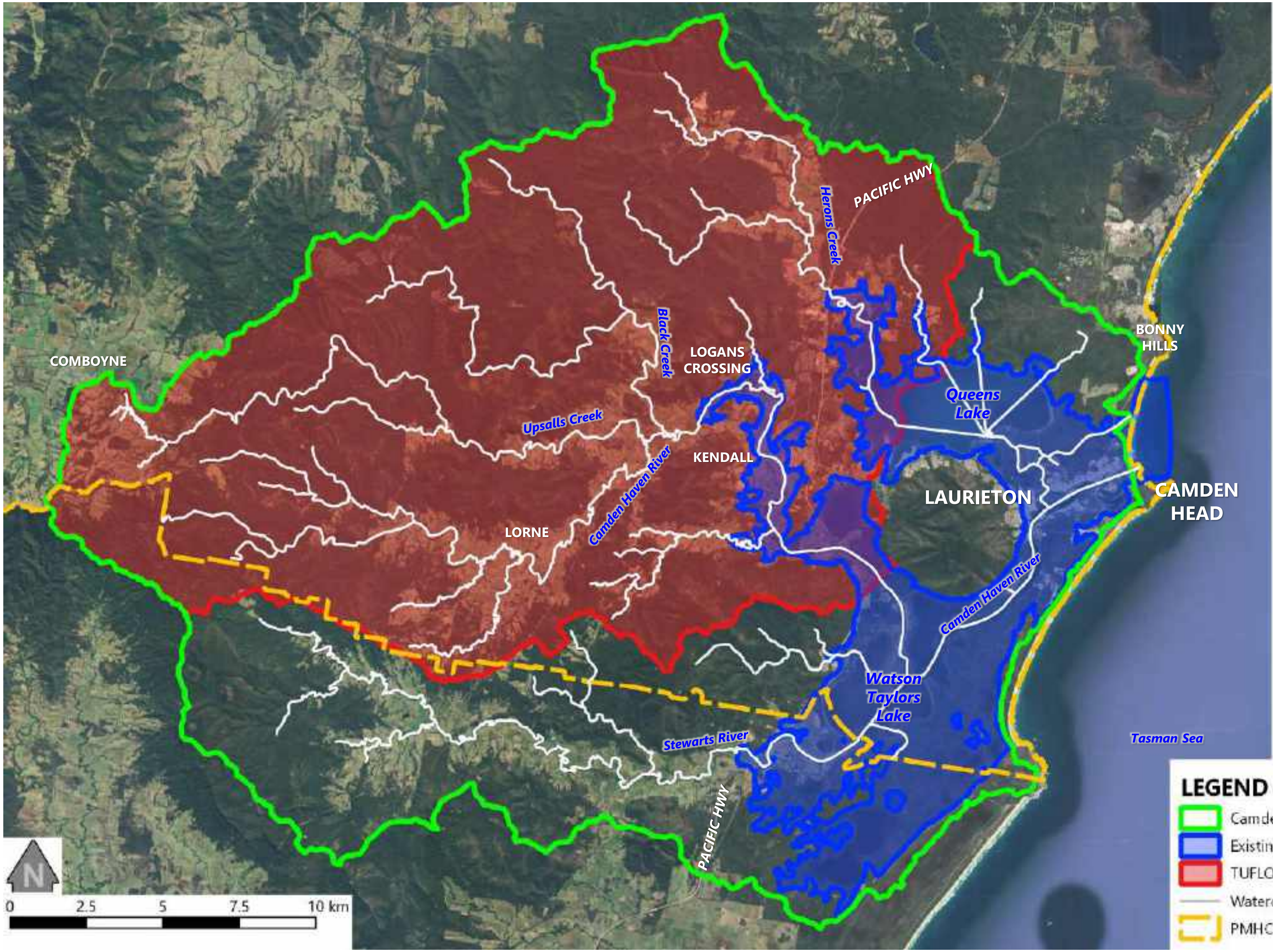
The existing RMA-2 flood model was developed as part of work undertaken in preparing the *'Camden Haven & Lakes System Flood Study'* (WorleyParsons, 2013). This model covers the lower reaches of the catchment, extending from the ocean entrance at Camden Head upstream along the Camden Haven River to Logans Crossing, upstream from Watson Taylors Lake along the Stewarts River to the Pacific Highway crossing near the village of Johns River, and along Stingray Creek, Queens Lake and Herons Creek to the Pacific Highway Bridge crossing. It effectively covers the tidal reaches of the rivers, creeks and lakes system.

A new TUFLOW hydraulic model has been developed to cover the upper catchment and tributaries of the Camden Haven River and Herons Creek. This model will have a total area of 383 km^2 and will include areas upstream of Kendall along the Camden Haven River and upstream of Queens Lake along Herons Creek. The extent of the TUFLOW model includes some overlap with the RMA-2 model. This allows a reliable downstream boundary condition to be applied and to allow for calibration to the Logans Crossing gauge. The upper catchment of Stewarts River has not been included within the additional modelling area. This is due to a significant portion of the catchment area not within the Port Macquarie Hastings Council LGA, as shown in **Figure 3-1**.

The extents of the RMA-2 and TUFLOW hydraulic models are shown in **Figure 3-1**.

Additionally, a new WBNM hydrologic model has been developed encompassing the entire catchment and will be used to derive inflow hydrographs to be applied to both hydraulic models. This WBNM model will replace the existing XP-RAFTS hydrologic model developed in the original flood study. WBNM was selected as it is a very robust software that has been validated against numerous catchments in NSW, while the XP-RAFTS software has been superseded by InfoWorks ICM and is longer supported by the developer.

FIGURE 3-1



PORT MACQUARIE HASTINGS

Prepared by: worley consulting

250205_QGIS_CamdenHaven_Figures.qgs
fg311015-00481_250205_CamdenHaven_A4L_P1.pdf

EXISTING RMA-2 AND TUFLOW HYDRAULIC MODEL EXTENTS

3.2 WBNM Hydrologic Model Development

3.2.1 Model Layout

The WBNM hydrologic modelling software will be used to simulate rainfall-runoff processes to determine flow hydrographs for input into the two hydraulic models. The sub-catchment delineation and linkage form the foundation of the WBNM hydrologic structure.

The hydrologic model extent for the Camden Haven River was determined from topographic data using the CatchmentSIM hydrologic and terrain analysis software. This was further delineated into 1,860 sub-catchments based on consideration of the catchment topography, watercourses, and the location of stream gauges and hydraulic structures such as bridges and culverts. The linkage between the sub-catchments was also determined by CatchmentSIM and was cross checked using GIS.

A higher resolution of sub-catchments was created within the TUFLOW hydraulic model area. The delineation was informed by initial TUFLOW direct rainfall modelling and was tailored to enable appropriate representation of key flow paths potentially posing flood risk to the community, property, or infrastructure to be achieved during the subsequent hydraulic modelling phase.

The original XP-RAFTS sub-catchment delineation was adopted across the remainder of the Camden Haven River catchment.

The resulting WBNM hydrologic model sub-catchment delineation is presented in **Figure 3-2**.

3.2.2 Runoff Lag and Stream Routing Parameters

The primary parameters required by the WBNM model are the runoff lag factor 'C' and the stream routing factor 'F'.

The runoff lag factor 'C' controls the timing of locally generated runoff from each sub-catchment. A low C value represents a rapid runoff response, while a high value represents a slow runoff response. WBNM documentation recommends a runoff lag parameter value between 1.3 and 1.8, with a value close to 1.6 generally appropriate. A lag factor for impervious areas is also defined, with a default value of 0.1 recommended.

The stream routing factor 'F' determines the time it takes to travel along streams. WBNM documentation recommends a value of 1.0 to represent natural streams and flow paths. Lower values can be adopted to define stream modification such as clearing or straightening. Higher values can also be adopted to represent slower, flatter or particularly meandering flow paths.

The final WBNM parameters are to be determined through the model calibration and validation process.

3.2.3 Catchment Imperviousness

The degree of imperviousness of a catchment influences both the quantity and timing of runoff generated by a rainfall event.

The effective impervious percentage of each sub-catchment was determined through analysis of the surface material delineation developed for use in the RMA-2 and TUFLOW hydraulic models (*refer* **Figure 3-3**).

An effective percentage imperviousness was assigned to each surface material type as presented in **Table 3-1**. A specific area-averaged imperviousness was then assigned to each sub-catchment, resulting in values ranging from 0% in forested areas to 62% in areas with a high proportion of development and roads.

Table 3-1 Effective Impervious Percentage for different material types

Material	Effective Impervious Percentage
Watercourses	100%
Open Space, Medium and Heavy Vegetation	0%
Roads	100%
Residential and Commercial areas	50%

3.2.4 Rainfall Loss Rates

The term 'rainfall losses' refers to precipitation that does not contribute to direct runoff. During a storm such losses occur primarily due to the processes of interception by vegetation, and infiltration into the soil. The initial loss-continuing loss (IL-CL) approach is typically used in Australia to account for losses in the rainfall-runoff process and has been adopted in this study.

Loss rates adopted for this study are to be developed through the calibration process, and in consideration of NSW Specific Advice associated with the ARR 2019 guidelines and data.

3.3 TUFLOW Hydraulic Model Development

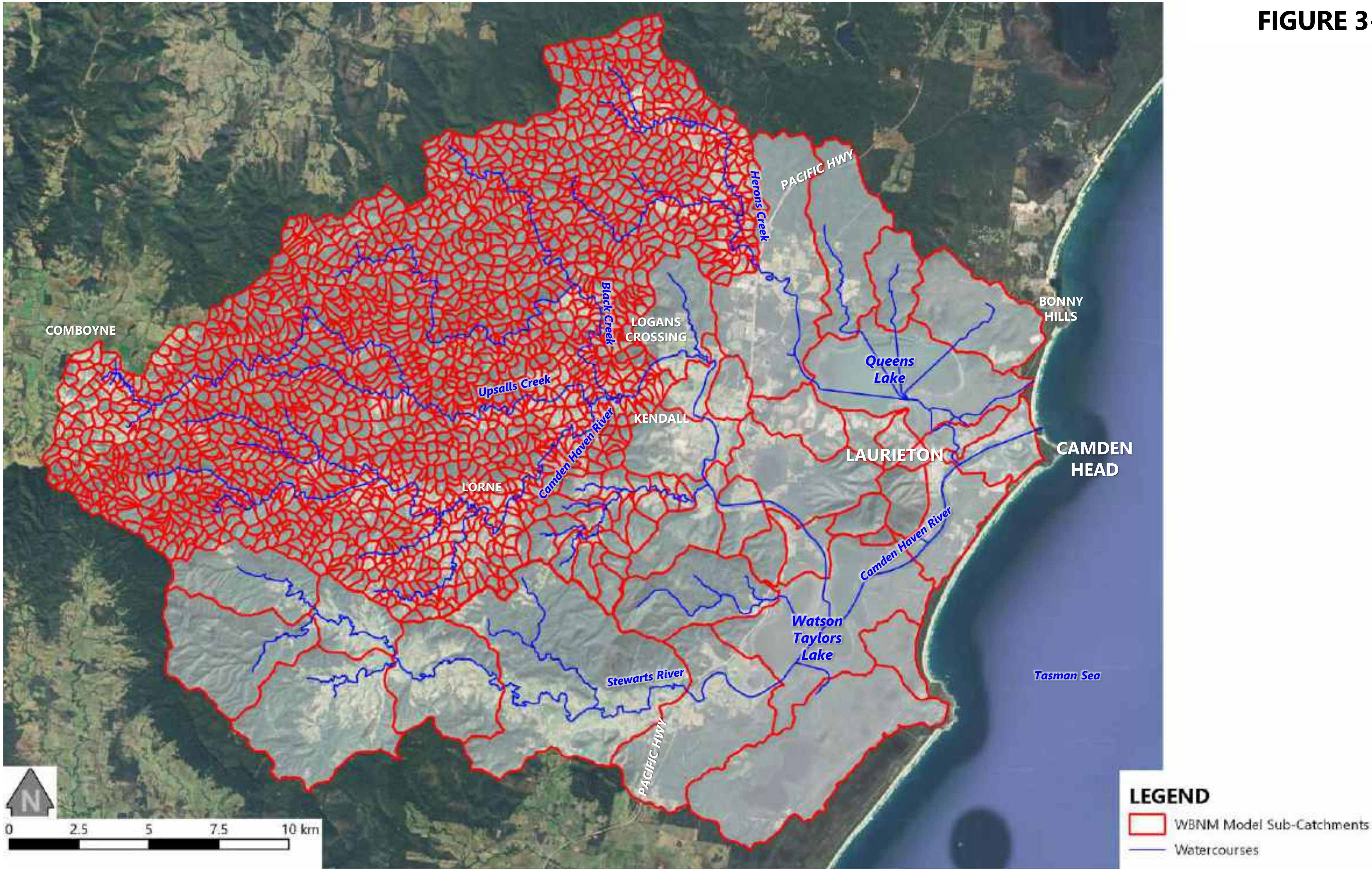
3.3.1 Software

The TUFLOW 2D/1D hydraulic modelling software package has been adopted to simulate flood hydraulics in the upper Camden Haven River Basin. The TUFLOW software was determined to be a suitable tool for replicating the complex 2D nature of flooding in the area based on consideration of the following.

- Allows accurate representation of catchment topography and bathymetry to be developed in 2D from various sources (e.g. a combination of LiDAR and detailed survey).
- Allows large areas to be efficiently and reliably modelled with tributaries and flowpaths identified based on the catchment topography rather than interpretation by the modeler.
- Allows integrated investigation and interaction of overland, mainstream, tidal and ocean driven components of flooding.
- Solves the full 2D surface water equations.
- Produces high quality, GIS compatible flood mapping outputs.

The latest version of the TUFLOW hydraulic modelling software available at the time of the model calibration was adopted (*2023-03-AC, released 15 September 2023*). Given the significant area to be modelled, the GPU-based 'TUFLOW HPC' software was selected to maintain manageable model simulation times.

FIGURE 3-2



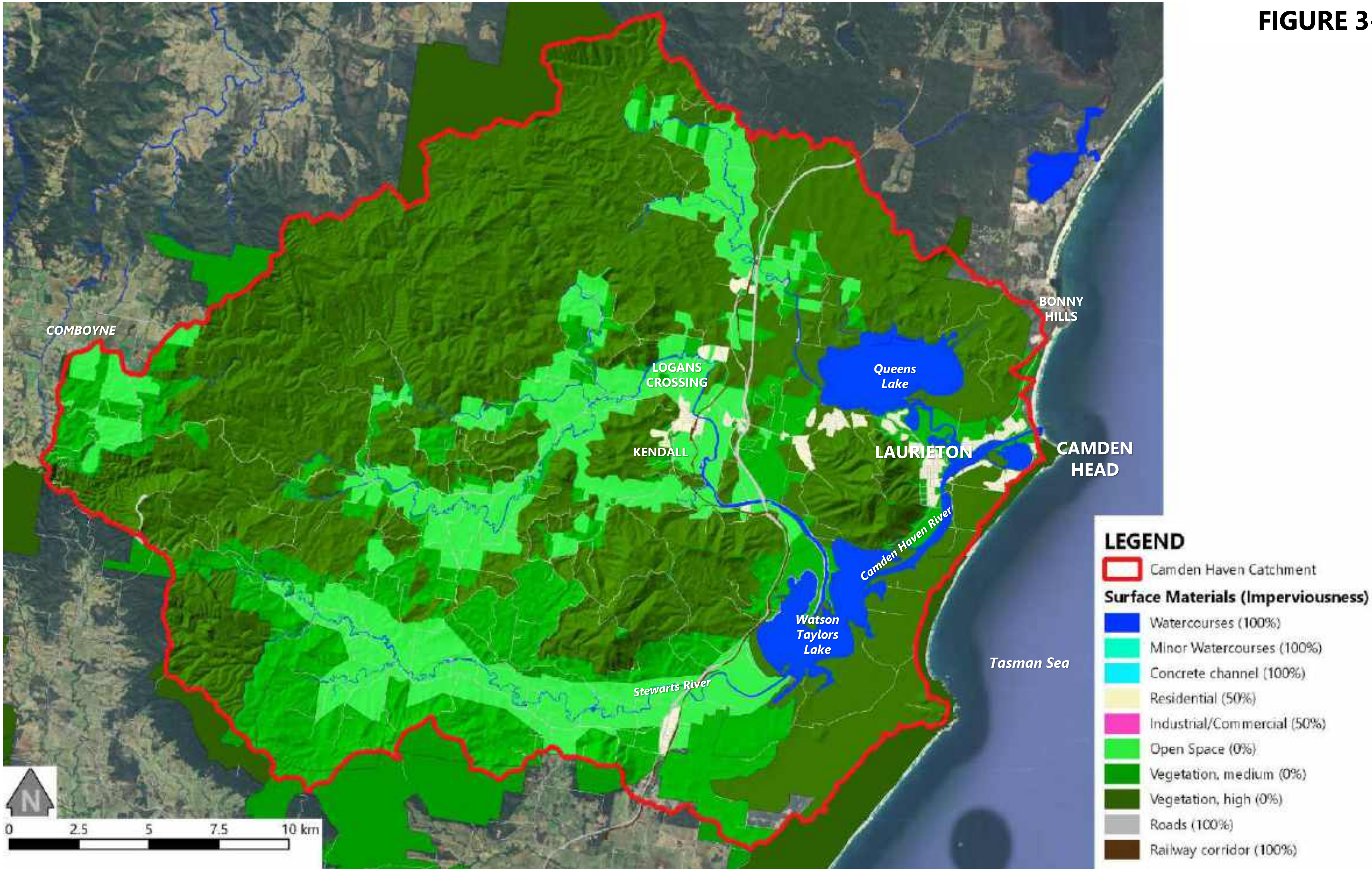
Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250205_CamdenHaven_A4L_P1.pdf

WBNM HYDROLOGIC MODEL
SUB-CATCHMENT DELINEATION

FIGURE 3-3



PORT MACQUARIE HASTINGS

Prepared by: worley consulting

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250205_CamdenHaven_A4L_P1.pdf

WBNM HYDROLOGIC MODEL
SURFACE MATERIAL DELINEATION AND IMPERVIOUSNESS

3.3.2 2D Model Domain

The 2D TUFLOW hydraulic model domain covers the catchments of the Camden Haven River upstream of Watson Taylors Lake and Herons Creek upstream of Queens Lake (*refer* **Figure 3-4**). This comprises a total model area of 383 km^2.

The TUFLOW model domain overlaps the existing RMA-2 model in areas along the Camden Haven River between Watson Taylors Lake and Logans Crossing, and along Herons Creek between Queens Lake and the Pacific Highway. This allowed for a more reliable downstream boundary conditions to be applied at the lakes. It will also allow the TUFLOW model to be calibrated to data from the Logans Crossing gauge on the Camden Haven River, in addition to anecdotal reports of flooding.

It is expected that RMA-2 model results will be given precedence in the areas of overlap.

3.3.3 2D Model Grid Size

A model grid size of 5 metres was adopted to adequately resolve flood characteristics in the study area while maintaining manageable model simulation times, resulting in over 15.3 million computational grid cells.

Each square grid cell contains information on ground surface elevation, hydraulic roughness and other parameters as necessary (*e.g. cell blockage and energy losses to represent the hydraulic effects of bridges*). The ground surface elevation is sampled at the centre, mid-sides and corners of each cell from a specified Digital Elevation Model (DEM). For a 5 m grid this results in DEM elevations being sampled at 2.5 m centres.

3.3.4 2D Model Terrain

The 2D TUFLOW model terrain was constructed from a combination of the latest LiDAR DEM and available bathymetric survey data as described in **Chapter 2** of this report.

LiDAR may capture a lower resolution of ground points in heavily vegetated areas and does not penetrate water surfaces. As such, LiDAR data will not always provide a satisfactory topographic representation of watercourses for hydraulic modelling purposes.

In order to improve the 2D TUFLOW representation of rivers, creeks and major tributaries, topographic modification techniques have been applied that use cross-sectional survey data and/or local LiDAR minima to enhance channel cross-sectional area, conveyance and flow continuity. One of the following approaches was adopted depending on the channel width and availability of survey data:

Triangulation: Where sufficient bathymetric survey data points are available 'triangulation lines' were digitised along the watercourse, creating interpolated elevation points between the survey points. The survey points and interpolated points are then triangulated to create a continuous terrain surface. A polygon region is also digitised to define the boundary of the triangulation zone, and elevations are extracted from the underlying TUFLOW terrain (*generally based on LiDAR*) along the edge of the polygon to ensure that the resulting triangulated surface is seamless with the surround TUFLOW terrain.

Enforced thalwegs: Where insufficient cross-sectional survey data points are available or the width of the channel does not warrant the use of the 'triangulation' approach described above, an alternative approach has been applied that enforces a continuous thalweg along watercourses. The thalweg is digitised as a continuous line and elevations are defined at regular intervals using the lowest data point from available survey or local LiDAR minima. A width is also assigned to the thalweg (or 'GULLY') line as selected based on inspection of aerial photographs and LiDAR DEMs.

The extent over which each of these approaches was applied is indicated in **Figure 3-5**.

3.3.5 Boundary Conditions

The TUFLOW hydraulic boundary conditions consist of the following:

- Local inflow hydrographs applied to the 2D hydraulic model domain at each hydrologic model sub-catchment using the TUFLOW 'surface area' approach. This has been coupled with the 'streamline' approach which defines more explicitly where the flows are to be applied and results in improved definition of flow paths in the upper sub-catchments.
- Downstream water level boundaries applied at the base of the Camden Haven River (Watson Taylors Lake) and Herons Creek (Queens Lake). For calibration, recorded water level data from Watson Taylor Lake gauge (207480) and Queens Lake at Lakewood gauge (207475) were applied. Downstream boundary conditions for design event modelling are discussed further in **Section 6.4.2**.

The locations of these boundary conditions are shown in **Figure 3-6**.

3.3.6 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 that may altered to achieve calibration of hydraulic models.

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 aerial photography and cadastral data. Manning's 'n' values assigned to each zone were determined based on previous work in the catchment, previous experience in calibrating TUFLOW models, and with reference to values recommended in the literature (*e.g. Chow 1959*). As resistance to flow due to surface and form roughness varies with depth (*e.g. Chow 1959, ARR 2019*), variable depth-dependent hydraulic roughness values have been adopted.

Manning's 'n' roughness coefficients applied in the TUFLOW model are listed in **Table 3-2**, with the delineation of hydraulic roughness zones shown in **Figure 3-7**. Below 'Depth 1' the first Manning's 'n' value is applied, while above 'Depth 2' the second Manning's 'n' value is applied. At depths between 'Depth 1' and 'Depth 2' Manning's values are determined by linear interpolation.

Table 3-2 TUFLOW Manning's 'n' values by depth for delineated Materials

Material	Depth 1 (m)	Manning's 1	Depth 2 (m)	Manning's 2
Watercourses	0.3	0.1	1.5	0.03
Open Space	0.1	0.06	0.3	0.05
Medium Vegetation	0.15	0.16	0.5	0.1
Heavy Vegetation	0.3	0.2	1.0	0.12
Residential	0.3	0.2	1.5	0.1
Commercial	0.1	0.1	0.3	0.06

Roads	0.05	0.03	0.15	0.015
Railway Corridor	0.1	0.16	0.3	0.08

3.3.7 Bridges

The influence of bridges on flood behaviour has been represented in 2D using 'layered flow constrictions' which assign blockages and energy losses that simulate the hydraulic effects of bridge piers, the bridge deck and handrails.

For many of the bridges in the model domain no detailed survey or design drawings were available. Reasonable assumptions were thus made to approximate the geometry of such bridges including pier arrangement, span, deck thickness and level, and detail of handrails as follows. These assumptions were informed based on typical values found in available survey.

Bridge pier(s) width: 0.7 metres

Bridge deck level: estimated from the LiDAR DEM

Bridge deck thickness: 0.7 metres

Height/blockage of railings: estimated from Google Street View (where possible).

A total of 24 bridges were incorporated into the TUFLOW model. Their locations are shown in **Figure 3-8**.

3.3.8 Major Culverts

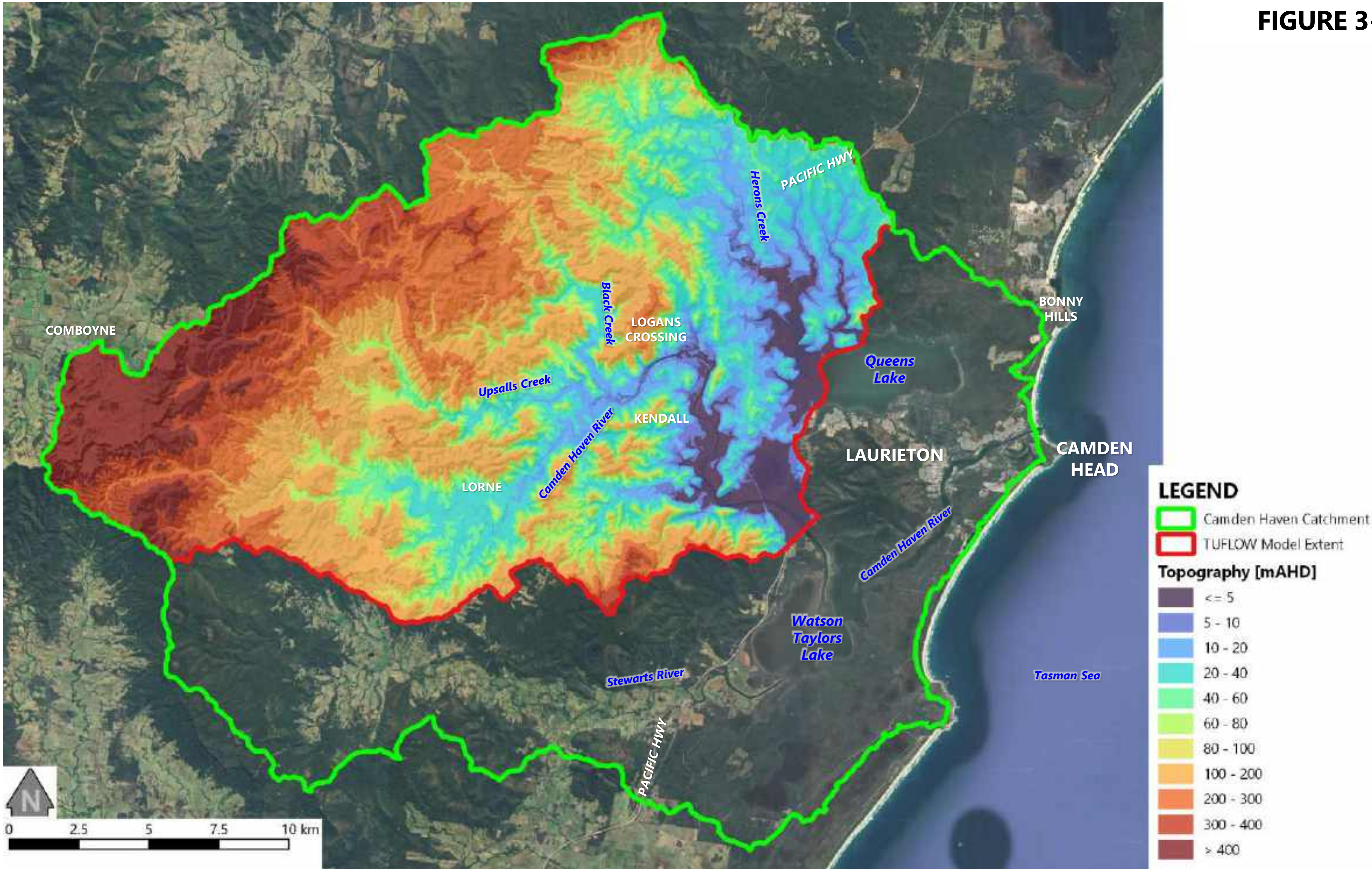
Major culverts were represented in the TUFLOW model by using 1D elements which are dynamically linked to the 2D grid surface to allow the transfer of flows.

A number of major culverts were identified in the study area from GIS layers provided by Council, and by reviewing flow paths predicted by an initial direct rainfall hydraulic model simulation. A total of 95 culverts were included in the model. Most of these allow flows to pass beneath the railway line and the Pacific Highway that both traverse the model domain in a roughly north-south alignment.

Culvert dimensions were obtained from GIS data supplied by Council. Information regarding invert levels was not provided. Invert levels were thus estimated by interrogating the minimum LiDAR ground elevations in the vicinity of the culvert inlets and outlets.

The locations of culverts included in the TUFLOW model are shown in **Figure 3-8.**

FIGURE 3-4



PORT MACQUARIE HASTINGS

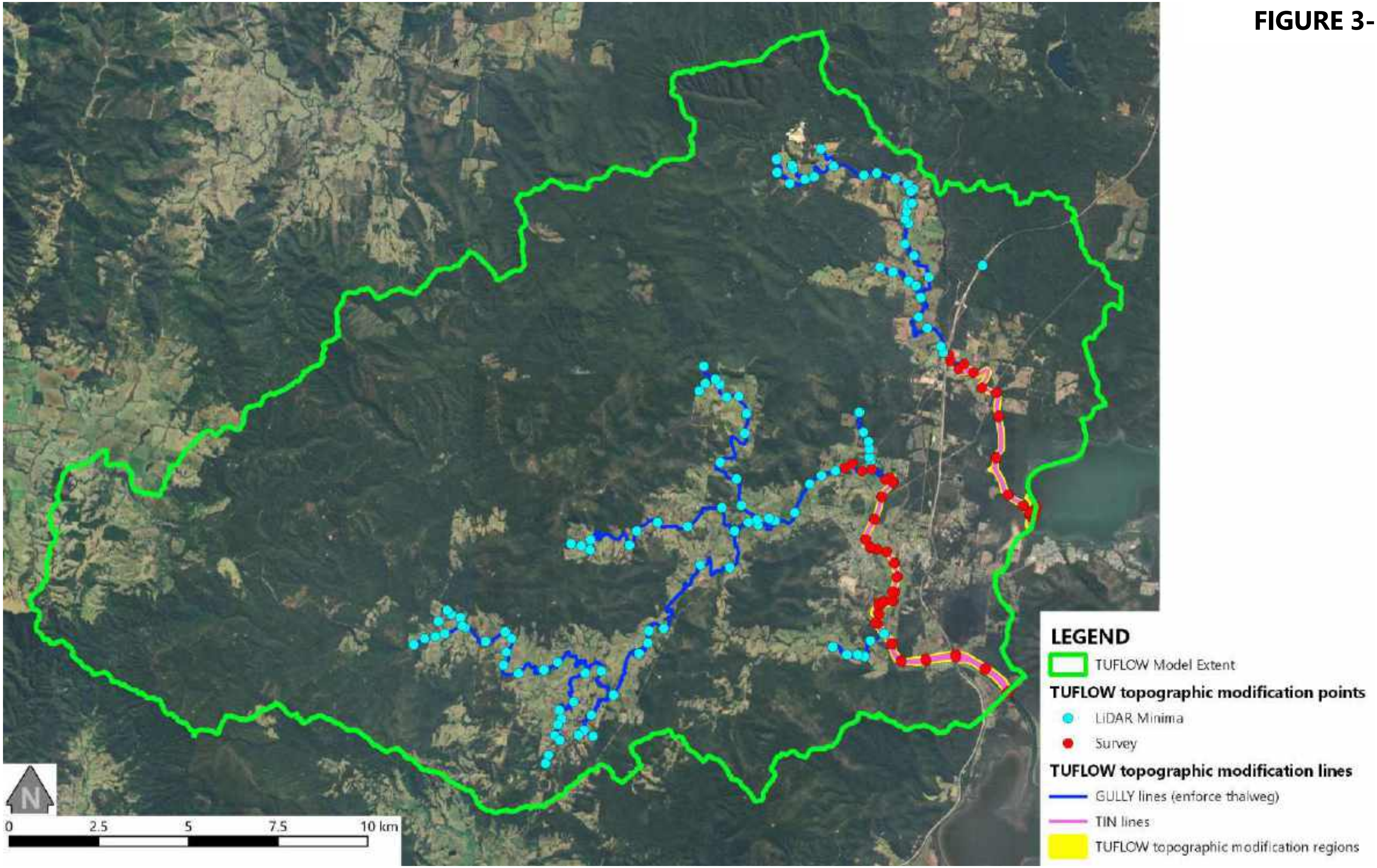
Prepared by: worley consulting

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250205_CamdenHaven_A4L_P1.pdf

TUFLOW HYDRAULIC MODEL EXTENT AND TOPOGRAPHY

FIGURE 3-5



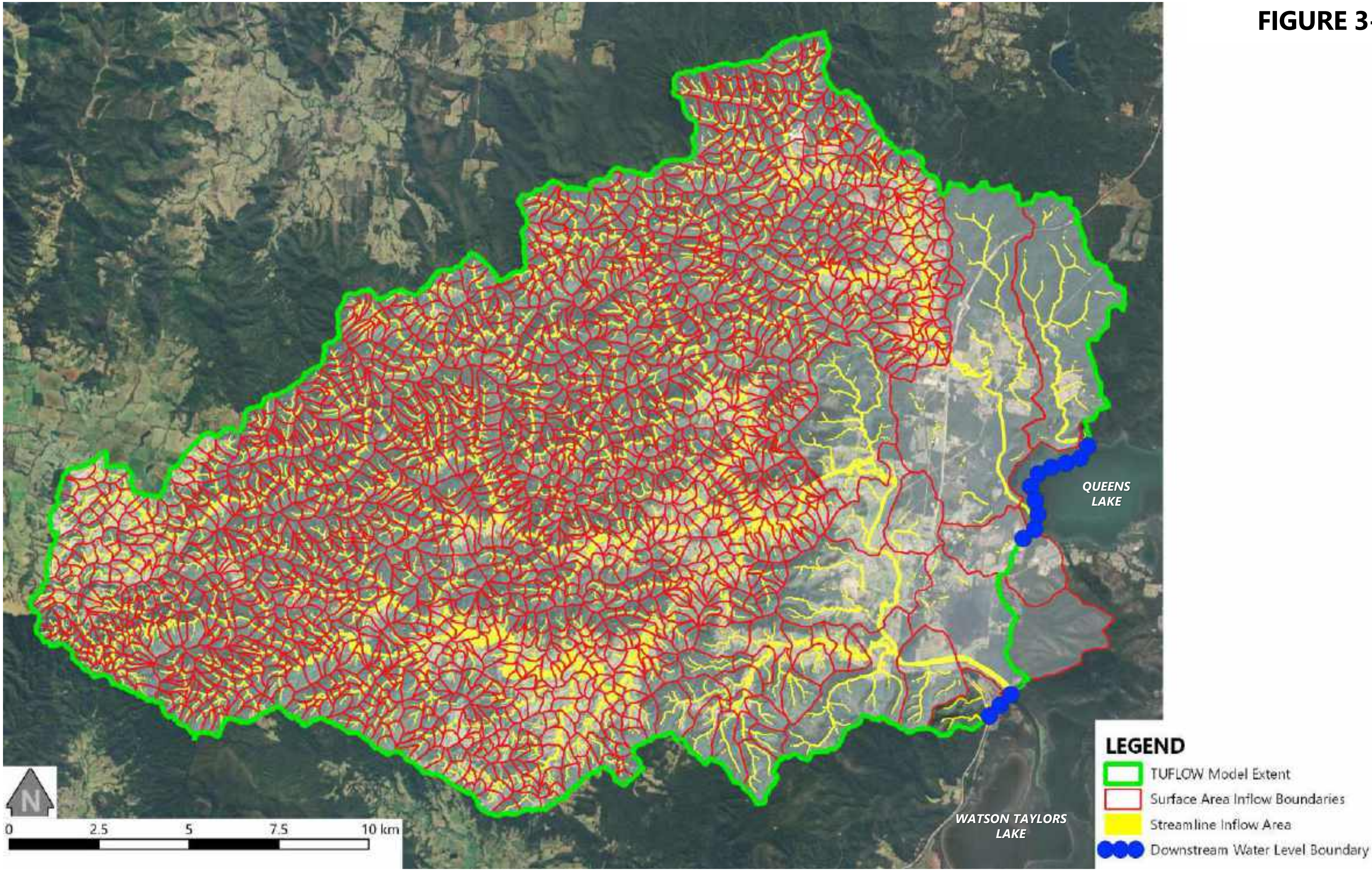
Prepared by: worley consulting

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250205_CamdenHaven_A4L_P1.pdf

TOPOGRAPHIC MODIFICATIONS TO ENHANCE TUFLOW REPRESENTATION OF WATERCOURSES

FIGURE 3-6



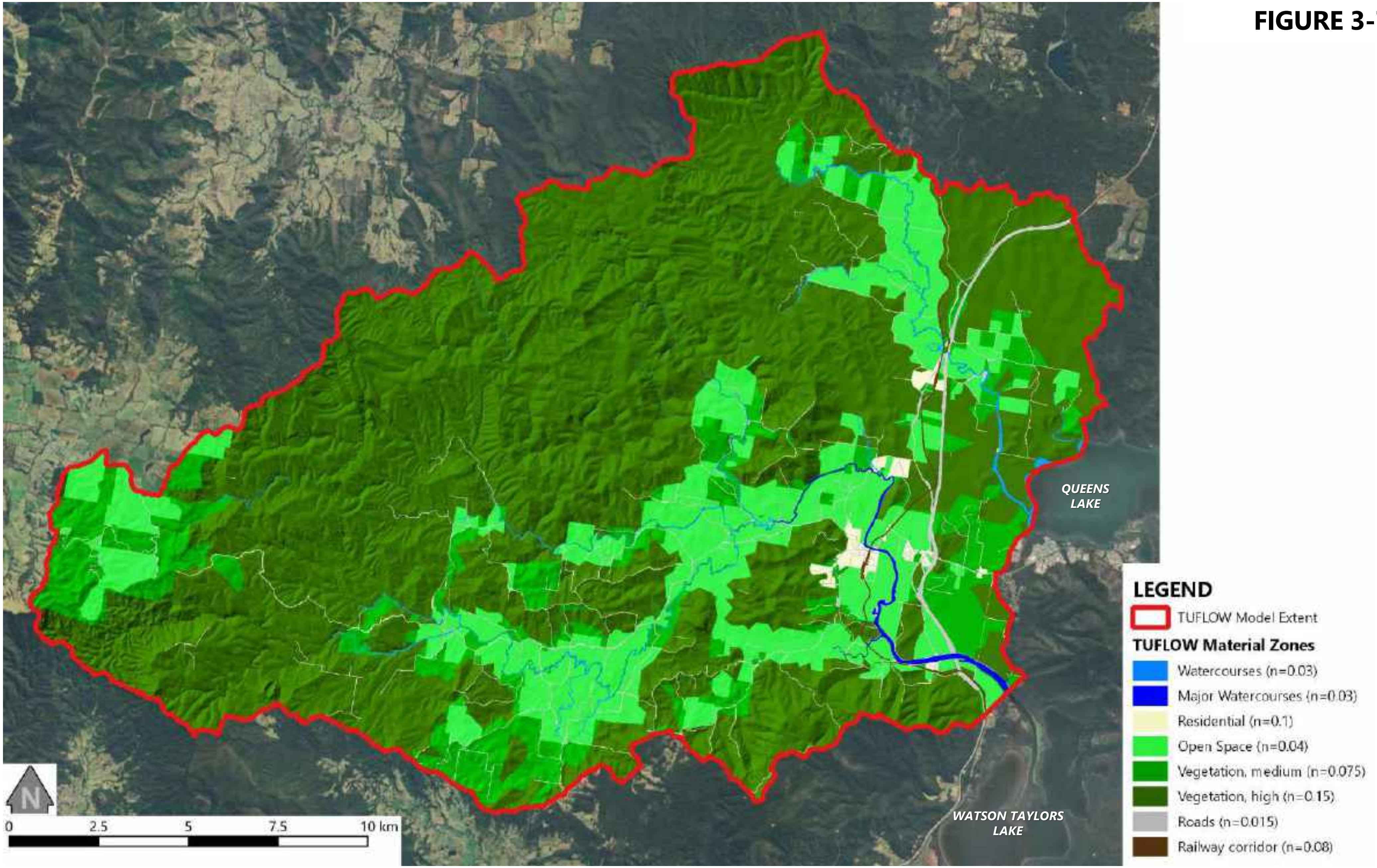
Prepared by: worley consulting

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250205_CamdenHaven_A4L_P1.pdf

TUFLOW HYDRAULIC MODEL BOUNDARY CONDITIONS

FIGURE 3-7



PORT MACQUARIE HASTINGS

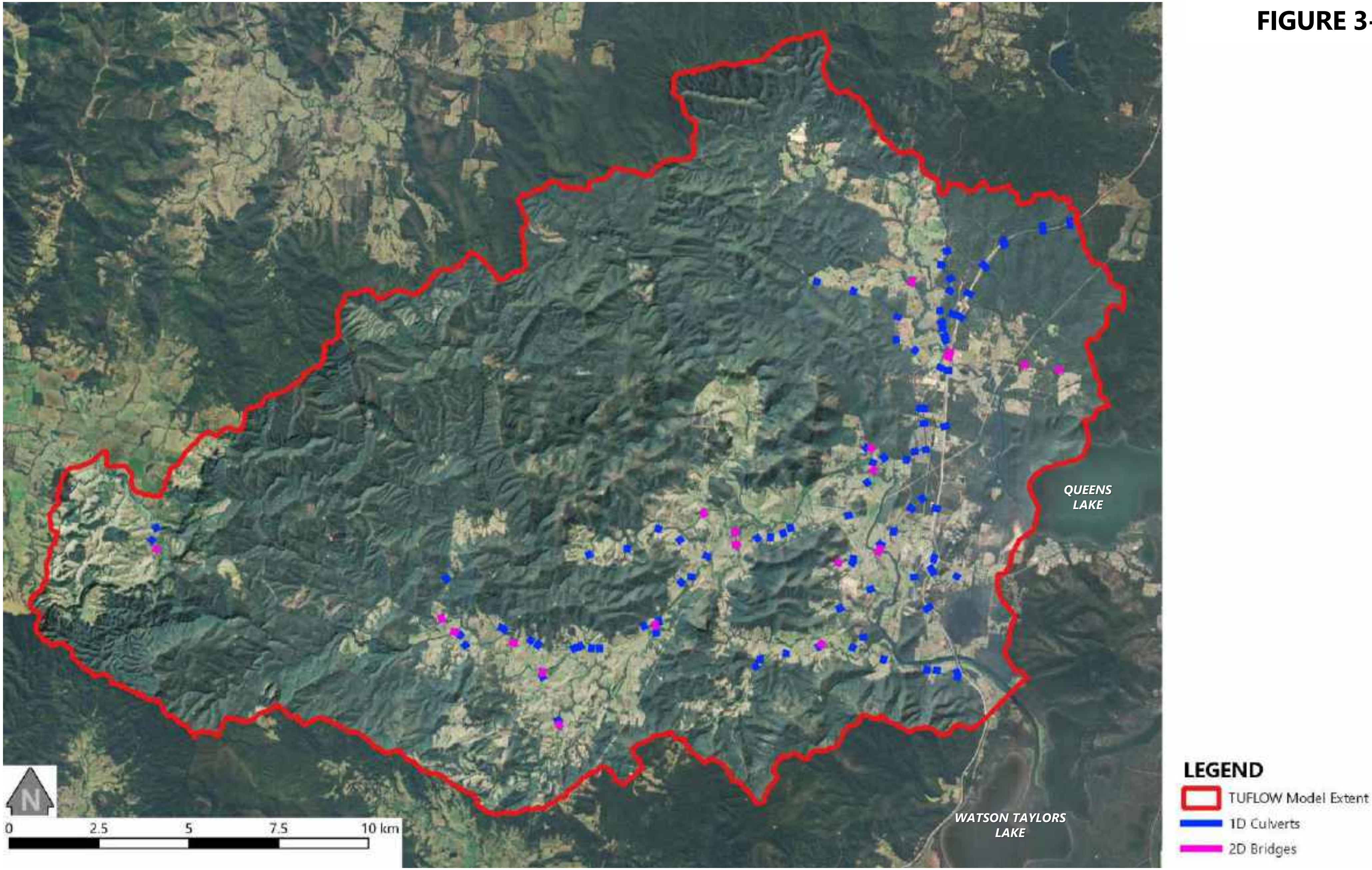
Prepared by: worley consulting

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250205_CamdenHaven_A4L_P1.pdf

TUFLOW HYDRAULIC MODEL
HYDRAULIC ROUGHNESS DELINEATION

FIGURE 3-8



Prepared by: worley consulting

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250205_CamdenHaven_A4L_P1.pdf

TUFLOW HYDRAULIC MODEL
HYDRAULIC STRUCTURES

4. Calibration and Validation

4.1 Overview

Calibration and validation of hydrologic and hydraulic models is an important step in the model development process. If an acceptable calibration of the model to recorded events can be achieved, it confirms the ability of the model to realistically simulate observed flood behaviour. It also provides confidence in the reliability of results generated by the model for design flood simulations such as the 1% Annual Exceedance Probability (AEP) flood.

The approach in the current study was to undertake model calibration and verification to recorded data from flood events which occurred in February 2013 and March 2021.

4.2 Selection of Model Calibration and Validation Events

The suitability of historical flood events for use in model calibration and verification is generally dependent on the availability, completeness and quality of recorded rainfall, flood level and stream flow data. It is also preferable to use a number of events of variable flood size including at least one major flood (if such data exists).

The flood events in March 2021 and February 2013 were selected for calibration and validation, respectively. A considerable amount of recorded flood data is available for both events which makes them ideal for the calibration / validation exercise. These events were also identified as being significant to the local community because of their relative currency compared to the older and smaller events that were used for calibration of previous studies.

4.3 Calibration to the March 2021 Event

4.3.1 Event Overview

The Bureau of Meteorology (BOM) prepared an overview of the March 2021 event which is documented in a Special Climate Statement titled, '*Special Climate Statement 74 – extreme rainfall and flooding in eastern and central Australia in March 2021*'. The following is a summary of the event which has been developed from that Statement.

Significant rainfall commenced along parts of the New South Wales coast on 17th and 18th March 2021. The heaviest rain occurred along the Mid North Coast on 19th March, but significant falls covered much of the coast from the Illawarra northwards (BOM 2021).

One of the most significant aspects of this event in coastal New South Wales was its persistence, which resulted in many very high multi-day rainfall totals. Rainfall totals for the week to 23rd March exceeded 400 mm along a vast stretch of the NSW coast (refer **Plate 4-1**). A number of sites on the Mid North Coast had four (4) consecutive days with 100 mm or more from 19th to 22nd March. Comboyne, in the hills south-west of Port Macquarie, had three (3) consecutive days with 200 mm or more from 19th to 21st March. Comboyne also had a four-day total of 853 mm from 19th to 22nd March (*a record for this location*), and a total of 943 mm for the week ending 24th March (BOM 2021).

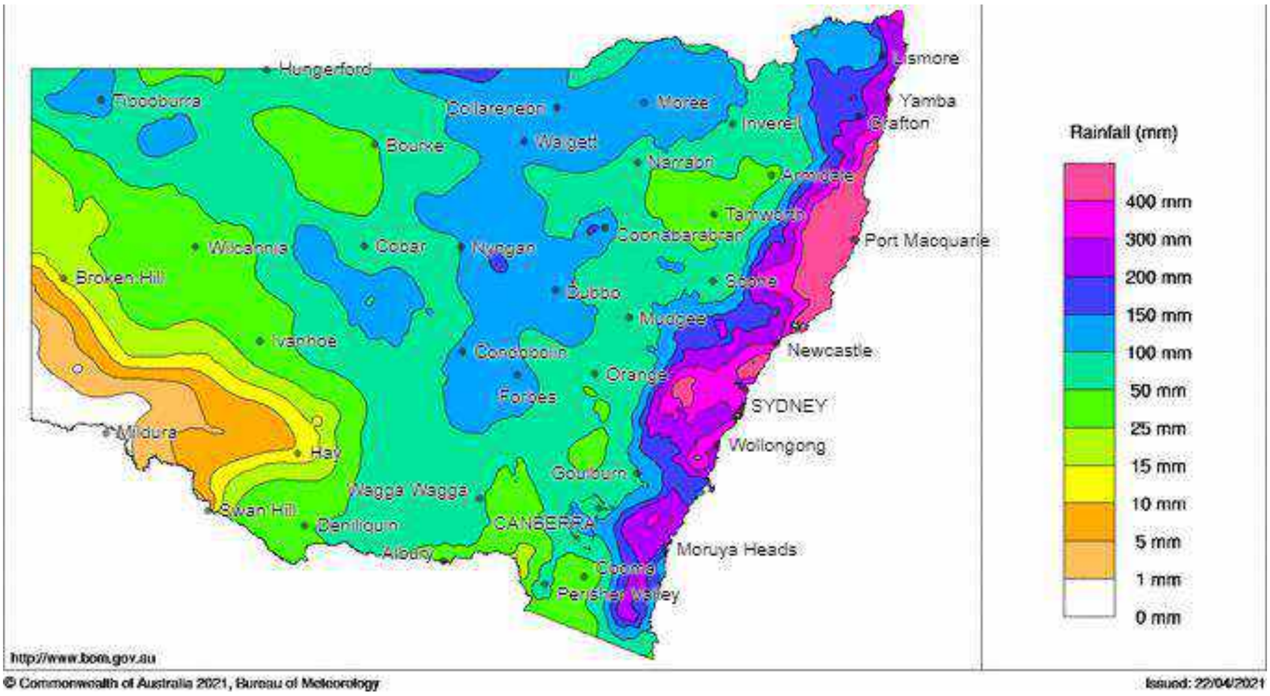


Plate 4-1 NSW rainfall totals for the week ending 23 March 2021 (Source: BOM)

The highest daily rainfall for the Mid North Coast region occurred over the 24 hours to 9am on 20th March, with the heaviest rainfall centred between Port Macquarie and Taree where over 200 mm was recorded across a significant area (refer **Plate 2-2**). The highest daily total of 405.5 mm was recorded in the Camden Haven River catchment at a flood warning gauge at Kendall (Delward).

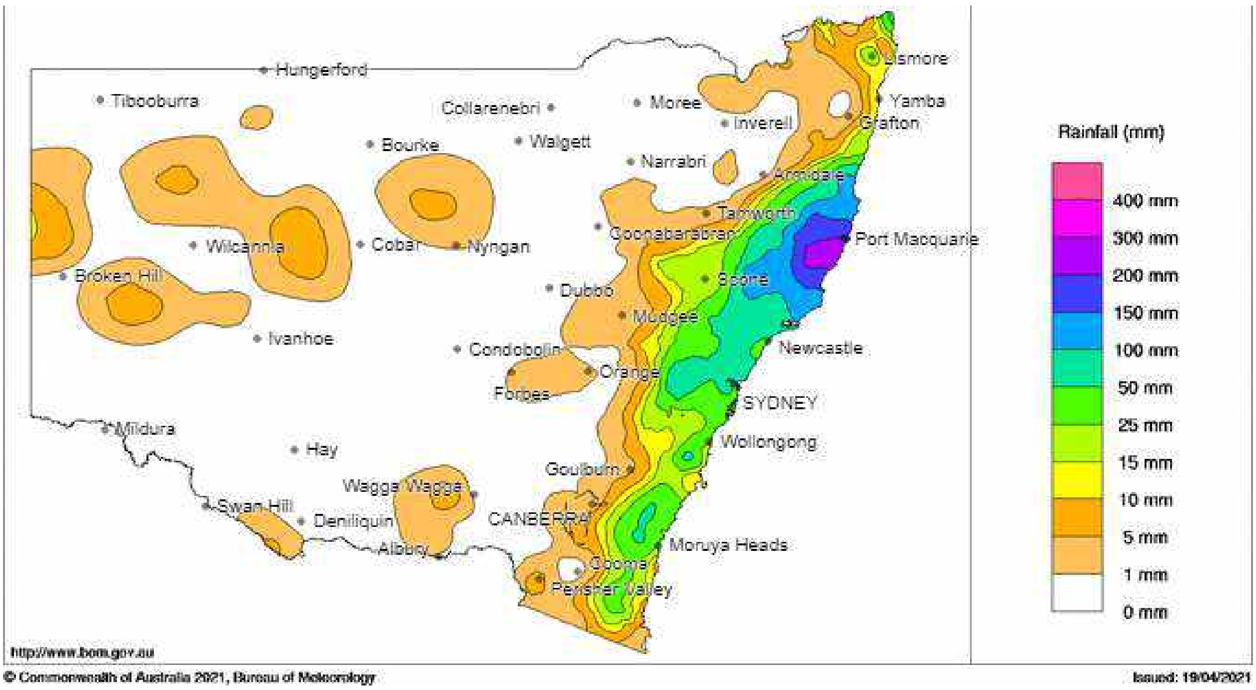


Plate 4-2 NSW rainfall totals for the 24 hour period to 9am 20th March 2021 (Source: BOM)

The adjacent Hastings River catchment had its second-wettest period on record for timescales from 3 to 7 days ranking only behind the February 1929 event (BOM 2021).

The heavy rainfall, which mostly fell on relatively wet catchments, contributed to significant and widespread flooding. The most significant flooding occurred in the Hastings, Camden Haven and Manning Rivers. Record flood heights were observed at Kindee Bridge on the Hastings River and Logans Crossing on the Camden Haven River (BOM 2021).

4.3.2 Recorded Data

Rainfall Data

A cumulative rainfall plot of recorded rainfall data for the period from 00:00 on 18th March 2021 to 00:00 on 23rd March 2021 is presented in **Plate 4-3**. It shows cumulative rainfall for this period as recorded at gauges from within, or in close proximity to the Camden Haven River catchment. These gauges are listed in **Table 4-1** and their locations are shown in **Figure 4-1**.

Table 4-1 Rainfall Gauges in the Camden Haven Catchment for the March 2021 Event

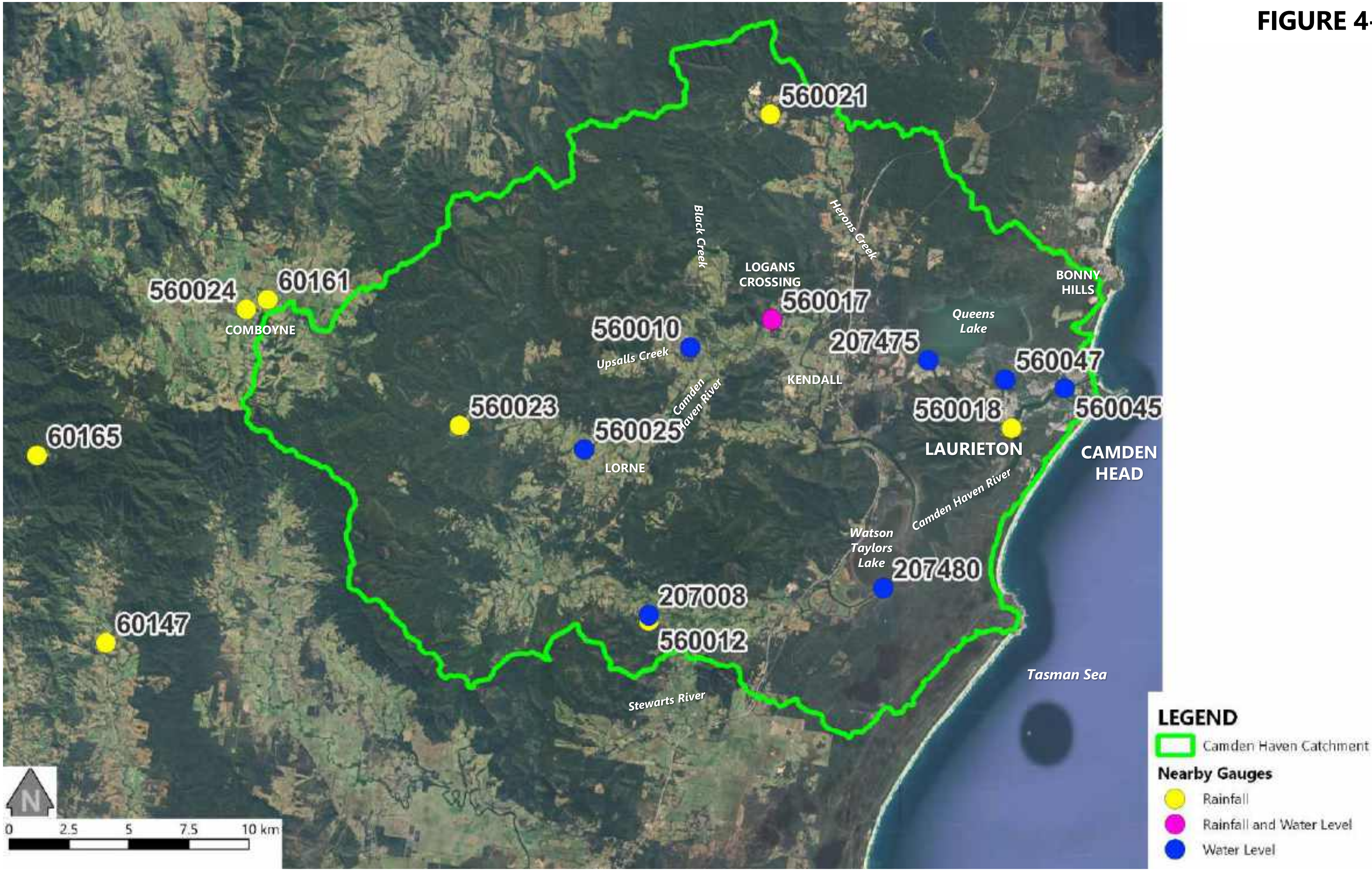
Gauge No.	Description / Location	Gauge Type	Period of Operation
60147	Killabakh	Pluviometer	June 2003 - Present
60161	Comboyne Public School	Pluviometer	August 2012 - Present
60165	Mooral Creek (The Den)	Pluviometer	July 2012 - Present
560012	Redoak (Stewarts River)	Pluviometer	
560017	Logans Crossing (Camden Haven River)	Pluviometer	October 1989 - Present
560018	Laurieton (Mill Street)	Pluviometer	
560021	Kerewong (Broken Bago)	Pluviometer	
560023	Kendall (Delward)	Pluviometer	
560024	Comboyne (Thone River)	Pluviometer	

The recorded rainfall presented in **Plate 4-3** highlights the intensity of the rainfall that fell across the region during the March 2021 event. The rainfall gauges located in the west of the catchment near Comboyne recorded the highest totals with rainfalls in excess of 900 mm over 6 days.

The daily rainfall gauge at Comboyne (60161) recorded 714 mm over the 3 day period to 9am on 21st March. This equates to a storm with an annual exceedance probability (AEP) of 1%; that is, a storm with an average recurrence interval of 1 in 100 years. The total rainfall over the most severe 4 day period during the event was 853 mm. This equates to a storm with an AEP of 1 in 200.

The Redoak gauge (560012), which is located near the Stewarts River, recorded 442 mm over a 24 hour period. This equates to a storm approximating the 1 in 500 AEP event; that is, a storm with an average recurrence interval of 1 in 500 years.

FIGURE 4-1



Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250205_CamdenHaven_A4L_P2.pdf

MARCH 2021 CALIBRATION EVENT
LOCATION OF GAUGES

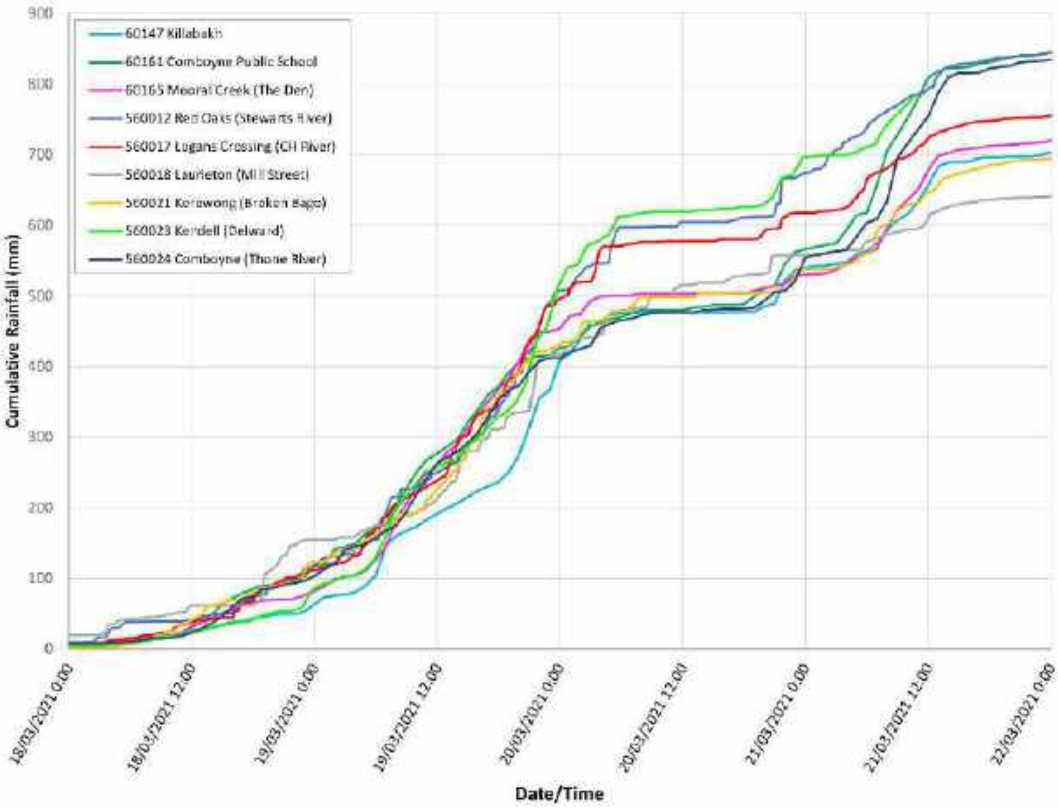


Plate 4-3 Recorded rainfall data for the March 2021 Event

River Level Data

A number of water level gauges located in the catchment were operational during the March 2021 event. These are located on the Camden Haven River and a number of its more major tributaries. Gauges positioned on Watson Taylors Lake and Queens Lake were also operational during the event.

The available water level gauges are listed in **Table 4-2**, and locations shown in **Figure 4-1**.

Water level data recorded at these gauges during the March 2021 flood is presented in **Plate 4-4**.

Of the gauges presented, only one gauge had an error during the calibration event, the Lorne Bridge gauge (560025). This gauge does not have any gauge recordings between 12:00 on 21st March to 14:00 on 23rd March, towards the later stages of the event. At the time of error, the water level was still climbing, and therefore the secondary peak level is unknown. Another gauge that failed during the event is the Herons Creek Pacific Highway Bridge Gauge (560022). This gauge had failed prior to the 2021 calibration event.

Table 4-2 Water Level Gauges in the Camden Haven River Catchment

Gauge No.	Description / Location	Period of Operation
207008	Stewarts at Stewarts River	July 1969 - Present
207475	Queens Lake at Lakewood	December 2001 - Present
207480	Watson Taylors Lake	December 2001 - Present
560010	Upsalls Creek	

560017	Logans Crossing (Camden Haven River)	August 1979 - Present
560025	Lorne Bridge	
560045	North Haven	October 1986 - Present
560047	Stingray Creek at West Haven	October 1986 - Present

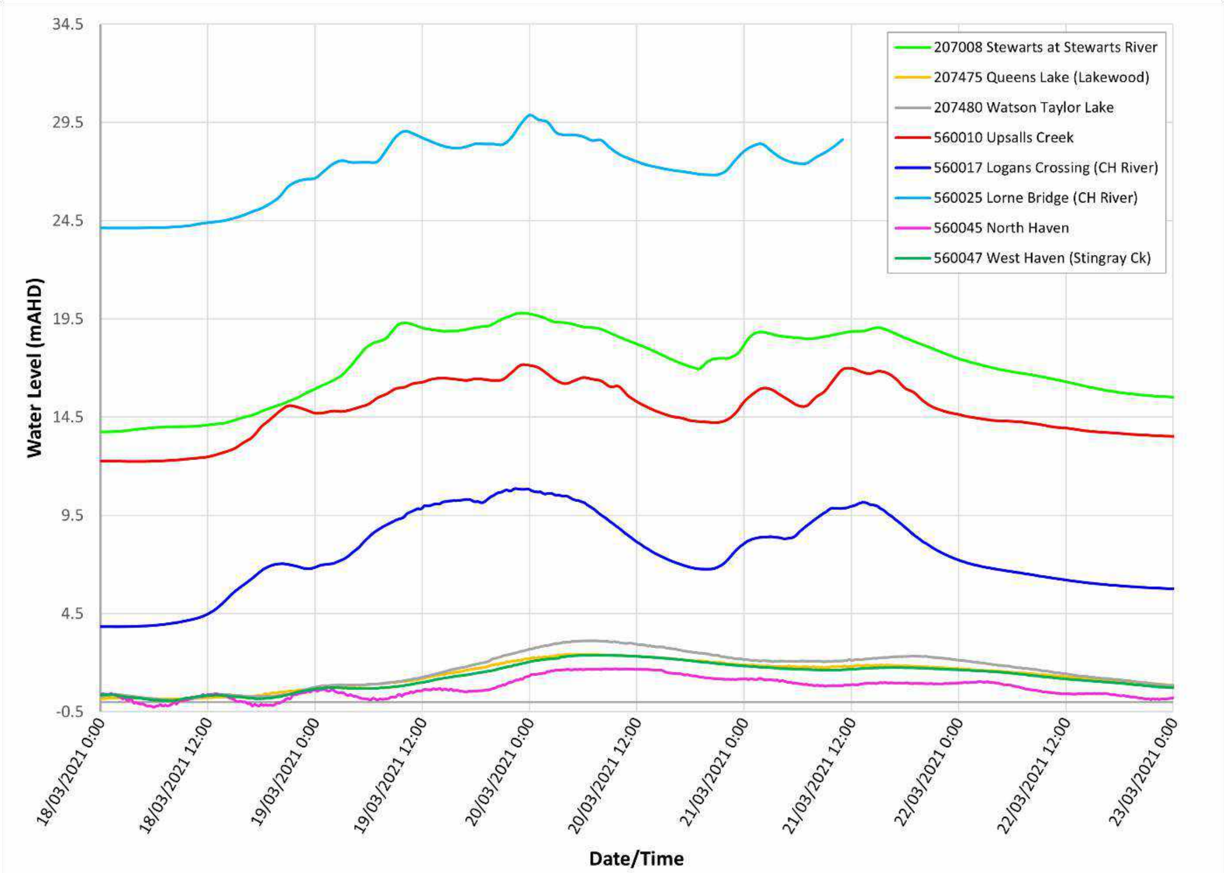


Plate 4-4 Recorded water level data for the March 2021 Event

4.3.3 WBNM Model Calibration and Validation

Calibration Process

As outlined in **Section 3.2**, a new WBNM hydrologic model has been developed which covers the entire catchment. This WBNM model replaces the existing XP-RAFTS hydrologic model that was developed for the 2013 Flood Study and will be used to derive flood hydrographs for application in the simulation of floods in the hydraulic models.

The WBNM software determines rainfall depths across each model sub-catchment from rainfall using an inverse distance weighting algorithm, with the temporal pattern across each sub-catchment taken from the nearest input rainfall gauge.

The rainfall gauge records for which data was able to be extracted for calibration of the WBNM model to the March 2021 event are as follows:

- 60147 Killabakh – *Pluviometer*

- 60161 Comboyne Public School – *Pluviometer*
- 60165 Mooral Creek (The Den) – *Pluviometer*
- 560012 Redoak (Stewarts River) - *Pluviometer*
- 560017 Logans Crossing (Camden Haven River) - *Pluviometer*
- 560018 Laurieton (Mill Street) - *Pluviometer*
- 560021 Kerewong (Broken Bago) - *Pluviometer*
- 560023 Kendall (Delward) - *Pluviometer*
- 560024 Comboyne (Thone River) - *Pluviometer*

A cumulative rainfall plot for these gauges for the period from 00:00 on 18th March 2021 to 00:00 on 23rd March 2021 is presented in **Plate 4-3**.

Calibration of the WBNM hydrologic model was completed by comparing flow hydrographs generated from the modelling against recorded flood hydrographs derived from the various river level gauges located in the catchment. Where differences between predicted and recorded flow hydrographs were observed, adjustment of WBNM hydrologic model parameters was undertaken to try to improve the "fit" and to better replicate the hydrograph shape and peak flow magnitude.

This involved adjustment of the WBNM runoff lag factor 'C', the stream routing factor 'F' and initial and continuing losses, with reference to acceptable ranges.

In order to select an appropriate value for the WBNM runoff lag parameter 'C', a range of values from 1.3 to 1.8 were tested. This was undertaken for both the March 2021 and February 2013 events resulting in a 'C' value of 1.6 which ended up providing the best fit to recorded data.

With the runoff parameter 'C' determined, the WBNM stream lag parameter 'F' was refined to achieve further improvements between WBNM generated hydrographs and hydrographs derived from recorded data. A value of 1.0 was used for the majority of the sub-catchments. Several smaller values were used on sub-catchments in the vicinity of Kendall, as they represent major Camden Haven River flows as well as stand-alone minor tributary runoff. These smaller values account for proportionally reduced major stream length of these catchments.

A few issues arose during the calibration process due to difficulties getting the WBNM model to generate hydrographs where the predicted peak flow matched those derived from recorded water levels at the corresponding gauges. Following considerable modelling and adjustments to model parameters it was concluded that the issue was likely to be caused by the unreliability of adopted rating curves for converting water levels recorded at gauges to flow hydrographs. This issue was evident at the Logans Crossing gauge (560017) and had been raised previously in the 2013 Flood Study. This issue is discussed further below.

<u>Rating Curve Issues</u>

The Logans Crossing gauge (560017) is located along the Camden Haven River about 5 kms upstream of Kendall. The gauge is located in the lower section of the catchment near the interface between the newly developed TUFLOW flood model (upper catchment) and the RMA-2 model flood model that was developed for lower catchment as part of the 2013 Flood Study.

The rating curve for the Logans Crossing gauge has a maximum height of 4.71 metres relative to zero-gauge height. However, the peak recorded flood level at this gauge during the March 2021 flood event was 8.81 metres. As a result, application of the rating curve for the Logans Crossing gauge would have required significant extrapolation to derive the hydrograph and peak flow magnitude recorded for the

March 2021 event. **Plate 4-5** shows the variation between the recorded discharge gaugings, the adopted rating curve and the calibration/validation events, 2013 and 2021. This shows that the 2013 and 2021 peak levels were around 2 metres and 4 metres, respectively, above the highest gauged discharge. This also shows that the rating curve derives a flow for the 2021 event to be one-third of the flow derived by from calibration of the WBNM and TUFLOW models.

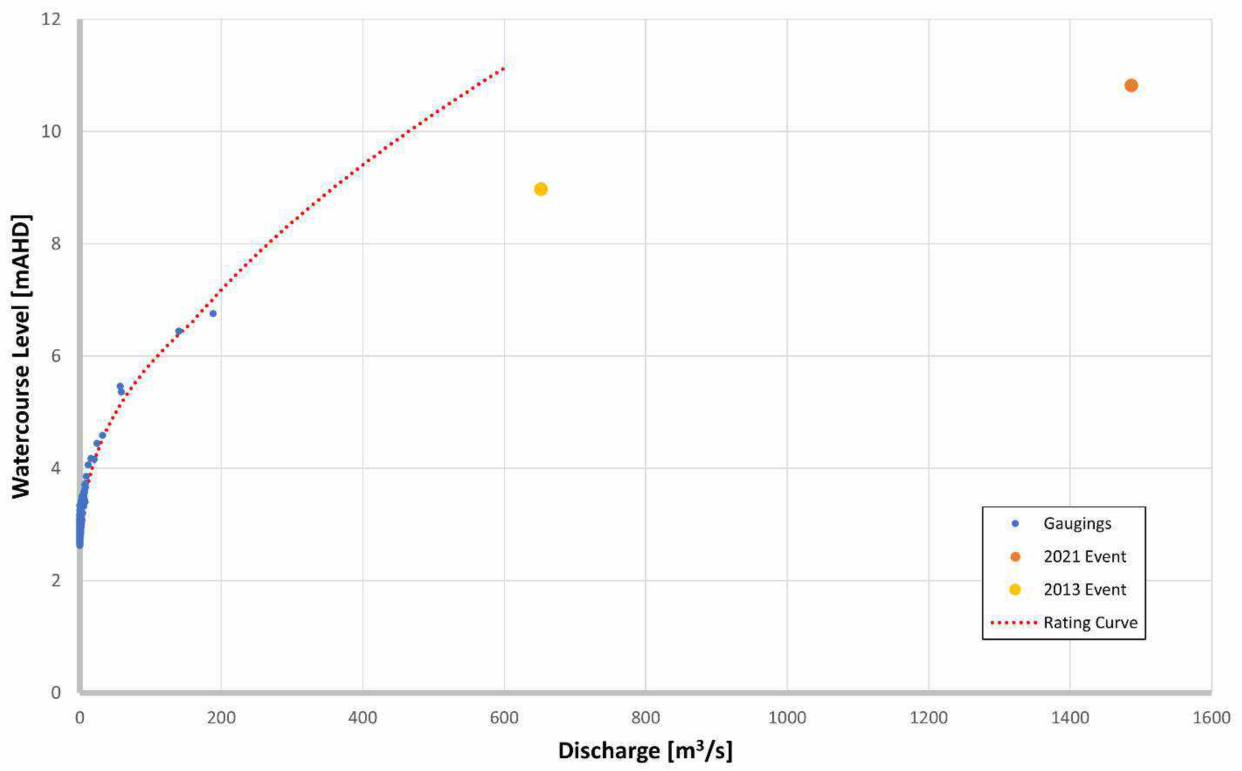


Plate 4-5 Comparison of calibration events to ratings and gaugings at Logans Crossing (560017)

As noted above, the unreliability of the rating curve for the Logans Crossing gauge (560017) was an issue that was raised as part of the 2013 Flood Study. **Section 5.2.2** of the 2013 Flood Study states that investigations completed to calibrate the XP-RAFTS hydrologic model concluded that the rating curve adopted for Logans Crossing was under-predicting peak discharges. This led to the creation of a local scale RMA-2 flood model which was used to develop a revised rating curve.

It is noted that the recommendations of the 2013 Flood Study regarding the Logans Crossing rating curve do not appear to have been implemented by WaterNSW. Accordingly, the flow hydrographs calculated for the March 2021 event appear to also under-predict flow magnitudes.

