Townsville City Council

Bluewater Creek Flood Study

Report




June 2013

M9300_001

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Signatures					

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1. INTRODUCTION

1.1 Overview

Engeny Management Pty Ltd (Engeny) has been commissioned by the Townsville City Council (TCC) to undertake a flood mapping study for Bluewater Creek including the following areas:

- Bluewater Park;
- Bluewater Plains;
- Bluewater; and
- Toolakea.

TCC has been undertaking an ongoing project known as the City Wide Flood Constraints Project with the purpose of developing accurate flood modelling for the city and immediate surrounds. The Bluewater Creek Flood Study and other studies undertaken for the project will provide up to date flooding information which will assist TCC with the:

- Identification of flood constraints for the new TCC planning scheme under development;
- Development of concept plans for trunk infrastructure and flood mitigation associated with future capital investment; and
- Provision of accurate flood levels and extents for development control using current information and techniques.

1.2 Background and Study Area

Bluewater Creek catchment is approximately 100 km^2 with the majority of its catchment area emanating from the south west from rural/forested steep terrain at the west of Hervey Range Road. Bluewater Creek catchment has a relatively short flood response time and ultimately discharges to the coast via a perched creek profile for most of the lower section extending approximately 14 km. Bluewater Creek has a narrow discharge location on the coast and is susceptible to blockage from sand build up during the dry season.

Four main residential areas exist along the 14 km length of Bluewater Creek. They are (from upstream to downstream):

- Bluewater Park – located to the western side of Bluewater Creek and consisting of predominately medium density rural residential properties;

- Bluewater Plains - located to the western side of Bluewater Creek and consisting of predominately low density rural residential properties with some medium density rural residential properties;
- Bluewater – Bluewater includes a small area located to the eastern side of Bluewater Creek between the Bruce Highway and rail crossing, consisting of predominately low density residential properties. The remainder of Bluewater is located to the western side of Bluewater Creek downstream of the rail crossing consisting of predominately medium density rural residential properties; and
- Toolakea Beach – located to the eastern side of Bluewater Creek in the coastal region of Toolakea adjacent to Fern Gully consisting of predominately low density residential properties.

Four structures transverse Bluewater Creek and are located approximately 5.5 km upstream of the coastal outlet. These are:

- Queensland Rail (QR) crossing (rail crossing);
- Pedestrian footbridge;
- The Bruce Highway; and
- A potable water transfer pipe.

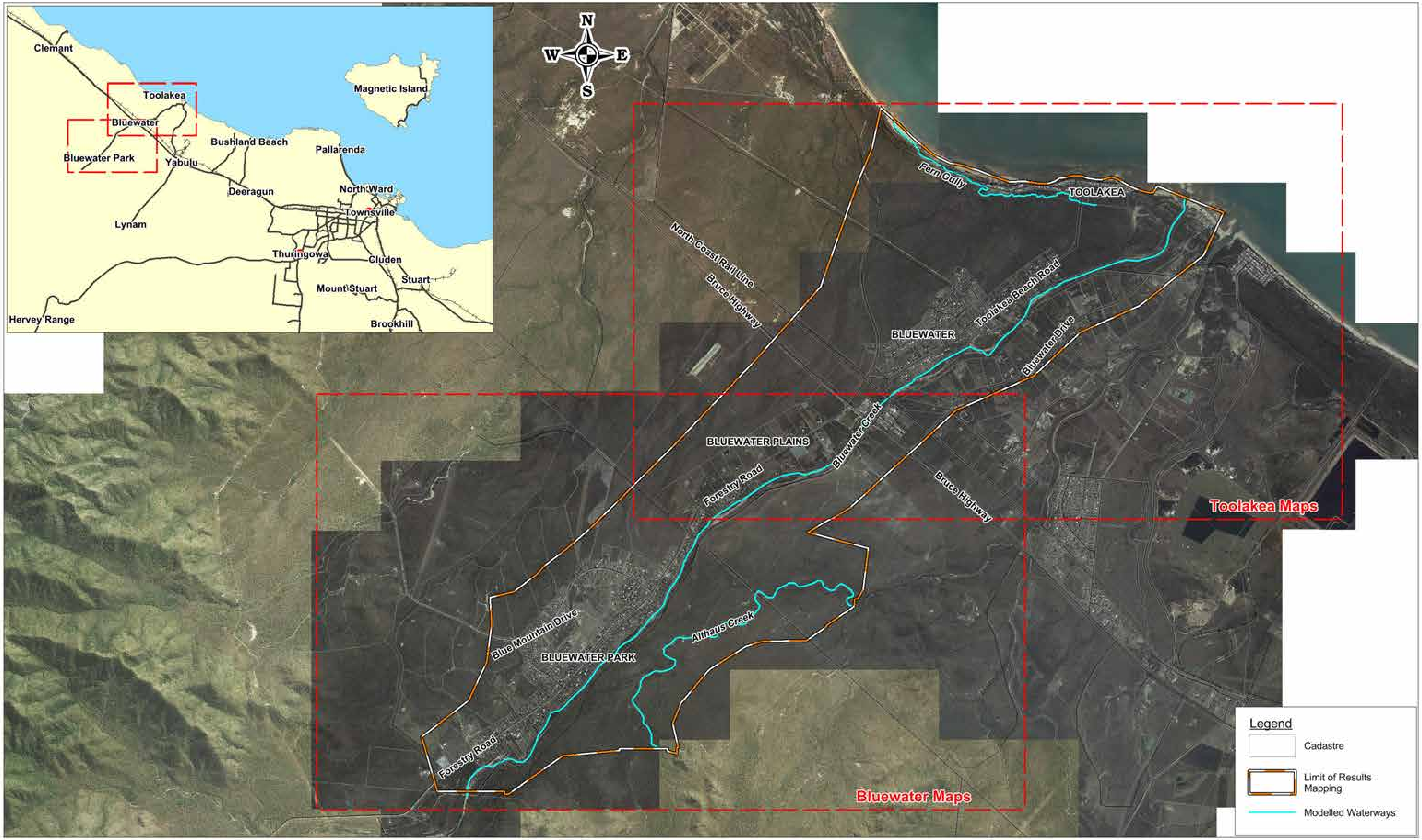
Significant flooding is known to occur when Bluewater Creek's capacity is exceeded with over bank flow discharging through urbanised areas to the north west (Bluewater and Toolakea) and to the south east (Bluewater Park and Bluewater).

Flooding is exacerbated on the coastal areas (along The Esplanade-Toolakea Beach) due to the large catchment of Fern Gully discharging through one major channel upstream of the Toolakea coastal urbanisation.

The main stream gauging station along Bluewater Creek, operated by the Department of Natural Resources and Mines (DNRM), is located approximately 7 km upstream of the coastal outlet.

Many minor and major overland flow paths exist within the study area that receive local runoff as well as flow from a Bluewater Creek breakout. TCC is interested in representing these flow paths to estimate flood levels from various events. Limited sub surface drainage infrastructure (pits and pipes) exist within the study area.

The Bluewater Creek study area is shown in Figure 1.1.



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Scale in Kilometer (1:50,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Bluewater Creek Flood Study

Figure 1.1

Study Area

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2. STUDY APPROACH

Based on an understanding of the local study area, a two dimensional (2D) MIKE FLOOD model using a combination of rainfall on grid and XP-RAFTS hydrological inputs was developed. This allowed more accurate representation of the floodplain to simulate both upstream catchments flows and local flows through urbanised areas.

Engeny utilised the following study approach and associated tasks as part of the Bluewater Creek Flood Study:

- Collation and review of available data relevant to the model development;
- Site inspection with the TCC project manager to gain an appreciation of the study site and subsequently identify additional survey of infrastructure that was required for modelling;
- An assessment and applicability of the required modelling area;
- Collection and spatial assessment of the local rainfall data for application to the hydrology model;
- Development of an XP-RAFTS hydrologic model for Bluewater Creek catchment and rainfall on grid inputs for the surrounding floodplain and overland flow paths;
- Estimation of design hydrographs for the 2, 5, 10, 20, 50, 100 and 500 year Average Recurrence Interval (ARI) events and the Probable Maximum Flood (PMF) event;
- Obtain TCC's Althaus Creek XP-RAFTS model for flow inputs in the upper reaches of the study area to ensure hydraulic connection between Bluewater Creek and Althaus Creek was represented;
- Development of a MIKE FLOOD model (cell size of 10 m) for Bluewater Creek and surrounding floodplain including flows upstream of Toolakea;
- Assessment of the viability of the Bluewater Creek gauging station records for hydrology calibration;
- Development of a complete rating curve (water level Vs flow) for the Bluewater Creek gauging station using a combination of the DNRM measured flows (low stage) and flows from the MIKE FLOOD model (high stage);
- Calibration of the XP-RAFTS hydrology model using the 2011 major Bluewater Creek rainfall event;
- Simulation of the MIKE FLOOD model for the 2, 5, 10, 20, 50, 100 and 500 year ARI design flood events and the PMF event;

- A sensitivity assessment due to climate change on the 50 and 100 year ARI design flood events; and
- Produced a report detailing hydrologic and hydraulic modelling and results.

3. PROJECT DATA

3.1 GIS Data

TCC supplied the following GIS data for use in the study:

- LiDAR topographical data (and associated contours) captured in 2009;
- Cadastre and aerial photography;
- Bluewater Creek cross section survey captured in 2001. This was supplied in CivilCAD format and subsequently used to further define the invert of Bluewater Creek; and
- Survey of structures identified during the site visit.

As a result of the review of the 2009 LiDAR topographical data, it was identified that this data has not accurately represented the invert of Bluewater Creek in some areas where water was evident both within the tidal influence area and upstream standing water. Fifteen cross sections (surveyed in 2001 and supplied by TCC) were used for interpolation and subsequent adjustment of the MIKE FLOOD 10 m grid to better represent the invert of Bluewater Creek.

The location of the fifteen sections used is shown in the Hydraulic Model Layout (refer Figure 3.1).

3.2 Bureau of Meteorology URBS Model

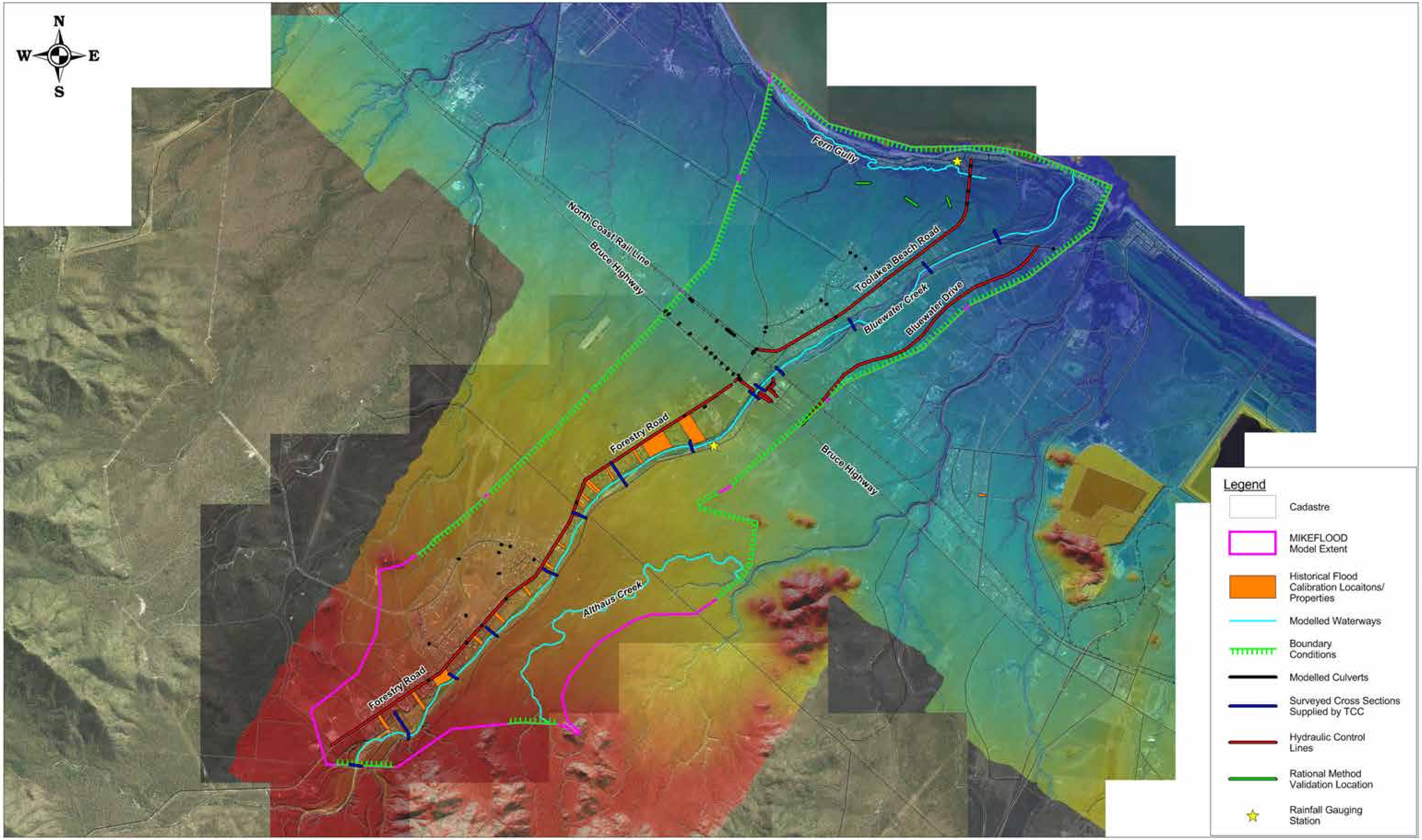
TCC facilitated the supply of the Bureau of Meteorology's (BoM) Bluewater Creek URBS model and catchment delineation. The URBS model including catchment delineation was used in the study for comparative purposes only. Following the development of a new rating curve for Bluewater Creek gauging station, the URBS was not used for any validation.

3.3 Althaus Creek XP-RAFTS Model

A section of upper Althaus Creek was included in the Bluewater Creek MIKE FLOOD model. TCC had developed a XP-RAFTS model for Althaus Creek and supplied the model to facilitate inclusion of an inflow boundary to the Bluewater Creek MIKE FLOOD model.

3.4 Tidal Data

The lower reaches of Bluewater Creek are subject to tidal influences. MIKE FLOOD modelling scenarios utilised the Mean High Water Spring Tide (MHWS) level and the Highest Astronomical Tide (HAT) tail water levels. These levels were sourced from Semidiurnal Tidal Planes, Queensland Tide Tables 2012, Maritime Safety Queensland, September 2011. Tidal planes are shown in Appendix F.



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Map Projection: Transverse Mercator
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Bluewater Creek Flood Study

Figure 3.1

Hydraulic Model Layout

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3.5 Cross Drainage Infrastructure

Four structures transverse Bluewater Creek and are located approximately 5.5 km upstream of the coastal outlet. They are:

- Rail crossing;
- Pedestrian footbridge;
- The Bruce Highway; and
- A potable water transfer pipe.

TCC supplied design drawings for the rail crossing and Bruce Highway crossings. Levels and arrangements used for modelling were extracted from these drawings.

The pedestrian bridge and potable water transfer pipe structures were detailed within the model from a combination of TCC supplied information, site observations and site survey supplied by TCC.

No subsurface drainage infrastructure (pits and pipes) were modelled as part of the current study. A number of culverts cross drainage structures were included in the model. Data for these structures was obtained from TCC supplied information, site observations and site survey supplied by TCC.

A site visit was undertaken with TCC at the inception stage. The site inspection was primarily used to assist key project team members in gaining a strong knowledge and understanding of the flood and drainage dynamics in the area, as well as assisting in the development of robust and accurate hydrologic and hydraulic models.

Following the site visit TCC undertook structure surveys of seventy six (76) culverts. TCC also gathered levels on the potable water pipe crossing, pedestrian bridge and rail crossing at Bluewater Creek. All surveyed information was used to develop structures within the MIKE FLOOD model.

3.6 Historical Rainfall and Streamflow Data

Various historical data was obtained for the Bluewater Creek Flood Study. Data included historical rainfall, historical streamflow records and surveyed historical flood levels.

3.6.1 Rainfall Data

Historical rainfall data was obtained from daily rainfall and pluviometric stations located within close proximity to the Bluewater Creek catchment. The following stations were used

- 1998 historical event:

- **Daily Rainfall Station** – Yabulu QLD Nickel, Yabulu, Rollingstone, Rangeview Ranch, Laroona Station and Horse Shoe Bend; and
- **Pluviometric Rainfall Stations** – Bluewater Creek (117003A).

- 2011 historical event:

  - **Daily Rainfall Station** – Yabulu QLD Nickel, Rollingstone; and
  - Pluviometric Rainfall Stations – Bluewater Creek (117003A).

3.6.2 Stream Flow Data

The Bluewater Creek Streamflow Gauging Station (Station no. 117003A) is located on the Bluewater Creek approximately 6.4 km upstream of the coastal outlet and has a catchment area reporting to it of approximately 84 km^2 (refer to Figure 3.2). The gauging station is operated by the Department of Natural Resources and Mines (DNRM) and has a data record from the 16/11/1973 to present (39 years).

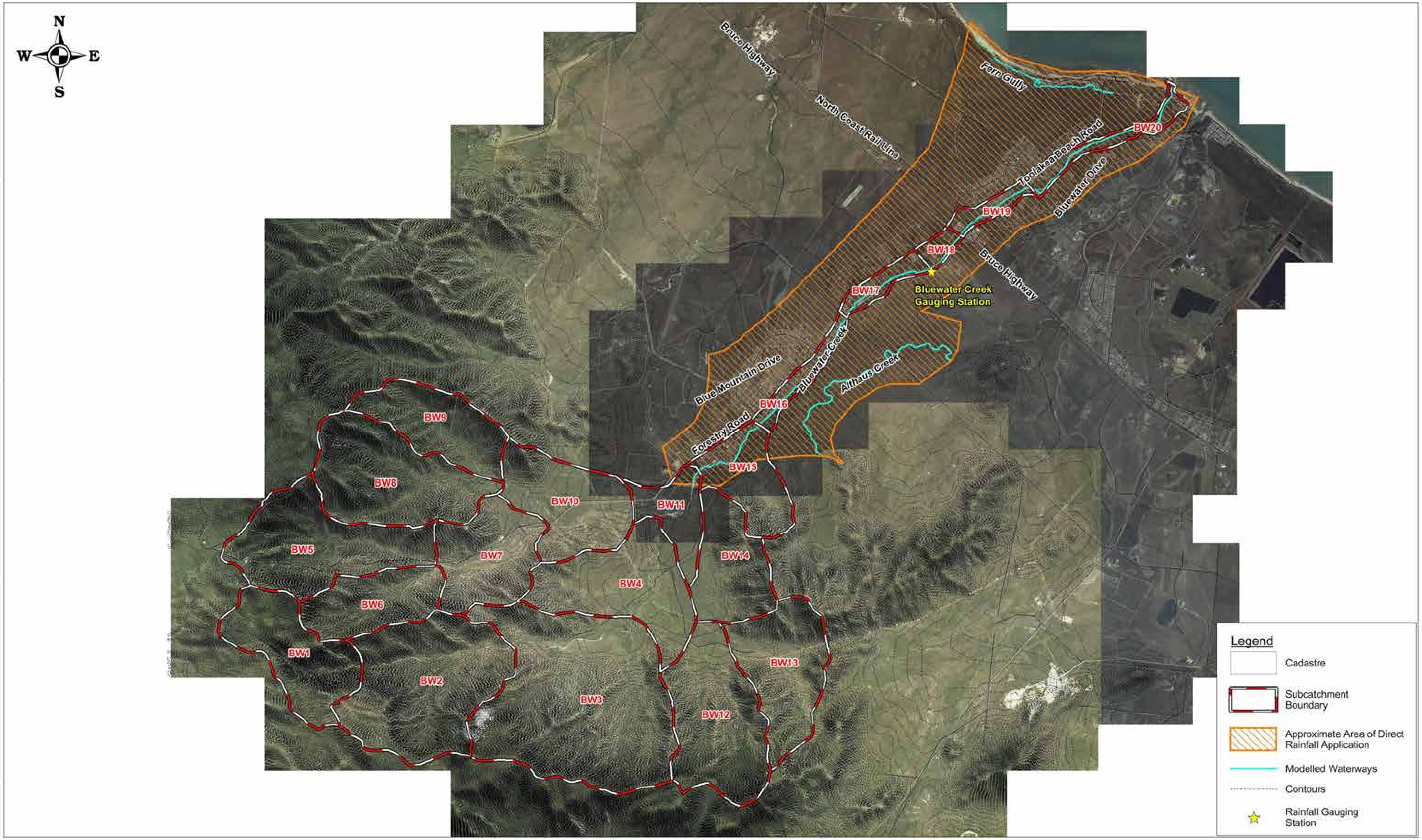
The largest flood recorded at the DNRM Bluewater Creek Gauging Station was the floods of 1998.

Historical data recorded at the Bluewater Creek Gauging Station was obtained from DNRM for the 2011 and 1998 flood event for input into the Bluewater Creek Flood Study.

3.6.3 Flood Level Survey

TCC supplied surveyed debris levels along a 6.5 km stretch upstream of the Bruce Highway and within properties east of Forestry Road adjacent to Bluewater Creek. These debris levels were recorded following the 1998 Bluewater Creek flood event (10 January 1998). These surveyed debris levels were used for calibration of the MIKE FLOOD model.

shows the locations of the properties where debris levels were surveyed. Appendix B contains surveyed debris levels data supplied by TCC.



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Bluewater Creek Flood Study

Figure 3.2

Hydrology Model Layout

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3.7 Previous Flood Studies

The study area has previously been the subject of a number of studies at varying levels of investigation. The most recent include:

- Bluewater Creek Flood Study (*Maunsell McIntyre, 2001*); and
- Toolakea Beach Flood Study (*Maunsell AECOM, 2008*).

Both studies were undertaken using 1D hydraulic models (MIKE11). Subsequent to the capture of the 2009 LiDAR survey, TCC requested a holistic 2D/1D modelling approach be undertaken to represent more accurately flood levels for future infrastructure planning and flood level reporting.

TCC also supplied a report that was written by Thuringowa City Council following the January 1998 flood event (City of Thuringowa 1998). It provides insight into the 1998 event and has been used as a reference for the current study. The most important information contained in the report is the surveyed debris levels along Forestry Road at Bluewater Park. These surveyed levels have been used for hydraulic calibration of the current MIKE FLOOD model.

4. HYDROLOGIC MODELLING

4.1 Introduction

Hydrologic modelling was undertaken for the Bluewater Creek catchment using XP-RAFTS modelling software. XP-RAFTS calculated flood hydrographs at various locations across a catchment for design and historical flood events.

Flood hydrographs have been estimated for a range of design flood events including the 2, 5, 10, 20, 50, 100, 500yr ARI events, PMF and selected climate change and tailwater sensitivity scenarios (50 and 100 year ARI design flood events).

4.2 Model Description

XP-RAFTS is an interactive runoff streamflow routing program that calculates catchment losses and streamflow hydrographs resulting from variable rainfall events. XP-RAFTS 2009 was used for the completion of this study.

The Bluewater Creek XP-RAFTS model has been developed and used for the Bluewater Creek catchment to the upstream extent of the 2D MIKE FLOOD model.

The extent and layout of the XP- RAFTS model is shown in Figure 3.2.

4.3 Design Rainfall Estimate

The 2, 5, 10, 20, 50, 100 and 500 year ARI design rainfall estimates were determined for the Bluewater Creek Flood Study. Rainfall increases due to climate change were also determined (refer section 4.3.5).

Spatial distribution of Intensity Frequency Duration (IFD) values across the Bluewater Creek catchment was investigated for uniformity. Slight variation was shown to exist in IFD rainfall intensities for the upper and lower catchment. The centroid of the upper catchment was selected as the most appropriated IFD location, with a single set of IFD values applied across the study area.

The design rainfall intensities for all events up to and including the 100 year ARI were developed based on the methods outlined in Australian Rainfall and Runoff (AR&R) using the IFD approach. A summary of IFD data are presented in Table 4.1 below. These rainfall intensities were used for both the XP-RAFTS model and the rainfall on grid application in MIKE FLOOD.

Table 4.1 Intensity Frequency Duration (mm/hours)

ARI							
Duration (Hours)	Q2	Q5	Q10	Q20	Q50	Q100	Q500 (Adjusted CRC-FORGE)
0.5	78	96	107	121	140	154	207.4
1	56	69	76	86	99	109	146.8
1.5	45.1	57	63	72	83	92	123.9
2	38.6	49	55	63	74	82	110.4
3	31	40	45.3	52	62	69	92.9
4.5	24.8	32.6	37.3	43.4	52	58	78.1
6	21.2	28.2	32.5	38	45.4	51	68.7
9	17	23.1	26.8	31.6	38	43.1	58.0
12	14.6	20	23.3	27.7	33.5	38.2	51.4
18	11.7	16.1	18.8	22.3	27.1	30.8	41.5
24	9.99	13.7	16.1	19.1	23.2	26.4	35.6
36	7.95	11	12.9	15.3	18.6	21.2	28.6
48	6.71	9.26	10.9	12.9	15.7	17.9	24.1
72	5.19	7.19	8.44	10.1	12.2	14	19.2

4.3.1 Large and Rare Rainfall Events

The 500 year ARI design rainfall was initially estimated using the CRC-FORGE methodology developed by Hargraves (2004).

A comparison between the 500 year ARI rainfall developed from CRC-FORGE with the adopted 100 year ARI IFD from AR&R showed little difference. Therefore the ratio of the 500 year ARI rainfall to 100 year ARI rainfall from the CRC_FORGE method was applied to the 100 year ARI IFD rainfall to obtain the 500 year ARI design rainfall shown in Table 4.1

4.3.2 Extreme Rainfall Events

The PMP rainfall estimates were determined using the BoM guidelines for “The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method (June 2003)” and the Revision of the Generalised Tropical Storm Method for Estimating Probable Maximum Precipitation (August 2003).

The Generalised Short Duration Method (GSDM) was adopted for design storm durations of less than 6 hours, while the Generalised Tropical Storm Method Revised (GTSMR) was adopted for design storm durations greater than 24 hours.

Design rainfall estimates for the 9, 12 and 18 hour storm durations were interpolated between the estimates derived from both the GSDM and GTSMR. Table 4.2 lists the PMP rainfall depths for varying durations for the Bluewater Creek catchment.

Table 4.2 Estimated PMP rainfall depths for the Bluewater Creek Flood Study

Duration (hours)	Depth (mm)
0.25	160
0.5	230
0.75	310
1	360
1.5	470
2	540
2.5	610
3	660
4	740
5	820
6	870
9	1000
12	1140
18	1430
24	1700
36	2080
48	2430
72	3060
96	3440
120	3590

4.3.3 Areal Reduction Factors

The Bluewater Creek catchment (to the hydraulic model boundary) is approximately 100 km^2. Areal reduction factors (ARF) have been applied to the design rainfall estimates (point values) for this catchment.

The Extreme Rainfall Estimation Project outlines the method to calculate ARF's for Queensland using the modified Bell's Method which involved the area-weighting of rainfalls between stations.

The equation used to calculate the ARF for Bluewater Creek is given below:

ARF = 1 - 0.2257 (Area*0.1685 - 0.8306*log(Duration))*Duration $^{0.3994}$

Table 4.3 lists the ARF's applied to the Bluewater Creek Catchment.

Table 4.3 Areal Reduction Factors for Bluewater Creek Catchment

≤24 hr	36 hr	48 hr	72 hr
0.938	0.955	0.965	0.976

4.3.4 Temporal Patterns

Temporal patterns for design rainfall events up to and including the 500 year ARI design storm have been sourced from AR&R Vol 2 (1987) for Zone 3.

The GSDM and GTSMR PMP temporal patterns have been adopted for their respective PMP storm duration limits (GSDM < 6 hrs and GTSMR >24 hrs). Both the GSDM and the 24hr GTSMR temporal patterns were used for the 9, 12 and 18 hour PMP design flood.

4.3.5 Climate Change Sensitivity

The effects of climate change on the 50 and 100 year ARI design storm events were estimated. An increase of rainfall intensity was determined based on the projected average temperature increase of the Townsville area.

Recommendations made by DNRM (2010) for assessing the impact of climate change on large design rainfall events for the purpose of the design of new developments were used and are:

- 3 degree increase of global temperature by year 2100; and
- 5% increase of rainfall intensity per degree.

These recommendations were applied to point rainfall intensities for the 50 and 100 year ARI design rainfall events.

To assess the potential impact of sea-level rise for the Bluewater Creek Flood Study, Mean High Water Spring Tide (MHWS) was increased by 0.8 m in accordance with the prediction for 2100 contained in the Queensland Coastal Plan (2011).

4.4 Model Development and Inputs

XP-RAFTS estimates the runoff hydrograph from an individual sub-catchment based on rainfall intensities, rainfall losses, temporal patterns and catchment area. XP-RAFTS is able to model two sub-catchments at one node for varying catchment conditions, however a single catchment model has been used.

4.4.1 Land Use

The land use for the Bluewater and Toolakea Catchments was determined from TCC supplied cadastre, site inspections and inspection of areal imagery. The land use for hydrology was broken into three categories with assigned manning's roughness values and fraction impervious as determined by the Queensland Urban Drainage Manual (QUDM, 2007) and the TCC planning scheme. The adopted values are displayed in Table 4.4.

Table 4.4 Adopted roughness and fraction impervious values for various land use

Land Use Type	Manning's roughness	Fraction Impervious (%)
Dense Vegetation	0.1	0
Medium Vegetation	0.09	0
Rural Residential	0.035	20

Weighted averages for the manning roughness and fraction impervious values were applied to the delineated sub catchments.

4.4.2 Sub-catchment Data

Sub-catchments for the Bluewater Creek catchment were delineated using 10 m interval contours information (DNRM). Sub-catchments boundaries are shown in Figure 3.2.

Table 4.5 lists the sub-catchment parameters adopted for the Bluewater Creek XP-RAFTS model.

Table 4.5 XP-RAFTS Sub-catchment Data

Sub-Catchment ID	Area (ha)	Fraction Impervious (%)	Surface Retardance	Catchment Slope (%)
BW1	465.8	0	0.1	10.92
BW2	862.3	0	0.1	7.33
BW3	1372.1	0	0.1	7.4
BW4	581.0	0	0.1	1.84
BW5	645.2	0	0.1	7.47
BW6	346.9	0	0.1	11.47
BW7	434.2	0	0.1	2.93
BW8	649.8	0	0.1	6.40
BW9	386.6	0	0.1	6.29
BW10	470.1	0	0.1	2.13
BW11	206.8	0	0.1	0.75
BW12	620.8	0	0.1	7.76
BW13	484.2	0	0.1	3.70
BW14	370.7	0	0.1	7.88
BW15	298.2	1.703	0.085	2.54
BW16	97.3	10.342	0.059	0.29
BW17	89.3	11.028	0.057	0.55
BW18	46.7	10.654	0.059	1.42
BW19	73.4	7.310	0.068	0.32
BW20	129.6	6.324	0.071	0.10

4.4.3 Model Parameters

The XP-RAFTS parameters defined include:

- Rainfall losses;
- Storage coefficient multiplication factor – Bx; and
- Link lag time.

XP-RAFTS represent rainfall loss as initial loss (IL) and continuous loss (CL). This model assumes that the initial loss represents the loss due to initial wetting of the catchment surface and the continuing loss represents the continuous infiltration through the catchment surface for the duration of the storm event.

The link lag time is dependent on the length of the link and the hydrograph velocity over this distance.

The Bx, link lag and continuing rainfall loss values adopted for the Bluewater Creek XP-RAFTS model were determined through calibration of a historical event at the Bluewater creek streamflow station (117003A) using the newly developed rating curve and calibration with the 2011 event (refer section 4.5).

4.5 Model Calibration

The Bluewater Creek XP-RAFTS model was calibrated using historical rainfall (annual and pluvio) and streamflow data obtained at the Bluewater Creek catchment. The calibration was based on the rating curve developed as part of this project.

The March 2011 storm event was simulated in the XP-RAFTS and compared with the historical streamflow data located on Bluewater Creek.

Historical rainfall data was obtained from a total of seven (7) rainfall stations within close proximity to the Bluewater creek catchment. Pluviographic rainfall data was available and used for the Bluewater Creek streamflow gauging station.

4.5.1 Stream flow data

A streamflow gauging station (Station no. 117003A) is located on Bluewater Creek approximately 6.4 km upstream of the coastal outlet. The gauging station is operated by DNRM and has a data record from the 16/11/1973 to present (39 years).

Extensive modelling iterations were used to develop a new and complete rating curve for this station (refer section 5.7 of this report) due to the following limitation:

- Exiting breakout upstream of this gauging station; and
- Measured to low only.

4.5.2 Calibration Events

The March 2011 was chosen for hydrological calibration as it was one of the largest flood events recorded over the last forty (40) years for Bluewater Creek and it did not cause excessive Bluewater Creek breakout flow upstream of the gauging site. The 1998 event exhibited breakout flow and therefore was only used for hydraulic calibration against surveyed debris marks recorded after the 1998 event. Table 4.6 shows a summary of the two events.

Table 4.6 Bluewater Calibration Flood Event

Event	Start and Finish Date	Gauged level (mAHD)	Rated flow (m^3/s)
March 2011	06/03/2011 – 08/03/2011	16.6	431.9*
January 1998	09/01/1998 – 14/01/1998	18.46	816.3*

* - Translated from new rating curve

4.5.3 Calibration Data

Rainfall data and temporal patterns were determined for the area utilising available historical data.