An issue also exists with the recorded data from the Stewarts at Stewarts River gauge (207008). The rating curve for this gauge is based on a maximum gauged level of 15.7 mAHD whereas the peak recorded level during the March 2021 event was 19.79 mAHD.

Adopted WBNM Model Parameters for March 2021 Event

The challenges with the data meant that it was not possible to generate hydrographs using the WBNM model that match the shape <u>and</u> peak of the hydrographs determined from the recorded data and rating curves for the Logans Crossing and Stewarts River gauges. Given the issues with the rating curves, it was decided that it would be better to focus on determining model parameters that generate a reasonable fit to the hydrograph shape. By focusing on the shape, peak flows can be determined through pseudocalibration of the WBNM model alongside the TUFLOW hydraulic model when comparing to water level data. This process is consistent with ARR19 guidelines.

Further validation of the flow hydrographs could then be undertaken by comparing flood levels predicted using the RMA-2 flood model to those recorded at the water level gauges.

Graphs comparing predicted and recorded hydrographs from this process for the March 2021 event are presented in **Figure A-1** and **Figure A-2** of **Appendix A** for the Logans Crossing and Stewart River gauges, respectively. The WBNM model parameters determined as an outcome of the calibration process are listed in **Table 4-3**.

Table 4-3 WBNM parameters for March 2021 calibration event

Parameter	**Parameter Value**
Runoff lag factor 'C'	1.6
Impervious runoff lag factor 'C'	0.1
Stream routing factor 'F'	0.5-1.0
Initial Loss (pervious)	10
Continuing Loss (pervious)	1.0
Initial Loss (effective impervious)	0
Continuing Loss (effective impervious)	0

4.3.4 Camden Haven RMA-2 model validation

The existing RMA-2 flood model that was developed as part of the 2013 Flood Study was validated using inflow hydrographs extracted from the results of simulations of the March 2021 event using the adopted WBNM model. Hydrographs were extracted at all sub-catchments within the model domain and applied to the model as either upstream boundary or local catchment inflows.

A comparison of predicted flood level hydrographs to recorded levels at gauges located within the RMA-2 model domain is provided in the following figures which are included in **Appendix B**.

- **Figure B-1** for the Logans Crossing (Camden Haven River) Gauge (*560017*)
- **Figure B-2** for the Watson Taylors Lake at Watson Taylors Lake Gauge (*207480*)
- **Figure B-3** for the Queens Lake at Lakewood Gauge (*207475*)
- **Figure B-4** for the Stingray Creek at West Haven Gauge (*560047*)
- **Figure B-5** for the Camden Haven at North Haven Gauge (*560045*)

The comparison plots indicate that the RMA-2 flood model generates flood levels that are a good fit to recorded water levels at each of the gauges located within the RMA-2 model domain. The following conclusions are drawn from review of **Figures B-1** to **B-5**.

(i) The shape and timing of the peak for all of the flood level hydrographs is well replicated by the RMA-2 flood model.

(ii) Differences in peak levels are generally within 0.1 to 0.2 metres.

A comparison between recorded and predicted peak March 2021 flood levels is presented in **Figure 4-2** to **Figure 4-4** for available flood marks. These recorded flood marks were sourced from surveyed high-water marks provided by PMHC and from independent inspections of flood affected properties undertaken by Advisian (now Worley Consulting) following the March 2021 East Coast Weather Event.

The RMA-2 flood model was found to predict flood levels for the March 2021 event that compare well to the recorded flood marks at the majority of locations. In the vicinity of Laurieton and North Haven for example, the RMA-2 model predicts peak flood levels that are typically within 0.10 metres of recorded levels (refer **Figure 4-4**). This close calibration was observed for nine (9) out of the eleven (11) flood marks available in this area. For the remaining two flood marks, the calibration exercise generated a reasonable fit with a maximum difference of 0.30 metres.

Seven (7) high water marks were also available along the Camden Haven River upstream of Watson Taylors Lake. As shown in **Figure 4-3**, the RMA-2 model predicts peak flood levels that are within 0.17 metres for three (3) of the seven (7) flood marks.

There is a poor validation to one flood mark that is located in close proximity (within 30 metres) of the Logans Crossing gauge. This is unexpected given the RMA-2 model predicts peak flood levels for the March 2021 event that are within 0.1 metres of those recorded at the gauge. This flood mark is considered to be in error as it corresponds to a flood level that is almost 1 metre higher than the level recorded at the gauge, while only being located a short distance downstream of it. It is also possible that the flood mark is higher due to its location on sloping ground near the edge of the floodplain. The peak level recorded may have therefore been influenced by overland runoff from the hillside.

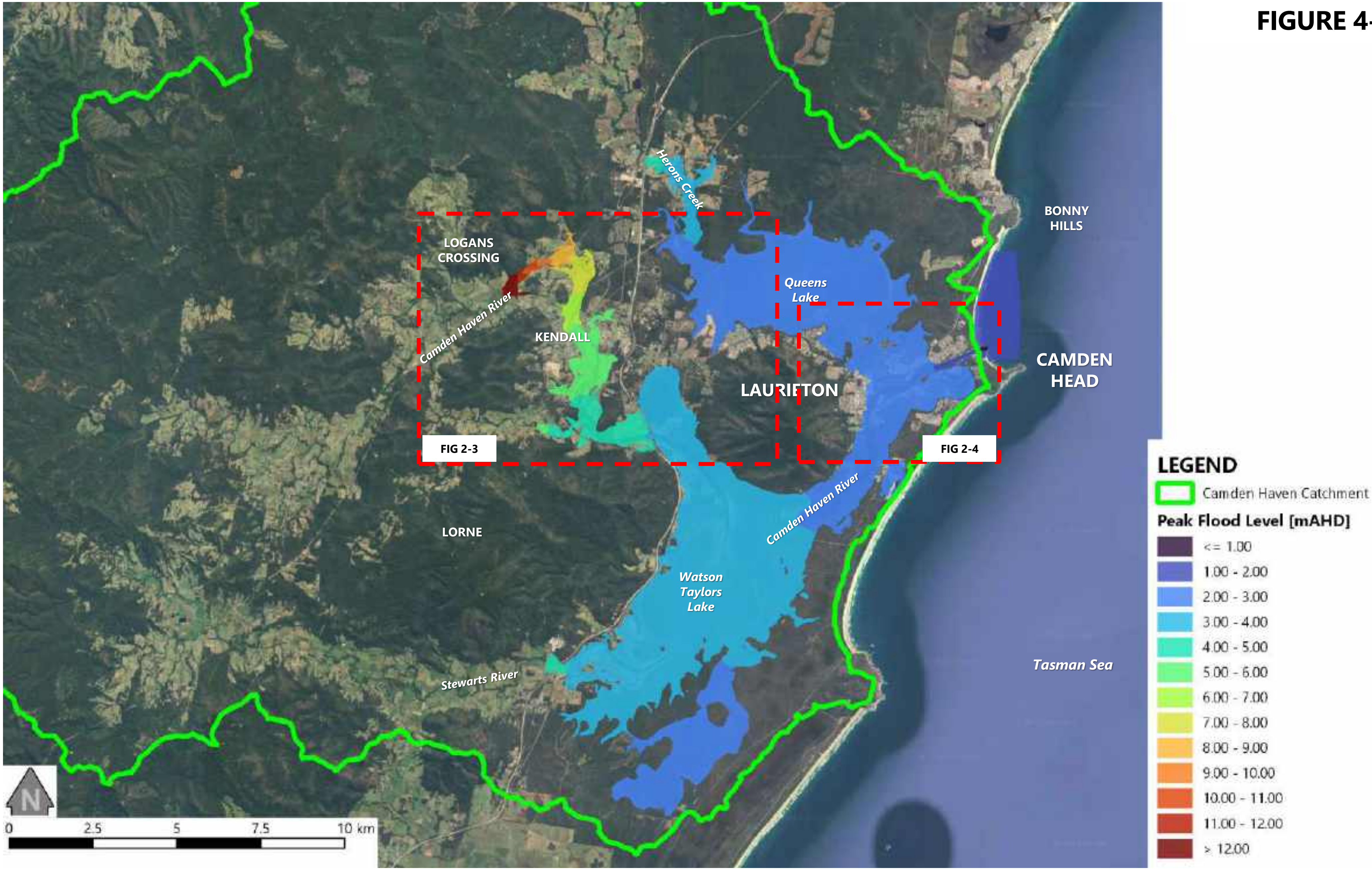
Two flood marks are located near the Pacific Highway Crossing of the Camden Haven River. As shown in **Figure 4-3**, the RMA-2 model does not replicate these two marks well with differences in levels of 0.79 metres recorded upstream of the crossing and 0.50 metres downstream. The difference between predicted and recorded flood levels appears to be associated with the Pacific Highway Bridge crossing, with RMA-2 predicting 0.54 metres of head loss through the crossing compared to only 0.15 metres based on recorded flood levels. As the Pacific Highway did not overtop at this location the differences are associated with the bridge hydraulics only. Further review of the flood model at this location may be warranted if the reliability of the recorded high water marks can be confirmed. In that regard, a head loss through the bridge crossing of only 0.15 metres is considered low given the size of the flood event and the magnitude of flow conveyed through the bridge waterway opening.

4.3.5 Camden Haven TUFLOW Hydraulic Model Calibration

To calibrate the TUFLOW hydraulic model to the March 2021 event, the WBNM inflow hydrographs were applied across the catchment. Relevant downstream boundary conditions were applied at the base of both waterways. Downstream boundaries for the Camden Haven River and Herons Creek were based on recorded levels from the Watson Taylors Lake gauge (207480) and the Lakewood gauge (207475) (Queens Lake), respectively.

Watson Taylors Lake is located 3.5 km from the downstream end of the TUFLOW hydraulic model. This is not considered an issue as the modelling for the *Camden Haven River & Lakes System Flood Study* (WorleyParsons, 2013) determined that levels at the Logans Crossing gauge varied by less than 0.1 metres for a variety of tailwater scenarios. Accordingly, the gauged level at Logans Crossing was determined to be insensitive to downstream tailwater conditions. It was therefore considered acceptable to apply gauged levels at Watson Taylors Lake as the downstream boundary condition for the Camden Haven River arm of the TUFLOW model.

FIGURE 4-2

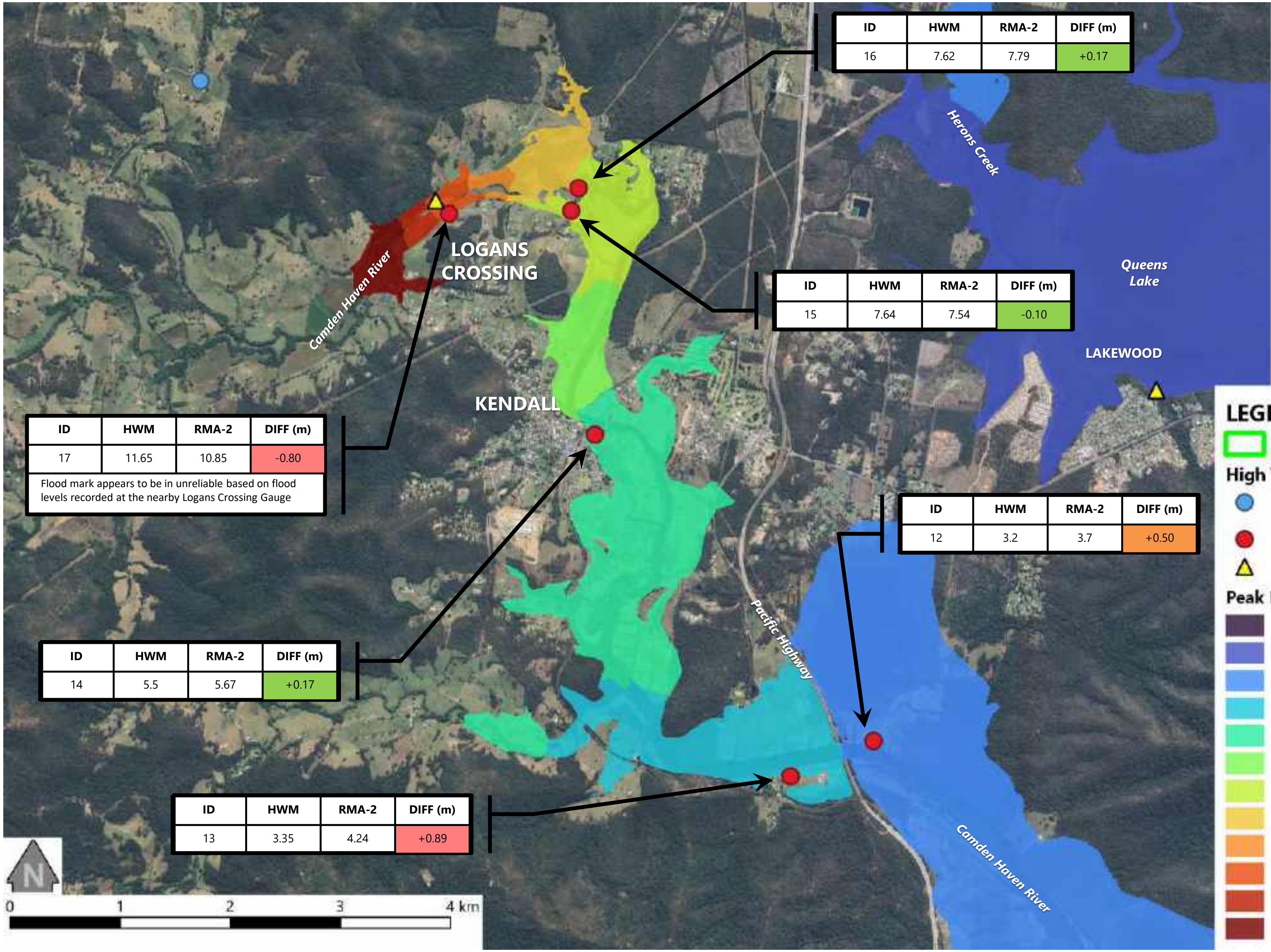


Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs
fg311015-00481_250205_CamdenHaven_A4L_P2.pdf

COMPARISON OF PREDICTED RMA-2 FLOOD LEVELS AND RECORDED HWMs FOR THE MARCH 2021 FLOOD
[STUDY AREA OVERVIEW]

FIGURE 4-3



ID	HWM	RMA-2	DIFF (m)
16	7.62	7.79	+0.17

ID	HWM	RMA-2	DIFF (m)
15	7.64	7.54	-0.10

ID	HWM	RMA-2	DIFF (m)
17	11.65	10.85	-0.80
Flood mark appears to be in unreliable based on flood levels recorded at the nearby Logans Crossing Gauge			

ID	HWM	RMA-2	DIFF (m)
12	3.2	3.7	+0.50

ID	HWM	RMA-2	DIFF (m)
14	5.5	5.67	+0.17

ID	HWM	RMA-2	DIFF (m)
13	3.35	4.24	+0.89

Prepared by:

worley consulting

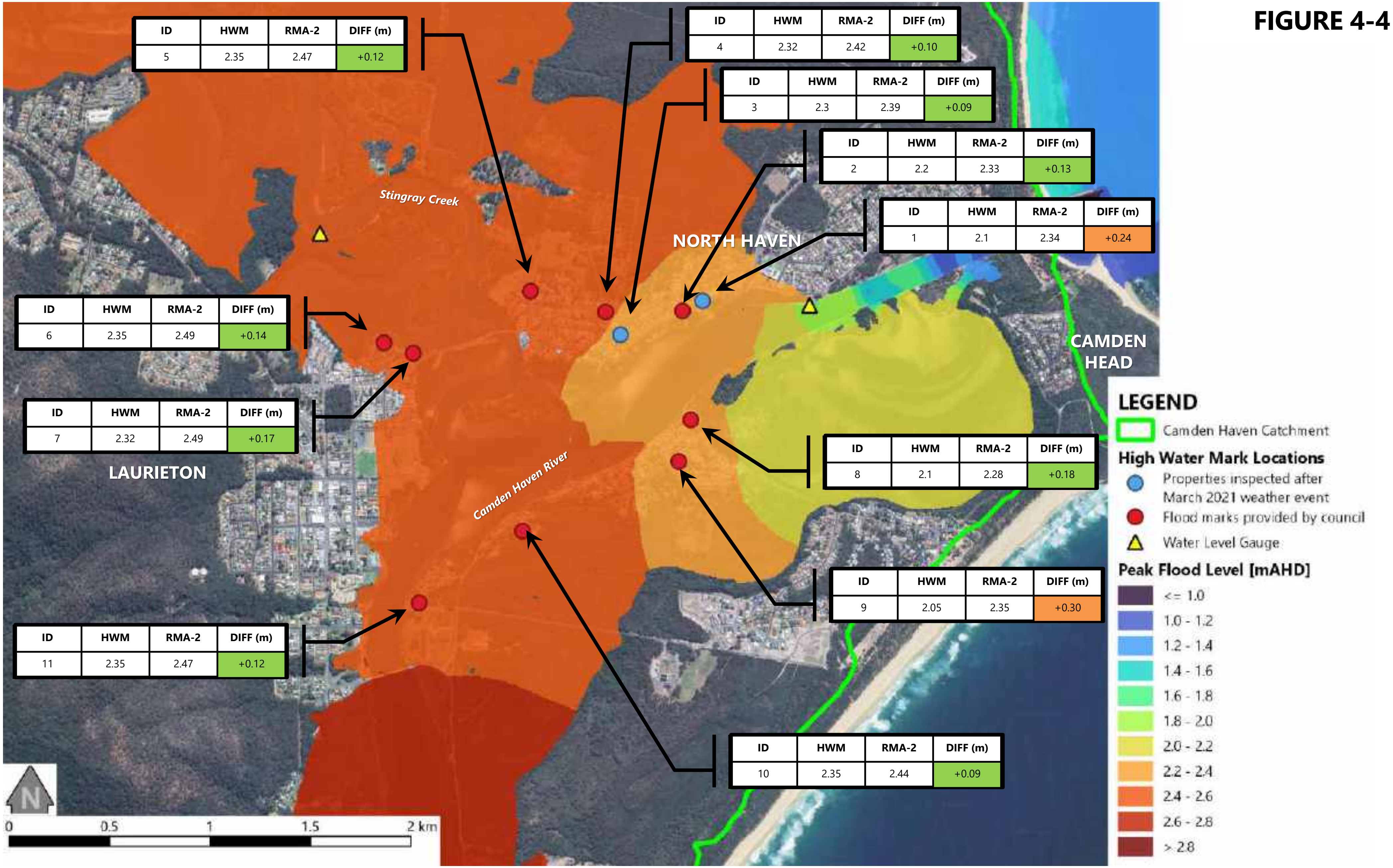
250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250205_CamdenHaven_A4L_P2.pdf

COMPARISON OF PREDICTED RMA-2 FLOOD LEVELS AND RECORDED HWMs FOR THE MARCH 2021 FLOOD

[EXTENT 1 OF 2]

FIGURE 4-4



Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs
fg311015-00481_250205_CamdenHaven_A4L_P2.pdf

COMPARISON OF PREDICTED RMA-2 FLOOD LEVELS AND RECORDED HWMs FOR THE MARCH 2021 FLOOD
[EXTENT 2 OF 2]

Calibration of the model was then undertaken by comparing flood levels determined from simulations using the TUFLOW model against recorded water levels from the available water level gauges in the catchment and from surveyed flood marks. A comparison between the flood level hydrograph predicted using the TUFLOW model and recorded levels at the Logans Crossing (Camden Haven River) Gauge (*560017*) is presented in **Figure C-1** of **Appendix C**.

Figure C-1 indicates that the TUFLOW model predicts the flood levels recorded at the Logans Crossing gauge to within 0.01 metres. This excellent match is in contrast to the results from the WBNM model which for this March 2021 event predicts flows that are significantly larger than those determined by application of the Logans Crossing rating curve (refer **Figure A-1**). The results from the TUFLOW model calibration further support the earlier commentary indicating that the Logans Crossing rating curve is unreliable and underpredicts peak flows.

The modelled results for Logans Crossing (560017) show a sudden drop in level at the beginning of the simulation. This is caused by the initial water in the system leaving before new inflows arrive. The model drops down to a level of roughly 2.7 mAHD, in line with the cease to flow (CTF) level quoted by WaterNSW for the gauge. Considering the catchment experienced above average rainfall in the 2 months prior, including in the week leading up to the event, it is possible that groundwater seepage and delayed runoff could be attributed to the 'missing' flow. The Comboyne PS (60161) gauge located near the western boundary of the catchment recorded 109 mm in the week prior to the 18th March 2021, and monthly rainfall totals of 511 mm and 370mm for January and February 2021, respectively.

Analysis of the modelled levels at Logans Crossing also show the main peak to arrive at the gauge roughly 3 hours after the recorded peak. Analysis of other recorded water level data at Lorne Bridge (560025) and Upsalls Creek (560010) shows good alignment in timing of the main peak. Good alignment between the flow hydrographs generated by the WBNM and TUFLOW models across the model domains and at the Logans Crossing gauge (560017, refer **Figure C-2**) suggests the difference is not related to the routing of flow by either model, and is instead, a function of the input rainfall data.

In that regard, rainfall across the Blacks Creek catchment and runoff from it, may be under-represented in both models. This is because no rainfall or water level gauges are located in this relatively large catchment and the rainfall applied to it is based on data recorded at nearby gauges. It is suggested that a variation in the rainfall temporal pattern in the upper reaches of the Blacks Creek catchment would result in an earlier peak flow carried along the tributary, causing an earlier rise in the peak at the Logans Crossing gauge. This however cannot be validated due to the lack of available data.

Figure C-2 of **Appendix C** shows a cross-comparison between the flow hydrograph predicted by WBNM at the Logans Crossing gauge and one extracted from the TUFLOW model. The WBNM and TUFLOW hydrographs are in good agreement which indicates that the stream lag parameter 'F' in WBNM determined through the calibration process is appropriate. This comparison gives greater confidence in the WBNM model.

A similar assessment was conducted across the catchment to further validate the alignment between the WBNM hydrologic model and TUFLOW hydraulic model.

Two other water level gauges are located further upstream of the Logans Crossing gauge. These are the Lorne Bridge gauge (560025) which is located upstream along the Camden Haven River, and the Upsalls Creek gauge (560010) which is located on Upsalls Creek, a major tributary.

Figure C-3 shows a comparison between recorded and modelled water levels at the Lorne Bridge gauge (560025). This shows a close match between the timing of all peaks throughout the event. However, the modelled peak levels show a disconnected double peak which is 0.5 metres lower than the corresponding recorded peaks. A closer inspection of the TUFLOW flow hydrographs upstream of the gauge shows a similar double peaked pattern. This forms a single peak further downstream from the gauge before it arrives at Logans Crossing (refer **Figure C-2**).

Inspection of the rainfall data recorded at the Comboyne Public School gauge (60161) and at the Kendall (Delward) gauge (560023) shows a similar double peak in rainfall. Both of these rainfall data-sets are recorded in hourly increments. It is suggested that a spatial delay in temporal pattern could align the double peak evident in these hydrographs. However, this exercise would involve an iterative trial process with limited justification for the assumptions.

Figure C-4 shows a comparison of recorded and modelled water levels at the Upsalls Creek gauge (560010). At this gauge, the TUFLOW model predicts flood levels at the gauge to be within 0.1 metres of the recorded peak level.

The TUFLOW hydraulic results were then compared to high-water marks recorded following the March 2021 event. PMHC provided forty-four (44) surveyed high-water marks across the Camden Haven River catchment, of which seven (7) fall within the TUFLOW model domain. Two (2) additional flood marks were obtained from inspections of flood affected properties undertaken by Worley Consulting (formerly Advisian) as part of independent assessments completed for the March 2021 East Coast Weather Event.

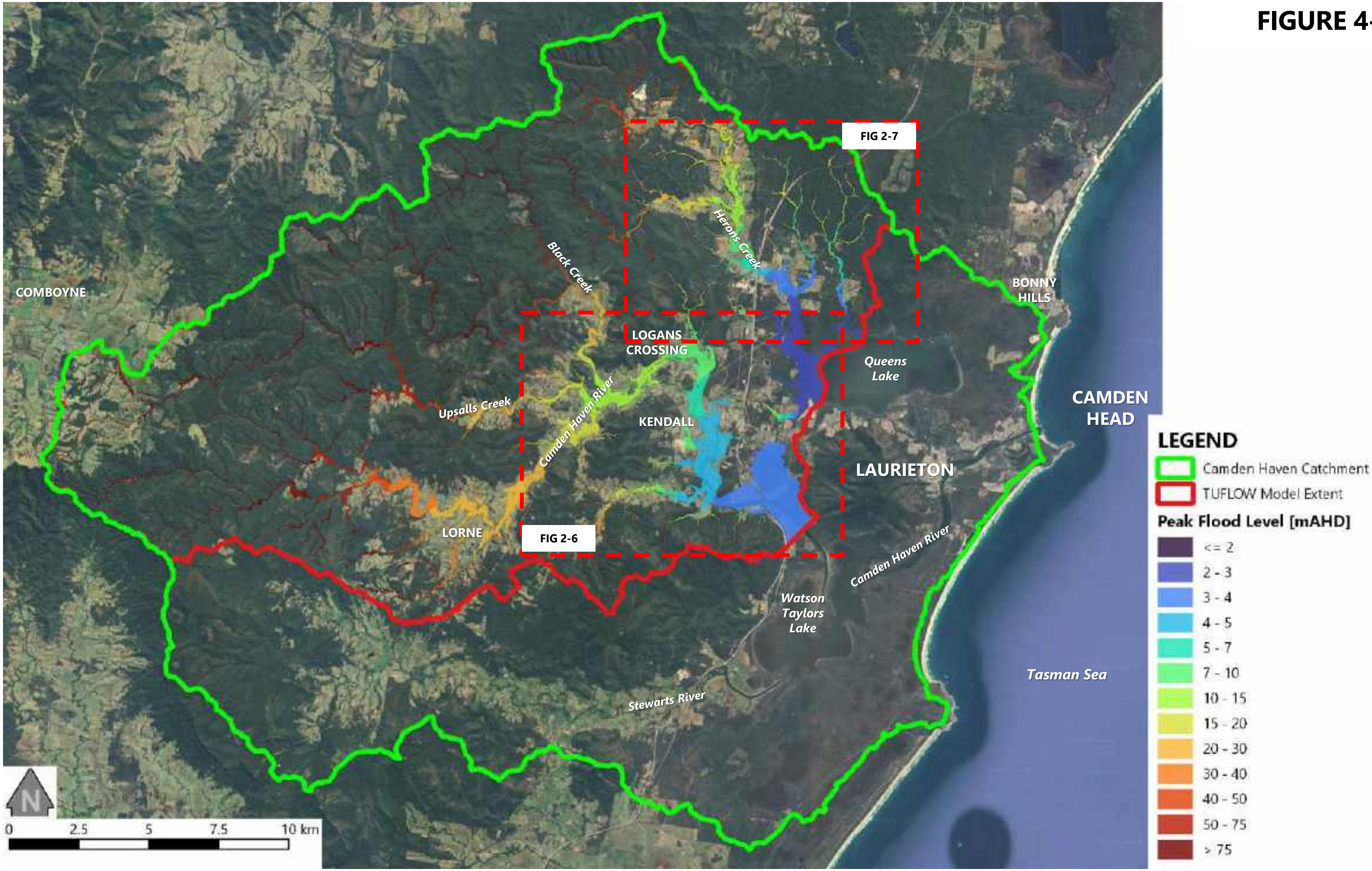
A comparison between recorded flood levels and those predicted using the TUFLOW model are shown in **Figure 4-5** to **Figure 4-7**. The available high-water marks are superimposed on flood mapping of peak water levels as predicted by the TUFLOW model.

The TUFLOW model predicts peak flood levels for the March 2021 event that are typically within +/- 0.20 metres of the recorded flood marks; including to within 0.07 metres and 0.05 metres along the Camden Haven River (refer **Figure 4-6**) and Herons Creek (refer **Figure 4-7**), respectively.

The calibration had mixed results along the Camden Haven River between Logans Crossing and Watson Taylors Lake. As shown in **Figure 4-6**, of the six (6) flood marks available, the TUFLOW model generated flood levels that are within +/- 0.20 metres for three (3) of them. One of the flood marks near the Logans Crossing gauge is considered to be erroneous based on the recorded flood height being in disagreement with the levels recorded at the Logans Crossing gauge. Accordingly, this flood mark was disregarded for the purposes of calibration.

Overall, the TUFLOW model predicts peak flood levels that correlate reasonably well with those recorded at the Logans Crossing gauge and the range of recorded flood marks that are available and reliable. It is unfortunate that there are no additional flood marks available in the upper reaches of the catchment such as at Lorne, Upsalls Creek and Kerewong.

FIGURE 4-5



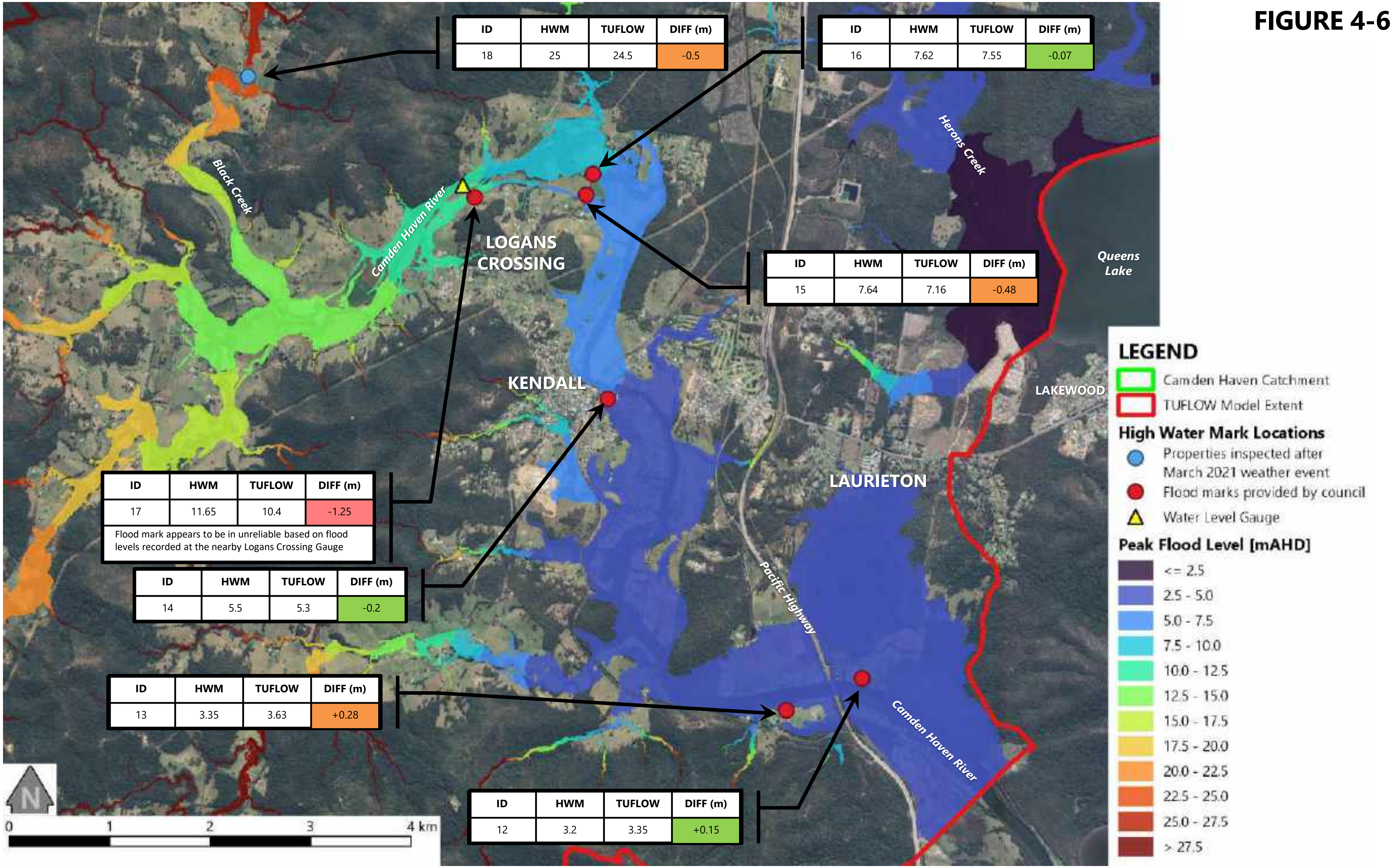
PORT MACQUARIE HASTINGS

Prepared by: worley consulting

250205_QGIS_CamdenHaven_Figures.qgs
fg311015-00481_250205_CamdenHaven_A4L_P2.pdf

COMPARISON OF TUFLOW MODELLED LEVELS FOR THE MARCH 2021 FLOOD TO SURVEYED HWMs
[STUDY AREA OVERVIEW]

FIGURE 4-6



Prepared by:

worley consulting

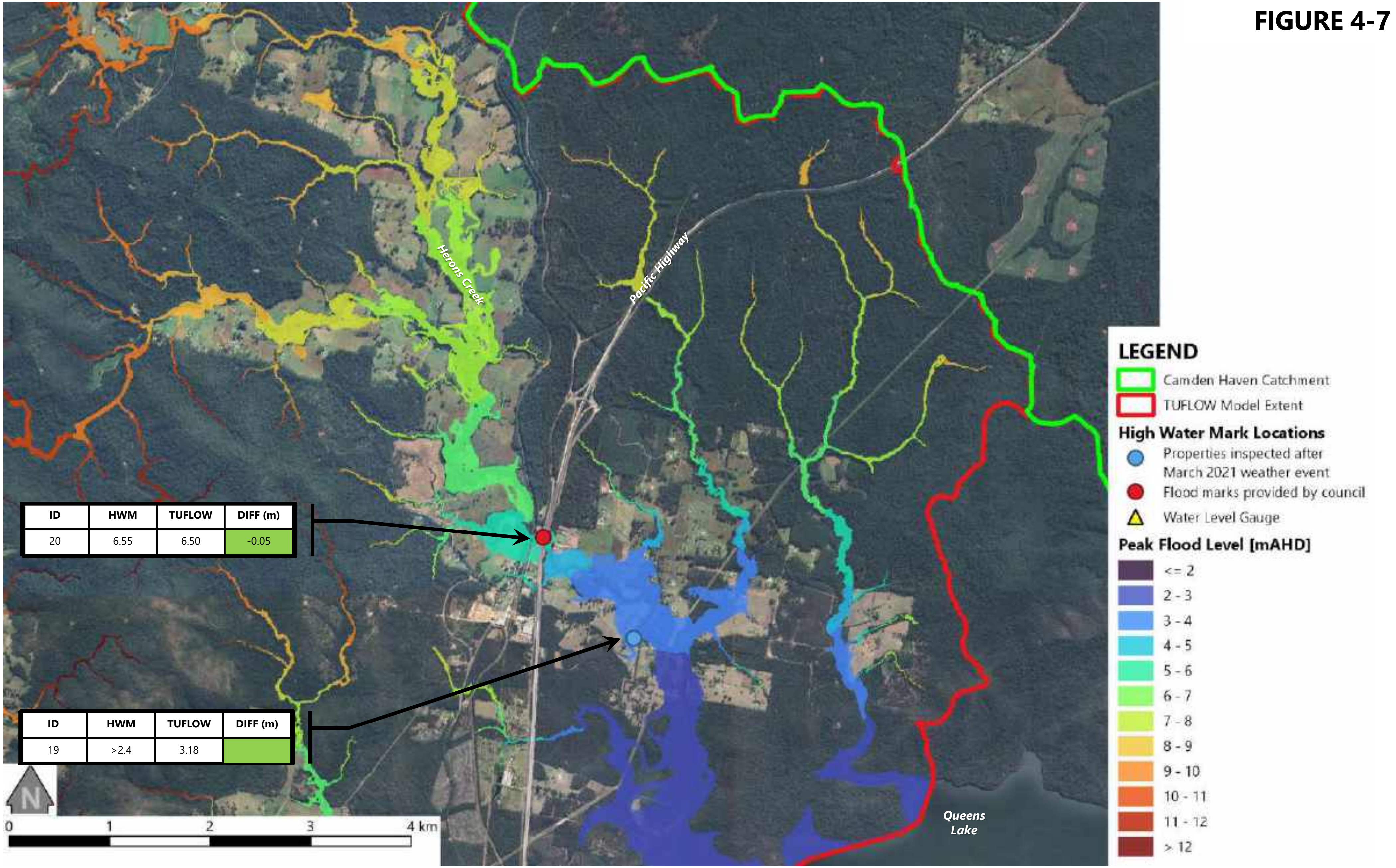
250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250205_CamdenHaven_A4L_P2.pdf

COMPARISON OF TUFLOW MODELLED LEVELS FOR THE MARCH 2021 FLOOD TO SURVEYED HWMs

[EXTENT 1 OF 2]

FIGURE 4-7



ID	HWM	TUFLOW	DIFF (m)
20	6.55	6.50	-0.05

ID	HWM	TUFLOW	DIFF (m)
19	>2.4	3.18	

Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250205_CamdenHaven_A4L_P2.pdf

COMPARISON OF TUFLOW MODELLED LEVELS FOR THE MARCH 2021 FLOOD TO SURVEYED HWMs

[EXTENT 2 OF 2]

4.4 Validation to the February 2013 Flood

4.4.1 Event Overview

A low-pressure system formed off the east coast of Australia on 18th February 2013. In the days that followed, the system tracked west, making landfall on the 22nd February on the north coast of New South Wales. This resulted in widespread, persistent and heavy rainfall across the Mid-North Coast including the Camden Haven River catchment.

Heavy thunderstorms affected large parts of the New South Wales east coast causing well above average rainfall to impact the state for the month of February 2013 (refer **Plate 4-6**). These thunderstorms caused heavy rainfall across the Camden Haven River catchment from 21st to 25th February 2013. Heavier rainfall was recorded in the vicinity of Kerewong (Broken Bago), which reported over 700 mm over those 4 days.

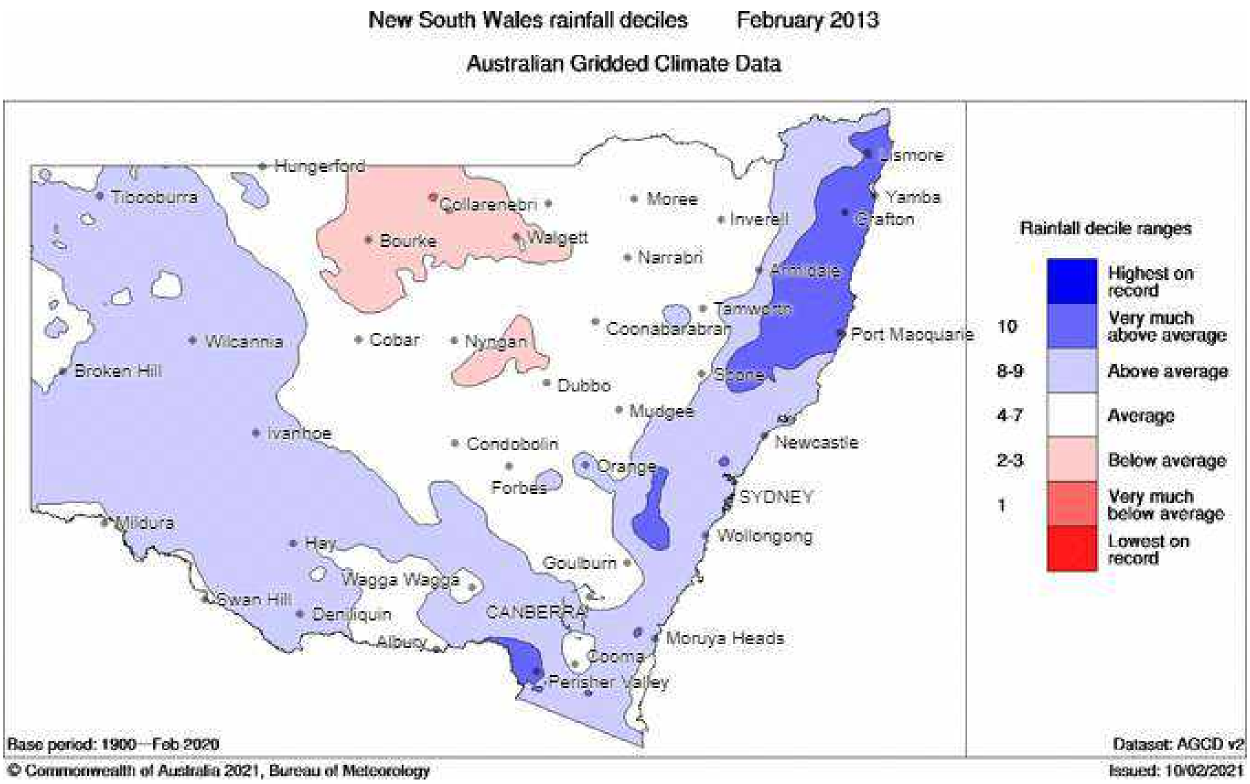


Plate 4-6 February 2013 Rainfall comparison to average across NSW (Source: BoM, 2024)

A second rainfall event then occurred a week later, starting on the 2nd March 2013 and lasting two days. This event was a cold front with a surface trough that travelled from central NSW before moving offshore on the 2nd, and being replaced by several days of strong easterly flow caused by a stationary high pressure system that lingered in the Great Australian Bight. This caused persistent rain and cool conditions along the mid north coast of NSW. The Comboyne Public School gauge (60161) recorded 209mm on the 3rd March and a four-day rainfall total of 451mm to 9am on 4th March 2013.

Plate 4-7 presents a cumulative rainfall plot for several key gauges in the Camden Haven River catchment across both rainfall events, from the 18th February to 6th March 2013. This shows the magnitude of rainfall for both events.

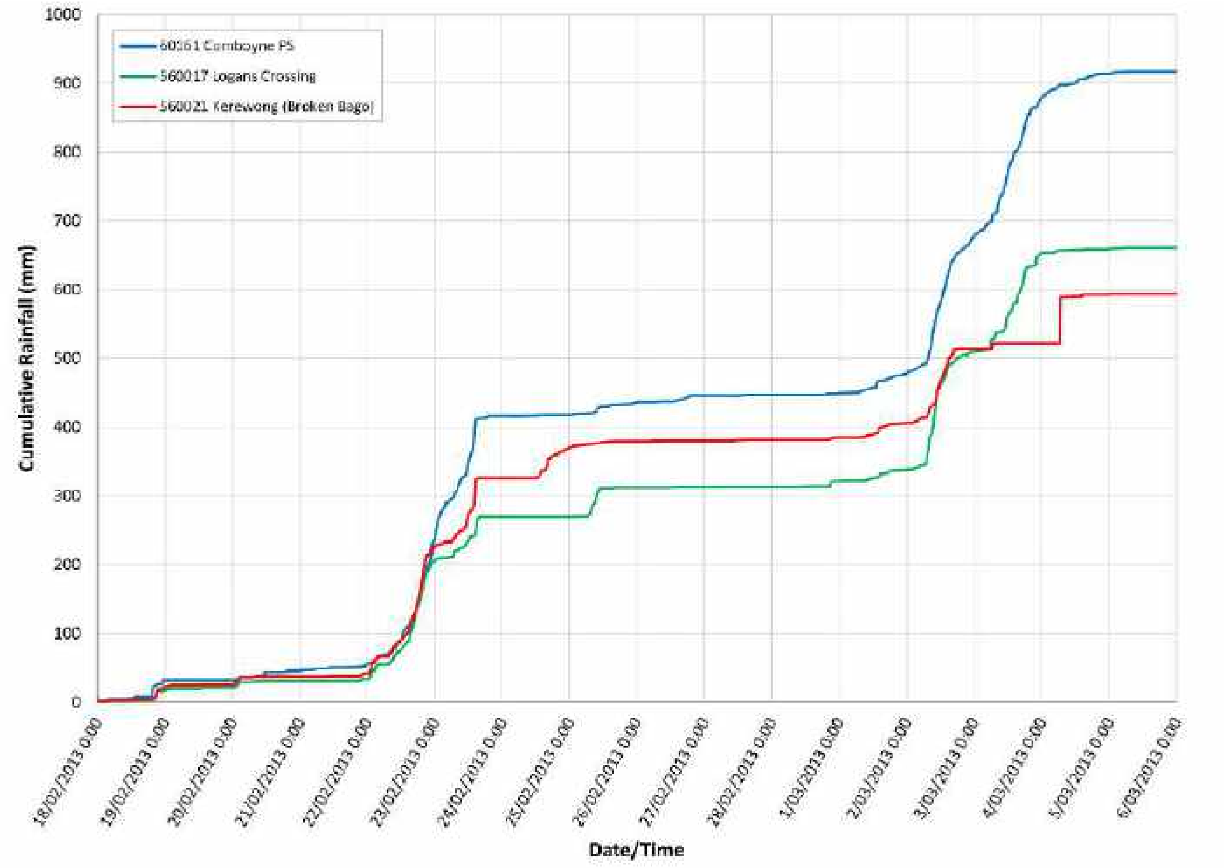


Plate 4-7 Recorded rainfall data for consecutive February-March 2013 events

This second rainfall event also caused widespread flooding along the Camden Haven River, with both events having a similar double peak flood pattern as recorded at the Logans Crossing (207428) gauge. Flood level records at this gauge are presented in **Plate 4-8** for both events. As observed in this plate, the second rainfall event caused slightly higher peak flood levels at both gauges, by approximately 0.3m.

Only the first rainfall event was used as a validation event. This is due to a number of modelling constraints which would make it unreasonable to run the entire double peaked event.

One of the modelling constraints is the excessive model run times required for a continuous simulation of what would be a 12 day event. As the Camden Haven catchment is large, the simulation of a single multi day event involves significant run times.

To get around this issue, each event could be simulated separately. However, this approach comes with its own issues. As observed in **Plate 4-8**, the flood levels do not return to base levels in between the two events. This is because some areas of the catchment experienced rainfall over the 25th and 26th February 2013.

As the system does not return to normal, many assumptions would have to be drawn throughout the catchment to incorporate accurate base flows to model an accurate representation of the weather event. These assumptions would involve the recharge of loss rates across the catchment, which are difficult to uniformly predict over such a varied catchment such as the Camden Haven River.

Accordingly, the first rainfall event which extended from 21st February and 26th February 2013, was adopted as the validation event for the TUFLOW model.

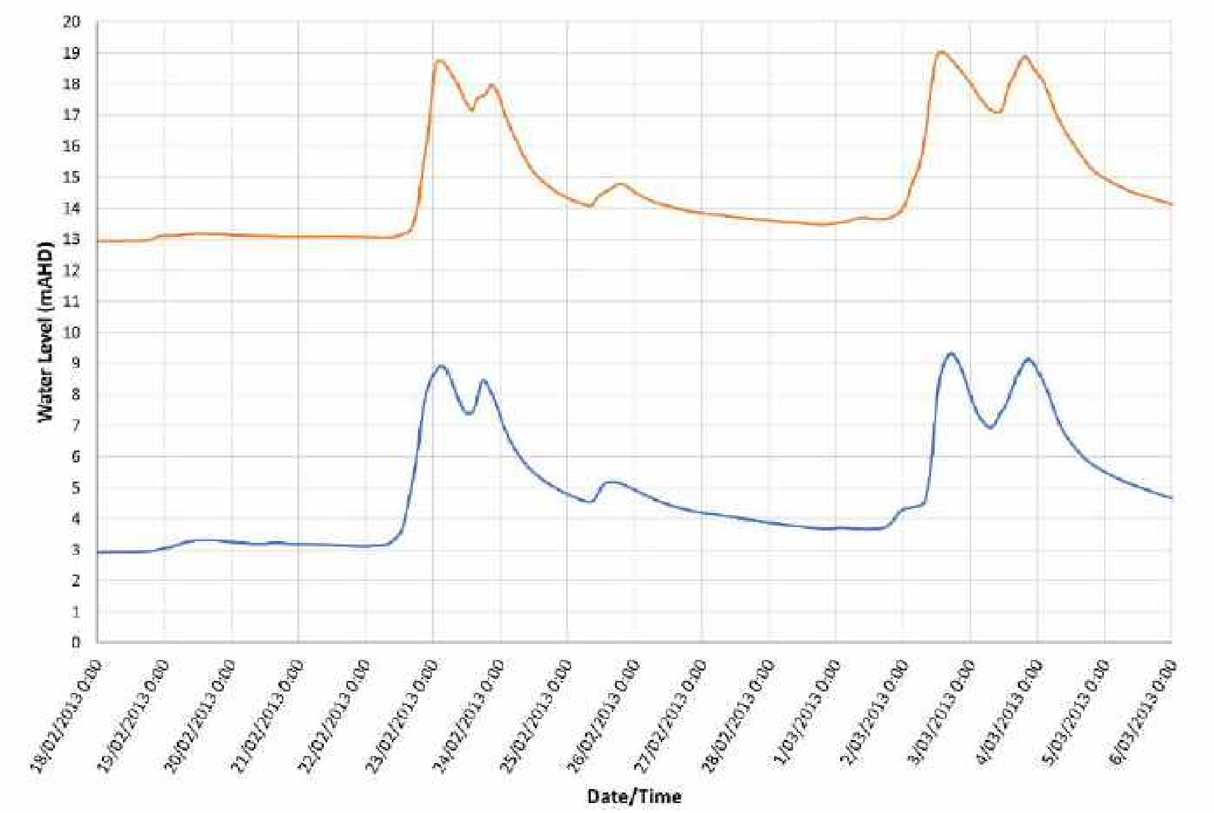


Plate 4-8 Recorded water level data for the Camden Haven River and Lakes System for the February-March 2013 events

4.4.2 Recorded Data

Rainfall Data

A cumulative rainfall plot of recorded rainfall data from within, or in close proximity to, the Camden Haven River catchment for the period from 00:00 on 21st February 2013 to 00:00 on 26th February 2013 is presented in **Plate 4-9**. These gauges are listed in **Table 4-4** and the locations are shown in **Figure 4-8**.

The recorded rainfall data in **Plate 4-8** highlights the variability in rainfall totals across the catchment, with lower rainfall totals recorded in the coastal regions. The Comboyne gauge recorded the second highest total in the Camden Haven region, reporting 325 mm of rainfall in a 24 hour period. This equates to a 5% AEP event. That is, a storm with an average recurrence of 20 years.

Table 4-4 Rainfall Gauges in the Camden Haven Catchment for the February 2013 Event

Gauge No.	Description / Location	Gauge Type	Period of Operation
60161	Comboyne Public School	Pluviometer	August 2012 – Present
560012	Redoak (Stewarts River)	Pluviometer	
560017	Logans Crossing	Pluviometer	October 1989 – Present
560018	Laurieton (Mill St)	Pluviometer	
560019	Lake Cathie	Pluviometer	

560021	Kerewong (Broken Bago)	Pluviometer

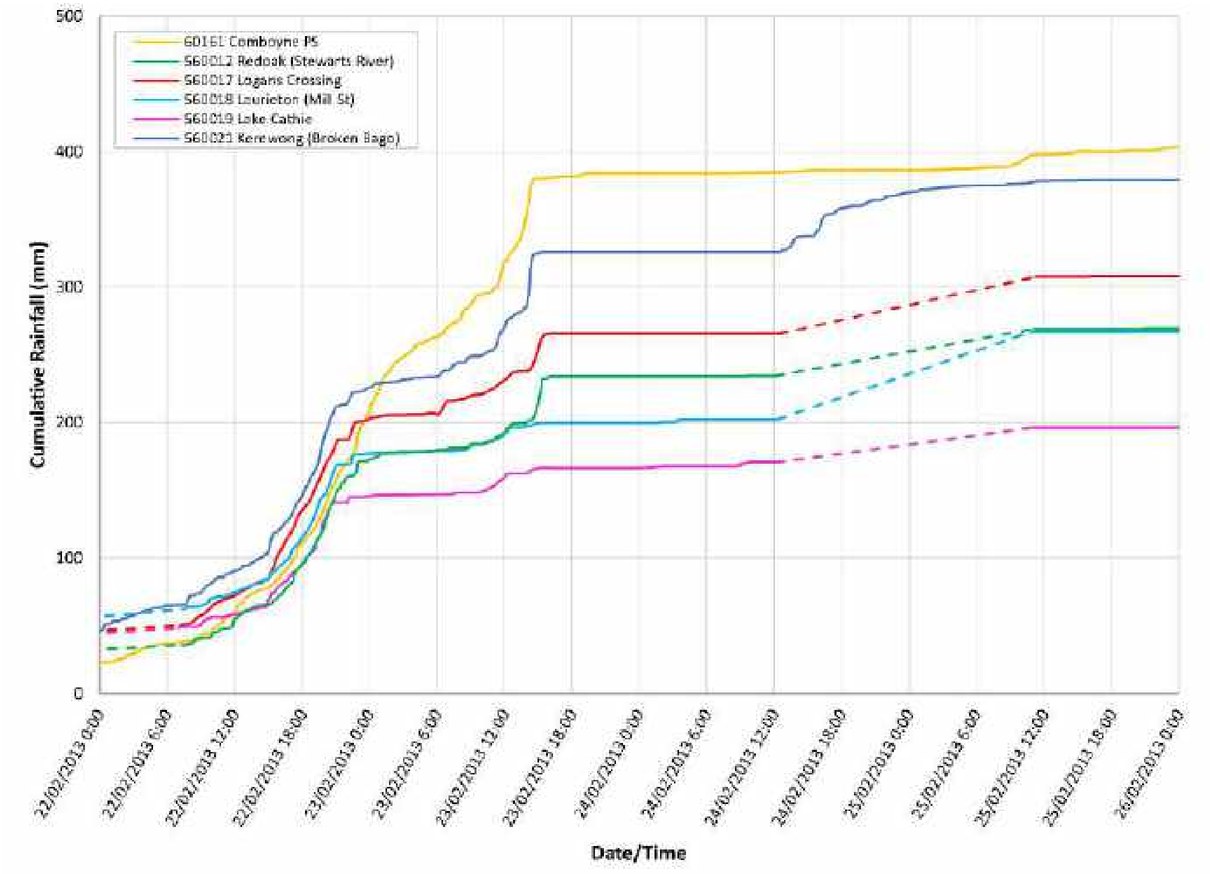


Plate 4-9 Recorded rainfall data for February 2013 event

River Level Data

River level data recorded during the February 2013 flood is presented in **Plate 4-10** for the Logans Crossing gauge along the Camden Haven River and the Stewarts River gauge (refer **Table 4-5**). Although other gauges were operational during the event, these are located outside of the TUFLOW model domain and as such are not relevant for calibration of the model. The location of the gauges is presented in **Figure 4-8**.

Table 4-5 Water Level Gauges in the Camden Haven Catchment

Gauge No.	Description / Location	Period of Operation
207008	Stewarts at Stewarts River	July 1969 - Present
207480	Watson Taylors Lake	December 2001 - Present
560010	Upsalls Creek	
560017	Logans Crossing (Camden Haven River)	August 1979 - Present
560018	Laurieton (Mill St)	August 1990 - Present
560025	Lorne Bridge	
560047	Stingray Creek at West Haven	October 1986 - Present

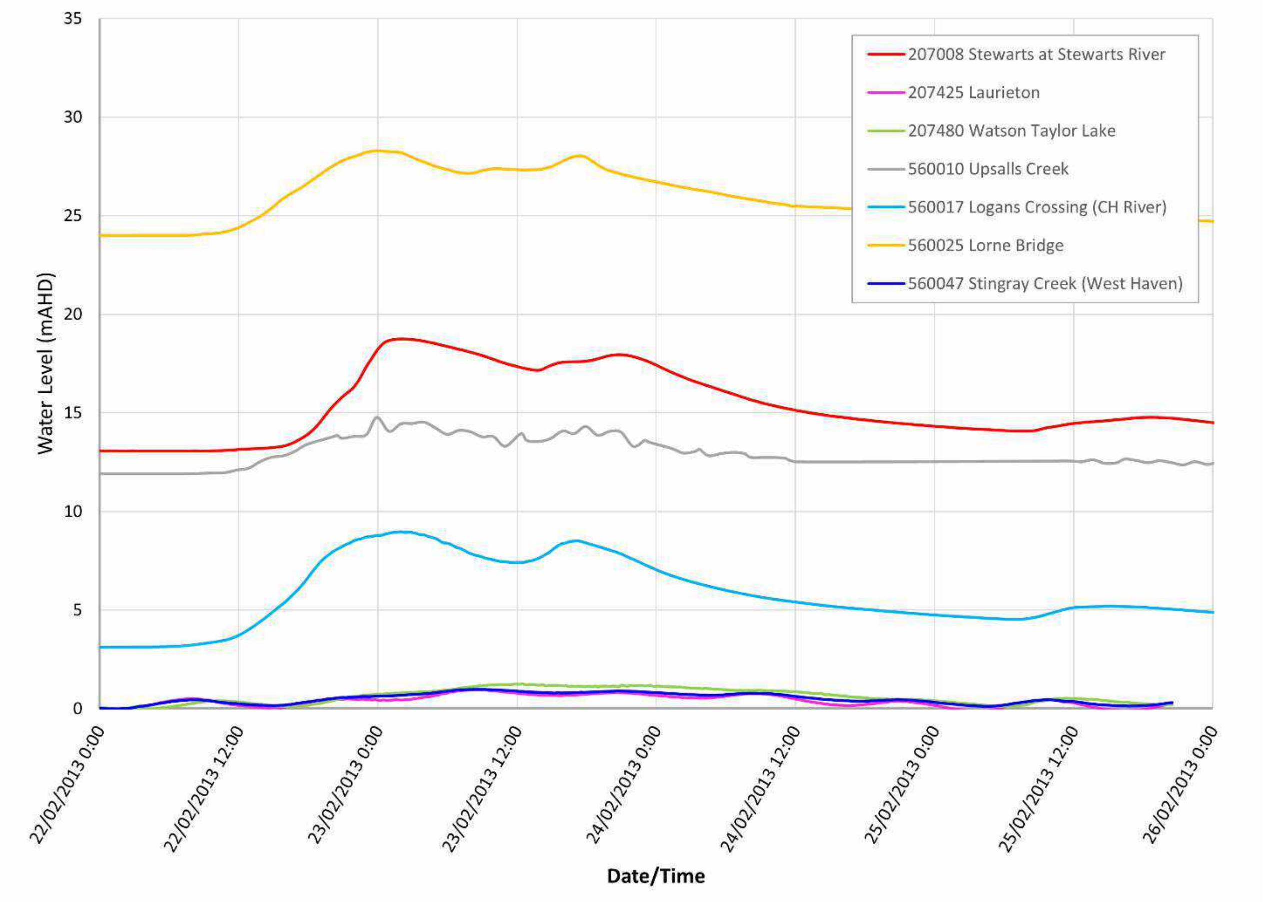


Plate 4-10 Recorded water level data for the Camden Haven River and Lakes System for the February 2013 Event

4.4.3 Camden Haven WBNM Model Validation

The rainfall data that was used as part of the WBNM model validation to the February 2013 event includes data from the following gauges:

- 60161 Comboyne Public School - *Pluviometer*
- 560012 Redoak (Stewarts River) – *Pluviometer*
- 560017 Logans Crossing – *Pluviometer*
- 560018 Laurieton (Mill St) - *Pluviometer*
- 560019 Lake Cathie - *Pluviometer*
- 560021 Kerewong (Broken Bago) - *Pluviometer*

A cumulative rainfall plot of the rainfall data from these gauges for the period from 00:00 on 21st February 2013 to 00:00 on 26th February 2013 is presented in **Plate 4-9**. The locations of these gauges are shown in **Figure 4-8**.

Inspection of the recorded rainfall data from each of the rainfall gauges indicates that there are periods of missing data all but two of the records over the duration of the event. As shown by the dashed lines in **Plate 4-9**, these "gaps" in the data occurred from 18:00 on 18th February to 07:00 on 22nd February and from 12:00 on 24th February to 11:00 on 25th February. Temporal patterns from the Comboyne Public School (60161) or Kerewong (560021) gauge records were adopted to generate a reliable representation of the likely rainfall patterns at these gauges over these periods. Testing of multiple combinations was undertaken to obtain a representative rainfall distribution over the duration of the event.

The validation of the WBNM hydrologic model was completed in unison with validation of the TUFLOW hydraulic model to overcome the issues identified with the rating curve adopted for the Logans Crossing gauge. As such, the WBNM runoff hydrographs were applied to the TUFLOW model to allow a comparison between predicted and recorded water levels.

The WBNM model parameters determined from calibration to the March 2021 event were used as part of the process of validating the model to the 2013 event. Various initial and continuing loss rates were tested throughout the process. Initially, the same loss values adopted for the March 2021 calibration event were adopted. However, it was noted that flood levels at the Logans Crossing gauge (207485) were marginally high. Accordingly, a variety of continuing loss values were simulated to find a value that generated the best fit for the validation simulations.

The final values adopted were – initial loss of 10 mm and a continual loss of 2 mm/hr. This initial loss rate aligns with the values adopted for the XP-RAFTS model that was developed for the 2013 Flood Study. The continuing loss rate is slightly higher than the 1mm/hr used for the 2021 calibration and in the 2013 Flood Study.

Graphs comparing discharge hydrographs generated by WBNM for the February 2013 event to those recorded at the Logans Crossing (Camden Haven River) (560017) and Stewarts at Stewarts River (207008) gauges are shown in **Figure A-3** and **Figure A-4** of **Appendix A**.

As previously mentioned in **Section 4.3.3**, the rating curve for the Logans Crossing gauge is considered to be unreliable and generates flows that are too low, particularly at higher flood levels. Validation of the WBNM flows was therefore focused on replicating the timing and shape of the hydrograph, rather than the magnitude of the peak flow.

As shown in **Figure A-3**, the WBNM model generates a flow hydrograph at the Logans Crossing gauge that matches the shape and timing very well. The predicted hydrograph replicates the double peak well with the timing of the highest peak matched to within 2 hours. The second peak is replicated by the WBNM model roughly 3 hours behind.

Figure A-4 shows the comparison between the WBNM model and the flow hydrograph from the recorded water level data. As previously discussed, the rating curve at the Stewarts River gauge (207008) is considered unreliable at the flood levels observed during the 2013 and 2021 events. As such, the shape and timing of the hydrographs were the primary focus, rather than the magnitude. The records show that both peaks are simulated to be 4 hours earlier than recorded. The catchment area at this gauge would largely be represented by the rainfall records at Redoak (560012) which shows heavy rainfall falling from midday on 22nd February, slowing into the evening and stopping by 10pm. This aligns with the hydrograph produced by the WBNM model. In reality, a moving cell would vary the timing of rainfall across the catchment, delaying the peak and potentially impacting the magnitude. However, there is no evidence to support this concept.

Unfortunately, there is a lack of stream flow gauges in the upper reaches of the study area, or along the smaller tributaries including Black, Herons, Savilles and Upsalls Creeks, to allow a comprehensive WBNM model validation to be completed.

4.4.4 Camden Haven TUFLOW Hydraulic Model Validation

To validate the TUFLOW hydraulic model to the February 2013 event, the WBNM inflow hydrographs were applied across the TUFLOW model domain and relevant downstream water level boundaries were incorporated. The recorded water levels were then compared to the Logans Crossing gauge (207485) in the same manner as was undertaken for the calibration to the March 2021 event. Additional water level records in the upper catchment at Lorne Bridge (560025) and along the tributary Upsalls Creek (560010) provide additional locations for validation. It is understood that there are no available flood marks within the TUFLOW model extent that can be used to further validate the model.

Water level data for the February 2013 event as recorded at the Watson Taylor gauge (207480) was applied at the downstream boundary of the Camden Haven River. Water level records at West Haven (207437) were applied to the Queens Lake boundary at the base of Herons Creek.

Peak flood levels for the February 2013 flood event are mapped on **Figure 4-9** for the TUFLOW model domain.

A comparison between the recorded flood level hydrograph at Logans Crossing and that predicted by TUFLOW is shown in **Figure C-3** of **Appendix C**. As discussed in **Section 4.4.3**, the TUFLOW model predicts flood levels at the gauge that are within 0.02 metres and 0.15 metres of those recorded at the first and second flood peaks. The timing of both peaks are slightly out, with the first peak arriving 2 hours early, and the second peak around 2 hours late. However, the shape is in good agreement, including the rising limb.

Additional water level records in the upper catchment allow further validation of the TUFLOW model with the WBNM inflow hydrographs. **Figure C-6** shows a comparison of flood levels at the Lorne Bridge gauge (560025), in the upper regions of the Camden Haven River. This shows that the TUFLOW model predicts flood levels at the gauge to within 0.06 metres and 0.50 metres to those recorded at the first and second flood peaks. The shape and timing of the first peak is in good agreement with the recorded data, including the rising limb. The second peak is larger, with a steeper peak and quicker falling limb.

A comparison of recorded and simulated flood levels at the Upsalls Creek gauge (560010) is presented in **Figure C-7**. This shows no resemblance between the recorded and simulated levels, in both magnitude and shape. Through considerable modelling and adjustment to model parameters it was concluded that the recorded data was potentially erroneous and was investigated further.

Further analysis of the results shows that the shape of simulated water levels at both the Lorne Bridge and Upsalls Creek gauges are very similar (refer **Figure C-6** and **Figure C-7**). This is consistent with the March 2021 calibration event modelling (refer **Figure C-3** and **Figure C-4**). This consistency in shape aligns with the applied rainfall, as the catchment areas of each gauge would have a similar applied rainfall as rainfall gauges are lacking in the western regions of the Camden Haven catchment (refer **Figure 4-8**). As the recorded data presents alternative water level patterns (refer **Plate 4-10**), the reliability of the recorded data is questioned.

The "jagged" shape of the record at this gauge for the February 2013 event provides further support to the view that the gauge record is unreliable. The raw data also states that several records before, during and after this event are to be voided. Accordingly, it appears that the water level gauge at Upsalls Creek (560010) failed to capture accurate or reliable data during the event.

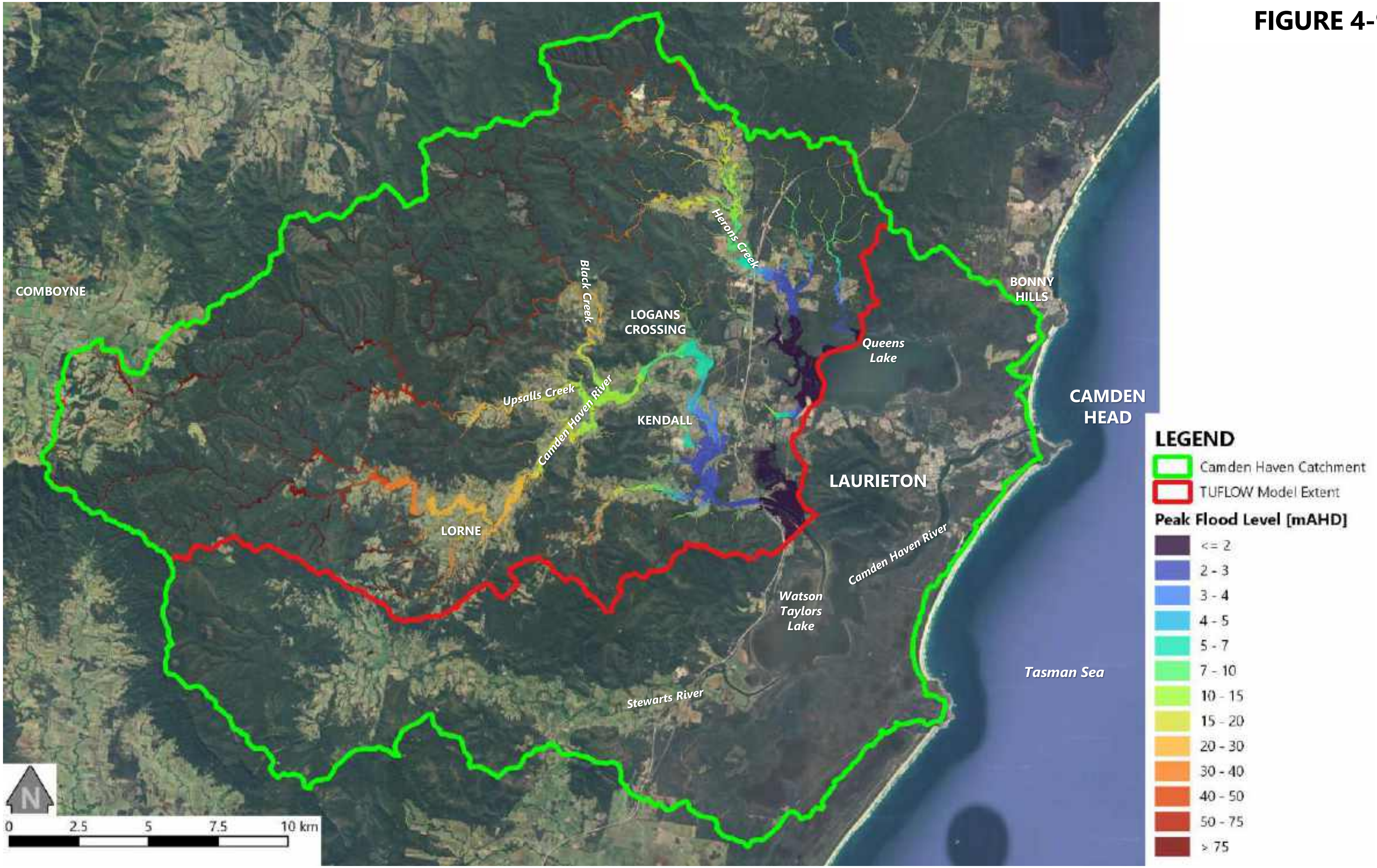
FIGURE 4-8

Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs
fg311015-00481_250205_CamdenHaven_A4L_P2.pdf

FEBRUARY 2013 CALIBRATION EVENT
LOCATION OF GAUGES

FIGURE 4-9



Prepared by:

PORT MACQUARIE HASTINGS

worley consulting

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250205_CamdenHaven_A4L_P2.pdf

TUFLOW MODELLED PEAK LEVELS FOR THE FEBRUARY 2013 FLOOD

[STUDY AREA OVERVIEW]

5. Calibration Summary

Calibration and validation of the WBNM hydrologic model and the RMA-2 and TUFLOW hydraulic flood models has been undertaken to the March 2021 and February 2013 events, respectively. The findings from this work are summarised in the following.

(i) March 2021 flow hydrographs predicted by the WBNM model are shown on **Figure A-1** and **A-2** for the Logans Crossing (Camden Haven River) and Stewarts at Stewarts River gauges. The recorded flow hydrographs are superimposed to allow comparison against the predicted flows. Difficulties replicating the recorded flow hydrographs led to investigation of the rating curves relied upon to generate flows from recorded water levels. As discussed in **Section 4.3.3**, the adopted rating curves are considered unreliable and result in flows being underpredicted at the two gauges. As a result of the rating curve issues, the WBNM hydrographs were instead validated by simulating them through the RMA-2 and TUFLOW models to allow a comparison between simulated and recorded water levels.

(ii) Simulation of the 2021 WBNM flows through the 2013 RMA-2 flood model enabled a comparison between predicted and recorded flood levels at available water level gauges and to recorded flood marks. Plots showing predicted and recorded flood level hydrographs are included in **Appendix B** for the following gauges:

- **Figure B-1** for the Logans Crossing (Camden Haven River) Gauge (*560017*)
- **Figure B-2** for the Watson Taylors Lake at Watson Taylors Lake Gauge (*207480*)
- **Figure B-3** for the Queens Lake at Lakewood Gauge (*207475*)
- **Figure B-4** for the Stingray Creek at West Haven Gauge (*207437*)
- **Figure B-5** for the Camden Haven at North Haven Gauge (*207423*)

Figures B-1 to **B-5** show that the 2013 RMA-2 model coupled with flows generated by the WBNM model, is able to produce flood level hydrographs that are a good fit to recorded water levels at each of the gauge locations. The following conclusions are drawn from **Figures B-1** to **B-5**.

(a) The shape and timing of the peak for all of the flood level hydrographs is well replicated by the RMA-2 model.

(b) Differences in peak levels are generally within 0.1 to 0.2 metres.

(iii) The RMA-2 flood model was found to predict flood levels for the March 2021 event that compare well to the recorded flood marks at the majority of locations, particularly around Laurieton and North Haven (refer **Figure 4-4**). Around Kendall and Logans Crossing, the RMA-2 model was able to predict flood levels for the March 2021 event that were within 0.19 metres for three (3) of the six (6) flood marks (refer **Figure 4-3**).

(iv) A comparison of the flood level hydrograph predicted by the TUFLOW model to recorded levels at the Logans Crossing (Camden Haven River) Gauge (*560017*) is presented in **Figure C-1** of **Appendix C**. **Figure C-1** indicates that the TUFLOW model was able to predict the peak water level at the gauge to within 0.01 metres. The difference in the flow hydrographs depicted in **Figure A-1** served to confirm the issues with the rating curve for this gauge which suggests the WBNM flows simulated via the TUFLOW model were significantly higher than recorded (*peak flow of 1485 m^3/s predicted versus 565 m^3/s based on the gauge rating curve and recorded water levels*).

The TUFLOW model predicts peak flood levels for the March 2021 event that are typically within +/- 0.20 metres of the recorded flood marks; including to within 0.05 metres along Herons Creek (refer **Figure 4-7**). The calibration had mixed results along the Camden Haven River between Logans Crossing and Watson Taylors Lake. As shown in **Figure 4-6**, of the six (6) flood marks available, the TUFLOW model predicted flood levels that were within +/- 0.20 metres for three (3) of them.

(v) The WBNM and TUFLOW models were also validated against recorded data from the February 2013 event. The validation found that simulation of the WBNM flows through the TUFLOW model generated level hydrographs at the Logans Crossing gauge that are a good fit in terms of shape and peak flood levels. As shown in **Figure C-5**, the TUFLOW model predicts flood levels that are within 0.06 metres at the peak, and within 0.15 metres of the second and smaller peak.

The calibration and validation of the WBNM hydrologic model and the TUFLOW and 2013 RMA-2 flood models shows that all tools can be used to generate flows and flood levels that are an acceptable fit to the available data for the March 2021 and February 2013 events. Notwithstanding, calibration of the models would have benefited from a greater spread of recorded data, particularly in areas upstream of Logans Crossing.