The rainfall distribution for the 2011 flood event at Bluewater Creek was relatively uniform. The rainfall depth form the nearby stations surrounding the Bluewater Creek catchment were plotted to calculate an average weighted rainfall cross the catchment. The average depth of rainfall that fell during the 2011 event was 240 mm over a 51 hour period. The pluviographic data available from the Bluewater Creek streamflow gauging station was used to develop a temporal pattern for the 2011 storm event (15 minute time step).

The rainfall distribution for the 1998 flood event at Bluewater Creek varied across sub-catchments. Due to the large variation in rainfall during the 1998 event a rainfall area distribution was completed to determine total weighted rainfall depth across each sub catchment over a period of 120 hours. Table 4.7 shows the rainfall areal distribution for the 1998 event.

Table 4.7 Rainfall Area Distribution for 1998 Storm Event

Sub-catchment ID	Total Rainfall Depth (mm)
BW1	893.6
BW2	919.6
BW3	911.5
BW4	837.3
BW5	840.2
BW6	876.2
BW7	852.4
BW8	805.1
BW9	773.5
BW10	807.5
BW11	769.7

Sub-catchment ID	Total Rainfall Depth (mm)
BW12	856.9
BW13	786.8
BW14	763.1
BW15	704.3
BW16	635.3
BW17	598.3
BW18	596.6
BW19	605.1
BW20	637.9

The rainfall was input into the hydrologic model as sub-catchment specific storms as opposed to a global storm method with an even rainfall distribution.

4.5.4 Calibration Results

The Bluewater Creek XP-RAFTS model was assessed by comparing the simulated historical 2011 flood hydrograph (XP-RAFTS) with the records hydrograph at the Bluewater Creek gauging station (translated via the new rating curve).

Table 4.8 compares the peak flow and time to peak for the 2011 historical flood event. The simulated flood hydrograph (XP-RAFTS) and the recorded hydrograph at Bluewater are shown in Figure 3.2.

Table 4.8 XP-RAFTS Calibration Results

Event	Modelled (XP-RAFTS)		Recorded (Bluewater Creek)	
	Peak Flow (m^3/s)	Time of Peak (date and time)	Peak Flow (m^3/s)	Time of Peak (date and time)
2011	431.9	7/03/2011 19:15	432.4	7/03/2011 19:48

The Bluewater Creek XP-RAFTS model produces a satisfactory estimate for both the peak flow and time to peak at the Bluewater Creek gauging station for the 2011 event. The small differences between the modelled and recorded hydrographs are likely due to base flow that was not included in the XP-RAFTS model.

An initial loss parameter of 50 mm was applied to the XP-RAFTS model to enable a good fit with the rising limb of observed flows.

The adopted model parameters from the 2011 calibration were applied to the 1998 calibration model to determine a peak flow for this event upstream of the gauging station. This flow was input into the hydraulic model to compare against the surveyed debris levels recorded for this event.

The calibration results indicates that the Bluewater Creek XP-RAFTS model suitably represents the recorded flood conditions during the 2011 flood event, based on the new rating curve, and therefore is suitable for estimating design flood events.

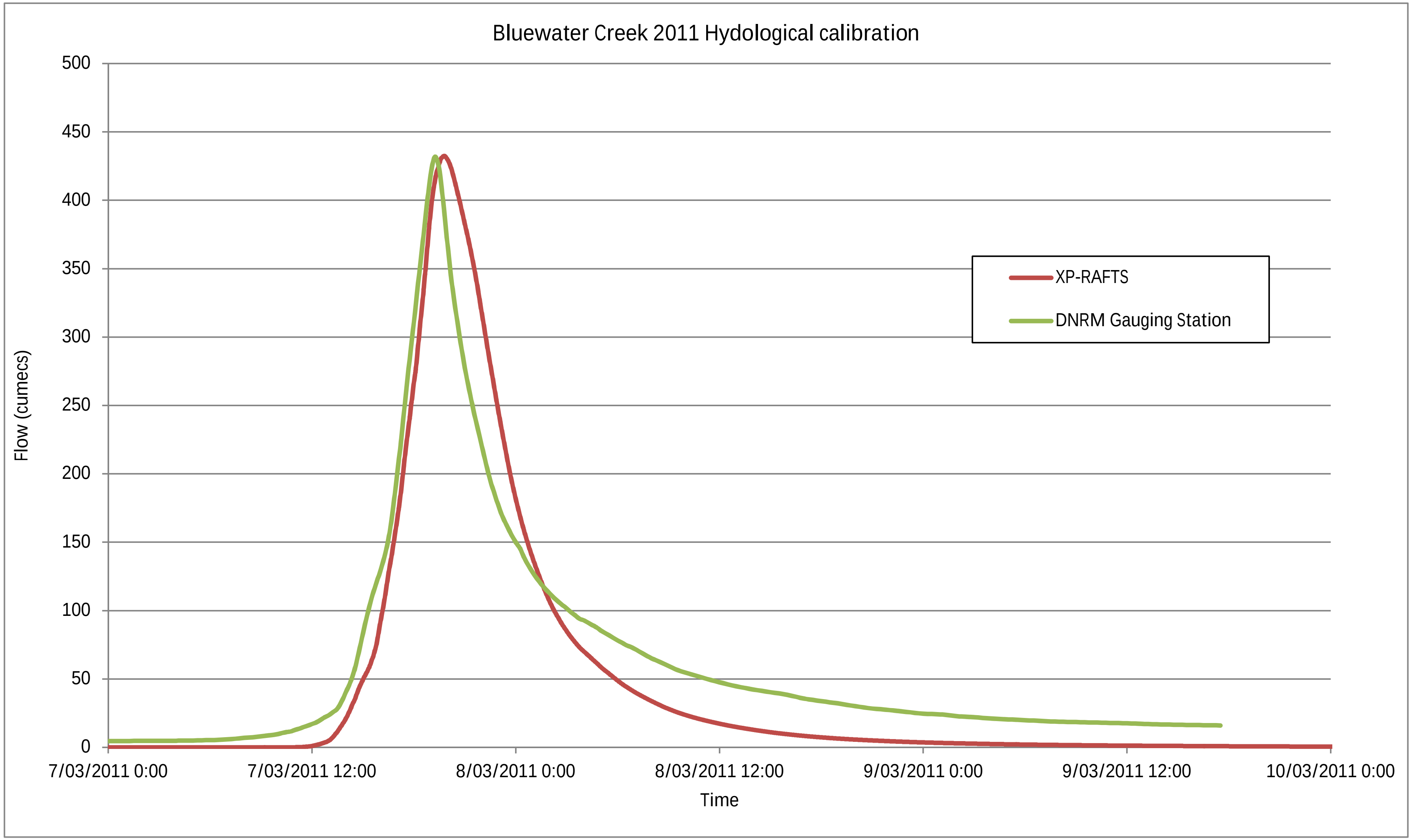


Figure 4.1 Simulated and Recorded (2011) Hydrograph

4.5.5 Selection of Design Parameters

The XP-RAFTS Bx, lag time and rainfall loss values were adjusted within acceptable limits to achieve the best possible fit to the recorded hydrograph for the 2011 event (refer Figure 4.1).

Table 4.9 lists the model parameters chosen for the historical event calibration and are the resultant parameters adopted for the simulation of design flood events for the Bluewater Creek XP-RAFTS model.

Table 4.9 XP-RAFTS Calibration Parameters

Event	Bx	Lag Velocity (m/s)	Initial Loss (mm)	Continuing Loss (mm/hr)
March 2011	1.75	1.5	50	2.5

A Bx value of 1.75 is justified and indicates a large amount of catchment storage within the upper reaches of the Bluewater Creek catchment. This is supported by the DNRM time weighted stream discharge duration curve at the gauging station. The curve indicates that there is baseflow in Bluewater Creek during both the dry and wet seasons indicating that there is storage in the upper temporal rain forested Bluewater Creek catchment.

4.6 Design Flood Hydrographs

Flood hydrographs for a range of design events and durations have been estimated utilising the calibrated Bluewater Creek XP-RAFTS model. Design hydrographs were simulated for the 2, 5, 10, 20, 50, 100 and 500 year ARI events, the PMP design flood, and selected climate change events for the 50 and 100 year ARI events.

The hydrographs for the design flood events were estimated at the location of the Bluewater Creek gauging station. The upper catchment area of Bluewater Creek generates proportionally higher rate of discharge than the lower catchment due to perched profile of Bluewater Creek (limited inflow from surrounding catchment). The hydrograph peak is consistent as it propagates down the length of Bluewater Creek.

Table 4.10 provides a summary of the peak flows and associated critical storm durations for the range of design storms modelled for Bluewater Creek.

Table 4.10 XP-RAFTS Model Results at Bluewater Creek

Design Storm	Peak Flow (m^3/s)	Critical Storm Duration (hrs)
2 yr ARI	255	36
5 yr ARI	396	36
10 yr ARI	488	36

Design Storm	Peak Flow (m^3/s)	Critical Storm Duration (hrs)
20 yr ARI	619	24
50 yr ARI	758	24
100 yr ARI	920	24
500 yr ARI	1399	24
50 yr ARI Climate Change	935	24
100 yr ARI Climate Change	1124	24
PMP Design Flood	3563	6

4.7 Flood Frequency Analysis

A Flood Frequency Analysis was undertaken for the Bluewater Creek gauging station (117003A) utilising the maximum annual peak flows over the last 40 years of record.

The annual series peak flow data set consisted of 40 values ranging in magnitude from 0.11 m^3/s to 833 m^3/s (hourly data) and is provided in Appendix G. The developed rating curve (refer section 5.7) was utilised to convert the recorded gauge heights to discharge. The Log Pearson Type 3 (LPIII) statistical distribution was fitted to the peak flow data set as outlined in Book 4 of Australian Rainfall and Runoff (IEAUST, 1989).

Table 4.11 lists the flood frequency analysis results for the Fitted LPIII Distribution flow series (1972 to 2012) at Bluewater Creek gauging station for various design ARI events.

Table 4.11 Bluewater Flood Frequency Analysis Results - Peak Flows

ARI	Fitted LPIII Distribution flows (m^3/s)	5% Confidence Limit	95% Confidence Limit
5	368	218	686
10	444	261	849
20	481	281	930
50	501	292	975
100	507	295	988

The fitted LPIII distribution of the flood frequency for Bluewater Creek gauge tends to flatten approaching the 100 year ARI. This is due to the large number of events (5 to 20 year ARI) exhibiting similar magnitude and drawing down the trend line. This is further highlighted by the marginal difference between the 100 and 50 year ARI which is unlikely to represent actual flow conditions in Bluewater Creek. Significant Bluewater Creek breakout flow does not occur at these flow magnitudes.

The XP-RAFTS design discharge for the Bluewater Creek catchment fit well with the flood frequency curve for the lower ARI storm events (5 and 10 year ARI). There is limited confidence in the higher ARI events of the FFA due to the limited variability of the larger magnitude historical floods (very flat profile).

The flood frequency analysis for Bluewater creek with the XP-RAFTS results are graphically shown in Figure 4.2.

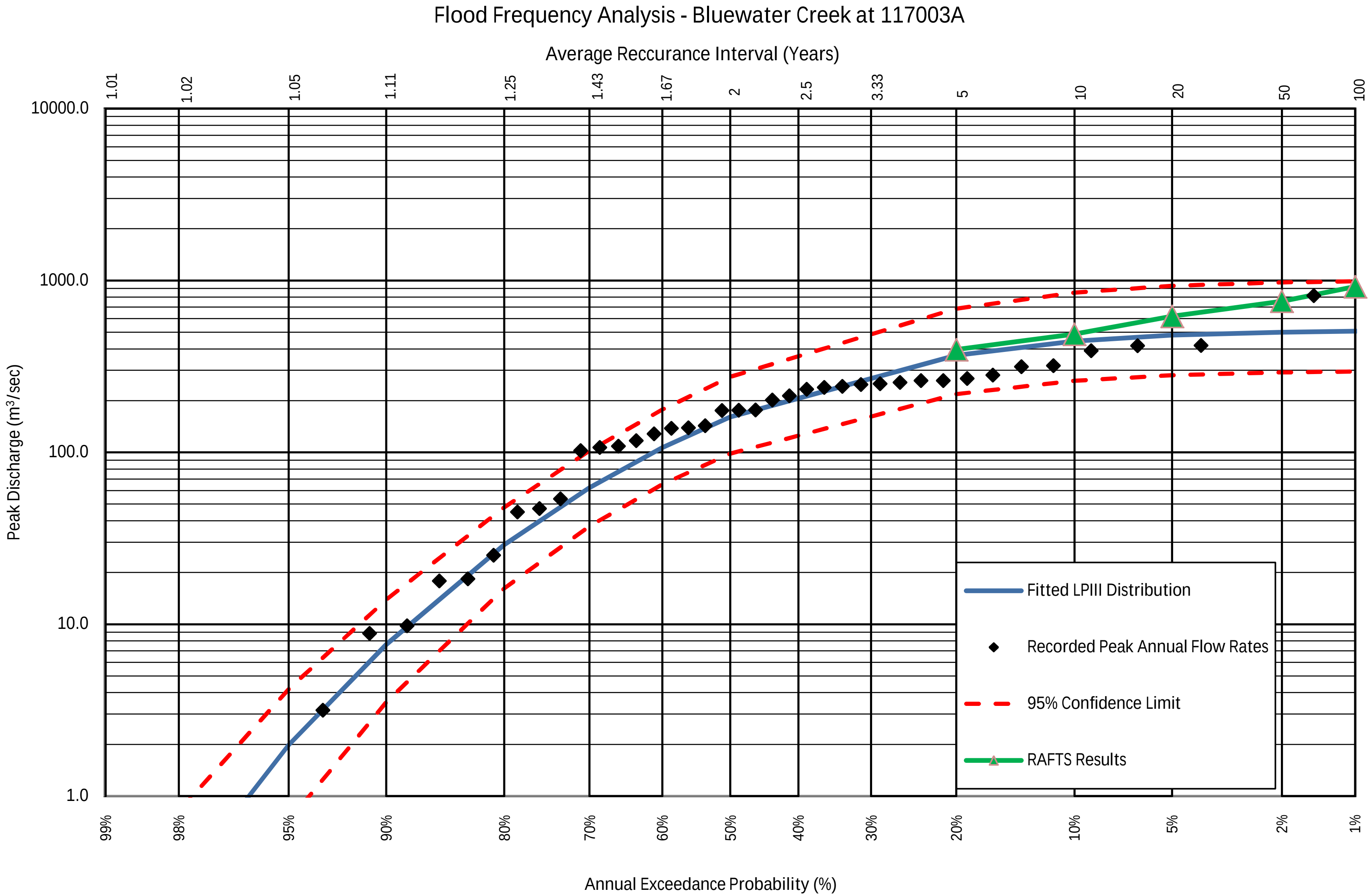


Figure 4.2 Bluewater Creek Flood Frequency

4.8 Results Validation

A validation of the design results from simulated by the calibrated XP-RAFTS model at Bluewater Creek was undertaken by comparing them with the results obtained from the flood frequency fitted distribution and previous study results (Maunsell 2002).

Table 4.12 lists the peak flows obtained from XP-RAFTS model, flood frequency and a previous study.

Table 4.12 Bluewater Creek Model Results Validation

Design Storm	XP-RAFTS (m^3/s)	Flood Frequency (m^3/s)	Maunsell Upper Bound (m^3/s)	Maunsell Lower Bound (m^3/s)
2 yr ARI	255			
5 yr ARI	396	368		
10 yr ARI	488	444		
20 yr ARI	619	481	810	500
50 yr ARI	758	501	977	626
100 yr ARI	920	507		

As previously discussed, there is limited confidence in the FFA at higher ARI events due to the limited variability of the larger magnitude historical floods (very flat profile) which is not a typical characteristic of most catchments.

The XP-RAFTS model results are within the range of the 20 and 50 year ARI upper and lower bound flow estimates from the previous Maunsell flood study.

Based on the above we believe that the XP-RAFTS results are reasonable for the Bluewater Creek Flood Study.

5. HYDRAULIC MODELLING

5.1 Introduction

A two-dimensional hydraulic analysis has been developed to investigate the flooding dynamics of Bluewater Creek and the immediately surrounding area including the Bluewater Park residential area south west of the Bruce Highway and the Toolakea residential area north east of the Bruce Highway downstream to the coastal outlet of the Bluewater Creek system.

A MIKE FLOOD two-dimensional hydraulic model has been developed to predict flood levels, flood depths and flood velocities. A range of design events were investigated to determine the flooding characteristics within the study area.

The MIKE Flood Software was adopted for the Bluewater Creek Flood Study as requested by TCC to ensure compatibility with other flood studies for surrounding areas undertaken with the MIKE FLOOD software. It is TCC's objective to eventually combine surrounding coastal flood models including the Althaus Creek MIKE FLOOD model recently completed.

5.2 Flood Plain Characteristics

For the purposes of discussion, the floodplain for the study area is divided into four urban areas:

- Bluewater Park;
- Bluewater Plains;
- Bluewater; and
- Toolakea (Toolakea Beach).

General flood plain characteristics of these areas are discussed in the following sections.

5.2.1 Bluewater Park and Bluewater Plains

Bluewater Creek is a perched creek system that travels north east through the study area. Waterways from the upstream catchment combine at Bluewater Park to form Bluewater Creek. The eastern bank of Bluewater Creek upstream of the Bruce Highway is generally perched with a high bank. However, the western side of Bluewater Creek exhibits a distinctive low and high flow channel as it travels through the Bluewater Park. As it travels past Bluewater Park and through the Bluewater Plains, it narrows and then displays two distinctive remanent braided flow paths on the western side of Bluewater Plains. Bluewater Creek then narrows again as it travels passed the Bruce Highway crossing.

Bluewater Park land use is characterised by medium density rural residential properties. Forestry Road is the main road linking Bluewater Park to Bluewater Plains. Forestry Road is the main road linking Bluewater Park to Bluewater Plains and ultimately the Bruce Highway. All lots on the eastern side of Forestry Road are within the high flow channel and remnant braided systems of Bluewater Creek. Drainage on the western side of Forestry road is characterised by open swale channel drains and cross drainage culverts. The majority of runoff from the Bluewater Park catchment travels north and discharges into Sleeper Log Creek.

Bluewater Plains land use is characterised by a mix of low and medium density rural residential properties. Lots on the eastern side of Forestry Road are within the vicinity of two remnant braided systems of Bluewater Creek. Drainage on the western side of Forestry road is characterised by open swale channel drains and cross drainage culverts. The majority of runoff from the Bluewater Plains catchment travels north via a series of braided channel systems and discharges into the coastal system between Fern and Sleeper Log Gully.

All flow travelling north from Bluewater Park and Bluewater Plains flows through culvert systems of the Bruce Highway and rail crossing.

5.2.2 Bluewater and Toolakea

Bluewater Creek continues north passed the Bruce Highway and rail crossing's travelling adjacent to Bluewater, passed Toolakea and ultimately discharges through a coastal outlet. The coastal outlet of Bluewater Creek is subject to sand bar formation, restricting the outlet opening in the dry season. This is a typical formation pattern common to North Queensland coastal outlets.

As Bluewater Creek travels past Bluewater it displays significant braiding/remnant braiding and two distinct low flow channels exist for approximately 1 km immediately downstream of Darley Road. Further downstream toward the Toolakea area, the Bluewater Creek transitions from a perched waterway to a low flow channel system with mangrove swamps dominating the high flow breakouts. Multiple braided channels of Bluewater Creek exist in this low lying coastal swamp area with some directed towards Toolakea Beach.

A relatively small Bluewater urban area is located on the eastern side of Bluewater Creek between the Bruce Highway and rail crossing consisting of predominately low density residential properties including the Bluewater Primary School. Drainage is characterised by open swale channel drains and cross drainage culverts that ultimately discharge west into Bluewater Creek between the Bruce Highway and the rail crossing. The remainder of Bluewater is located on the western side of Bluewater Creek downstream of the rail crossing and consists predominately of medium density rural residential properties. Toolakea Beach Road is the main road linking Bluewater to Toolakea Beach and the Bruce Highway. Similar to its south western extents, Bluewater Creek exhibits a distinctive low and high flow channel as it travels past Bluewater and it is noticeably braided. Drainage is characterised by open swale channel drains and cross drainage culverts. The majority of runoff from the Bluewater catchment travels north via a series of braided channel systems and discharges into the coastal system of Fern Gully.

Toolakea (Toolakea Beach) is a coastal strip of development consisting of predominately low density residential properties and located on the coastal dune system. Whilst the majority of the coastal development is located on the western side of Bluewater Creek, a small area of development exists on the eastern side of Bluewater Creek (west of Althaus Creek). The Esplanade is the main road connecting the coastal development to Toolakea Beach Road and ultimately to the Bruce Highway.

The area immediately upstream of The Esplanade is designated as a low lying coastal swamp land and receives runoff from three main overland flow systems originating south west of Toolakea Beach. This area is known as Fern Gully and ultimately drains runoff west adjacent to the Esplanade to ultimately discharge from the Fern Gully western coastal outlet. The Fern Gully system provides a significant coastal inland storage area.

5.3 MIKE FLOOD Overview

The MIKE FLOOD is a DHI developed software program that allows coupling of a MIKE 11 (1D) model and a MIKE 21 (2D) model to run together in parallel. The fundamental principle of the MIKE FLOOD is that features smaller than the MIKE 21 grid resolution (e.g. small channels and structures) can be represented in MIKE 11, with linkages (couples) that transfer water levels and discharges between MIKE 11 and MIKE 21 at each time step.

In urban environments, the hydraulic structures (culverts, bridges and weirs) can dominate the hydraulic grade line, and accurate assessment of head loss across structures using a 1D model like MIKE 11 is very important. MIKE 21 generally gives a better representation of floodplain storage and complex flow paths that cannot be adequately represented in MIKE 11. MIKE FLOOD draws on the best features of each model and can be used in applications (like the Bluewater Creek Flood Study) where MIKE 11 and MIKE 21 models run in isolation do not adequately replicate the known flood behaviour.

5.4 Development of Hydraulic Model

The Bluewater Creek Flood Study has been undertaken using the MIKE FLOOD (DHI) two-dimensional hydraulic modelling software.

The MIKE Flood model is effectively a combined 2D-1D hydraulic model, simulating unsteady flow regimes in dynamically linked 1D and 2D dimensional domains.

Bluewater Creek and surrounding areas were represented in the 2D domain using a grid cell size of 10 m. Following discussions with TCC it was considered that the 10 m grid resolution adequately defined the waterway profile and floodplain topography.

The four structures on Bluewater Creek were represented in the 1D domain (MIKE11) using the TCC supplied design drawings and structure survey information.

The MIKE FLOOD model extends from the extent of development on Forestry Road in the south west to the coast in the north east. It extends to Bluewater Drive in the east to the limit of development in the west.

Figure 3.1 shows the extent and layout of the Bluewater Creek MIKE FLOOD model.

5.4.1 Model Topography and Grid

The Bluewater Creek MIKE FLOOD model is based on a rotated 10 m topographical grid covering an area of 36.5 km^2. The rotation of the grid was aligned to the general Bluewater Creek alignment.

The 10 m MIKE FLOOD grid was based on LiDAR topographical data captured in 2009 and provided by TCC.

As a result of the review of the LiDAR topographical data, it was identified that the supplied LiDAR had not represented the invert of Bluewater Creek in some areas where water was evident (tidal water in lower reaches and standing water in upper reaches). Fifteen cross sections (surveyed in 2001 and supplied by TCC) were used for interpolation and subsequent adjustment of the MIKE FLOOD 10 m grid to better represent the invert of Bluewater Creek.

Narrow flow paths around Buckby Street were represented in the MIKE FLOOD grid by inclusion of control lines (refer to section 5.4.7). The location of the fifteen sections used, are shown in .

5.4.2 Boundary Conditions

Boundary conditions within the model consisted of:

- Downstream coastal static tidal water levels including:
  - MHWS tide level (R.L.1.254 m AHD);
  - HAT tide level (R.L. 2.254 m AHD); and
  - MHWS tide level + 0.8 m (R.L 2.054 m AHD).
- Upstream point inflow boundaries; and
- Model outflow boundaries.

Constant water levels were adopted for the downstream boundary condition at the coastal outlet of Bluewater Creek. MHWS was used as a fixed boundary condition for all events, whilst a sensitivity of tailwater increase to HAT and a 0.8 m increase to MHWS due to sea level rise was undertaken for the 50 and 100 year ARI design storm events.

The upstream boundary conditions adopted for the hydraulic model comprised flood hydrograph inputs obtained from the Bluewater Creek and Althaus Creek XP-RAFTS model.

Outflow boundaries were applied to the hydraulic model at the appropriate locations to allow flow to exist the model unobstructed. No tailwater/restriction conditions were applied to outflow boundaries except for the coastal tailwater conditions.

5.4.3 Rainfall on Grid

Rainfall excess was directly applied to the entire MIKE FLOOD 2D grid. The approximate extent of the “Rain on Grid” area is shown in Figure 3.2. The rainfall excess was applied to the MIKE FLOOD 2D grid with a spatial distribution representing the impervious areas within study area. The impervious areas were identified from review of aerial photography, TCC land use and TCC flood modelling guidelines. Land use impervious fractions adopted are shown in Table 5.1.

Rainfall loss values were determined from the hydrological model calibration (refer to 4.5.5).

The loss values adopted for the design flood events were:

- Pervious initial loss - 50mm;
- Pervious continuing loss - 2.5 mm/hr;
- Impervious initial loss – 0 mm; and
- Impervious continuing loss – 0 mm/hr.

5.4.4 Inflow Locations

Two inflow locations were used in the Bluewater Flood Study for areas outside of the rainfall on grid area:

- Input of the upper Bluewater Creek catchment at the upstream boundary of the Bluewater Creek model extent; and
- Input of the upper Althaus Creek catchment (supplied by TCC).

Flows hydrographs were extracted from the Bluewater Creek and Althaus Creek XP-RAFTS models.

5.4.5 Hydraulic Roughness

The hydraulic roughness of ground surfaces within the model is specified as Manning’s ‘n’ values.

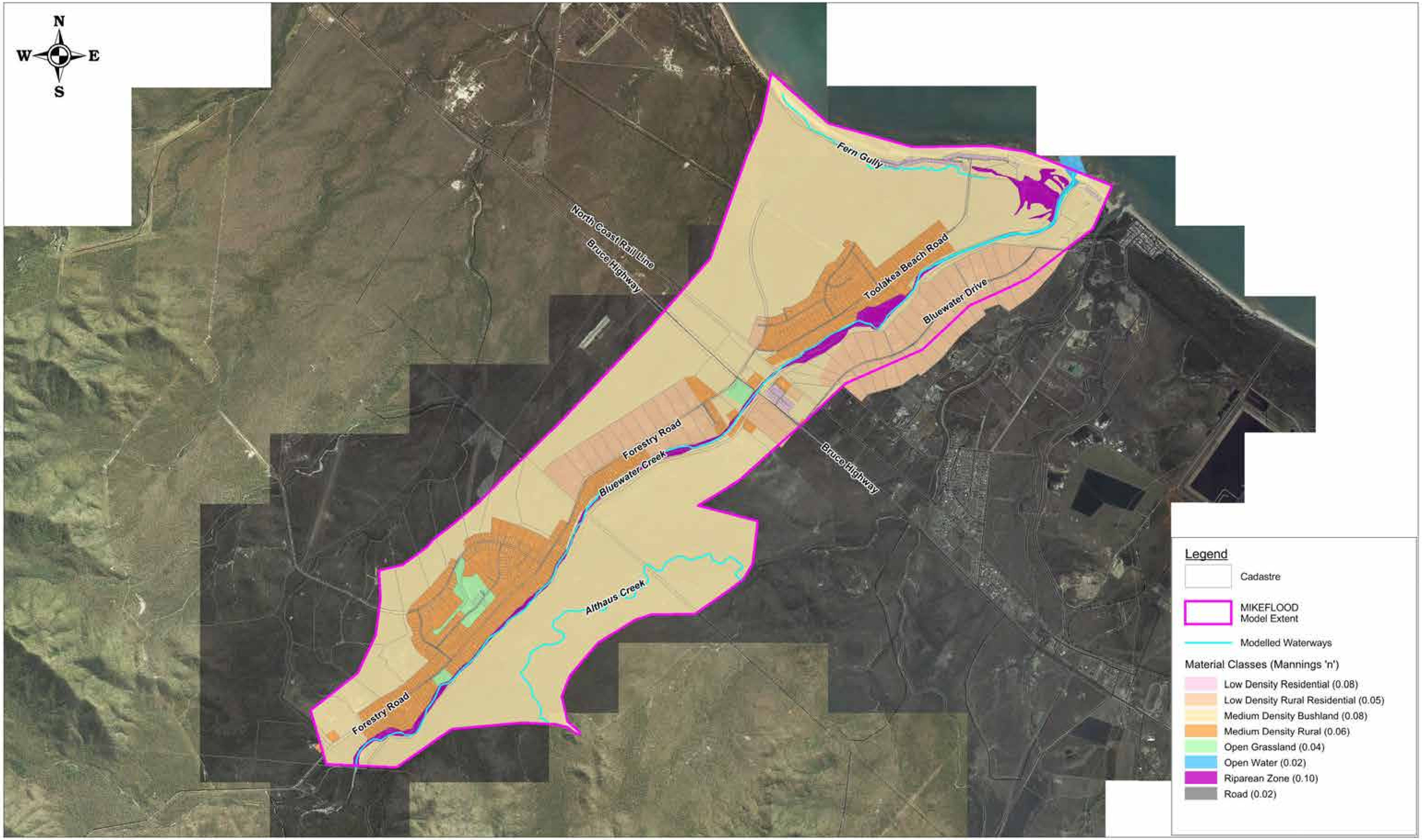
A variable Manning’s ‘n’ distribution was applied within the models due to the changes in vegetation and land type within the study area. Roughness values were determined from a combination of a review of land use data, a review of aerial photography, observations undertaken during site inspections, values reported in TCC flood modelling guidelines and discussions with TCC. Manning's roughness and fraction impervious for the different land uses used within the hydraulic model are listed in Table 5.1 below.

Table 5.1 MIKE Flood Roughness Values

Material Classification	Manning's 'n' Roughness Coefficient	Fraction Impervious
Medium Density Rural Residential	0.06	0.20
Low Density Rural Residential	0.05	0.05
Low Density Residential	0.08	0.60
Road	0.02	1.00
Riparian Zone	0.10	0.00
Water Course	0.02	1.00
Medium Density Bushland	0.08	0.00
Park Land (Open Grassland)	0.04	0.00

Hydraulic roughness parameters were confirmed following hydraulic calibration of Bluewater Creek flood levels to the 1998 historical flood event using surveyed debris levels (refer section 5.5).

The MIKE FLOOD materials layer is shown in Figure 5.1.



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Townsville

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Bluewater Creek Flood Study

Figure 5.1

MIKEFLOOD Materials Layout

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 5 Jun 2013

M:\Projects\M9300_Townsville City Council\M9300_001_Bluewater Creek Flood Study\Design\MapInfo\Figures

5.4.6 Hydraulic Structures

Culvert and bridge structures located within the study area have been represented in the MIKE FLOOD model as 1D flow structures and have been modelled using a combination of implicit and explicit culvert/weir arrangements.

The four major structures modelled transverse Bluewater Creek and are located approximately 5.5 km upstream of the coastal outlet. They are:

- Rail crossing;
- Pedestrian footbridge;
- The Bruce Highway; and
- A potable water transfer pipe.

TCC supplied design drawings for the Bluewater Creek rail crossing and Bruce Highway crossing. Levels and arrangements used for modelling were extracted from these drawings.

The pedestrian bridge and potable water transfer pipe structures were detailed within the model from a combination of TCC supplied information, site observations and site survey supplied by TCC.

No subsurface drainage infrastructure (pits and pipes) was modelled as part of the current study. A number of culvert cross drainage structures were modelled within the urbanised areas. Data for these structures was obtained from TCC supplied information, site observations and site survey supplied by TCC.

One dimensional hydraulic validation of head loss across the Bruce Highway crossing and the rail crossing was undertaken using HEC-RAS. It was shown that MIKE FLOOD was estimated head loss within acceptable limits to those predicted by HEC-RAS.

Table 5.2 shows the head loss calculated by MIKE FLOOD compared with the head loss calculated by HEC-RAS for the 100 year ARI event.

Table 5.2 Comparison between MIKE FLOOD and HEC-RAS Head Loss for Bluewater Creek Major Structures

	MIKE FLOOD Head Loss (m)	HEC-RAS Head Loss (m)
Bruce Highway	0.49	0.48
Rail Crossing	0.14	0.14

Figure 3.1 shows the location of each bridge and culvert structure included in the Bluewater Creek model.

Details of the bridge and culvert structures represented within the Bluewater Creek model are provided in Appendix D.

No sensitivity on blockage was undertaken for any structures.

5.4.7 Narrow Flow Paths and Road Controls

Due to the 10 m grid adopted, elevation control lines were adopted to accurately represent key hydraulic control locations and areas of interest. Control line elevations were extracted from the LiDAR survey surface and digitally imprinted onto the MIKE FLOOD 10 m grid surface.

Key control lines included:

- Forestry Road from the Bruce Highway to the upstream extent of the model; and
- Toolakea Beach Road.

Minor drainage channels around Buckby Street that provided hydraulic connectivity with Bluewater Creek. Figure 3.1 shows the location of each control line included in the Bluewater Creek model.

5.5 Hydraulic Model Calibration

The January 1998 flood event was selected for calibration. Following the 1998 flood event, survey of debris levels was undertaken by the City of Thuringowa predominately along properties inundated by Bluewater Creek breakout flow on Forestry Drive. The survey extended 7 km along the Bluewater Creek upstream of the Bruce Highway.

Following final selection of roughness parameters for the MIKE FLOOD model, a comparison was undertaken between the 1998 surveyed debris levels and the corresponding water levels produced by MIKE FLOOD for the 1998 calibration model run. Figure 5.2 shows this comparison.