The lack of rainfall gauges in the Black Creek catchment is a weakness that will make it difficult to reliably validate the WBNM model to future events. It is recommended that an additional pluviometer be installed to better understand the spatial and temporal distribution of rainfall across this section of the catchment.

Notwithstanding, based on the calibration/validation that has been possible and which is documented in this report, the WBNM and TUFLOW models are considered suitable to progress to Stage 3 of the project which involves the simulation of design events.

6. Design Flood Estimation

6.1 Overview

Design flood conditions are estimated from hypothetical design rainfall events that have a particular statistical probability of occurrence. The assessment of design flood conditions presented in this report has been based on the guidance and techniques outlined in *Australian Rainfall and Runoff: A Guide to Flood Estimation* (*Geoscience Australia 2019*) (*ARR 2019*).

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 5%, 2%, 1%, 1 in 200, 1 in 500 and 1 in 2000 AEP design events have been investigated in this study along with the Probable Maximum Flood (PMF).

It is important to note that the adoption of ARR 2019 is new for the Camden Haven River and Lakes catchment with previous catchment wide flood studies having been based on Australian Rainfall and Runoff 1987 (ARR 1987). These studies include:

- 'Camden Haven River and Lakes System Flood Study' (July 2013)

In addition to ARR 2019, this study varies to those above based on:

- Inclusion of the 1 in 500 and 1 in 2000 AEP design events.
- Extension of the modelling domain to model the Camden Haven River upstream of Logans Crossing and Herons Creek upstream of the Pacific Highway (*refer* **Section 3.3.2**).

An important component of the ARR 2019 guidelines is the recommendation that design event flood hydrology be based on observed data and Flood Frequency Analysis (FFA) where possible and available.

6.2 Flood Frequency Analysis

Flood Frequency Analysis (FFA) enables the magnitude of floods of a selected probability of exceedance to be estimated by statistical analysis of recorded floods. This had previously been completed as part of the 2013 flood study for gauge records at Logans Crossing gauge at Kendall (560017). This was completed from annual peak discharge records from 1970 to 2013, including the moderate to major flood event in March 2013 used for model validation.

The FFA was not updated as a part of this study, and to be revisited at a later date. Accordingly. the 2013 FFA has been adopted for design event estimation. The 2013 FFA results are summarised in **Table 6-1.**

A level was not able to be derived for the 1 in 200 AEP event as the flow was above the upper limit of the defined rating curve. Extrapolation of the curve would likely result in a level between 11.05 and 11.1 mAHD for a 1 in 200 AEP event.

Table 6-1 Summary of Flood Frequency Analysis from 2013 Flood Study

Design Event	Flood Frequency Analysis (2013 FS)	
	Flow (m^3/s)	Level (mAHD)
5% AEP	1184	10.22
2% AEP	1379	10.62
1% AEP	1530	10.91
1 in 200 AEP	1685	-

6.3 Design Rainfall

6.3.1 Design Rainfall Depths

Design rainfall depths for the 5% AEP to 1 in 2000 AEP design events were obtained online from the Australian Rainfall and Runoff Data Hub. As discussed in the following section, Intensity-Frequency-Duration (IFD) data was sampled from eight (8) locations was used to resolve spatial variation in design rainfall depths across the catchment.

6.3.2 Design Rainfall Spatial Pattern

As discussed in Book 2, Chapter 6 of ARR 2019, it is recommended that spatial variation be adopted across the catchment. For the Camden Haven catchment of 710 km^2, it is suggested that AEP events more frequent than the 1% AEP event be distributed based on IFD grids of the relevant duration and AEP. For rarer events, with a duration of 6 hours or less, spatial variability be derived in accordance with Woolhiser (1992), or with a duration of 9 hours or greater spatial variability be based on the Topographic Adjustment Factor (TAF) of the generalised PMP method relevant for the location of the catchment.

To satisfy the above methods of spatial variability, gridded IFD data and the TAF for both GSAM and GTSMR PMP calculations were reviewed to assess the variation in design rainfall across the catchment. Based on an agreement in spatial variation between the two methods, variation by IFD grid was adopted as it was considered that the use of IFD data from eight (8) locations across the catchment.

6.3.3 Design Rainfall Temporal Patterns

To estimate a design flood hydrograph a temporal pattern must be applied to the design rainfall depths to describe how rain falls over time. Traditionally a single burst temporal pattern has been applied for each design rainfall event and duration; however, this approach has been questioned as a wide variety of temporal patterns is possible.

The ARR 2019 guidelines now recommend that 'ensembles' of 10 temporal rainfall patterns that have been derived to represent variability in observed patterns be analysed for each design storm magnitude and duration.

ARR 2019 states that the 10 patterns within an ensemble provide a range of plausible answers, with testing demonstrating that peak flows for a number of the patterns tend to cluster around the mean for most catchments. For the purposes of selecting a single representative design rainfall pattern, the average of the 10 resulting peak flows is taken to be the actual peak design flood flow at a given location, and the temporal pattern resulting in a peak flow nearest to (but not more than 5% less than) this average would typically be adopted to determine the design flood hydrograph.

6.3.4 Rainfall Losses

The term 'rainfall losses' refers to precipitation that does not contribute to direct runoff. During a storm such losses occur primarily due to the processes of interception by vegetation, and infiltration into the soil. The initial loss-continuing loss (IL-CL) approach is typically used in Australia to account for losses in the rainfall-runoff process and has been adopted in this study.

Initial losses for pervious surfaces adopted in this study are in line with the approach documented in NSW specific advice provided by NSW Department of Climate Change, Energy the Environment and Water (NSW DCCEEW). This approach adjusts the average calibration losses (20mm) with the Probability Neutral Burst Initial Losses (PNBIL). This results in a variable initial loss depending on AEP and duration of storm.

The adopted continuing loss rate of 1.0 mm/hr was adopted which aligned with the value adopted for the March 2021 calibration and which resulted in a good fit to the FFA prepared in the 2013 Flood Study (refer **Section 6.2**).

For the PMF, initial and continuing loss rates of 0 mm and 1 mm/hr were adopted in accordance with guidance outlined in Book 8 Chapter 6 of ARR 2019.

6.3.5 Assessment of Critical Storm Duration and Temporal Patterns

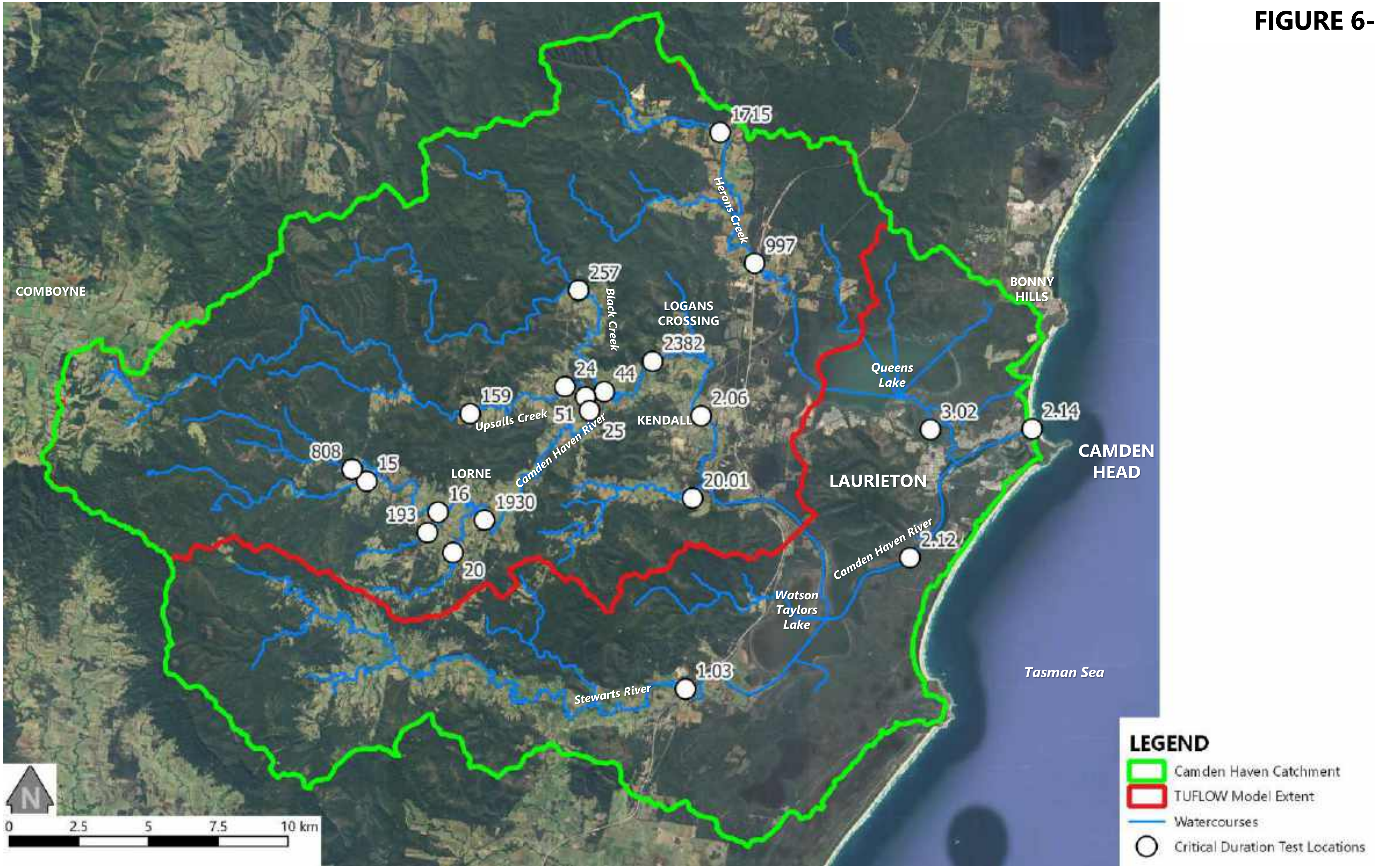
Critical storm duration refers to the duration of design storm that will result in the highest peak flood flows or levels at a particular location. The critical duration is influenced by various factors including upstream catchment area and may vary between locations of interest throughout a catchment or study area. With the introduction of ARR 2019 a representative temporal pattern must also be identified which produces a peak flow closest to but not less than the design peak flow (*that being the average of peak flows from an ensemble set of 10 temporal patterns*).

For the purposes of this study, definition of design flood conditions is required at various locations of interest which have varying catchment sizes and properties (e.g. slope, degree of urbanisation, stream type and size etc.), and therefore may have varying critical storm durations and applicable temporal rainfall patterns.

Given the run time of the developed RMA-2 and TUFLOW hydraulic models, it is not practical to simulate multiple temporal patterns for multiple durations for each design flood (i.e. AEP). A more practical approach was thus adopted, as follows:

- The WBNM hydrologic model was used to determine critical storm durations, associated temporal patterns and average peak design flows at 35 assessment locations as shown in **Figure 6-1**. This shows the location and catchment number of each comparison point. Location descriptions for each catchment number is included in **Table 6-3**.

FIGURE 6-1



Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs
fg311015-00481_250205_CamdenHaven_A4L_P3.pdf

CRITICAL DURATION AND TEMPORAL PATTERN ASSESSMENT LOCATION

- From this a number of critical storm durations and associated temporal patterns of interest were identified for further investigation for each flood magnitude.
- From the investigated storms, two durations were selected for each flood magnitude that in combination provided the overall best match to 'average peak design flows' across the assessment locations.

A summary of the selected critical storm durations and temporal patterns for each design event are presented in **Table 6-2**.

Table 6-2 Critical design storm durations and selected representative temporal patterns

Design Event	Selected critical storm durations and representative temporal patterns		
	Critical Duration (min)	Pattern Set	'Average' Pattern No.
5% AEP	360	East Coast South – Intermediate	4660
	720	East Coast South - 500 km^2	28
2% AEP	270	East Coast South - rare	4620
	720	East Coast South - 500 km^2	28
1% AEP	180	East Coast South - rare	4653
	720	East Coast South - 500 km^2	28
1 in 200 AEP	180	East Coast South - rare	4653
	720	East Coast South - 500 km^2	28
1 in 500 AEP	180	East Coast South - rare	4653
	720	East Coast South - 500 km^2	28
	1440	East Coast South - 500 km^2	203
1 in 2000 AEP	180	East Coast South - rare	4653
	720	East Coast South - 500 km^2	28
	1440	East Coast South - 500 km^2	203
PMF	360	Temporal Pattern for GSDM from '*The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method*' (BoM, 2003)	

A comparison of peak design flood flows from the selected storm duration and temporal pattern combinations above with the average peak flow from the temporal pattern ensemble at each site are presented for the 5% AEP to 1 in 2000 AEP design events in **Table 6-3** to **Table 6-8**. The results presented are based on a 'no blockages' scenario.

Resulting peak flood flows are generally comparable to the averaged peak flood flows, within a range of percentage difference that is typical of the ARR 2019 temporal pattern ensemble approach (i.e. 5 to 10%). It is considered that the selected storm durations and temporal patterns are the most suitable of those available to provide an appropriate balance of peak design flood flows across all assessment locations, and therefore that the selected design rainfall hyetographs and parameters are appropriate for determining design flood hydrographs for the study catchments.

There was a focus to include a longer duration event to account for the significant volume of flood storage that exists in the lower reaches of the study area. These larges storages have the potential to absorb a significant portion of a short duration event leading to lower peak flood levels. Longer duration storms also typically result in higher flows for large catchment due to the closer relative timing between main channel and tributary flows.

As with a comparison with 35 locations, there is never a complete agreement, and the aim of the critical duration analysis is to determine the most appropriate duration and temporal pattern to demonstrate the average peak flow.

It is considered that the selected storm durations and temporal patterns are the most suitable of those available to simulate an appropriate balance of peak design flood flows across all assessment locations. The selected design rainfall hyetographs and parameters are therefore considered appropriate for determining design flood hydrographs for the study catchments.

6.3.6 Probable Maximum Precipitation (PMP)

The Probable Maximum Precipitation (PMP), as used to determine the Probable Maximum Flood (PMF), was derived using the methods outlined in in ARR 2019. The Camden Haven River Catchment is located within the "GSAM-GTSMR Coastal Transition Zone". Both the Generalised Southeast Australia Method (GSAM) and Generalised Tropical Storm Method Revised (GTSMR) therefore apply as potential PMP calculation methods for the region. Based on the catchment size, the Generalised Short-Duration Method (GSDM) for shorter durations is also a possibility for PMF estimation. The 2013 flood study conducted PMP/PMF modelling and concluded that a 6hr GSDM PMP storm created a higher peak flow throughout most of the catchment.

The WBNM was used to run all variations of PMP calculation methods, and confirmed the 6hr GSDM PMP calculation resulted in peak flows across the catchment. However, the peak flows reported by the WBNM model varied significantly from those calculated by the 2013 XP-RAFTS model. After heavily scrutinizing both models, the root cause of the variation was determined to be the lag times within the XP-RAFTS model. These lag times had been developed through calibration, and were underestimating the velocity of flow in larger events such as the PMF with an average velocity of 0.6 m/s. At the time of development, it did not have the benefit of TUFLOW results/velocities on which to validate the adopted lag times. By updating the lag times with more appropriate velocities derived from the TUFLOW model of 2.5m/s in the steep areas, and 2.0m/s along the floodplain, the XP-RAFTS model was able to reproduce similar curves to that of the WBNM model. As such, the larger flow modelled by the WBNM model was validated and adopted.

Loss rates for the PMF simulations were adopted in accordance with guidelines outlined in Book 8, Chapter 4 of ARR 2019. This describes an initial loss and continuing loss rates of 0 mm and 1 mm/hr, respectively, were suitable values to adopt for a rural catchment such as the Camden Haven River catchment.

Location	WBNM Subarea	Upstream Catchment Area (km²)	All Durations, All Patterns: Critical Duration (min)	Averaged Peak Flow (m^3/s)	'Average' Temporal Pattern No.	Patt. Peak Flow (m^3/s)	% Difference (Patt. - Avg) /Avg	Selected Durations and Patterns (5% AEP 360min TP 4660 + 5% AEP 720min TP28): Duration (min)	Pattern No.	Patt. Peak Flow (m^3/s)	% Difference (Patt. - Avg)/Avg
Stewarts River	1	156	720	479	28	493.4	3.1%	720	28	493	3.1%
Kendall	2	238	720	1136	26	1140.4	0.4%	720	28	1180.2	3.9%
Watson Taylor Lake Outlet	2	550	1080	1825	118	1835.6	0.6%	360	4660	1748.4	-4.2%
Outlet	2	710	1080	2394	114	2438.4	1.9%	360	4660	2290.6	-4.3%
Queens Lake Outlet	3	139	720	682	28	708.4	3.8%	720	28	708.4	3.8%
CHR befoer Mcleods Ck	15	36	360	224	4660	224.4	0.3%	360	4660	224.4	0.3%
Lorne Bridge Gauge	16	64	360	369	4672	364.4	-1.2%	720	28	365.5	-0.9%
Savilles Ck	20	7	180	64	4663	64.7	0.7%	360	4660	66.4	3.4%
Batar Ck	20	17	180	141	4667	141.9	0.6%	360	4660	147.6	4.7%
Upsalls Ck Gauge	24	62	720	317	28	324.8	2.5%	720	28	324.8	2.5%
CHR before Upsalls Ck	25	94	720	468	29	466.8	-0.2%	720	28	494.0	5.7%
Black Ck Outlet	44	60	360	321	4660	322.5	0.3%	720	28	328.7	2.3%
Upsalls Ck Outlet	51	67	720	333	28	339.8	2.0%	720	28	339.8	2.0%
Upper Upsalls Ck	159	53	720	287	28	297.9	3.6%	720	28	297.9	3.6%
Gills Ck	193	4	180	36	4663	36.3	1.5%	360	4660	37.0	3.6%
Upper Black Ck	257	51	360	302	4726	298.0	-1.3%	360	4660	293.4	-2.9%
Mcleods Ck	808	14	180	104	4663	105.8	1.4%	360	4660	112.2	7.4%
Herons Creek Pacific Hwy	997	55	360	369	4672	379.5	2.8%	360	4660	386.8	4.8%
Upper Herons Ck	1715	22	180	185	4668	185.9	0.3%	360	4660	193.6	4.4%
Mid CHR	1930	76	360	417	4660	410.4	-1.5%	720	28	425.1	2.0%
Logans Crossing Gauge	2382	226	720	1123	29	1120.2	-0.2%	720	28	1169.2	4.2%

Location	WBNM Subarea	Upstream Catchment Area (km²)	All Durations, All Patterns: Critical Duration (min)	Averaged Peak Flow (m³/s)	'Average' Temporal Pattern No.	Patt. Peak Flow (m³/s)	% Difference (Patt. - Avg) /Avg	Selected Durations and Patterns (2% AEP 270min TP 4620 + 2% AEP 720min TP28): Duration (min)	Pattern No.	Patt. Peak Flow (m³/s)	% Difference (Patt. - Avg)/Avg
Stewarts River	1	156	720	595	28	612.1	2.9%	720	28	612	2.9%
Kendall	2	238	720	1405	29	1409.8	0.3%	720	28	1463.6	4.2%
Watson Taylor Lake Outlet	2	550	1080	2253	112	2250.0	-0.1%	720	28	2221.7	-1.4%
Outlet	2	710	1080	2958	114	2998.3	1.4%	720	28	2931.6	-0.9%
Queens Lake Outlet	3	139	540	860	4745	880.6	2.4%	720	28	878.0	2.1%
CHR befoer Mcleods Ck	15	36	360	264	4406	274.0	3.7%	270	4620	272.2	3.1%
Lorne Bridge Gauge	16	64	360	442	4719	442.1	0.1%	270	4620	454.0	2.8%
Savilles Ck	20	7	120	78	4431	77.2	-1.4%	270	4620	77.4	-1.2%
Batar Ck	20	17	180	168	4648	163.8	-2.6%	270	4620	170.1	1.1%
Upsalls Ck Gauge	24	62	720	390	28	401.5	2.9%	720	28	401.5	2.9%
CHR before Upsalls Ck	25	94	720	577	29	573.3	-0.6%	720	28	610.4	5.8%
Black Ck Outlet	44	60	360	391	4406	395.8	1.3%	720	28	405.1	3.6%
Upsalls Ck Outlet	51	67	720	411	28	420.9	2.4%	720	28	420.9	2.4%
Upper Upsalls Ck	159	53	720	353	28	365.3	3.6%	720	28	365.3	3.6%
Gills Ck	193	4	120	44	4499	43.3	-1.3%	270	4620	43.5	-0.8%
Upper Black Ck	257	51	360	365	4719	377.0	3.2%	270	4620	378.3	3.6%
Mcleods Ck	808	14	180	125	4648	123.3	-1.6%	270	4620	131.3	4.7%
Herons Creek Pacific Hwy	997	55	180	442	4599	450.1	1.8%	270	4620	446.3	0.9%
Upper Herons Ck	1715	22	180	222	4599	232.3	4.8%	270	4620	213.1	-3.8%
Mid CHR	1930	76	360	506	4406	517.2	2.3%	720	28	519.9	2.8%
Logans Crossing Gauge	2382	226	720	1385	29	1378.1	-0.5%	720	28	1445.9	4.4%

TABLE 6-5

Location	WBNM Subarea	Upstream Catchment Area (km²)	All Durations, All Patterns: Critical Duration (min)	All Durations, All Patterns: Averaged Peak Flow (m³/s)	All Durations, All Patterns: 'Average' Temporal Pattern No.	All Durations, All Patterns: Patt. Peak Flow (m³/s)	All Durations, All Patterns: % Difference (Patt. - Avg) /Avg	Selected Durations and Patterns (1% AEP 180min TP 4653 + 1% AEP 720min TP28): Duration (min)	Selected Durations and Patterns: Pattern No.	Selected Durations and Patterns: Patt. Peak Flow (m³/s)	Selected Durations and Patterns: % Difference (Patt. - Avg)/Avg
Stewarts River	1	156	720	692	28	710.4	2.6%	720	28	710	2.6%
Kendall	2	238	720	1629	29	1631.1	0.1%	720	28	1699.4	4.3%
Watson Taylor Lake Outlet	2	550	720	2610	23	2613.4	0.1%	720	28	2635.4	1.0%
Outlet	2	710	720	3461	25	3460.7	0.0%	720	28	3500.3	1.1%
Queens Lake Outlet	3	139	540	1004	4745	1028.0	2.4%	720	28	1017.6	1.3%
CHR befoer Mcleods Ck	15	36	360	308	4720	317.8	3.2%	720	28	305.1	-0.9%
Lorne Bridge Gauge	16	64	360	516	4719	525.9	1.9%	720	28	514.0	-0.4%
Savilles Ck	20	7	120	93	4431	91.6	-1.5%	180	4653	95.4	2.6%
Batar Ck	20	17	180	199	4648	192.9	-3.1%	180	4653	213.9	7.4%
Upsalls Ck Gauge	24	62	720	451	28	464.9	3.0%	720	28	464.9	3.0%
CHR before Upsalls Ck	25	94	720	668	26	679.2	1.7%	720	28	707.3	5.9%
Black Ck Outlet	44	60	360	462	4406	466.1	0.9%	720	28	468.0	1.3%
Upsalls Ck Outlet	51	67	720	476	28	488.2	2.6%	720	28	488.2	2.6%
Upper Upsalls Ck	159	53	720	407	28	420.7	3.4%	720	28	420.7	3.4%
Gills Ck	193	4	120	52	4499	51.2	-1.3%	180	4653	53.0	2.1%
Upper Black Ck	257	51	360	429	4406	442.2	3.1%	180	4653	416.1	-3.0%
Mcleods Ck	808	14	180	147	4648	144.5	-1.8%	180	4653	158.2	7.4%
Herons Creek Pacific Hwy	997	55	180	533	4599	543.2	2.0%	180	4653	546.8	2.6%
Upper Herons Ck	1715	22	180	263	4599	275.0	4.5%	180	4653	279.8	6.3%
Mid CHR	1930	76	360	594	4719	589.3	-0.7%	720	28	598.2	0.8%
Logans Crossing Gauge	2382	226	720	1603	29	1591.5	-0.7%	720	28	1675.1	4.5%

TABLE 6-6

Location	WBNM Subarea	Upstream Catchment Area (km²)	All Durations, All Patterns					Selected Durations and Patterns 1in 200 AEP 180min TP 4653 + 1 in 200 AEP 720min TP28			
			Critical Duration (min)	Averaged Peak Flow (m³/s)	'Average' Temporal Pattern No.	Patt. Peak Flow (m³/s)	% Difference (Patt. - Avg) /Avg	Duration (min)	Pattern No.	Patt. Peak Flow (m³/s)	% Difference (Patt. - Avg)/Avg
Stewarts River	1	156	720	772	28	790.3	2.4%	720	28	790	2.4%
Kendall	2	238	720	1818	29	1818.1	0.0%	720	28	1900.2	4.5%
Watson Taylor Lake Outlet	2	550	720	2946	27	2939.5	-0.2%	720	28	2974.7	1.0%
Outlet	2	710	720	3910	25	3911.1	0.0%	720	28	3958.4	1.2%
Queens Lake Outlet	3	139	360	1132	4587	1131.1	-0.1%	720	28	1134.7	0.2%
CHR befoer Mcleods Ck	15	36	270	346	4685	346.1	-0.1%	720	28	340.6	-1.7%
Lorne Bridge Gauge	16	64	360	578	4719	595.2	3.0%	720	28	572.4	-1.0%
Savilles Ck	20	7	120	105	4431	103.0	-1.7%	180	4653	106.9	2.0%
Batar Ck	20	17	120	224	4431	224.0	-0.1%	180	4653	240.5	7.2%
Upsalls Ck Gauge	24	62	720	504	28	520.5	3.2%	720	28	520.5	3.2%
CHR before Upsalls Ck	25	94	720	745	27	758.6	1.9%	720	28	789.3	6.0%
Black Ck Outlet	44	60	360	519	4406	523.4	0.9%	720	28	521.3	0.5%
Upsalls Ck Outlet	51	67	720	532	28	547.0	2.9%	720	28	547.0	2.9%
Upper Upsalls Ck	159	53	720	454	28	469.5	3.4%	720	28	469.5	3.4%
Gills Ck	193	4	120	59	4499	57.9	-1.1%	180	4653	59.5	1.6%
Upper Black Ck	257	51	360	481	4406	495.4	3.0%	180	4653	472.5	-1.7%
Mcleods Ck	808	14	180	166	4648	163.0	-2.0%	180	4653	179.1	7.7%
Herons Creek Pacific Hwy	997	55	180	603	4599	615.7	2.1%	180	4653	619.9	2.8%
Upper Herons Ck	1715	22	120	297	4431	298.4	0.4%	180	4653	314.3	5.8%
Mid CHR	1930	76	360	666	4719	666.0	0.0%	720	28	665.2	-0.1%
Logans Crossing Gauge	2382	226	720	1789	29	1772.6	-0.9%	720	28	1870.4	4.6%

CRITICAL DURATION AND TEMPORAL PATTERN ASSESSMENT
1 IN 200 AEP

TABLE 6-7

Location	WBNM Subarea	Upstream Catchment Area (km^2)	All Durations, All Patterns					Selected Durations and Patterns 1in 500 AEP 180min TP 4653 + 1 in 500 AEP 720min TP28 + 1 in 500 AEP 1440min TP203			
			Critical Duration (min)	Averaged Peak Flow (m^3/s)	'Average' Temporal Pattern No.	Patt. Peak Flow (m^3/s)	% Difference (Patt. - Avg) /Avg	Duration (min)	Pattern No.	Patt. Peak Flow (m^3/s)	% Difference (Patt. - Avg)/Avg
Stewarts River	1	156	720	897	28	914.9	2.0%	720	28	915	2.0%
Kendall	2	238	720	2109	29	2104.6	-0.2%	720	28	2209.5	4.8%
Watson Taylor Lake Outlet	2	550	720	3472	27	3472.0	0.0%	720	28	3511.6	1.1%
Outlet	2	710	720	4615	25	4615.1	0.0%	720	28	4679.8	1.4%
Queens Lake Outlet	3	139	360	1328	4587	1311.3	-1.3%	720	28	1311.9	-1.2%
CHR befoer Mcleods Ck	15	36	270	402	4685	402.6	0.0%	720	28	394.5	-2.0%
Lorne Bridge Gauge	16	64	360	670	4406	690.0	3.0%	720	28	662.3	-1.1%
Savilles Ck	20	7	120	122	4499	119.9	-1.9%	180	4653	123.7	1.2%
Batar Ck	20	17	120	264	4431	263.1	-0.2%	180	4653	279.9	6.2%
Upsalls Ck Gauge	24	62	720	584	28	603.9	3.3%	720	28	603.9	3.3%
CHR before Upsalls Ck	25	94	720	863	27	878.7	1.9%	720	28	915.7	6.2%
Black Ck Outlet	44	60	360	604	4406	608.7	0.7%	720	28	602.9	-0.2%
Upsalls Ck Outlet	51	67	720	617	28	635.7	3.1%	720	28	635.7	3.1%
Upper Upsalls Ck	159	53	720	525	28	542.0	3.3%	720	28	542.0	3.3%
Gills Ck	193	4	120	68	4499	67.6	-0.9%	180	4653	68.8	0.9%
Upper Black Ck	257	51	360	560	4406	574.7	2.6%	180	4653	555.8	-0.8%
Mcleods Ck	808	14	180	194	4648	188.9	-2.4%	180	4653	208.7	7.8%
Herons Creek Pacific Hwy	997	55	180	708	4599	723.8	2.2%	180	4653	729.1	3.0%
Upper Herons Ck	1715	22	120	348	4431	349.9	0.5%	180	4653	365.3	4.9%
Mid CHR	1930	76	360	772	4719	780.9	1.1%	720	28	767.6	-0.6%
Logans Crossing Gauge	2382	226	720	2073	29	2049.6	-1.1%	720	28	2169.7	4.7%

TABLE 6-8

Location	WBNM Subarea	Upstream Catchment Area (km²)	All Durations, All Patterns					Selected Durations and Patterns 1in 2000 AEP 180min TP 4653 + 1 in 2000 AEP 720min TP28 + 1 in 2000 AEP 1440min TP203			
			Critical Duration (min)	Averaged Peak Flow (m^3/s)	'Average' Temporal Pattern No.	Patt. Peak Flow (m^3/s)	% Difference (Patt. - Avg) /Avg	Duration (min)	Pattern No.	Patt. Peak Flow (m^3/s)	% Difference (Patt. - Avg)/Avg
Stewarts River	1	156	720	1097	28	1111.9	1.3%	720	28	1112	1.3%
Kendall	2	238	720	2571	29	2559.2	-0.5%	720	28	2702.5	5.1%
Watson Taylor Lake Outlet	2	550	720	4314	27	4334.6	0.5%	720	28	4392.6	1.8%
Outlet	2	710	720	5741	25	5737.5	-0.1%	720	28	5838.7	1.7%
Queens Lake Outlet	3	139	360	1646	4596	1633.9	-0.7%	720	28	1590.2	-3.4%
CHR befoer Mcleods Ck	15	36	360	492	4720	491.8	0.0%	180	4653	489.9	-0.4%
Lorne Bridge Gauge	16	64	270	823	4685	823.9	0.1%	180	4653	810.0	-1.6%
Savilles Ck	20	7	120	151	4499	148.1	-1.8%	180	4653	151.4	0.4%
Batar Ck	20	17	120	327	4431	326.5	-0.2%	180	4653	344.3	5.2%
Upsalls Ck Gauge	24	62	720	711	28	735.9	3.4%	720	28	735.9	3.4%
CHR before Upsalls Ck	25	94	360	1060	4720	1083.6	2.2%	720	28	1115.9	5.3%
Black Ck Outlet	44	60	360	744	4406	747.4	0.5%	720	28	732.7	-1.5%
Upsalls Ck Outlet	51	67	720	752	28	776.4	3.3%	720	28	776.4	3.3%
Upper Upsalls Ck	159	53	360	645	4694	645.4	0.1%	720	28	655.9	1.7%
Gills Ck	193	4	120	84	4499	83.4	-0.6%	180	4653	84.0	0.0%
Upper Black Ck	257	51	360	691	4406	703.9	1.9%	180	4653	694.6	0.6%
Mcleods Ck	808	14	120	241	4611	239.0	-0.7%	180	4653	257.4	6.9%
Herons Creek Pacific Hwy	997	55	180	883	4599	904.7	2.4%	180	4653	911.6	3.2%
Upper Herons Ck	1715	22	120	431	4431	433.1	0.5%	180	4653	449.7	4.4%
Mid CHR	1930	76	360	945	4406	966.8	2.3%	720	28	931.1	-1.5%
Logans Crossing Gauge	2382	226	720	2524	27	2594.8	2.8%	720	28	2644.1	4.7%

6.4 Downstream Boundary Conditions

6.4.1 RMA-2 Model

The Camden Haven River and Lakes System RMA-2 model has a singular downstream ocean boundary to the Pacific Ocean at the river outlet.

Flood levels in the lower lakes of the Camden Haven catchment are heavily influenced by coinciding ocean water levels. A time varying tidal boundary with a peak ocean level of 2.7 mAHD was selected for the downstream boundary. This level aligns with a 1 in 200 AEP peak ocean level first derived in the 1989 Flood Study and adopted in the 2013 Flood Study.

6.4.2 TUFLOW Model

The TUFLOW model has two downstream boundaries, Queens Lake at the base of Herons Creek and Watson Taylor Lake at the bottom of Camden Haven River. Both of these lakes are heavily influenced by tidal water levels and coincidental floodwater peaks.

To define downstream water level boundaries, two approaches are to be adopted. This variation is due to the different hydrology between the two hydraulic model.

For the 1 in 500 AEP and 1 in 2000 AEP events, as we are simulating a catchment wide design flood event, the use of time series water levels could be obtained from the downstream RMA-2 model and applied at the downstream end to define simultaneous flood levels.

For the remainder of events, from 5% AEP to 1 in 200 AEP and PMF, the newer WBNM hydrology differs to that from the 2013 flood study, the 36hr ARR87 XP-RAFTS hydrology. As such, time series water levels data cannot be adopted within the TUFLOW model as they relate to different design rainfalls. As a way of defining an accurate water level boundaries were first tested with the 1% AEP event in the TUFLOW model to define the magnitude of impact to the overall peak flood levels. The was conducted by adopting a uniform boundary condition in both lakes, first a uniform 1 mAHD, and secondly, the peak level from the 2013 flood study. This approach had different levels for each lake.

Comparisons of the resultant flood model results show the model results for the upper catchment is mostly unaffected by the downstream lake flood levels, a result echoed from the 2013 flood study. It was found that at Kendall, there was a 150-200 mm variation in flood levels when looking at both durations individually. However, when looking in the area around the Logans Crossing gauge (560017), there was less than 1mm variation between the two boundary conditions. Similarly, along Herons Creek, downstream boundary conditions had no influence on flood levels around the Pacific Highway Bridge.

Accordingly, peak flood levels from the 2013 flood study were adopted as a uniform downstream boundary for the TUFLOW model for the 5% AEP to 1 in 200 AEP events as well as the PMF.

The adopted downstream boundary conditions are summarised in **Table 6-9**.

Table 6-9 Adopted downstream boundary conditions for the TUFLOW Model

Design Event	Critical Duration (min)	Constant or Time-Varying	Queens Lake Peak Level [mAHD]	Watson Taylor Lake Peak Level [mAHD]
5% AEP	360	Constant	2.35	2.85
	720			
2% AEP	270	Constant	2.69	3.22
	720			
1% AEP	180	Constant	2.93	3.49
	720			
1% AEP with CC	180	Constant	3.7	4.15
	720			
1 in 200 AEP	180	Constant	3.13	3.71
	720			
1 in 500 AEP	180	Time-varying	1.90	2.58
	720	Time-varying	2.76	3.48
1 in 2000 AEP	180	Time-varying	2.04	2.84
	720	Time-varying	3.00	3.86
PMF	360	Constant	3.50	4.18

6.5 Climate Change Scenario

The investigation of a climate change scenario is becoming increasingly necessary, as a way of analysing the potential future conditions. This can be used for planning purposes, to inform future decision making.

As part of the 2013 Flood Study, several climate change scenarios were tested:

- *Scenario 1* – 100 year ARI catchment event with 900 mm Sea Level Rise + 10% increase in rainfall intensity and volume
- *Scenario 2* – 100 year ARI catchment event with 900 mm Sea Level Rise
- *Scenario 3* – 100 year ARI catchment event with 400 mm Sea Level Rise + 10% increase in rainfall intensity and volume
- *Scenario 4* – 100 year ARI catchment event with 400 mm Sea Level Rise
- *Scenario 5* – PMF event with 900 mm Sea Level Rise (applied to 200yr tidal tailwater of 2.7 mAHD)

Following interrogation of flood levels, it was determined that *Scenario 1* would provide the most conservative estimate for flood level increases both tidally and areas further upstream, and as such was adopted as the benchmark climate change scenario.

Scenario 1, a 10% increase in rainfall intensity and 900 mm Sea Level Rise, was adopted as the climate change scenario for this study as it follows the current Port Macquarie-Hasting Council's Flood Policy (2018), and consistent with climate change modelling of the lower lakes system completed as part of the 2013 Flood Study. This provides an outlook at 2100 conditions across the catchment.

7. Design Event Results

7.1 Hydrology

Design flood hydrographs determined using the WBNM hydrologic model were used to define new inflows for the RMA-2 and TUFLOW hydraulic models.

Summaries of peak discharges at key locations along the Camden Haven River and along their major tributaries are provided in **Table 7-1** and **Table 7-2**. **Table 7-1** lists peak discharges for events up to and including the 1% AEP flood with climate change. **Table 7-2** includes all larger events up to and including the PMF.

Shaded cells in the tables indicate the critical duration; that is, the storm duration that produces the highest peak discharge. It is important to note that these critical durations are based on flow magnitudes only and may not generate the highest flood levels when routed through the hydraulic models. For example, factors that will influence flooding include the coincident timing of flows from other watercourses and the attenuation of flows via flood storages.

As shown in **Table 7-1** and **Table 7-2**, the peak flow magnitudes across the catchment vary between a short duration storm, 3 to 6 hours, and a longer duration 12-hour storm. Although the 24-hour storm produced lower peak flows, the longer duration event resulted in larger flow volumes which are critical in the Lake regions of the Camden Haven River system.

Table 7-1 Comparison of Predicted Peak Discharges at Key Locations for Events up to the 1% AEP with Climate Change

Location	WBNM sub-catchment name	Peak Discharge (m3/s)							
		5% AEP		2% AEP		1% AEP		1% AEP with CC	
		6hr	12hr	4.5hr	12hr	3hr	12hr	3hr	12hr
Locations along the Camden Haven River									
Upper Camden Haven River	15	224	247	272	265	288	305	326	339
Lorne Bridge Gauge	16	364	366	454	446	477	514	539	571
Somerville Rd Crossing	7	434	463	512	569	538	657	608	730
U/S of Upsalls Creek and Black Creek confluence	25	447	494	512	610	539	707	610	788
Logans Crossing Gauge	2382	1033	1169	1202	1446	1262	1675	1429	1867
Kendall	2.06	1025	1180	1184	1464	1229	1699	1392	1897
Pacific Highway Bridge (CHR)	2.09	1031	1240	1168	1549	1201	1810	1361	2027
Watson Taylor Lake Outlet	2.12	1311	1748	1455	2222	1474	2635	1671	2975
Outlet	2.14	1663	2291	1857	2932	1886	3500	2138	3958
Locations along Herons Creek									

Upper Herons (Nelson Rd crossing)	1715	194	148	213	182	280	210	313	233
Pacific Highway Bridge (Herons Creek)	997	387	334	446	410	547	473	616	527
Queens Lake Outlet	3.02	622	708	835	878	777	1018	876	1132
Locations along Tributaries and Outlets discharging to the Camden Haven River									
McLeod's Creek Outlet	808	112	92	131	113	158	130	177	145
Gill's Creek Outlet	193	37	28	43	34	53	39	59	44
Saville's Creek Outlet	1927	410	425	504	520	529	598	598	664
Upper Upsalls Creek	159	258	298	308	365	317	421	358	467
Upsalls Creek Gauge	24	266	325	319	402	331	465	375	518
Upsalls Creek Outlet	51	277	340	325	421	339	488	384	545
Upper Black Creek	257	293	286	378	352	416	407	469	453
Black Creek Outlet	44	323	329	385	405	425	468	480	520
Batar Creek Outlet	20.01	148	115	170	142	214	164	239	182
Stewarts River Outlet	1.03	434	493	508	612	523	710	592	791

Table 7-2 Comparison of Predicted Peak Discharges at Key Locations for Events up to the PMF

Location	WBNM sub-catchment name	Peak Discharge (m3/s)								
		1 in 200 AEP		1 in 500 AEP			1 in 2000 AEP			PMF
		3hr	12hr	3hr	12hr	24hr	3hr	12hr	24hr	6hr
Locations along the Camden Haven River										
Upper Camden Haven River	15	330	341	390	394	344	490	480	418	845
Lorne Bridge Gauge	16	545	572	644	662	585	810	806	709	1531
Somerville Rd Crossing	7	615	731	727	844	737	914	1022	894	1987
U/S of Upsalls Creek and Black Creek confluence	25	616	789	728	916	792	917	1116	962	2163
Logans Crossing Gauge	2382	1443	1870	1707	2170	1906	2150	2644	2315	5156
Kendall	2.06	1406	1900	1664	2209	1953	2100	2702	2374	5212
Pacific Highway Bridge (CHR)	2.09	1375	2030	1629	2371	2132	2058	2917	2596	5564
Watson Taylor Lake Outlet	2.12	1686	2975	2000	3512	3403	2531	4393	4168	7420
Outlet	2.14	2151	3958	2553	4680	4531	3238	5839	5572	9195
Locations along Herons Creek										
Upper Herons (Nelson Rd crossing)	1715	314	234	365	271	201	450	329	243	529
Pacific Highway Bridge (Herons Creek)	997	620	529	729	613	193	912	747	598	1382
Queens Lake Outlet	3.02	882	1135	1039	1312	1120	1301	1590	1366	2592

Locations along Tributaries and Outlets discharging to the Camden Haven River										
McLeod's Creek Outlet	808	179	145	209	168	135	257	205	163	380
Gill's Creek Outlet	193	59	44	69	50	37	84	61	45	117
Saville's Creek Outlet	1927	604	665	713	768	679	897	934	824	267
Upper Upsalls Creek	159	362	470	427	542	482	536	656	585	1172
Upsalls Creek Gauge	24	379	521	448	604	541	564	736	656	1320
Upsalls Creek Outlet	51	388	547	459	636	573	578	773	694	1404
Upper Black Creek	257	473	454	556	527	457	695	643	554	1337
Black Creek Outlet	44	484	521	571	603	528	715	733	629	1524
Batar Creek Outlet	20.01	241	182	280	210	159	344	256	193	680
Stewarts River Outlet	1.03	595	790	705	915	818	892	1112	997	1853

7.1.1 Comparison to Previous Studies

As discussed in **6.1,** previous catchment wide flood studies for the Camden Haven River and Lakes catchment have been based on procedures and data outlined in *Australian Rainfall and Runoff 1987* (ARR 1987). This includes the currently adopted *Camden Haven River and Lake System Flood Study* (2013) which considers the lower reaches of the Camden Haven River downstream of the Logans Crossing gauge as well as Stewarts River and Herons Creek downstream of the Pacific Highway crossing.

The existing hydrology used to establish peak flood levels in the RMA-2 model for the lower catchment will be retained. Meanwhile, the WBNM model will supply updated hydrological data to define rainfall inputs in the TUFLOW model and to account for previously unmodeled rare events, specifically the 1 in 500 and 1 in 2000 AEP events within the RMA-2 model area.

The use of procedures outlined in ARR 2019 and the application of a new WBNM hydrologic model of the catchment is a major modification to the hydrologic modelling that had been undertaken previously for the catchment. It is therefore warranted to undertake a comparison between the design flows and flow hydrographs predicted as part of previous studies to this flood study extension. The outcomes of this comparison are discussed below.

- A comparison between peak flow magnitudes predicted at the upstream boundaries of the Camden Haven River RMA-2 model is presented in **Table 7-3**. Hydrograph comparison plots between the updated hydrology and the previous hydrology adopted for the lower catchment are included in **Appendix D**. Flow hydrographs are provided for the for the Logans Crossing and Herons creek location in **Table 7-3**, i.e. at the upstream boundaries of the RMA-2 flood model.
- The comparison shows that peak discharges have decreased along the Camden Haven River for design events up to and including the 1 in 200 AEP scenario. The decrease is largest for the 5% AEP event with a reduction of 16% predicted. Reductions in the order of 8-10% are predicted for the other events (*refer* **Table 7-3**).
- Peak flows along the Camden Haven River for the PMF event are predicted to be 98% higher than those predicted for the previously adopted PMF flood event. This increase in flow was due to defined lag times underestimating the velocity of flows in the upper catchment and has been discussed in more detail in **6.3.6**. As shown in **Figure D-5**, the new PMF peak is a single peak, compared with the previously adopted double peak, caused by the delay in upper catchment flows due to model lag time.

- Peak flows along Herons Creek have decreased by up to 13% in events up to and including the 1% AEP event. Peak flows are predicted to increase in the 1 in 200 AEP event by 9% and by 5% when comparing flows generated for the PMF (*refer* **Table 7-3**).
- Peak flows along the Stewarts River have decreased in all events up to and including the 1 in 200 AEP event, by a maximum of 31% in the 5% AEP event. Other reductions are in the order of 14-25% and an increase in PMF flows by 17% (*refer* **Table 7-3**).
- Similarly to Stewarts River, Batar Creek experiences a decrease in design flows in all events up to an including the 1 in 200 AEP event, with a peak decrease in the 5% AEP event, and other decreases in between 6-11%. In the PMF, flows are predicted to increase by 32% (*refer* **Table 7-3**). This increase would be attributed to the finer WBNM sub-catchment delineation and location near the centre of the GSDM ellipse.

Table 7-3 Comparison of Peak Design Flows at Existing Continuity Lines

Location	Peak Discharge (m^3/s)									
	5% AEP		2% AEP		1% AEP		1 in 200 AEP		PMF	
	XP-RAFTS	WBNM	XP-RAFTS	WBNM	XP-RAFTS	WBNM	XP-RAFTS	WBNM	XP-RAFTS	WBNM
Logans Crossing	1332	1123 *(-16%)*	1541	1385 *(-10%)*	1744	1603 *(-8%)*	1948	1789 *(-8%)*	2607	5156 (+98%)
Herons Creek (Pacific Hwy Bridge)	425	369 *(-13%)*	486	442 *(-9%)*	552	533 *(-3%)*	552	603 (+9%)	1313	1382 (+5%)
Stewarts River Inflow	695	479 *(-31%)*	793	595 *(-25%)*	895	692 *(-23%)*	895	772 *(-14%)*	1580	1853 (+17%)
Batar Creek Inflow	168	141 *(-16%)*	188	168 *(-11%)*	213.17	199 *(-7%)*	238.76	224 *(-6%)*	1153	1517 (+32%)

Notes: 1. *Peak flows predicted using XP-RAFTS have been adopted for the 2013 flood study. Previous hydrologic modelling was based on ARR 87 procedures and IFD .*

2 Peak flows predicted using WBNM adopt a 6 and 12 hour storm duration for 5% AEP, 4.5 and 12 hour storm duration for 2% AEP and 3 and 12 hour storm durations for all other design events excluding the PMF. The PMF is based on a 6 hour duration.

7.1.2 Comparison to Flood Frequency Analysis

Table 7-4 shows a comparison between flows predicted using the WBNM model and those estimated based on the 2013 FFA prepared for the Camden Haven River at Logans Crossing gauge (refer **Section 6.2**).

Table 7-4 Comparison of Peak Flows to Logans Crossing (Camden Haven River) 2013 FFA

Annual Exceedance Probability (AEP)	Estimated Flow Values (m^3/s)		
	2013 FFA	2025 WBNM Model	Difference
5% AEP	1184	1123	- 61 (-5%)
2% AEP	1379	1385	+ 6 (+0%)
1% AEP	1540	1603	+ 63 (+4%)
1 in 200 AEP	1680	1789	+109 (+6%)

The comparison in **Table 7-4** shows that the WBNM model incorporating ARR 2019 produces peak flows that are within 6% of those predicted by the 2013 FFA for the Logans Crossing (Camden Haven River) gauge. This is a good fit that supports the use of the 2024 WBNM model for design event flow estimation.

7.2 Camden Haven River and Lakes RMA-2 Hydraulic Model

7.2.1 Design Flood Mapping

Design flood mapping produced using the RMA-2 hydraulic model is provided in **Appendix E**. This includes mapping of peak flood levels and depths and flow velocities in accordance with the following figure breakdown:

- Predicted Peak 1 in 500 AEP Flood Levels (refer **Figure E-1**)
- Predicted Peak 1 in 2000 AEP Flood Levels (refer **Figure E-2**)
- Predicted Peak 1 in 500 AEP Depths & Velocities (refer **Figure E-3** to **Figure E-7**)
- Predicted Peak 1 in 2000 Depths & Velocities (refer **Figure E-8** to **Figure E-12**)

The modelling for design events was based on the use of the RMA-2 model network adopted for calibration to the March 2021 event combined with flow hydrographs described in **Section 7.1**.

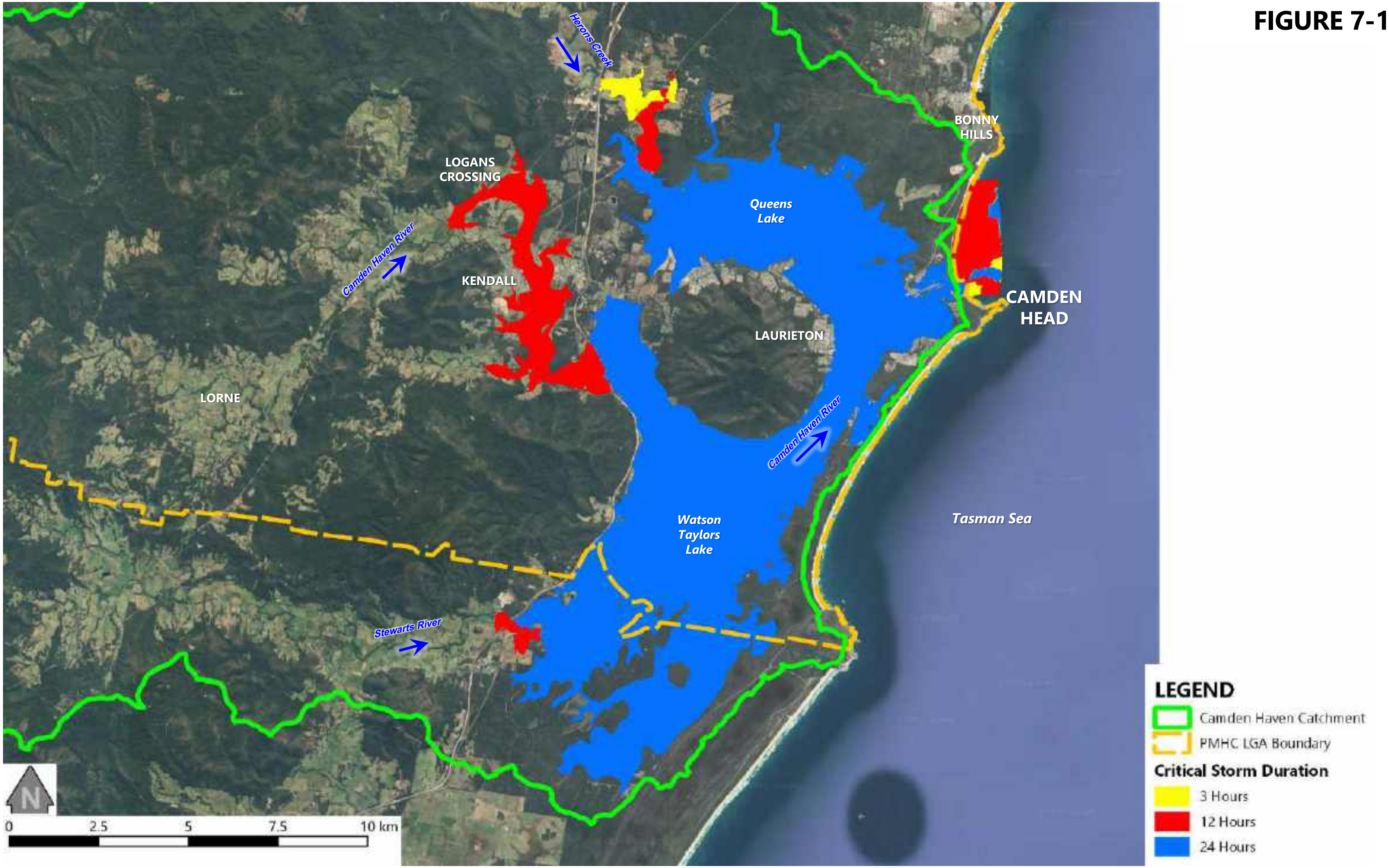
The flood mapping represents peak flood conditions produced by a process of 'flood enveloping'. For each design AEP, this process combines maximum flood level results from the adopted storm durations to produce a 'design flood envelope'. Peak flow magnitudes for these design event durations are listed in **Table 7-1** and **Table 7-2** for key locations throughout the RMA-2 model extent.

The storm durations used to produce the peak design flood envelopes are summarised in **Table 7-5.** Mapping for the 1 in 2000 AEP event showing where each critical duration applies is shown as **Figure 7-1**.

Table 7-5 Summary of scenarios used to produce peak design flood envelopes

Design Flood Event	Storm Duration for Local Catchment Flows	Downstream Boundary Conditions
1 in 500 AEP	3, 12 & 24hr	Ocean Boundary – Tidal varying with peak of 2.7 mAHD
1 in 2000 AEP	3, 12 & 24hr	Ocean Boundary – Tidal varying with peak of 2.7 mAHD

FIGURE 7-1



Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs
fg311015-00481jc250205-CamdenHavenFS_A4L_P3.pdf

'PEAK-OF-PEAKS' DESIGN ENVELOPE SHOWING LOCATIONS WHERE THE 3-, 12- AND 24-HOUR CRITICAL STORM DURATIONS APPLY 1 IN 2000 AEP DESIGN EVENT

7.2.2 Peak Flood Levels

Peak flood levels for the full range of design events are listed below in **Table 7-6** on the following page. The selected locations for comparison are indicated on **Figures E-3** to **E-7**.

Table 7-6 Predicted Flood Levels at Key Locations throughout the RMA-2 Model Extent

Location	Point Identifier (refer App E)	Predicted Peak Flood Level (mAHD)	
		1 in 500 AEP	1 in 2000 AEP
Camden Haven River			
Logans Crossing Bridge (upstream)	CH1	8.85	9.3
Kendall Road Bridge (upstream)	CH2	6.68	7.37
Pacific Highway Road Bridge (upstream)	CH3	4.68	5.04
Watson Taylor Lake Confluence (Inflow)	CH4	3.67	4.09
Watson Taylor Lake Confluence (Outflow)	CH5	3.47	3.9
Dunbogan Bridge (upstream)	CH6	3.35	3.75
Confluence with Stingray Creek	CH7	3.24	3.64
Gogley's Lagoon (upstream)	CH8	3.19	3.58
Breakwater Entrance	CH9	2.78	2.88
Stewarts River			
Pacific Highway Road Bridge (upstream)	ST1	4.71	4.99
Watson Taylor Lake Confluence	ST2	3.67	4.09
Herons Creek			
Confluence with Queens Lake	HC1	3.29	3.68
Stingray Creek			
Confluence with Queens Lake	SC1	3.29	3.68
Stingray Creek Bridge (upstream)	SC2	3.24	3.65
Confluence with Camden Haven River	SC3	3.21	3.61

7.2.3 Comparison to Previous Studies

Flood levels from the 2013 flood study, and the additional AEP events simulated in this study have been compared at a few key locations across the catchment area is shown in **Table 7-7**. The 1% AEP with Climate Change refers to Scenario 1 from the 2013 flood study, referring to a 10% increase in rainfall intensity and a sea level rise of 0.9 metres.

The results in **Table 7-7** show that the modelling of the 1 in 500 and 1 in 2000 AEP events adopting the updated ARR19 hydrology are generally in line with an upwards trend from the previously completed modelling and hydrology. However, levels at Watson Taylor Lake do not conform with this trend as levels from the 1 in 200 AEP event present a higher level than that from the new 1 in 500 AEP results. This could be due to a decrease in design flows shown in **Table 7-3** likely to extend to rarer events. This is due to the updated hydrology following ARR2019 guidelines by aligning more closely with the FFA completed in the 2013 flood study (refer **Table 7-4**).

Similarly to the above point, in most of the comparison points, the 1 in 2000 AEP event results in levels above the 2013 flood study PMF results. This follows the discussion in **Section 6.3.6**, whereby the 2013 flood study underestimated PMF design flows. It also reiterates the need for the PMF to be re-tested by the revised PMF flows.

Table 7-7 Comparison of peak flood Levels for different AEP events, 2013 flood study and 2025 flood study update

Location	2013 Flood Study (mAHD)					2025 Flood Study (mAHD)		2013 (mAHD)
	5% AEP	2% AEP	1% AEP	1% AEP with CC	1 in 200 AEP	1 in 500 AEP	1 in 2000 AEP	PMF
Kendall Road Bridge (upstream)	5.45	5.85	6.20	6.50	6.50	6.68	7.37	7.25
Watson Taylor Lake	2.85	3.22	3.49	4.15	3.71	3.67	4.09	4.18
Dunbogan Bridge (upstream)	2.40	2.78	3.03	3.78	3.25	3.35	3.75	3.65
Queens Lake	2.35	2.69	2.93	3.70	3.13	3.29	3.68	3.49
Gogley's Lagoon (upstream)	2.20	2.60	2.85	3.50	3.05	3.19	3.58	3.42

7.3 Upper Catchment TUFLOW Hydraulic Model

7.3.1 Design Flood Mapping

Design flood mapping produced using the TUFLOW hydraulic model is provided in **Appendix F**. This includes mapping of peak flood levels and depths and flow velocities (as velocity vectors) in accordance with the following study area breakdown shown in **Figure 7-2** and the figure sets listed below:

- Predicted Peak 5% AEP Flood Levels (refer **Figure F-1** to **Figure F-4**)
- Predicted Peak 1% AEP Flood Levels (refer **Figure F-5** to **Figure F-8**)
- Predicted Peak 1% AEP with Climate Change Flood Levels (refer **Figure F-9** to **Figure F-12**)
- Predicted Peak 1 in 500 AEP Flood Levels (refer **Figure F-13** to **Figure F-16**)
- Predicted Peak PMF Flood Levels (refer **Figure F-17** to **Figure F-20**)
- Predicted Peak 5% AEP Depths & Velocities (refer **Figure F-21** to **Figure F-24**)
- Predicted Peak 1% AEP Depths & Velocities (refer **Figure F-25** to **Figure F-28**)
- Predicted Peak 1% AEP with Climate Change Depths & Velocities (refer **Figure F-29** to **Figure F-32**)
- Predicted Peak 1 in 500 AEP Depths & Velocities (refer **Figure F-33** to **Figure F-36**)
- Predicted Peak PMF Depths & Velocities (refer **Figure F-37** to **Figure F-40**)

The flood mapping represents peak flood conditions produced by a process of 'flood enveloping'. For each design AEP, this process combines maximum flood level results from the adopted storm durations to produce a 'design flood envelope'. Peak design flood envelopes were produced by combining the 2 storm durations for each AEP event. These storm duration combinations are defined in **Table 6-2From this** a number of critical storm durations and associated temporal patterns of interest were identified for further investigation for each flood magnitude.

- From the investigated storms, two durations were selected for each flood magnitude that in combination provided the overall best match to 'average peak design flows' across the assessment locations.

A summary of the selected critical storm durations and temporal patterns for each design event are presented in **Table 6-2.**

Table 6-2.

For the rarer events of the 1 in 500 and 1 in 2000 AEP, the 24 hour duration storm was not run through the TUFLOW model. This was because the design flows determined the 12 hour duration was to be critical by the WBNM model. This was confirmed by the RMA-2 model results (refer **Figure 7-1**), which shows the 24 hour duration storm is critical in the Lake areas of the catchment, where volume is more of a contributing factor to flood levels.

A review of the design envelopes showed that the longer duration (12 hour) storm was critical across all events along the majority of the Camden Haven River, and the shorter duration storms were critical in the upper areas and along the tributaries including Herons Creek, Upsalls Creek and Black Creek. Mapping for the 1% AEP event showing where each critical duration applies is shown in **Figure 7-3**.

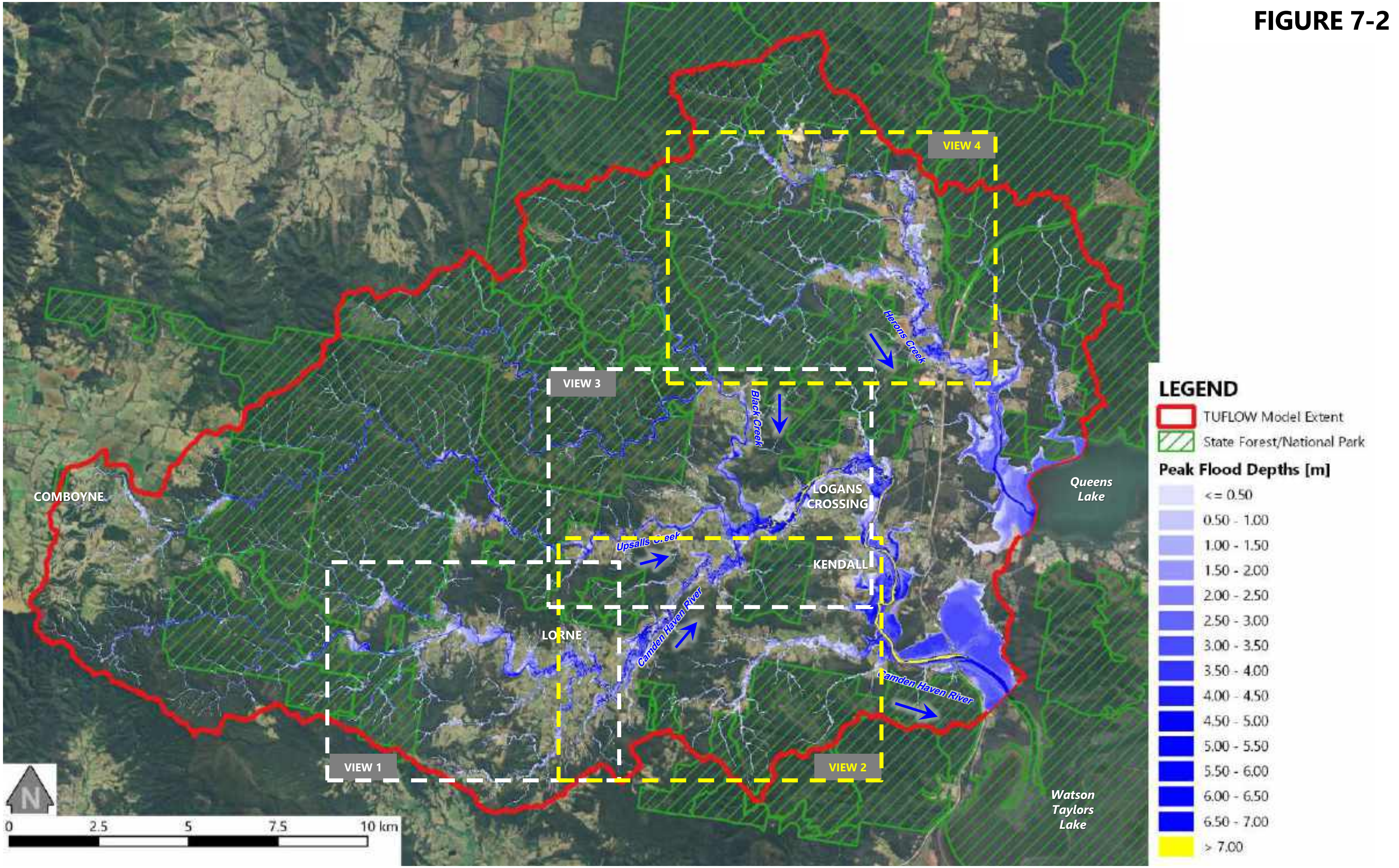
7.3.2 Peak Flood Levels

Peak flood levels for the full range of design events are listed below in **Table 7-8**. The selected locations for comparison are indicated on **Figures F-1** to **F-16** included as **Appendix F**.

Table 7-8 Predicted Flood Levels at Key Locations throughout the TUFLOW Model Extent

Location	Point Identifier (refer App F)	Predicted Peak Flood Level (mAHD)							
		5% AEP	2% AEP	1% AEP	1% AEP with CC	1 in 200 AEP	1 in 500 AEP	1 in 2000 AEP	PMF
Upper Camden Haven R U/S of Lorne Rd	C1	46.49	46.643	46.73	46.821	46.83	46.962	47.16	47.441
Upper Camden Haven R U/S of Lorne Rd 2	C2	34.479	34.71	34.885	35.022	35.037	35.23	35.502	35.983
Camden Haven R U/S of Stewarts River Rd (Lorne Bridge Gauge)	C3	29.076	29.336	29.589	29.788	29.808	30.094	30.489	31.259
Savilles Ck U/S of Stewarts R Rd	S1	32.551	32.956	33.153	33.267	33.275	33.46	33.61	33.853
Camden Haven R U/S of Somervilles Rd	C4	21.614	22.065	22.359	22.561	22.564	22.856	23.315	25.186
Lower Camden Haven R U/S of Lorne Rd	C5	14.872	15.395	15.704	15.88	15.882	16.158	16.479	18.001
Upsalls Ck U/S of Upsalls Ck Rd (Gauge)	U1	16.844	17.19	17.348	17.521	17.526	17.785	18.188	19.763
Upsalls Ck U/S of Black Ck Rd	U2	13.917	14.382	14.711	14.951	14.955	15.281	15.757	17.972
Black Ck U/S of Black Ck Rd	B1	13.408	13.996	14.353	14.606	14.61	14.945	15.419	17.656
Upper Black Ck U/S of Black Creek Rd	B2	29.408	29.583	29.634	29.73	29.738	29.909	30.267	31.781
Logans Crossing Gauge	C6	10.235	10.699	11.052	11.356	11.36	11.757	12.308	14.415
Batar Ck U/S of The Old Coach Rd	B3	26.647	26.843	26.933	27.011	27.015	27.13	27.292	27.807
Batar Ck U/S of Batar Ck Rd	B4	9.093	9.184	9.296	9.371	9.374	9.481	9.634	10.188
Batar Ck U/S of Foxes Ck Rd	B5	4.797	4.886	5.001	5.41	5.203	5.236	5.844	8.391
Herons Ck U/S of Nelsons Rd	H1	21.171	21.387	21.608	21.737	21.744	21.921	22.229	22.414
Cedar Ck U/S of Old School Rd	H2	11.456	11.608	11.771	11.879	11.885	12.04	12.286	12.686
Herons Creek U/S of Pacific Hwy (Gauge)	H3	6.505	7.051	7.512	7.846	7.861	8.292	8.844	9.499

FIGURE 7-2



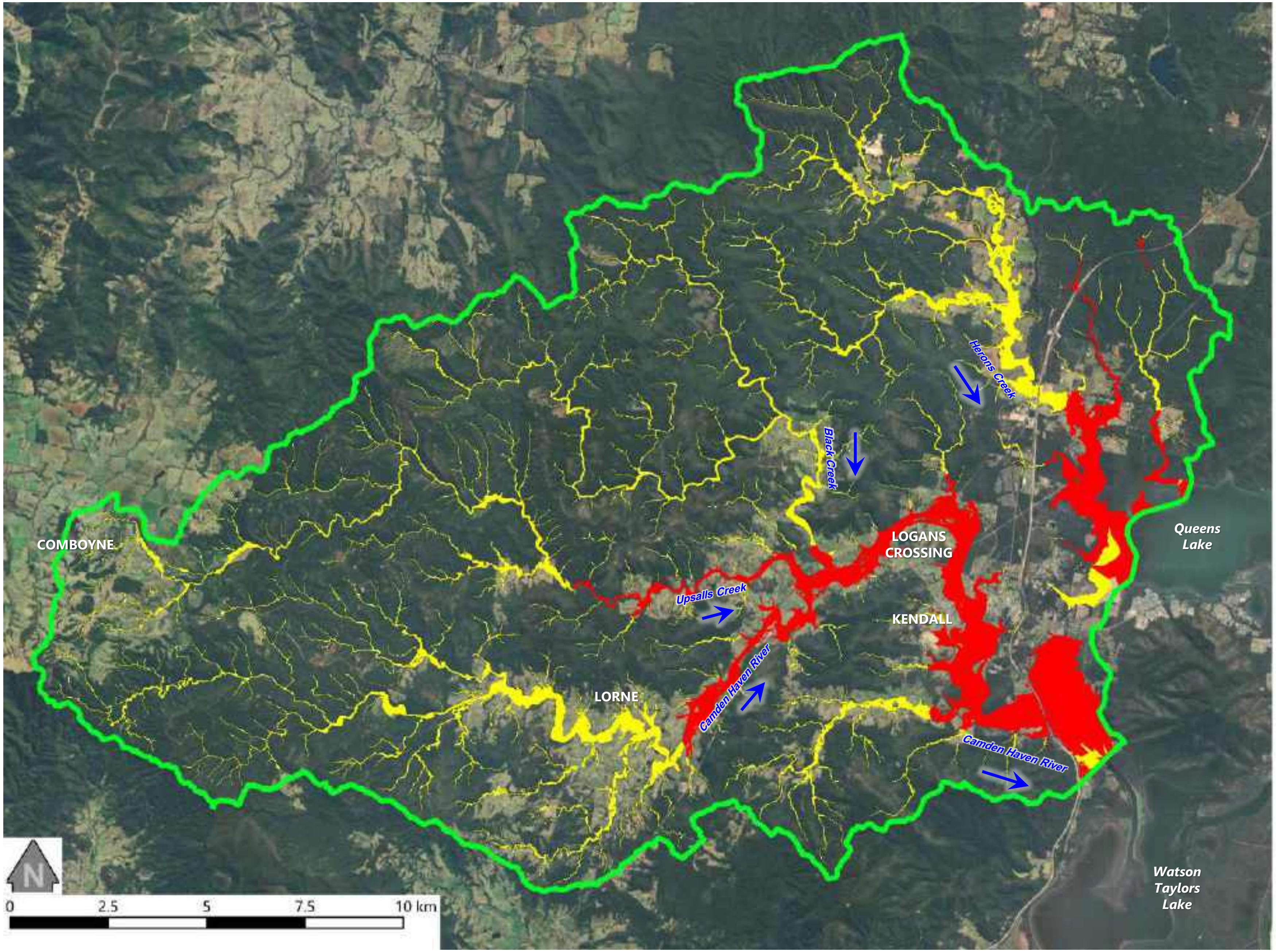
Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481jc250205-CamdenHavenFS_A4L_P3.pdf

STUDY AREA BREAKDOWN ADOPTED FOR TUFLOW DESIGN FLOOD MAPPING

FIGURE 7-3



Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481jc250205-CamdenHavenFS_A4L_P3.pdf

DESIGN ENVELOPE SHOWING LOCATIONS WHERE THE 3- AND 12-HOUR CRITICAL STORMS APPLY 1% AEP DESIGN EVENT

7.3.3 Comparison to Previous Studies

The TUFLOW hydraulic model domain covers major tributaries that have not previously been modelled as part of any flood study. A comparison to previous studies was therefore not possible.

7.3.4 Comparison to Flood Frequency Analysis

As part of the 2013 Flood Study, a FFA was conducted on the peak annual discharge records at the Logans Crossing gauge (560017). This has been discussed in

The TUFLOW hydraulic model domain includes this gauge and simulated peak flood levels at this location. These peak levels can be compared to the FFA to confirm the alignment of the TUFLOW model when adopting the updated design flows. These are compared in **Table 7-9**.

This comparison shows that the TUFLOW model is able to closely replicate the levels defined by the 2013 Flood Frequency Analysis.

Table 7-9 Comparison of peak flood levels from the TUFLOW model to 2013 FFA levels.

Design Event	Flood Frequency Analysis (2013 FS)	TUFLOW model
	Level (mAHD)	Level (mAHD)
5% AEP	10.22	10.24
2% AEP	10.62	10.70
1% AEP	10.91	11.05
1 in 200 AEP	-	11.36

7.4 Provisional Flood Hazard Mapping

The personal danger and physical property damage caused by a flood varies both in time and place across the floodplain. Accordingly, the variability of flood patterns across the floodplain over the full range of floods, needs to be understood by flood prone landholders and by floodplain risk managers.

Representation of the variability of flood hazard across the floodplain provides floodplain risk managers with a tool to assess the existing flood risk and to determine the suitability of land use and future development. The hazard associated with a flood is represented by the static and dynamic energy of the flow, which is in essence, the depth and velocity of the floodwaters. Therefore, the flood hazard at a particular location within the floodplain, is a function of the velocity and depth of the floodwaters at that location.

Guideline 7.3 – Flood Hazard of '*Handbook 7 – Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia*' of the Australian Disaster Resilience Handbook Collection (*2017*) presents a set of hazard curves which assess the vulnerability of people, vehicles and buildings to flooding based on the velocity and depth of flood flows. These curves have been adopted to define flood hazard in this study and are reproduced in **Plate 7-1**.