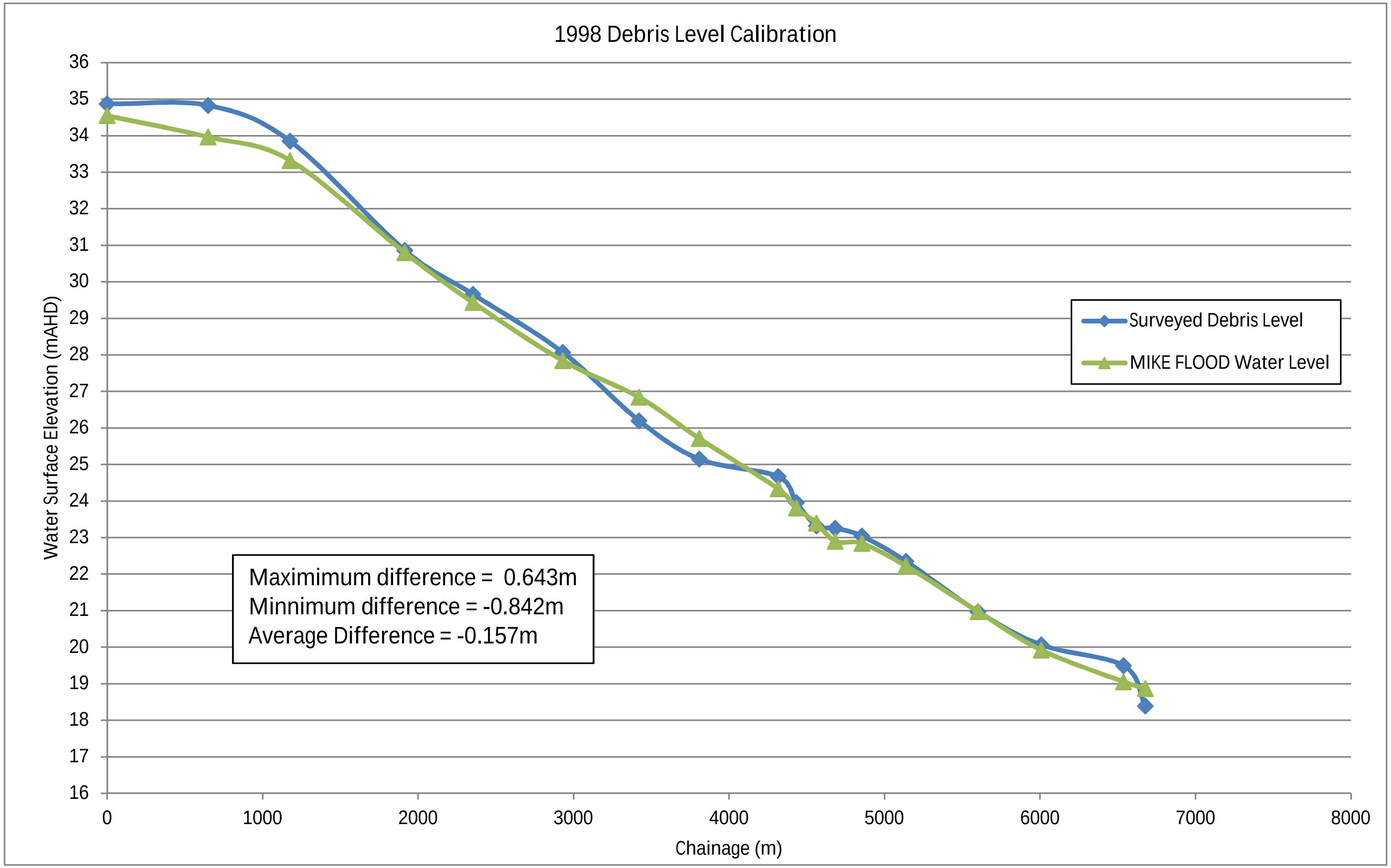

Figure 5.2 1998 Event Surveyed Debris Level Hydraulic Calibration

Figure 5.2 shows a good correlation between the recorded flood levels and the MIKE FLOOD levels with an average difference of 0.157 m along a 7 km reach of Bluewater Creek upstream of the Bruce Highway. The maximum variation exists in the most upper reaches of the surveyed area and is likely an anomaly in the survey (flat hydraulic grade 650 m chainage differences).

A number roughness values were tested to calibrate water levels and the adopted final roughness values are shown in Table 5.1.

5.6 Validation of Rainfall on Grid

Three locations were selected to validate results produced from MIKE FLOOD (rainfall on grid technique) using the rational method. All locations were chosen based on no significant structures being present within the general flow conveyance area. The three rainfall on grid, rational method validation locations are shown in Figure 3.1.

Rational method validation was performed for the 2 and 50 year ARI events using both the QUDM (10 year ARI, 1 hour intensity method) and the Department of Transport and Main Roads (50 year ARI, 1 hour method). Results of the rational method validation are shown below in Table 5.3.

Table 5.3 Rational Method Validation Results

	2 year ARI				50 year ARI		
Catchment	Area (ha)	MIKE FLOOD (m^3/s)	QUDM (m^3/s)	DTMR (m^3/s)	MIKE FLOOD (m^3/s)	QUDM (m^3/s)	DTMR (m^3/s)
1 (western)	5.5	5.4	7.9	6.0	20.2	20.3	14.2
2 (middle)	6.5	6.3	8.0	6.0	24.0	20.7	14.5
3 (eastern)	3.0	0.4	0.9	0.6	1.8	2.6	1.7

The rational method validation shows good agreement between flows estimated using MIKE FLOOD rainfall on grid technique and both rational method techniques for the two (2) year ARI and the QUDM method for the 50 year ARI.

5.7 Development of Rating Curve for Bluewater Creek Station

A streamflow gauging station (Station no. 117003A) is located on Bluewater Creek approximately 6.4 km upstream of the coastal outlet and has an upstream catchment of approximately 84 km^2. The gauging station is operated by DNRM and has a data record from the 16/11/1973 to present (39 years).

The maximum gauged level at the Bluewater Creek Gauging Station (Station no. 117003A) is 3.94 m (R.L 12.67 m AHD) and corresponding to a flow rate of 116 m^3/s.

DNRM has extended the rating curve above this level to medium and high stage, using a simple Mannings equation representing the channel by a single cross section.

Following the 1998 flood event, the rating curve was linearly extended to the recorded height of the 1998 flood event (18.46 m AHD) which translates to a flow of 1525 m^3/s based on the DNRM rating curve.

Appendix C contains a detailed explanation from DNRM as to the production of the Bluewater Creek rating curve. It details the basic extrapolation of the rating curve using a manning's calculation for medium and high water levels using a Manning's roughness value of 0.035.

Following initial hydrology and hydraulic modelling simulations it was determined that there were inconstancies with the DNRM rating curve at medium and high stage. It was found that the DNRM curve overestimated flows at high stage elevations required to produce recorded water levels at the gauging station. It is believed this is due to the simple Manning's extrapolation method not accurately accounting for hydraulic conditions and topographical channel profiles of Bluewater Creek.

The following tasks were undertaken to assess the existing DNRM rating curve and subsequently develop an updated rating curve:

- Hydrological calibration for the 1998 historical event using the existing DNRM rating curve. The XP-RAFTS model was calibrated to match the peak flow, volume of runoff and catchment response time associated with the 1998 historical hydrograph produced from DNRM recorded water levels translated to flow using the DNRM rating curve;
- Hydraulic modelling of calibrated flows;
- Identification of inconsistent flow versus water level data for the DNRM rating curve. Flows produced significantly higher water levels than DNRM rating curve predicted;
- Sensitivity checks were undertaken on Bluewater Creek structures head loss to ascertain if water level at the gauging station was sensitive to structure loss. Water levels at the gauging station were found not to be sensitive to headloss at Bluewater Creek structures;
- Sensitivity checks were undertaken on Manning's Roughness values. Water levels were found to be sensitive to changes in Manning's roughness. An average manning's roughness of 0.1 was used and is justified based on site observations and bank vegetation. DNRM have adopted a Manning's roughness value of 0.035 for their rating calculations. We believe this Manning's roughness value is too low and does not adequately represent Bluewater Creek channel roughness at medium to high flow conditions;

- Linearly increasing flows were applied to the MIK FLOOD model up to approximate bank full conditions (approximately 800 m^3/s) and an elevation versus flow rating curve was extracted at the gauging station;

- A one dimensional HEC-RAS model was developed at the gauging station to assist with validating the new rating curve. The HEC-RAS model covered 1.7 km of Bluewater Creek (0.7 km upstream and 1 km downstream). Using the same roughness values as MIKE FLOOD, the HEC-RAS rating curve showed good similarity with the new MIKE FLOOD rating curve (refer Figure 5.4);

- The new rating curve was combined with the DNRM rating curve. As the DNRM rating curve was gauged at low stage, an interpolation between the DNRM rating at low stage (R.L 12.67 m AHD) to the new rating curve at high stage (R.L 16.5 m AHD) was performed; and

- The combined rating curve was used for recalibrating the XP-RAFTS hydrology model using the March 2011 historical event (refer to Figure 5.3 for final rating curve).

The variation at low stage of the DNRM rating curve and the rating curve produced from MIKE FLOOD can be attributed to changing stream bed profiles and/or Manning's roughness adopted at low stage. As discussed, whilst a Manning's roughness value of 0.035 may be applicable for low stage flow conditions, this value is not representative of the roughness of Bluewater Creek during medium to high flow conditions.

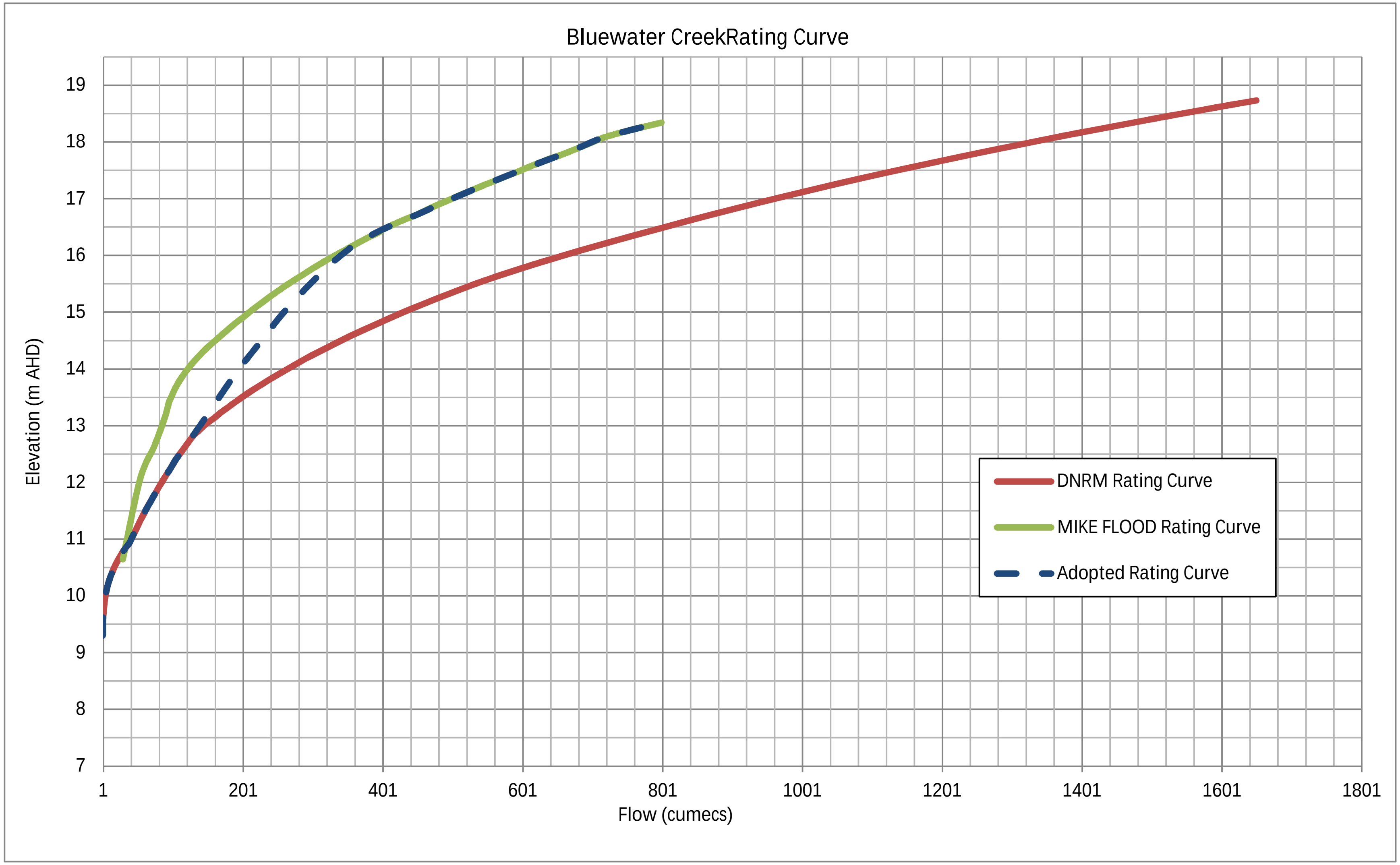

Figure 5.3 Bluewater Creek Rating Curve

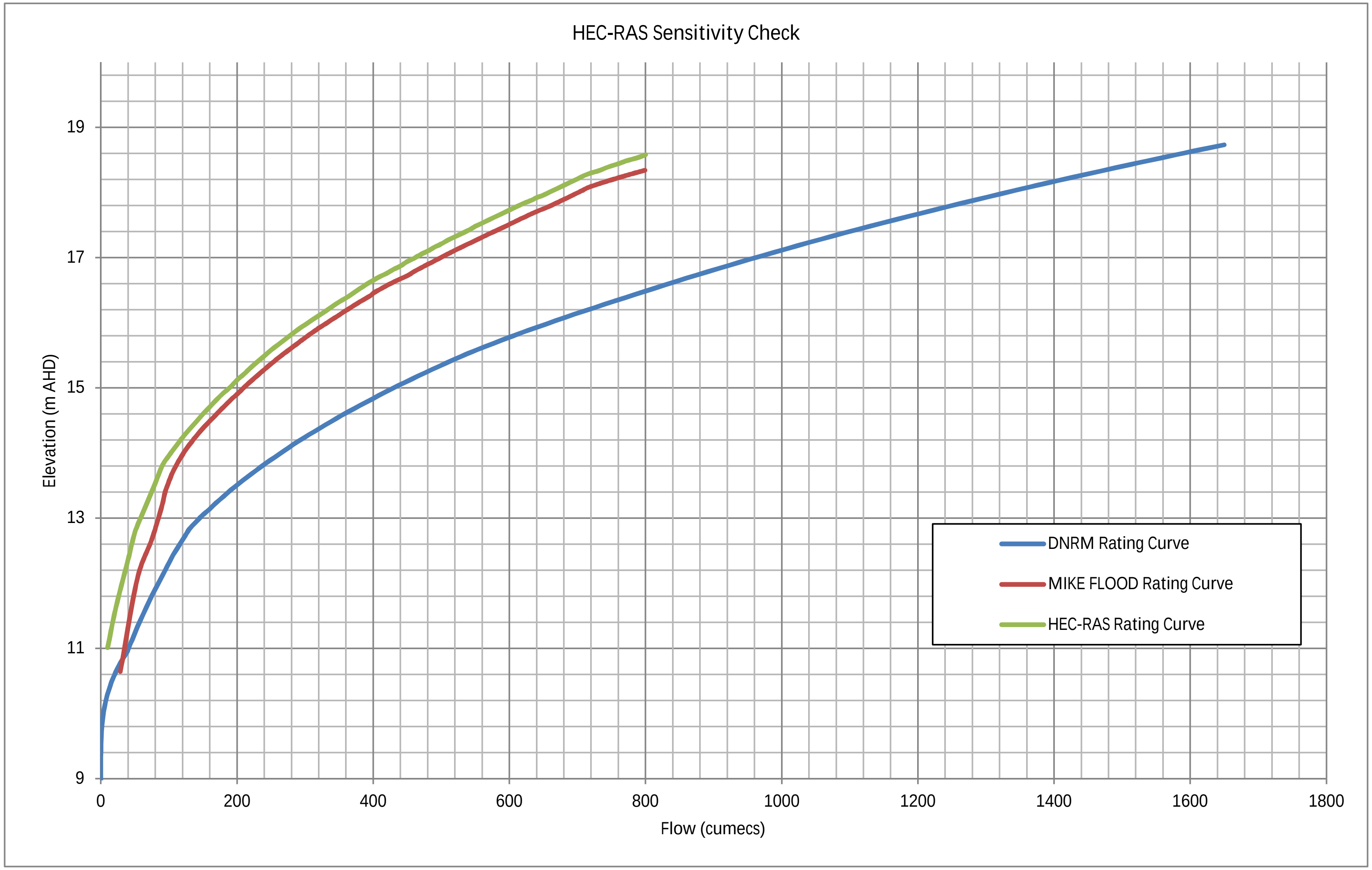

Figure 5.4 HEC-RAS Rating Curve Validation

5.8 Design Flood Simulations

Following the development of a new rating curve and the joint calibration of the hydrology and hydraulic models the selection of critical storm durations for final design runs was undertaken.

Three distinct flooding regimes exist within the study area:

- Creek flooding within Bluewater Creek;
- Urban flooding outside of the perched Bluewater Creek system due to direct rainfall; and
- Urban flooding as a result of Bluewater Creek breakout flow contributing to direct rainfall flooding.

As such, the 50 and 100 year ARI design storm events were simulated without Bluewater Creek inflows to determine critical durations that caused peak flood levels within the study area. This was achieved by application of the rainfall on grid approach for a range of durations (30 min to 36 hrs). An assessment was made of critical durations across the study area and it was found that the range of critical durations causing peak water levels included the 2, 3 9, 12, 24 and 36 hour duration events. As a result of this assessment, and with consideration to the critical storm duration of Bluewater Creek, the suit of storm durations considered included those that caused peak flood levels for Bluewater Creek and for the surrounding study area. Appendix E shows the full range of design storms and associated critical storm durations analysed for the Bluewater Creek Flood Study.

The final MIKE FLOOD model was used to assess the following design floods and hydraulic outputs:

- 2 year ARI – level, depth and velocity;
- 5year ARI– level, depth and velocity;
- 10 year ARI– level, depth and velocity;
- 20 year ARI– level, depth and velocity;
- 50 year ARI– level, depth and velocity;
- 50 year ARI (Tailwater level sensitivity and climate change)– Depth difference;
- 100 year ARI– level, depth and velocity;
- 100 year ARI– (Tailwater level sensitivity and climate change)– Depth difference;
- 500 year ARI– level, depth and velocity; and

- PMF event– level, depth and velocity.

All results are presented in mapping contained in Appendix A. Appendix A also contains long sections of Bluewater Creek and the major flow path running parallel to The Esplanade at Toolakea Beach. The long sections display bed profile with the 50 and 100 year ARI results. All results show the absolute maximum results for any given time step in the model simulation therefore peak flood results shown are unlikely to occur simultaneously. As rainfall on grid was used for the study all mapping has been filtered to not display flooding depths less than 100 mm.

6. HYDRAULIC MODELLING RESULTS

The MIKE FLOOD hydraulic model utilised both inflow hydrographs from the upstream Bluewater Creek catchment and direct rain on grid hydrology for the floodplain area to simulate flood behaviours at the study area. Mapping of all model outputs are contained in Appendix A.

The following sections provide a summary of the results.

6.1 Bluewater Park and Bluewater Plains

The following flooding observations are made within the Bluewater Park and Bluewater Plains development areas:

- For the 2 and 5 year ARI events;
    - Bluewater Creek breakout occurs across properties (476 and 452 Forestry Road) at bend in creek (downstream of Sportsman Parade). Depths up to 3 m;
    - Bluewater Creek flood extent (high flow channel-eastern side) impacts eastern properties along Forestry Road;
    - Urban flooding is generally contained within drainage channels with inundation evident at location of overtopping of Blue Mountain Road Crossing (Properties 13-21 Blue Mountain Drive); and
    - Velocities are generally below 3 m/s in Bluewater Creek and below 2 m/s in urban areas.

- For the 10 and 20 year ARI events;
    - Significant breakout across properties (476 and 452 Forestry Road) at bend in creek (downstream of Sportsman Parade). Depths exceeding 3m;
    - Additional breakout occurs impacting Wil-Win Park;
    - Bluewater Creek flood extent (high flow channel-eastern side) widens and further impacts properties along Forestry Road. Significant inundation of eastern properties along Forestry road. Depths up to 1.5 m;
    - Remanent channels on the eastern side of Bluewater Creek begin to convey Bluewater Creek breakout flow (properties 66-298 Forestry Road). Depths up to 1 m;
    - The majority of road crossings are overtopped and flooding of properties west of Forestry Road is evident;
    - Overtopping of Blue Mountain Road Crossing (Properties 13-21 Blue Mountain Drive) increases flood extent upstream;
    - Ponding occurs upstream of the Bruce Highway; and
    - Velocities are generally below 3 m/s in Bluewater Creek and below 2 m/s in urban areas.

- For the 50 and 100 year ARI events:
  - Extensive breakout across properties (476 and 452 Forestry Road) at bend in creek (downstream of Sportsman Parade). Depths exceeding 3 m;
  - Significant breakout occurs impacting Wil-Win Park;
  - All eastern properties along Forestry Road inundated. Areas where depth exceeds 2 m;
  - Extensive additional breakout occurs impacting Wil-Win Park;
  - Remanent channels on the eastern side of Bluewater Creek begin to convey additional Bluewater Creek breakout flow (properties 66-298 Forestry Road). Areas where depth exceeds 3 m;
  - The majority of road crossings are overtopped and flood extent of properties west of Forestry Road increases. Properties south west of Blue Mountain Road and Forestry Road junction culvert impacted. Depths up to 0.75 m;
  - Overtopping of Blue Mountain Drive Crossing (Properties 13-21 Blue Mountain Drive) increases flood extent upstream. Depths up to 0.75 m;
  - Breakout from remnant channel (84-102 Forestry Road) flows north and overtops Forestry Road;
  - The Bruce Highway is overtopped in the 50 year ARI. Depth of overtopping is 0.1-0.2 m;
  - Overtopping of Bruce Highway flows into Bluewater area;
  - Significant ponding occurs upstream of the Bruce Highway. Depths up to 1 m; and
  - Velocities are generally below 3 m/s in Bluewater Creek and below 2 m/s in urban areas.

- For the 500 ARI event:
  - Severe inundation of all eastern properties along Forestry Road. Areas where depth exceeds 3 m;
  - Flooding of all urban areas in the 50 and 100 year ARI increases;
  - Breakout from remnant channel (84-102 Forestry Road) completely inundates Forestry Road;
  - Significant urban flooding of Bluewater Plains;
  - Significant overtopping of the Bruce Highway and flow into Bluewater area; and
  - Velocities exceed 3 m/s in Bluewater Creek and remnant channels. Velocities generally below 2 m/s in urban areas.

- For the PMF event:
  - Widespread flooding of all urban areas. Depths up to 2 m;
  - Complete flooding of all roads;
  - Significant overtopping of the Bruce Highway and flow into Bluewater; and
  - Velocities exceed 3 m/s in Bluewater Creek and urban areas.

6.2 Bluewater and Toolakea

The following flooding observations are made within the Bluewater and Toolakea development areas;

- For the 2 and 5 year ARI events:
  - Bluewater Creek breakout occurs in the downstream low lying coastal areas. Breakout flows west towards Toolakea Beach Road. Breakout impacts properties 2-26 The Esplanade on the eastern side of Bluewater Creek with depths up to 1 m;
  - Northern Toolakea Beach Road culverts overtopped;
  - Flooding of properties on The Esplanade. Properties 113-121 and 15-63 impacted; Depths up to 0.75 m;
  - Flooding of properties immediately upstream and downstream of the Lodestone Drive crossing (properties 4-16 Loadstone Drive). Depths up to 0.5 m; and
  - Velocities are generally below 3m/s in Bluewater Creek and below 1 m/s in urban areas.

- For the 10 and 20 year ARI events:
  - Significant breakout occurs in the downstream low lying coastal areas. Breakout flows west towards Toolakea Beach Road. Increased flooding of properties 2-26 The Esplanade on the eastern side of Bluewater Creek with depths up to 1.5 m;
  - Northern Toolakea Beach Road culverts overtopped;
  - Flooding of properties on The Esplanade. Properties 113-121 and 15-63 The Esplanade impacted. Depths up to 1 m;
  - Bluewater Creek breakout occurs immediately downstream of the rail crossing. Breakout flows along a remnant channel and renters Bluewater Creek downstream of the Toolakea Beach Road and Darley Road junction impacting properties 1-50 Toolakea Beach Road. Areas where depth exceeds 3 m;
  - Bluewater Creek breakout occurs adjacent to the Toolakea Beach Road and Lodestone junction impacting properties 90-122 Toolakea Beach Road. Depths up to 1 m;
  - Increased flooding of properties immediately upstream and downstream of the Lodestone Drive crossing (properties 4-16 Loadstone Drive). Flooding extends south west to Darley Road. Depths up to 1 m; and
  - Velocities exceed 3m/s in Bluewater Creek. Velocities generally below 1m/s in urban areas.

- For the 50 and 100 year ARI events:
  - Significant breakout occurs in the downstream low lying coastal areas. Breakout flows west towards Toolakea Beach Road. Increased flooding of properties 2-26 The Esplanade on the eastern side of Bluewater Creek with depths up to 1.5 m;
  - Northern Toolakea Beach Road culverts overtopped. Toolakea Beach road completely inundated. Depths exceed 0.25 m;
  - Increased flooding of properties on The Esplanade. The majority of properties on The Esplanade are impacted. Depths up to 1.5 m.

- Further inundation of properties at western Bluewater Creek breakout locations. Areas where depth exceeds 3 m;
- Additional Bluewater Creek breakout occurs on the eastern side of Bluewater Creek impacting properties 325-381 Bluewater Drive. Depths up to 3 m;
- Increased flooding of properties immediately upstream and downstream of the Lodestone Drive crossing (properties 4-16 Loadstone Drive). Flooding extent increased south west to Darley Road and south west of Darely Road crossing. Depths up to 1.5 m;
- Significant inflow from Bluewater Plains to western Fern Gully as a result of Bluewater Creek breakout upstream of the Bruce Highway;
- Significant flooding occurs within the Bluewater urban area between the Bruce Highway and the rail crossing as a result of The Bruce Highway overtopping and via Bluewater Creek flow travelling up into local drainage channels. Depths up to 1 m; and
- Velocities exceed 3 m/s in Bluewater Creek. Velocities generally below 1m/s in urban areas.

▪ For the 500 ARI event:

- Increased breakout in the downstream low lying coastal areas;
- Toolakea Beach road completely inundated. Depths up to 0.5 m;
- Increased flooding of properties on The Esplanade. The majority of properties on The Esplanade are impacted. Depths up to 1.5 m;
- All Bluewater Creek breakouts increase in severity;
- Significant flooding of properties occurs within the drainage area between Salamander Street and Toolakea Beach Road, across Darley Road and Loadstone Drive;
- Flooding increases within the Bluewater urban area between the Bruce Highway and the rail crossing as a result of The Bruce Highway overtopping and via Bluewater Creek flow travelling up into local drainage channels. Depths up to 1.5 m;
- Inflow increases from Bluewater Plains to western Fern Gully as a result of Bluewater Creek breakout upstream of the Bruce Highway; and
- Velocities exceed 3 m/s in Bluewater Creek and remnant channels. Velocities generally below 2 m/s in urban areas.

▪ For the PMF event:

- Widespread flooding of all urban areas. Areas where depth exceeds 3 m;
- Toolakea Beach road completely inundated. Depths up to 0.75 m;
- Significant overtopping of the Bruce Highway and flow into Bluewater; and
- Velocities exceed 3 m/s in Bluewater Creek and remnant channels. Velocities generally below 1.5 m/s in urban areas.

In 2009 at the time of the LiDAR topographical data being collected the outlet of Bluewater Creek was significantly restricted by a sand bar. The outlet restriction that exists at Bluewater Creek outlet (approximately 150 m flow width) causes an increase of the hydraulic grade line to all ARI events of approximately 1.5 m. This raises flood water levels upstream in Bluewater Creek causing further breakout to the west and east. The current outlet condition is likely to be a worst case scenario and it is expected that the Bluewater Creek outlet will widen following the first significant rainfall event (erosion of sand bar). The sand bar formation is typical of North Queensland coastal beach outlets.

6.3 Sensitivity Analysis Results

6.3.1 Impact of Highest Astronomical Tide

A tidal tailwater sensitivity analysis was undertaken to assess the impacts on flood levels. The tailwater level was updated from MHWS (R.L. 1.254 m AHD) to HAT (R.L. 2.254 m AHD). An increase in tailwater level was applied to the 50 and 100 year ARI events only.

For the 50 year ARI event increased tailwater impacts were generally localised to the coastal areas. Flood level differences up to 0.1 m were observed. Properties on The Esplanade, east of Bluewater Creek appear to be the only properties affected.

For the 100 year ARI event increased tailwater impacts were generally localised to the coastal areas with minor flood level depth increase evident in Bluewater Creek upstream to the Bruce Highway. Flood level differences up to 0.1 m were observed and affect all properties inundated adjacent to Bluewater Creek.

6.3.2 Impact of Climate Change

A climate change sensitivity analysis was undertaken to assess the impacts on flood depths. Climate change sensitivity was undertaken for the 50 and 100 year ARI events. This was achieved by:

- Increasing rainfall intensities by 15% for both the XP-RAFTS model and the rainfall on grid (refer section 4.3.5);
- Increasing the MHWS tide level by 0.8 m.

The following modelling parameters remained unchanged:

- Initial and continuing losses;
- Temporal patterns;
- Surface retardences;
- Hydraulic roughness; and
- Fraction impervious.

6.3.3 Bluewater Park and Bluewater Plains

The following observations in the Bluewater Park and Bluewater Plains urban areas as a result of the 50 and 100 year ARI event climate change sensitivity analysis:

- Flood depths in Bluewater Park and Bluewater Plains urban areas generally increased by up to 100 mm;
- Flood depths along Forestry Road properties inundated by Bluewater Creek generally increased up to 1 m;
- Previous Bluewater Creek breakout flow across Forestry Road in the vicinity of 128 to 84 Forestry Road now occurs in the 50 year ARI (previously caused by the 100 year ARI event);
- Flood depths immediately upstream of the Bruce Highway and in the Bluewater area generally increased by up to 500 mm;
- Increased overtopping depths and flow over the Bruce Highway occurs; and
- The general extent of flooding increased in all areas especially immediately upstream of the Bruce Highway.

6.3.4 Bluewater and Toolakea

The following observations in the Bluewater and Toolakea development areas as a result of the 50 and 100 year ARI event climate change sensitivity analysis:

- Flood depths in Bluewater and Toolakea urban areas generally increased by up to 0.3 m and 0.1 m in the 50 and 100 year ARI events respectively;
- Flood depths along Toolakea Beach Road and Bluewater Drive properties inundated by Bluewater Creek generally increased up to 0.5 m and 0.3 m in the 50 and 100 year ARI respectively; and
- The general extent of flooding increased in all areas especially immediately upstream of the Bruce Highway.

It should be noted that the 50 year ARI event generally has a larger flood depth difference compared with the 100 year ARI event analysis for areas affected by flooding from Bluewater Creek. This is due to the 100 year ARI Bluewater Creek breakout flow increasing upstream of the Bruce Highway and subsequently travelling west and east out of the Bluewater Creek system. Whilst the 50 year ARI event shows breakout in the same location, the proportion that remains in the Bluewater Creek system causes a greater depth difference in the downstream Bluewater creek reaches when compared with the 100 year ARI event.

6.4 Comparison with Previous Studies

As previously mentioned, the study area has been the subject of a number of studies at varying levels of investigation. The most recent include:

- Bluewater Creek Flood Study (*Maunsell McIntyre, 2001*); and
- Toolakea Beach Flood Study (*Maunsell AECOM, 2008*).

Both studies were undertaken using 1D hydraulic models (MIKE11).

Hydrology comparisons have been made to the Bluewater Creek Flood Study (*2001*) in section 4.8. The current hydrology results are within the range of the 20 and 50 year ARI.

The Bluewater Creek Flood Study (*2001*) also uses the flood debris levels that were surveyed along Forestry Road following the 1998 flood event. The MIKE 11 hydraulic grade line upstream of the Bruce Highway shows reasonable replication of the 1998 survey stating that in areas the hydraulic grade line underestimates or overestimates recorded levels by up to 0.5 m.

The current study showed similar replication of the 1998 surveyed flood debris levels and this is discussed in section 5.5.

The Bluewater Creek Flood Study (*2001*) produced results for the 20 and 50 year ARI. Generally the hydraulic grade line for the 20 and 50 year ARI event for the present study was consistent along Bluewater Creek. However, at the location of the Bluewater Creek structures there were differences in water level due to hydraulic loss across modelled structures. For the 50 year ARI the following differences occurred:

- Approximately 1.2 m head loss was predicted across the three structures at the Bruce Highway (pipe, highway and footbridge) for the current study whereas the previous 2001 report predicted only 0.5 m due to the only structure included in the model being the Bruce Highway.

Given that the current study included all four structures crossing Bluewater Creek, HEC-RAS assessments of head loss were undertaken and the joint development of these hydraulic structures was undertaken in collaboration with TCC, flood levels predicted in the current model are considered suitable.