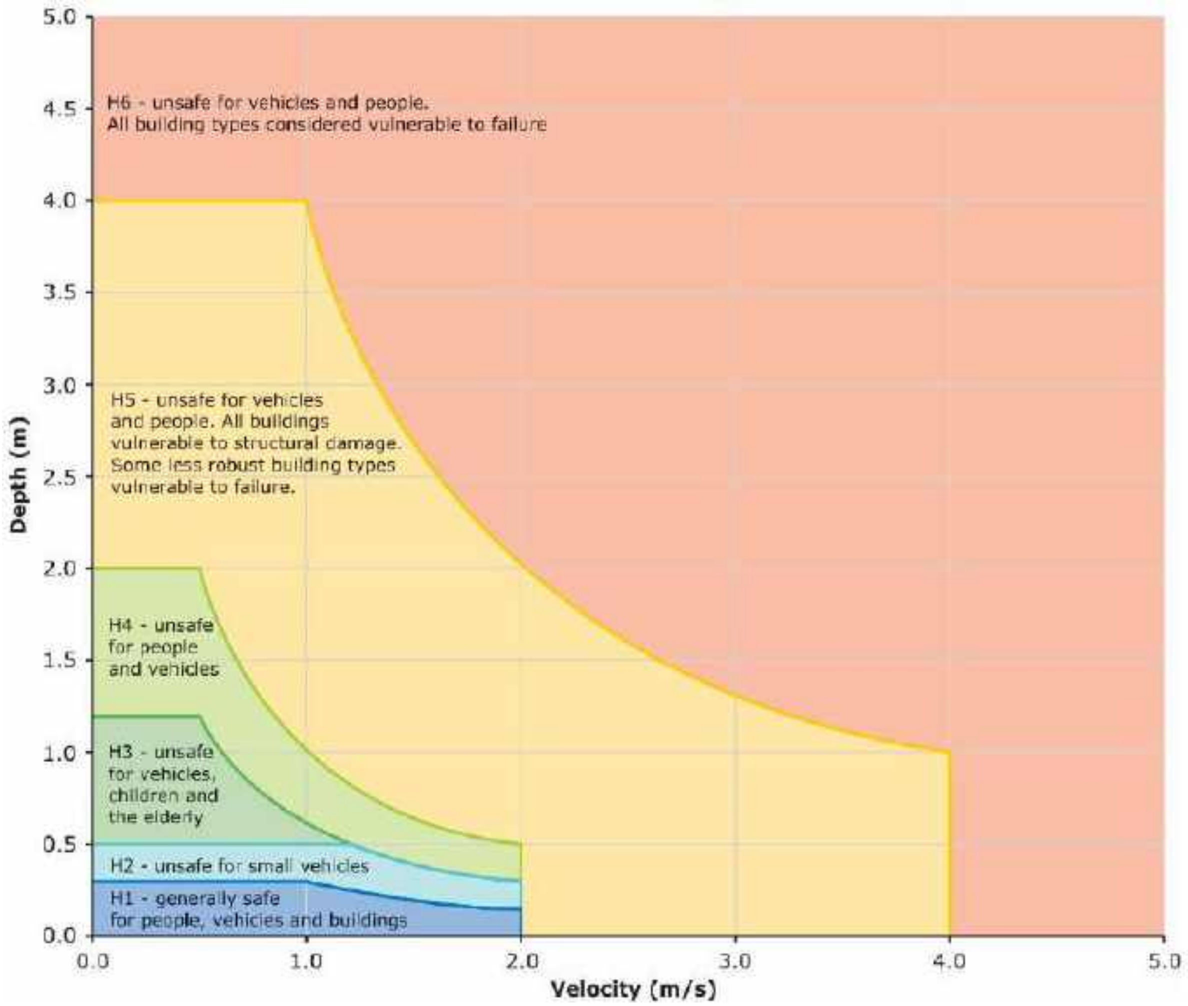


Plate 7-1 Flood Hazard Hydraulic Criteria (Handbook 7 – Managing the Floodplain 2017)

The modelling results generated using the TUFLOW model were used to prepare provisional flood hazard mapping for the study area. Provisional flood hazard mapping for the 1% AEP event is presented in **Figures G-1** to **G-4** in **Appendix G** for the RMA-2 and TUFLOW model extents.

The mapping is based on a 'peak-of-peaks' design envelope in accordance with discussion in **Section 7.3.1**.

7.5 Flood Function Mapping

7.5.1 General

The hydraulic category or flood function for a site identifies the potential for development to impact on existing flood behaviour. The NSW Government's '*Floodplain Development Manual*' (*2005*) divides flood prone land into three hydraulic categories; namely Floodway, Flood Storage and Flood Fringe. The 2005 Manual defines the three categories as described below:

- **Floodway areas** are those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels, and even their partial blockage would cause a significant redistribution of flood flow or a significant increase in flood level.

- **Flood storage areas** are those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. Loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation.
- **Flood fringe areas** are the remaining area of the floodplain after floodway and flood storage areas have been defined. Development in flood fringe areas would not have any significant effect on the pattern of flood flows and/or flood levels.

The latest advice for the delineation of floodway corridors is documented in *Floodplain Risk Management Guideline FB02* titled '*Flood Function*' included in the NSW Government's *Flood Risk Management Manual: the policy and manual for the management of flood liable land* (2023). FB02 replaces the FRM guideline on floodway definition (DECC 2007).

FRM Guideline FB02 outlines the following three methodologies that can be used to delineate floodway corridors.

- Indicator techniques are in most cases only suitable to provide an estimate of the floodway extent with further testing and manual assessment required.
- Encroachment techniques are generally only undertaken when using 1D models and is considered unsuitable for identifying floodways on its own.
- Conveyance techniques which rely on the identification of floodways based on a review of flow distributions.

Review of the '*Conveyance Technique*' shows that it is similar to the approach first adopted by WorleyParsons in the delineation of floodway corridors as part of the 'Camden Haven River and Lakes System Flood Study' (2013) without the additional verification undertaken through blockage analysis/modelling. A description of the methodology adopted as a part of that study is included in Section 8.3 of the report.

7.5.2 Extended Floodway Mapping

The conveyance technique was adopted to delineate floodway corridors for those new areas of the floodplain covered by the TUFLOW model. This involved the following steps:

1. Review of flow distributions at regular intervals along watercourses to identify width of the floodplain that conveys 80% of the total flow. Although this focused on the 1% AEP event, the 1 in 500 AEP flood was also interrogated in locations were new breakouts, or flood runners, appeared to form.
2. Velocity x Depth (VxD) and flow velocity mapping was prepared to assess flood behaviour at the edges of the identified 80% flow extents. Representative values of VxD and flow velocities were identified and used to 'map' the floodway extent between locations of flow analysis (refer point 1 above). The following ranges of VxD thresholds were identified to apply to the various watercourses:
   - Typically 6-10 m^2/s along the length of the Camden Haven River, but as high as 14 m^2/s in very incised sections or as low as 2 m^2/s in areas where floodwaters are distributed over a wider extent.
   - Typically 2-6 m^2/s along Upsalls Creek, Black Creek, Herons Creek and Batar Creek
   - Typically 1-3 m^2/s along the other watercourses where the floodplain is not as incised and flow magnitudes are smaller.
3. Preparation of mapping of areas where VxD exceeds 8 m^2/s and velocities exceed 2 m/s. This step was undertaken to identify any additional areas that are predicted to convey significant flows and velocities, but which may have fallen outside of the 80% flow corridor identified during Step 1 (refer above).
4. Extension of the floodway corridor to include areas mapped during Step 3 (refer above).

5. Manual review and editing of GIS layers against aerial photography and cadastral boundaries. This final step was undertaken to streamline the extent of the floodway and minimise minor encroachment into properties. Manual refinement was typically limited to changes to the floodway width of no more than 1 to 2 metres.

A review of the previous floodway delineation undertaken as part of the 2013 Flood Study was also completed. This was completed by interrogating the 1 in 500 AEP results to determine if there were any new breakouts or flood runners that appeared in new, previously unmodelled, events.

7.5.3 Extended Mapping of Flood Storage and Fringe

Flood storage and fringe was mapped based on the same criteria adopted as part of the 'Camden Haven River and Lakes System Flood Study' (2013). Accordingly, flood storage and flood fringe were defined as:

- Flood Storage - those parts of the floodplain outside of the floodway corridor and with depths of <u>over</u> 0.5 metres at the peak of the 1% AEP flood.
- Flood Fringe - those parts of the floodway outside of the floodway corridor and with depths of <u>up to</u> 0.5 metres at the peak of the 1% AEP flood.

7.5.4 Flood Function Mapping

Updated Flood function mapping for areas covered by the RMA-2 model and the TUFLOW model are presented in **Figures H-1** to **H-9** in **Appendix H**.

8. References

Australian Institute for Disaster Resilience *'Australian Disaster Resilience Handbook - Flood Preparedness'* https://knowledge.aidr.org.au/resources/handbook-flood-planning

Australian Institute for Disaster Resilience (*2017*), *'Australian Disaster Resilience Handbook 7 – Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia'*; © Commonwealth of Australia 2017 third edition.

Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors), (2016), *'Australian Rainfall and Runoff: A Guide to Flood Estimation, Commonwealth of Australia'*

Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors), (2019), *'Australian Rainfall and Runoff: A Guide to Flood Estimation, Commonwealth of Australia'*

Bewsher Consulting & Don Fox Planning (2001), '*Camden Haven Floodplain Management Study*'; prepared for Port Macquarie Hastings Council

Bewsher Consulting & Don Fox Planning (2004), 'Camden Haven Floodplain Management Plan'; prepared for Port Macquarie Hastings Council

Bureau of Meteorology (2006), 'Guidebook to the Estimation of Probable Maximum Precipitation: Generalised Southeast Australia Method'. Hydrometeorological Advisory Service, Bureau of Meteorology.

Bureau of Meteorology (2003b), Guidebook of the Estimation of Probable Maximum Precipitation: Generalised Tropical Storm Method. Hydrometeorological Advisory Service, Bureau of Meteorology.

Bureau of Meteorology (2003a), 'The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method'. Hydrometeorological Advisory Service, Bureau of Meteorology

Catchments and Creeks (*2011*), *'Background to Rock Sizing Equations Waterway and Stormwater Management'*

Hastings Municipal Council (1991), '*Camden Haven Floodplain Management Study*'

Hemphill RW & Bramley ME (*1989*), *'Protection of River and Canal Banks'*; published by Construction Industry Research & Information Association (CIRIA) ISBN 0-408-03945-0

Hewlett, H.W.M., Boorman, L.A. and Bramley, M.E. (*1987*), *'Design of Reinforced Grass Waterways'*; CIRIA Report 116. CIRIA.

Institution of Engineers (*1987*), *'Australian Rainfall and Runoff – A Guide to Flood Estimation'*; edited by DH Pilgrim.

Manly Hydraulic Laboratory (*2021*), '*NSW Coastal Flood Summary – March 2021*'; Prepared for NSW Planning Industry & Environment

New South Wales Government (*2005*), *'Floodplain Development Manual: the management of flood liable land'*; ISBN 0 7347 5476 0.

NSW Department of Planning and Environment (2022), *'Flood Function - Flood Risk Management Guide FB02'* ISBN 978-1-922767-37-0.

Patterson Britton & Partners (*1999*), '*Camden Haven Estuary Processes Study*'; prepared for Hastings Council

Port Macquarie – Hastings Council (*2018*), *'Port Macquarie-Hastings LGA Flood Policy'* (*adopted December 2018*)

WorleyParsons (*2013*), '*Camden Haven River & Lakes System Flood Study*; prepared for Port Macquarie-Hastings Council

Willing & Partners Pty Ltd (1989), '*Camden Haven River Flood Study*'; prepared for Public Works Department (1989)

9. Glossary

The following glossary and abbreviations have been sourced from the *Flood Risk Management Manual* (DPE 2023a).

Term	Short form	Definition	Context for use/additional information
Annual exceedance probability	AEP	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage	AEP is generally the preferred terminology. ARI is the historical way of describing a flood event, for example, a 1% AEP flood has a 1% or 1 in 100 chance of being reached or exceeded in any given year. Further information on the preferred terminology of design events of varying magnitudes is available online through the Bureau of Meteorology website: http://www.bom.gov.au/water/designRainfalls/index.shtml#faq
Australian height datum	AHD	A common national surface level datum often used as a referenced level for ground, flood, and flood levels	0.0 m AHD corresponds approximately to mean sea level
Average recurrence interval	ARI	The long-term average number of years between the occurrence of a flood equal to or larger in size than the selected event	ARI is the historical way of describing a flood event. AEP is generally the preferred terminology, for example, a 100-year ARI flood that has 1 in 100 chance of being reached or exceeded in any given year. It is equivalent to a 1% AEP flood
Catchment		The area of land draining to a specific location	It includes the catchment of the primary waterway as well as any tributary streams and flowpaths
Catchment flooding		Flooding due to prolonged or intense rainfall (e.g. severe thunderstorms, monsoonal rains in the tropics, tropical cyclones)	Types of catchment flooding include riverine, local overland and groundwater flooding
Chance		The likelihood of something happening that will have adverse or beneficial consequences	In FRM this generally relates to the adverse consequences of floods with chance being related to AEP, for example, 1% chance or 1 in 100 chance per year is equivalent to 1% AEP
Consequence		The outcomes of an event or situation affecting objectives, expressed qualitatively or quantitatively	Consequences can be adverse (e.g. death or injury to people, damage to property and disruption of the community) or beneficial

Term	Short form	Definition	Context for use/additional information
Continuing flood risk		Risk to existing and future development that may be reduced by EM measures	Flood risk to the existing development and future development may be reduced by EM measures depending on flood constraints, however, these measures cannot remove all risk and a residual risk will remain
Defined flood event	DFE	The flood event selected as a general standard for the management of flooding to development	Aims to reduce the frequency of flooding but does not remove all flood risk, for example, in selecting a 1% AEP flood as a DFE you are accepting that there is a 1 in 100 chance that a larger event will occur in any year. This risk is being built into the decision
Design flood		The flood selected as part of the FRM process that forms the basis for physical works to modify the impacts of flooding	The design flood may be considered the flood mitigation standard, for example, a levee may be designed to exclude a 2% AEP flood, which means that floods rarer than this may breech the structure and impact upon the protected area. In this case, the 2% AEP flood would not equate to the crest level of the levee, because this generally has a freeboard allowance, but it may be the level of the spillway to allow for controlled levee overtopping
Development		May be treated differently depending on the following categorisation: ▪ infill development: the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under current land zoning ▪ new development: development of a completely different nature to that associated with the former land-use (e.g. the urban subdivision of a previously rural area) ▪ redevelopment: rebuilding in an area (e.g. as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale)	New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power Redevelopment generally does not require either rezoning or major extensions to urban services
Development control plan	DCP	See Environmental Planning and Assessment Act 1979	
Emergency management	EM	A comprehensive approach to dealing with risks to the community arising from hazards. It is a systematic method for identifying, analysing, evaluating, and managing these risks	May include measures to reduce flood frequency or consequences through prevention and mitigation. measures, and preparation, as well as response and recovery should a flood occur (see PPRR)

Term	Short form	Definition	Context for use/additional information
Existing flood risk		The risk an existing community is exposed to as a result of its location on the floodplain	Existing flood risk may be reduced by existing or proposed FRM measures leaving a residual flood risk to the existing community. Residual flood risk may be further reduced by addressing continuing risk
Flood		A natural phenomenon that occurs when water covers land that is normally dry. It may result from coastal inundation (excluding tsunamis) or catchment flooding, or a combination of both	Flooding results from relatively high stream flow that overtops the natural or artificial banks in any part of a stream, river, estuary, lake, or dam, and/or local overland flowpaths associated with major drainage, and/or oceanic inundation resulting from super-elevated ocean levels
Flood (hydrologic and hydraulic) modelling		Hydrologic and hydraulic computer models to simulate catchment processes of rainfall, run-off, stream flow and distribution of flows across the floodplain or similar	They typically involve consideration of the local flood history, available collected data, and the development of models that are calibrated and validated, where possible, against historic flood events and extended to determine the full range of flood behaviour
Flood affected land		Equivalent to flood prone land	See the definition of flood prone land
Flood awareness		An appreciation of the likely effects of flooding, and a knowledge of the relevant flood warning, response and evacuation procedures facilitating prompt and effective community response to a flood threat	In communities with a low degree of flood awareness, flood warnings may be ignored or misunderstood, and residents confused about what they should do, when to evacuate, what to take with them and where to go
Flood constraints		Key constraints that flooding place on land	These include flood function, flood hazard, flood range, and flood emergency response classification. These can be used to inform FRM including consideration of options such as mitigation works, EM and land-use planning
Flood damage		The tangible (direct and indirect) and intangible costs (financial, opportunity costs, clean-up) of flooding	Tangible costs are quantified in monetary terms (e.g. damage to goods) Intangible damages are difficult to quantify in monetary terms and include the increased levels of physical, emotional and psychological health problems suffered by flood affected people that are attributed to a flood
Flood evacuation		The movement of people from a place of danger to a place of relative safety, and their eventual return	People are usually evacuated to areas outside of flood prone land with access to adequate community support Livestock may be relocated to areas outside of the influence of flooding

Term	Short form	Definition	Context for use/additional information
Flood fringe areas		That part of the flood extents for the event remaining after the flood function areas of floodway and flood storage areas have been defined	
Flood function		The flood related functions of floodways, flood storage and flood fringe within the floodplain	Flood function is equivalent to hydraulic categorisation
Flood hazard		A flood that has the potential to cause harm or conditions with the potential to result in loss of life, injury, and economic loss	The degree of hazard varies with the severity of flooding and is affected by flood behaviour (extent, depth, velocity, isolation, etc.)
Flood impact and risk assessment	FIRA	A study to assess flood behaviour, constraints, and risk, understand offsite flood impacts on property and the community resulting from the development, and flood risk to the development and its users	These studies are generally undertaken for development and are to be prepared by a suitably qualified engineer experienced in hydrological and hydraulic analysis for FRM
Flood liable land		Equivalent to flood prone land	See the definition of flood prone land
Flood plan (local or state)	Local (LFP)	A sub-plan of an EM plan that deals specifically with flooding; they can exist at state, zone, and local levels	The NSW Government develops flood plans as a legislative responsibility to determine how best to respond to floods. These community-based plans describe the risk to the community, outline agency roles and responsibilities, the agreed community emergency response strategy and how floods will be managed
Flood planning area	FPA	The area of land below the FPL	The FPA is generally developed based on the FPL for typical residential development. Different types of development may have different FPLs applied within the FPA. In addition development controls will vary across the FPA due to varying flood constraints
Flood planning level	FPL	The combination of the flood level from the DFE and freeboard selected for FRM purposes	Different FPLs may apply to different types of development Determining the FPL for typical residential development should generally start with a DFE of the 1% AEP flood plus an appropriate freeboard (typically 0.5 m). This assists in determining the FPA
Flood prone land		Land susceptible to flooding by the PMF event	Flood prone land is also known as the floodplain, flood liable land and flood affected land
Flood risk		Risk is based on the consideration of the consequences of the full range of flood behaviour on communities and their social settings, and the natural and built environment	See also risk. The degree of risk varies with circumstances across the full range of floods. It is affected by factors including flood behaviour and hazard, topography, and EM difficulties

Term	Short form	Definition	Context for use/additional information
Flood risk management	FRM	The management of flood risk to communities	
Flood risk management manual: the policy and manual for the management of flood liable land	the manual	This manual	
Flood storage areas		Areas of the floodplain that are outside floodways which generally provide for temporary storage of floodwaters during the passage of a flood and where flood behaviour is sensitive to changes that impact on temporary storage of water during a flood	See also flood function, floodways, and flood fringe areas
Flood study		A comprehensive technical investigation of flood behaviour undertaken in accordance with the principles in this manual and consistent with associated guidelines A flood study defines the nature of flood behaviour and hazard across the floodplain by providing information on the extent, level, and velocity of floodwaters, and on the distribution of flood flows considering the full range of flood events up to and including extreme events, such as the PMF	A flood study is undertaken in accordance with the FRM process outlined in this manual to support the understanding and management of flood risk. It is different from a flood impact and risk assessment (FIRA)
Flood warnings		Warnings issued when there is more certainty that flooding is expected, are more targeted and are issued for specific catchments	Flood warnings include more specific predictions of the severity of expected flooding and may give quantitative figures such as expected river water heights at gauge stations
Floodplain		Equivalent to flood prone land	See the definition of flood prone land
Floodways		Areas of the floodplain which generally convey a significant discharge of water during floods and are sensitive to changes that impact flow conveyance. They often align with naturally defined channels or form elsewhere in the floodplain	See also flood function, floodways and flood fringe areas Floodways are sometimes known as flow conveyance areas
Flow		The rate of flow of water measured in volume per unit time, for example, cubic metres per second (m^3/s)	Flow is different from the speed or velocity of flow, which is a measure of how fast the water is moving

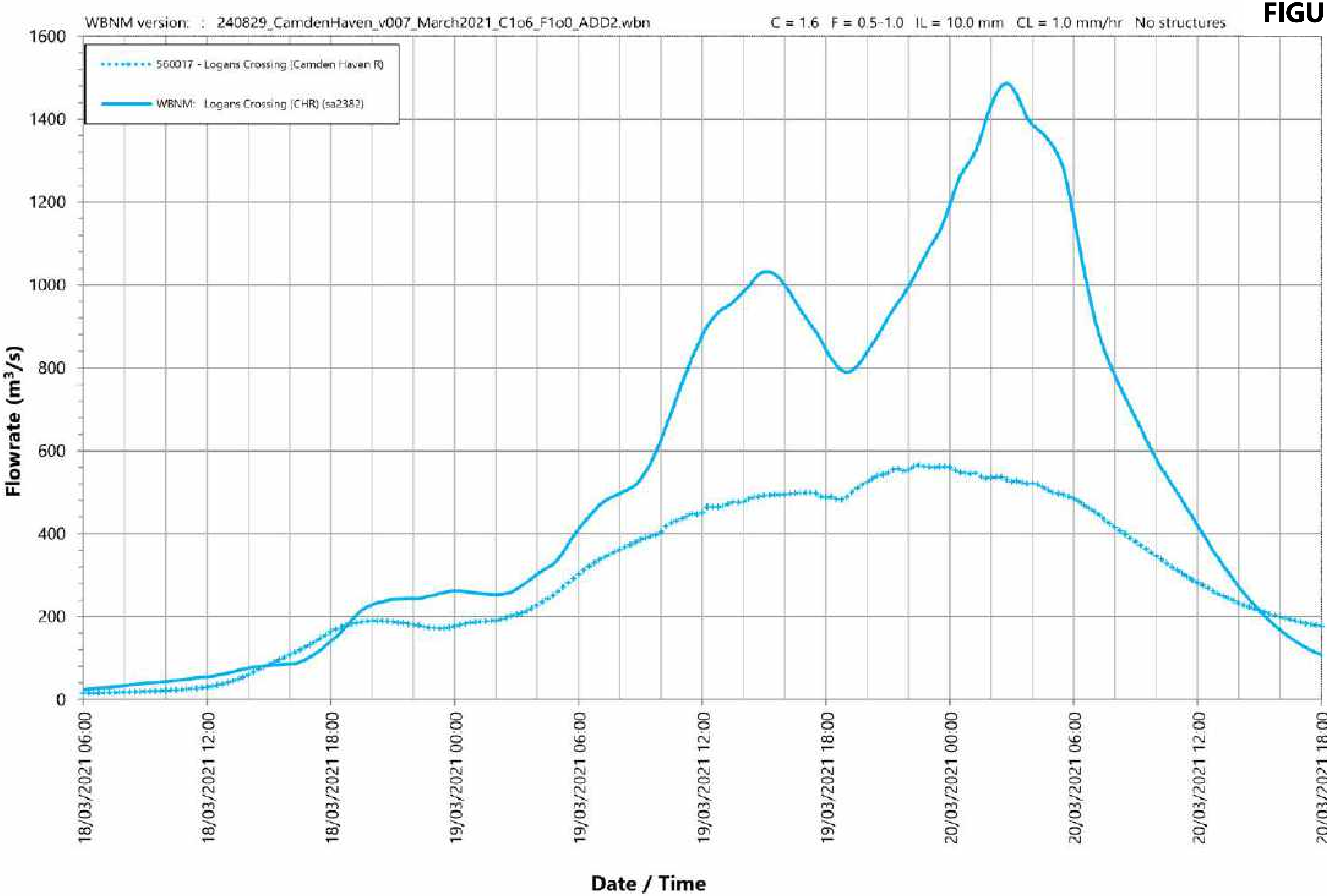
Term	Short form	Definition	Context for use/additional information
Freeboard		A factor of safety typically used in relation to the setting of minimum floor levels or levee crest levels	Freeboard aims to provide reasonable certainty that the risk exposure selected in deciding on a specific event for development controls or mitigation works is achieved. Freeboards for development controls and mitigation works will differ. In addition freeboards for development control may vary with the type of flooding and with the type of development
Frequency		The measure of likelihood expressed as the number of occurrences of a specified event in a given time	For example, the frequency of occurrence of a 20% AEP or 5-year ARI flood is once every 5 years on average
Future flood risk		The risk future development and its users are exposed to as a result of its location on the floodplain	Future flood risk may be reduced by existing or proposed FRM measures and land-use planning controls that consider the flood constraints on the land. This leaves a residual flood risk to the new development and its users. This residual flood risk may be further reduced by addressing continuing flood risk
Gauge height		The height of a flood level at a particular water level gauge site related to a specified datum	The datum or may not be the AHD
Hazard		A source of potential harm or conditions that may result in loss of life, injury, and economic loss due to flooding	
Hydraulics		The study of water flow in waterways and flowpaths; in particular, the evaluation of flow parameters such as water level and velocity	
Hydrology		The study of the rainfall and run-off process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods	
Likelihood		A qualitative description of probability and frequency	See also frequency and probability
Likelihood of occurrence		The likelihood that a specified event will occur	With respect to flooding, see also AEP and ARI
Local environmental plan	LEP	See Environmental Planning and Assessment Act 1979	

Term	Short form	Definition	Context for use/additional information
Local government area	LGA		The area serviced by the local government council
Local overland flooding	LOF	Inundation by local run-off on its way to a waterway, rather than overbank flow from a waterway	
Local strategic planning statement	LSPS		Local strategic planning statements assist councils to implement the priorities set out in their community strategic plan and actions in regional and district plans
Loss		Any negative consequence or adverse effect, financial or otherwise	
NSW Floodplain Management Program	the program	The NSW Government's program of technical support and financial assistance to local councils to enable them to understand and manage their flood risk	The program, manual and FRM guides support the delivery of the policy through a partnership across governments
NSW Flood prone land policy	the policy	The NSW Flood prone land policy included in this document	
Probability		A statistical measure of the expected chance of a flood	For example, AEP
Probable maximum flood	PMF	The largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation (PMP), and where applicable, snow melt, coupled with the worst flood-producing catchment conditions	This is equivalent to the probable maximum precipitation flood in Australian Rainfall and Runoff (ARR) The PMF in ARR is used for estimating dam design floods
Probable maximum precipitation	PMP	The greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long term climatic trends (World Meteorological Organization 1986)	PMP is the primary input to PMF estimation
Rainfall intensity		The rate at which rain falls, typically measured in millimetres per hour (mm/h)	Rainfall intensity varies throughout a storm in accordance with the temporal pattern of the storm
Residual flood risk		The risk to the existing and future community that remains with FRM, EM and land-use planning measures in place to address flood risk	FRM measures cannot remove all flood risk, but rather they reduce residual flood risk

Term	Short form	Definition	Context for use/additional information
Risk		The effect of uncertainty on objectives' (ISO 2018)	See also flood risk. Note 4 of the definition in ISO31000: 2018 also states that 'risk is usually expressed in terms of risk sources, potential events, their consequences and their likelihood'
Run-off		The amount of rainfall that ends up as streamflow, also known as rainfall excess	
State environmental planning policy	SEPP	See Environmental Planning and Assessment Act 1979	
Scenario		A scenario may relate to current, historical, or assumed future floodplain, catchment and climate conditions	Flood behaviour varies over time with changes in key catchment and floodplain (such as the scale of development) and climatic conditions (including climate change), and due to the implementation of FRM measures. A range of scenarios are generally needed to understand and assess flood behaviour
Stage		Equivalent to water level ; measured with reference to a specified datum	Measurement may relate to AHD, a local datum, or a local water level gauge
Storm surge		The increases in coastal water levels above predicted astronomical tide level (i.e. tidal anomaly) resulting from a range of location-dependent factors	These factors may include the inverted barometer effect, wind and wave setup and astronomical tidal waves, together with any other factors that increase tidal water level
Velocity		The speed of floodwaters, measured in metres per second (m/s)	
Vulnerability		The degree of susceptibility and resilience of a community, its social setting, and the built environment to flooding	Vulnerability is assessed in terms of ability of the community and environment to anticipate, cope, and recover from flood events

Appendix A. WBNM Hydrologic Model Calibration and Validation Plots

FIGURE A-1



Prepared by:

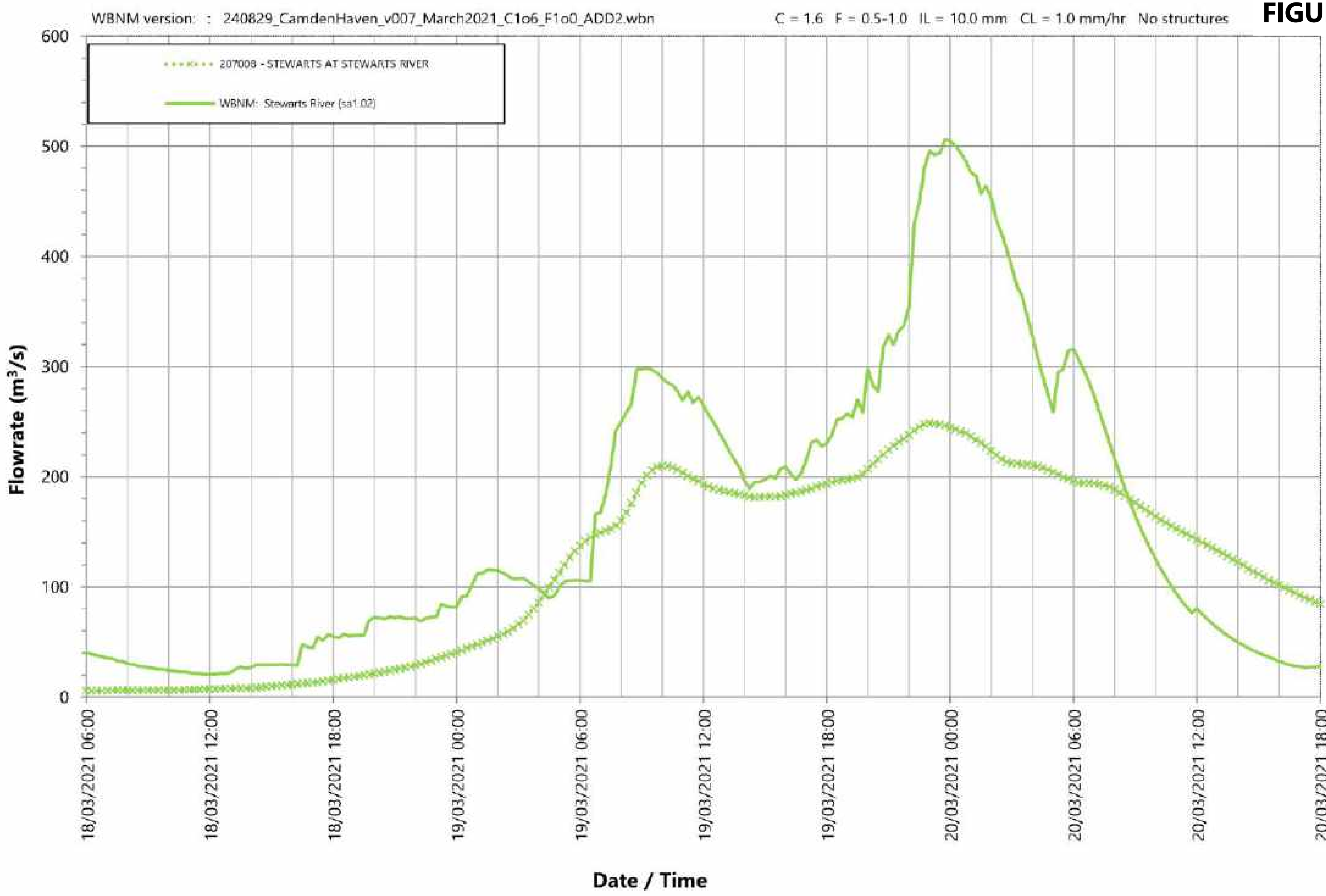
worley consulting

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250205_CamdenHaven_A4L_APPA.pdf

MARCH 2021 FLOOD EVENT
LOGANS CROSSING (CAMDEN HAVEN RIVER)
(Gauge No. 560017)

FIGURE A-2

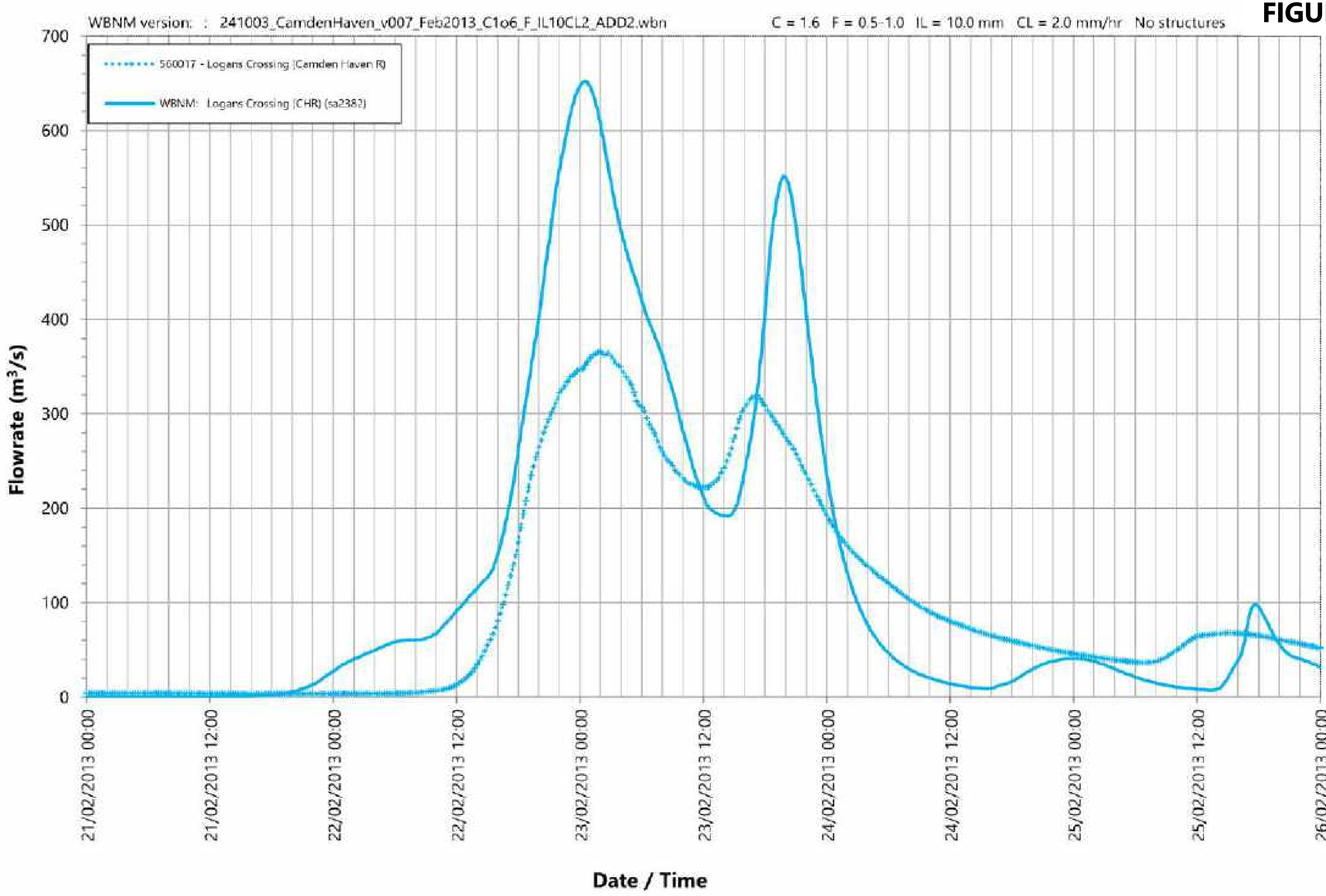


Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs
fg311015-00481_250205_CamdenHaven_A4L_APPA.pdf

MARCH 2021 FLOOD EVENT
STEWARTS AT STEWARTS RIVER
(Gauge No. 207008)

FIGURE A-3



Prepared by:

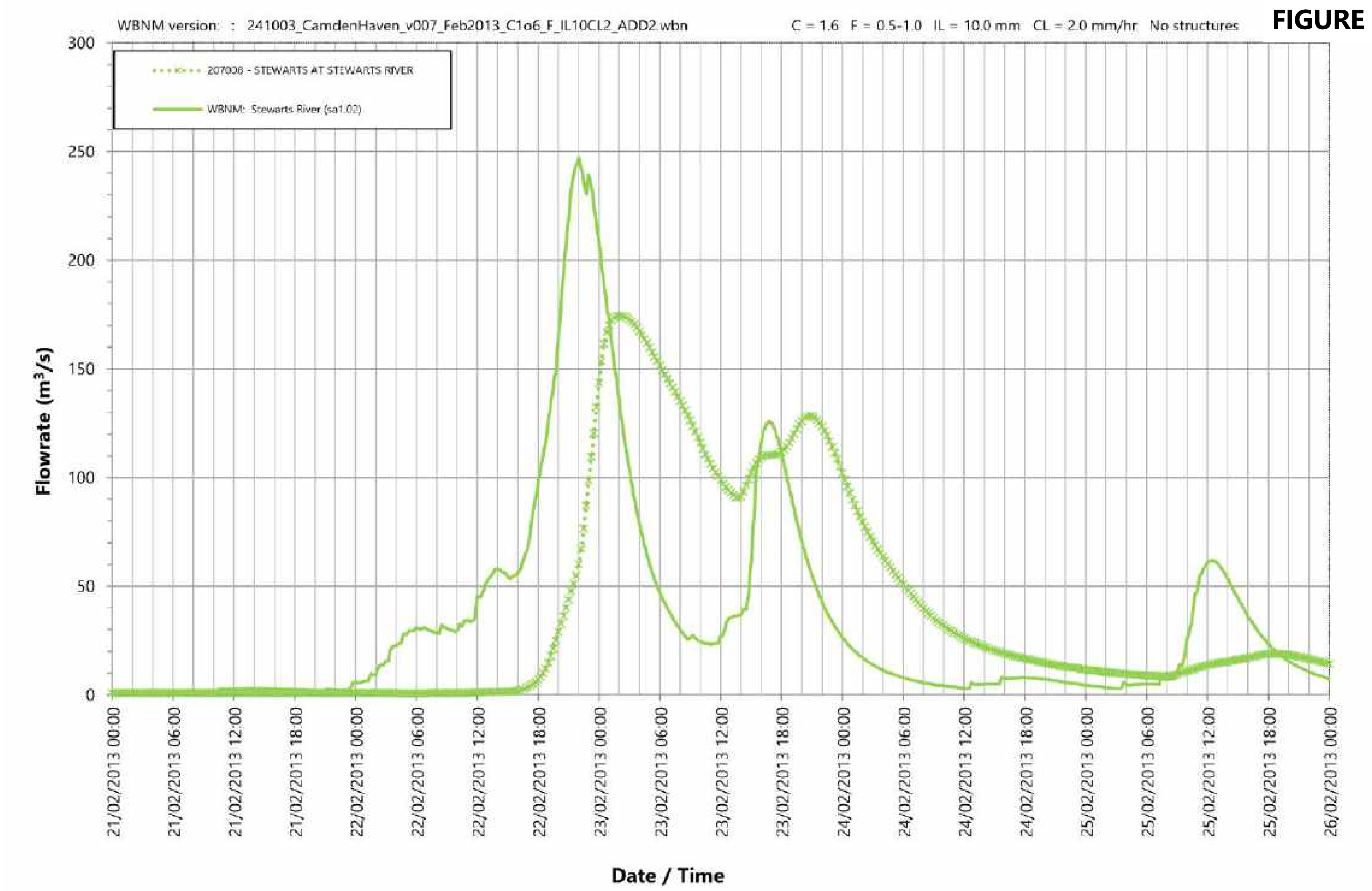
worley consulting

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250205_CamdenHaven_A4L_APPA.pdf

FEBRUARY 2013 FLOOD EVENT
LOGANS CROSSING (CAMDEN HAVEN RIVER)
(Gauge No. 560017)

FIGURE A-4



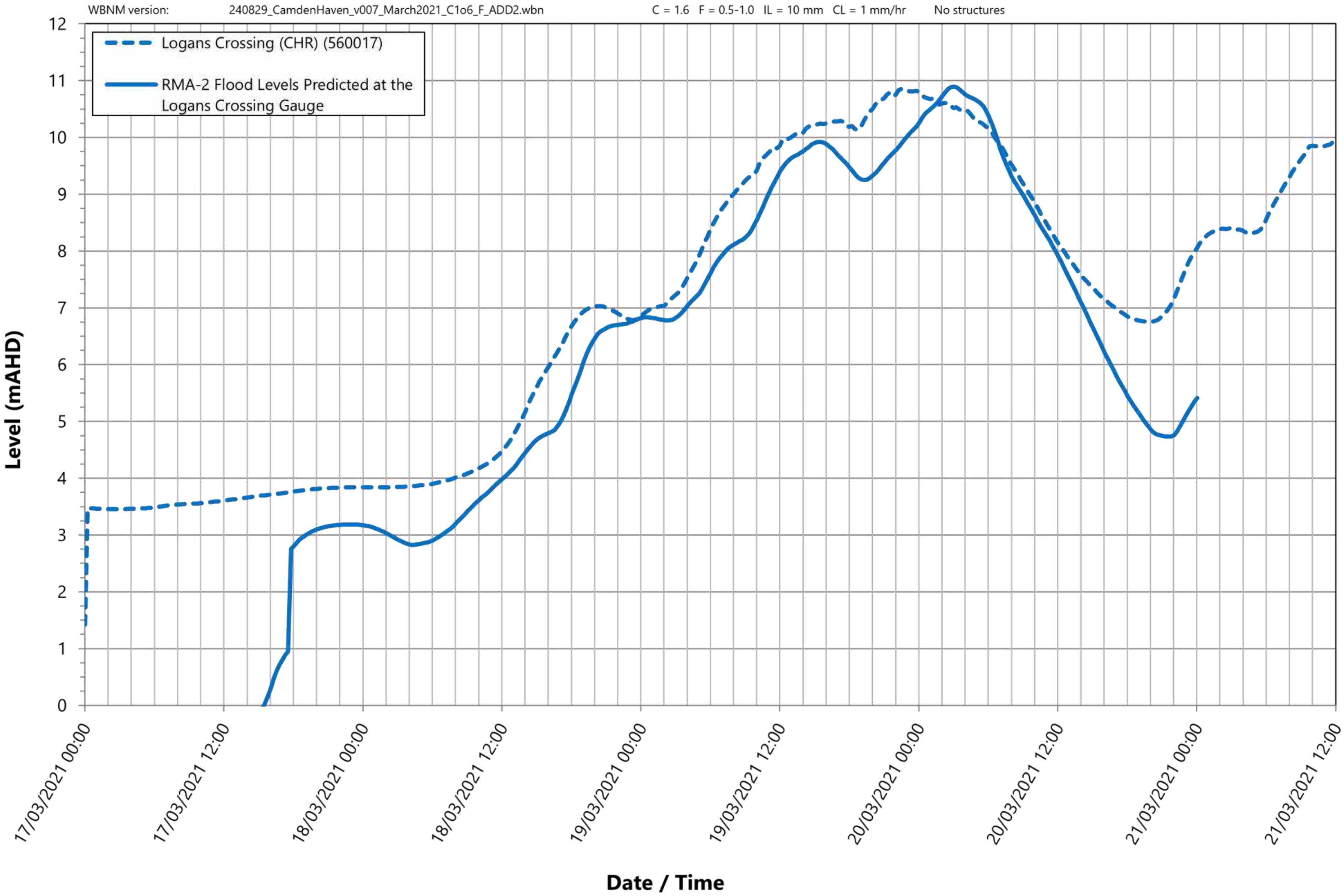
Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs
fg311015-00481_250205_CamdenHaven_A4L_APPA.pdf

FEBRUARY 2013 FLOOD EVENT
STEWARTS AT STEWARTS RIVER
(Gauge No. 207008)

Appendix B. RMA-2 Hydraulic Model Validation Plots

FIGURE B-1



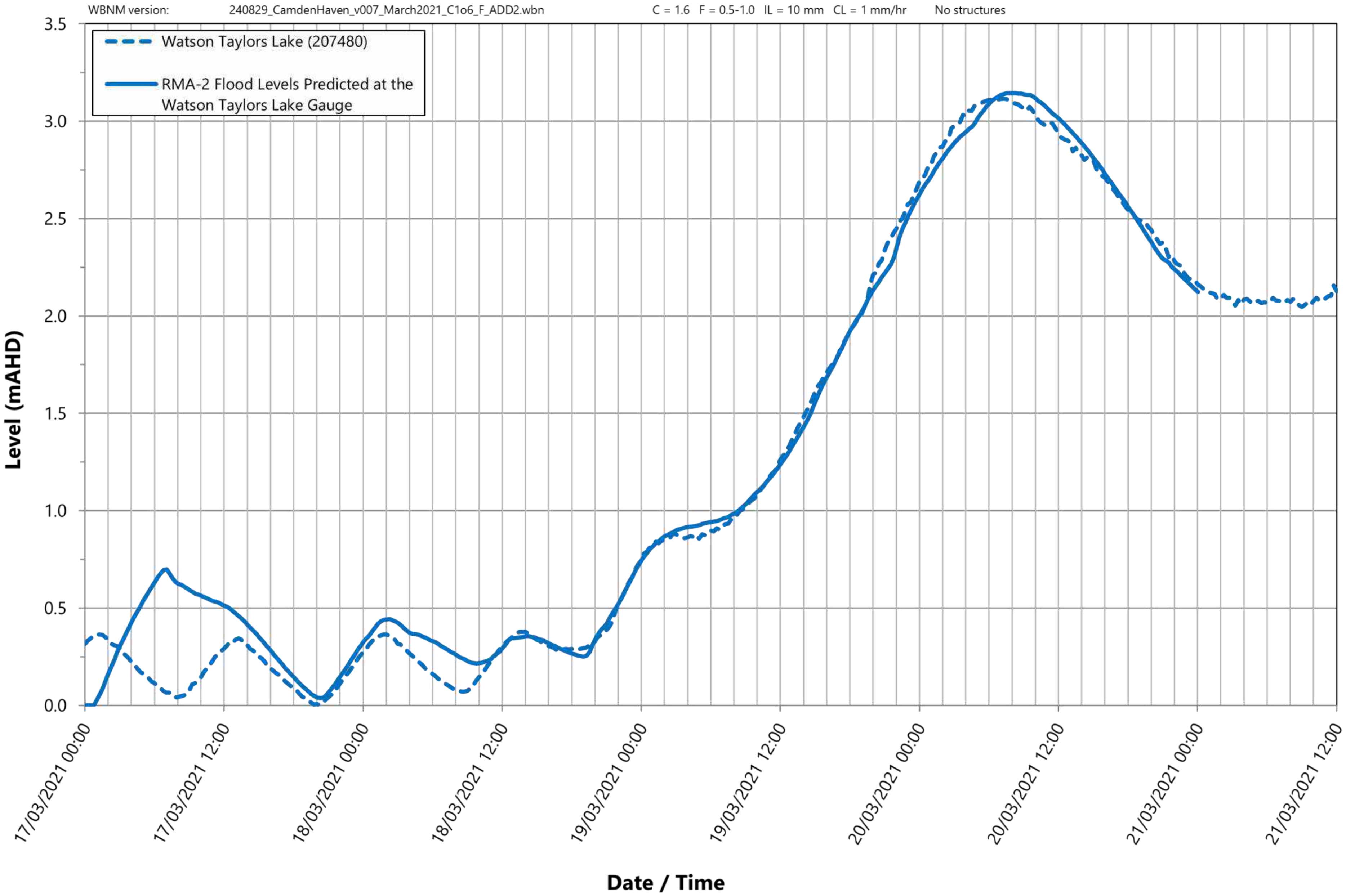
Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250205_CamdenHaven_A4L_APPB.pdf

MARCH 2021 FLOOD EVENT
LOGANS CROSSING (CAMDEN HAVEN RIVER)
(Gauge No. 560017)

FIGURE B-2



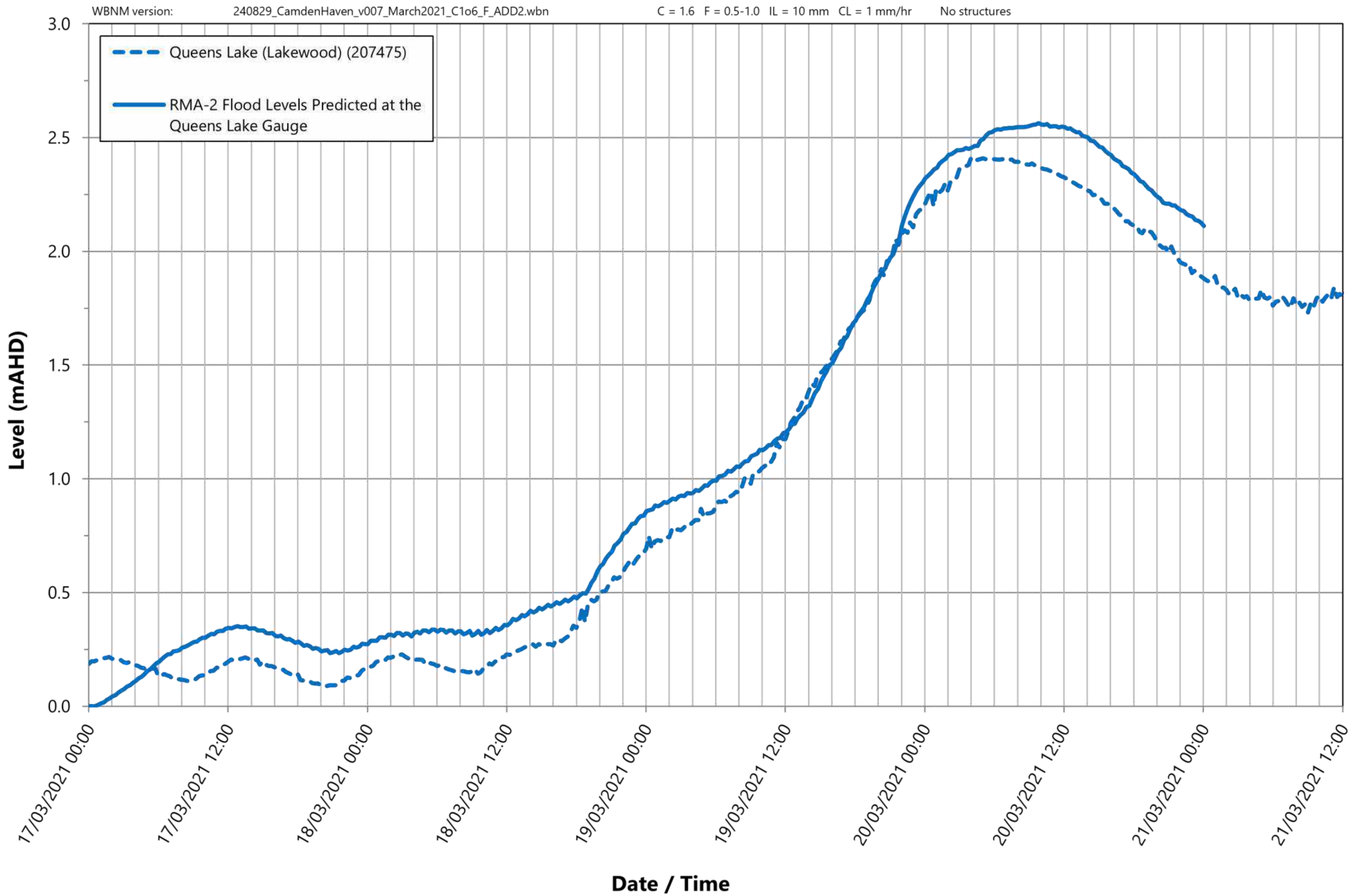
Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250205_CamdenHaven_A4L_APPB.pdf

MARCH 2021 FLOOD EVENT
WATSON TAYLORS LAKE
(Gauge No. 207480)

FIGURE B-3



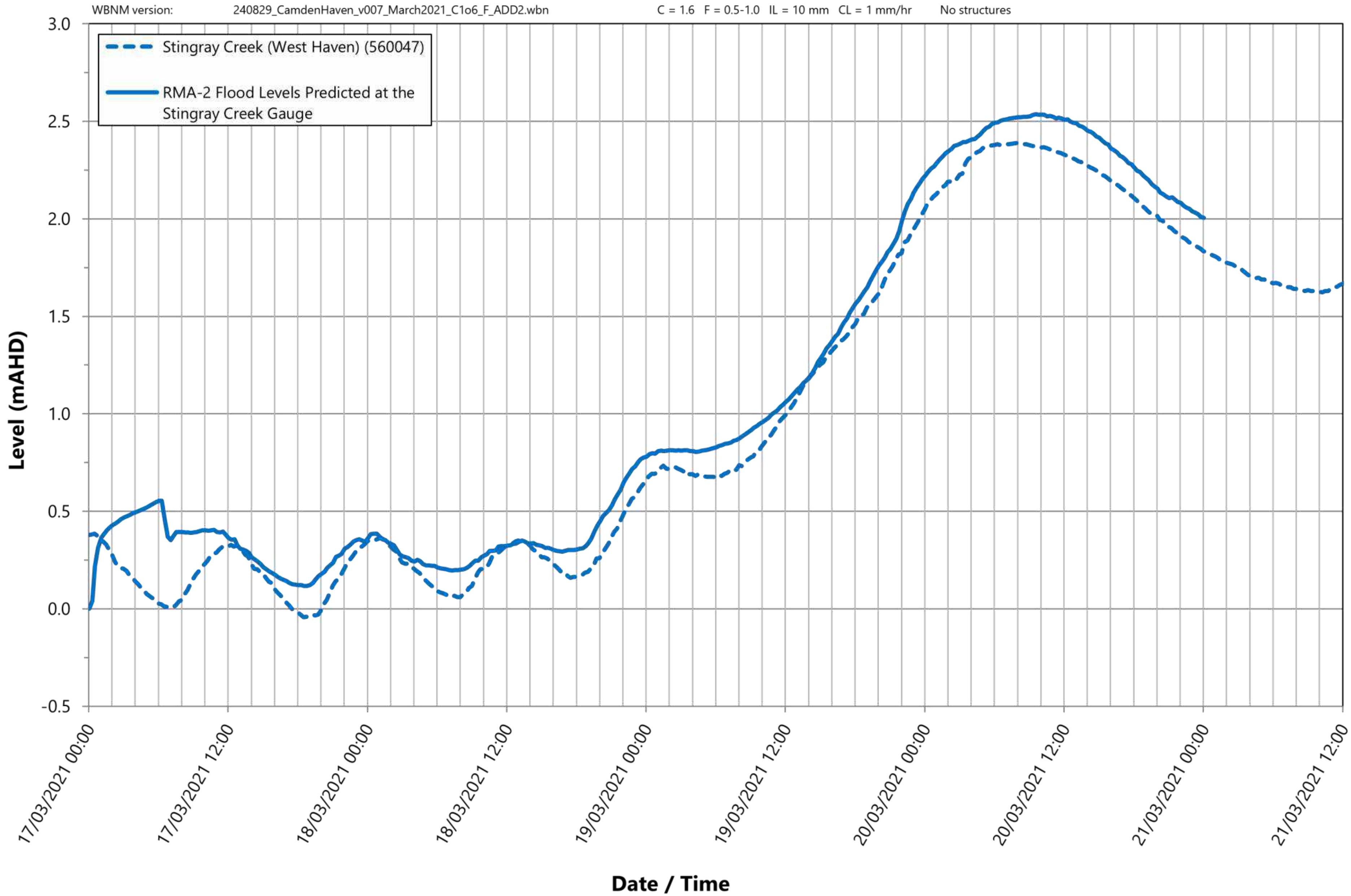
Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250205_CamdenHaven_A4L_APPB.pdf

MARCH 2021 FLOOD EVENT
QUEENS LAKE AT LAKEWOOD
(Gauge No. 207475)

FIGURE B-4

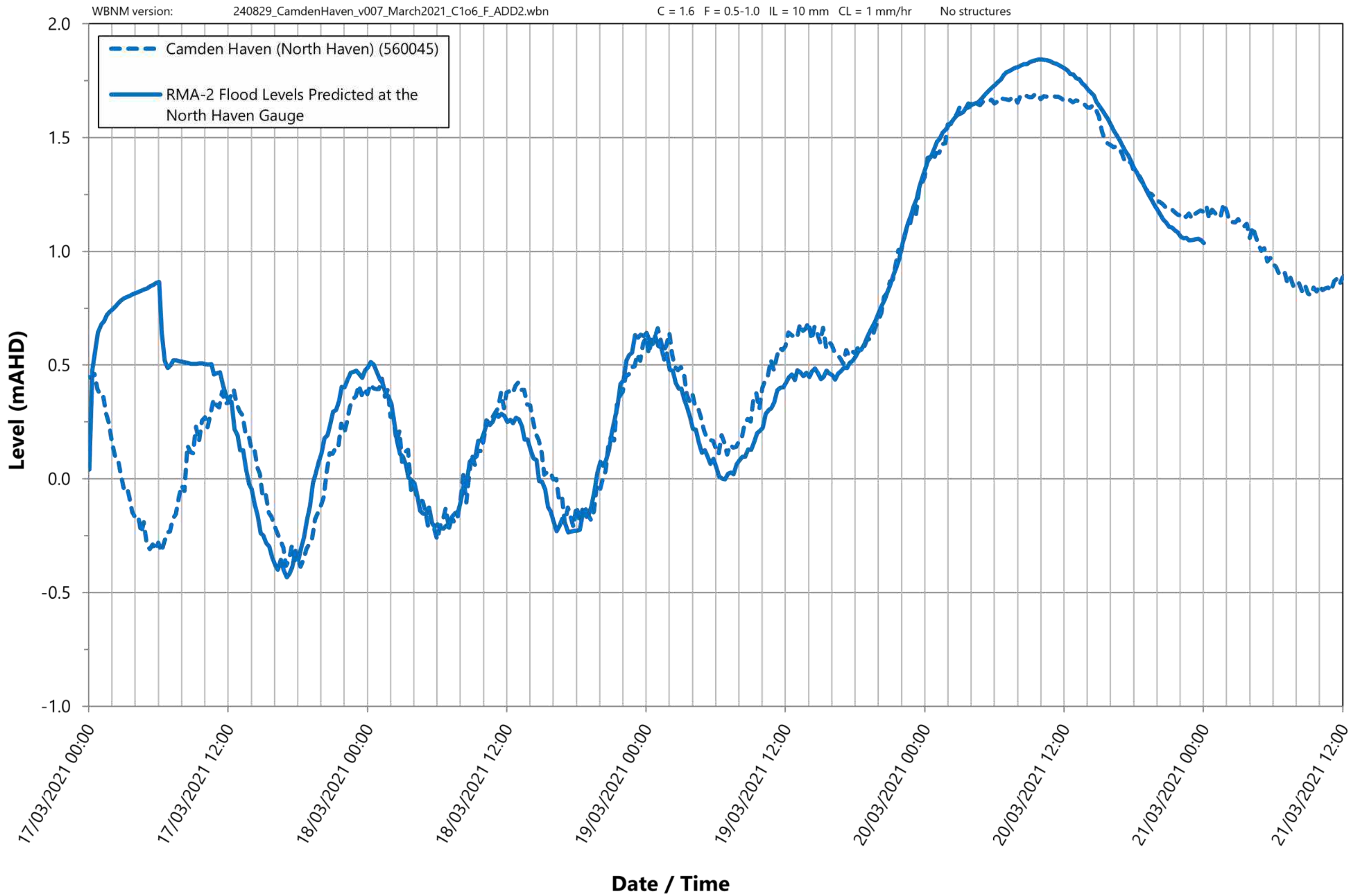


Prepared by: worley consulting

250205_QGIS_CamdenHaven_Figures.qgs
fg311015-00481_250205_CamdenHaven_A4L_APPB.pdf

MARCH 2021 FLOOD EVENT
STINGRAY CREEK AT WEST HAVEN
(Gauge No. 560047)

FIGURE B-5



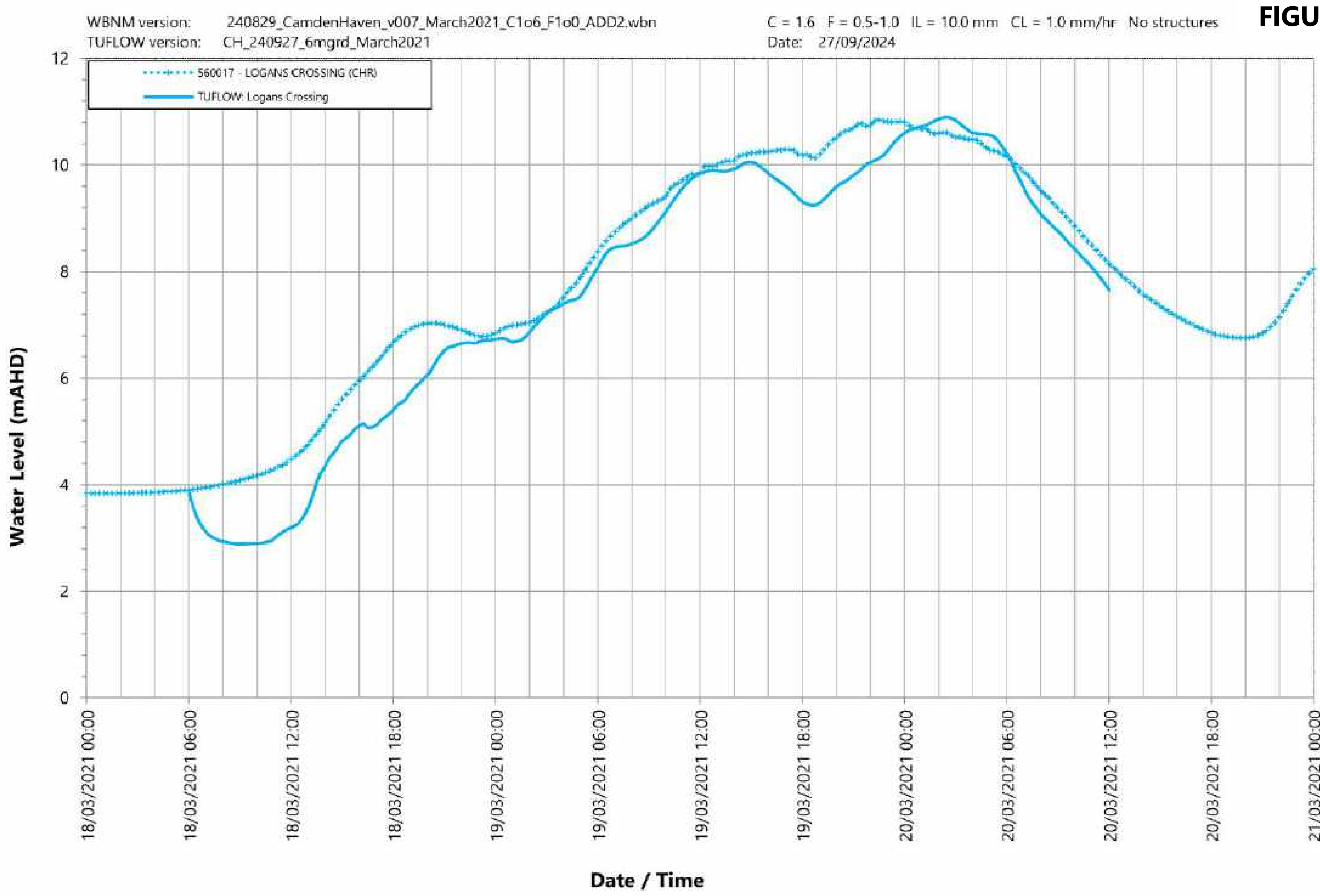
Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs
fg311015-00481_250205_CamdenHaven_A4L_APPB.pdf

MARCH 2021 FLOOD EVENT
NORTH HAVEN
(Gauge No. 560045)

Appendix C. TUFLOW Hydraulic Model Calibration and Validation Plots

FIGURE C-1

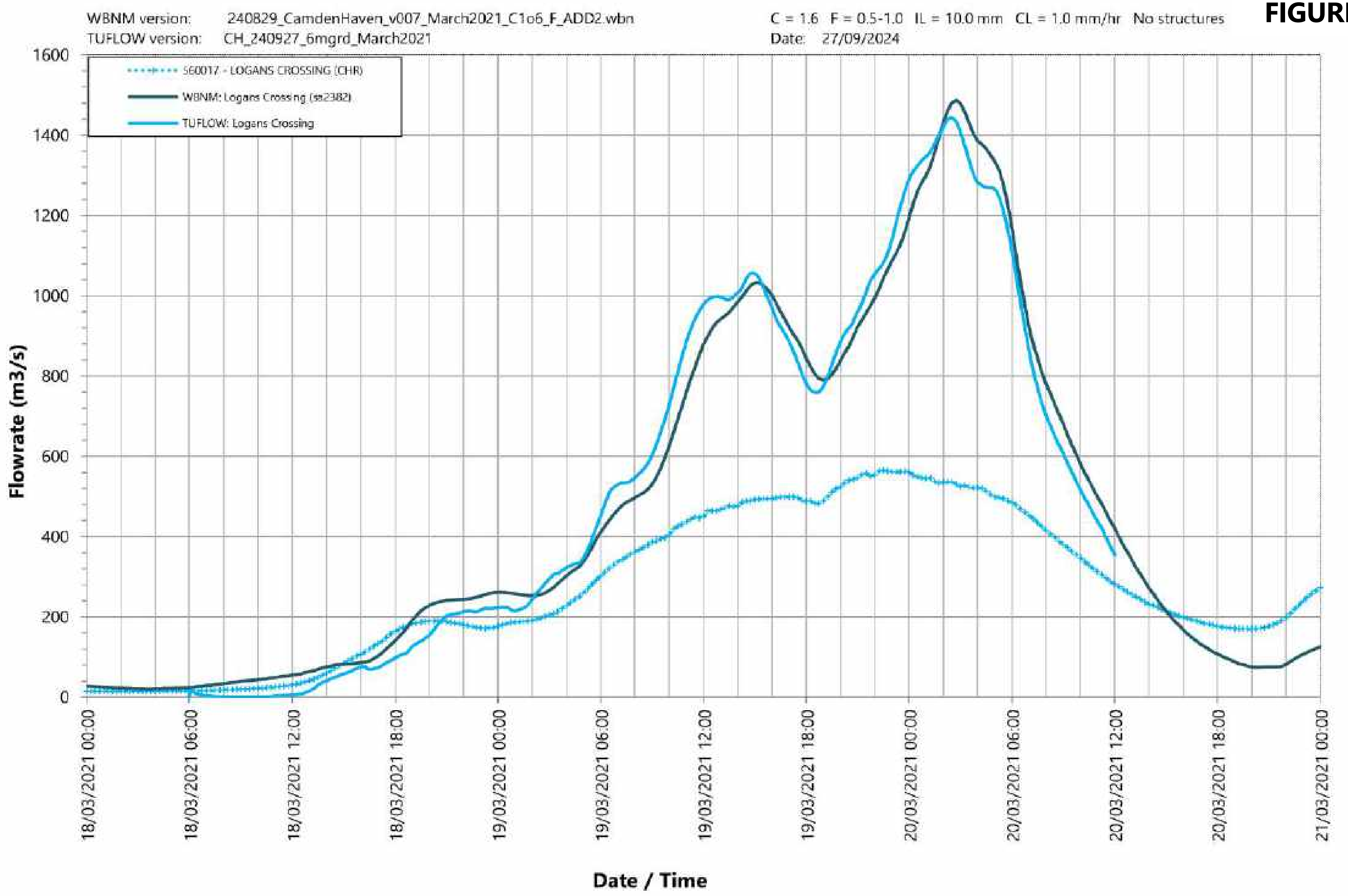


Prepared by: worley consulting

250205_QGIS_CamdenHaven_Figures.qgs
fg311015-00481_250205_CamdenHaven_A4L_APPC.pdf

MARCH 2021 FLOOD EVENT
LOGANS CROSSING (CAMDEN HAVEN RIVER)
(Gauge No. 560017)

FIGURE C-2



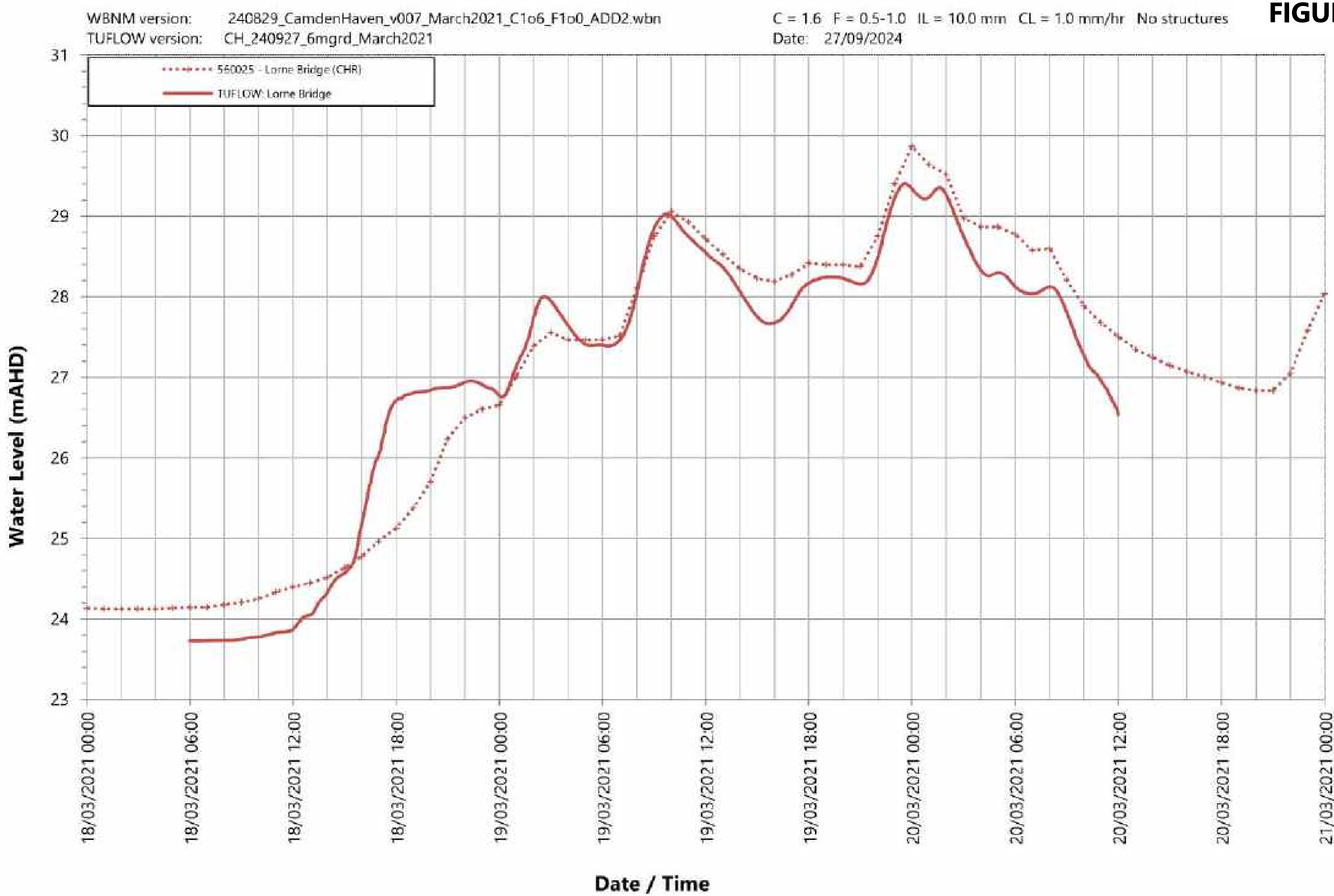
Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250205_CamdenHaven_A4L_APPC.pdf

MARCH 2021 FLOOD EVENT
LOGANS CROSSING (CAMDEN HAVEN RIVER)
(Gauge No. 560017)

FIGURE C-3

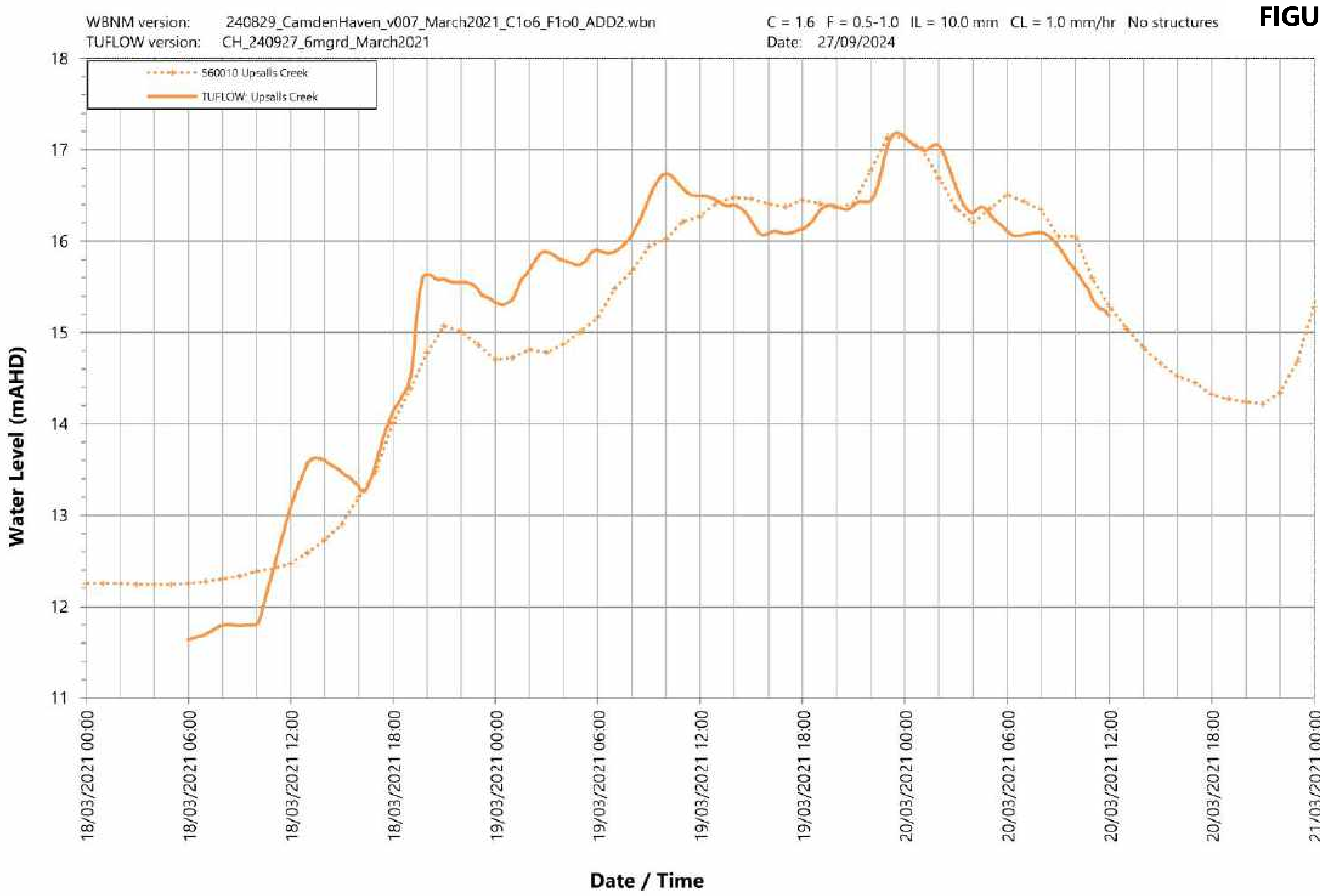


Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs
fg311015-00481_250205_CamdenHaven_A4L_APPC.pdf