A hydrology comparison with the Toolakea Beach Flood Study (2008) was not undertaken. Hydraulic grade line comparisons were undertaken along Fern Gully. Flood levels predicted by the current study were consistently higher (up to 1 m) than the previous 2008 study. Suggested reasons include:

- The current model uses the 2009 aerial survey. Noticeable constrictions exist at the outlet locations of Bluewater Creek (breakout flows towards Toolakea Beach) and Fern Gully. The current model could be better representing restricted outlet conditions therefore increasing upstream flood levels compare with the 2008 study; and

- The current study shows Bluewater Creek breakout flow upstream of the Bruce Highway and at the coastal area contributing to the Fern Gully system. It is unlikely the 2008 study could have accurately predicted the magnitude of breakout given 1D limitations.

Given that the current study uses 2D and rain on grid approach and that the 2D model represents constrictions at both the Bluewater Creek and Fern Gully outlets (representing outlet conditions before the wet season), predictions are considered conservative and suitable for the intended purposes.

7. CONCLUSIONS AND RECOMENDATIONS

Engeny has undertaken a detailed flood study of Bluewater Creek and surrounding areas to investigate the flooding characteristics for the 2, 5 10, 20, 50, 100, 500 year ARI events and the PMF. Urban areas surrounding Bluewater Creek included in the study were:

- Bluewater Park;
- Bluewater Plains;
- Bluewater; and
- Toolakea (Toolakea Beach).

A calibrated hydrologic model (XP-RAFTS) and two-dimensional hydraulic model (MIKE FLOOD) was developed for the study area using 1998 topographical data and incorporating all Bluewater Creek hydraulic structures to simulate a range of both historical and design flood events.

The review undertaken of the DNRM Bluewater gauging station showed that above a low flow manually gauged level of R.L 12.67 m AHD. The rating curve was extrapolated using simple Manning's calculations considering a single cross section and low Manning's roughness value. Following the review of the rating curve a new rating curve was produced using the developed 2D MIKE FLOOD model and is considered to provide better representation of high stage Bluewater Creek hydraulics.

Based on the findings from this study the following conclusions are made:

- Local rainfall can cause minor localised flooding in urban areas, however, the most severe flooding is due to Bluewater Creek high flow and breakout. Significant flooding of properties located directly adjacent to Bluewater Creek is predicted to occur for the majority of events analysed. A wide high flow channel system, remnant Bluewater Creek braided channels and the proximity of properties to Bluewater Creek all contribute to significant flooding issues;
- For the Bluewater Park and Bluewater Plains urban areas affected by local rainfall the maximum depth and velocities in the 100 year ARI event are 0.75 m and 2 m/s respectively;
- For the Bluewater Park and Bluewater Plains urban areas affected by Bluewater Creek flooding the maximum depth and velocities in the 100 year ARI event are 2 m and 3 m/s respectively;
- For the Bluewater and Toolakea urban areas affected by local rainfall the maximum depth and velocities in the 100 year ARI event are 1.5 m and 1 m/s respectively;

- For the Bluewater Park and Bluewater Plains urban areas affected by Bluewater Creek flooding the maximum depth and velocities in the 100 year ARI event are above 3 m and 3 m/s respectively;

- The Bruce Highway is predicted to be overtopped in the 50 year ARI and the rail crossing has an immunity greater than the 100 year ARI event. The potable water supply pipeline, Bruce Highway and pedestrian bridge crossings are predicted to cause an afflux of up to 1.3 m; however, sensitivity analysis undertaken on the structures shows the influence of these three structures on the water levels in Bluewater Creek decreases to 0.05 m at the Bluewater Creek gauging station;

- Breakout of flow from Bluewater Creek occurs upstream of the Bruce Highway which then crosses the Bruce Highway to contributes to Fern Gully flooding in larger ARI events;

- Bluewater Creek and Fern Gully outlets show constrictions due to sand bars and were modelled in MIKE FLOOD as per the elevations within the LiDAR with no accounting for erosion likely to occur during a flooding event. These constrictions cause elevated flood levels at Toolakea impacting properties along The Esplanade;

- Cross drainage culverts at the northern extent of Toolakea Beach Road have insufficient capacity to convey minor ARI events (less than 2 year ARI) as well as the Bluewater Creek breakout flow and therefore cause Toolakea Beach Road to be inundated;

- Cross drainage culverts at the northern end of Blue Mountain Road have insufficient capacity to convey minor ARI events (less than 2 year ARI) causing inundation of upstream properties;

- Cross drainage culvert at Lodestone Drive crossing has insufficient capacity to convey minor ARI events (less than 2 year ARI) causing inundation of upstream properties; and

- Sensitivity analysis shows that rise in sea level of 0.8m and to HAT has a minor effect on flood levels in Bluewater Creek and is limited to the area downstream of the Bruce Highway. The increase in rainfall by 15% has resulted in more measurable wide spread flooding increases along Bluewater Creek which has proportionately large catchment.

The Bluewater Creek Flood Study provides flood levels for a range of events which will assist TCC with:

- Identification of flood constraints for the new TCC planning scheme which is currently under development;

- Development of plans for trunk infrastructure concepts and flood mitigation associated with future capital investment;

- Provision of accurate flood levels and extents for development control using current information and techniques; and
- Identification of flood risks.

The following recommendations are offered in relation to the outcomes of the Bluewater Creek Flood Study:

- TCC to consider undertaking sensitivity analysis on Bluewater Creek and Fern Gully outlet conditions to include an erosion dependant outlet flush scenario;
- TCC to consider undertaking sensitivity analysis on debris blockage at the potable water supply pipeline, Bruce Highway and footbridge structures;
- TCC to consider undertaking a flood hazard assessment and isolation analysis for the study area, in particular northern Toolakea Beach Road; and
- Prepare a flood risk management strategy using outcomes from this study.

8. QUALIFICATIONS

a. In preparing this document, including all relevant calculation and modelling, Engeny Management Pty Ltd (Engeny) has exercised the degree of skill, care and diligence normally exercised by members of the engineering profession and has acted in accordance with accepted practices of engineering principles.

b. Engeny has used reasonable endeavours to inform itself of the parameters and requirements of the project and has taken reasonable steps to ensure that the works and document is as accurate and comprehensive as possible given the information upon which it has been based including information that may have been provided or obtained by any third party or external sources which has not been independently verified.

c. Engeny reserves the right to review and amend any aspect of the works performed including any opinions and recommendations from the works included or referred to in the works if:

   (i) additional sources of information not presently available (for whatever reason) are provided or become known to Engeny; or

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d. Engeny does not give any warranty nor accept any liability in relation to the completeness or accuracy of the works, which may be inherently reliant upon the completeness and accuracy of the input data and the agreed scope of works. All limitations of liability shall apply for the benefit of the employees, agents and representatives of Engeny to the same extent that they apply for the benefit of Engeny.

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f. If any claim or demand is made by any person against Engeny on the basis of detriment sustained or alleged to have been sustained as a result of reliance upon the report or information therein, Engeny will rely upon this provision as a defence to any such claim or demand.

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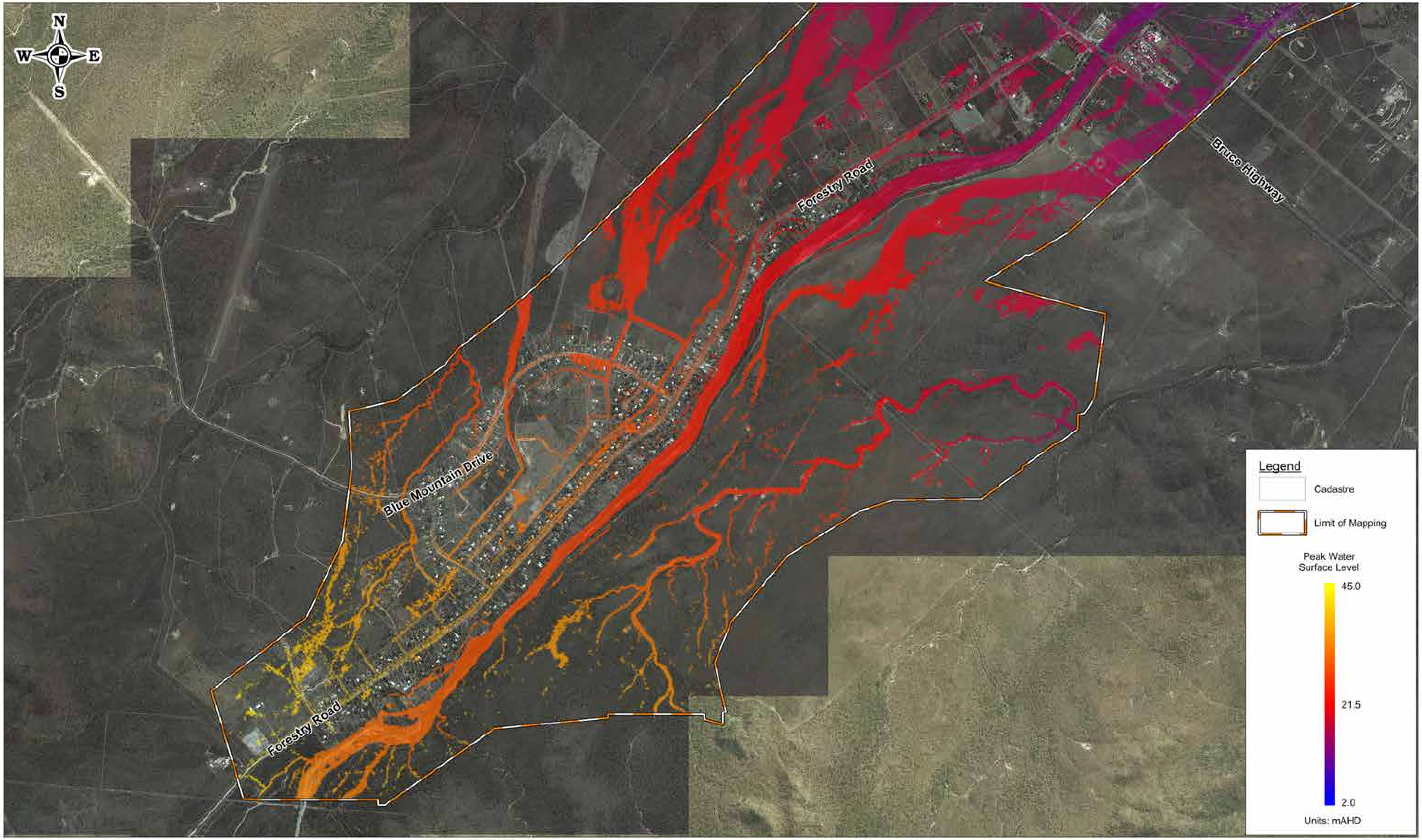
APPENDIX A

Flood Study Result Mapping



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ENGENY WATER MANAGEMENT

Townsville

0 500 1000

Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Bluewater Creek Flood Study

Appendix A1

Bluewater
2 Year ARI Peak Water Surface Level

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 27 May 2013

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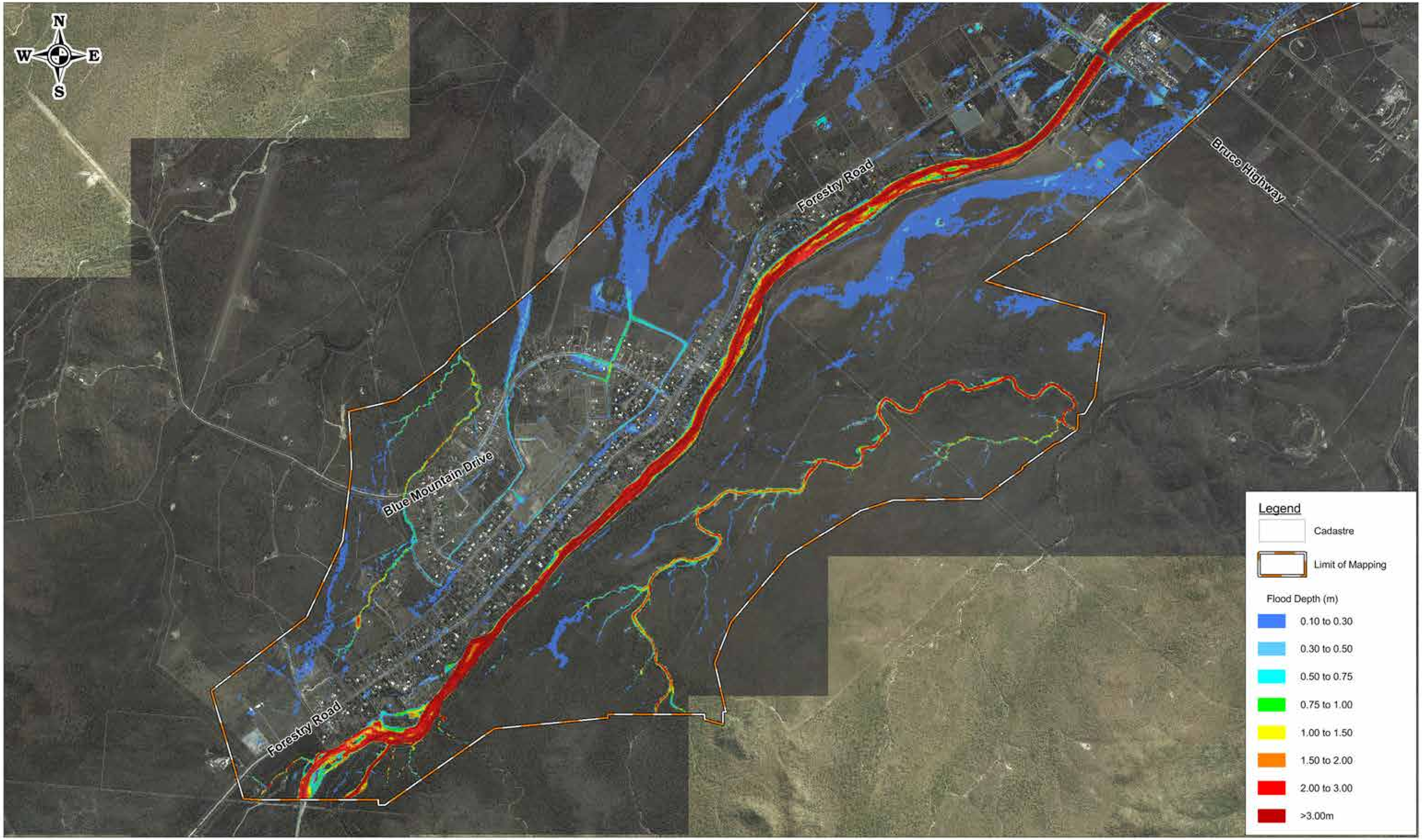

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Townsville

0 500 1000

Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Bluewater Creek Flood Study

Appendix A2

Bluewater
2 Year ARI Peak Flood Depth

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 27 May 2013

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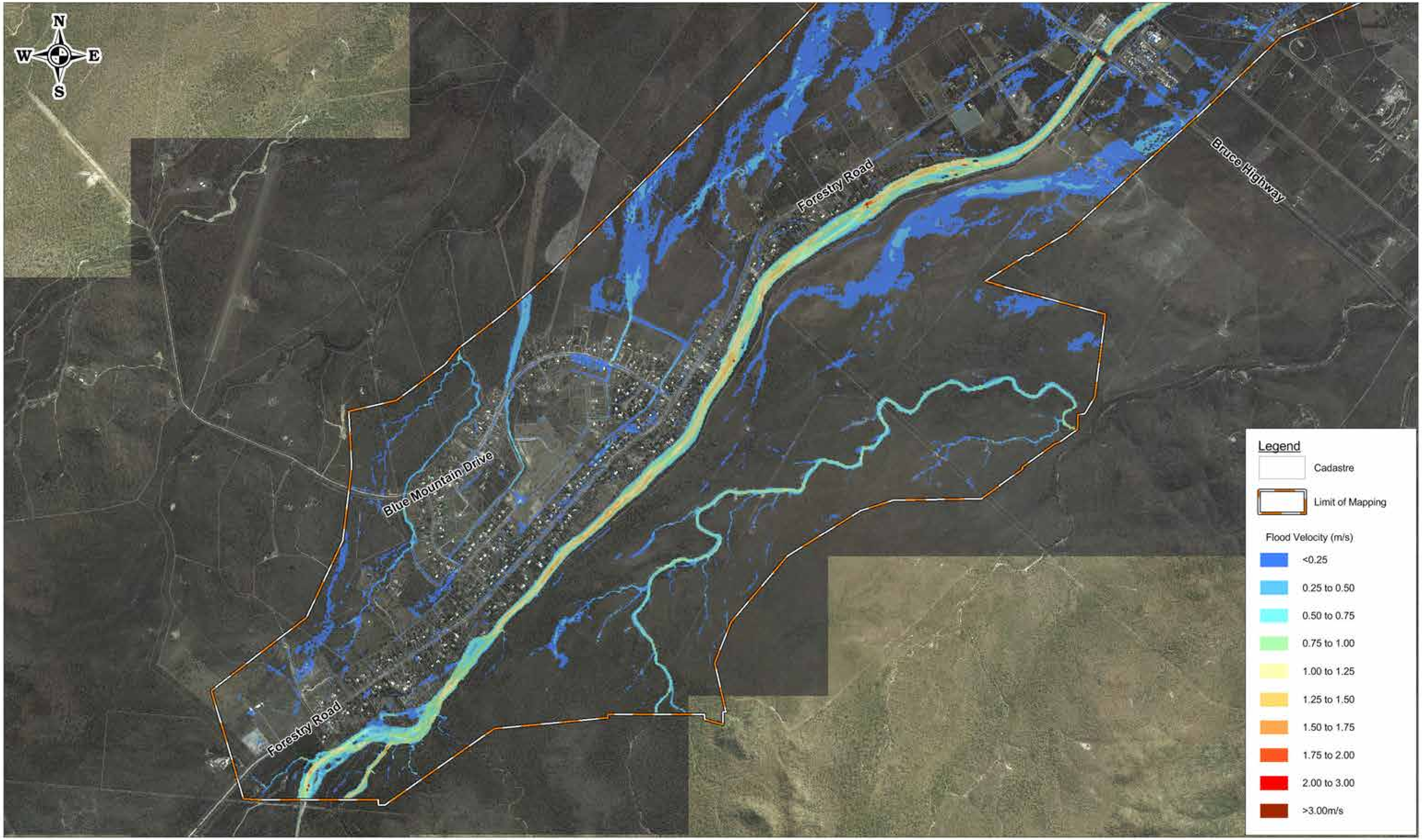

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Townsville

0 500 1000

Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Bluewater Creek Flood Study

Appendix A3

Bluewater
2 Year ARI Peak Flood Velocity

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 27 May 2013

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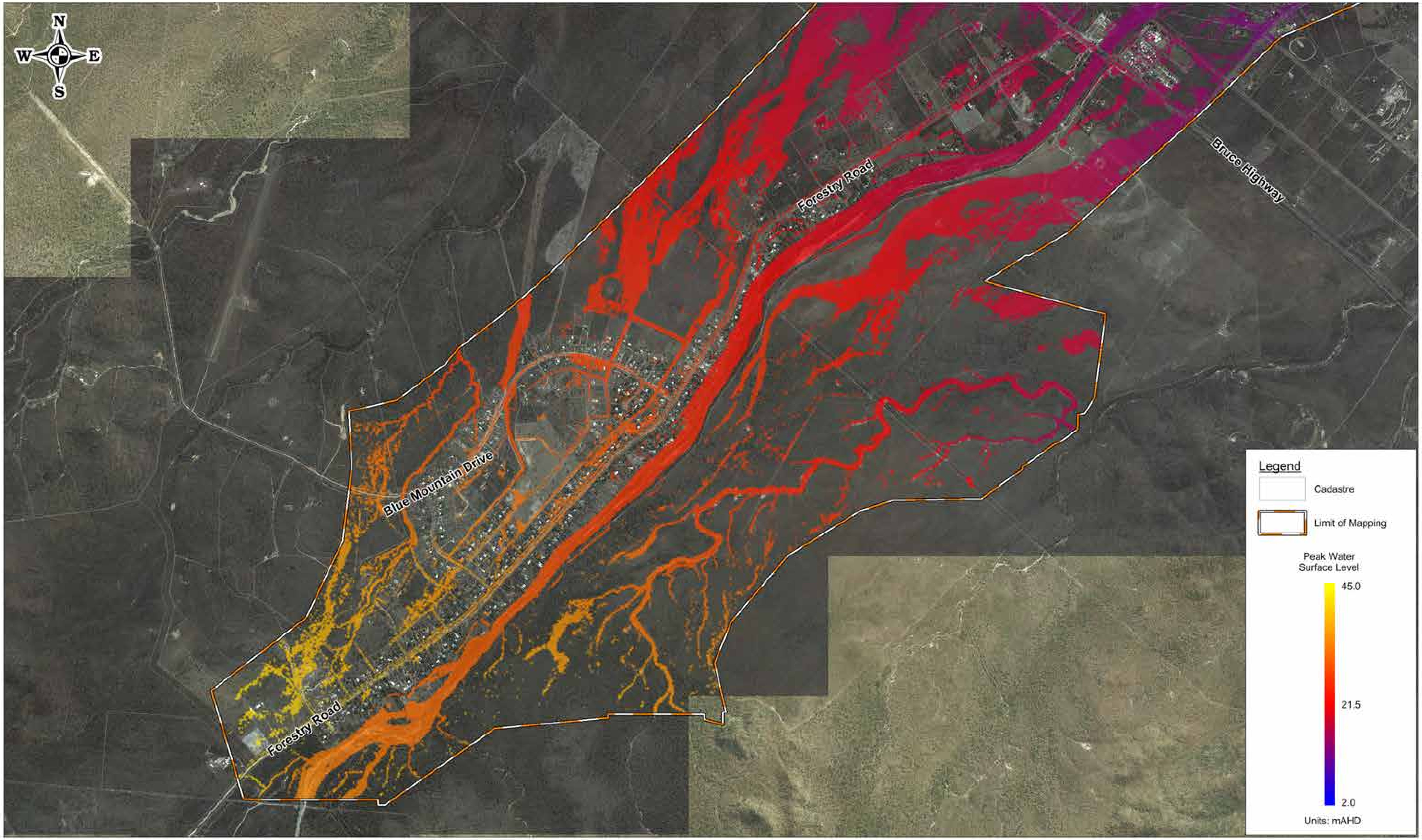

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ENGENY WATER MANAGEMENT

Townsville

0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Bluewater Creek Flood Study

Appendix A4

Bluewater
5 Year ARI Peak Water Surface Level

Job Number: M9300_001
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Drawn: JNA
Date: 27 May 2013

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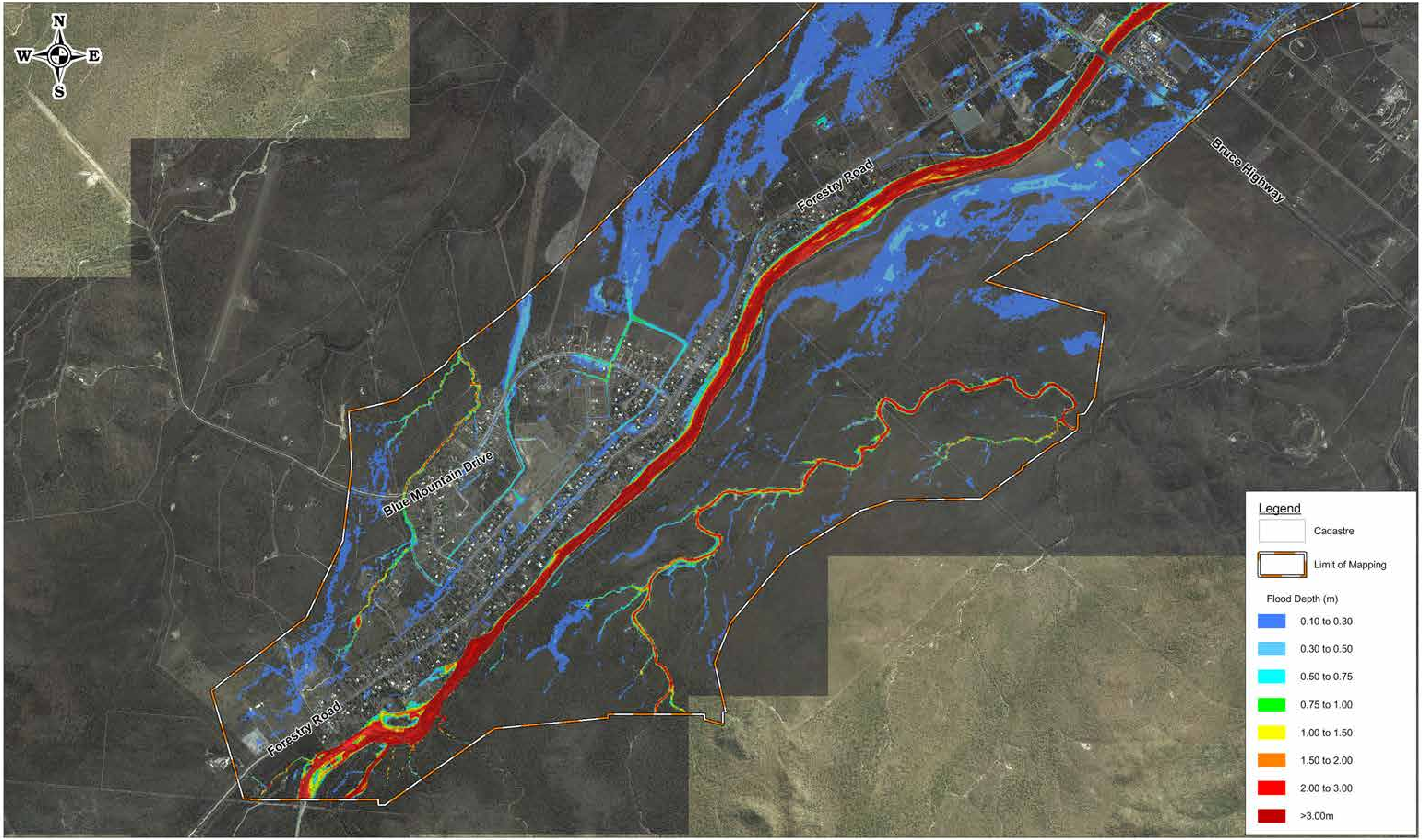

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ENGENY WATER MANAGEMENT

Townsville

0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Bluewater Creek Flood Study

Appendix A5

Bluewater
5 Year ARI Peak Flood Depth

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 27 May 2013

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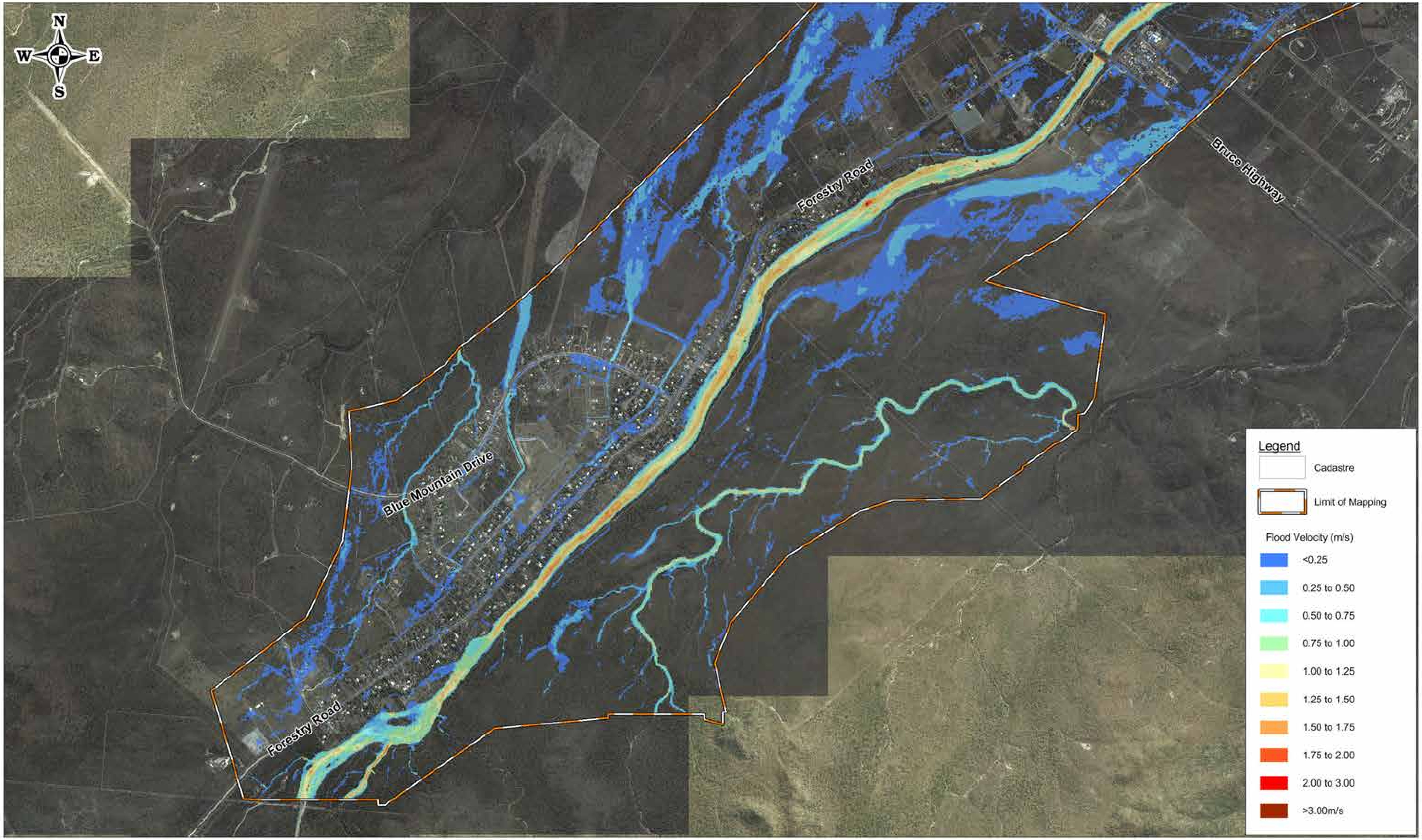

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Townsville

0 500 1000
Scale in Meters (1:25,000 @ A3)

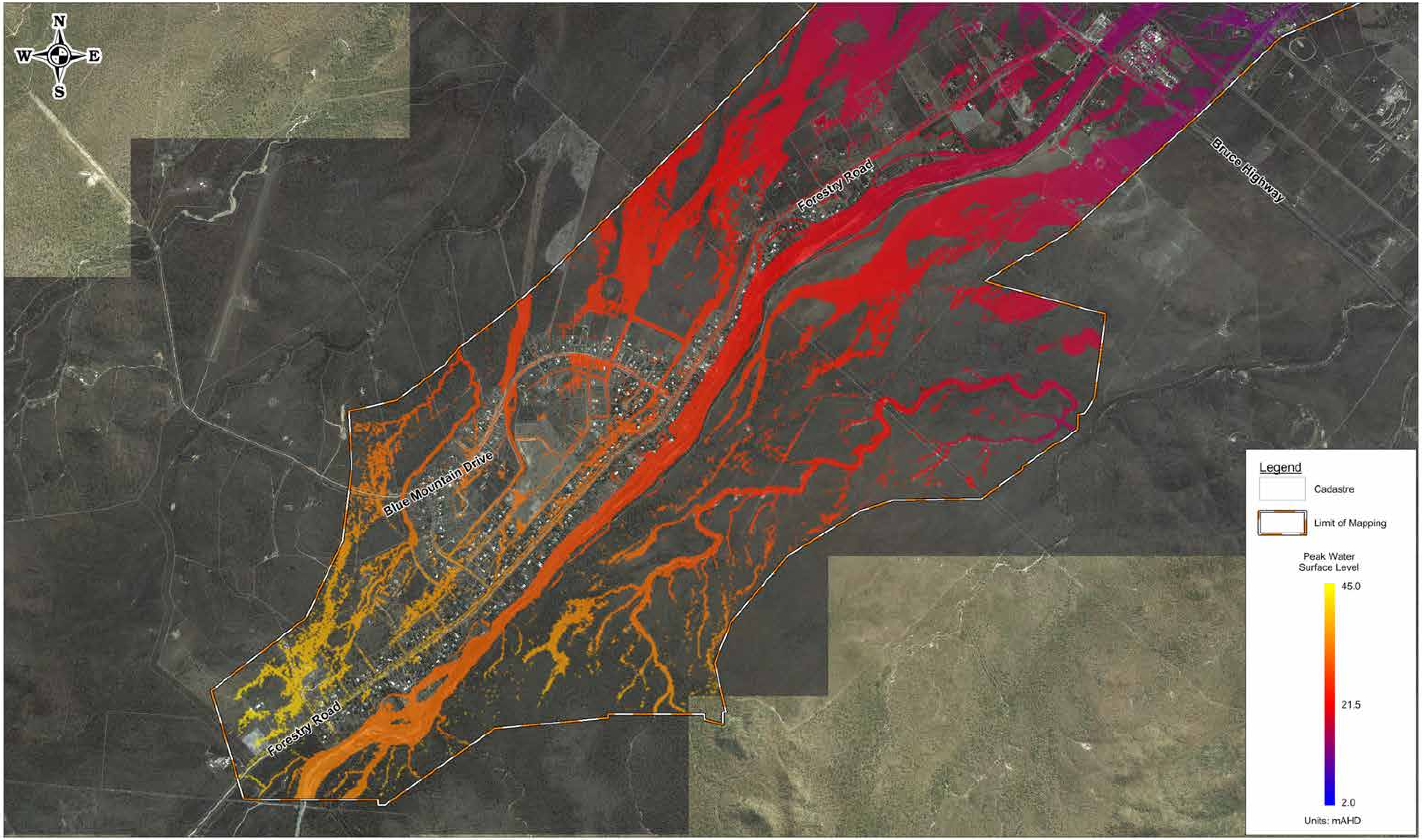
Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Bluewater Creek Flood Study