MARCH 2021 FLOOD EVENT
LORNE BRIDGE (CAMDEN HAVEN RIVER)
(Gauge No. 560025)

FIGURE C-4

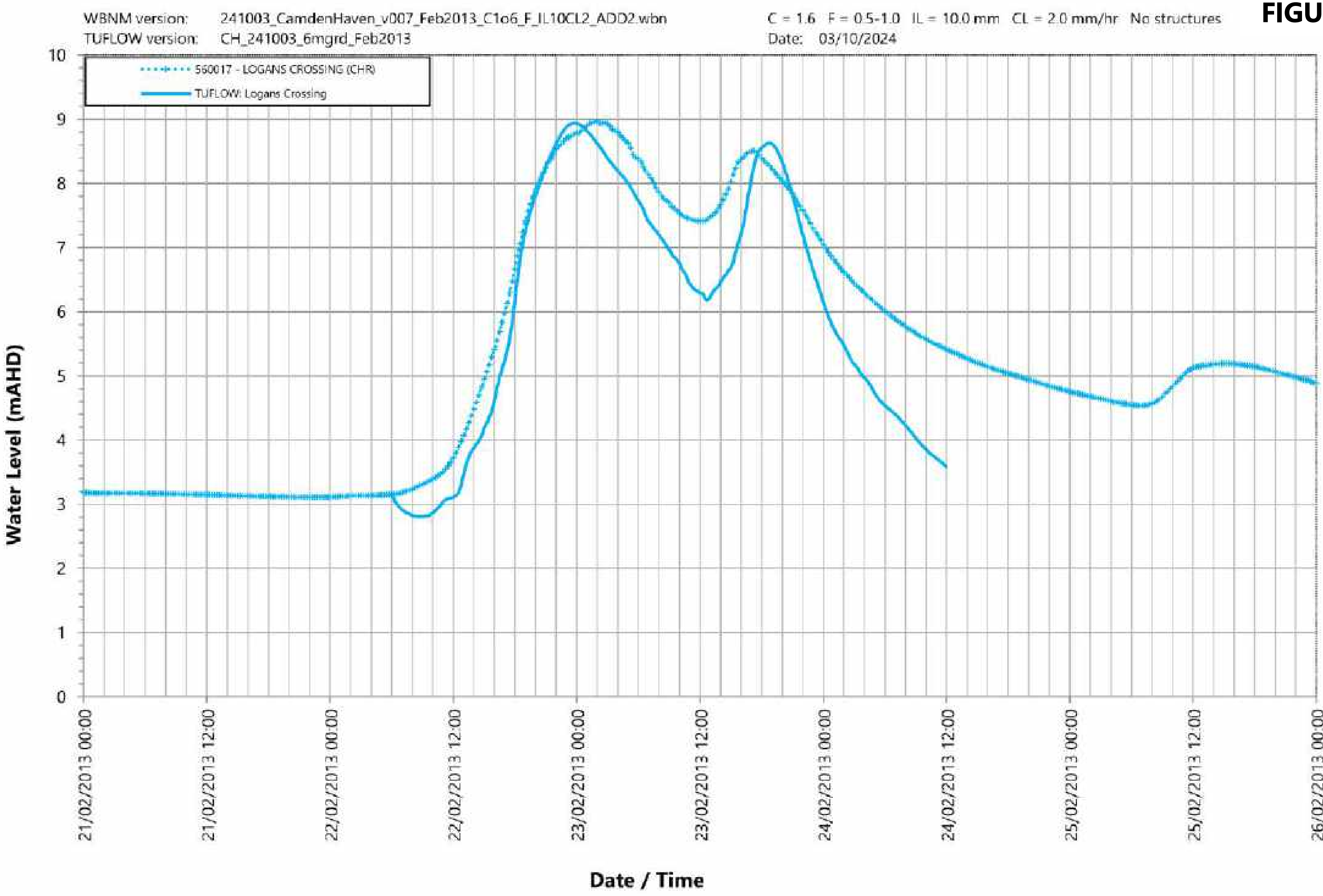


Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs
fg311015-00481_250205_CamdenHaven_A4L_APPC.pdf

MARCH 2021 FLOOD EVENT
UPSALLS CREEK
(Gauge No. 560010)

FIGURE C-5



Prepared by:

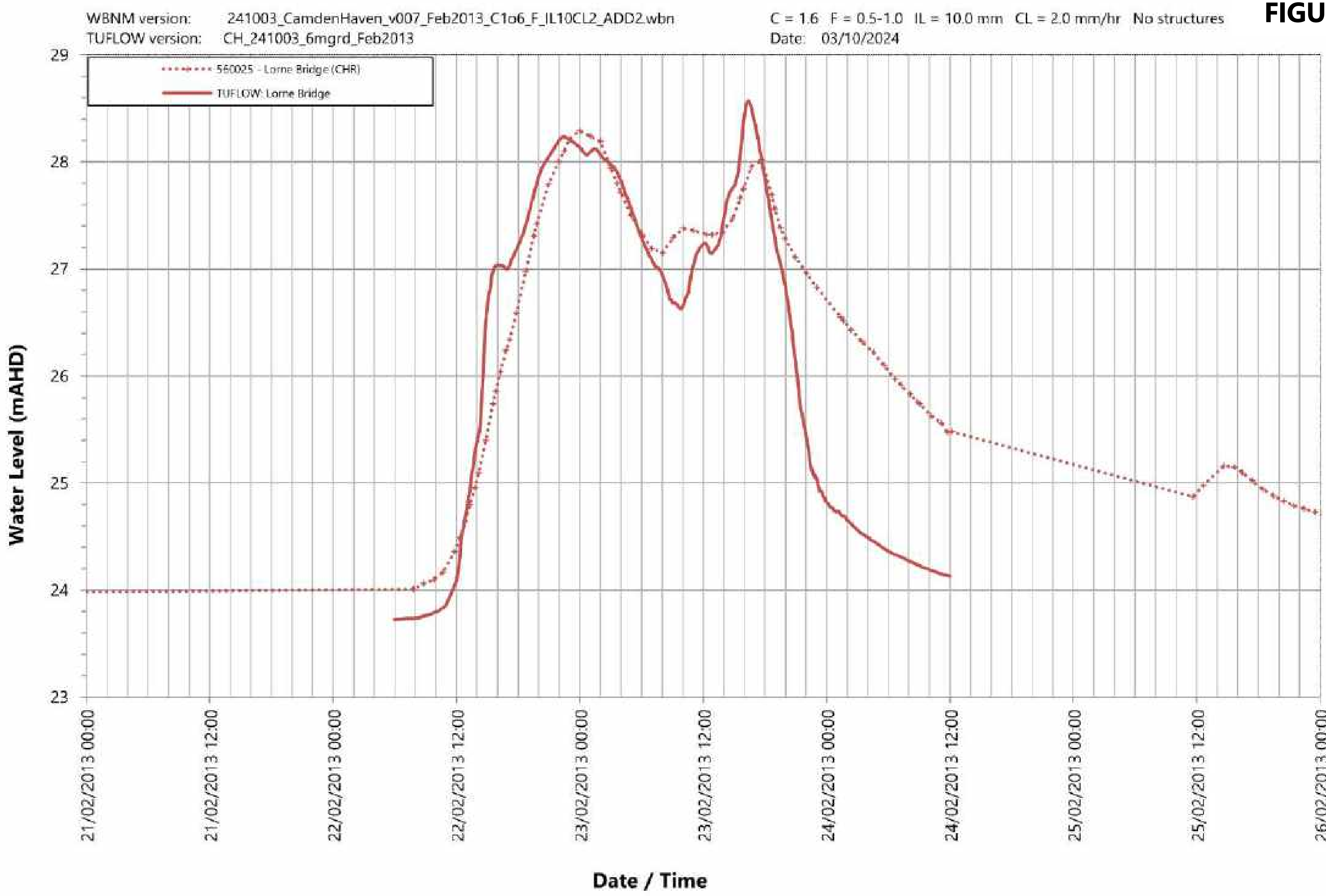
worley consulting

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250205_CamdenHaven_A4L_APPC.pdf

FEBRUARY 2013 FLOOD EVENT
LOGANS CROSSING (CAMDEN HAVEN RIVER)
(Gauge No. 560017)

FIGURE C-6

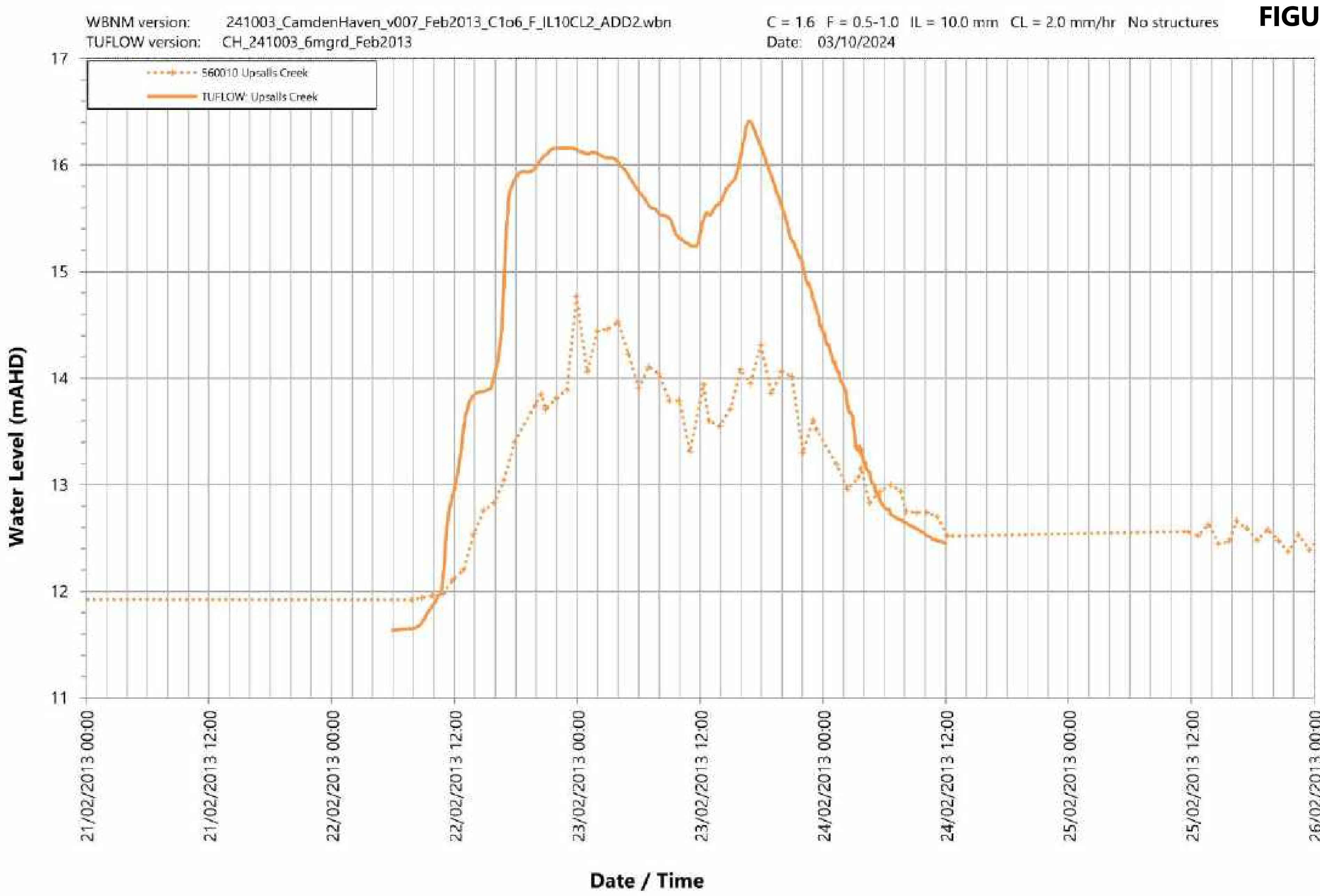


Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs
fg311015-00481_250205_CamdenHaven_A4L_APPC.pdf

FEBRUARY 2013 FLOOD EVENT
LORNE BRIDGE (CAMDEN HAVEN RIVER)
(Gauge No. 560025)

FIGURE C-7



Prepared by:

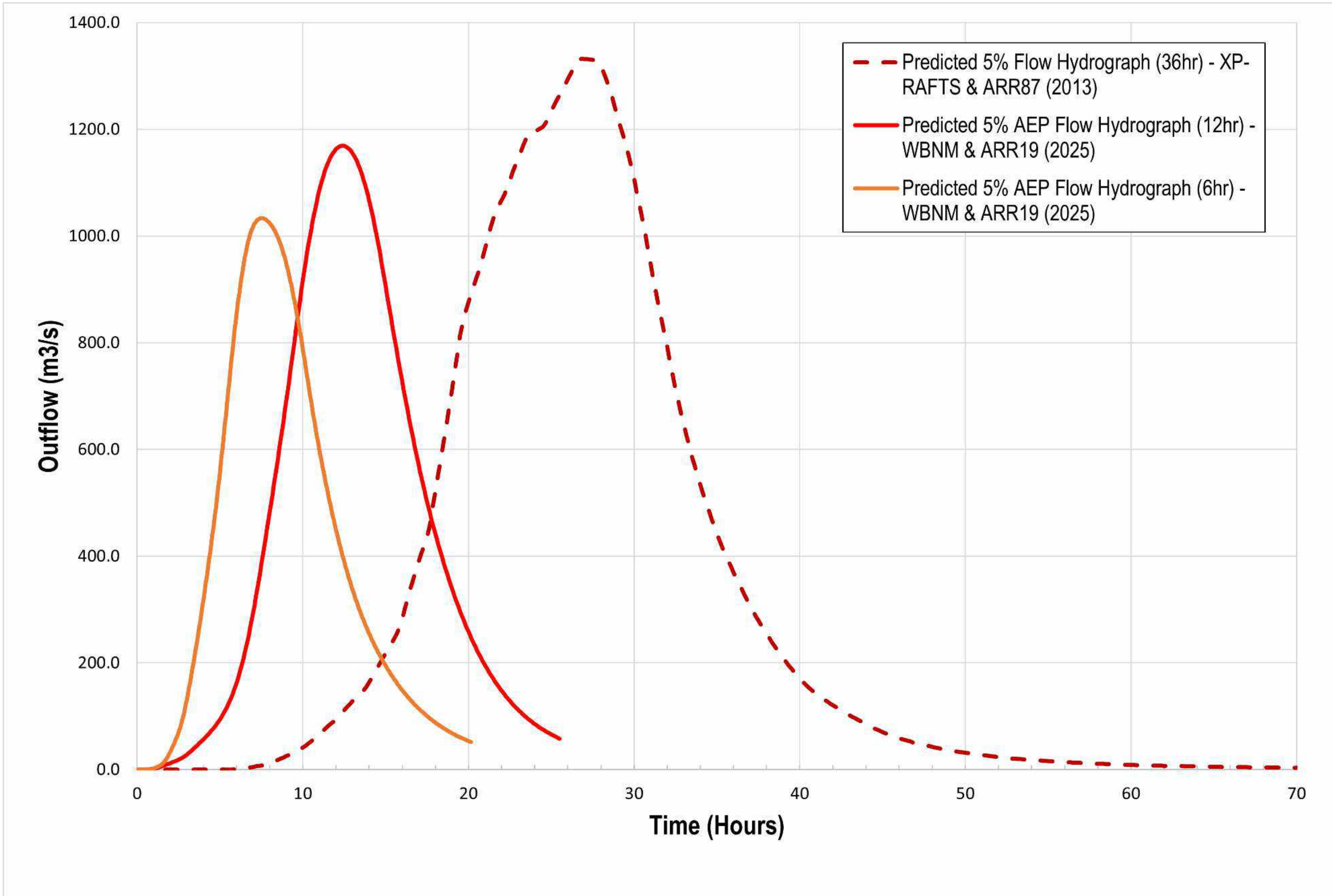
250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250205_CamdenHaven_A4L_APPC.pdf

FEBRUARY 2013 FLOOD EVENT
UPSALLS CREEK
(Gauge No. 560010)

Appendix D. Comparison Between Updated and Previous Design Event Hydrographs

FIGURE D-1



Note: Refer Table 7-3 for peak design flow magnitudes

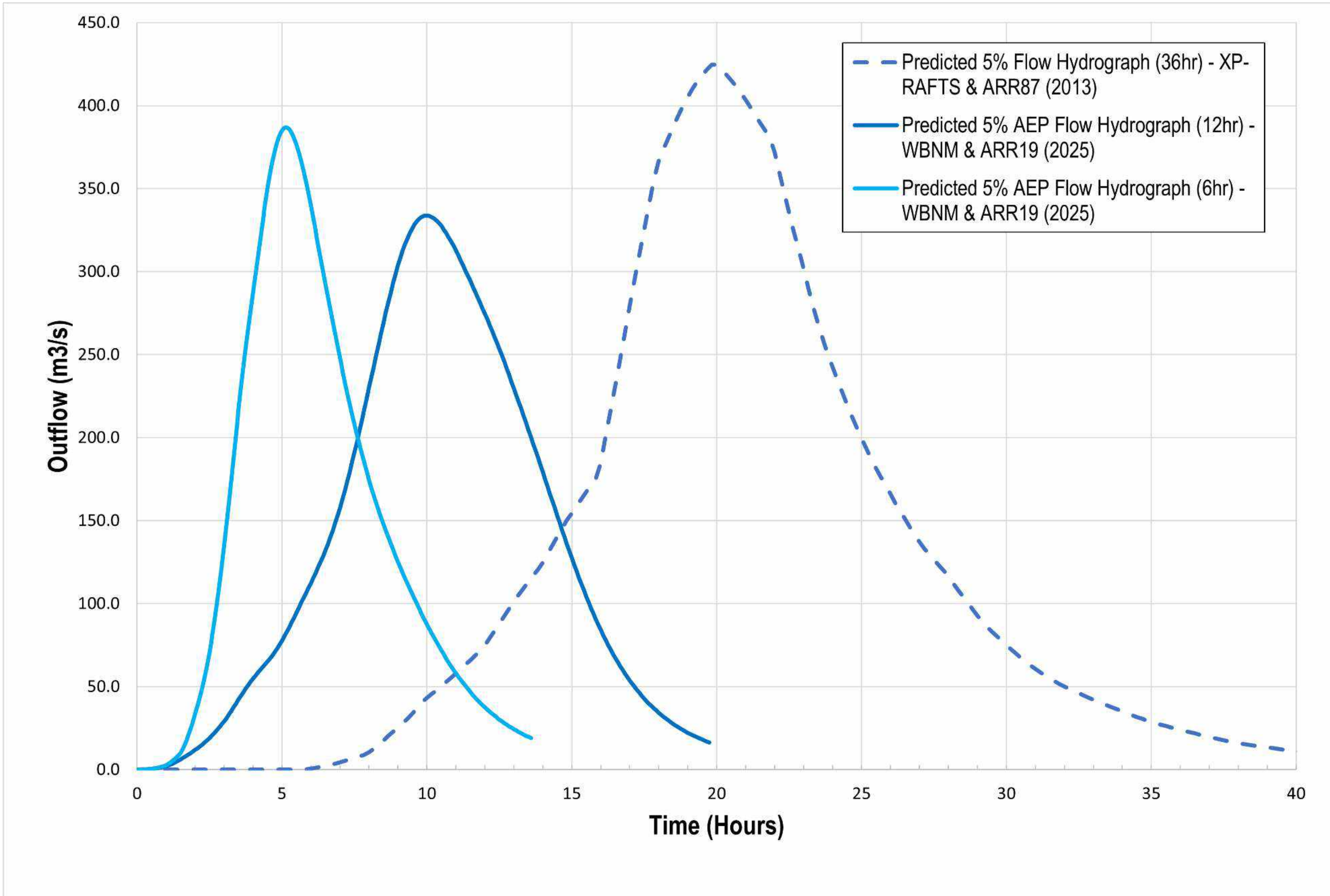
Prepared by: worley consulting

250214_CamdenHaven_DesignPlots.xlxs

fg311015-00418_241108_Appendix D.pdf

COMPARISON BETWEEN UPDATED AND ADOPTED 5% AEP FLOW HYDROGRAPHS AT THE LOGANS CROSSING RMA-2 INFLOW LOCATION

FIGURE D-2



Note: Refer Table 7-3 for peak design flow magnitudes

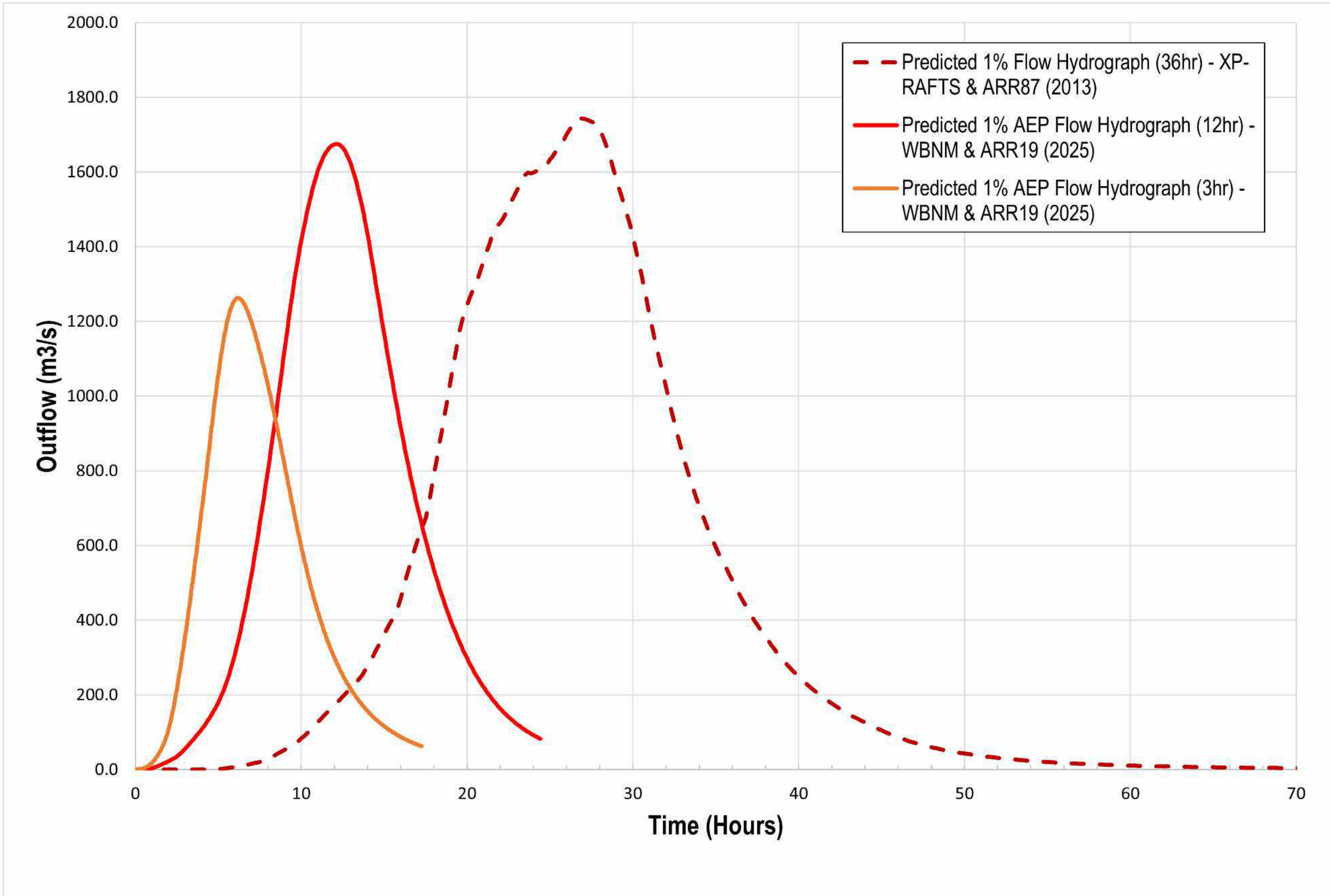
Prepared by:

250214_CamdenHaven_DesignPlots.xlxs

fg311015-00418_241108_Appendix D.pdf

COMPARISON BETWEEN UPDATED AND ADOPTED 5% AEP FLOW HYDROGRAPHS AT THE HERONS CREEK RMA-2 INFLOW LOCATION

FIGURE D-3



Note: Refer Table 7-3 for peak design flow magnitudes

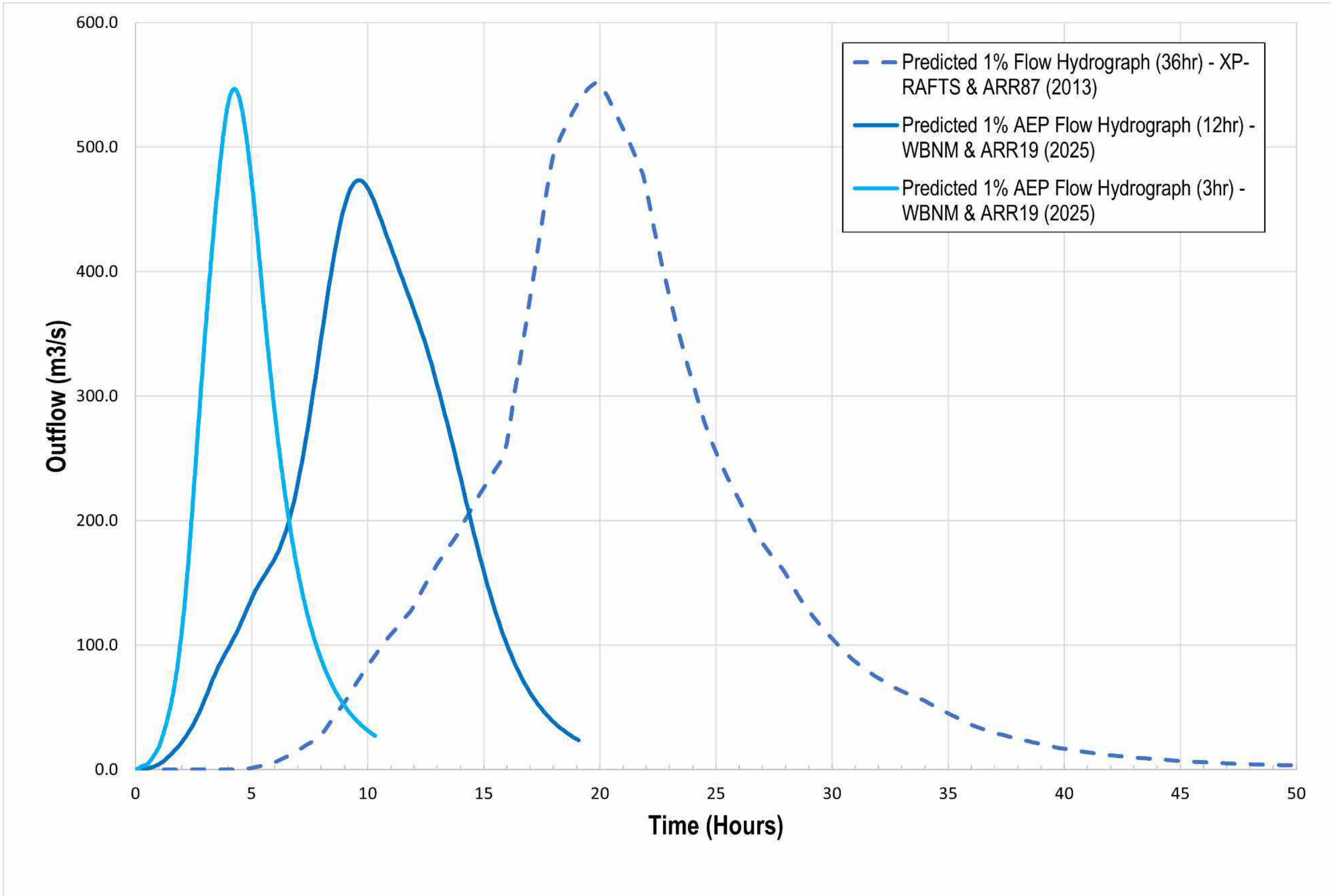
Prepared by:

250214_CamdenHaven_DesignPlots.xlxs

fg311015-00418_241108_Appendix D.pdf

COMPARISON BETWEEN UPDATED AND ADOPTED 1% AEP FLOW HYDROGRAPHS AT THE LOGANS CROSSING RMA-2 INFLOW LOCATION

FIGURE D-4



Note: Refer Table 7-3 for peak design flow magnitudes

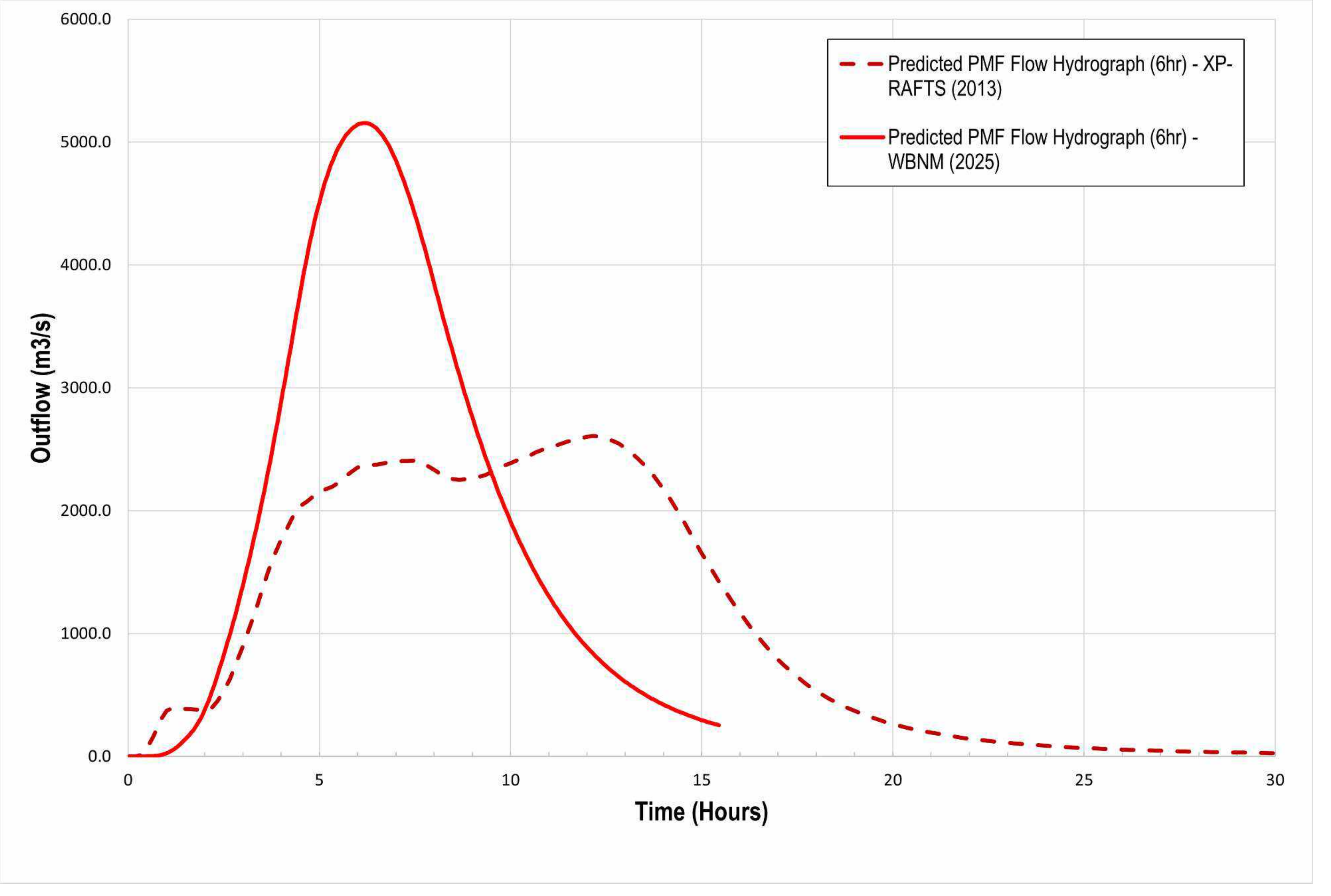
Prepared by: worley consulting

250214_CamdenHaven_DesignPlots.xlxs

fg311015-00418_241108_Appendix D.pdf

COMPARISON BETWEEN UPDATED AND ADOPTED 1% AEP FLOW HYDROGRAPHS AT THE HERONS CREEK RMA-2 INFLOW LOCATION

FIGURE D-5



Note: Refer Table 7-3 for peak design flow magnitudes

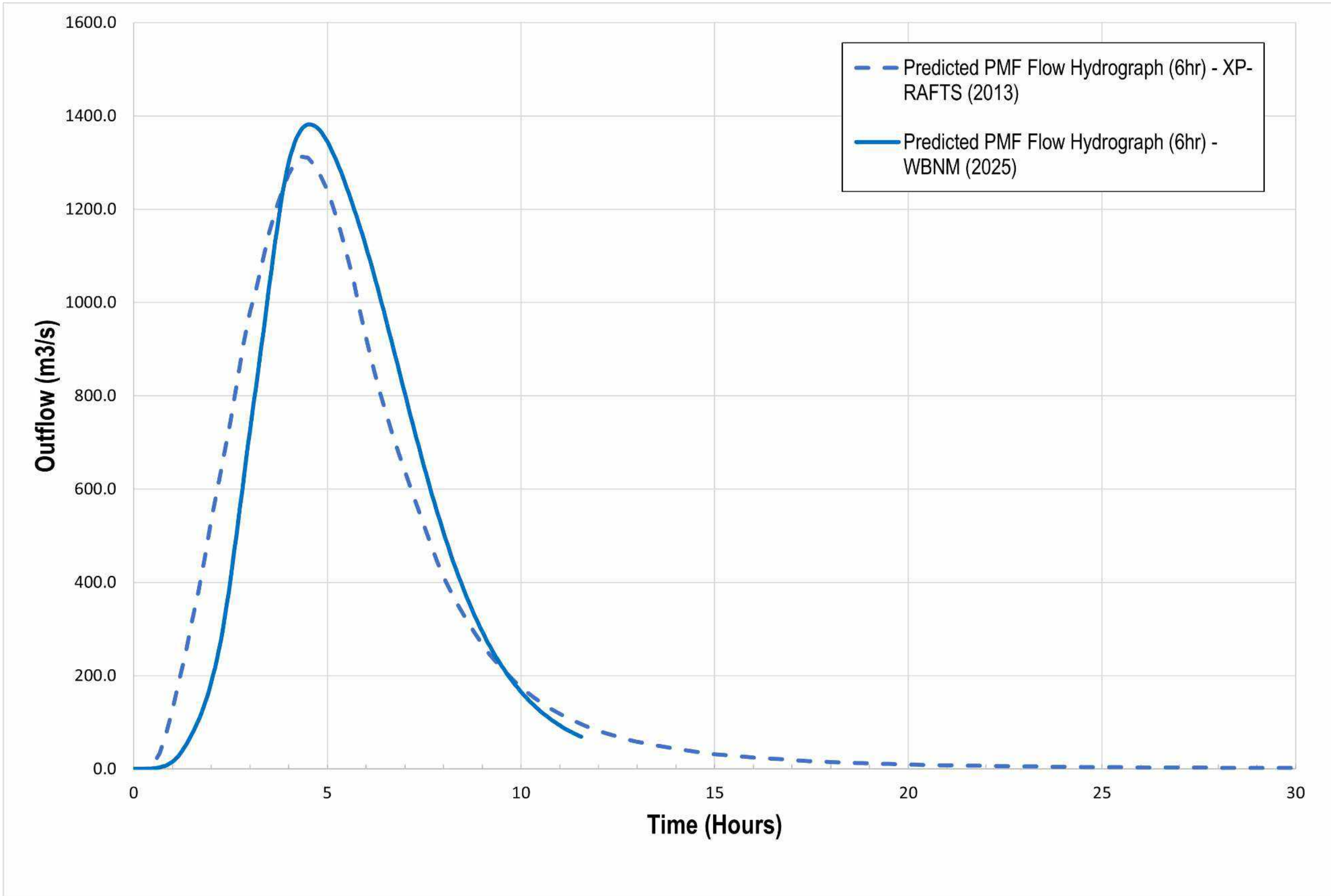
Prepared by:

250214_CamdenHaven_DesignPlots.xlxs

fg311015-00418_241108_Appendix D.pdf

COMPARISON BETWEEN UPDATED AND ADOPTED PMF FLOW HYDROGRAPHS AT THE LOGANS CROSSING RMA-2 INFLOW LOCATION

FIGURE D-4



Note: Refer Table 7-3 for peak design flow magnitudes

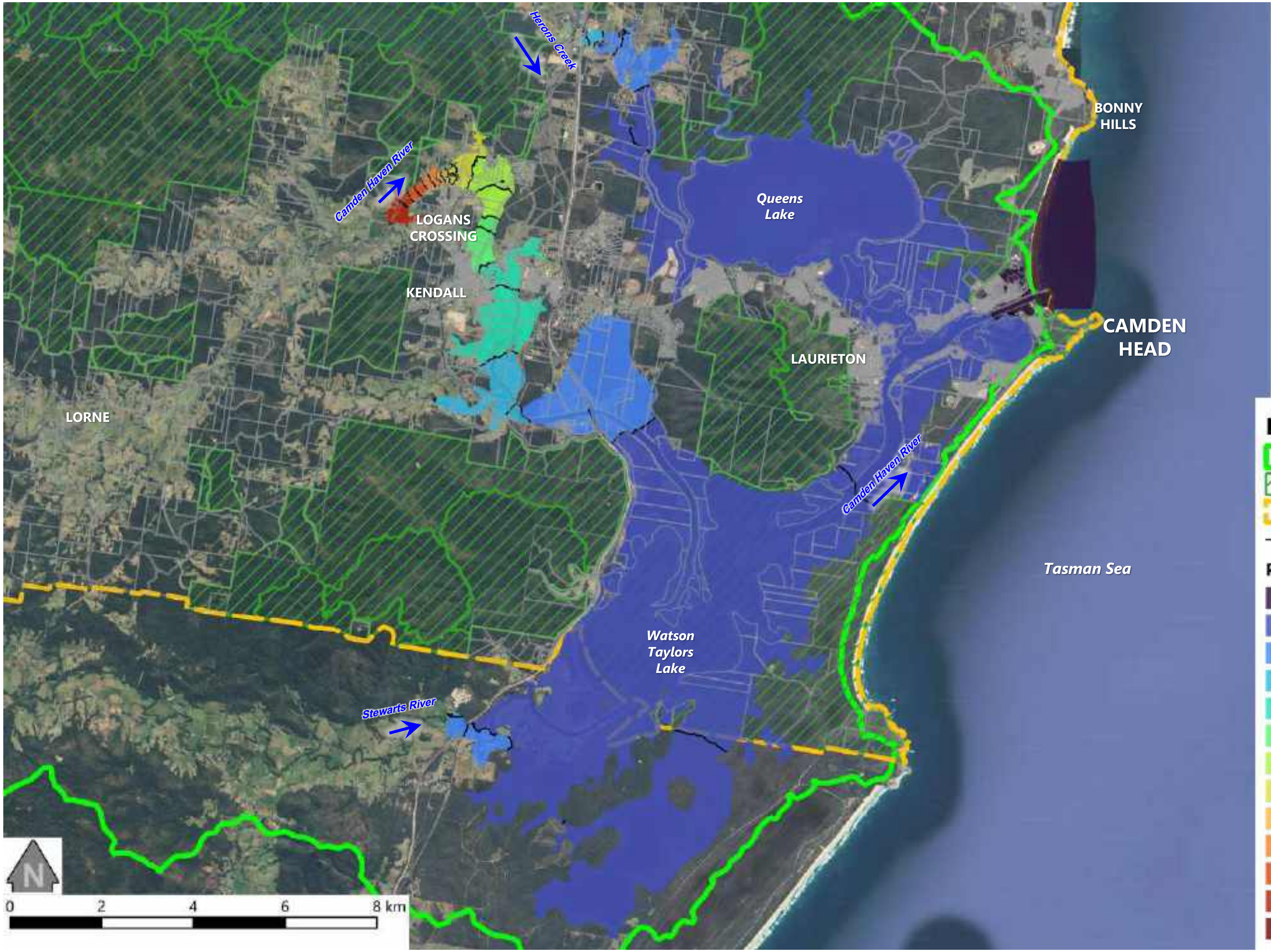
Prepared by: worley consulting

250214_CamdenHaven_DesignPlots.xlxs
fg311015-00418_241108_Appendix D.pdf

COMPARISON BETWEEN UPDATED AND ADOPTED PMF FLOW HYDROGRAPHS AT THE HERONS CREEK RMA-2 INFLOW LOCATION

Appendix E. RMA-2 Model Design Flood Event Mapping

FIGURE E-1



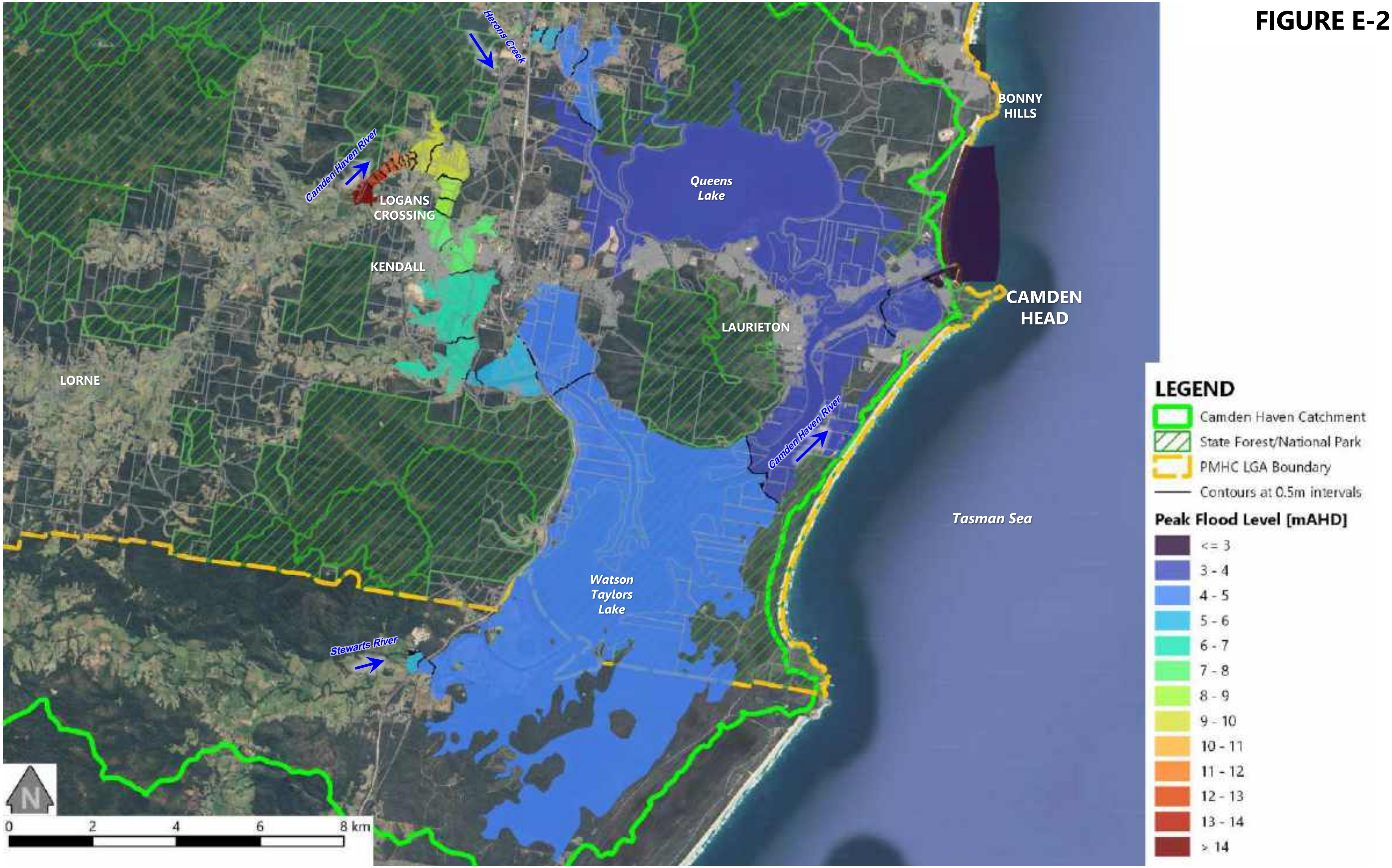
Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481jc250205-CamdenHavenFS_A4L_APPE.pdf

PREDICTED FLOOD LEVELS AT THE PEAK OF THE DESIGN 1 IN 500 AEP FLOOD

FIGURE E-2

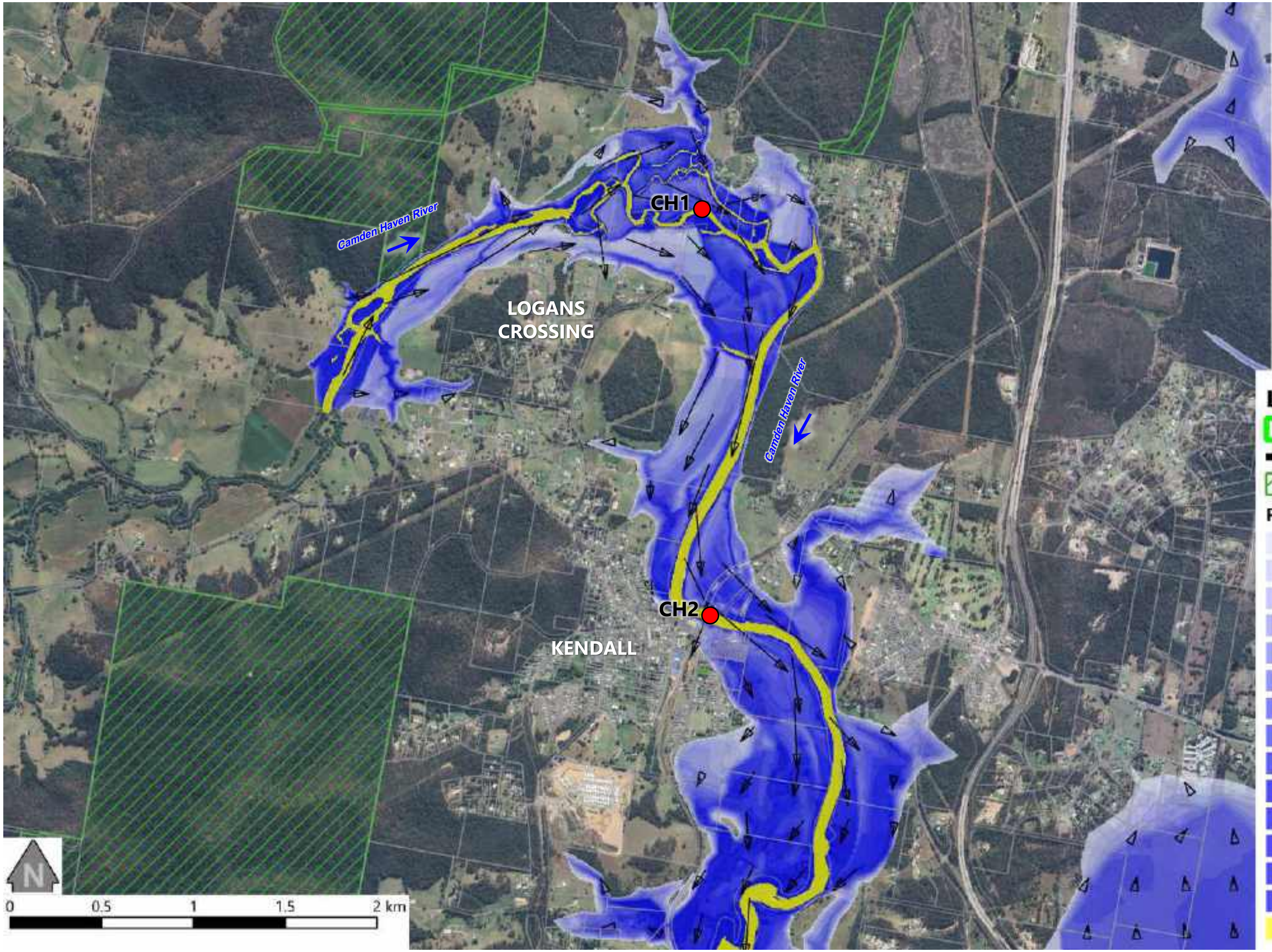


Prepared by: worley consulting

250205_QGIS_CamdenHaven_Figures.qgs
fg311015-00481jc250205-CamdenHavenFS_A4L_APPE.pdf

PREDICTED FLOOD LEVELS AT THE PEAK OF THE DESIGN 1 IN 2000 AEP FLOOD

FIGURE E-3



PORT MACQUARIE HASTINGS

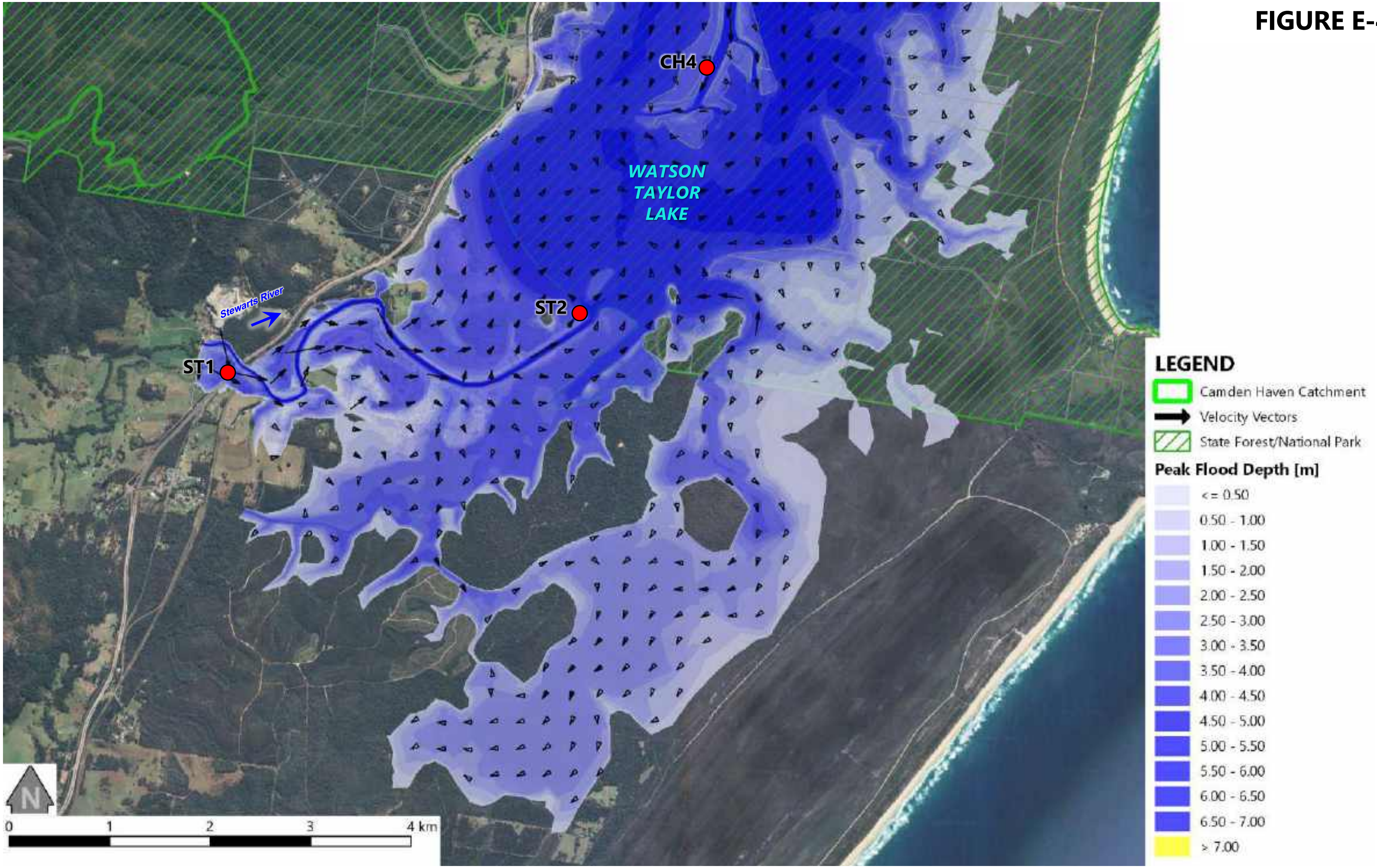
Prepared by: worley consulting

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L.pdf

PREDICTED FLOOD DEPTHS AT THE PEAK OF THE DESIGN 1 IN 500 AEP FLOOD (EXTENT 1 OF 5)

FIGURE E-4

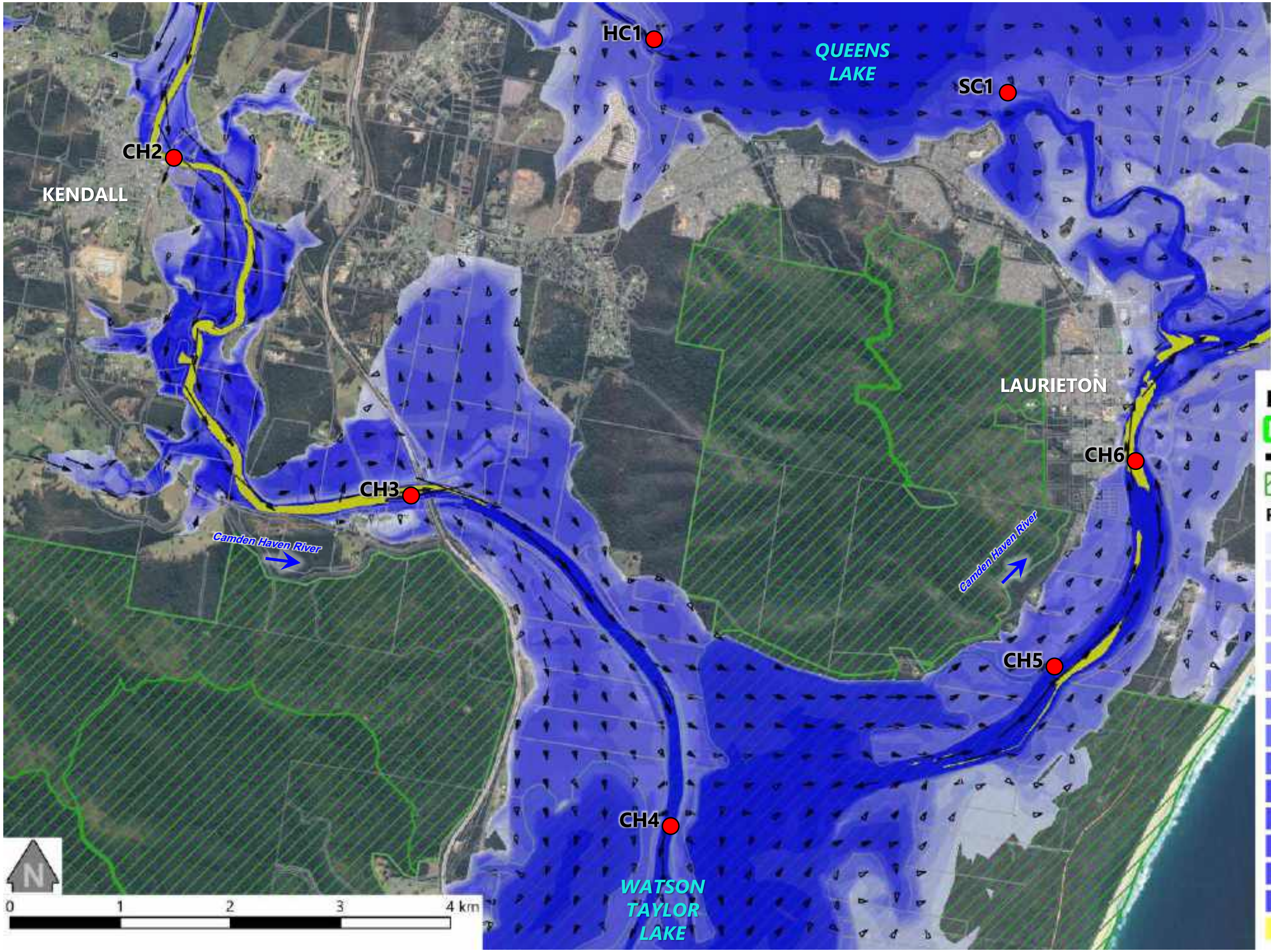


Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs
fg311015-00481_250214_CamdenHaven_A4L.pdf

PREDICTED FLOOD DEPTHS AT THE PEAK OF THE DESIGN 1 IN 500 AEP FLOOD (EXTENT 2 OF 5)

FIGURE E-5



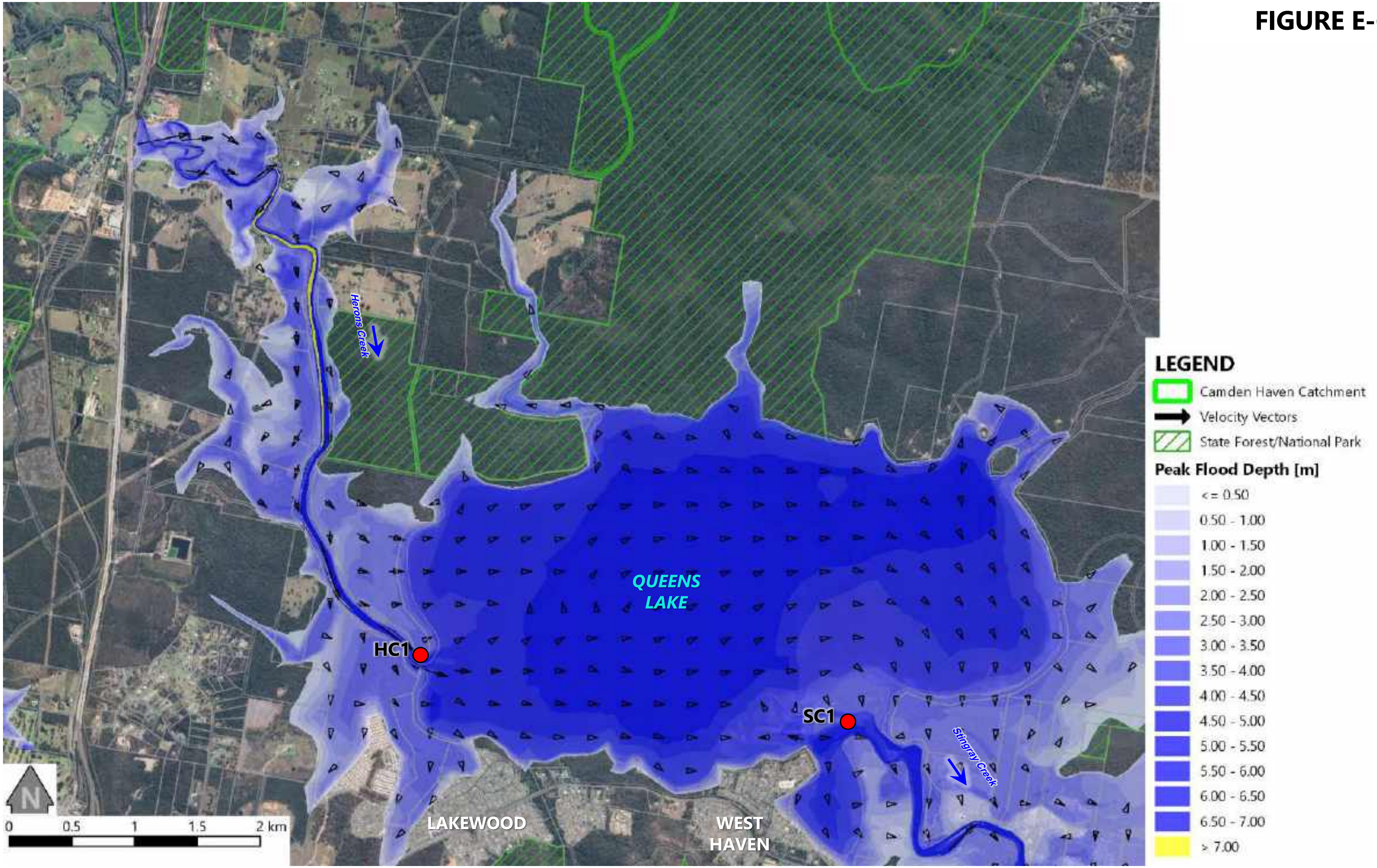
Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L.pdf

PREDICTED FLOOD DEPTHS AT THE PEAK OF THE DESIGN 1 IN 500 AEP FLOOD (EXTENT 3 OF 5)

FIGURE E-6



PORT MACQUARIE HASTINGS

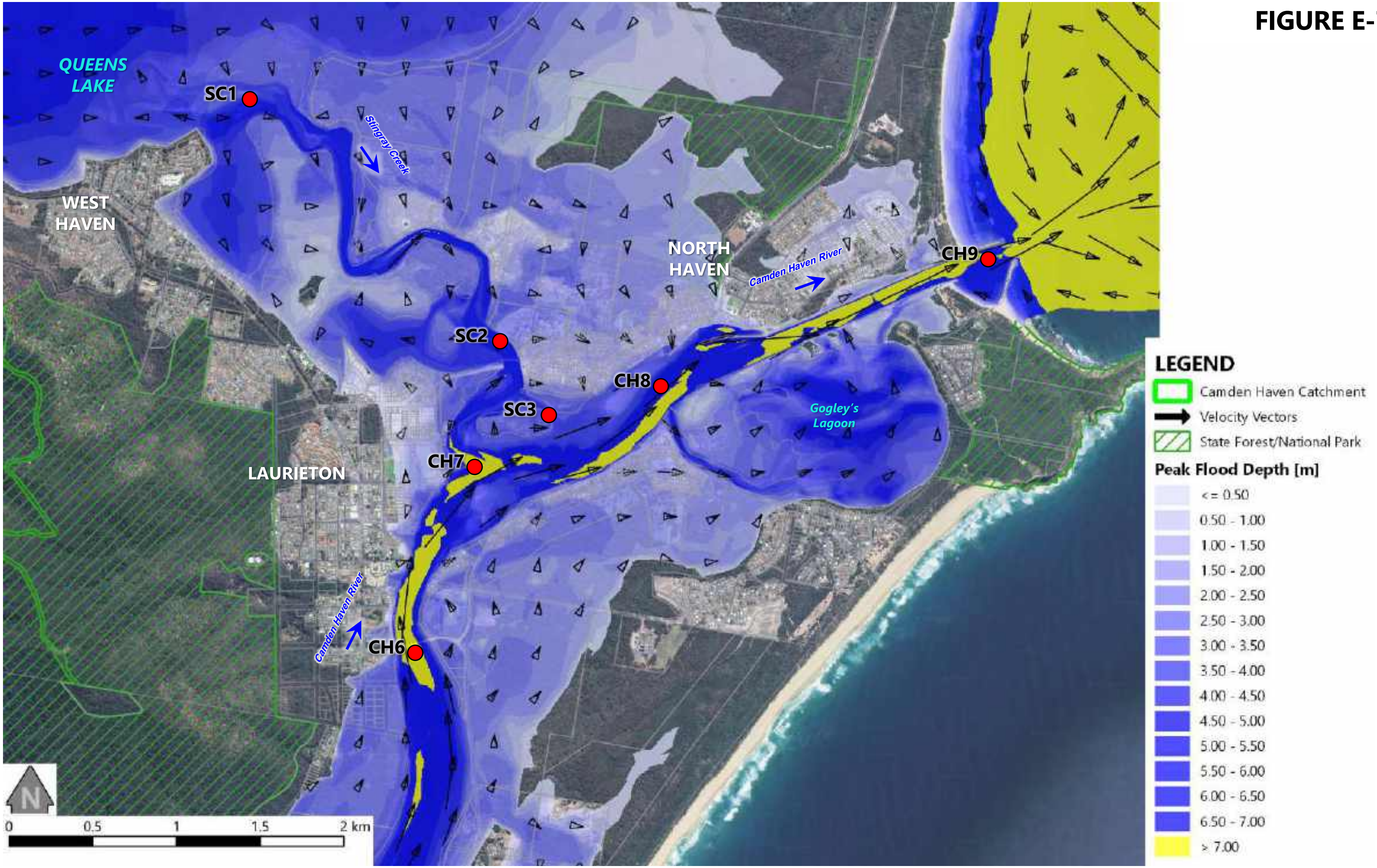
Prepared by: worley consulting

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L.pdf

PREDICTED FLOOD DEPTHS AT THE PEAK OF THE DESIGN 1 IN 500 AEP FLOOD (EXTENT 4 OF 5)

FIGURE E-7

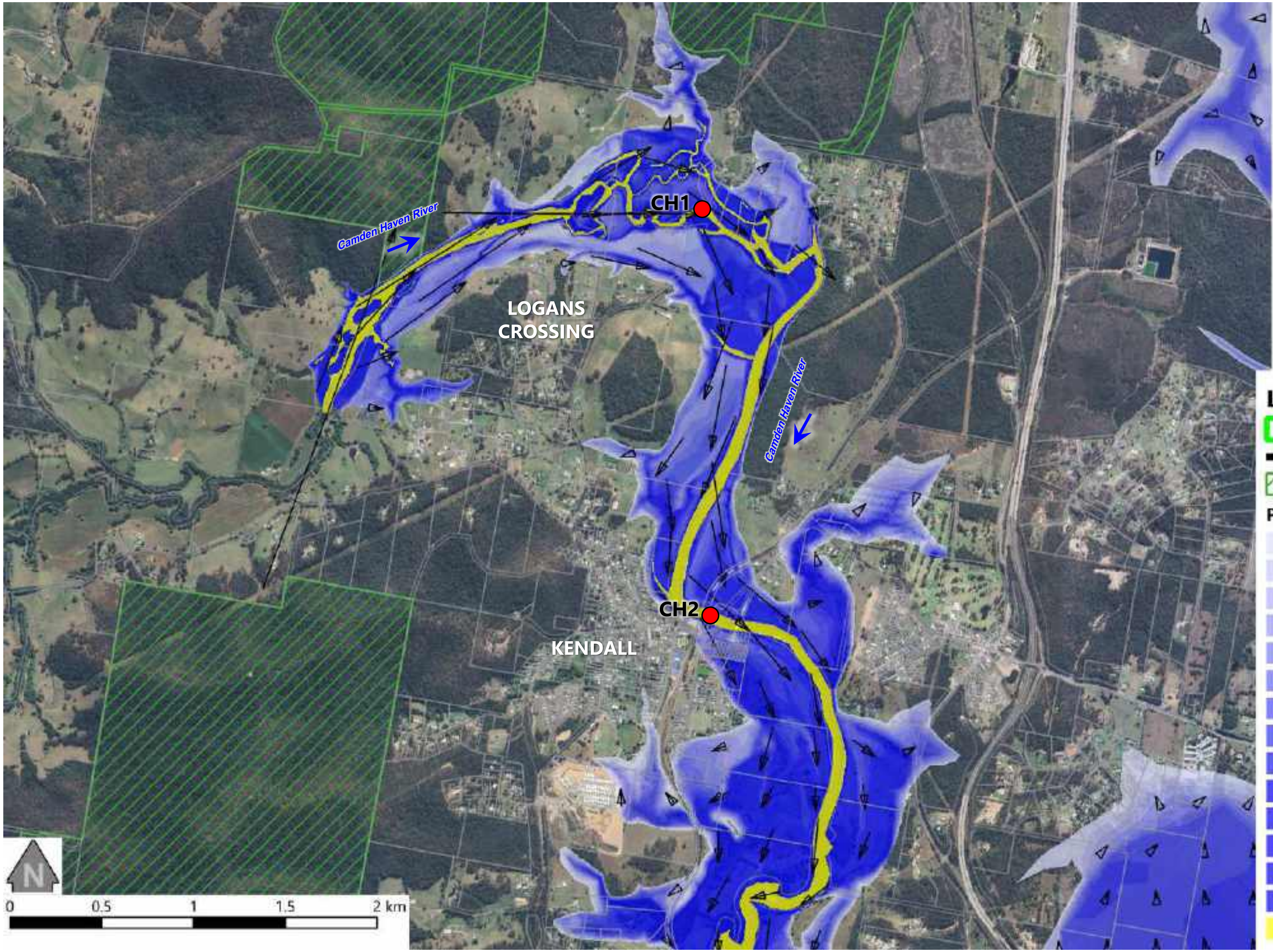


Prepared by: worley consulting

250205_QGIS_CamdenHaven_Figures.qgs
fg311015-00481_250214_CamdenHaven_A4L.pdf

PREDICTED FLOOD DEPTHS AT THE PEAK
OF THE DESIGN 1 IN 500 AEP FLOOD
(EXTENT 4 OF 5)

FIGURE E-8



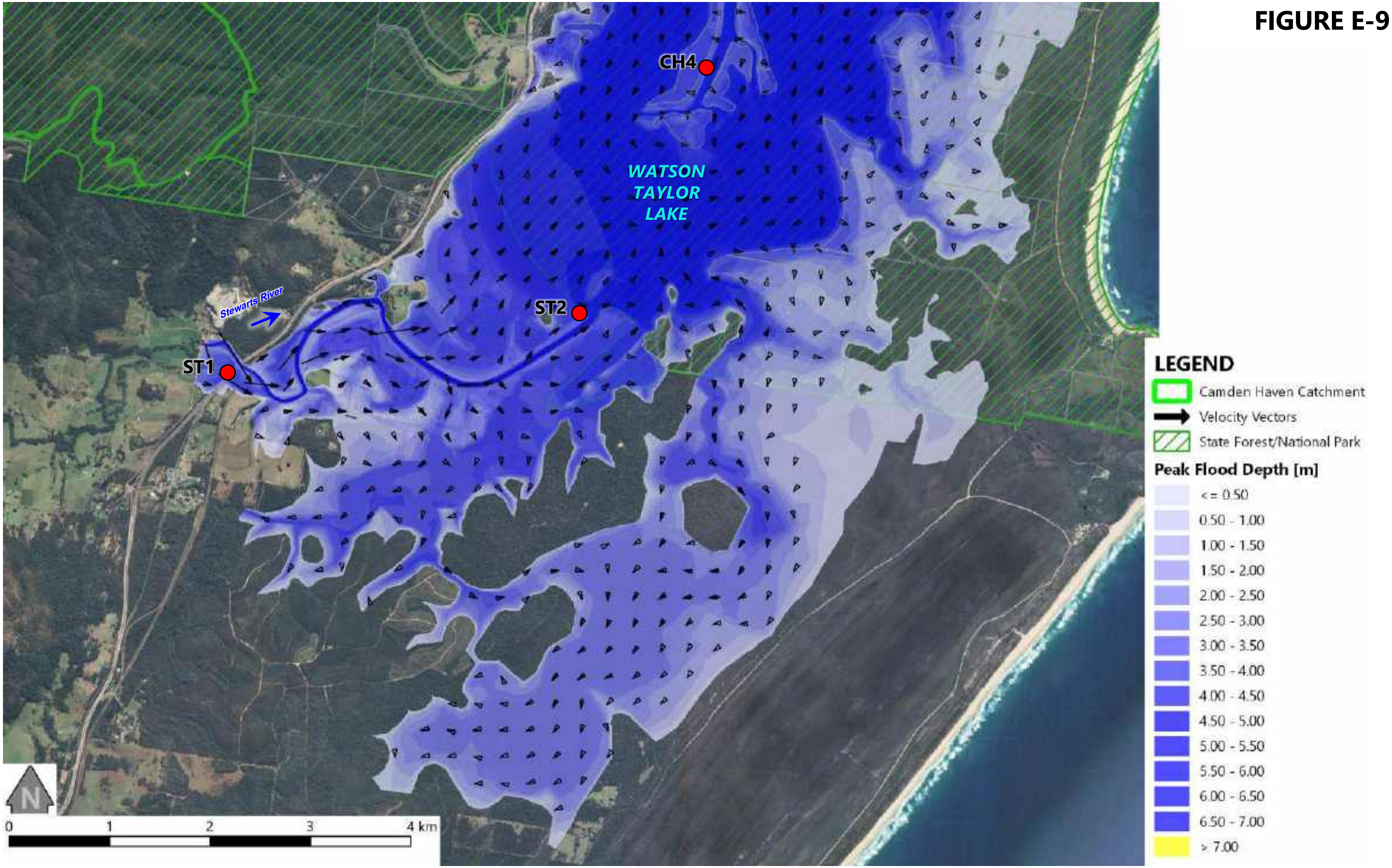
Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L.pdf

PREDICTED FLOOD DEPTHS AT THE PEAK OF THE DESIGN 1 IN 2000 AEP FLOOD (EXTENT 1 OF 5)