Appendix A6

Bluewater
5 Year ARI Peak Flood Velocity

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 27 May 2013



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Townsville

0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

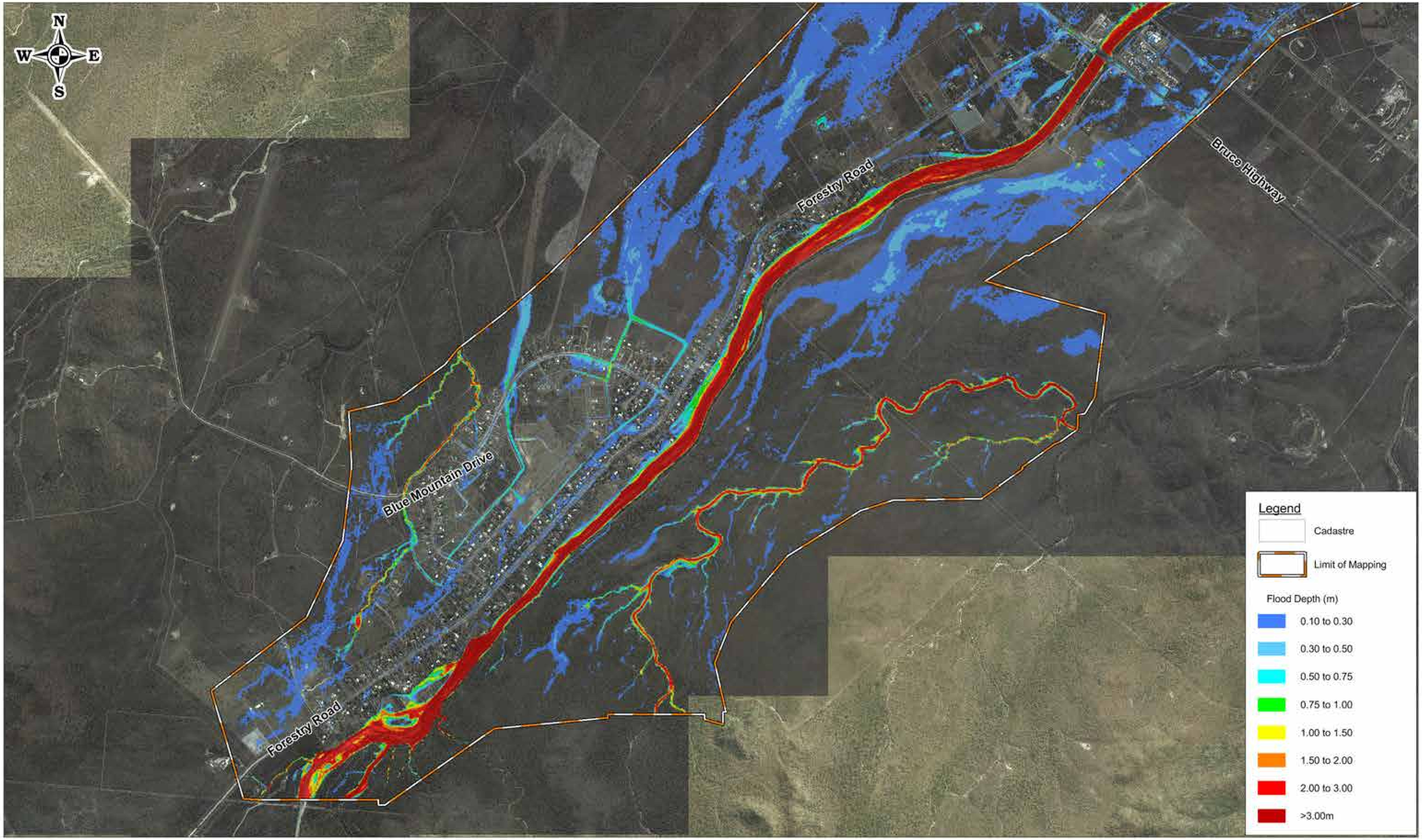
Bluewater Creek Flood Study

Appendix A7

Bluewater
10 Year ARI Peak Water Surface Level

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 27 May 2013

M:\Projects\M9300_Townsville City Council\M9300_001_Bluewater Creek Flood Study\Design\MapInfo\Figures



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Townsville

0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

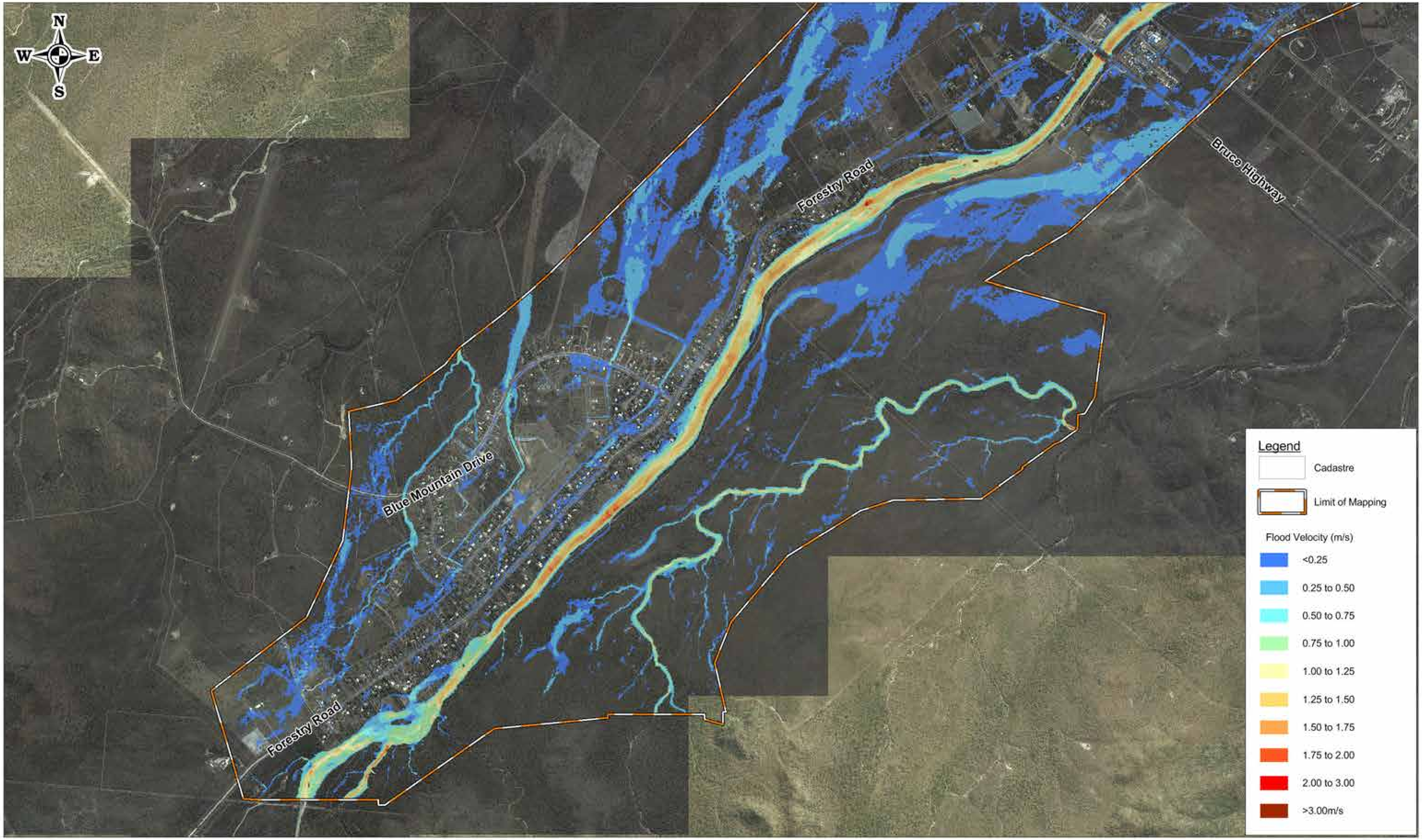
Bluewater Creek Flood Study

Appendix A8

Bluewater
10 Year ARI Peak Flood Depth

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 27 May 2013

M:\Projects\M9300_Townsville City Council\M9300_001_Bluewater Creek Flood Study\Design\MapInfo\Figures



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0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Bluewater Creek Flood Study

Appendix A9

Bluewater
10 Year ARI Peak Flood Velocity

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 27 May 2013

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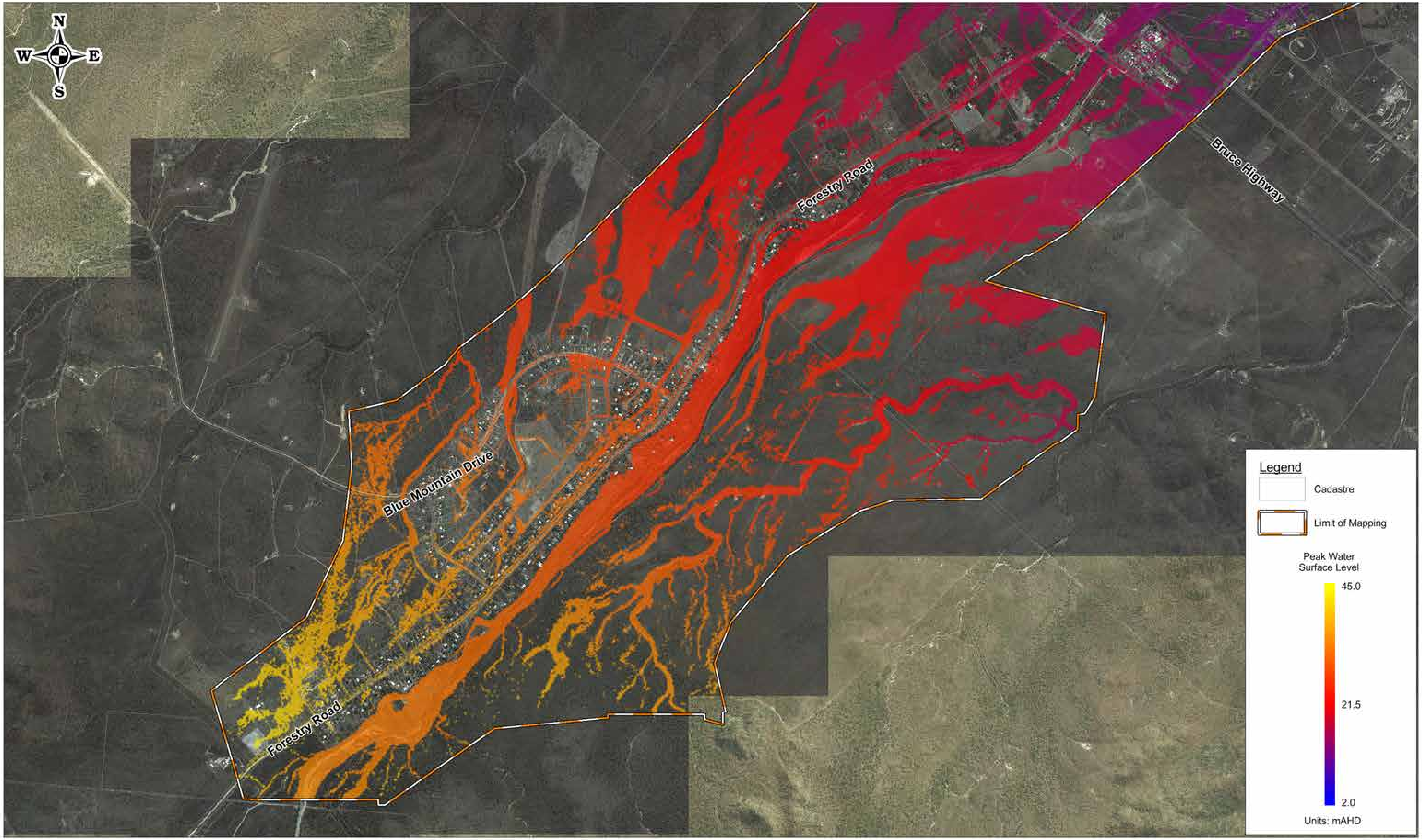

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0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Bluewater Creek Flood Study

Appendix A10

Bluewater
20 Year ARI Peak Water Surface Level

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 27 May 2013

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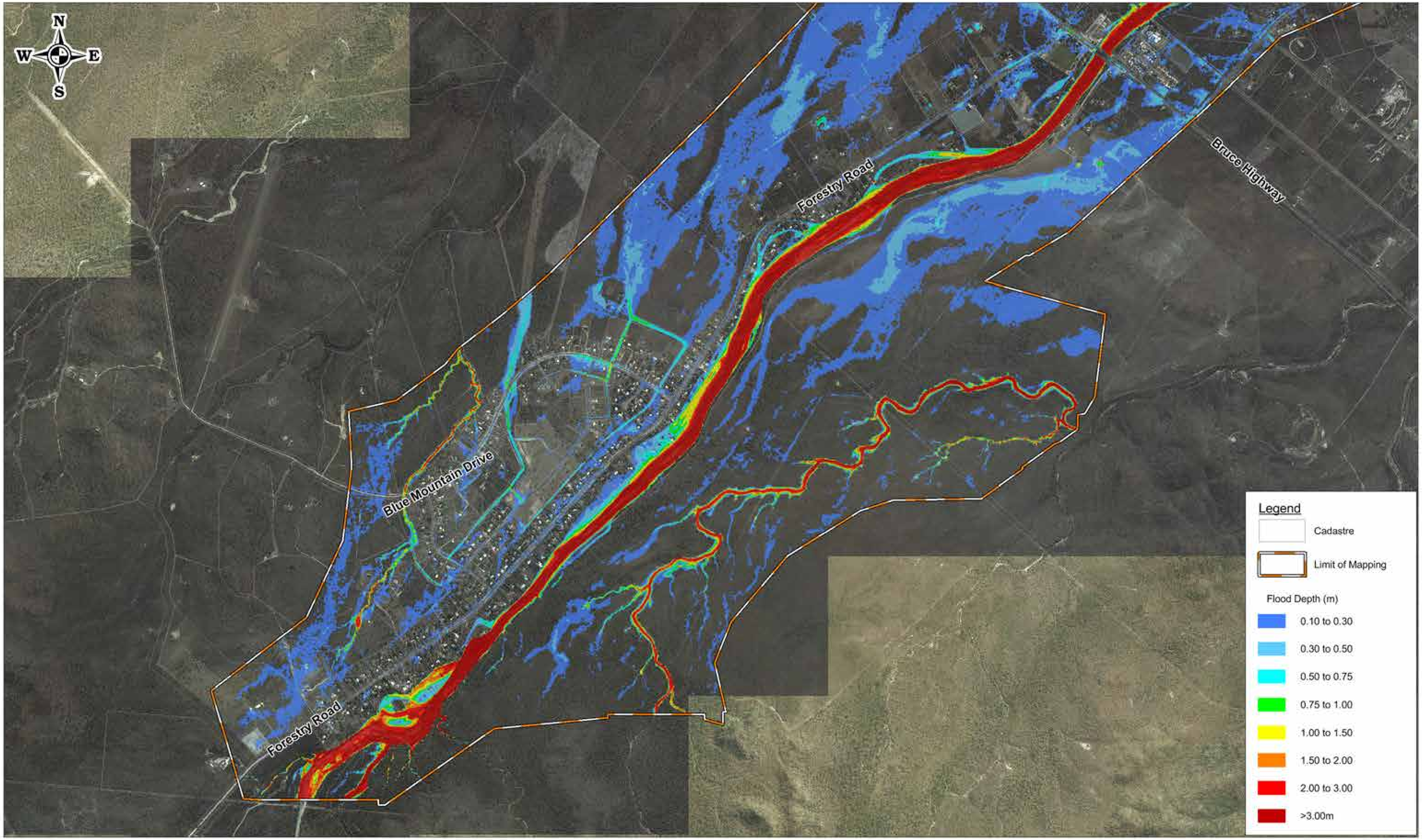

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0 500 1000
Scale in Meters (1:25,000 @ A3)

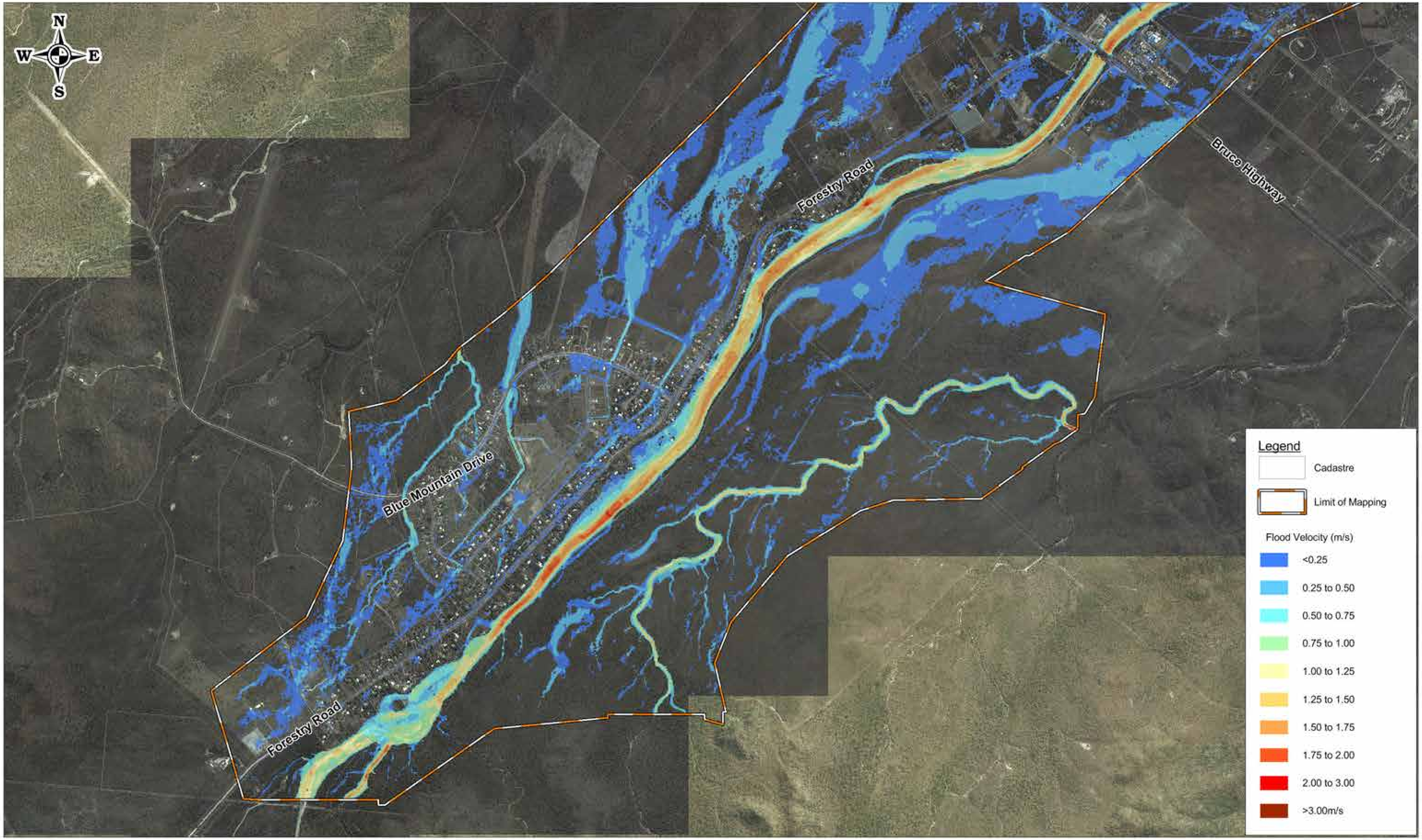
Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Bluewater Creek Flood Study

Appendix A11

Bluewater
20 Year ARI Peak Flood Depth

Job Number: M9300_001
Revision: A
Drawn: JNA
Date: 27 May 2013



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0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

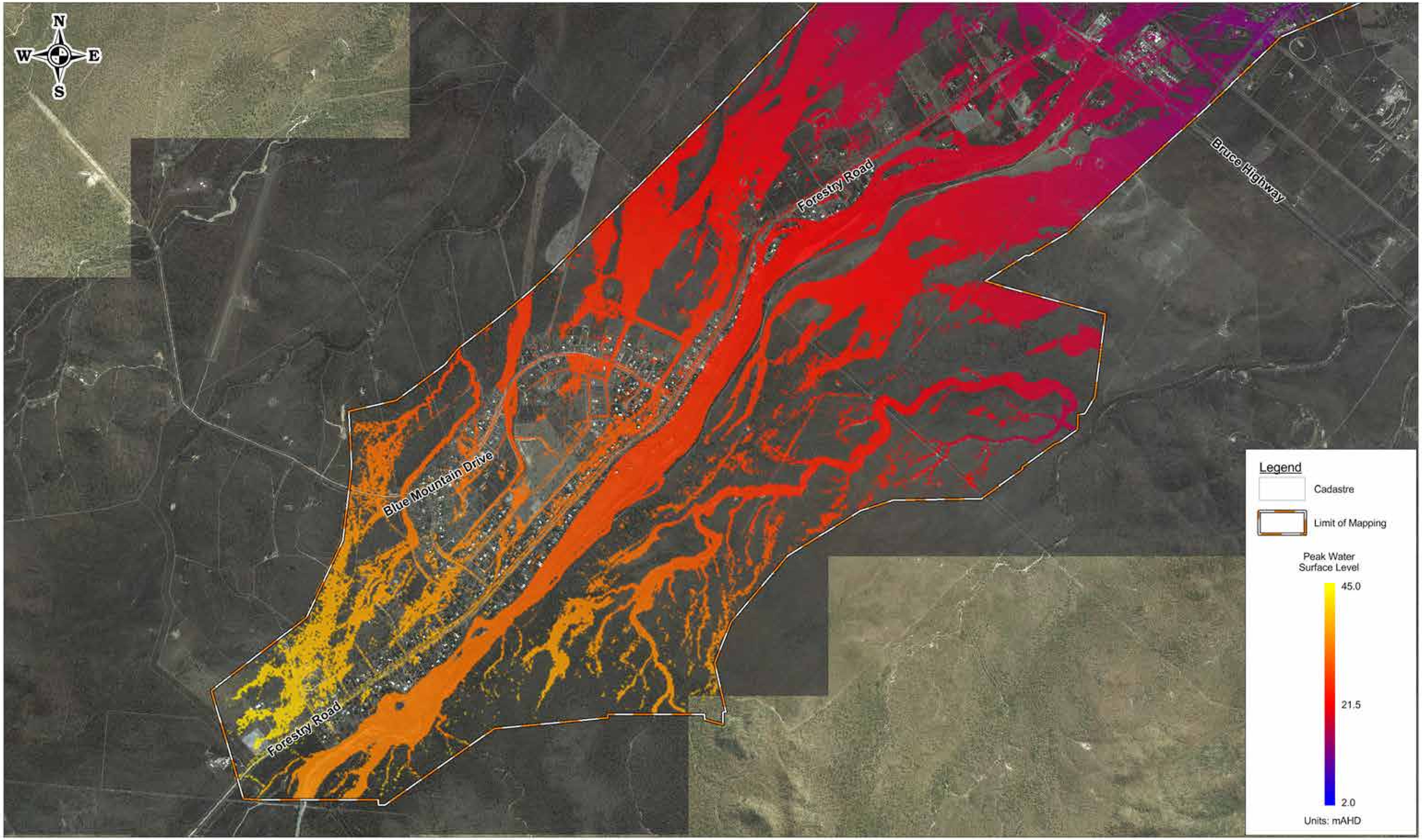
Bluewater Creek Flood Study

Appendix A12

Bluewater
20 Year ARI Peak Flood Velocity

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 27 May 2013

M:\Projects\M9300_Townsville City Council\M9300_001_Bluewater Creek Flood Study\Design\MapInfo\Figures



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0 500 1000

Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

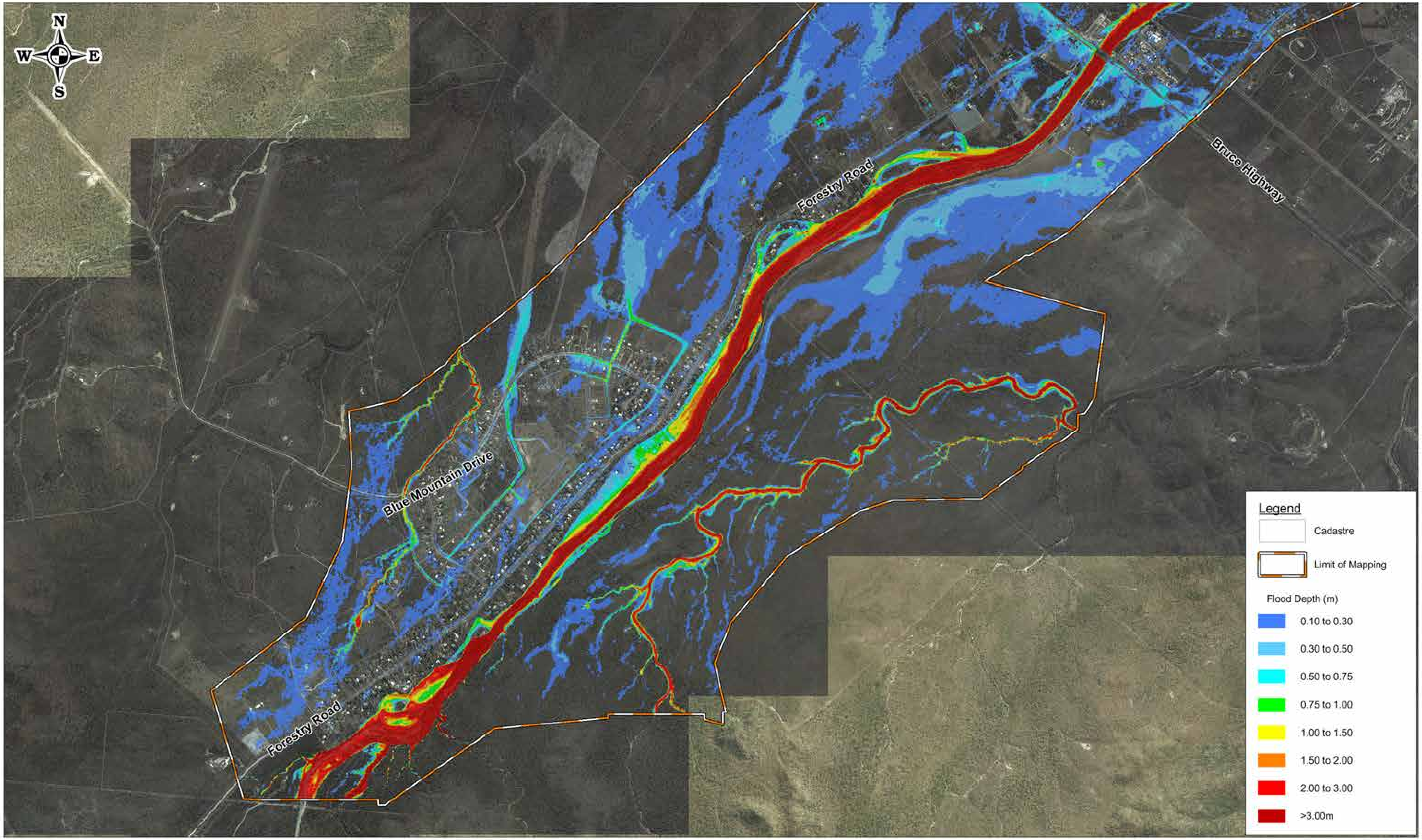
Bluewater Creek Flood Study

Appendix A13

Bluewater
50 Year ARI Peak Water Surface Level

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 17 May 2013

M:\Projects\M9300_Townsville City Council\M9300_001_Bluewater Creek Flood Study\Design\MapInfo\Figures



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Townsville

0 500 1000
Scale in Meters (1:25,000 @ A3)

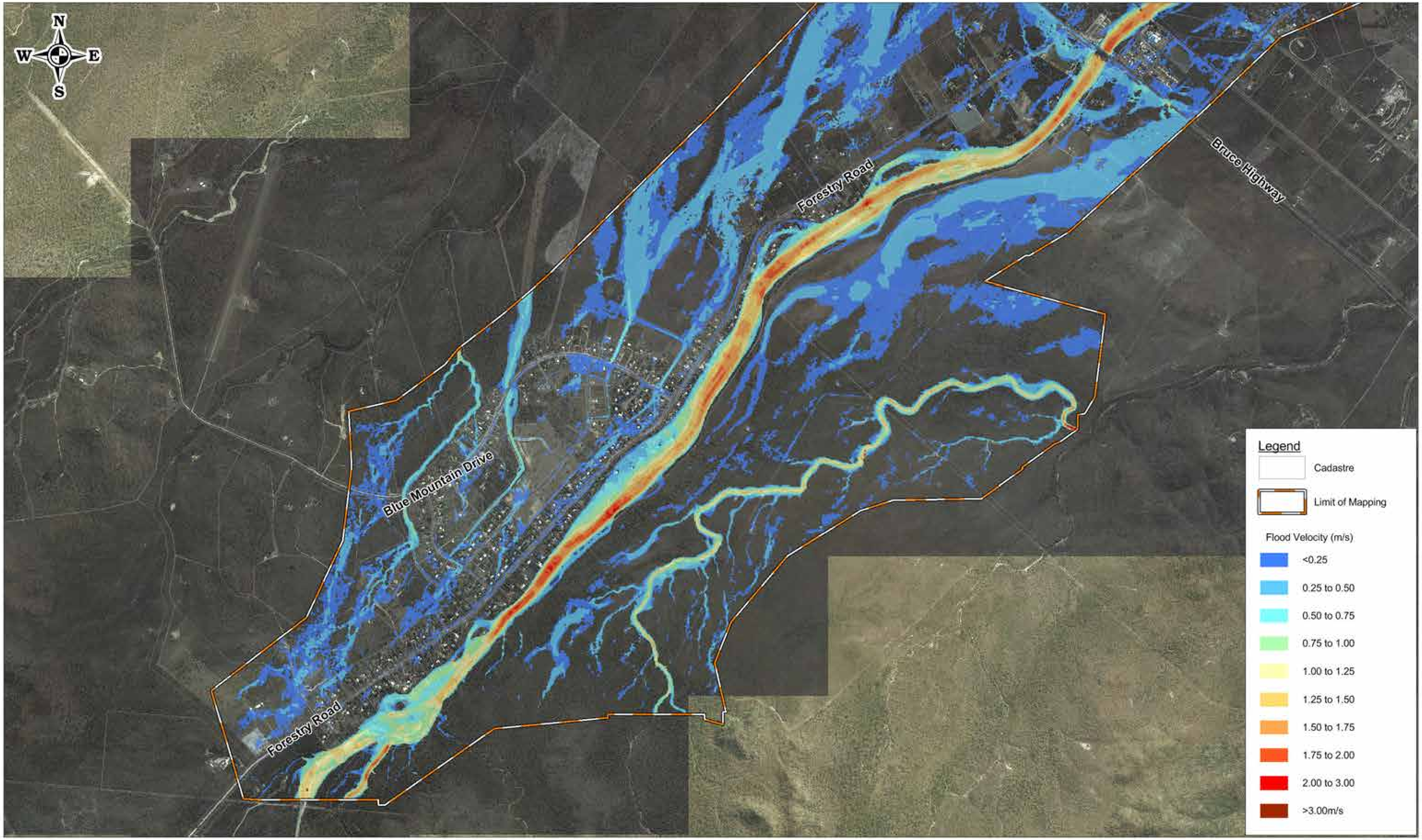
Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Bluewater Creek Flood Study

Appendix A14

Bluewater
50 Year ARI Peak Flood Depth

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 17 May 2013



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0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Bluewater Creek Flood Study

Appendix A15

Bluewater
50 Year ARI Peak Flood Velocity

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 17 May 2013

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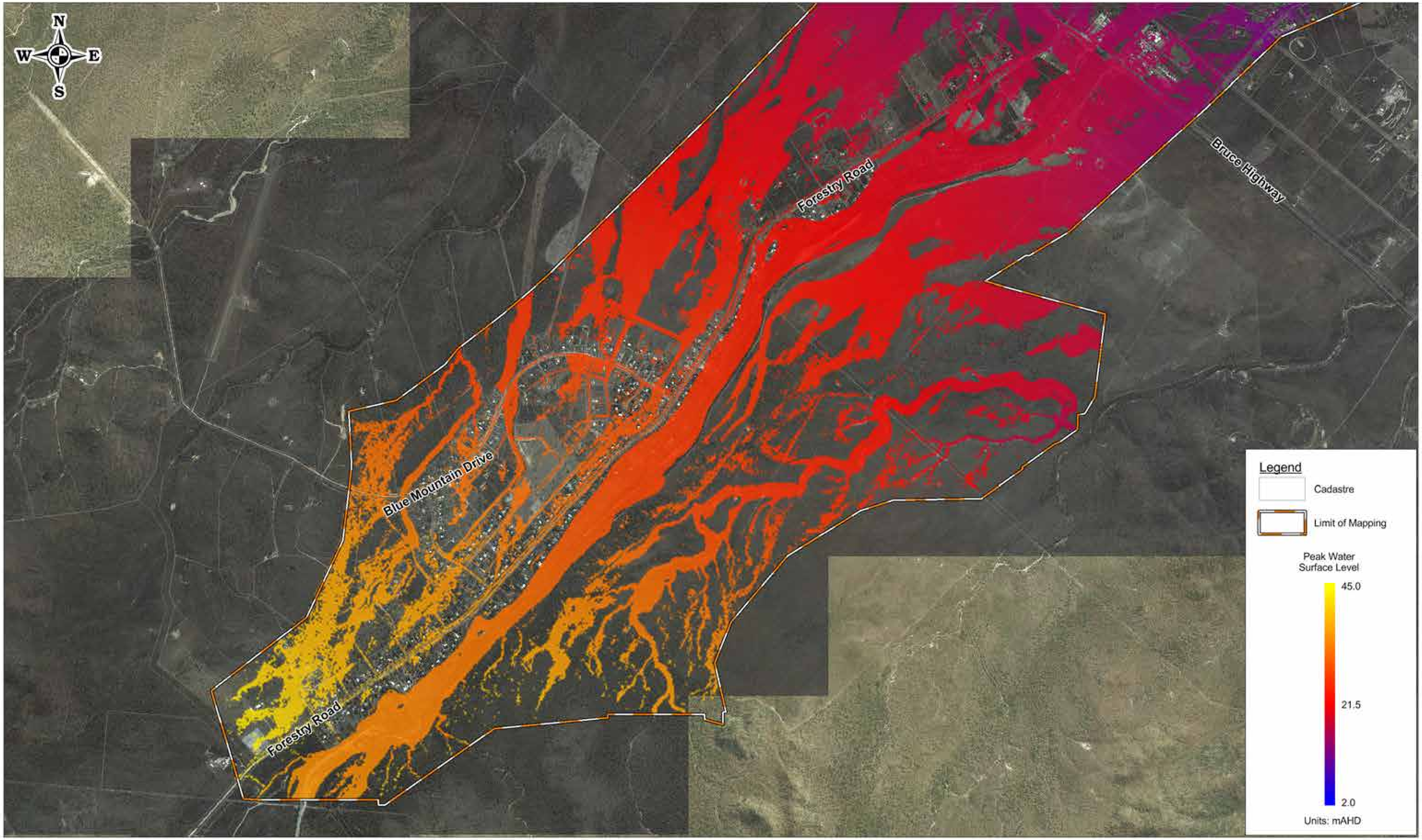

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0 500 1000

Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Bluewater Creek Flood Study

Appendix A16

Bluewater
100 Year ARI Peak Water Surface Level

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 17 May 2013

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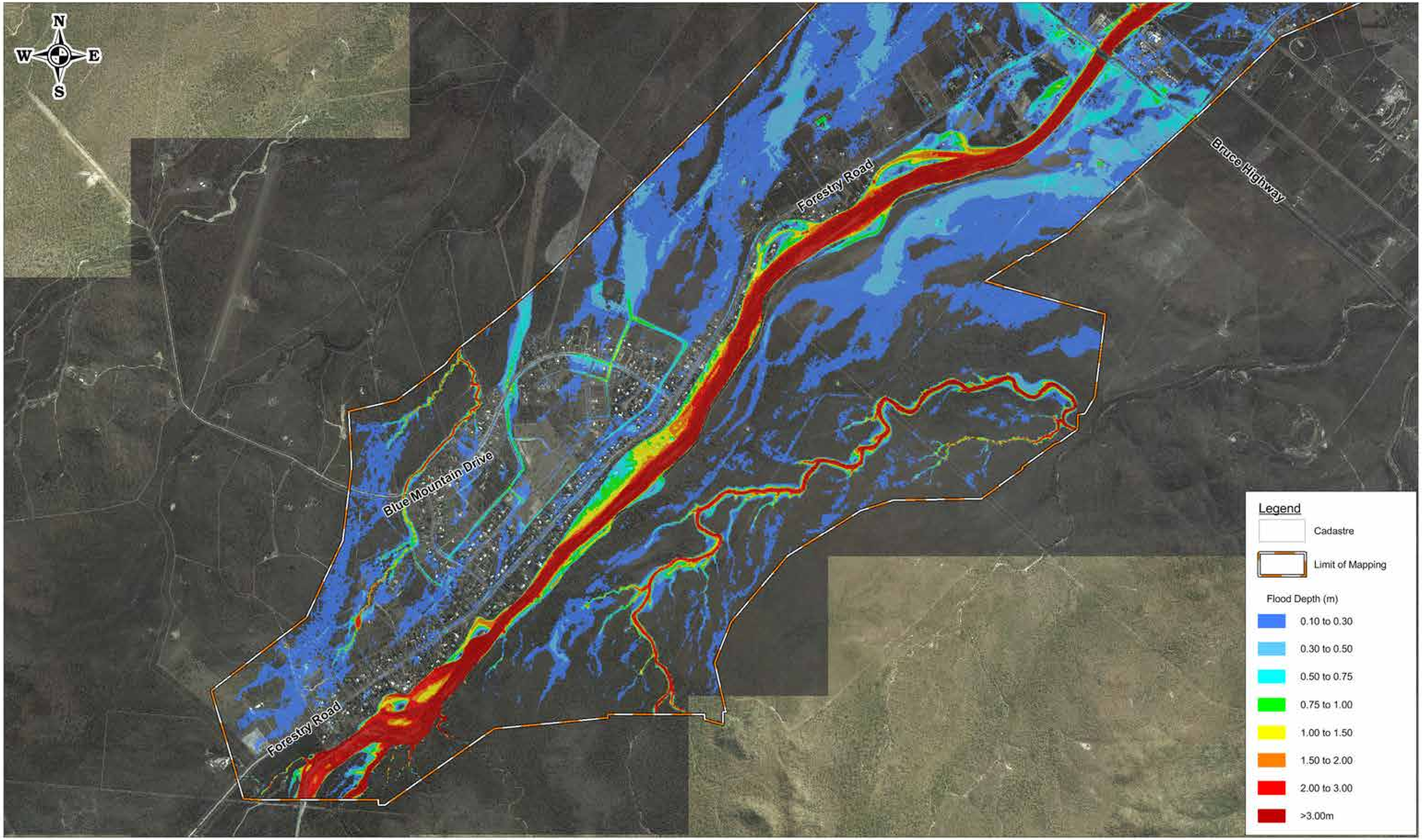

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0 500 1000
Scale in Meters (1:25,000 @ A3)

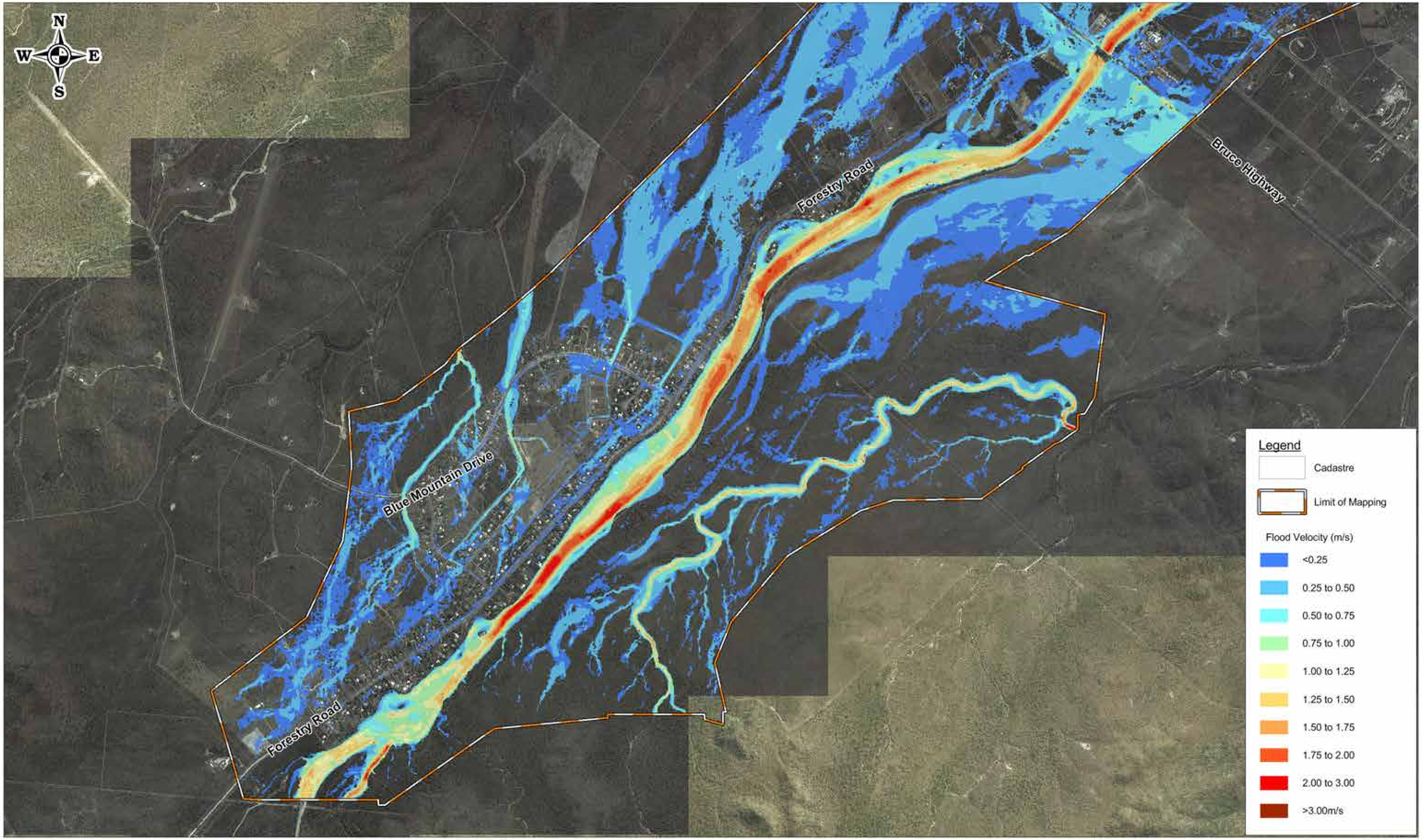
Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Bluewater Creek Flood Study

Appendix A17

Bluewater
100 Year ARI Peak Flood Depth

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 17 May 2013



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0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

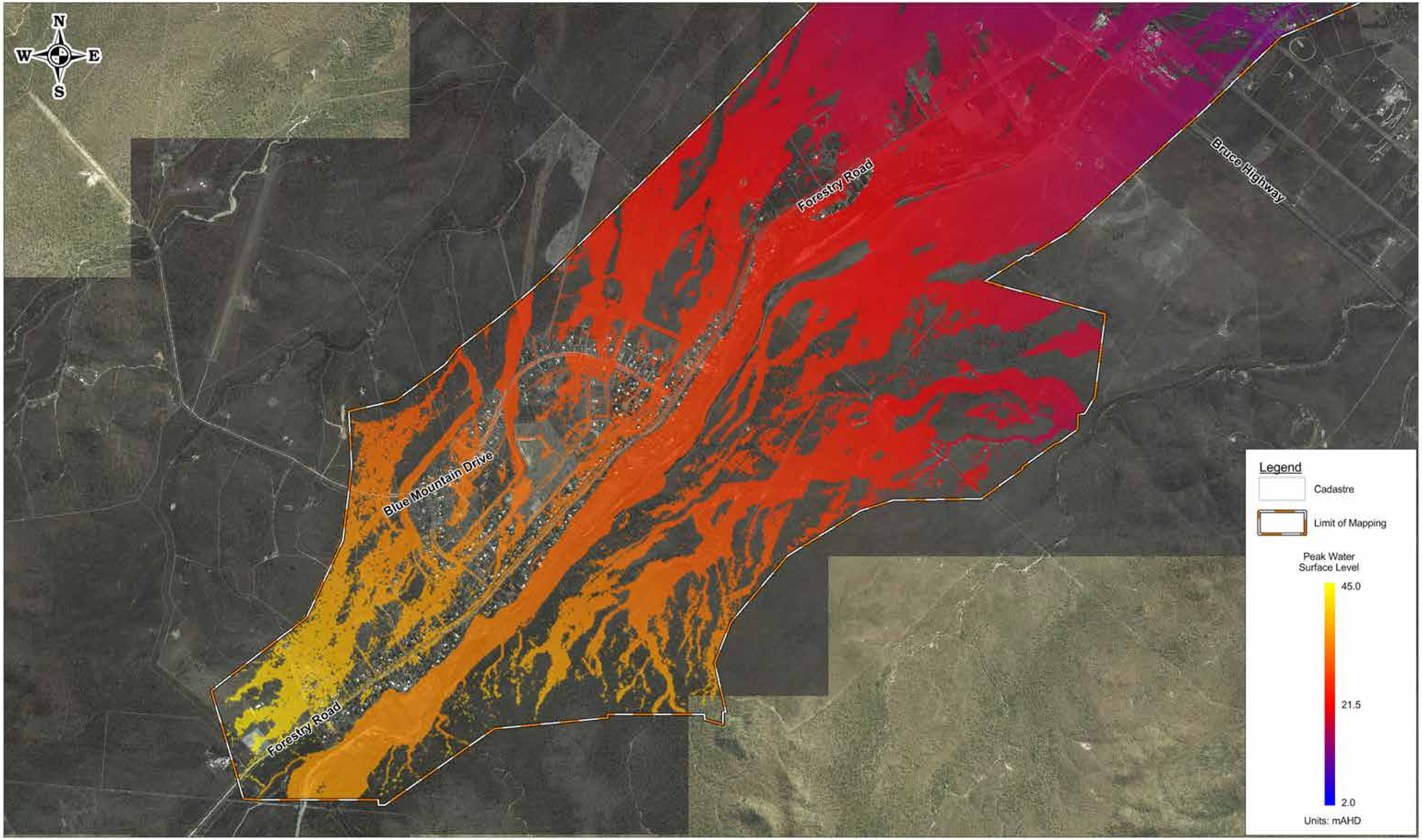
Bluewater Creek Flood Study

Appendix A18

Bluewater
100 Year ARI Peak Flood Velocity

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 17 May 2013

M:\Projects\M9300_Townsville City Council\M9300_001_Bluewater Creek Flood Study\Design\MapInfo\Figures



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0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Bluewater Creek Flood Study

Appendix A19

Bluewater
500 Year ARI Peak Water Surface Level

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 27 May 2013

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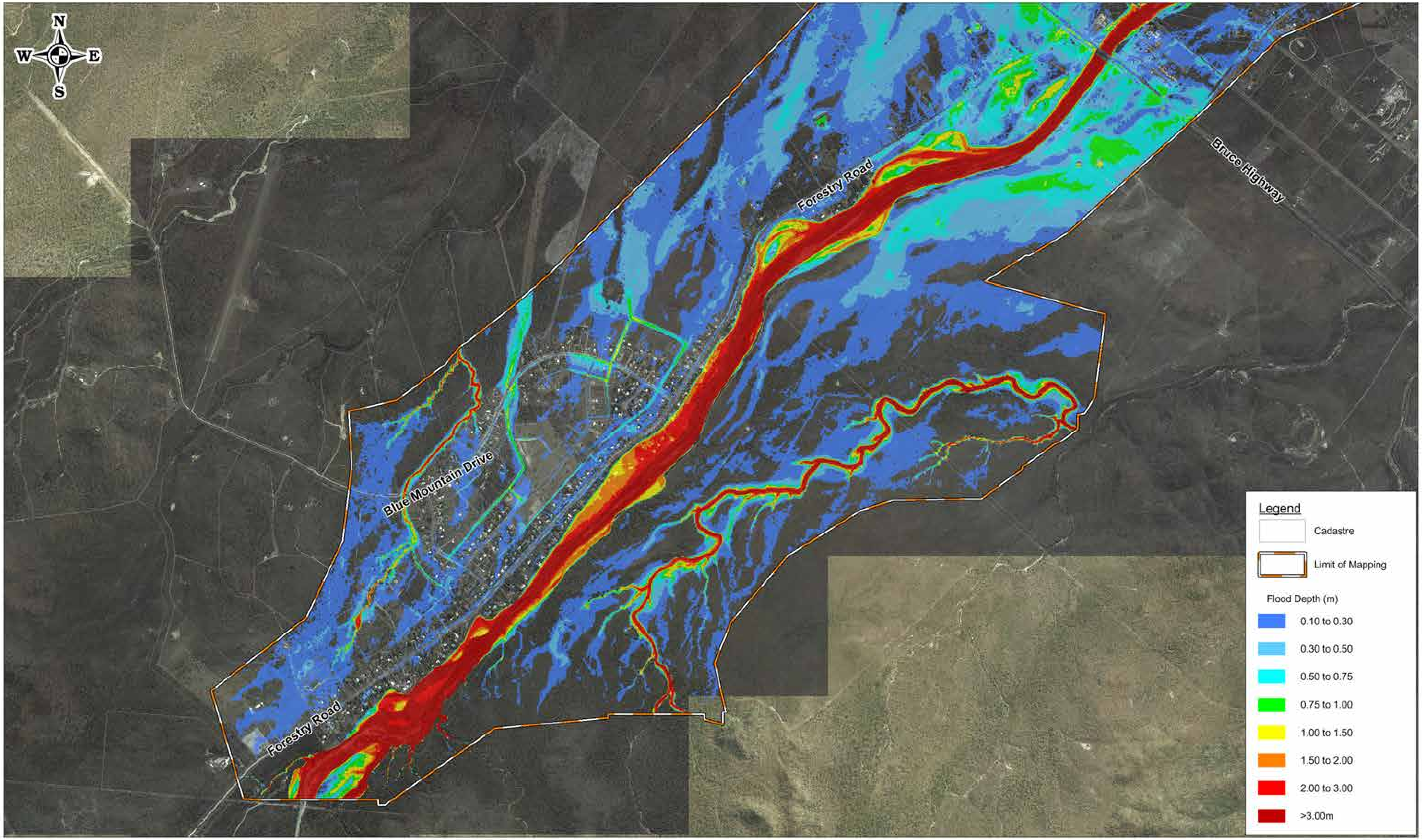

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0 500 1000
Scale in Meters (1:25,000 @ A3)

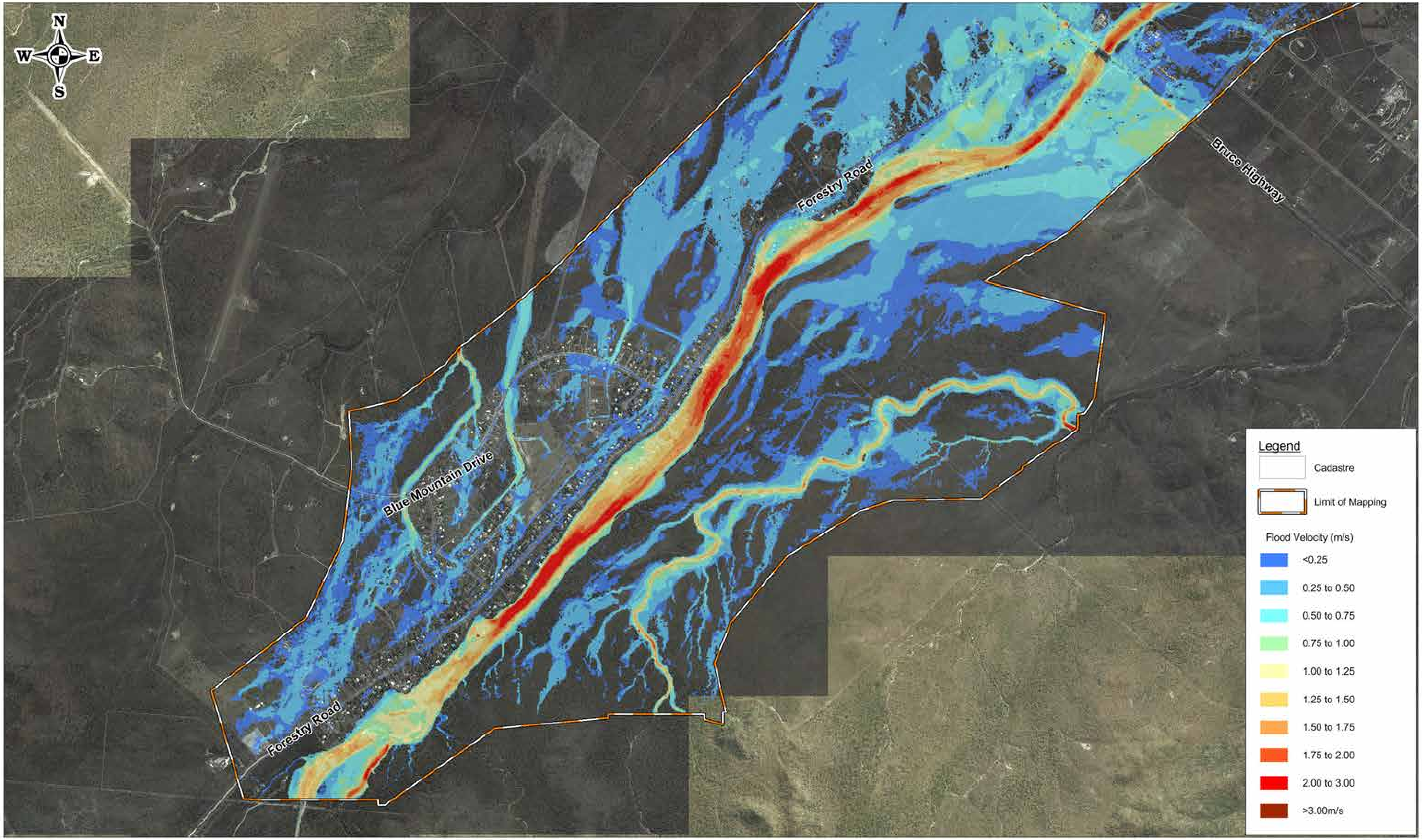
Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Bluewater Creek Flood Study

Appendix A20

Bluewater
500 Year ARI Peak Flood Depth

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 27 May 2013



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0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

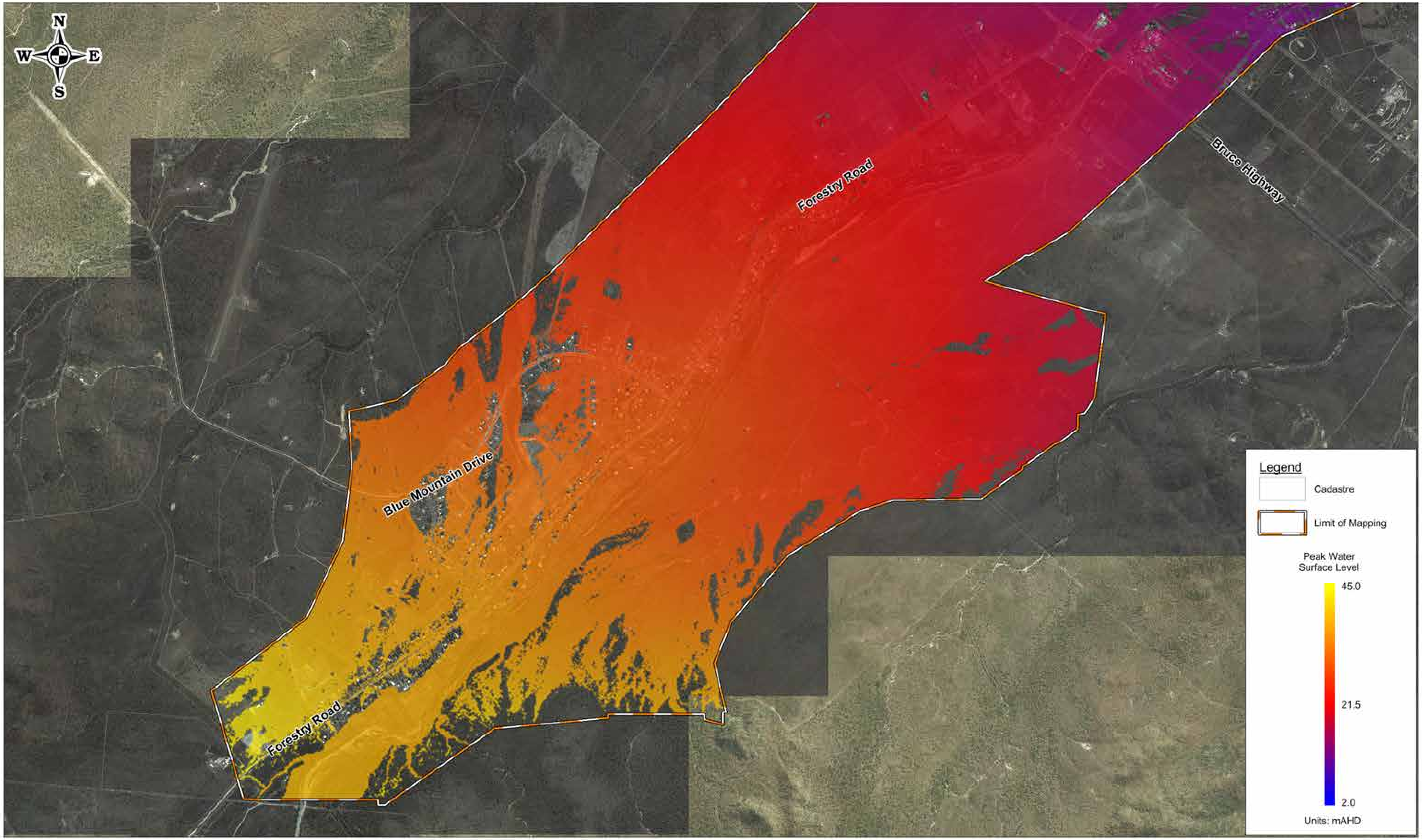
Bluewater Creek Flood Study

Appendix A21

Bluewater
500 Year ARI Peak Flood Velocity

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 27 May 2013

M:\Projects\M9300_Townsville City Council\M9300_001_Bluewater Creek Flood Study\Design\MapInfo\Figures



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Townsville

0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994, (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

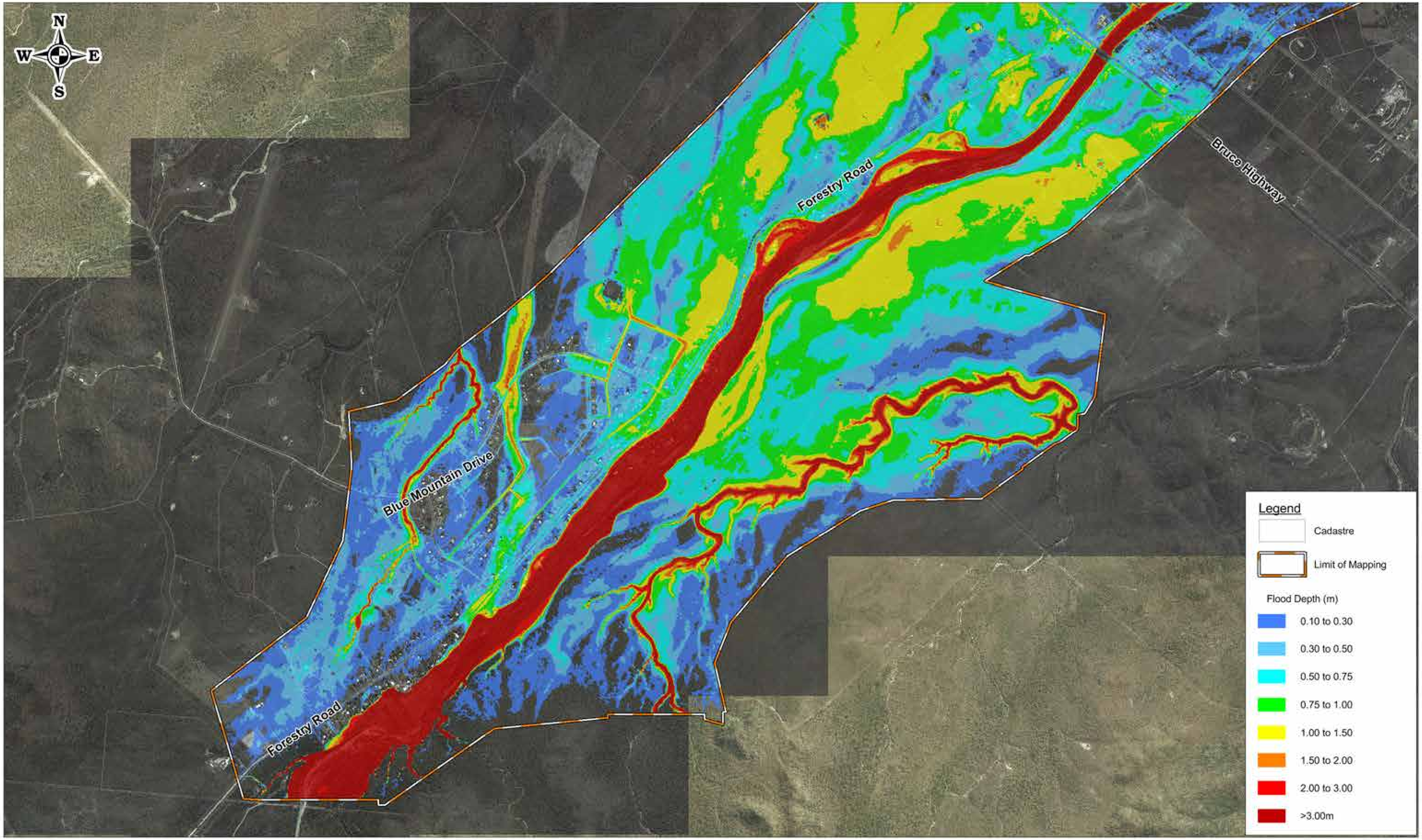
Bluewater Creek Flood Study

Appendix A22

Bluewater
PMF Peak Water Surface Level

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 17 May 2013

M:\Projects\M9300_Townsville City Council\M9300_001_Bluewater Creek Flood Study\Design\MapInfo\Figures



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F: 07 3236 2399
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0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

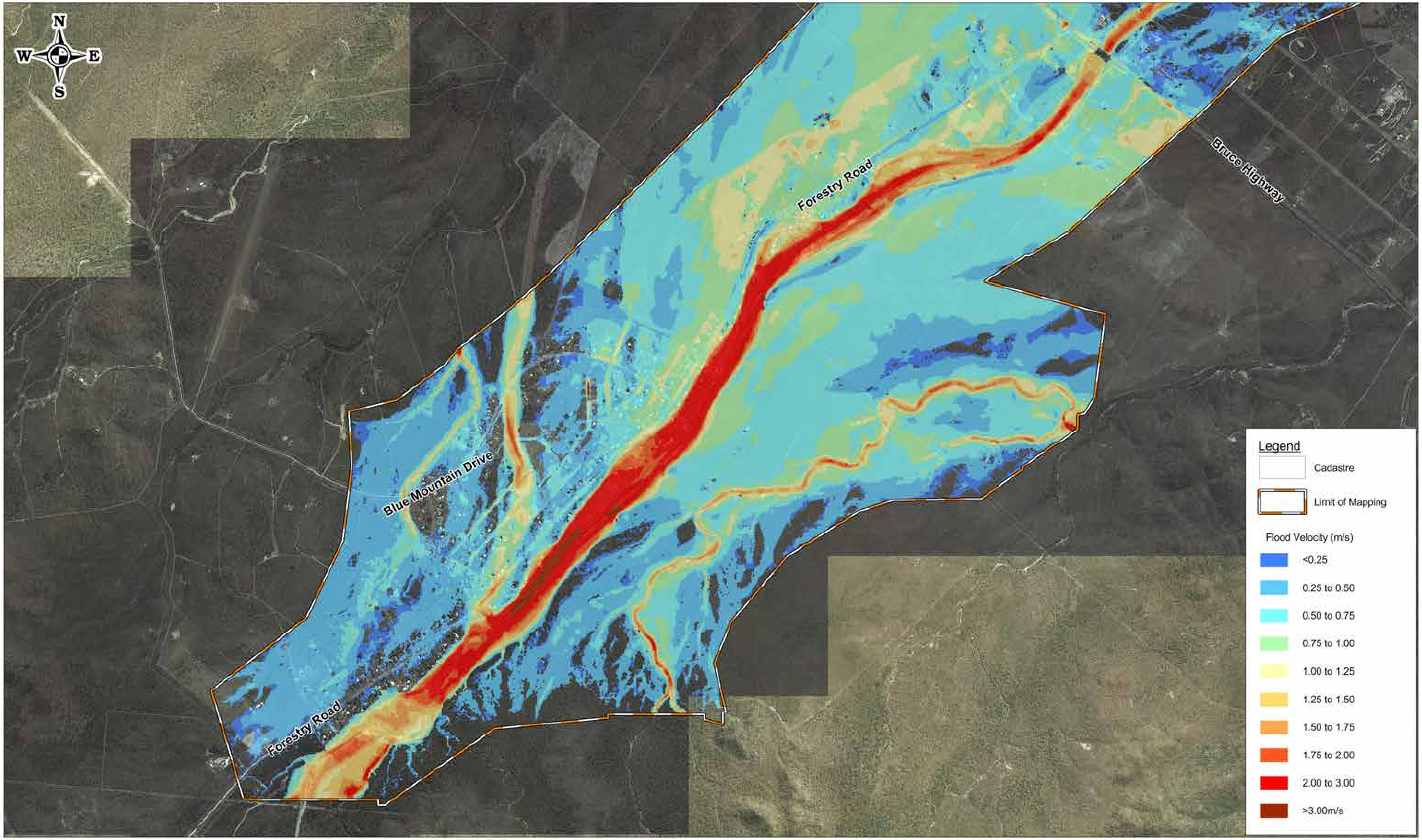
Bluewater Creek Flood Study

Appendix A23

Bluewater
PMF Peak Flood Depth

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 17 May 2013

M:\Projects\M9300_Townsville City Council\M9300_001_Bluewater Creek Flood Study\Design\MapInfo\Figures



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0 500 1000

Scale in Meters (1:25,000 @ A3)