FIGURE E-9



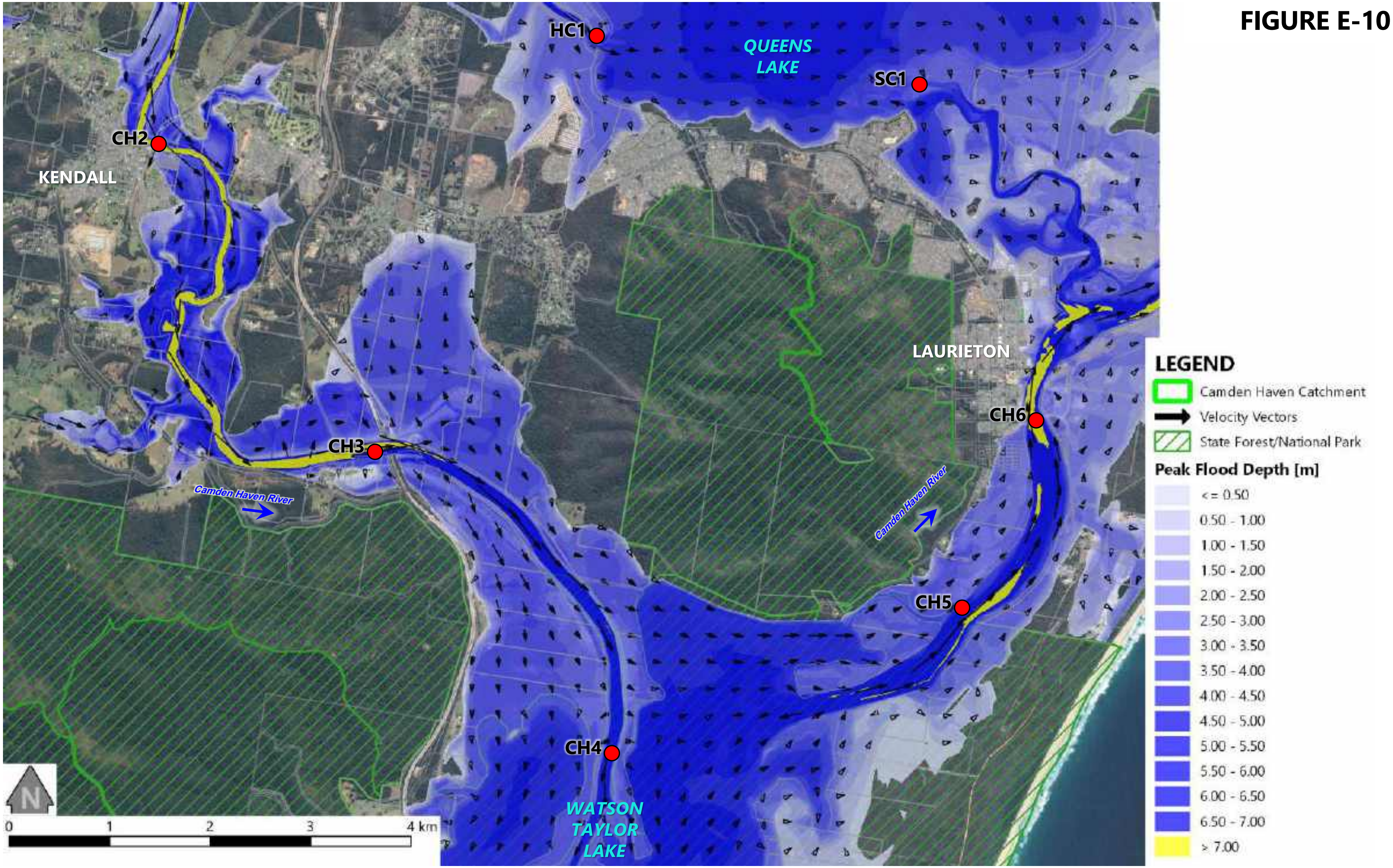
Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L.pdf

PREDICTED FLOOD DEPTHS AT THE PEAK OF THE DESIGN 1 IN 2000 AEP FLOOD (EXTENT 2 OF 5)

FIGURE E-10



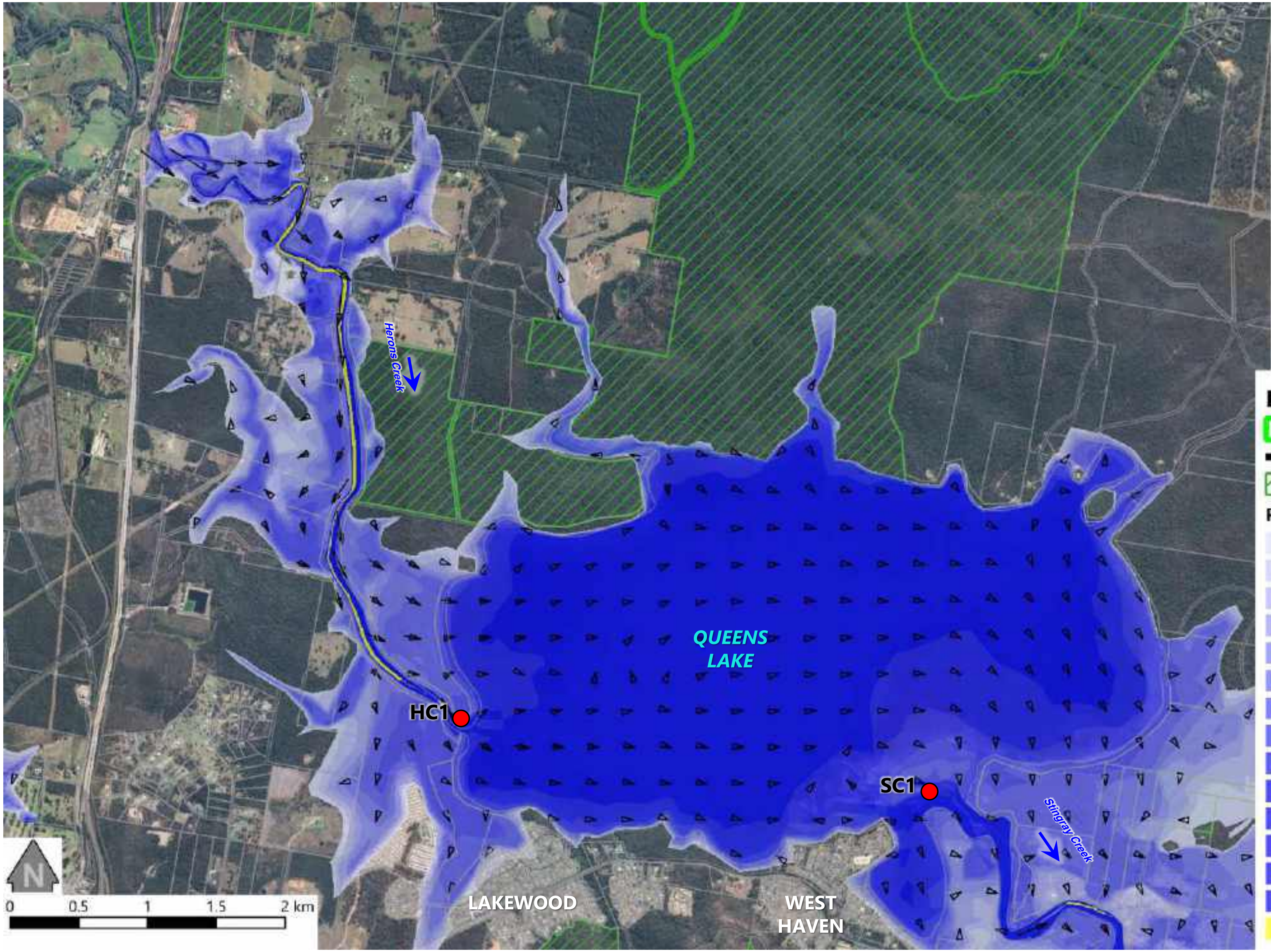
Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L.pdf

PREDICTED FLOOD DEPTHS AT THE PEAK OF THE DESIGN 1 IN 2000 AEP FLOOD (EXTENT 3 OF 5)

FIGURE E-11



LEGEND

- Camden Haven Catchment
- Velocity Vectors
- State Forest/National Park

Peak Flood Depth [m]

- <= 0.50
- 0.50 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- 2.00 - 2.50
- 2.50 - 3.00
- 3.00 - 3.50
- 3.50 - 4.00
- 4.00 - 4.50
- 4.50 - 5.00
- 5.00 - 5.50
- 5.50 - 6.00
- 6.00 - 6.50
- 6.50 - 7.00
- > 7.00

PORT MACQUARIE HASTINGS

Prepared by:

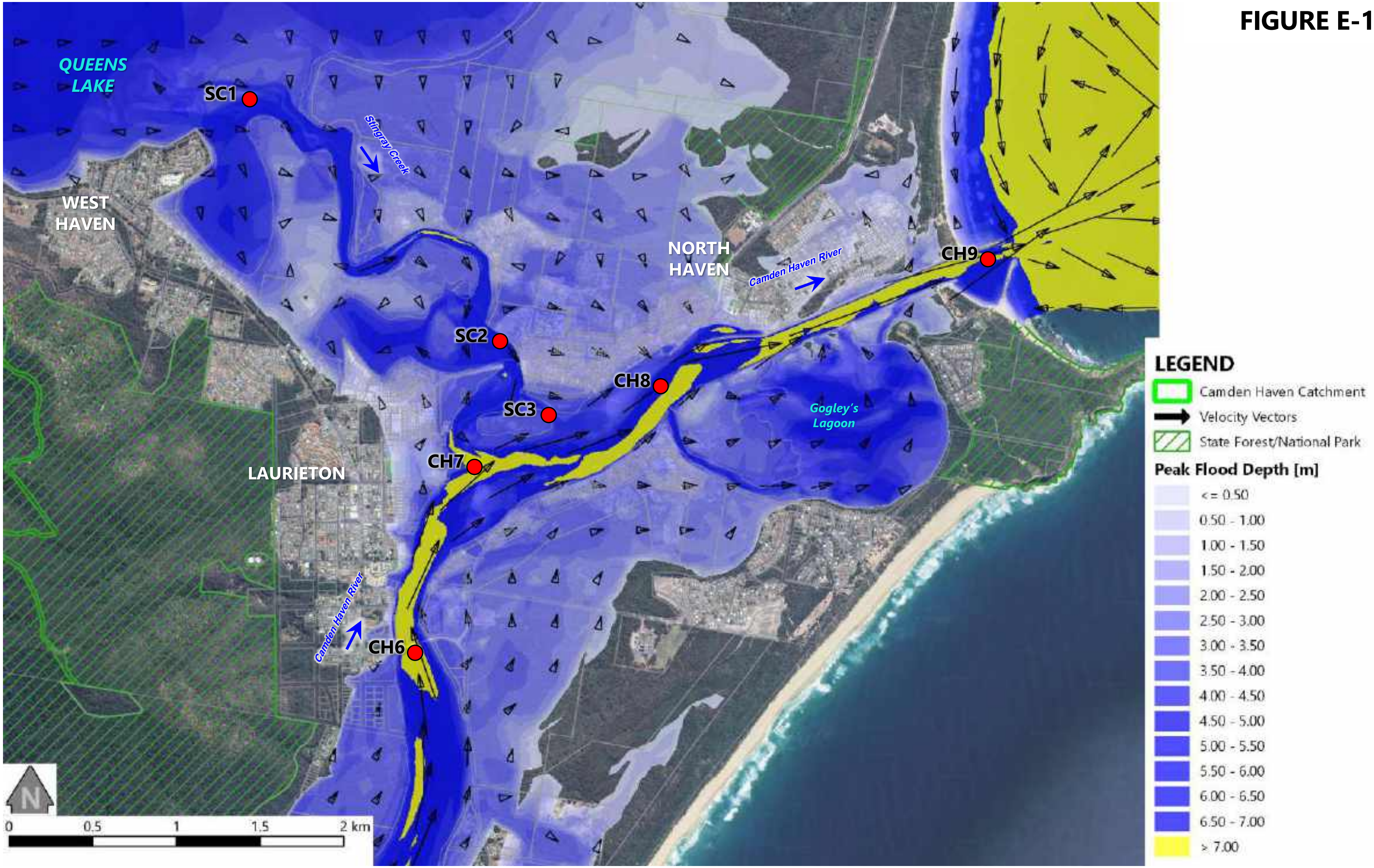
worley consulting

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L.pdf

PREDICTED FLOOD DEPTHS AT THE PEAK OF THE DESIGN 1 IN 2000 AEP FLOOD (EXTENT 4 OF 5)

FIGURE E-12



PORT MACQUARIE HASTINGS

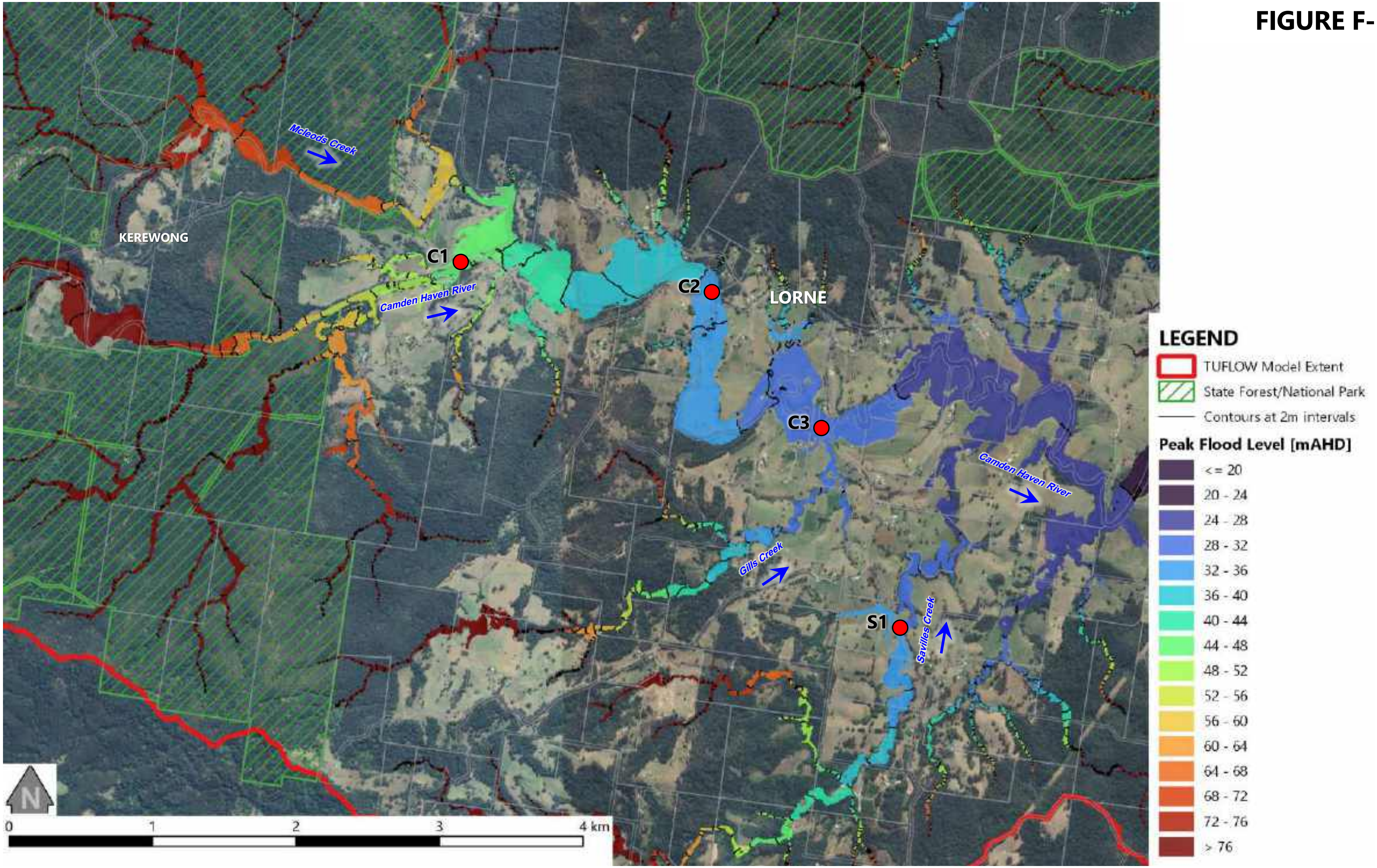
Prepared by: worley consulting

250205_QGIS_CamdenHaven_Figures.qgs
fg311015-00481_250214_CamdenHaven_A4L.pdf

PREDICTED FLOOD DEPTHS AT THE PEAK OF THE DESIGN 1 IN 2000 AEP FLOOD (EXTENT 4 OF 5)

Appendix F. TUFLOW Model Design Event Flood Mapping

FIGURE F-1



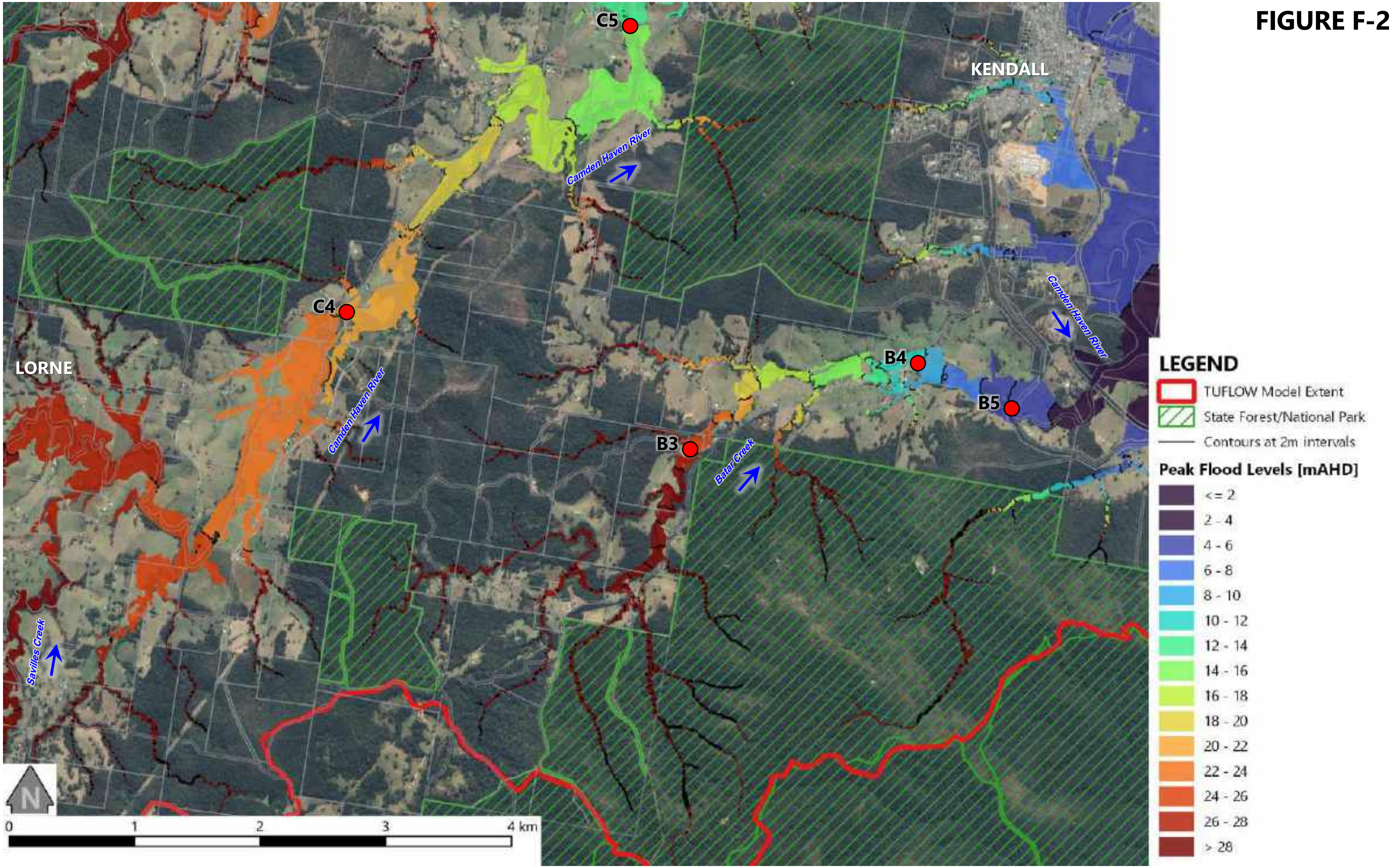
PORT MACQUARIE HASTINGS

Prepared by: worley consulting

250205_QGIS_CamdenHaven_Figures.qgs
fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD LEVELS AT THE PEAK OF THE DESIGN 5% AEP FLOOD (EXTENT 1 OF 4)

FIGURE F-2

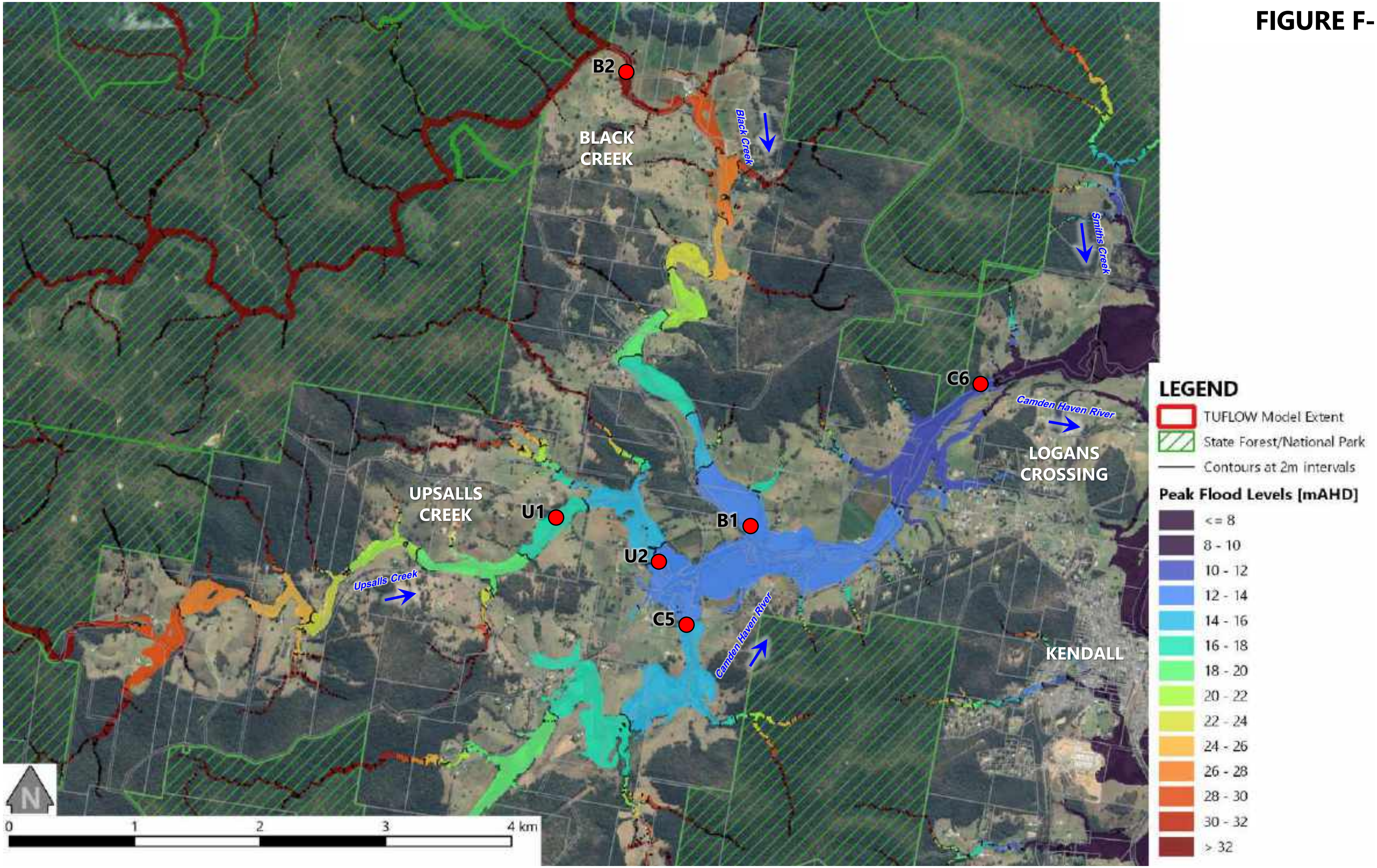


Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs
fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD LEVELS AT THE PEAK OF THE DESIGN 5% AEP FLOOD (EXTENT 2 OF 4)

FIGURE F-3



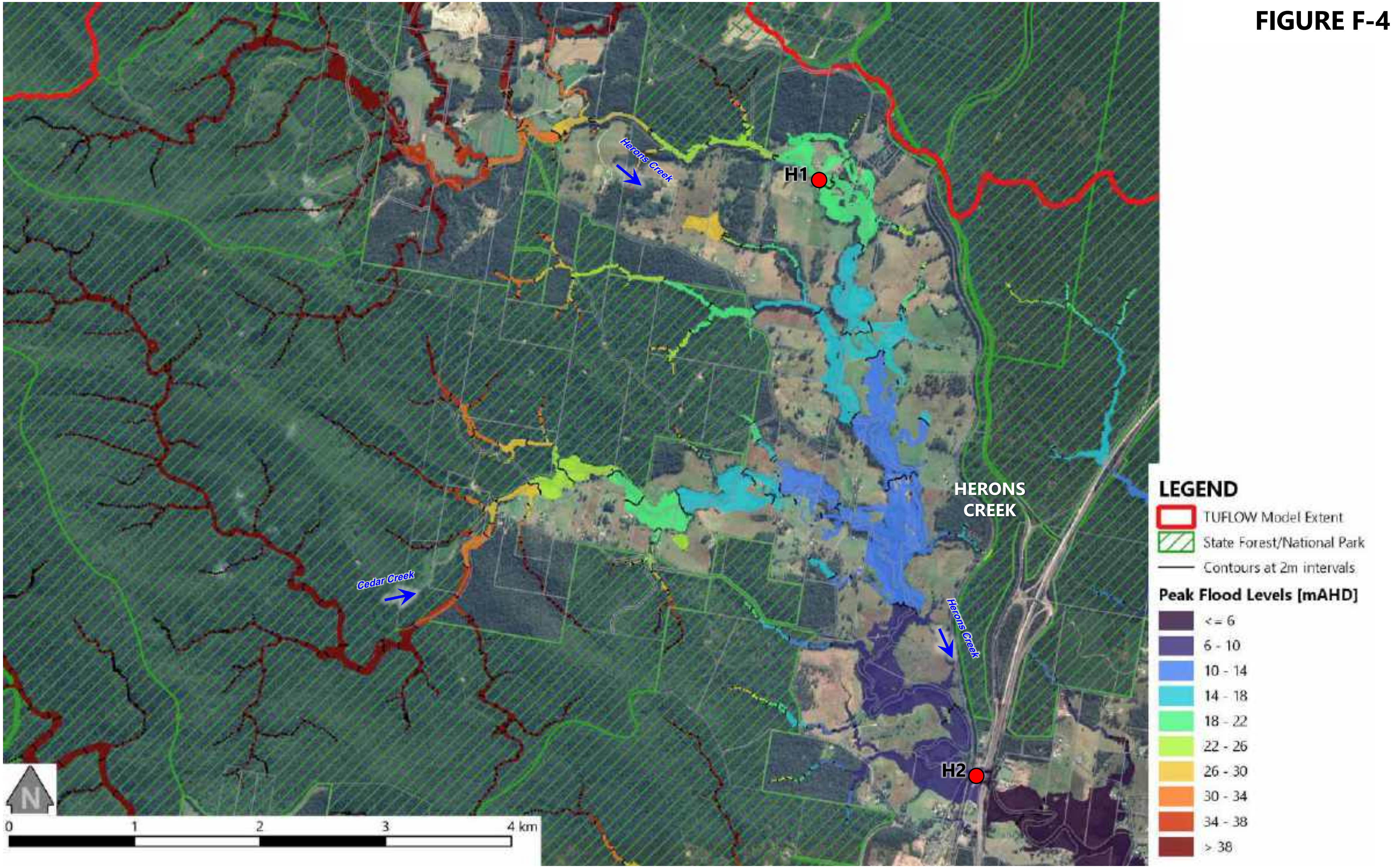
Prepared by: worley consulting

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD LEVELS AT THE PEAK OF THE DESIGN 5% AEP FLOOD (EXTENT 3 OF 4)

FIGURE F-4



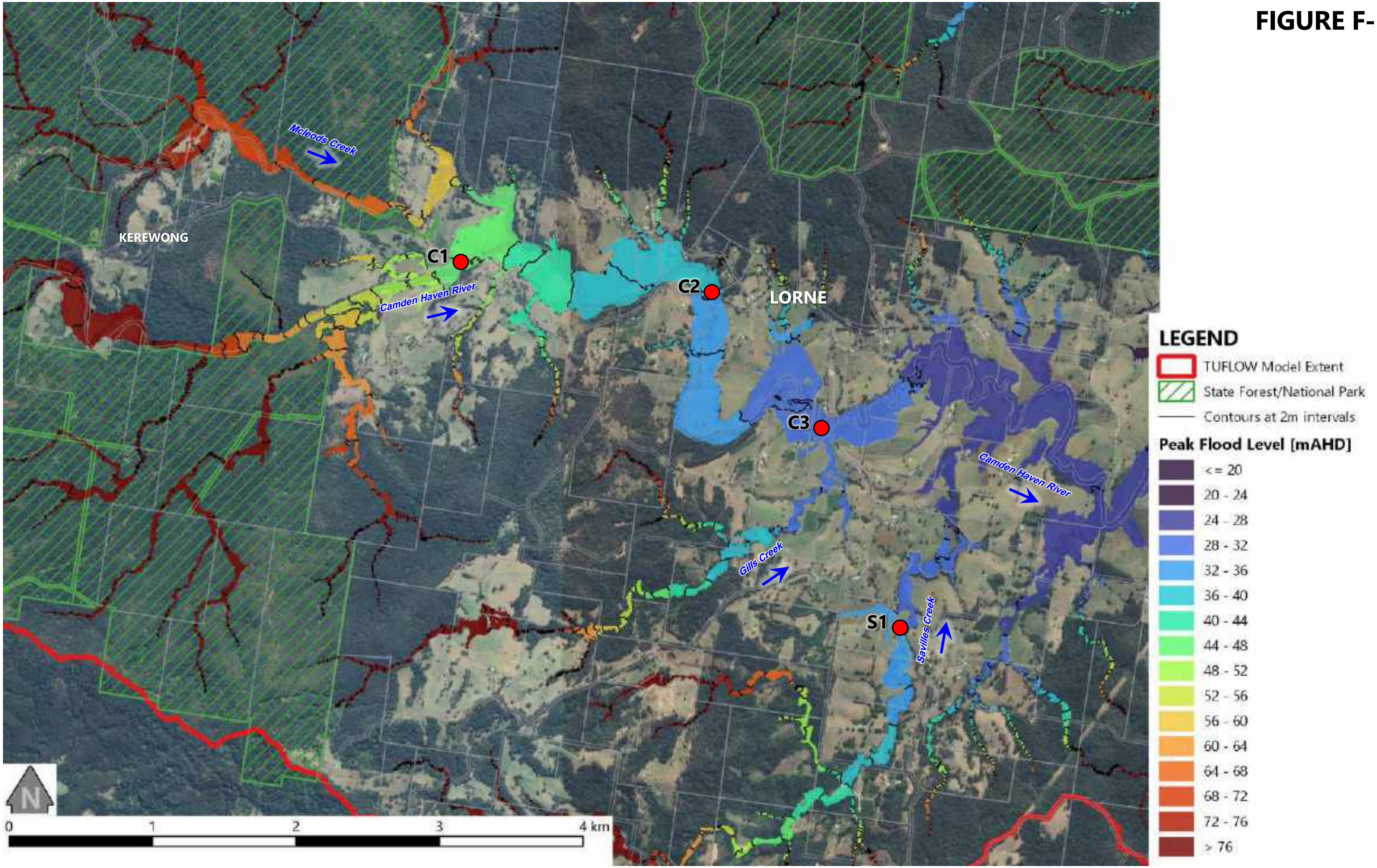
Prepared by: worley consulting

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD LEVELS AT THE PEAK OF THE DESIGN 5% AEP FLOOD (EXTENT 4 OF 4)

FIGURE F-5



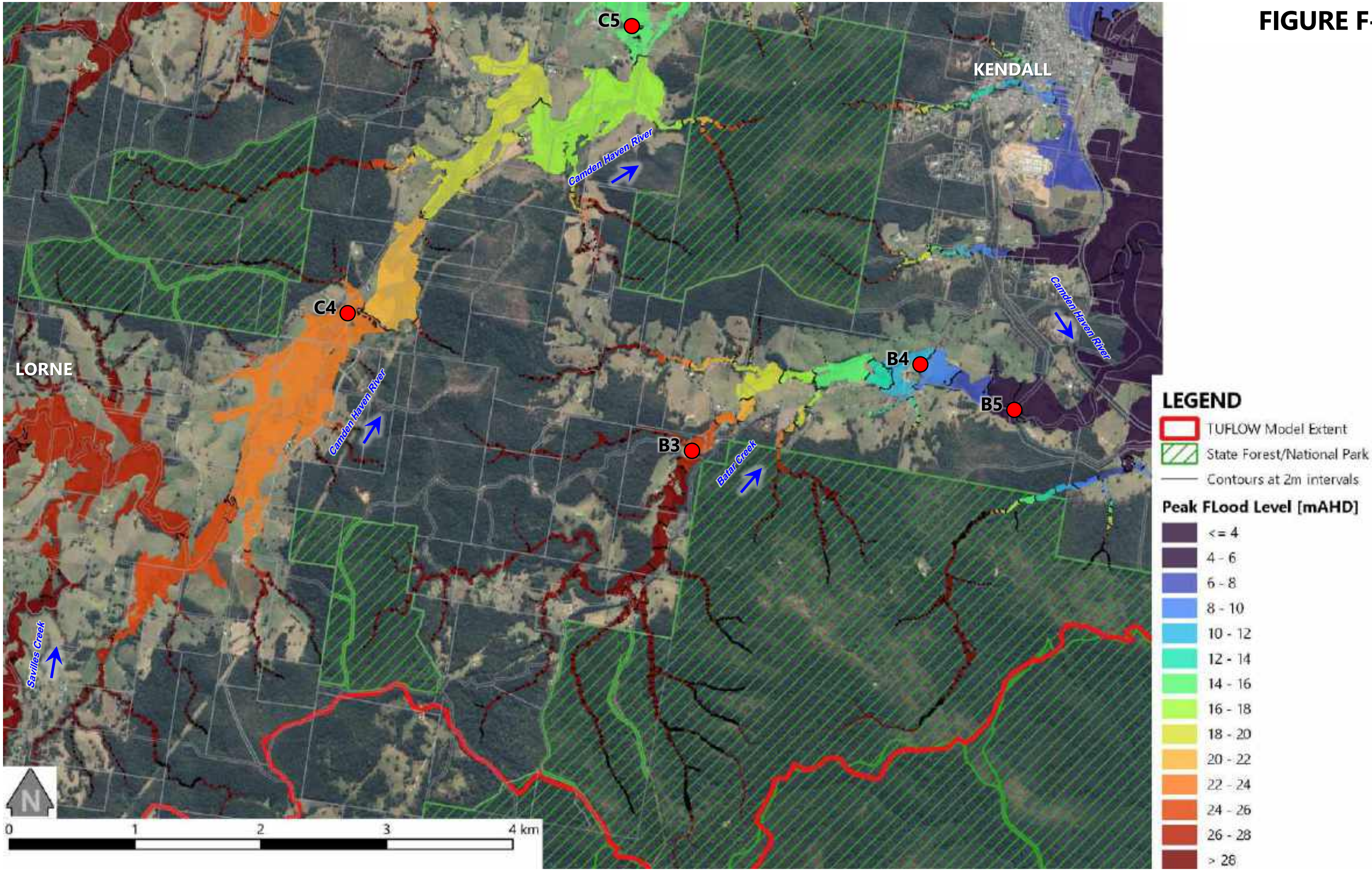
PORT MACQUARIE HASTINGS

Prepared by: worley consulting

250205_QGIS_CamdenHaven_Figures.qgs
fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD LEVELS AT THE PEAK OF THE DESIGN 1% AEP FLOOD (EXTENT 1 OF 4)

FIGURE F-6



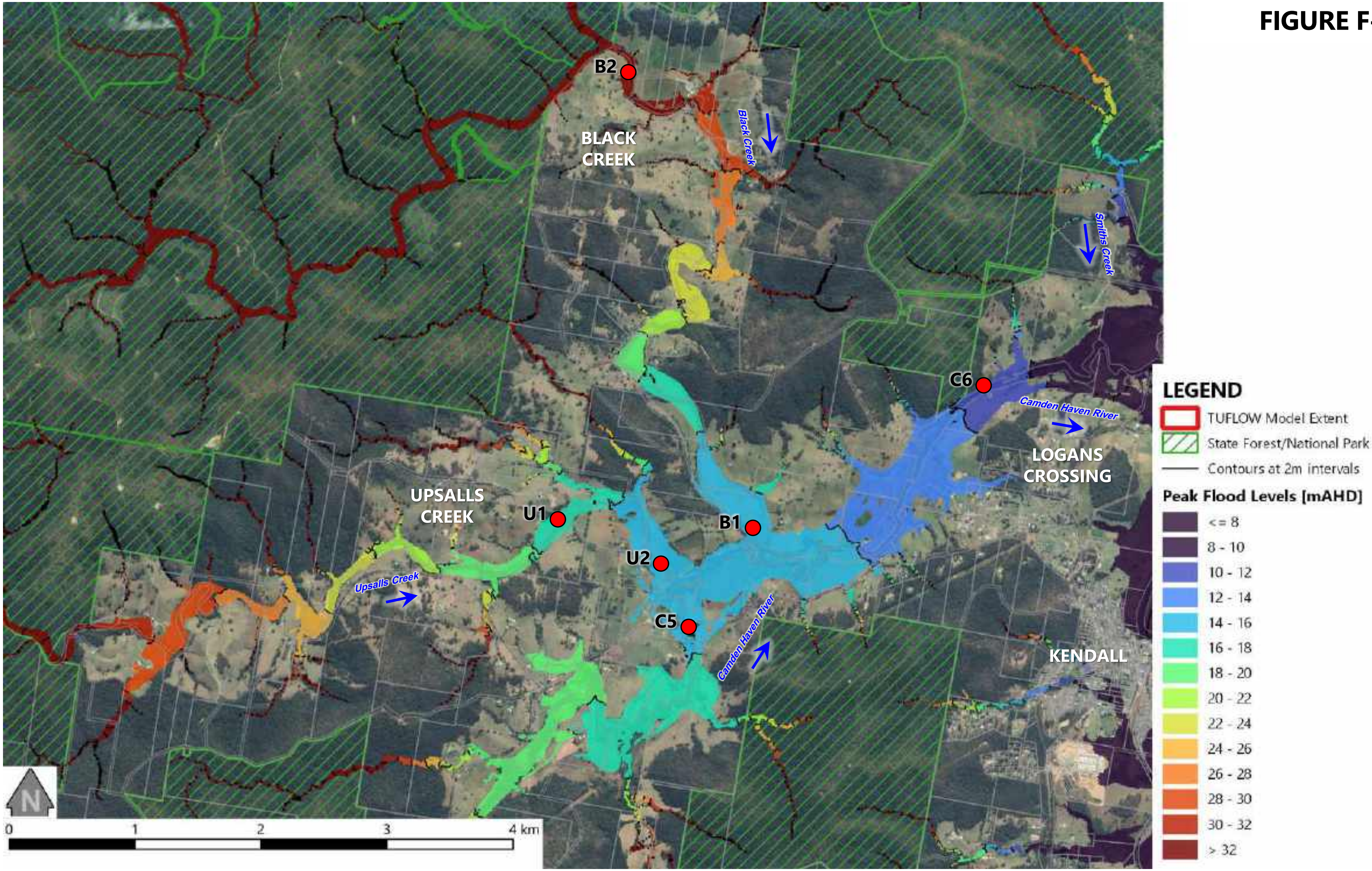
Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD LEVELS AT THE PEAK OF THE DESIGN 1% AEP FLOOD (EXTENT 2 OF 4)

FIGURE F-7

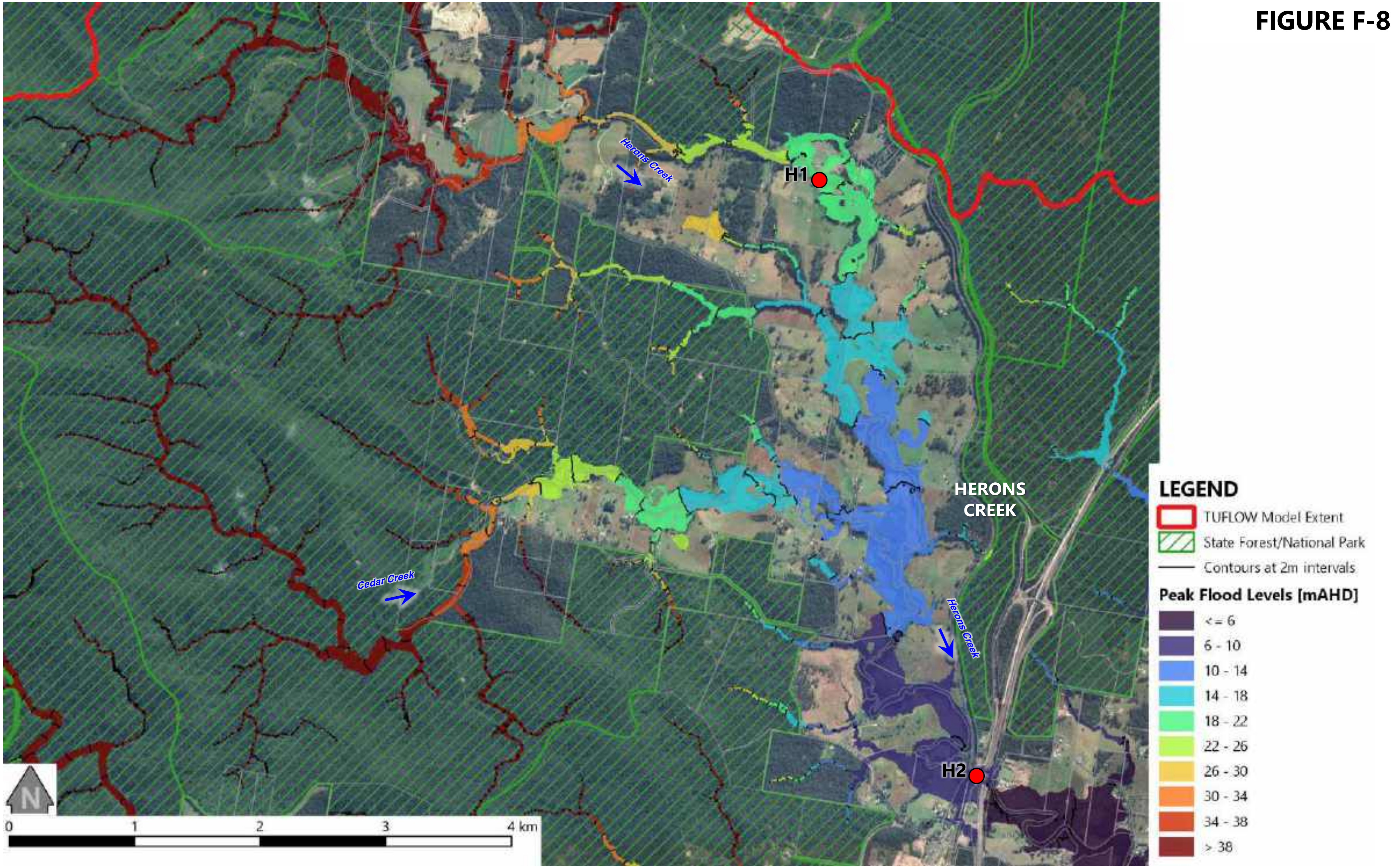


Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs
fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD LEVELS AT THE PEAK OF THE DESIGN 1% AEP FLOOD (EXTENT 3 OF 4)

FIGURE F-8



Prepared by:

PORT MACQUARIE HASTINGS

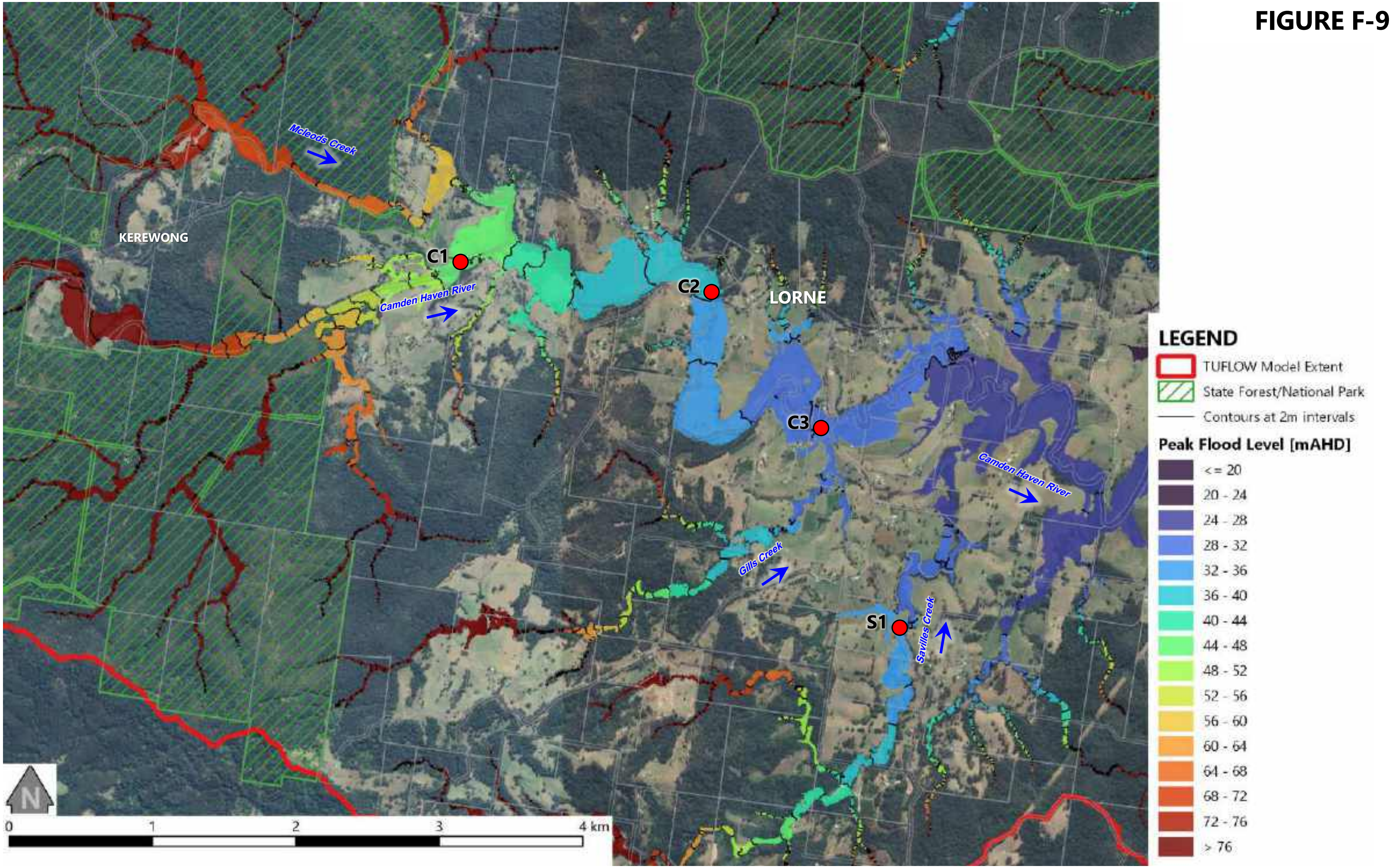
worley consulting

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD LEVELS AT THE PEAK OF THE DESIGN 1% AEP FLOOD (EXTENT 4 OF 4)

FIGURE F-9



PORT MACQUARIE HASTINGS

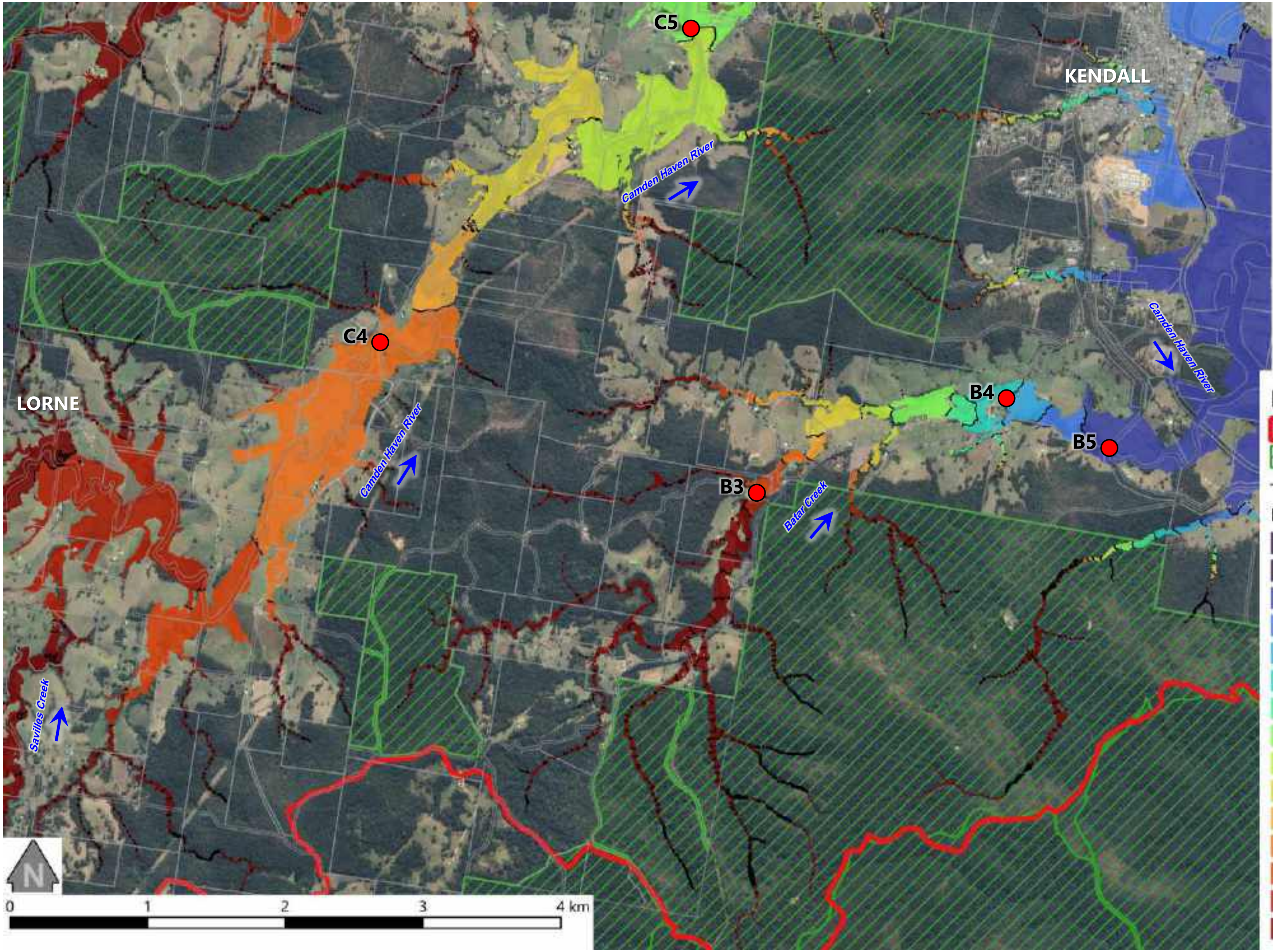
Prepared by: worley consulting

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD LEVELS AT THE PEAK OF THE DESIGN 1% AEP WITH CLIMATE CHANGE FLOOD (EXTENT 1 OF 4)

FIGURE F-10



LEGEND

- TUFLOW Model Extent
- State Forest/National Park
- Contours at 2m intervals

Peak Flood Level [mAHD]

- <= 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10
- 10 - 12
- 12 - 14
- 14 - 16
- 16 - 18
- 18 - 20
- 20 - 22
- 22 - 24
- 24 - 26
- 26 - 28
- > 28

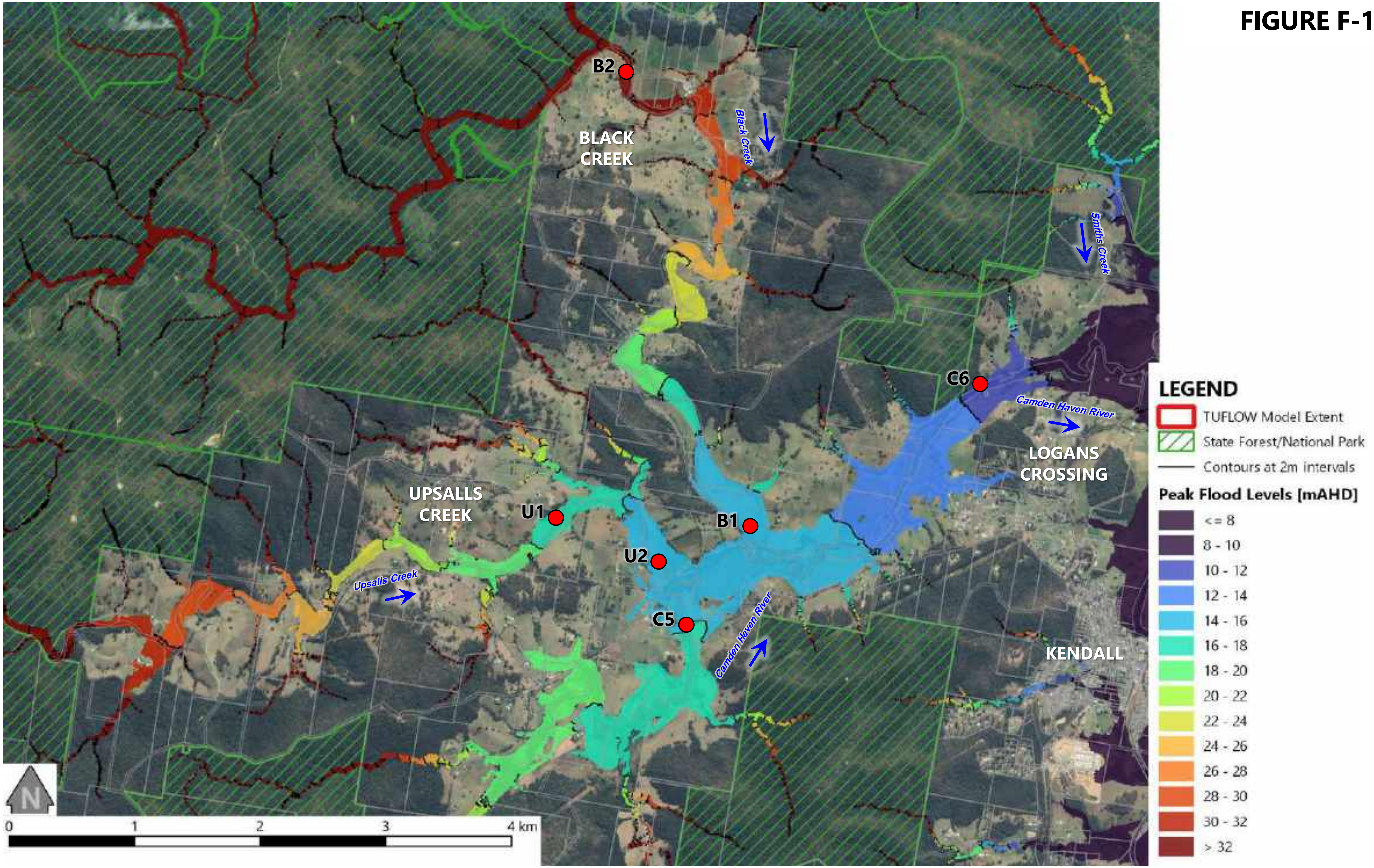
Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD LEVELS AT THE PEAK OF THE DESIGN 1% AEP WITH CLIMATE CHANGE FLOOD (EXTENT 2 OF 4)

FIGURE F-11



PORT MACQUARIE HASTINGS

Prepared by:

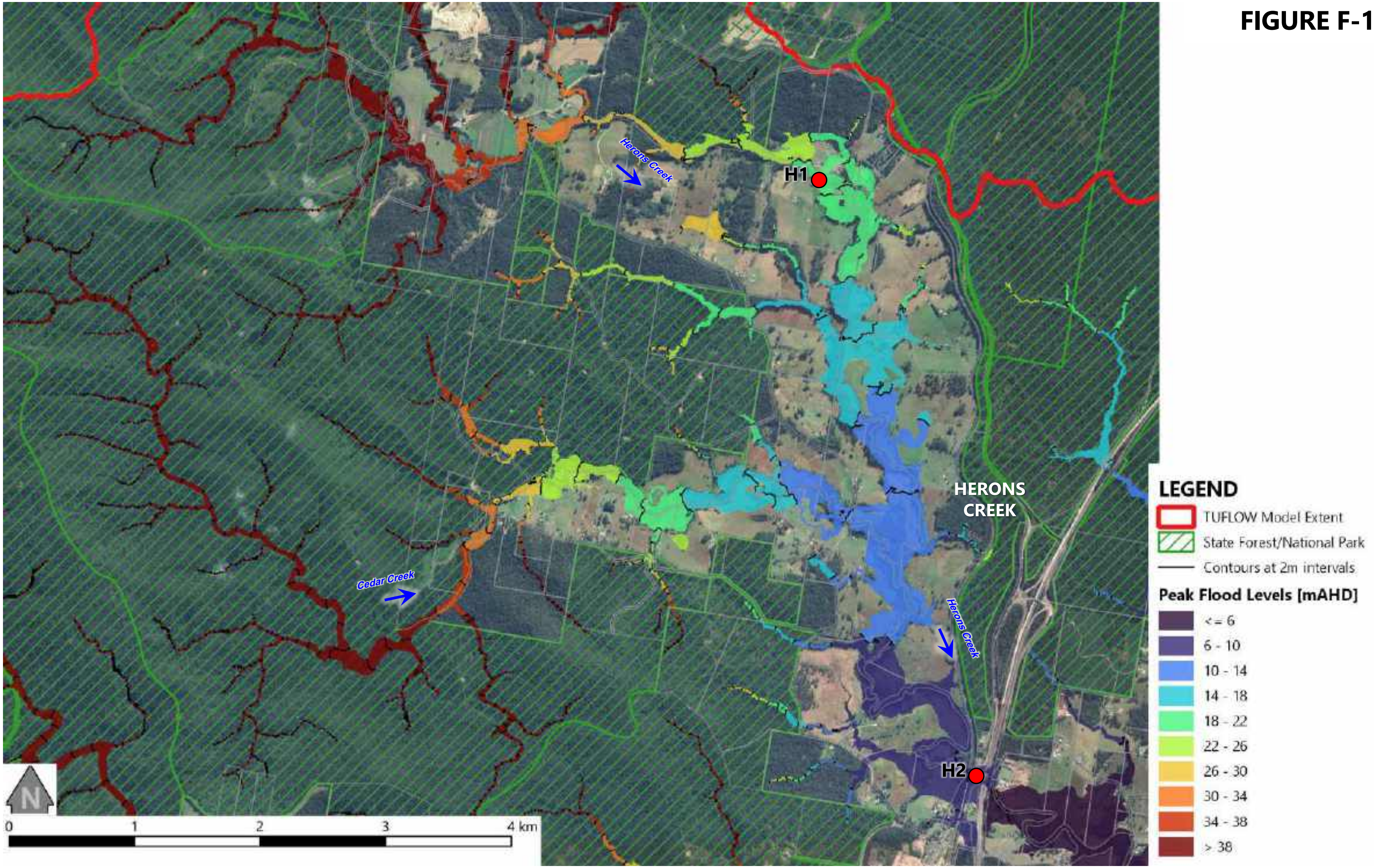
worley consulting

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD LEVELS AT THE PEAK OF THE DESIGN 1% AEP WITH CLIMATE CHANGE FLOOD (EXTENT 3 OF 4)

FIGURE F-12



PORT MACQUARIE HASTINGS

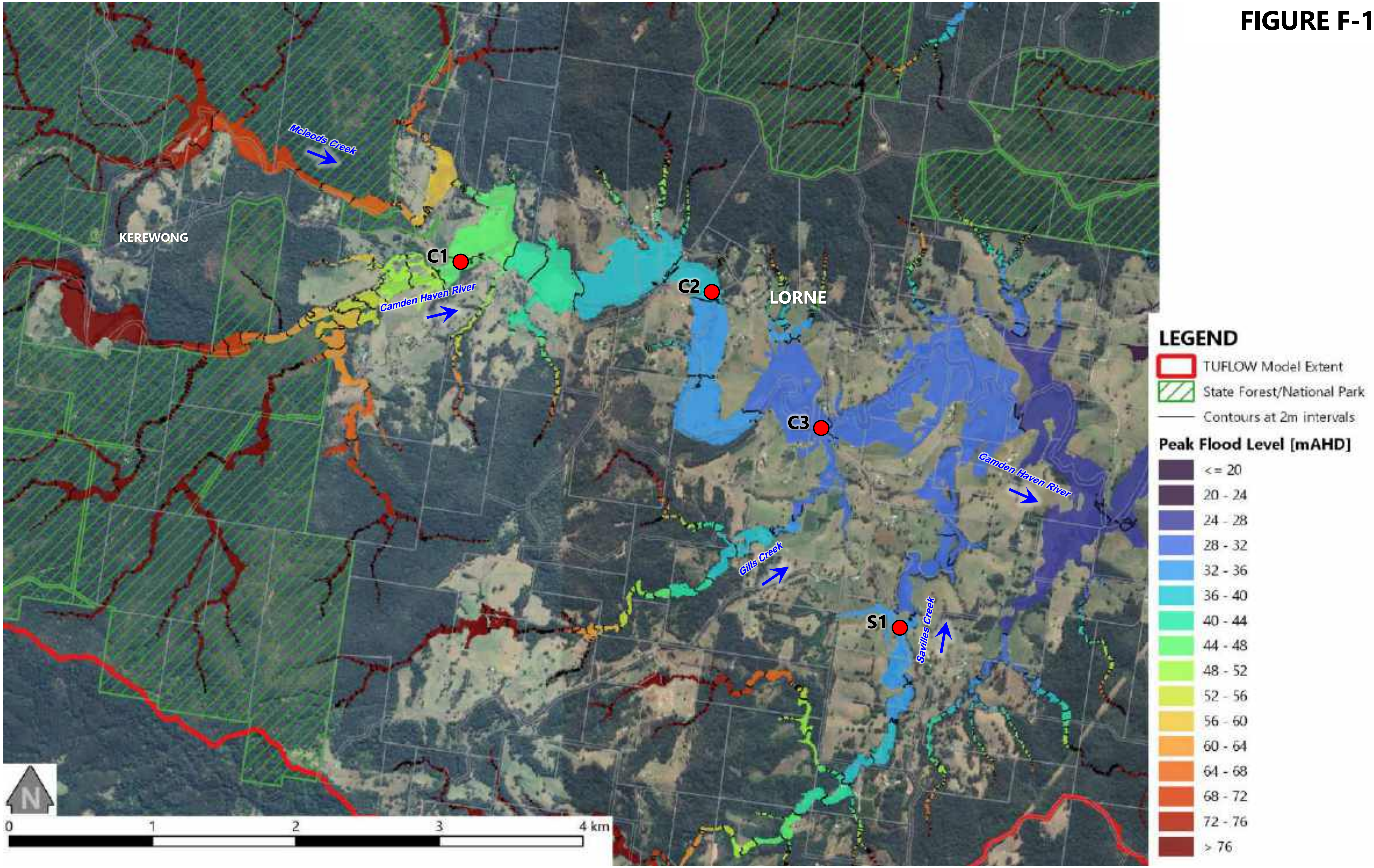
Prepared by: worley consulting

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD LEVELS AT THE PEAK OF THE DESIGN 1% AEP WITH CLIMATE CHANGE FLOOD (EXTENT 4 OF 4)

FIGURE F-13



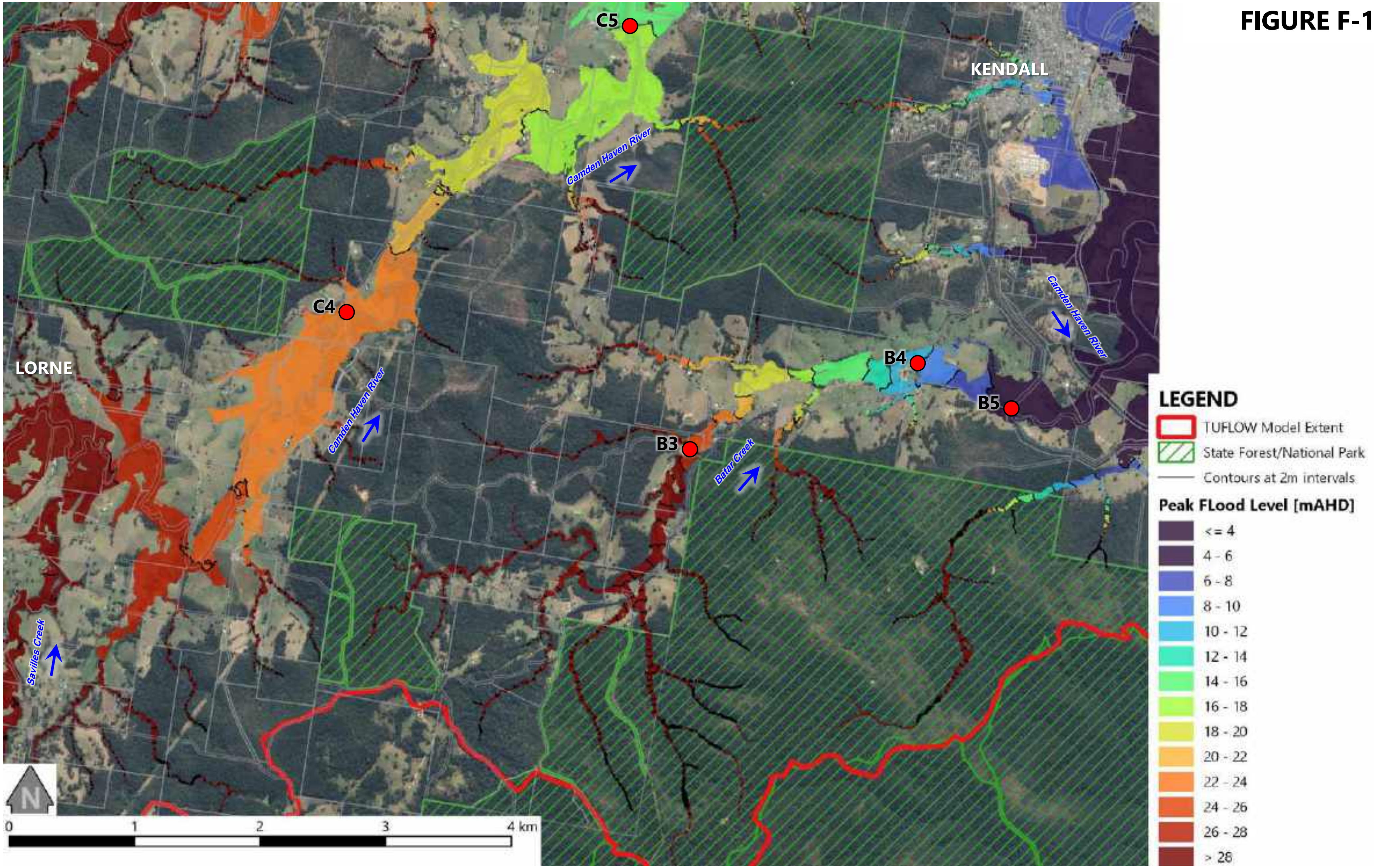
Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD LEVELS AT THE PEAK OF THE DESIGN 1 IN 500 AEP FLOOD (EXTENT 1 OF 4)

FIGURE F-14



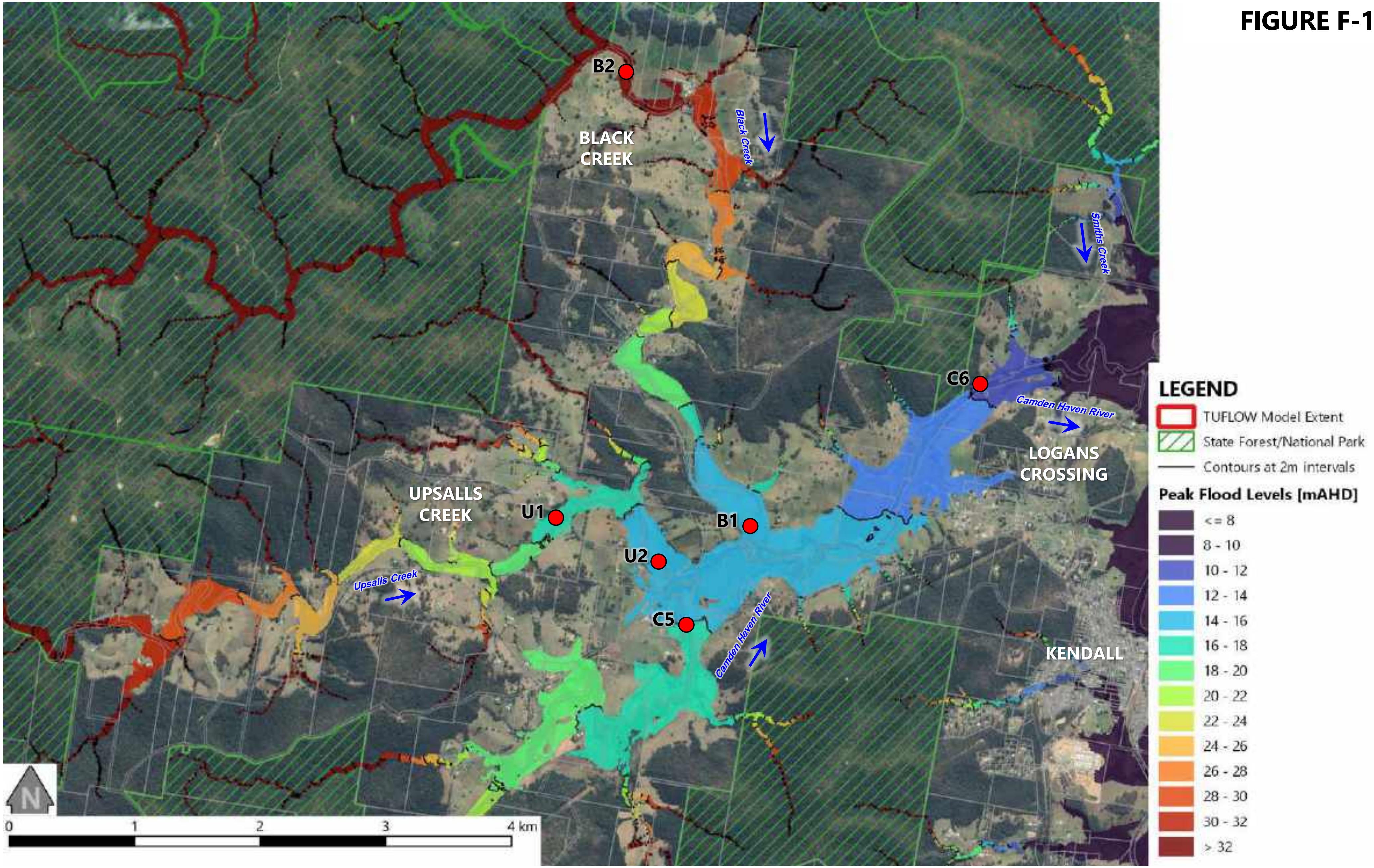
Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD LEVELS AT THE PEAK OF THE DESIGN 1 IN 500 AEP FLOOD (EXTENT 2 OF 4)

FIGURE F-15

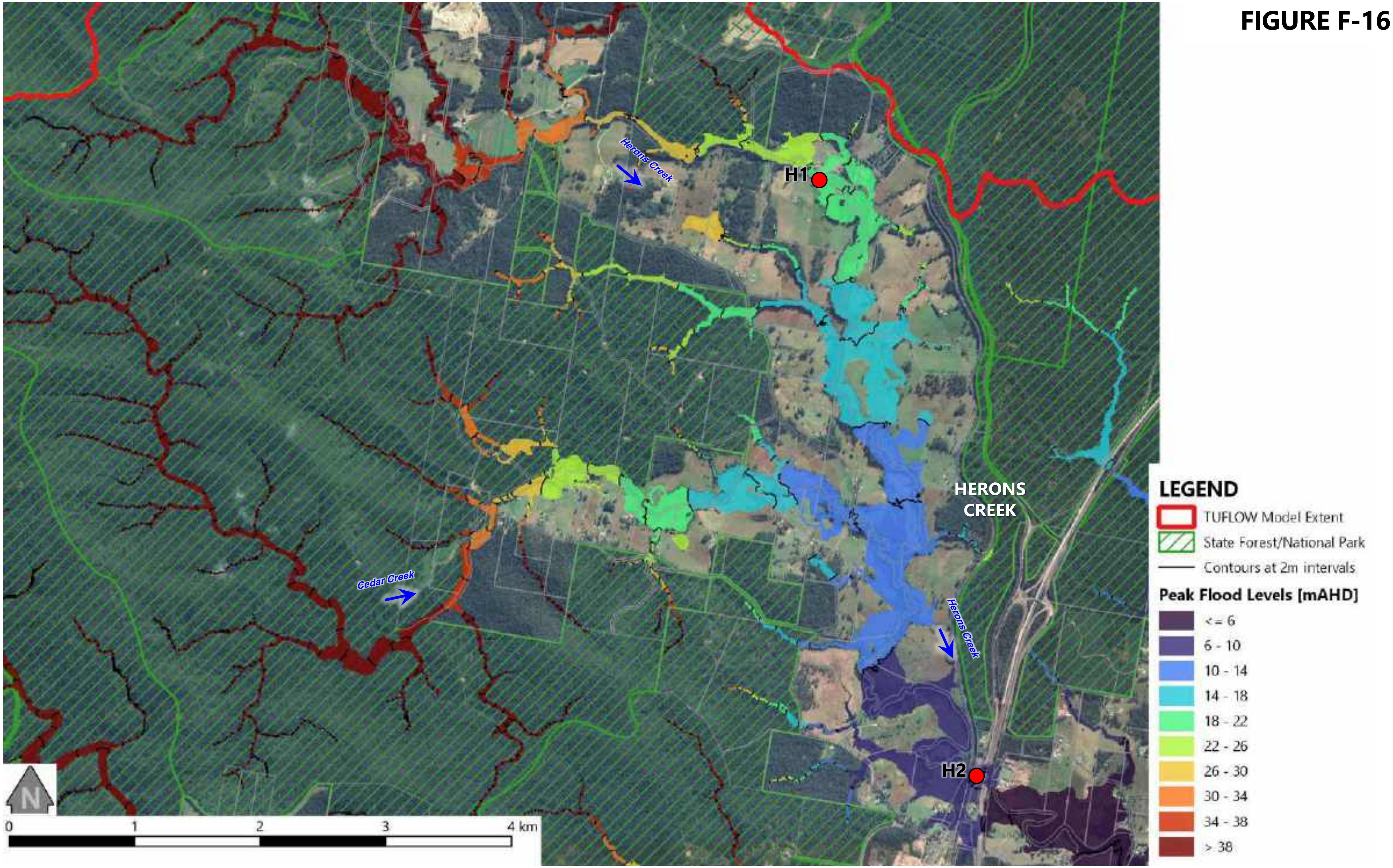


Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs
fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD LEVELS AT THE PEAK OF THE DESIGN 1 IN 500 AEP FLOOD (EXTENT 3 OF 4)