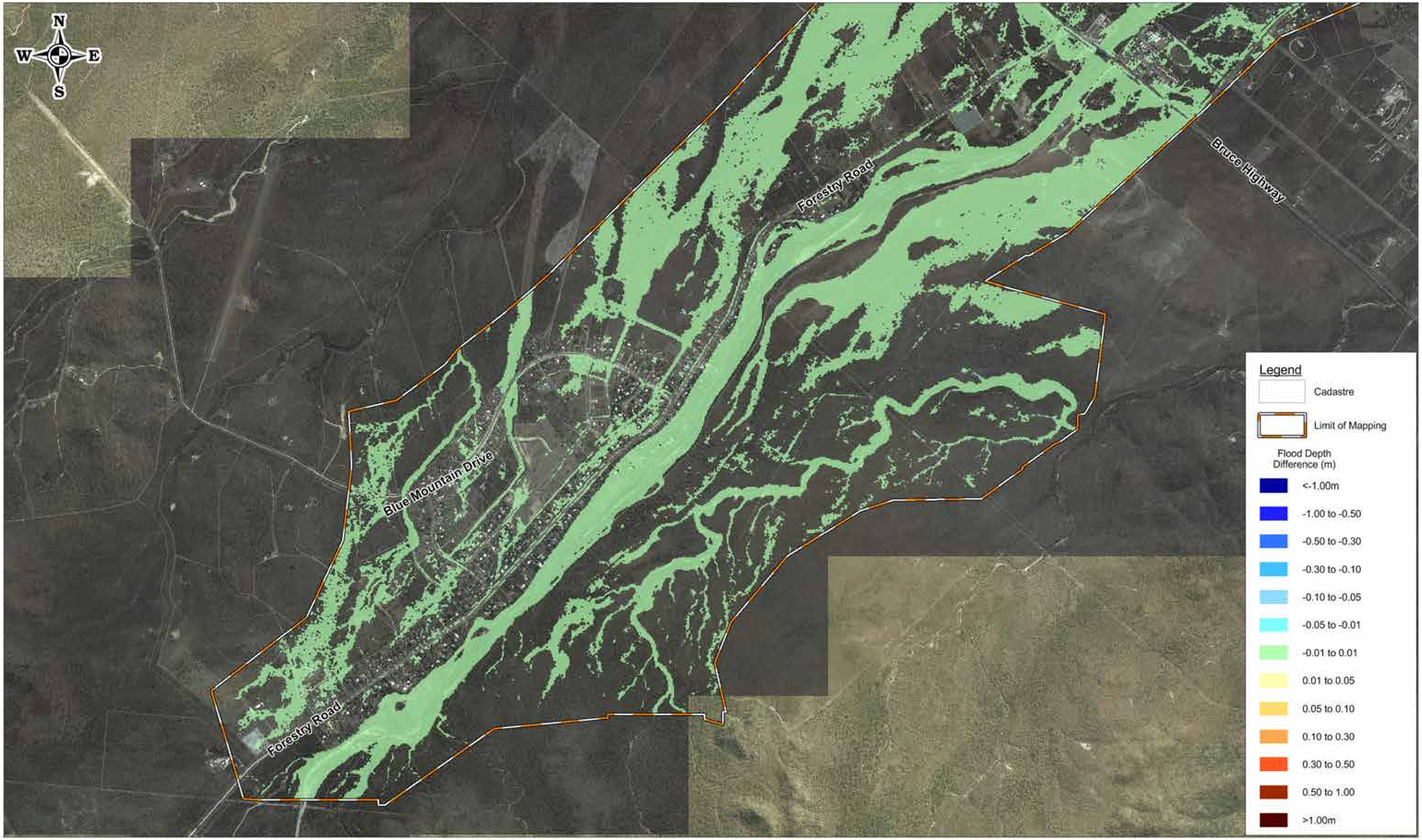
Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Bluewater Creek Flood Study

Appendix A24

Bluewater PMF Peak Flood Velocity

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 17 May 2013



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E: admin@engeny.com.au
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0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994, (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

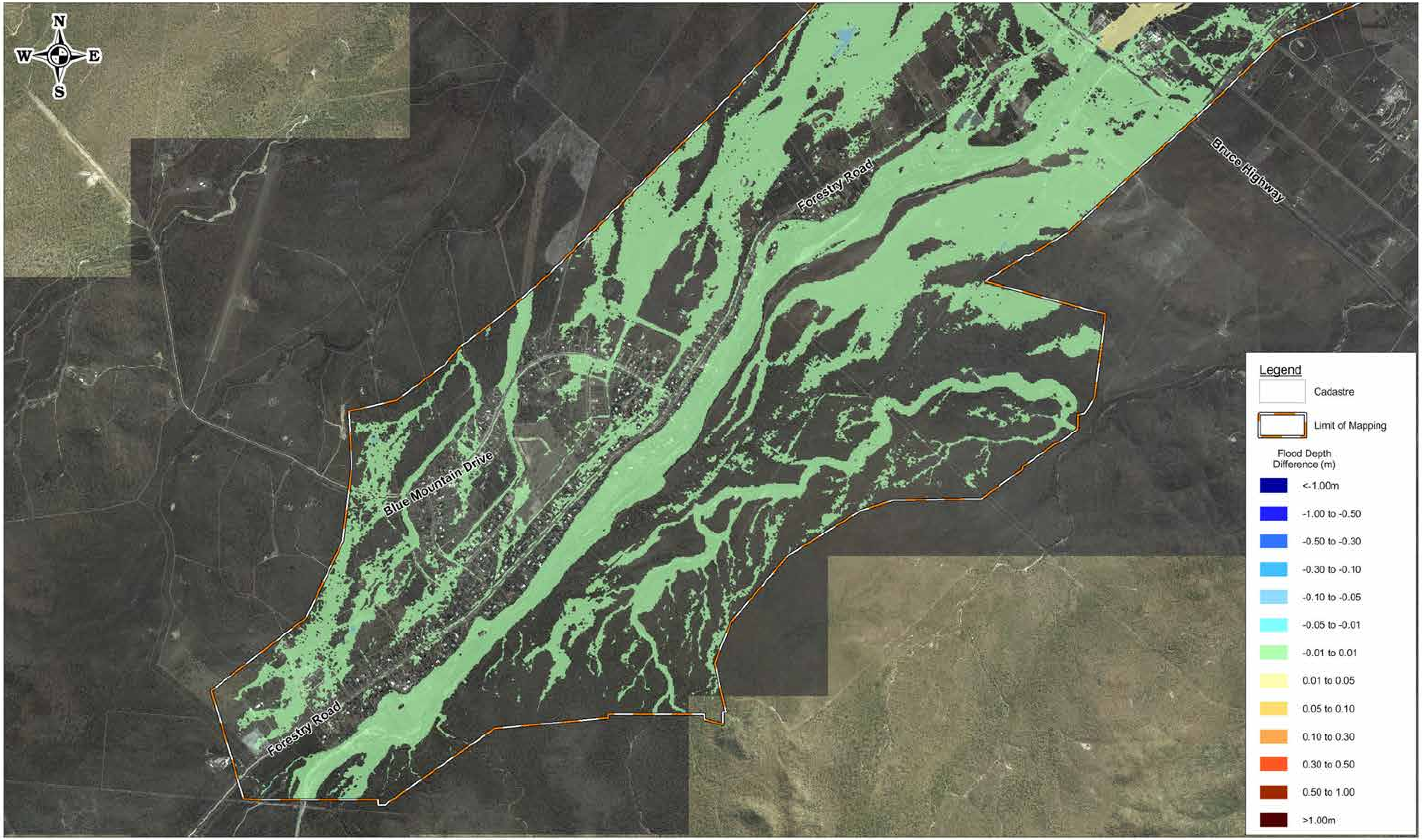
Bluewater Creek Flood Study

Appendix A25

Bluewater
50 Year ARI Highest Astromonical Tide Scenario
Flood Depth Difference

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 17 May 2013

M:\Projects\M9300_Townsville City Council\M9300_001_Bluewater Creek Flood Study\Design\MapInfo\Figures



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Townsville

0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

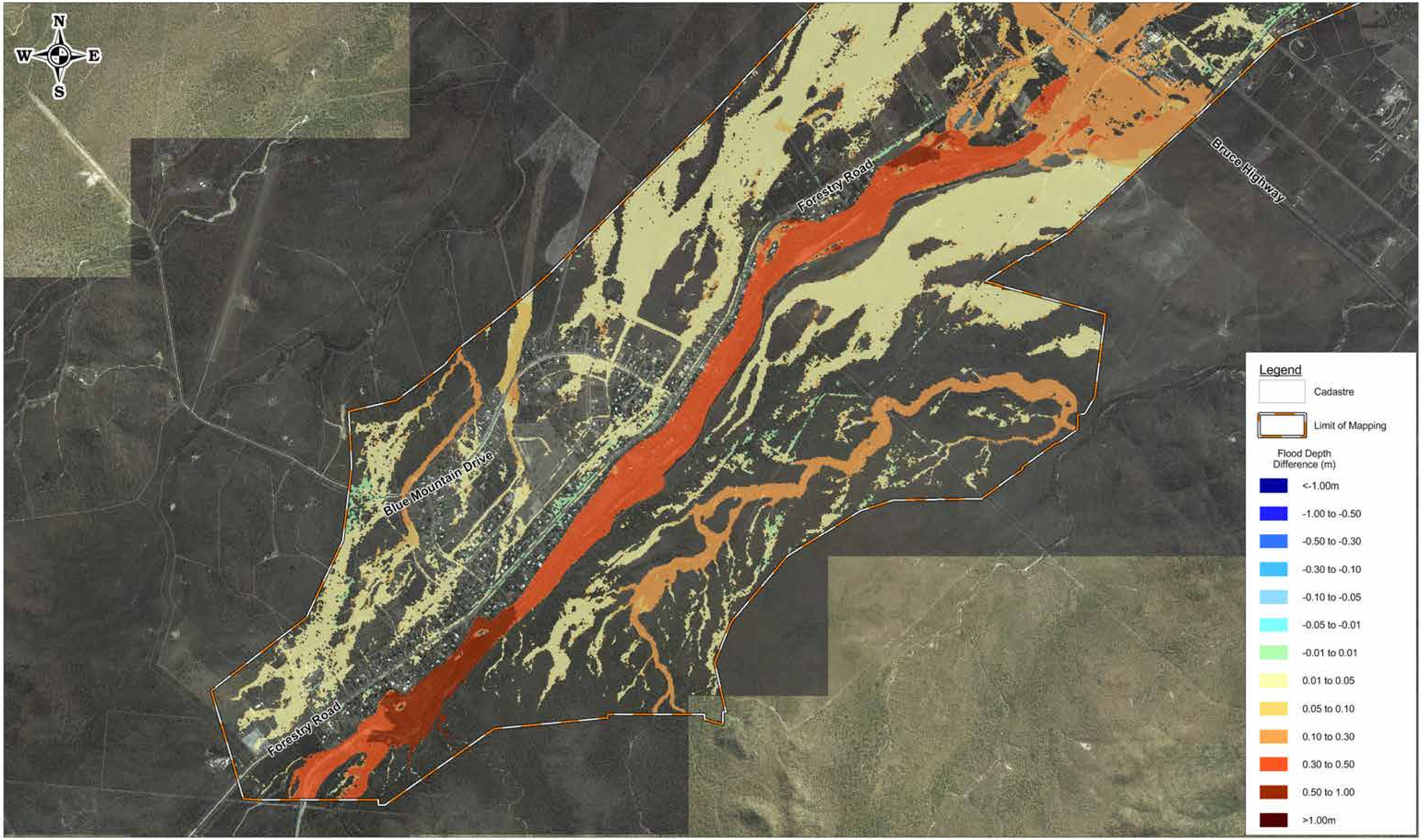
Bluewater Creek Flood Study

Appendix A26

Bluewater
100 Year ARI Highest Astromonical Tide Scenario
Flood Depth Difference

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 17 May 2013

M:\Projects\M9300_Townsville City Council\M9300_001_Bluewater Creek Flood Study\Design\MapInfo\Figures



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Townsville

0 500 1000
Scale in Meters (1:25,000 @ A3)

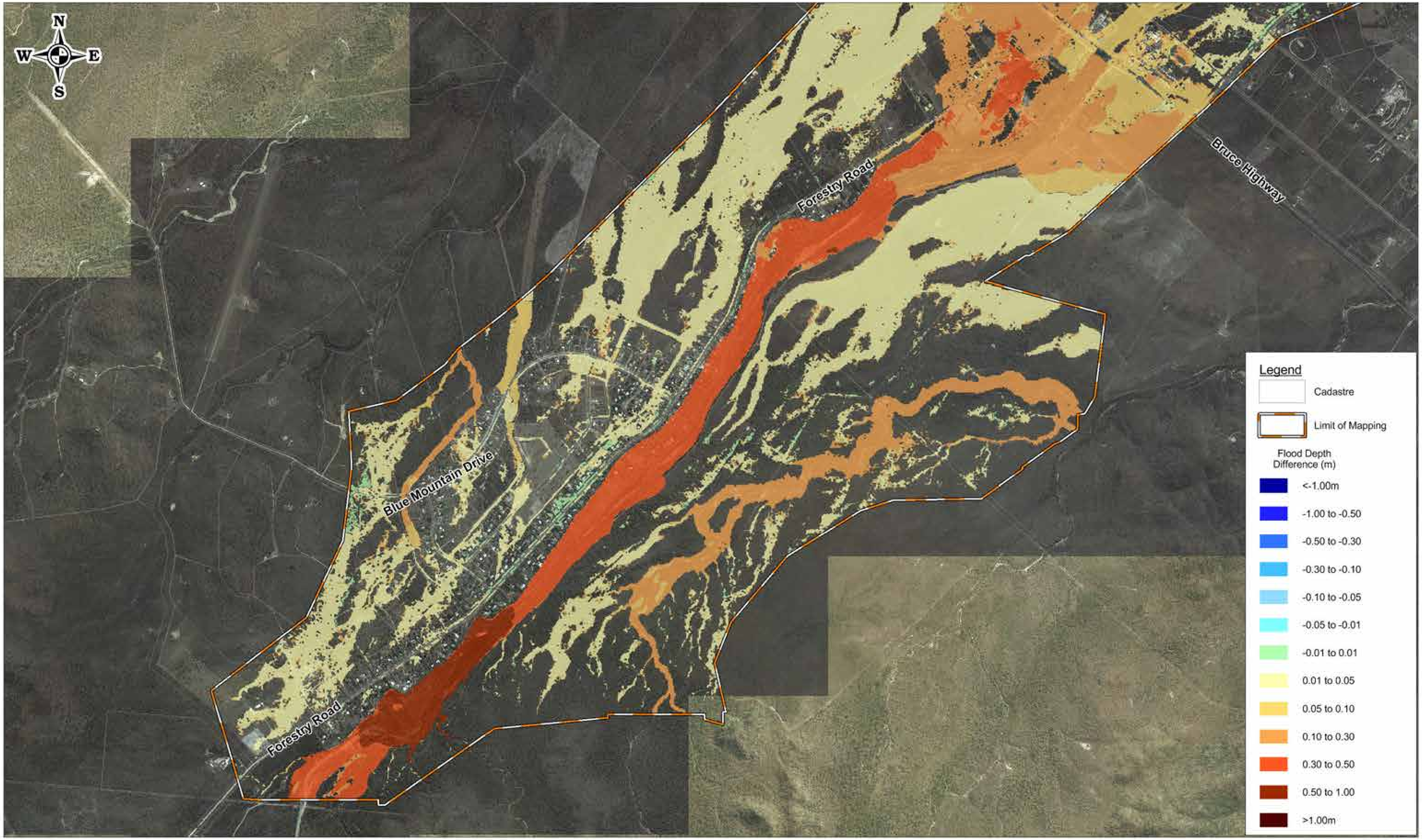
Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Bluewater Creek Flood Study

Appendix A27

Bluewater
50 Year ARI Climate Change Scenario
Flood Depth Difference

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 17 May 2013



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F: 07 3236 2399
E: admin@engeny.com.au

0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

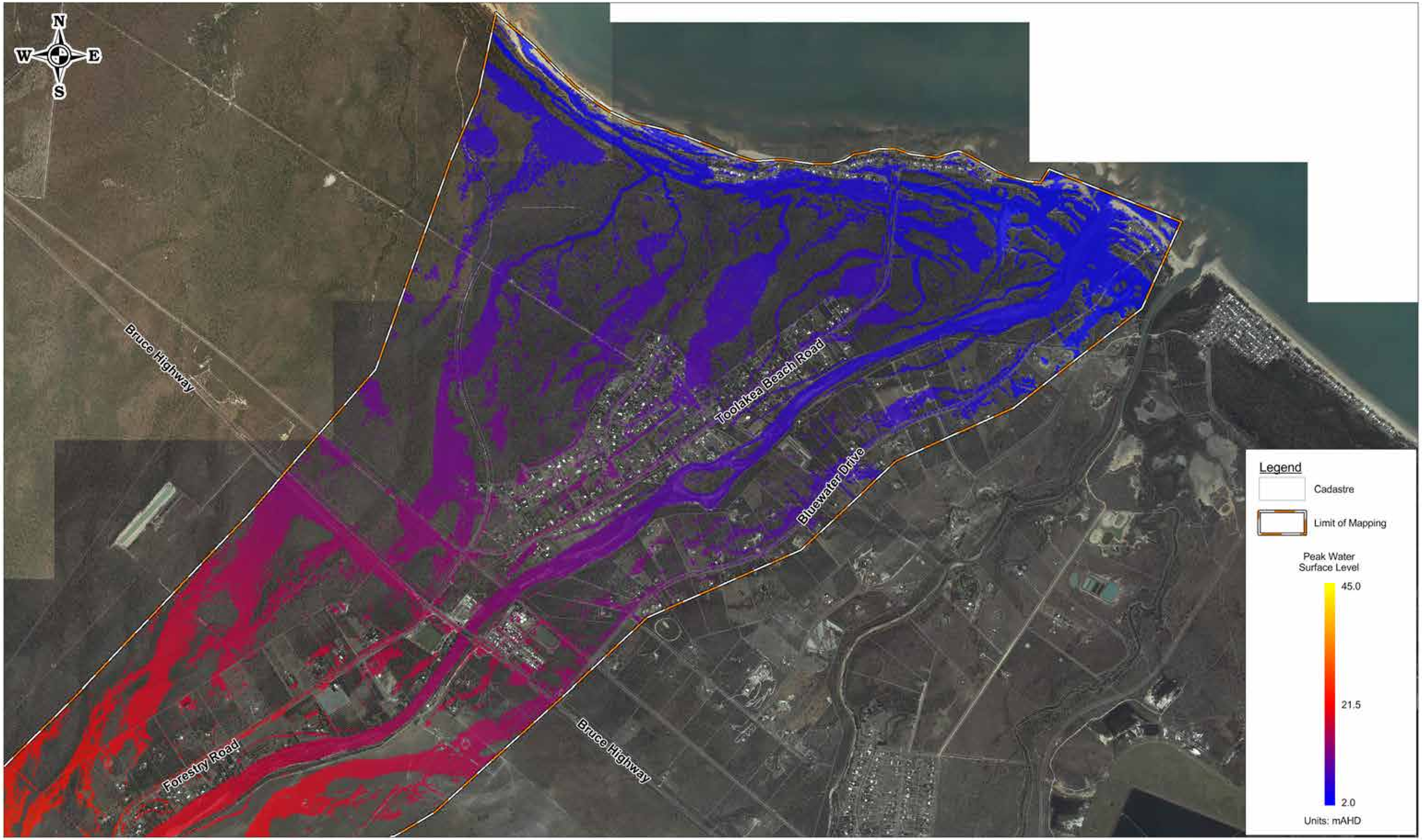
Bluewater Creek Flood Study

Appendix A28

Bluewater
100 Year ARI Climate Change Scenario
Flood Depth Difference

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 17 May 2013

M:\Projects\M9300_Townsville City Council\M9300_001_Bluewater Creek Flood Study\Design\MapInfo\Figures



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ENGENY WATER MANAGEMENT

Townsville

0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

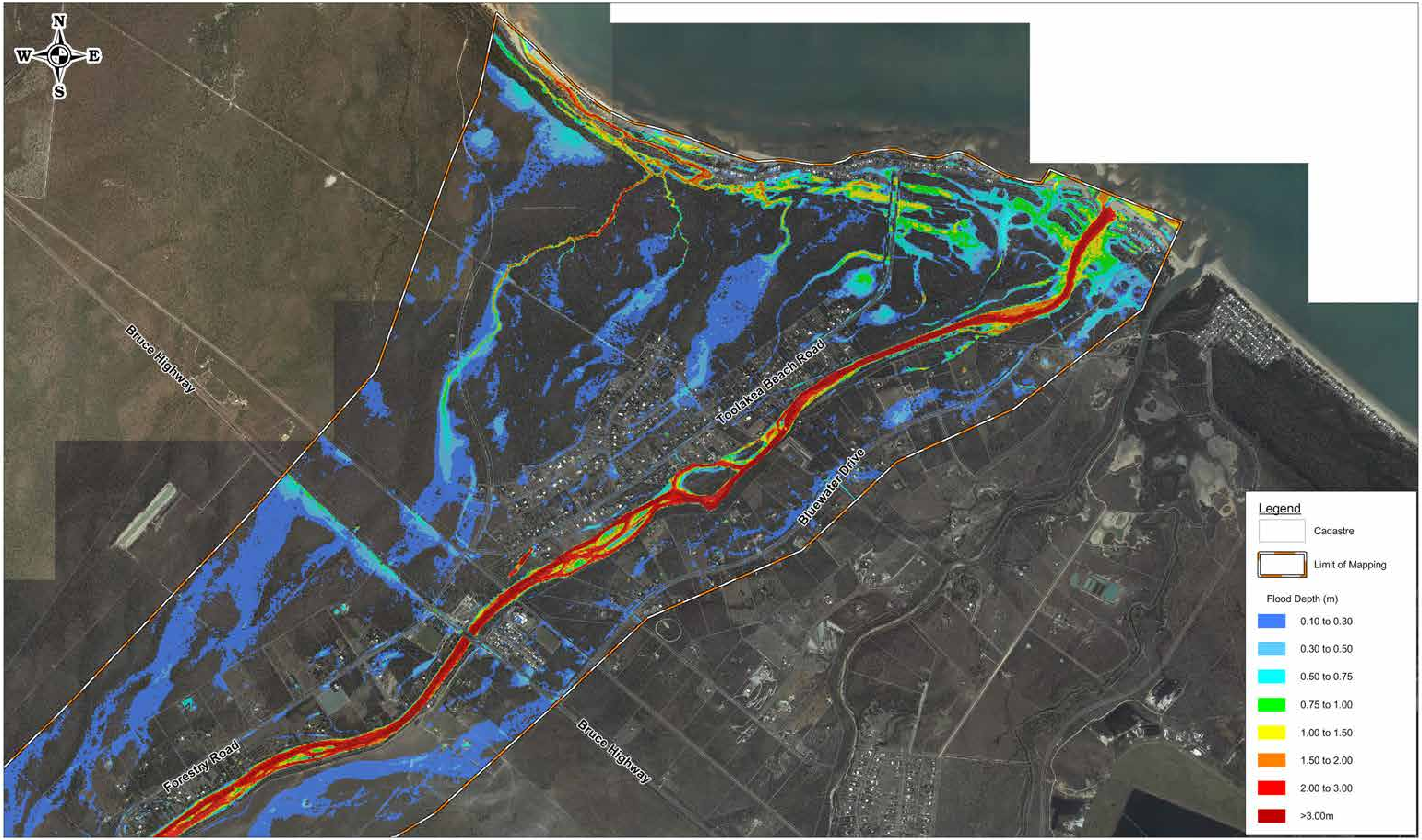
Bluewater Creek Flood Study

Appendix A29

Toolakea
2 Year ARI Peak Water Surface Level

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 27 May 2013

M:\Projects\M9300_Townsville City Council\M9300_001_Bluewater Creek Flood Study\Design\MapInfo\Figures



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Townsville

0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

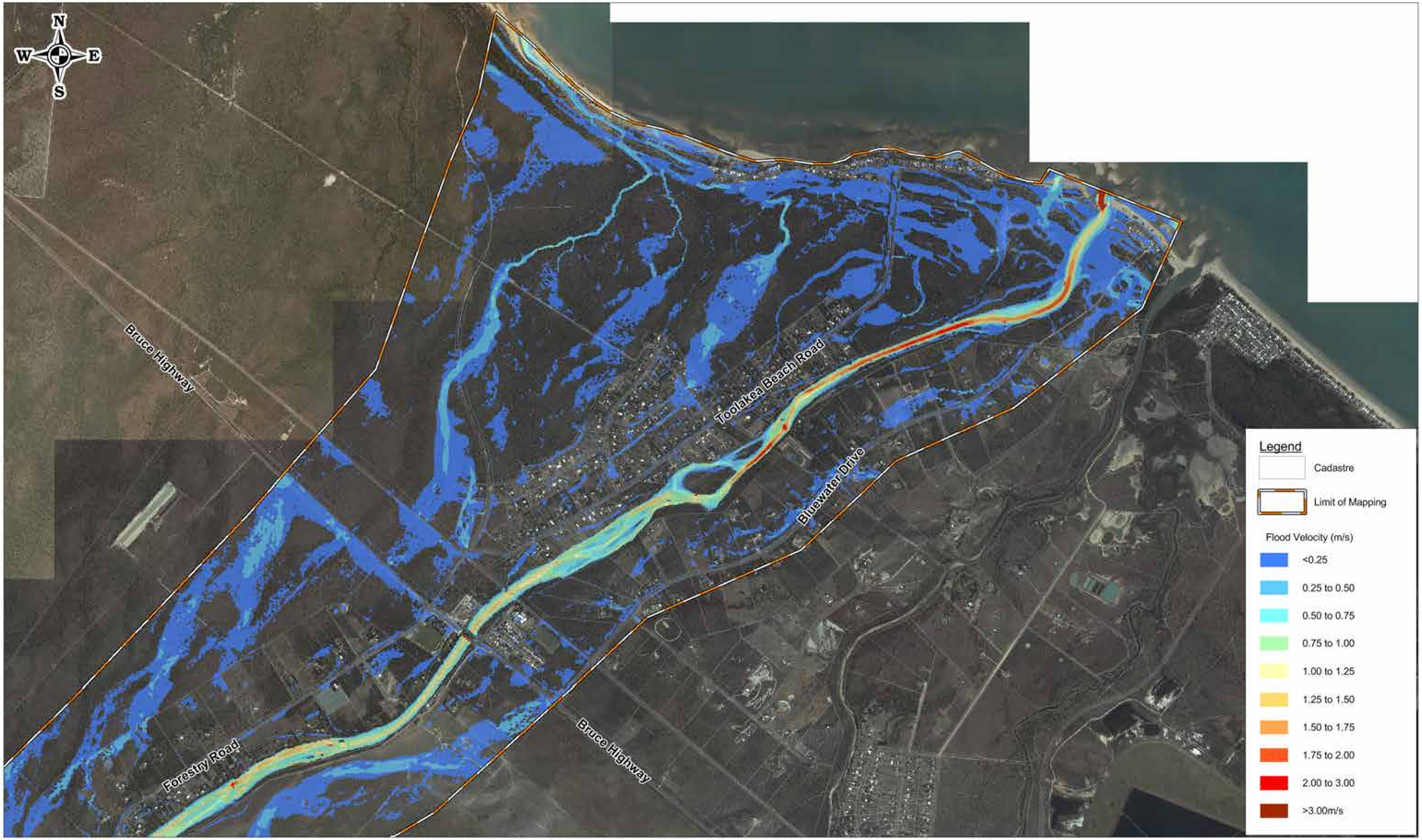
Bluewater Creek Flood Study

Appendix A30

Toolakea
2 Year ARI Peak Flood Depth

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 27 May 2013

M:\Projects\M9300_Townsville City Council\M9300_001_Bluewater Creek Flood Study\Design\MapInfo\Figures



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ENGENY WATER MANAGEMENT

Townsville

0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

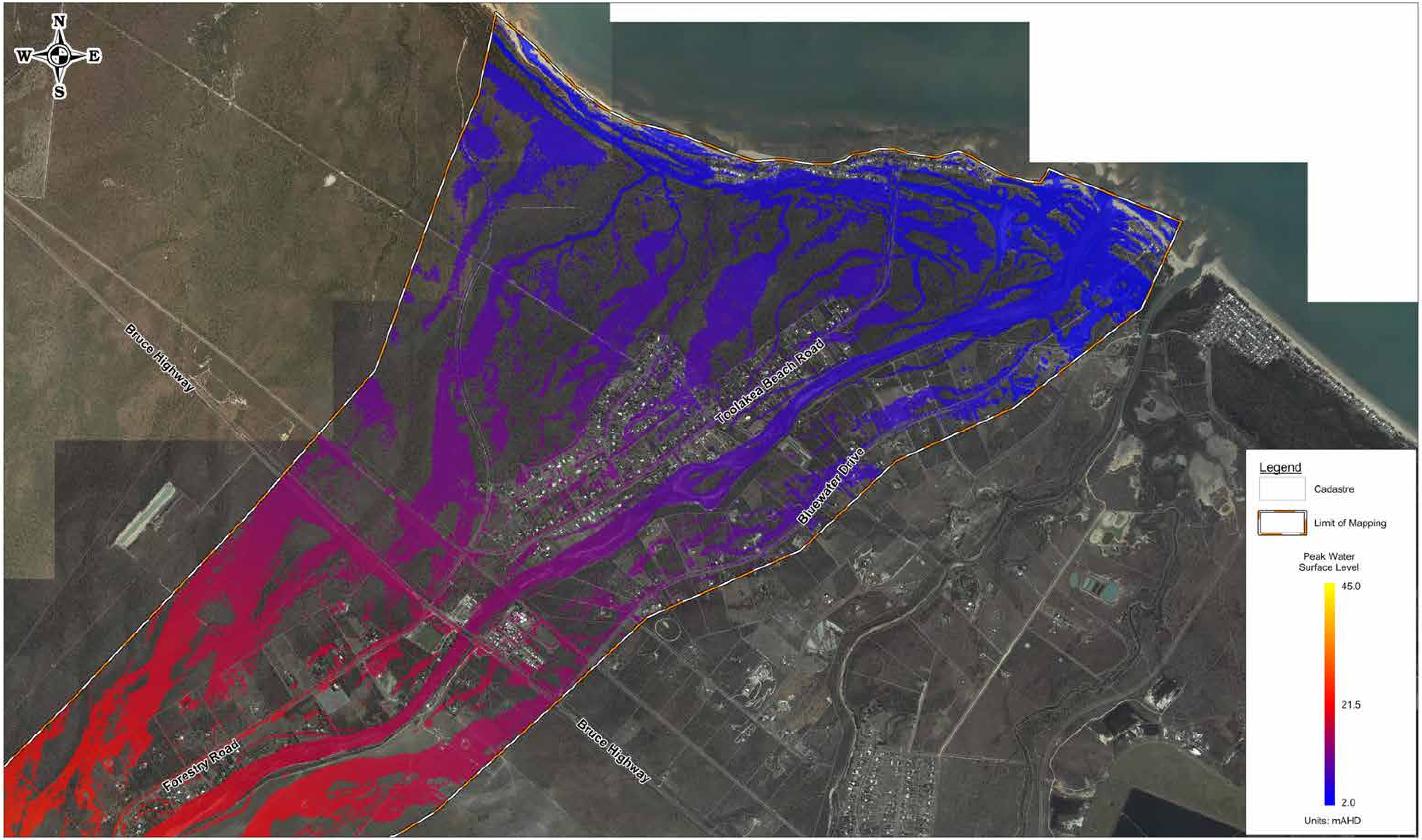
Bluewater Creek Flood Study

Appendix A31

Toolakea
2 Year ARI Peak Flood Velocity

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 27 May 2013

M:\Projects\M9300_Townsville City Council\M9300_001_Bluewater Creek Flood Study\Design\MapInfo\Figures



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ENGENY WATER MANAGEMENT

Townsville

0 500 1000

Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

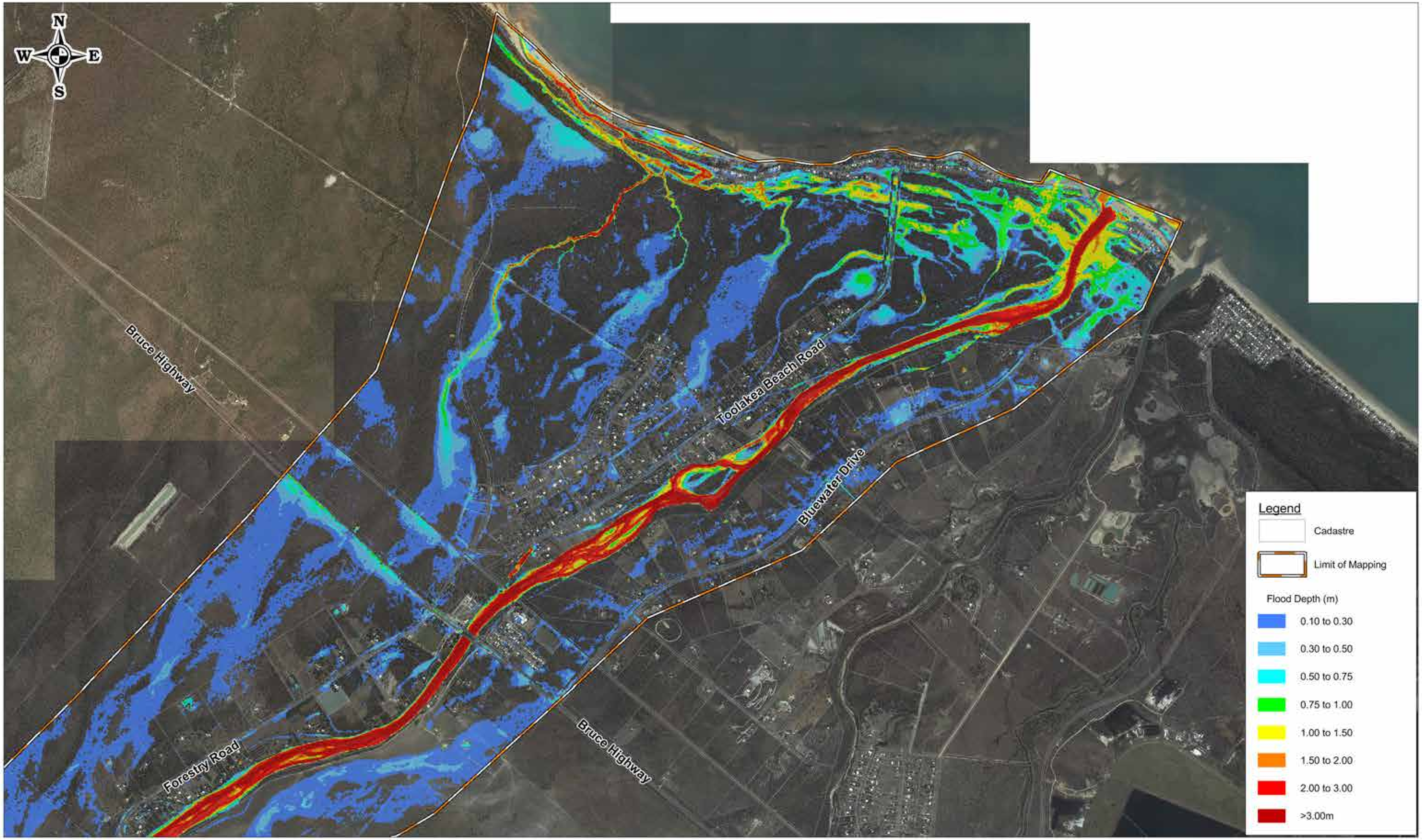
Bluewater Creek Flood Study

Appendix A32

Toolakea
5 Year ARI Peak Water Surface Level

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 27 May 2013

M:\Projects\M9300_Townsville City Council\M9300_001_Bluewater Creek Flood Study\Design\MapInfo\Figures