FIGURE F-16



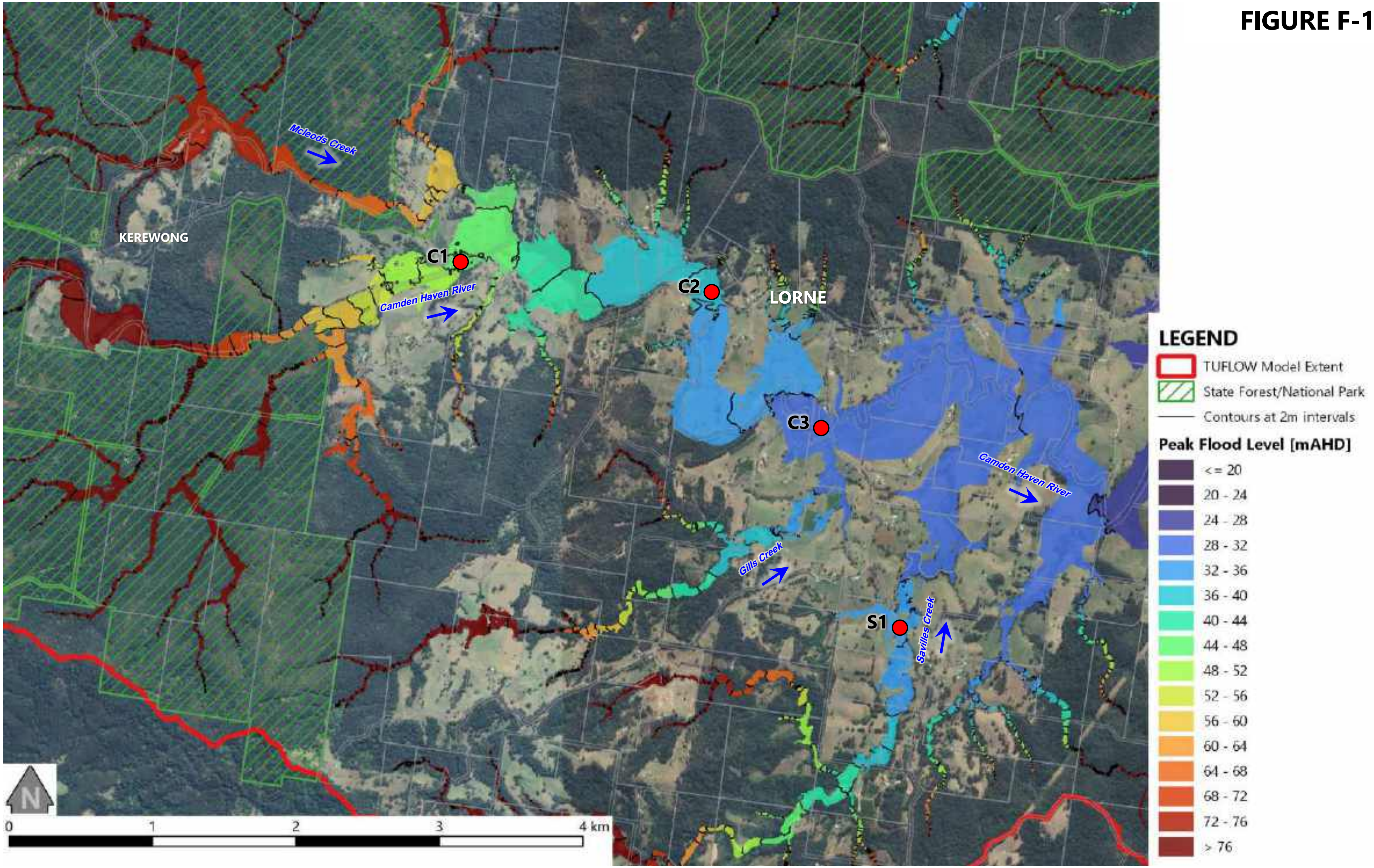
Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD LEVELS AT THE PEAK OF THE DESIGN 1 IN 500 AEP FLOOD (EXTENT 4 OF 4)

FIGURE F-17



Prepared by:

PORT MACQUARIE HASTINGS

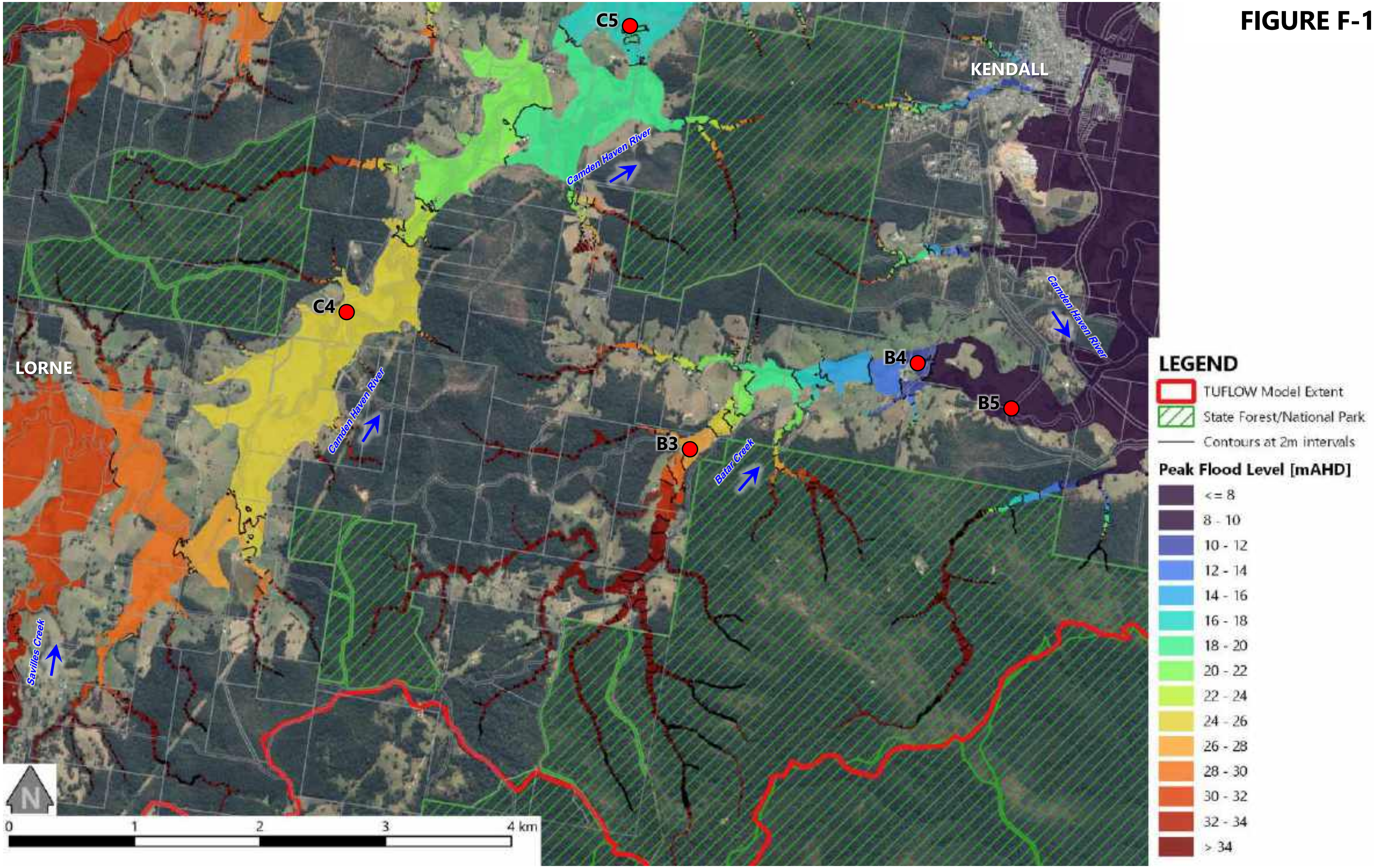
worley consulting

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD LEVELS AT THE PEAK OF THE DESIGN PMF FLOOD (EXTENT 1 OF 4)

FIGURE F-18



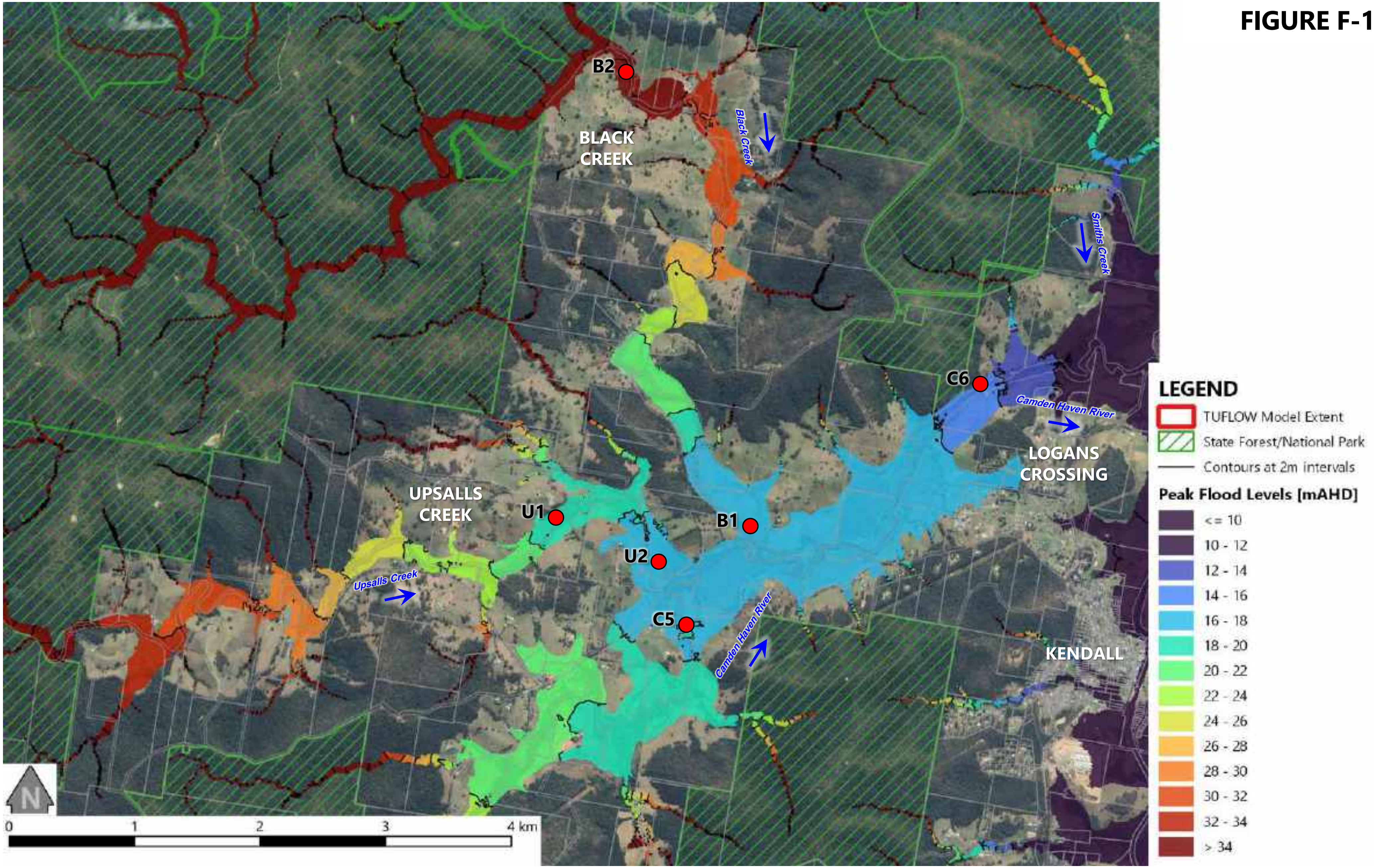
Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD LEVELS AT THE PEAK OF THE DESIGN PMF FLOOD (EXTENT 2 OF 4)

FIGURE F-19



Prepared by: worley consulting

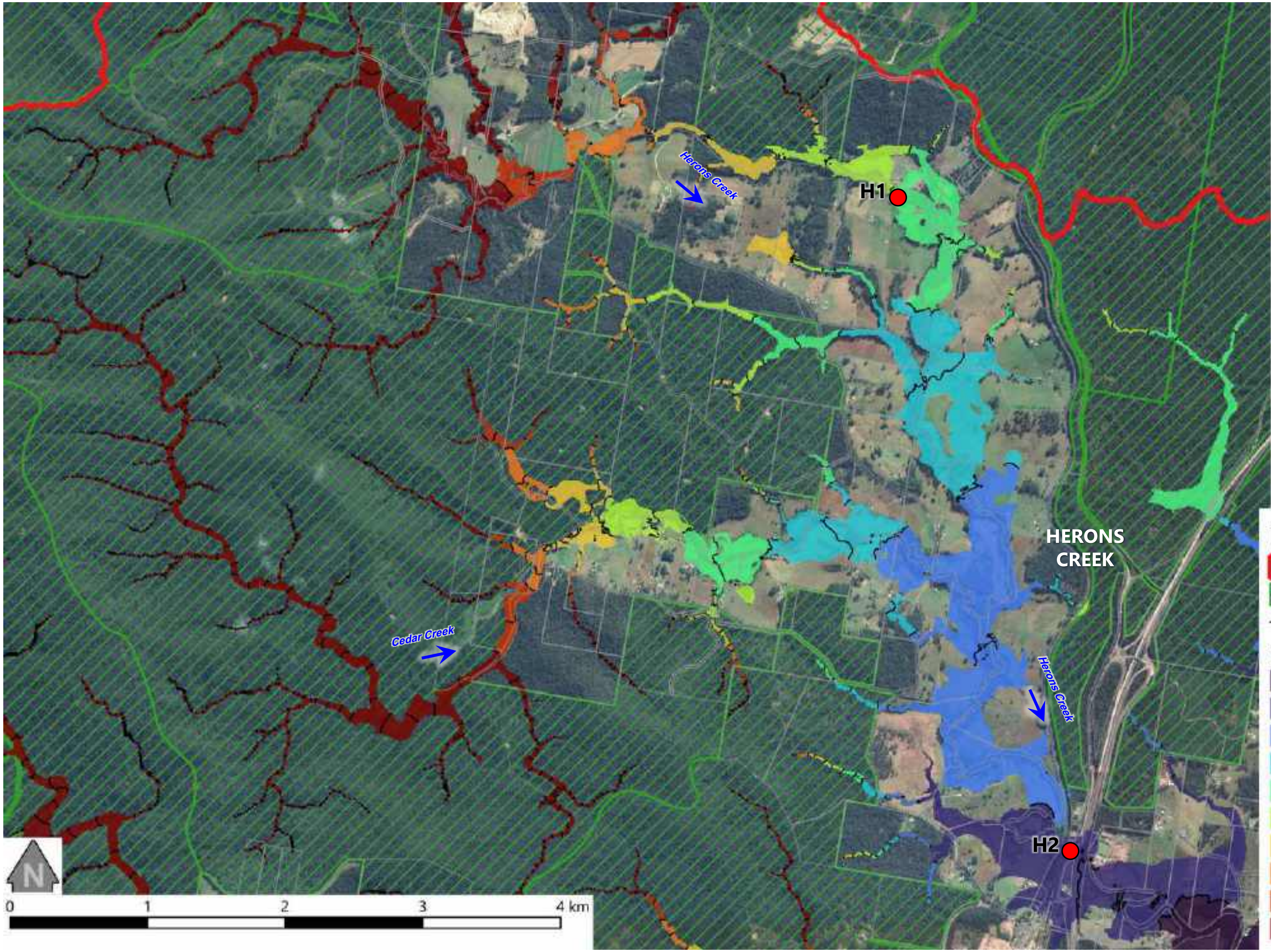
PORT MACQUARIE HASTINGS

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD LEVELS AT THE PEAK OF THE DESIGN PMF FLOOD (EXTENT 3 OF 4)

FIGURE F-20



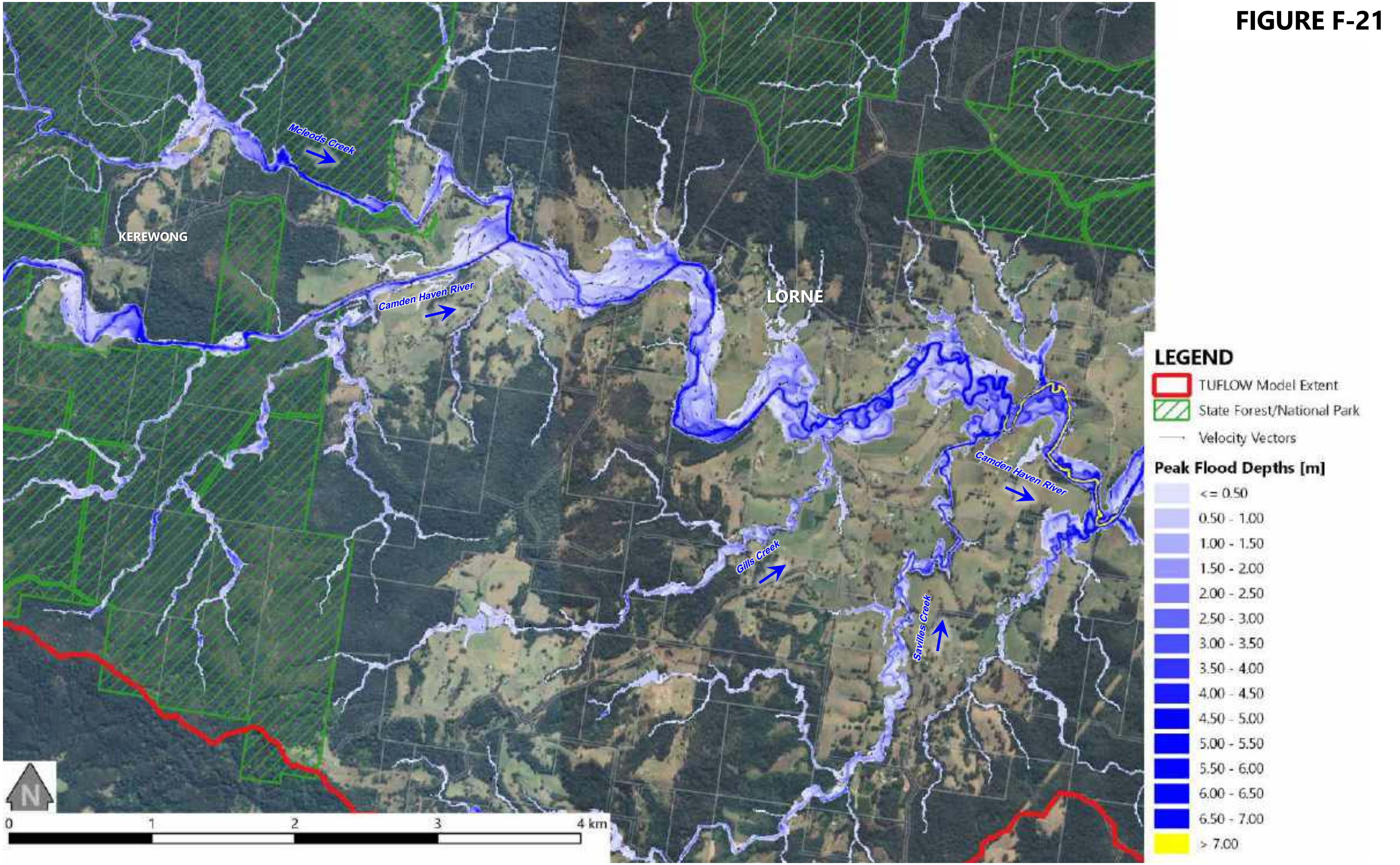
Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD LEVELS AT THE PEAK OF THE DESIGN PMF FLOOD (EXTENT 4 OF 4)

FIGURE F-21

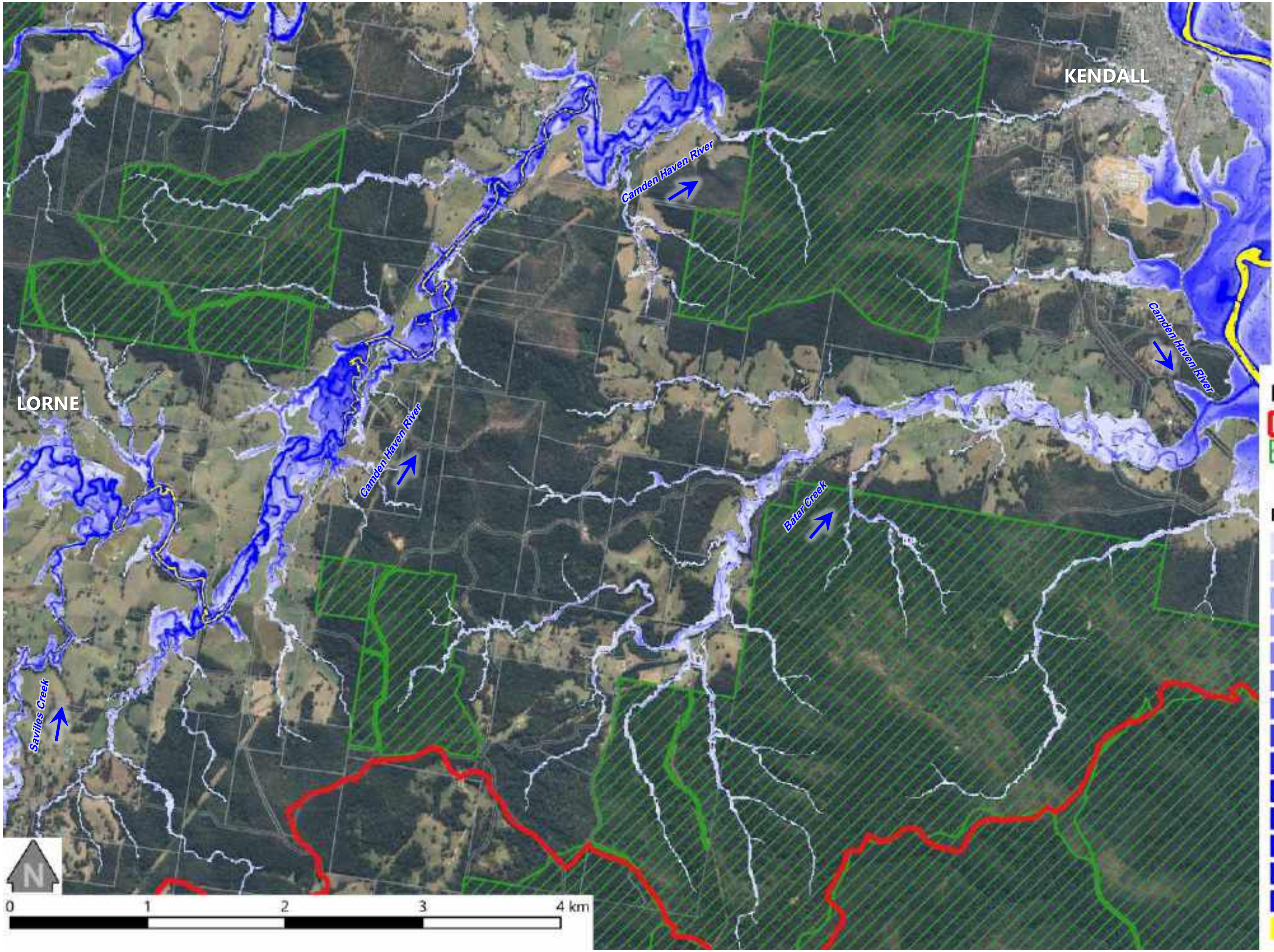


Prepared by: worley consulting

250205_QGIS_CamdenHaven_Figures.qgs
fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD DEPTHS AT THE PEAK OF THE DESIGN 5% AEP FLOOD (EXTENT 1 OF 4)

FIGURE F-22



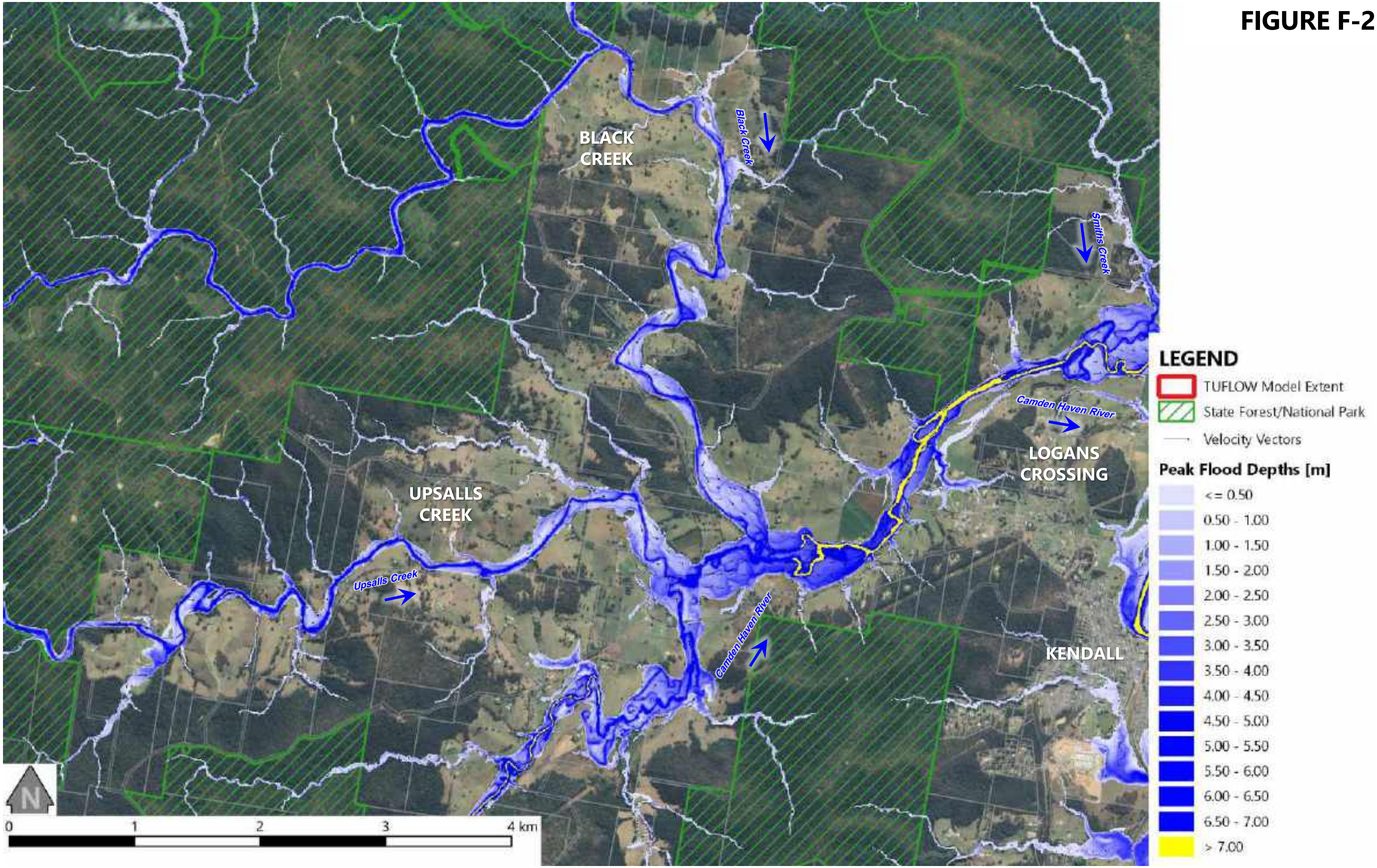
Prepared by: worley consulting

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD DEPTHS AT THE PEAK OF THE DESIGN 5% AEP FLOOD (EXTENT 2 OF 4)

FIGURE F-23



PORT MACQUARIE HASTINGS

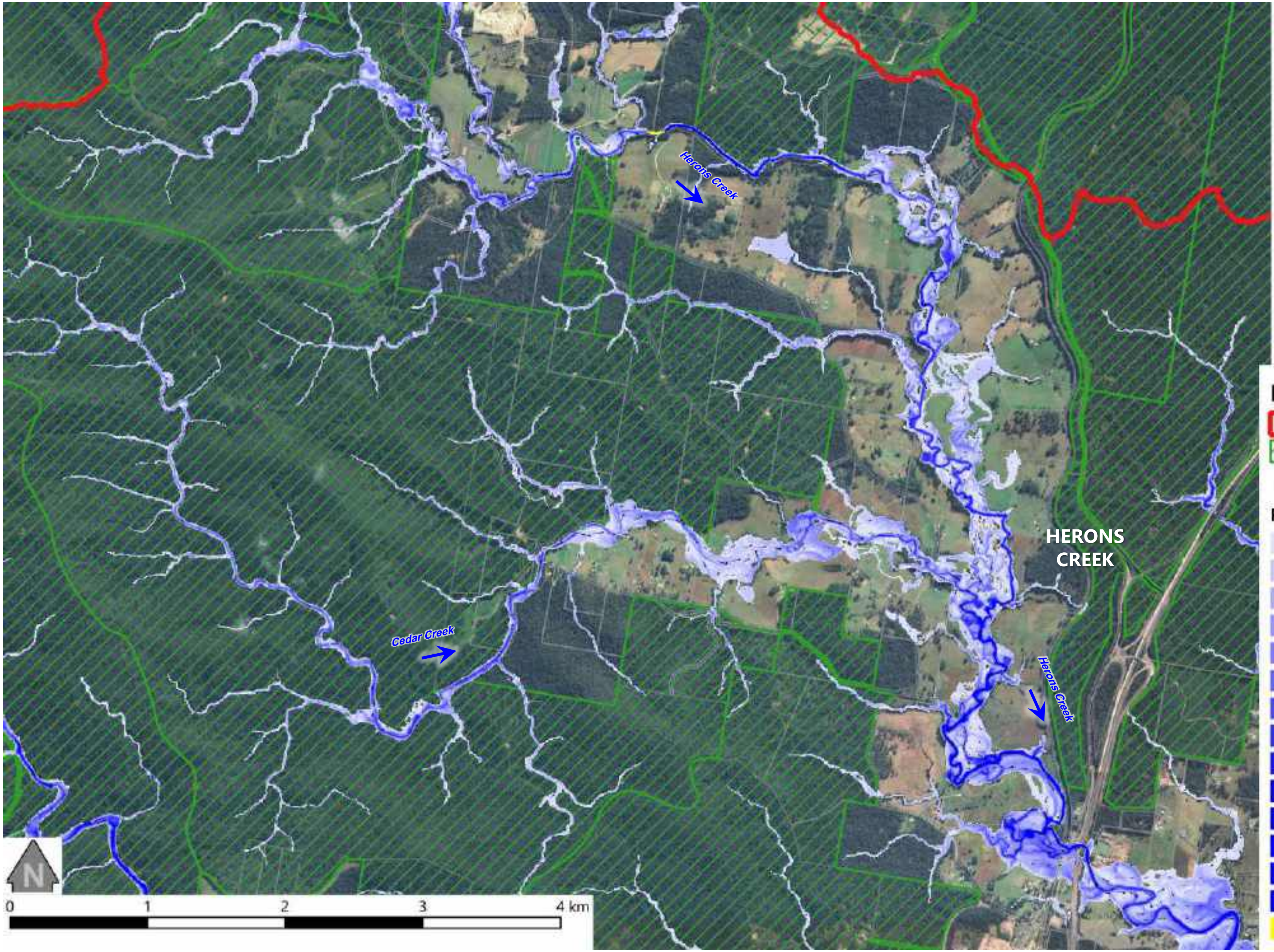
Prepared by: worley consulting

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD DEPTHS AT THE PEAK OF THE DESIGN 5% AEP FLOOD (EXTENT 3 OF 4)

FIGURE F-24



PORT MACQUARIE HASTINGS

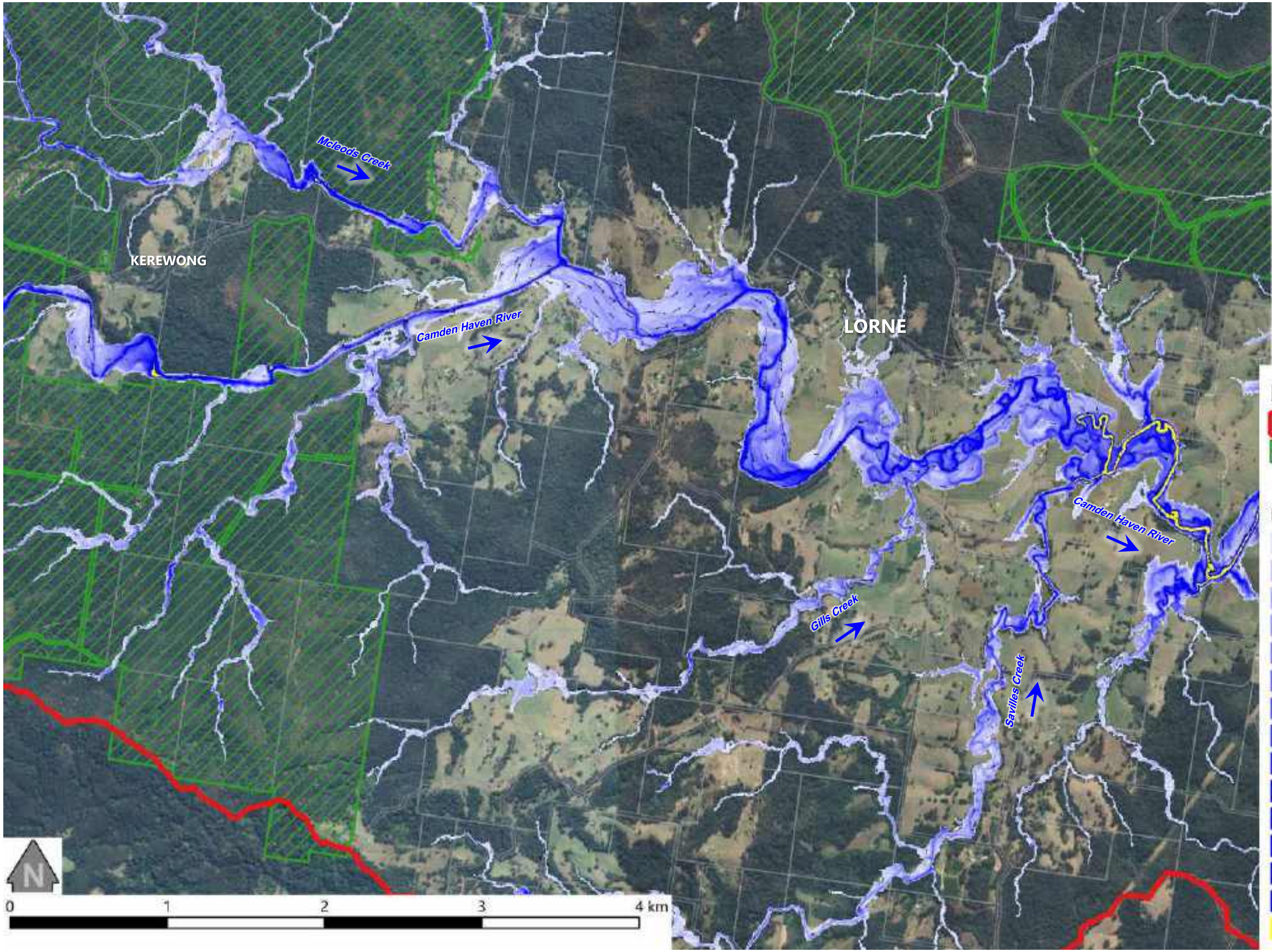
Prepared by: worley consulting

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD DEPTHS AT THE PEAK OF THE DESIGN 5% AEP FLOOD (EXTENT 4 OF 4)

FIGURE F-25



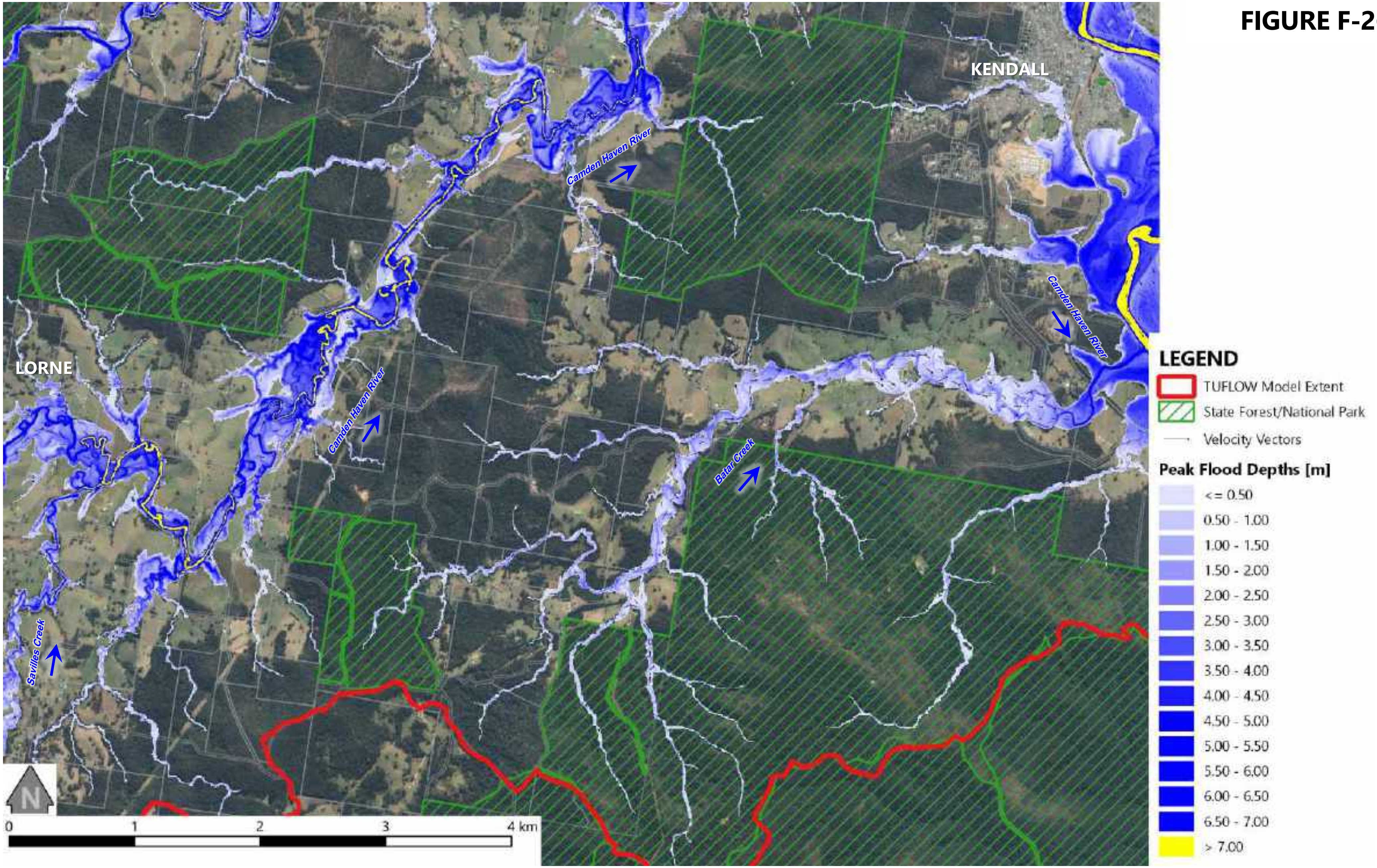
Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD DEPTHS AT THE PEAK OF THE DESIGN 1% AEP FLOOD (EXTENT 1 OF 4)

FIGURE F-26



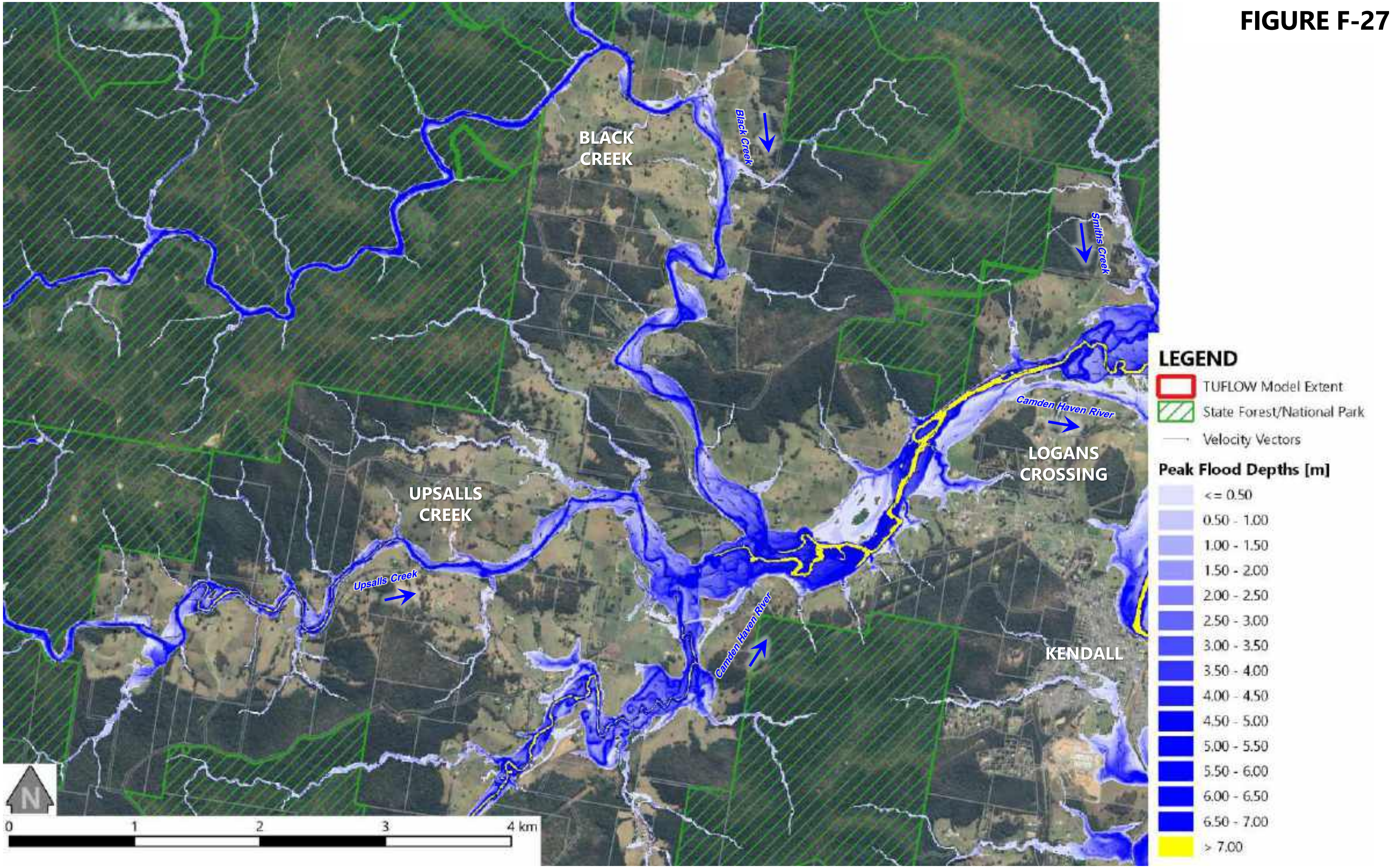
Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD DEPTHS AT THE PEAK OF THE DESIGN 1% AEP FLOOD (EXTENT 2 OF 4)

FIGURE F-27



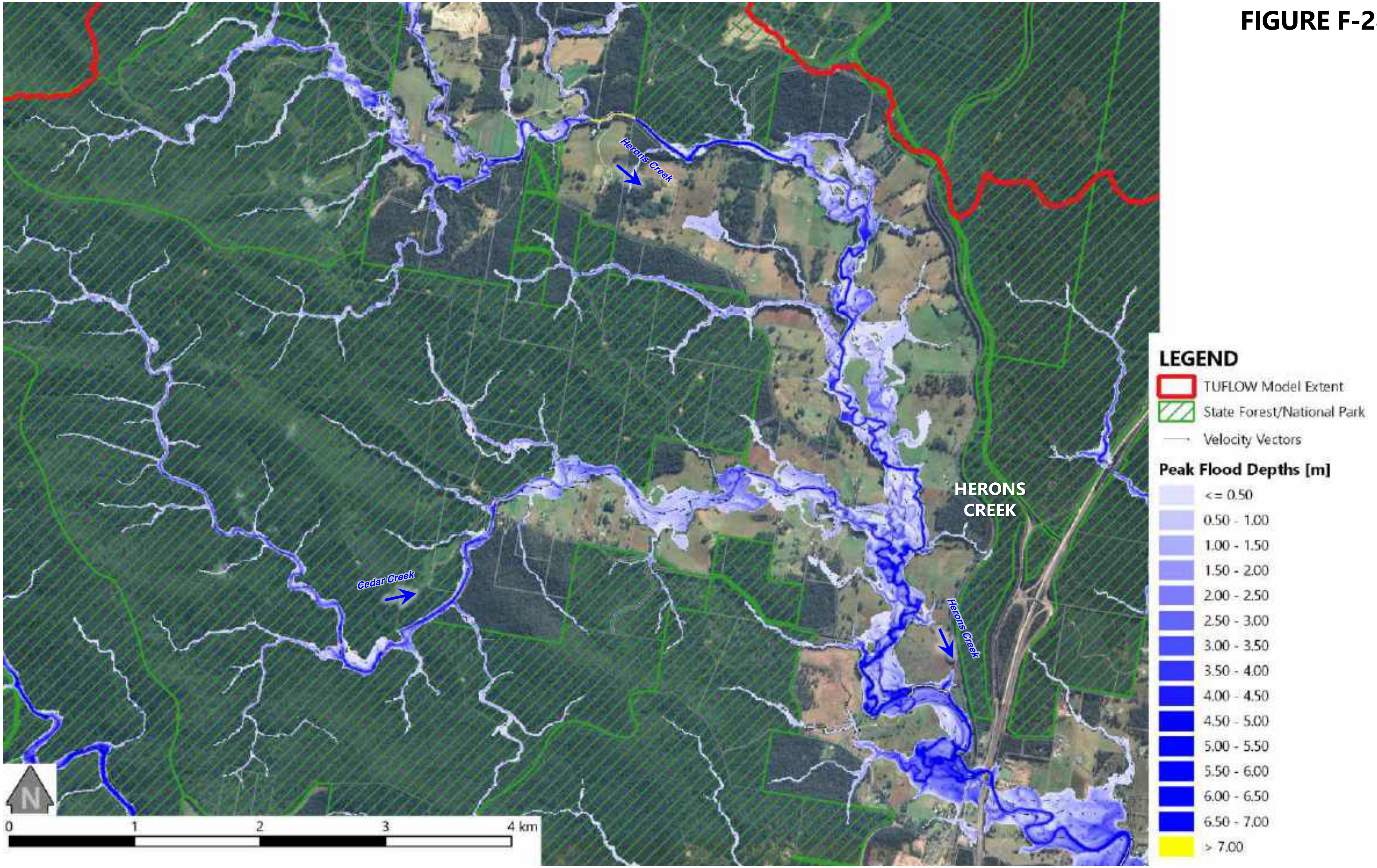
PORT MACQUARIE HASTINGS

Prepared by:
worley consulting

250205_QGIS_CamdenHaven_Figures.qgs
fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD DEPTHS AT THE PEAK OF THE DESIGN 1% AEP FLOOD (EXTENT 3 OF 4)

FIGURE F-28



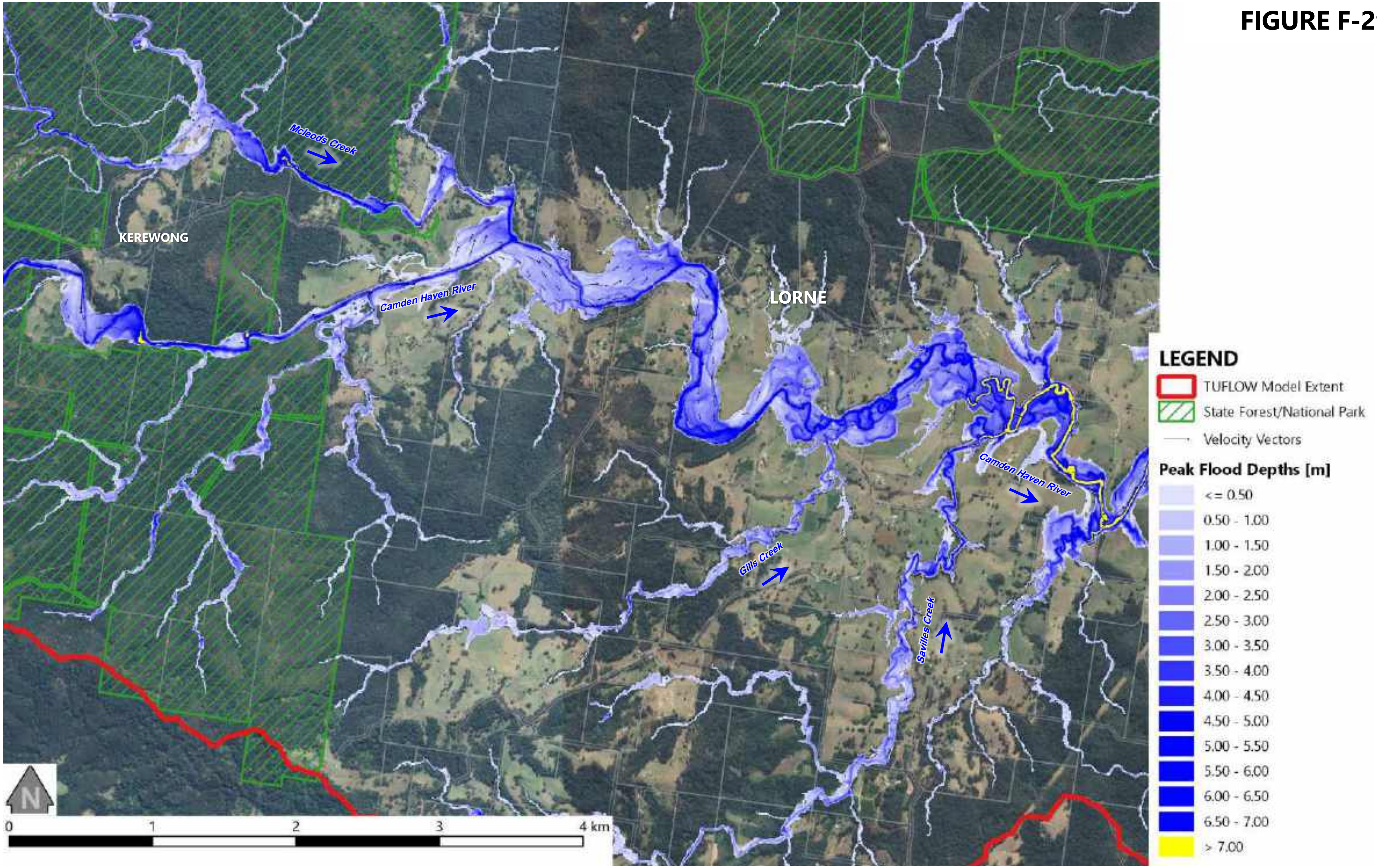
Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD DEPTHS AT THE PEAK OF THE DESIGN 1% AEP FLOOD (EXTENT 4 OF 4)

FIGURE F-29



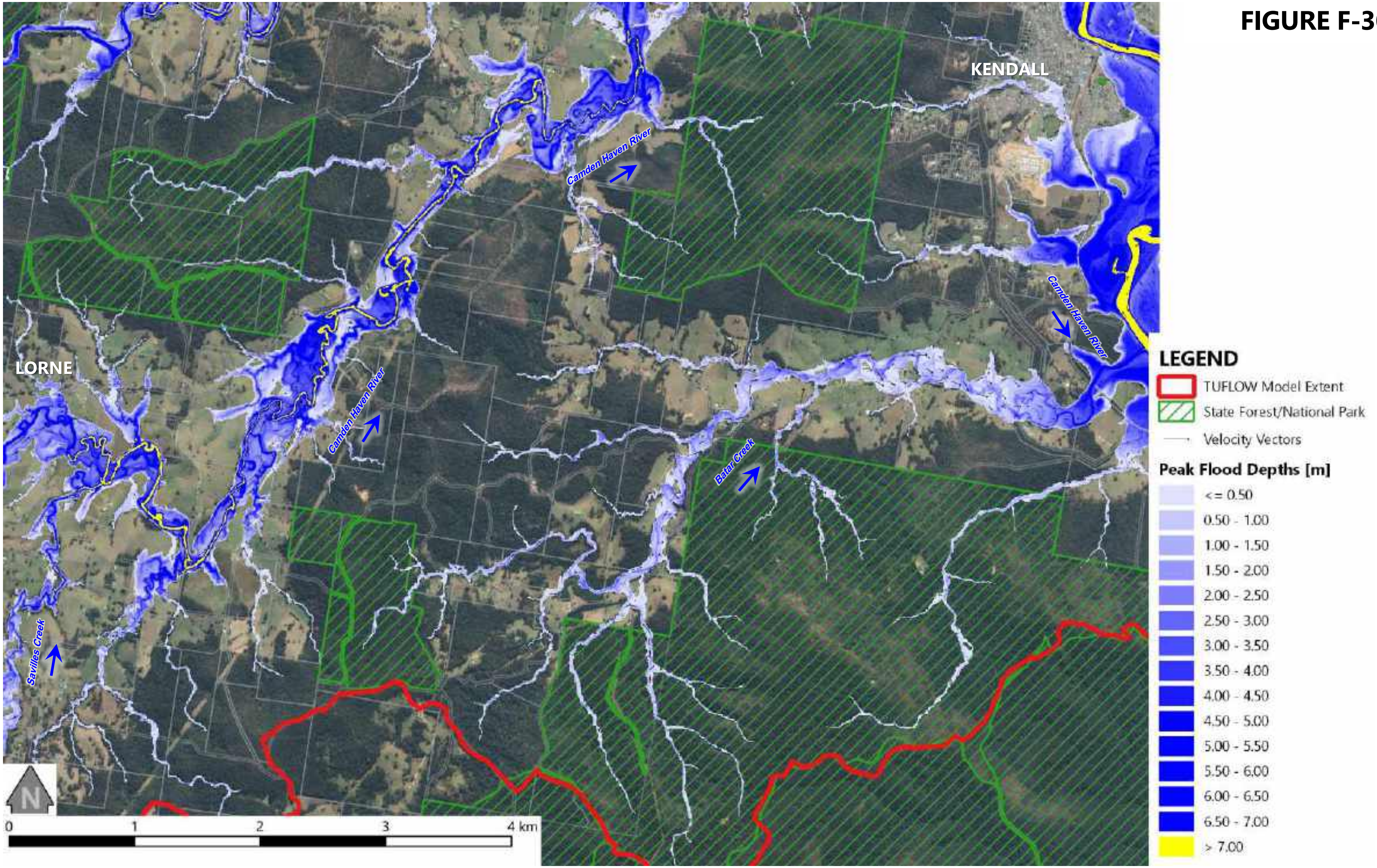
Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD DEPTHS AT THE PEAK OF THE DESIGN 1% AEP WITH CLIMATE CHANGE FLOOD (EXTENT 1 OF 4)

FIGURE F-30

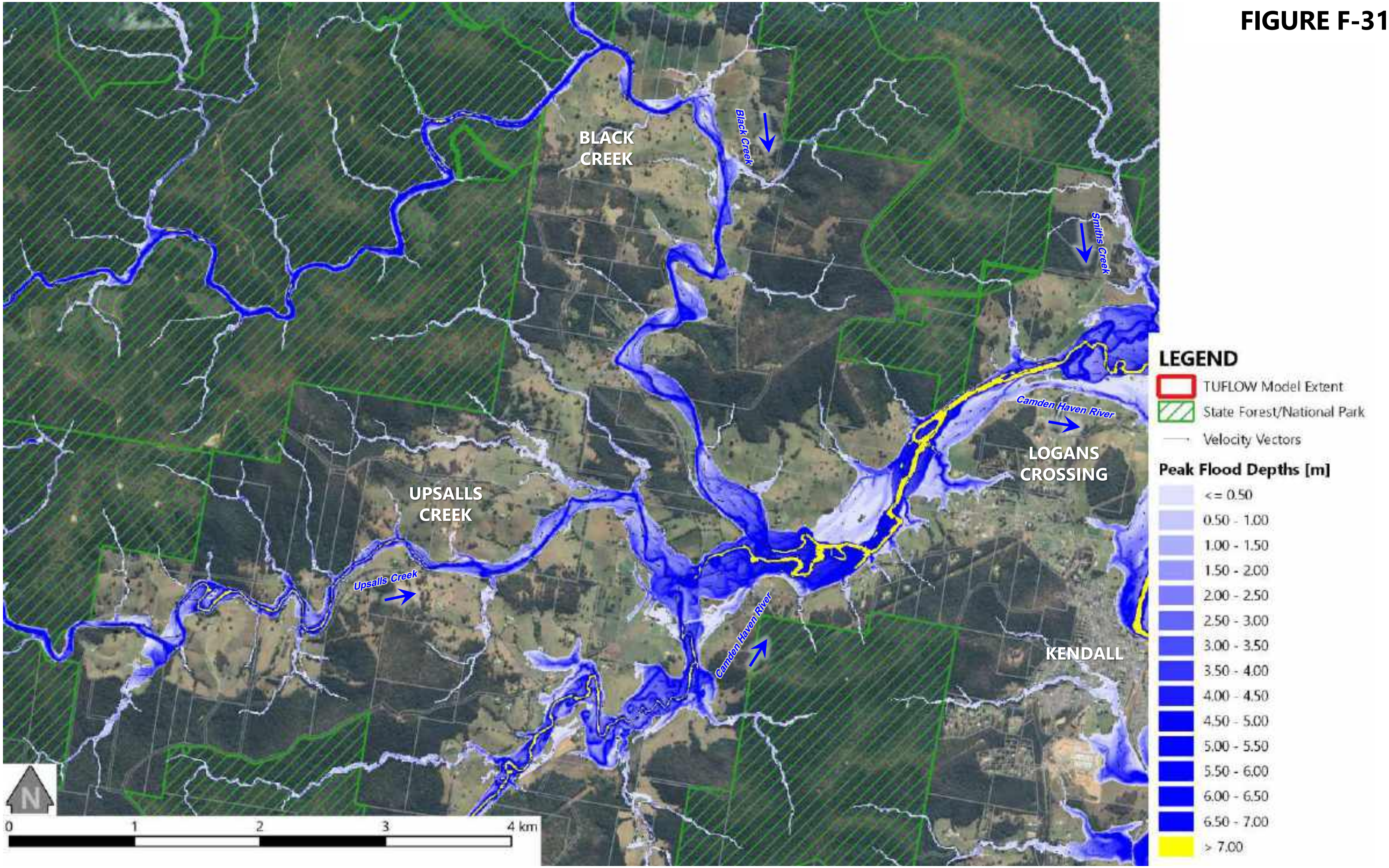


Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs
fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD DEPTHS AT THE PEAK OF THE DESIGN 1% AEP WITH CLIMATE CHANGE FLOOD (EXTENT 2 OF 4)

FIGURE F-31



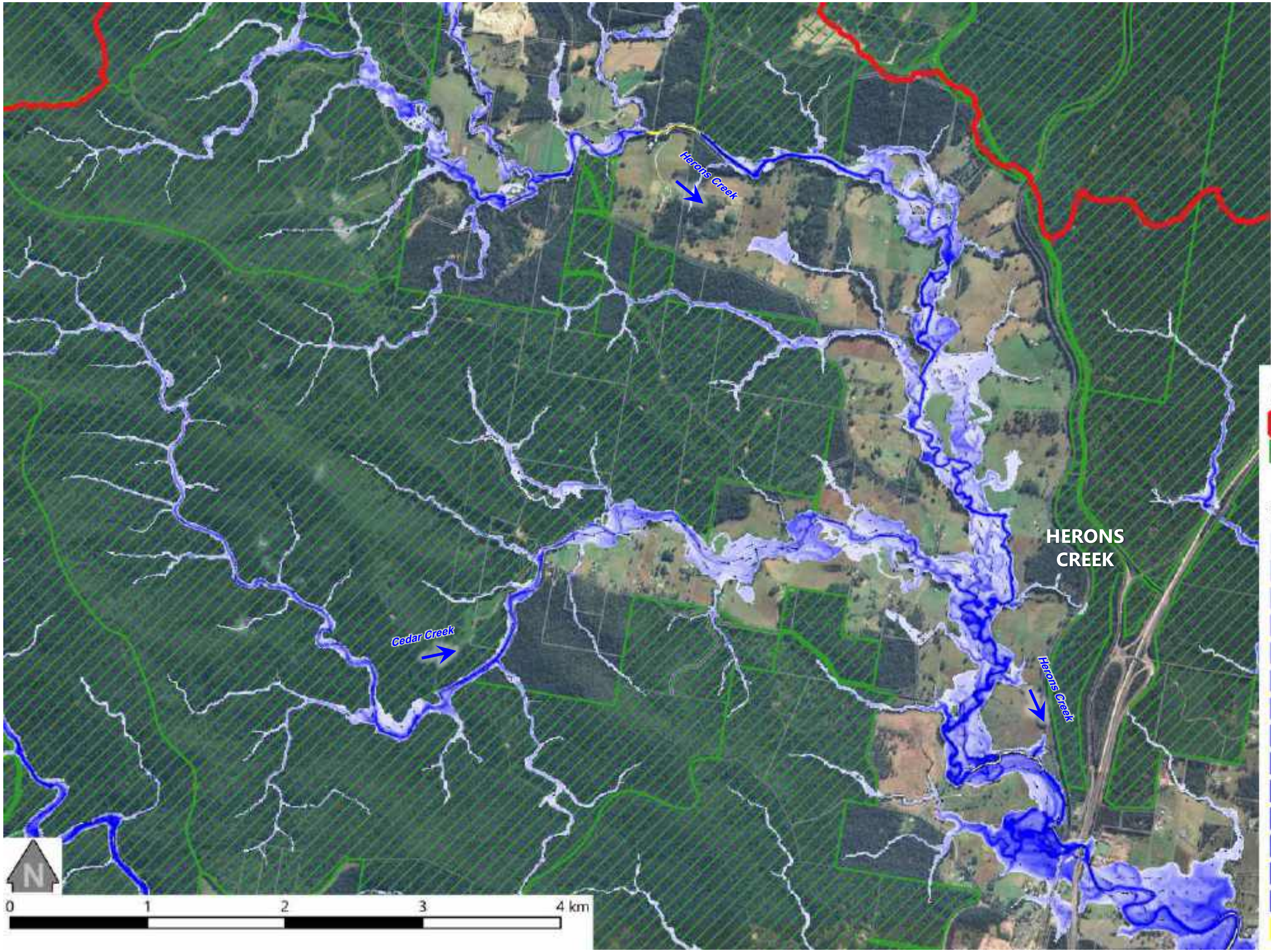
Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD DEPTHS AT THE PEAK OF THE DESIGN 1% AEP WITH CLIMATE CHANGE FLOOD (EXTENT 3 OF 4)

FIGURE F-32



PORT MACQUARIE HASTINGS

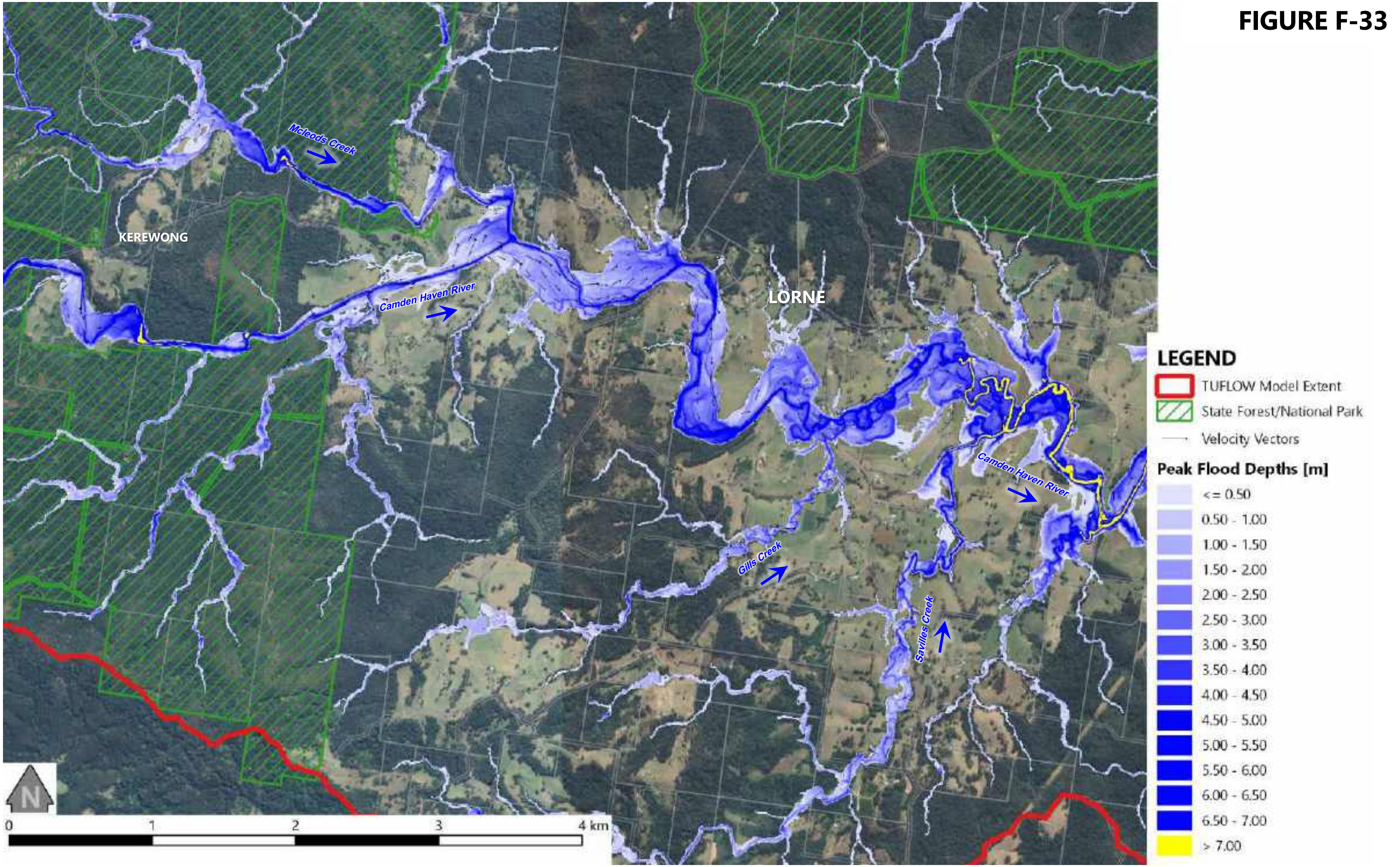
Prepared by: worley consulting

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD DEPTHS AT THE PEAK OF THE DESIGN 1% AEP WITH CLIMATE CHANGE FLOOD (EXTENT 4 OF 4)

FIGURE F-33



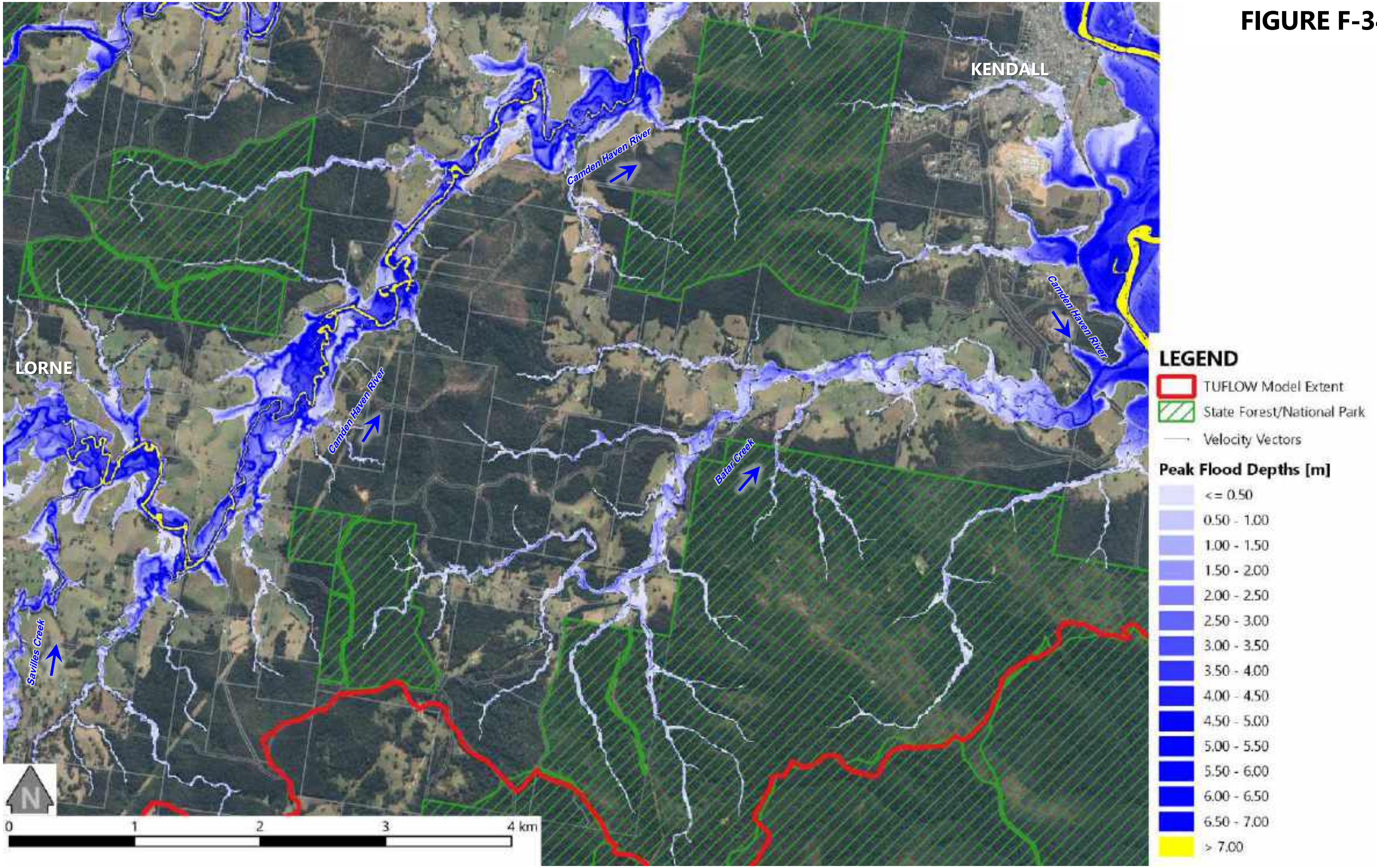
Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD DEPTHS AT THE PEAK OF THE DESIGN 1 IN 500 AEP FLOOD (EXTENT 1 OF 4)

FIGURE F-34



PORT MACQUARIE HASTINGS

Prepared by:

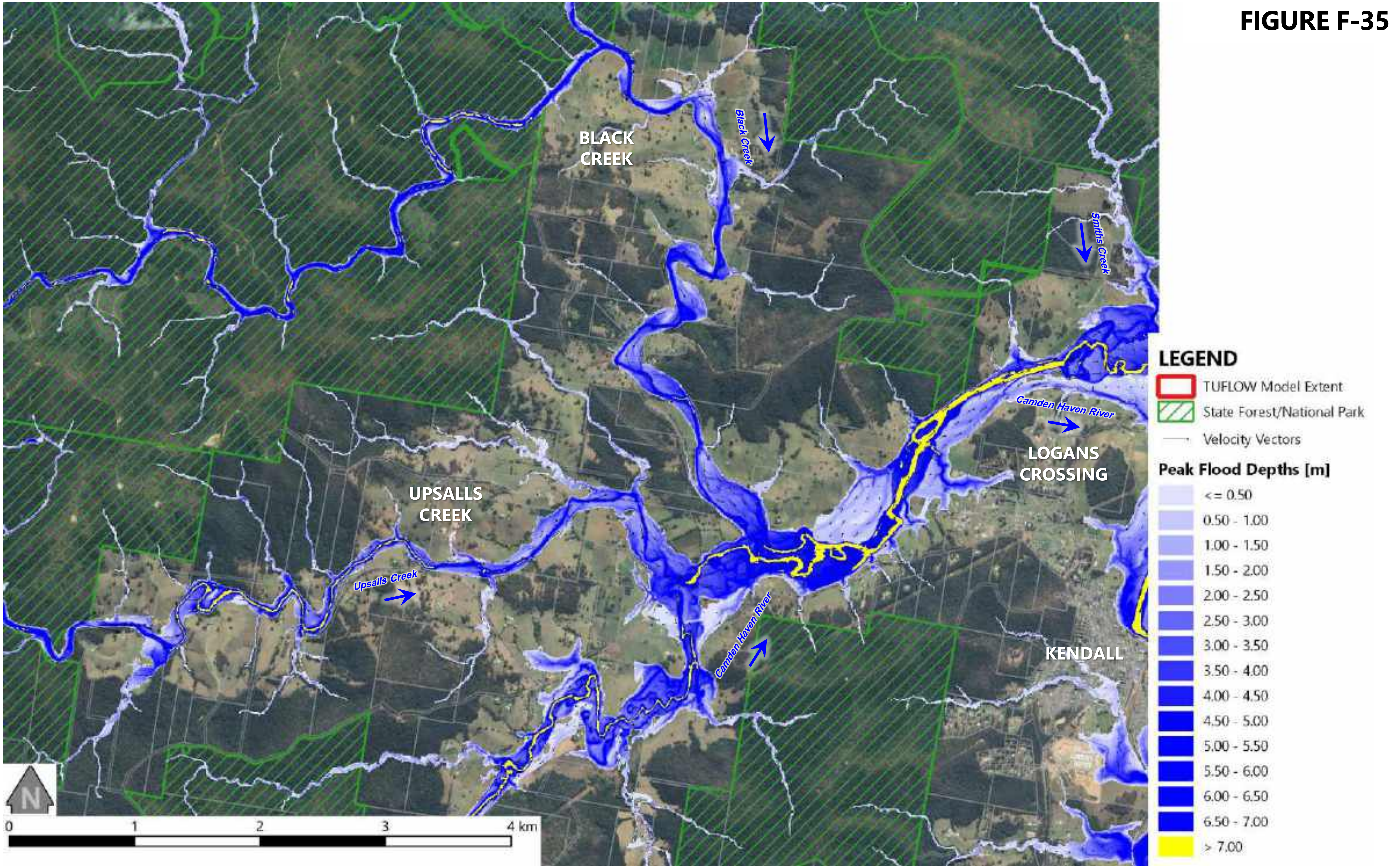
worley consulting

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD DEPTHS AT THE PEAK OF THE DESIGN 1 IN 500 AEP FLOOD (EXTENT 2 OF 4)

FIGURE F-35

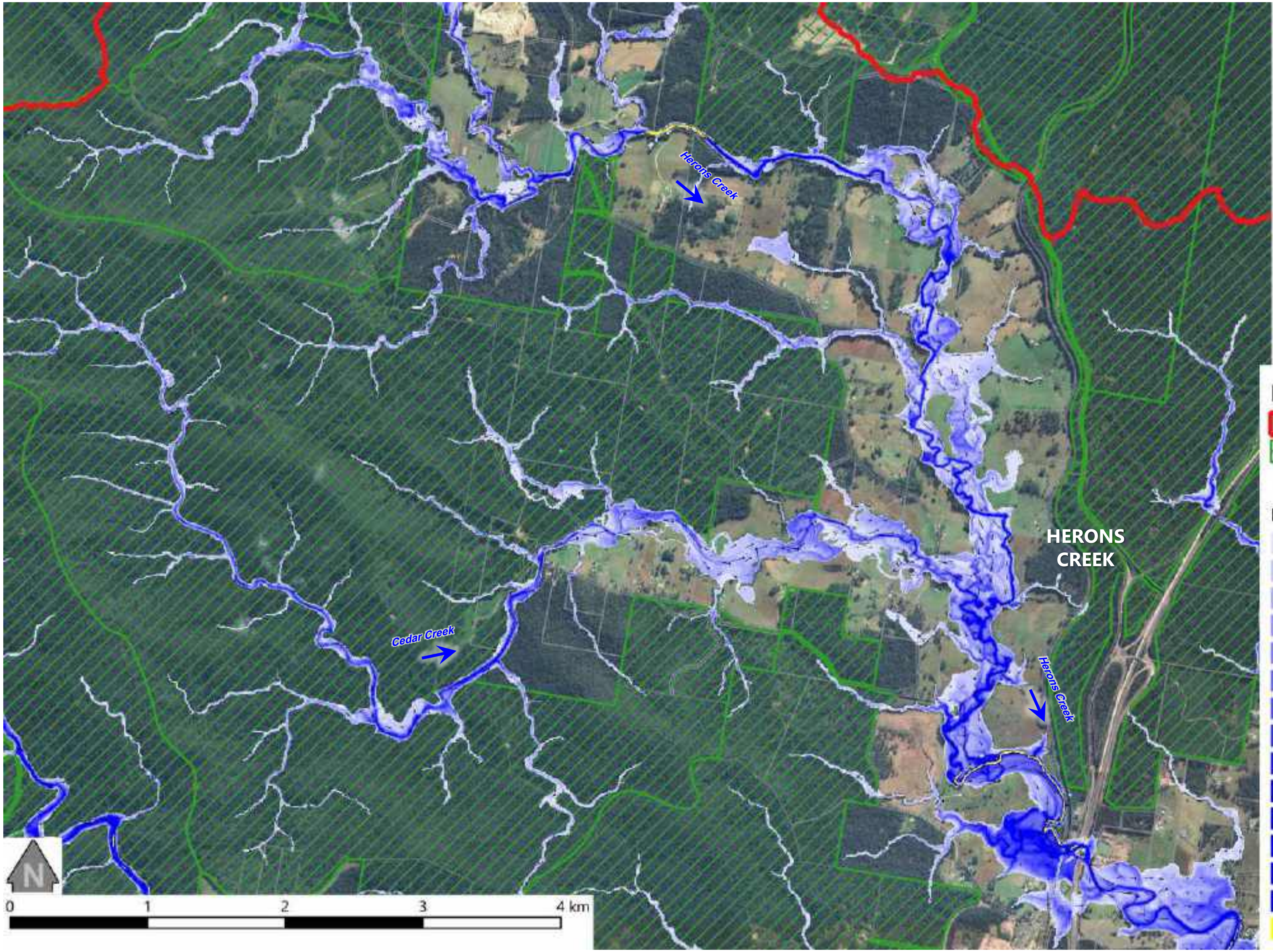


Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs
fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD DEPTHS AT THE PEAK OF THE DESIGN 1 IN 500 AEP FLOOD (EXTENT 3 OF 4)

FIGURE F-36



PORT MACQUARIE HASTINGS

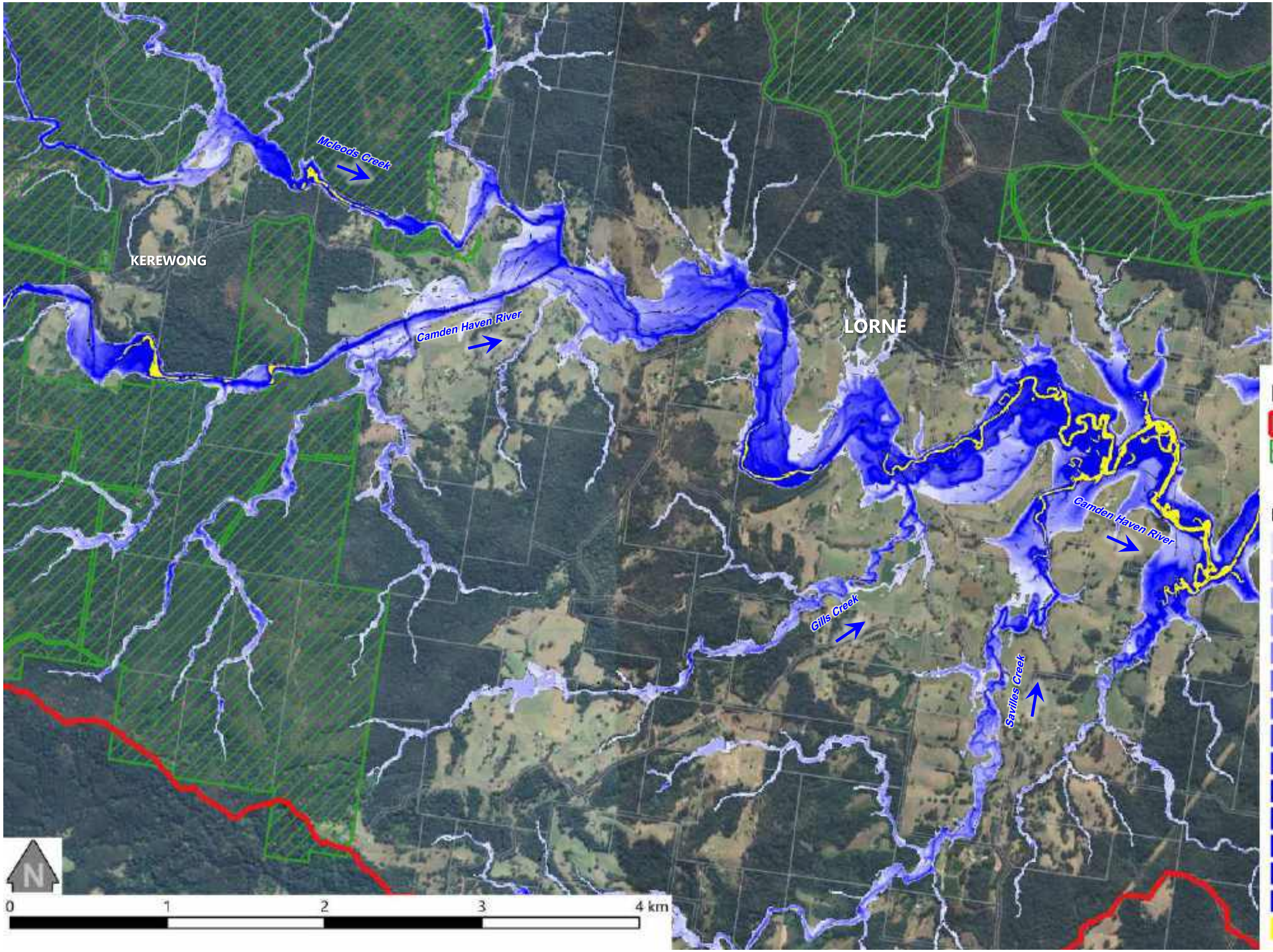
Prepared by: worley consulting

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD DEPTHS AT THE PEAK OF THE DESIGN 1 IN 500 AEP FLOOD (EXTENT 4 OF 4)

FIGURE F-37



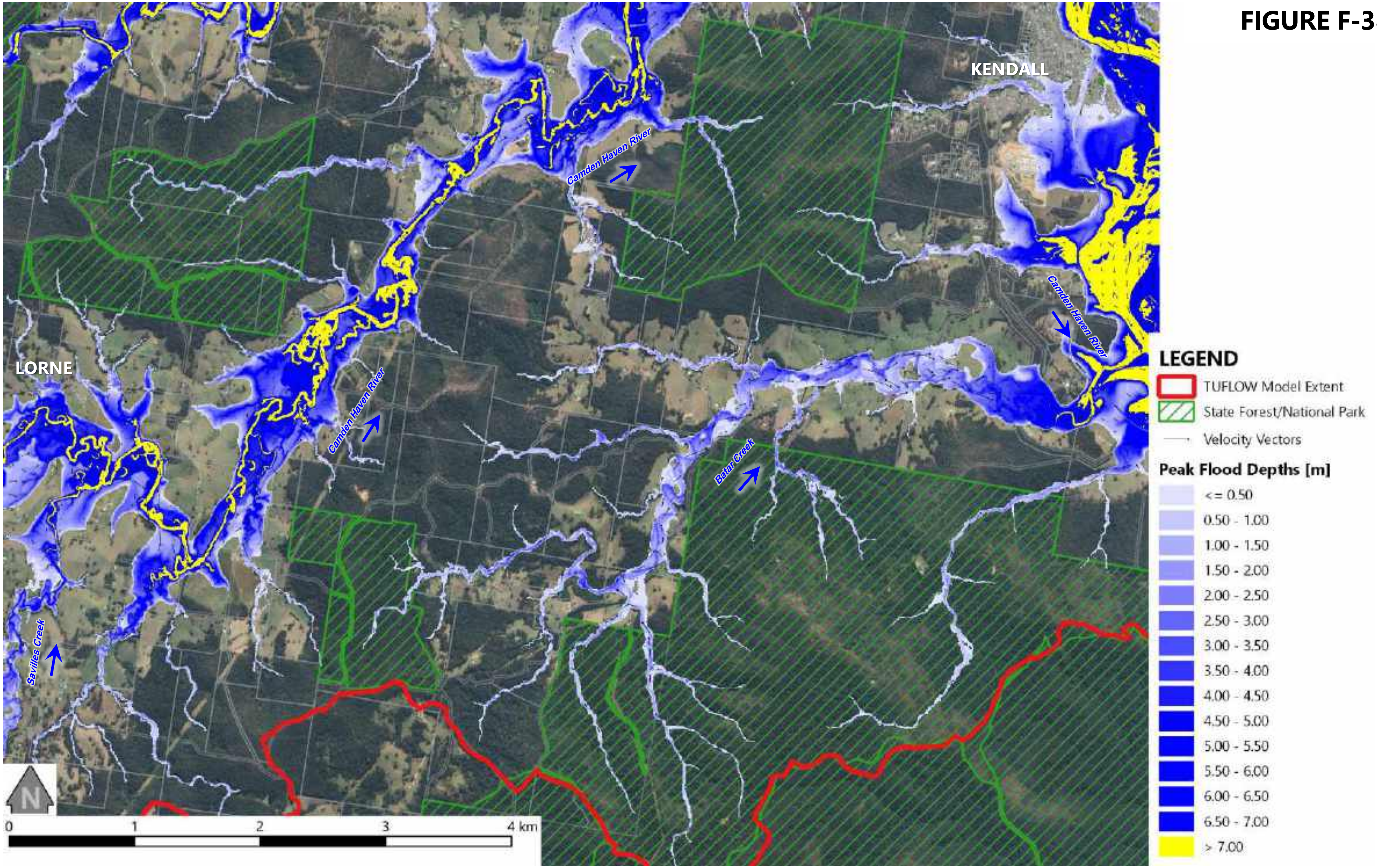
Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD DEPTHS AT THE PEAK OF THE DESIGN PMF FLOOD (EXTENT 1 OF 4)

FIGURE F-38



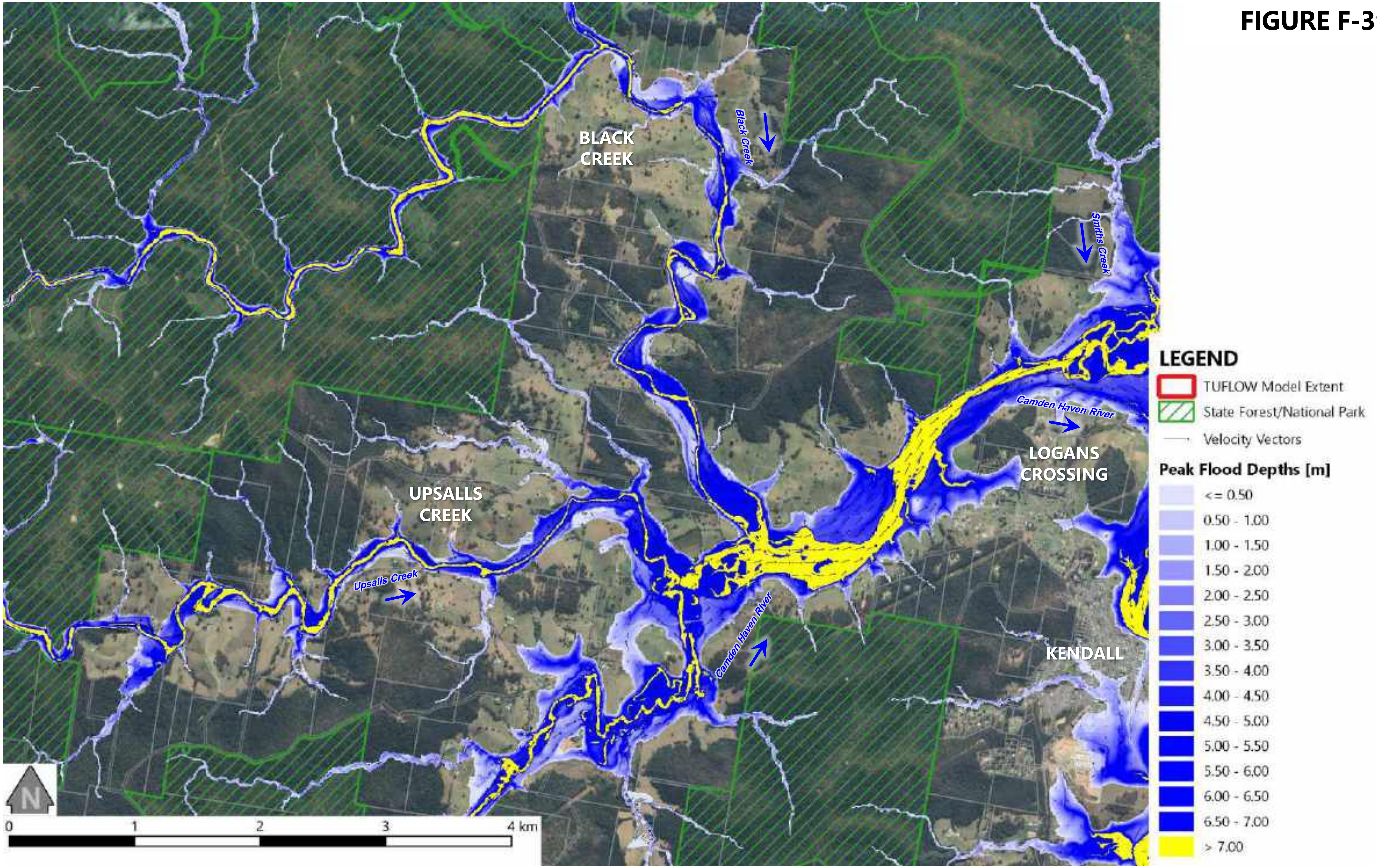
Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD DEPTHS AT THE PEAK OF THE DESIGN PMF FLOOD (EXTENT 2 OF 4)

FIGURE F-39



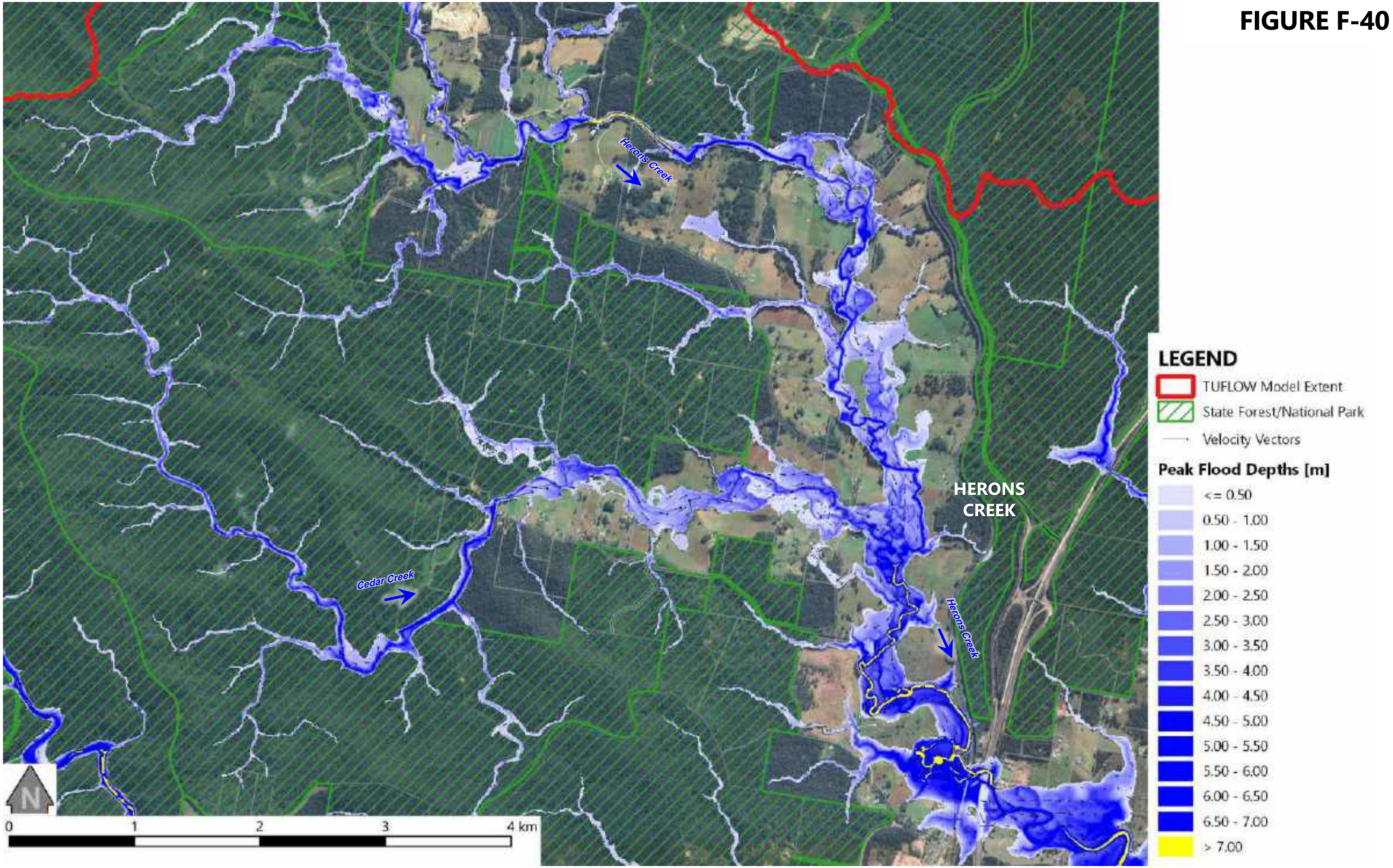
Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD DEPTHS AT THE PEAK OF THE DESIGN PMF FLOOD (EXTENT 3 OF 4)

FIGURE F-40



Prepared by:

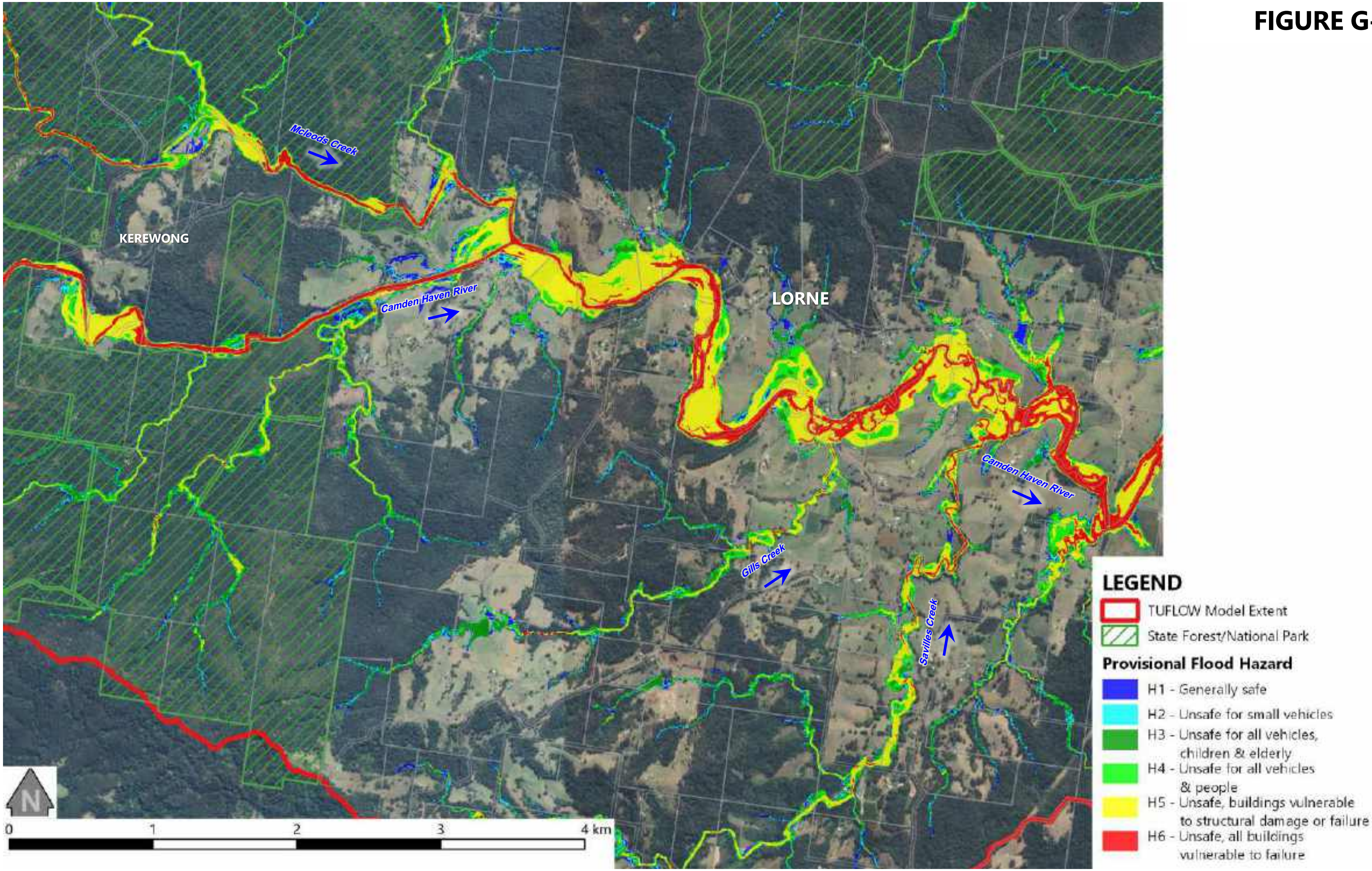
250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPF.pdf

PREDICTED FLOOD DEPTHS AT THE PEAK OF THE DESIGN PMF FLOOD (EXTENT 4 OF 4)

Appendix G. Provisional Flood Hazard Mapping

FIGURE G-1



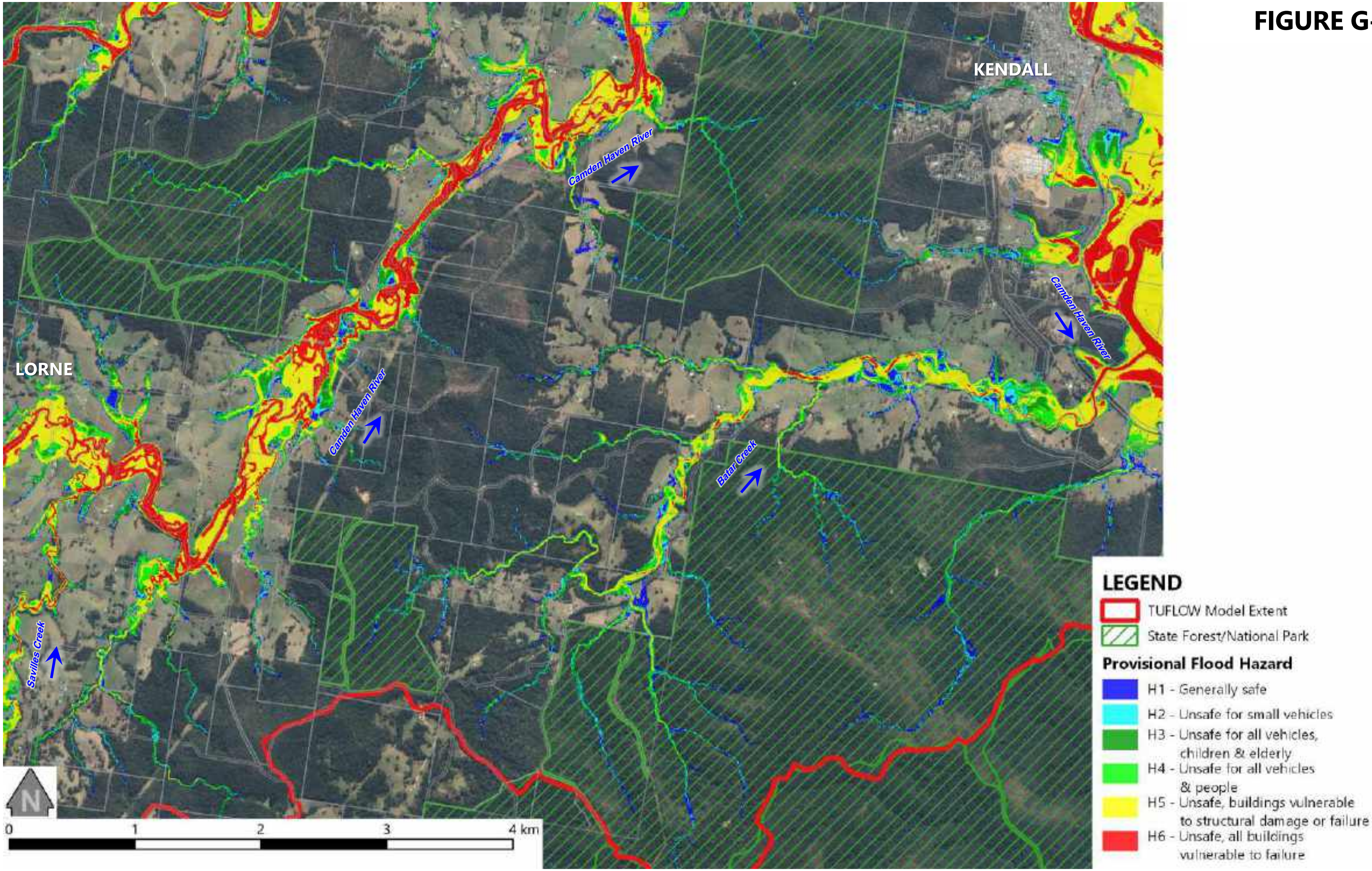
Prepared by:

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPG.pdf

MAPPING OF PROVISIONAL FLOOD HAZARDS AT THE PEAK OF THE DESIGN 1% AEP FLOOD (EXTENT 1 OF 4)

FIGURE G-2



Prepared by:

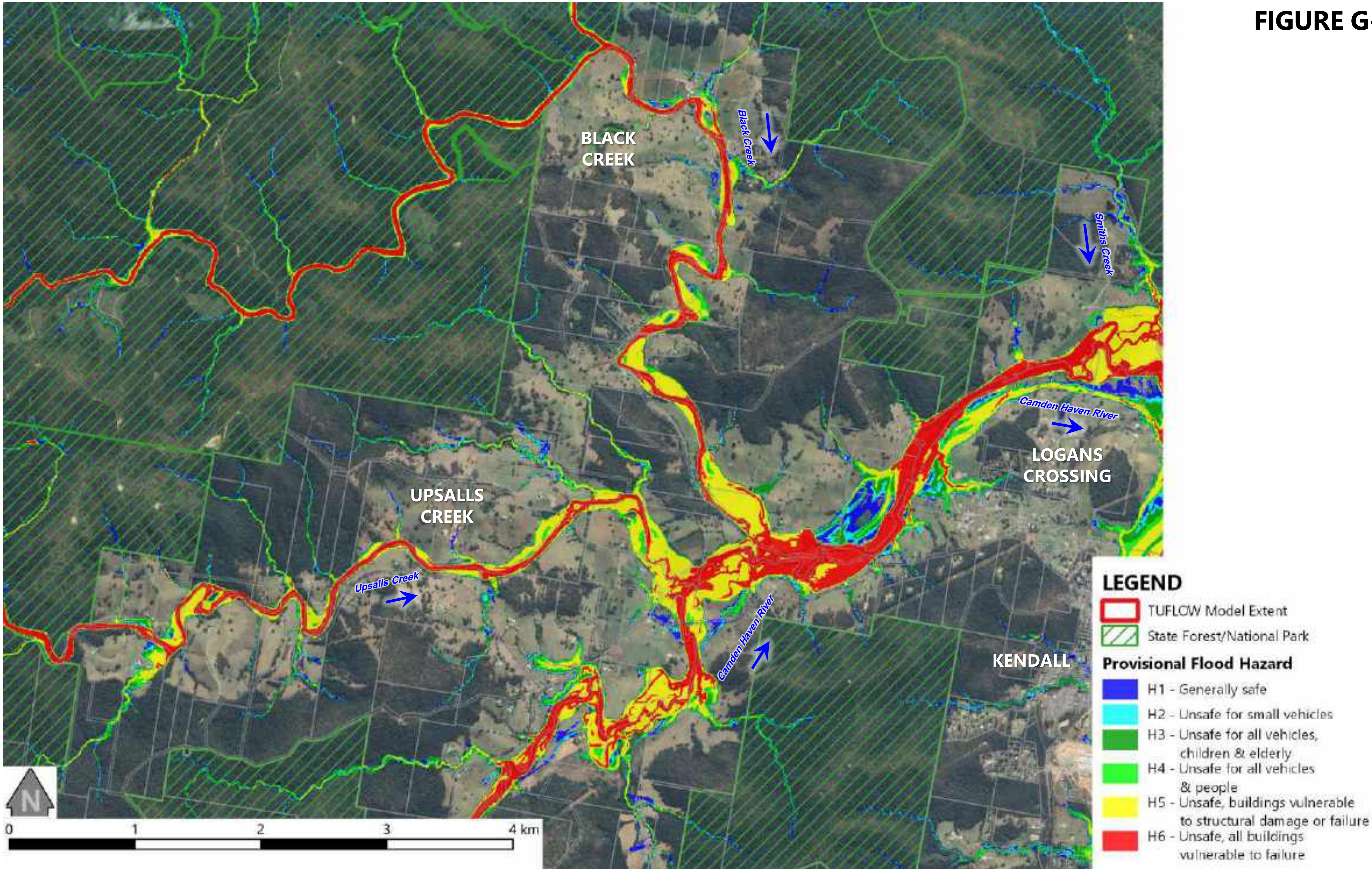
worley consulting

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPG.pdf

MAPPING OF PROVISIONAL FLOOD HAZARDS AT THE PEAK OF THE DESIGN 1% AEP FLOOD (EXTENT 2 OF 4)

FIGURE G-3



PORT MACQUARIE HASTINGS

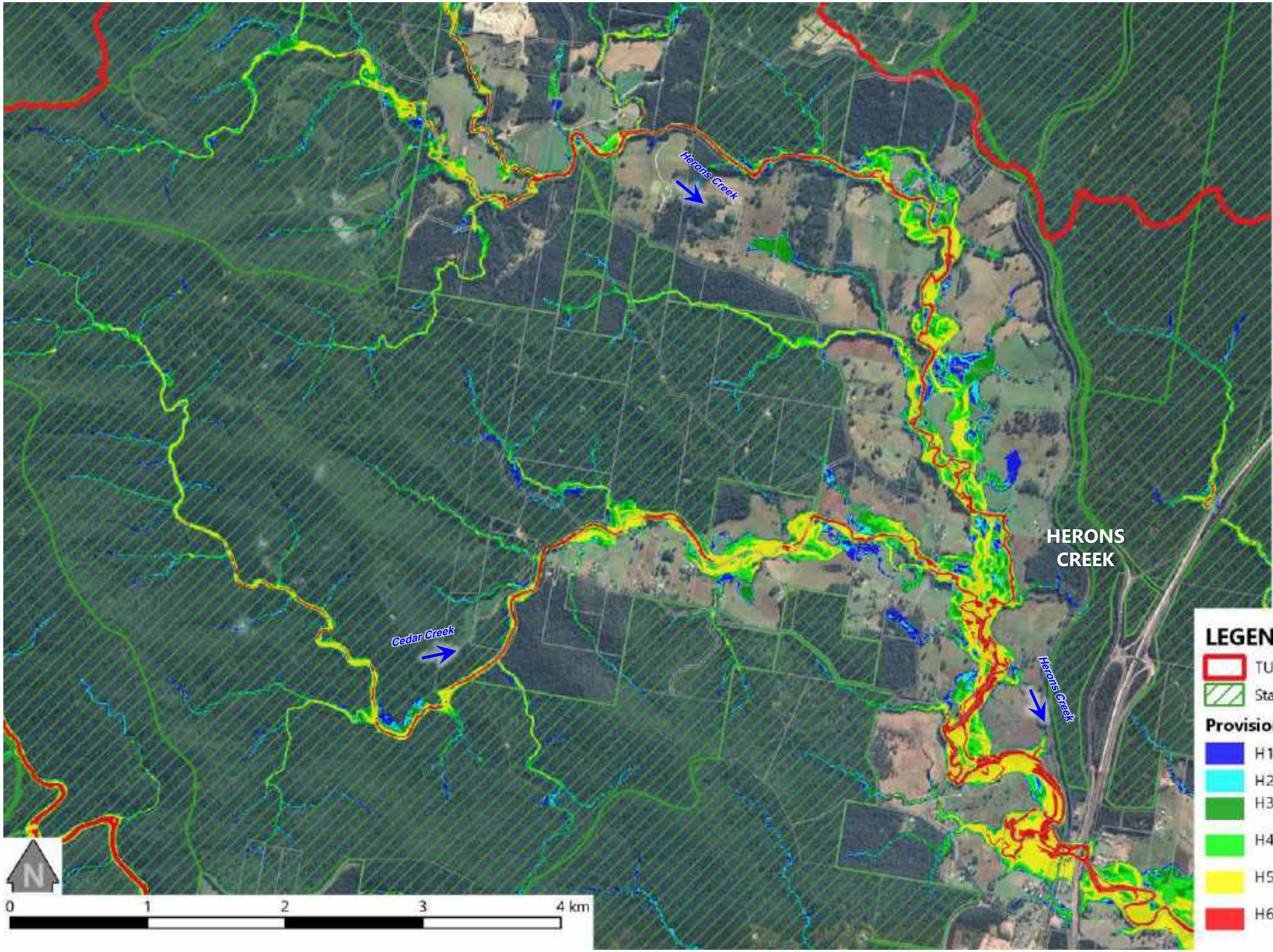
Prepared by: worley consulting

250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPG.pdf

MAPPING OF PROVISIONAL FLOOD HAZARDS AT THE PEAK OF THE DESIGN 1% AEP FLOOD (EXTENT 3 OF 4)

FIGURE G-4



Prepared by: worley consulting

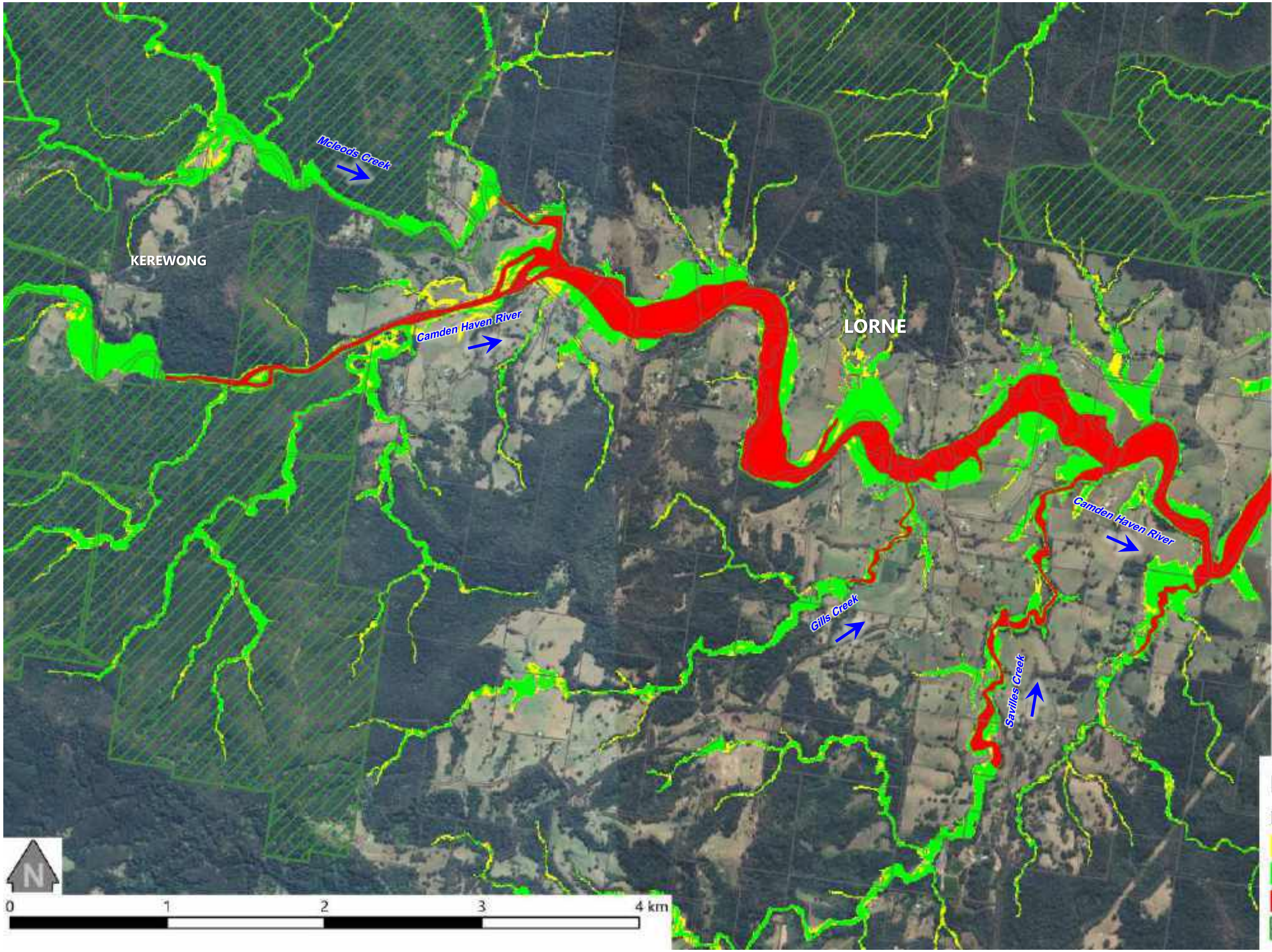
250205_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250214_CamdenHaven_A4L_APPG.pdf

MAPPING OF PROVISIONAL FLOOD HAZARDS AT THE PEAK OF THE DESIGN 1% AEP FLOOD (EXTENT 4 OF 4)

Appendix H. Flood Function Mapping

FIGURE H-1



LEGEND

Flood Function

- Flood Fringe
- Flood Storage
- Floodway
- State Forest/National Park

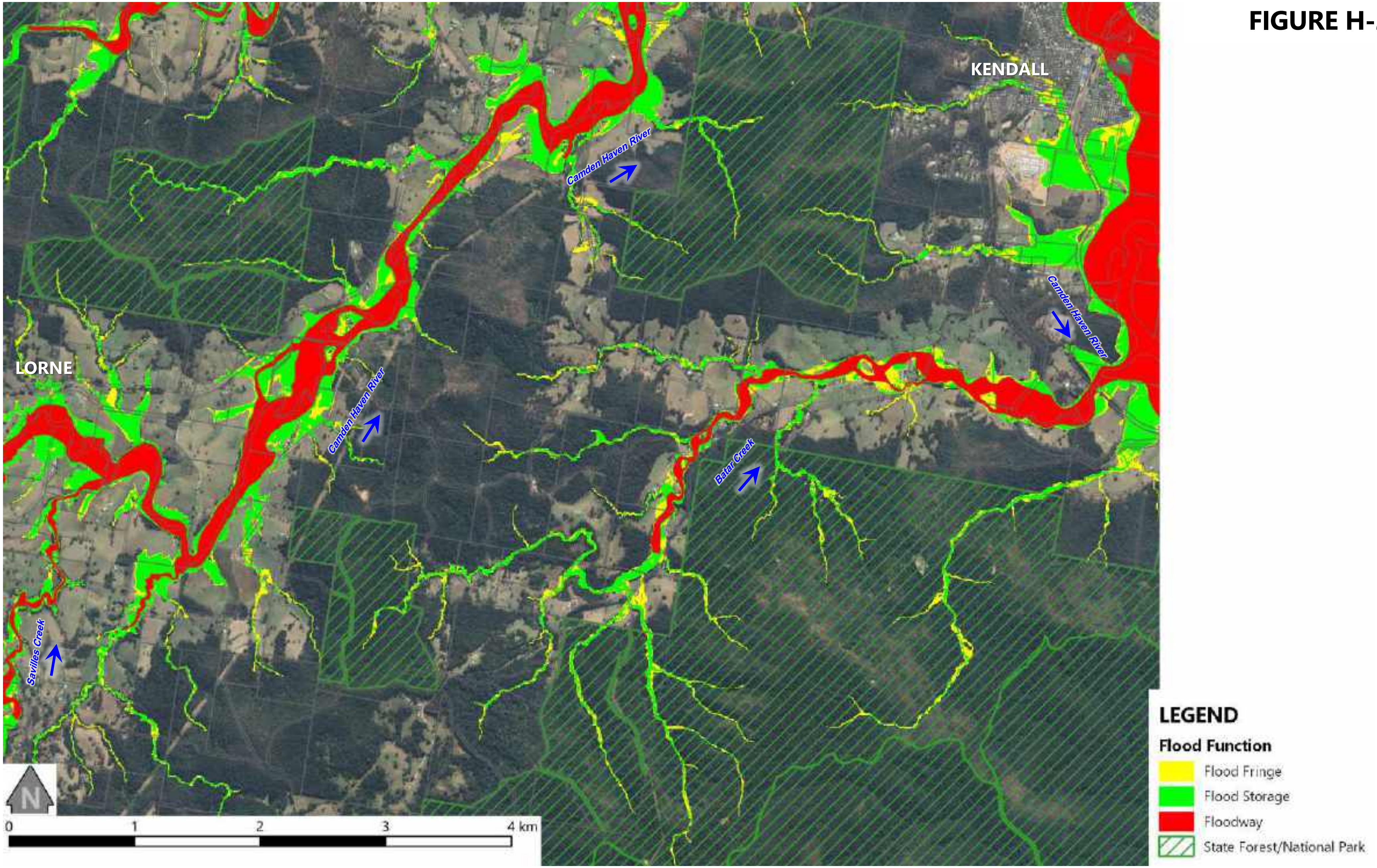
Prepared by:

250318_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250318_CamdenHaven_A4L_APPH.pdf

FLOOD FUNCTION MAPPING FOR CAMDEN HAVEN RIVER (EXTENT 1 OF 9)

FIGURE H-2



Prepared by:

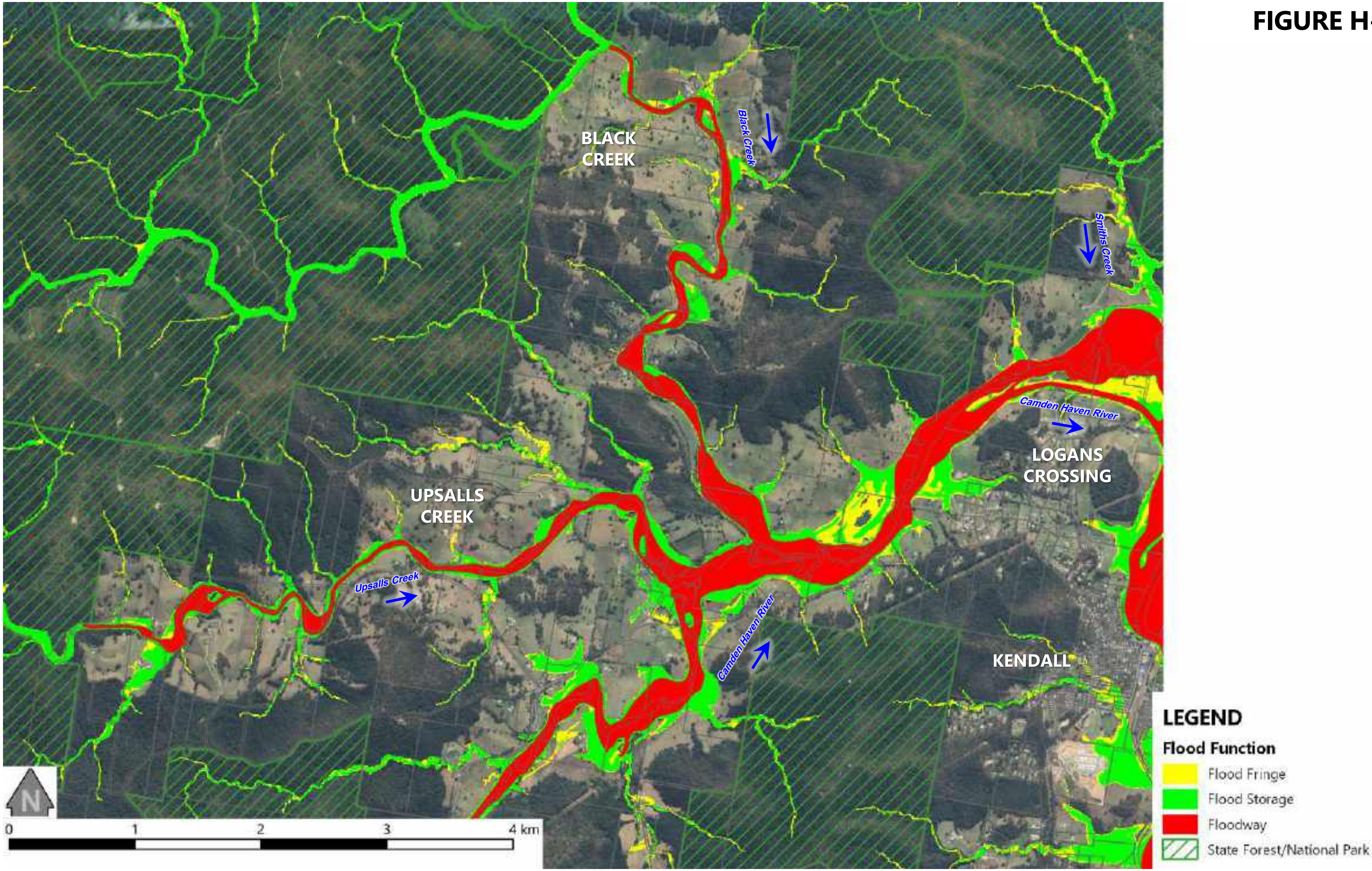
worley consulting

250318_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250318_CamdenHaven_A4L_APPH.pdf

FLOOD FUNCTION MAPPING FOR CAMDEN HAVEN RIVER (EXTENT 2 OF 9)

FIGURE H-3



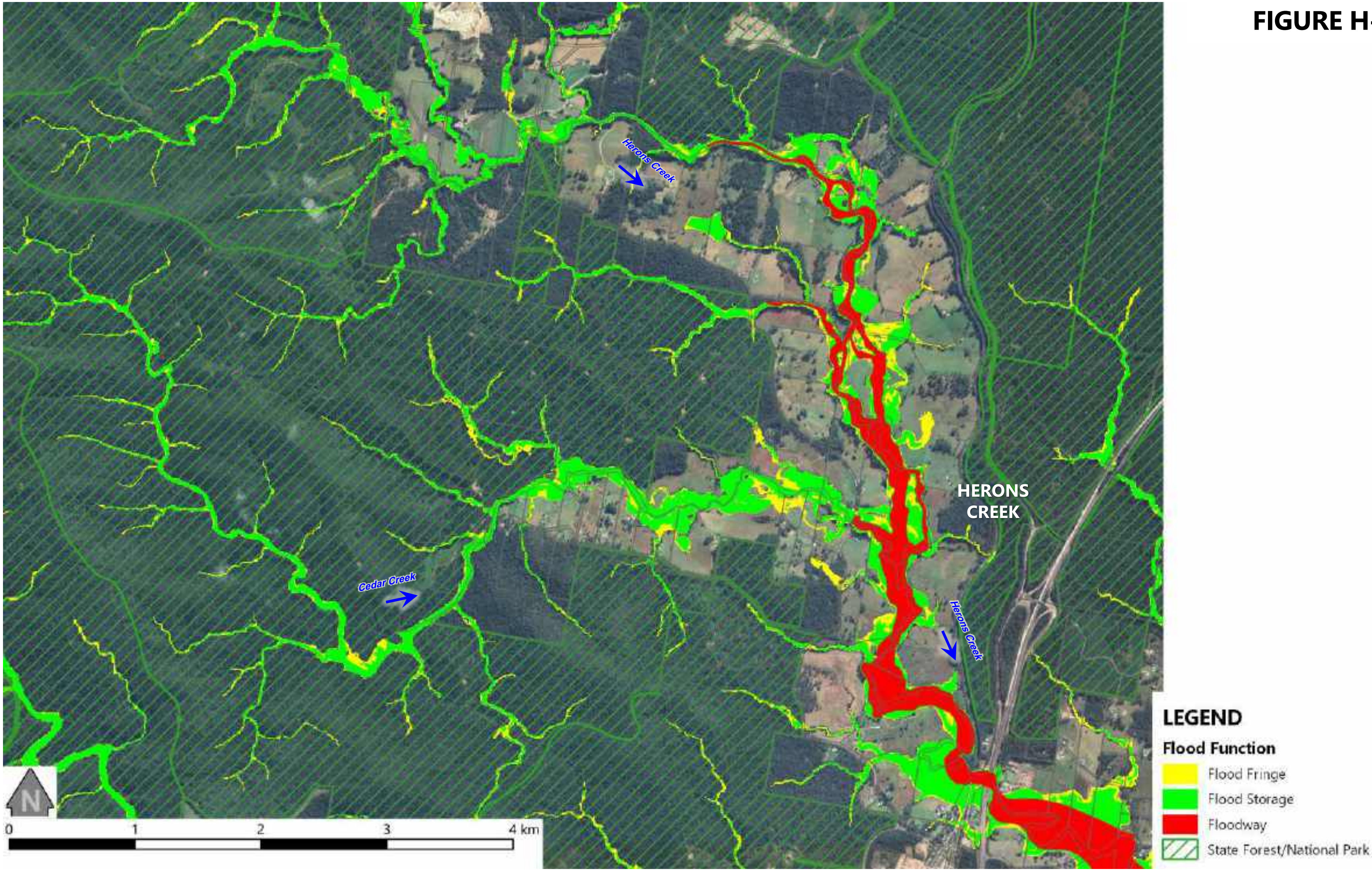
Prepared by:

250318_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250318_CamdenHaven_A4L_APPH.pdf

FLOOD FUNCTION MAPPING FOR CAMDEN HAVEN RIVER (EXTENT 3 OF 9)

FIGURE H-4



Prepared by:

PORT MACQUARIE HASTINGS

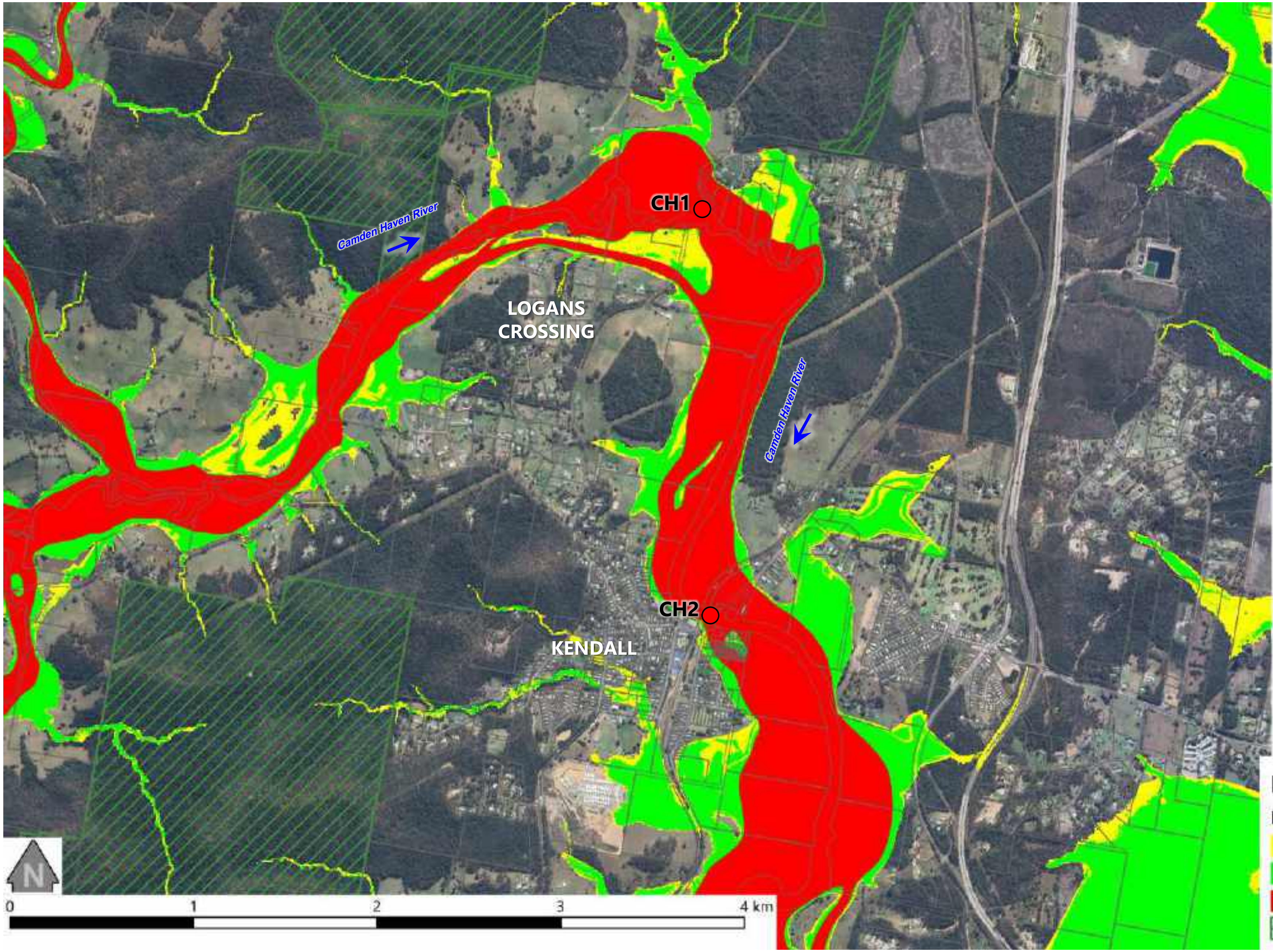
worley consulting

250318_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250318_CamdenHaven_A4L_APPH.pdf

FLOOD FUNCTION MAPPING FOR CAMDEN HAVEN RIVER (EXTENT 4 OF 9)

FIGURE H-5



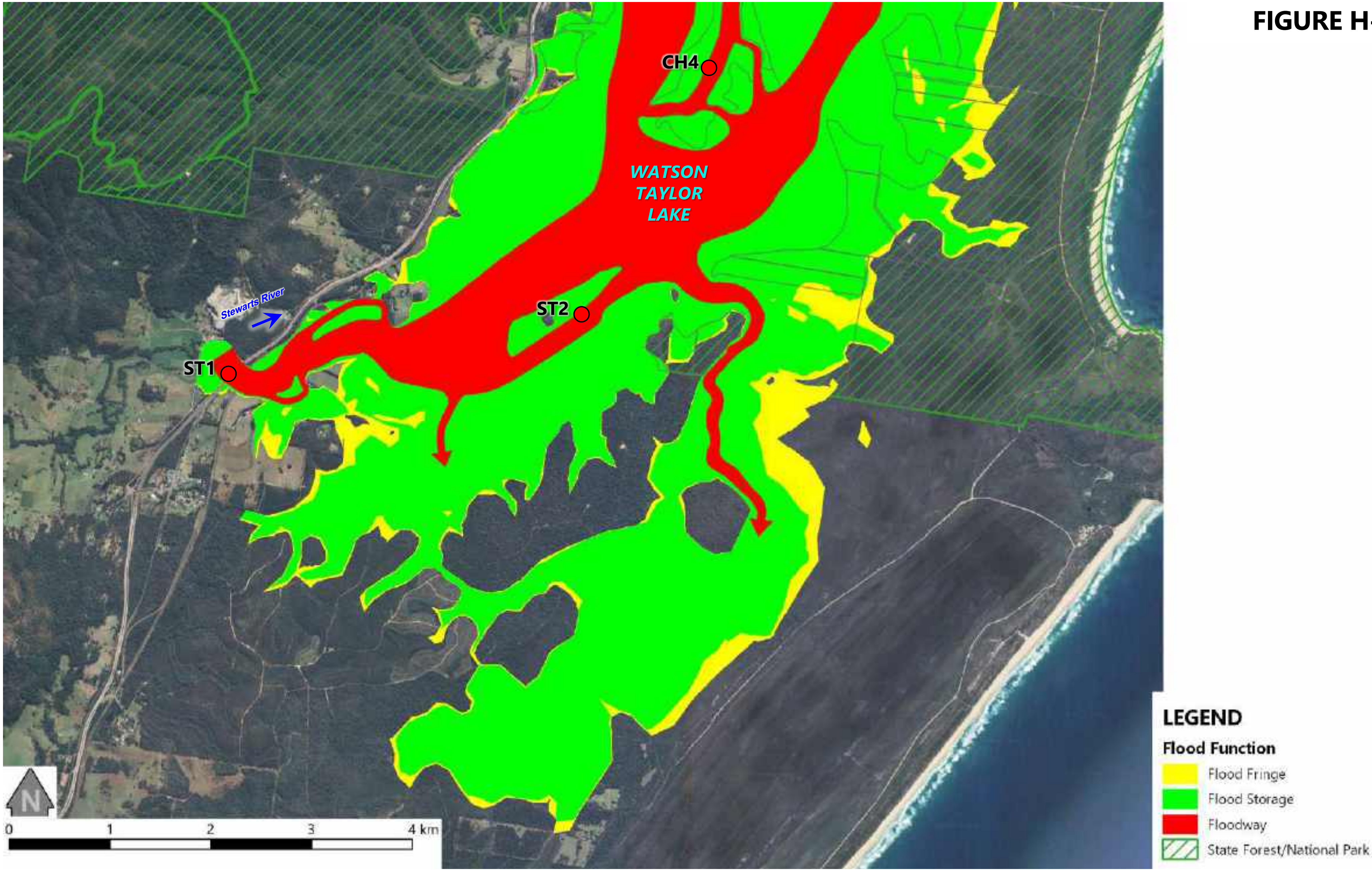
Prepared by:

250318_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250318_CamdenHaven_A4L_APPH.pdf

FLOOD FUNCTION MAPPING FOR CAMDEN HAVEN RIVER (EXTENT 5 OF 9)

FIGURE H-6



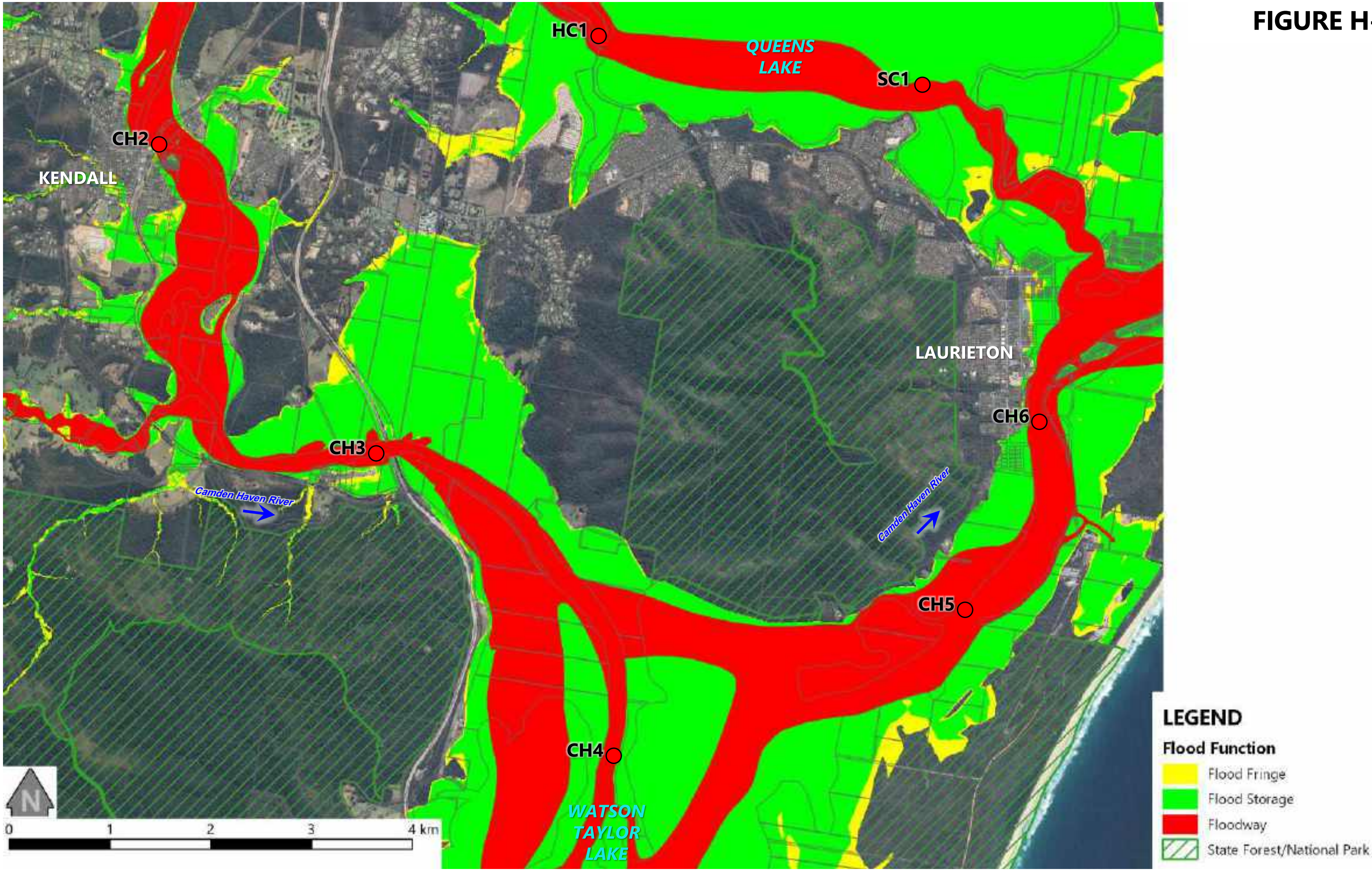
Prepared by:

250318_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250318_CamdenHaven_A4L_APPH.pdf

FLOOD FUNCTION MAPPING FOR CAMDEN HAVEN RIVER (EXTENT 6 OF 9)

FIGURE H-7



Prepared by:

worley consulting

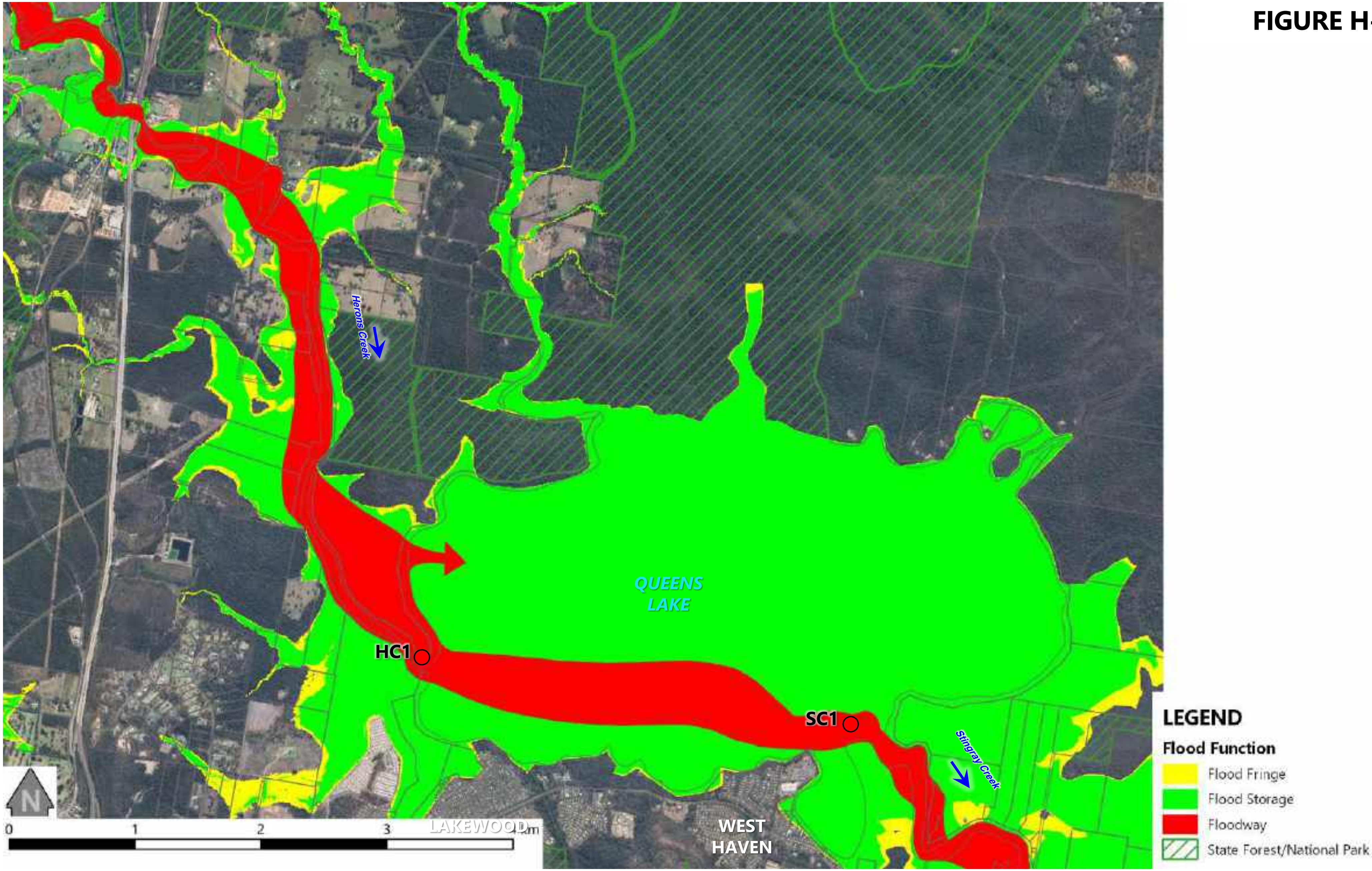
PORT MACQUARIE HASTINGS

250318_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250318_CamdenHaven_A4L_APPH.pdf

FLOOD FUNCTION MAPPING FOR CAMDEN HAVEN RIVER (EXTENT 7 OF 9)

FIGURE H-8



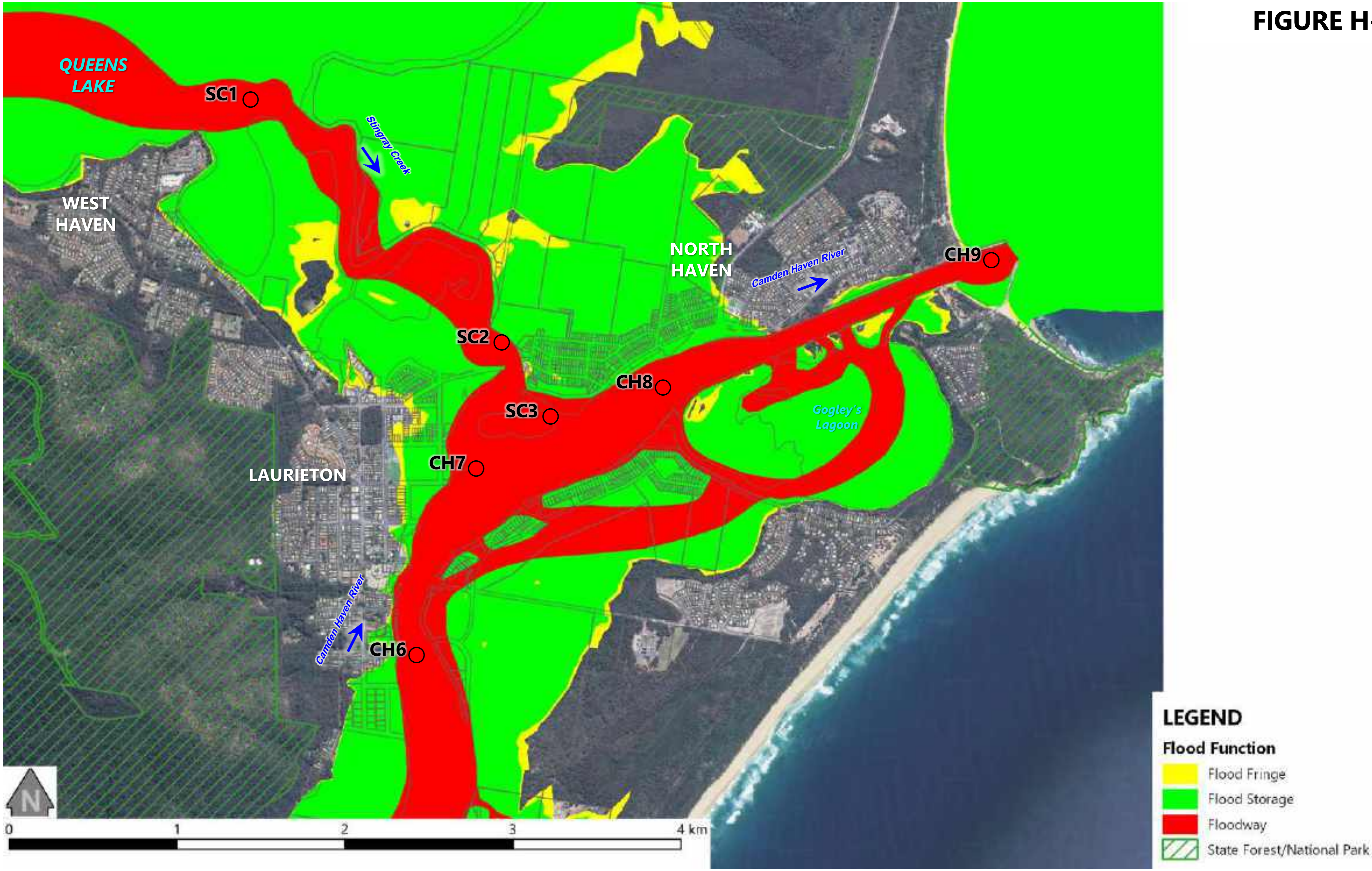
Prepared by:

250318_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250318_CamdenHaven_A4L_APPH.pdf

FLOOD FUNCTION MAPPING FOR CAMDEN HAVEN RIVER (EXTENT 8 OF 9)

FIGURE H-9



Prepared by:

250318_QGIS_CamdenHaven_Figures.qgs

fg311015-00481_250318_CamdenHaven_A4L_APPH.pdf

FLOOD FUNCTION MAPPING FOR CAMDEN HAVEN RIVER (EXTENT 9 OF 9)