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ENGENY WATER MANAGEMENT

Townsville

0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994, (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

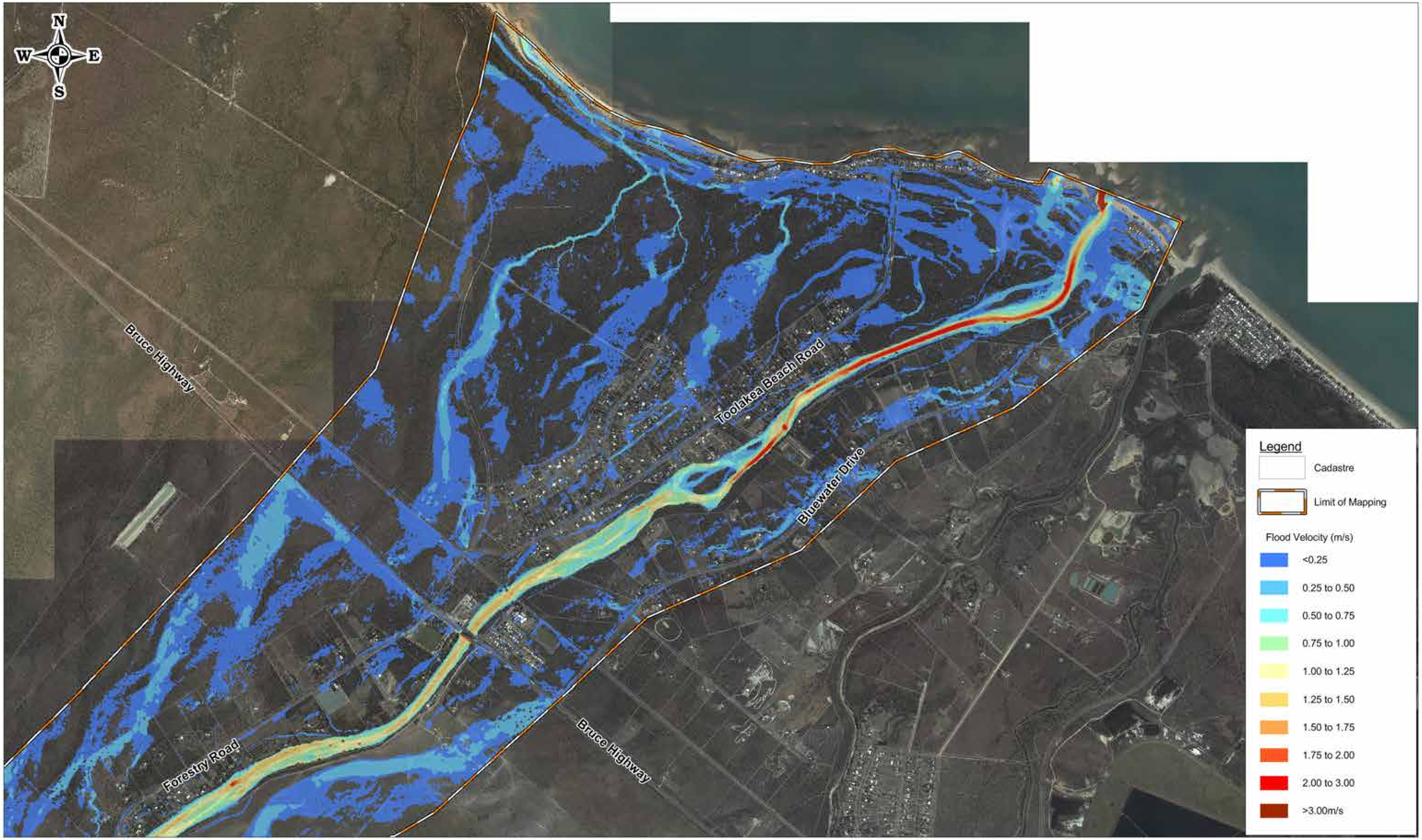
Bluewater Creek Flood Study

Appendix A33

Toolakea
5 Year ARI Peak Flood Depth

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 27 May 2013

M:\Projects\M9300_Townsville City Council\M9300_001_Bluewater Creek Flood Study\Design\MapInfo\Figures



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Townsville

0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

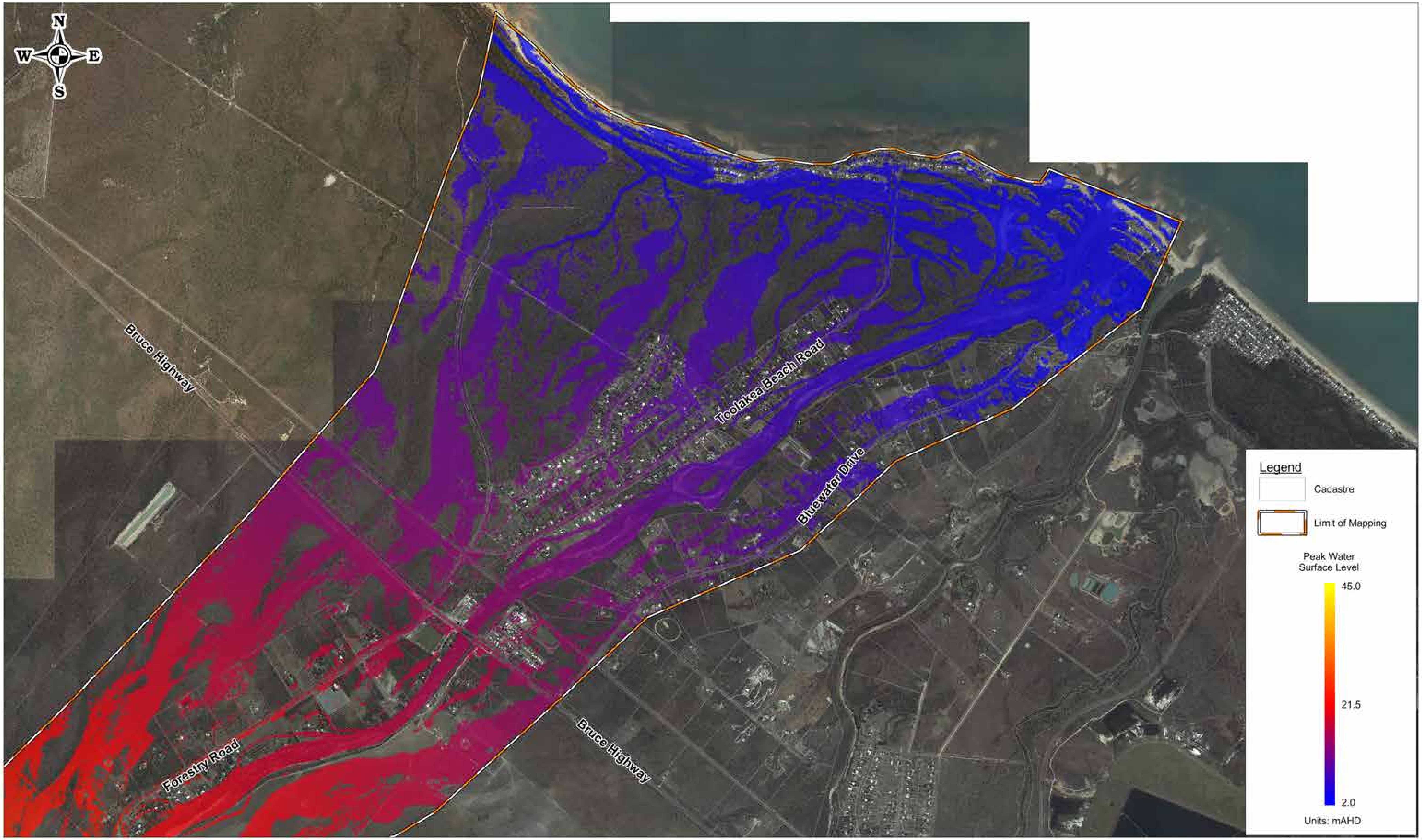
Bluewater Creek Flood Study

Appendix A34

Toolakea
5 Year ARI Peak Flood Velocity

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 27 May 2013

M:\Projects\M9300_Townsville City Council\M9300_001_Bluewater Creek Flood Study\Design\MapInfo\Figures



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Townsville

0 500 1000

Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

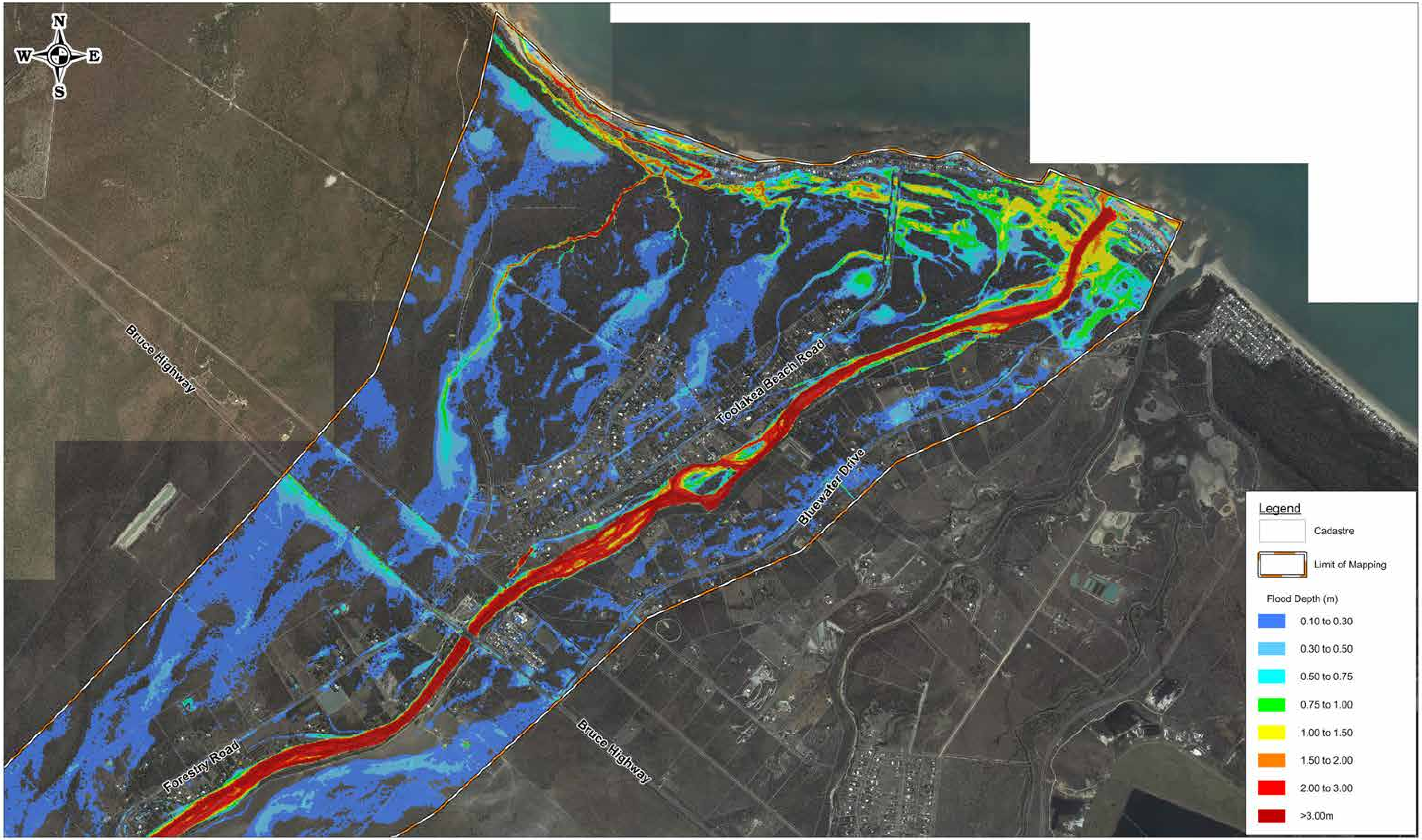
Bluewater Creek Flood Study

Appendix A35

Toolakea
10 Year ARI Peak Water Surface Level

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 27 May 2013

M:\Projects\M9300_Townsville City Council\M9300_001_Bluewater Creek Flood Study\Design\MapInfo\Figures



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0 500 1000

Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

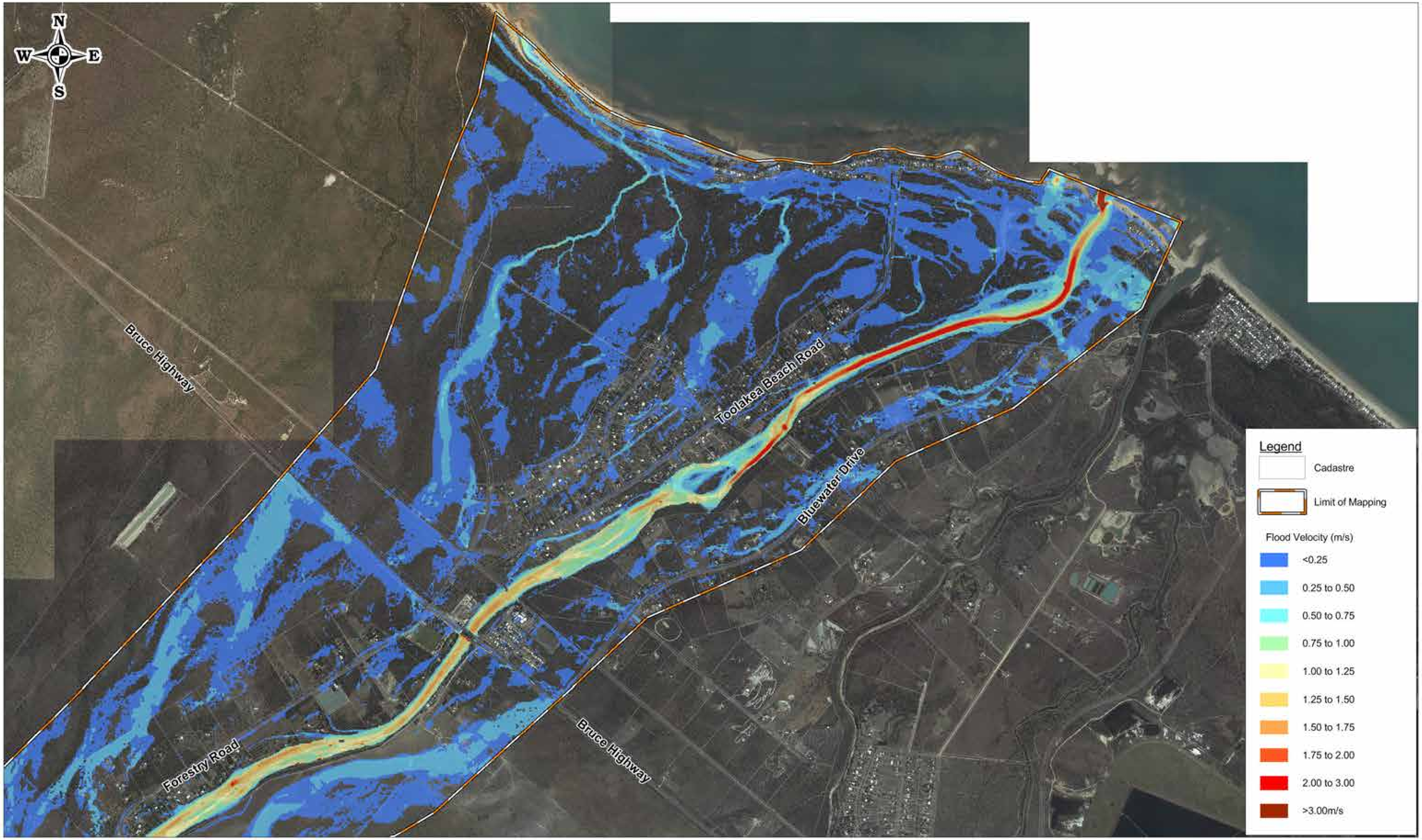
Bluewater Creek Flood Study

Appendix A36

Toolakea
10 Year ARI Peak Flood Depth

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 27 May 2013

M:\Projects\M9300_Townsville City Council\M9300_001_Bluewater Creek Flood Study\Design\MapInfo\Figures



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Townsville

0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

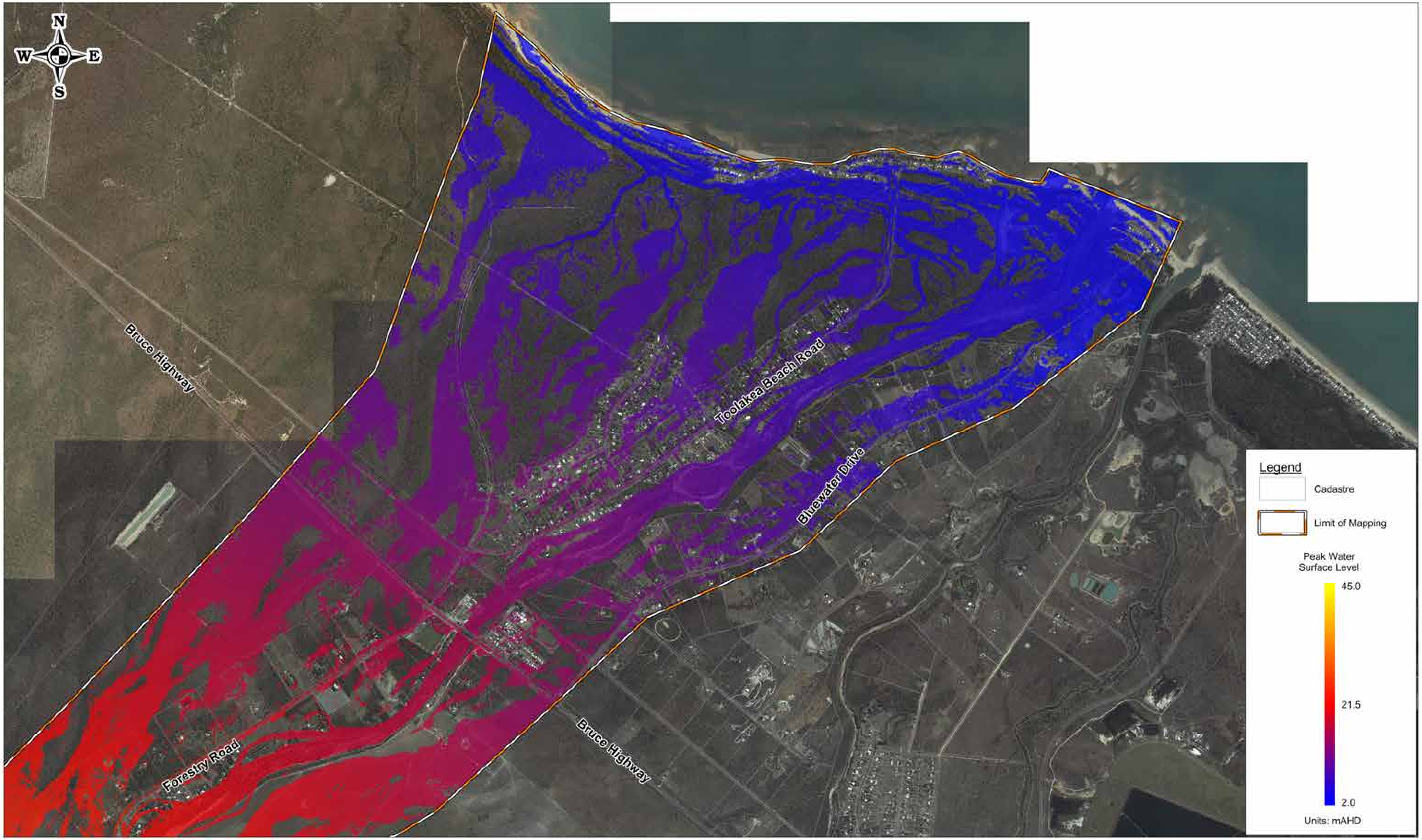
Bluewater Creek Flood Study

Appendix A37

Toolakea
10 Year ARI Peak Flood Velocity

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 27 May 2013

M:\Projects\M9300_Townsville City Council\M9300_001_Bluewater Creek Flood Study\Design\MapInfo\Figures



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Townsville

0 500 1000
Scale in Meters (1:25,000 @ A3)

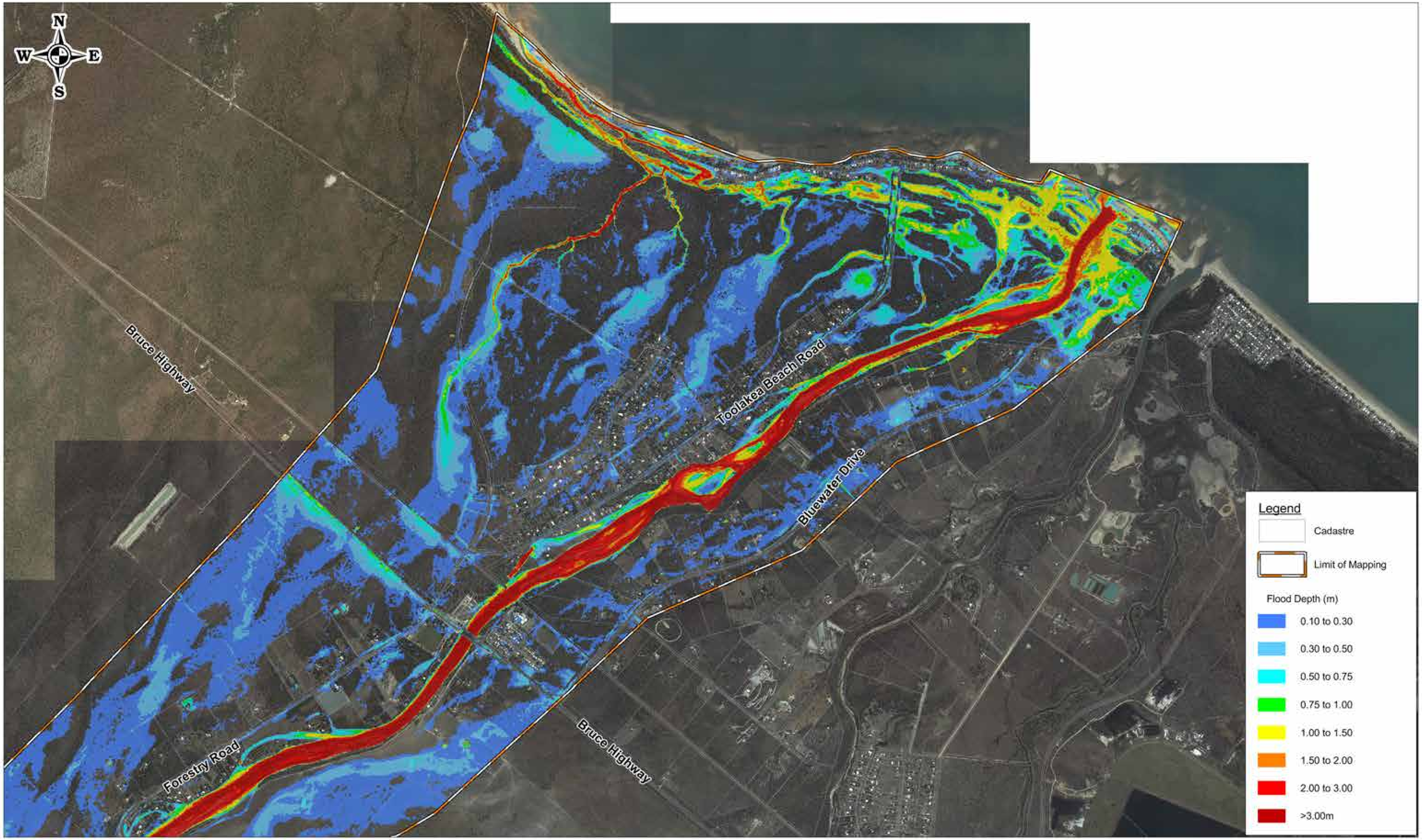
Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Bluewater Creek Flood Study

Appendix A38

Toolakea
20 Year ARI Peak Water Surface Level

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 27 May 2013



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Townsville

0 500 1000

Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

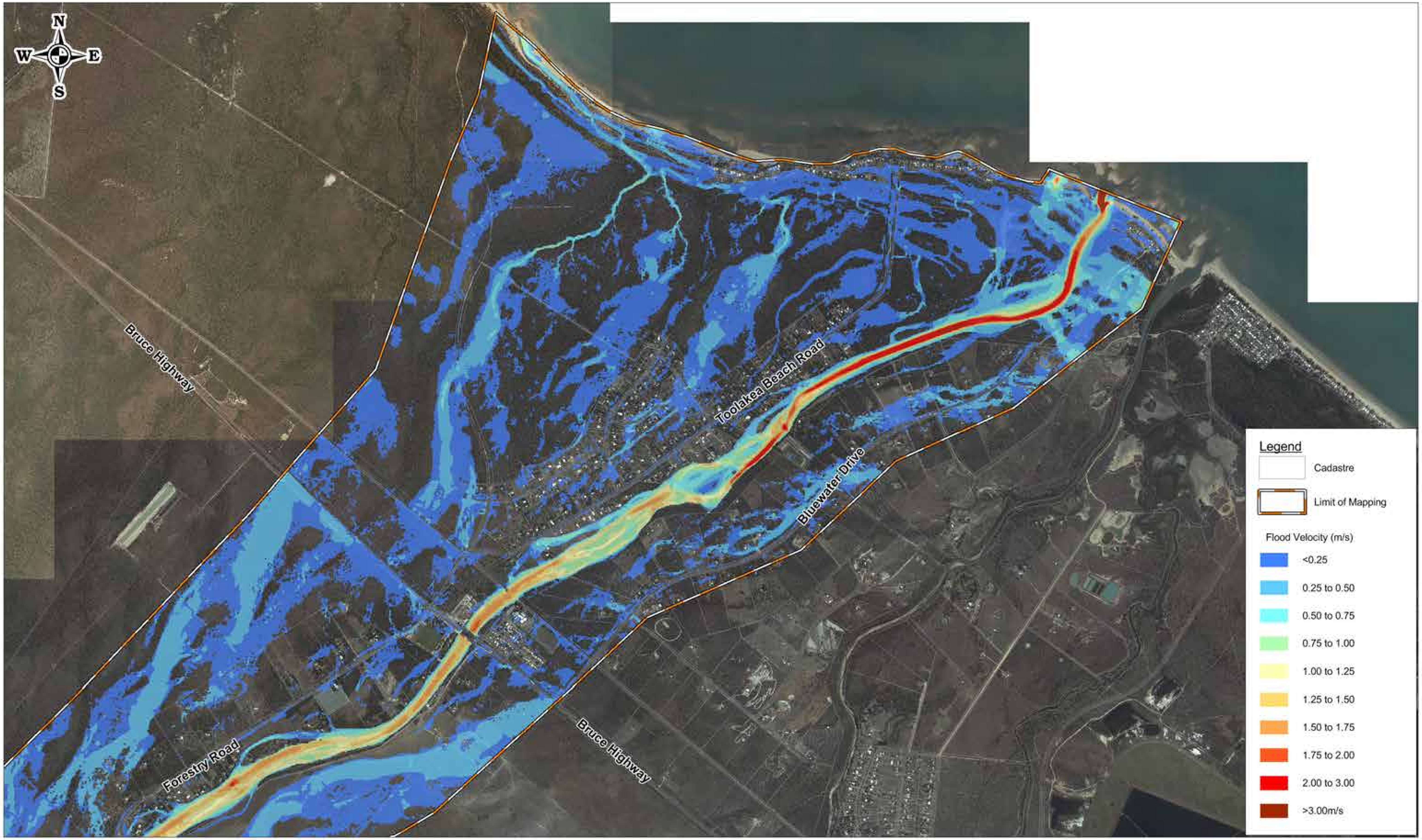
Bluewater Creek Flood Study

Appendix A39

Toolakea
20 Year ARI Peak Flood Depth

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 27 May 2013

M:\Projects\M9300_Townsville City Council\M9300_001_Bluewater Creek Flood Study\Design\MapInfo\Figures



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ENGENY WATER MANAGEMENT

Townsville

0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

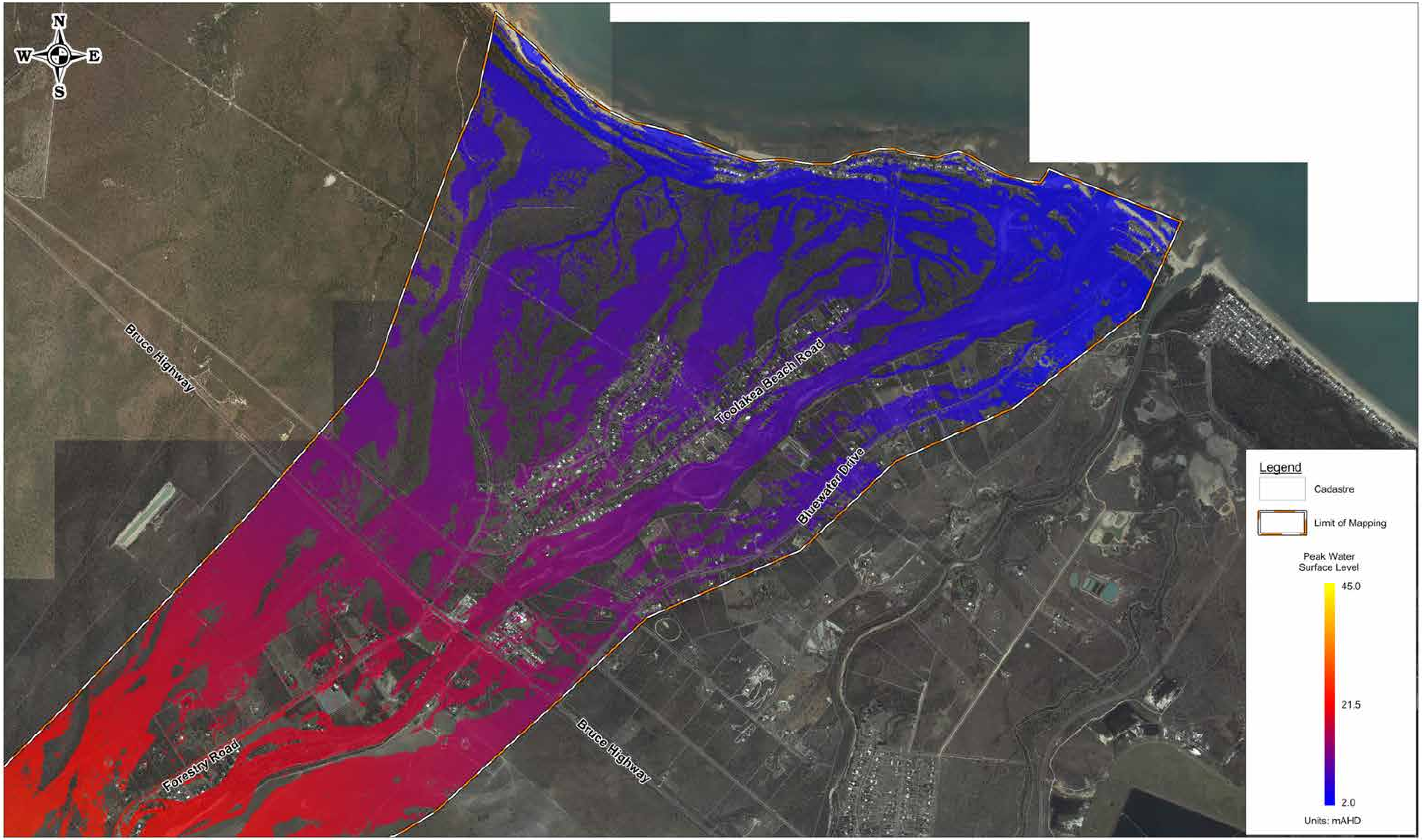
Bluewater Creek Flood Study

Appendix A40

Toolakea
20 Year ARI Peak Flood Velocity

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 27 May 2013

M:\Projects\M9300_Townsville City Council\M9300_001_Bluewater Creek Flood Study\Design\MapInfo\Figures



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ENGENY WATER MANAGEMENT

Townsville

0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

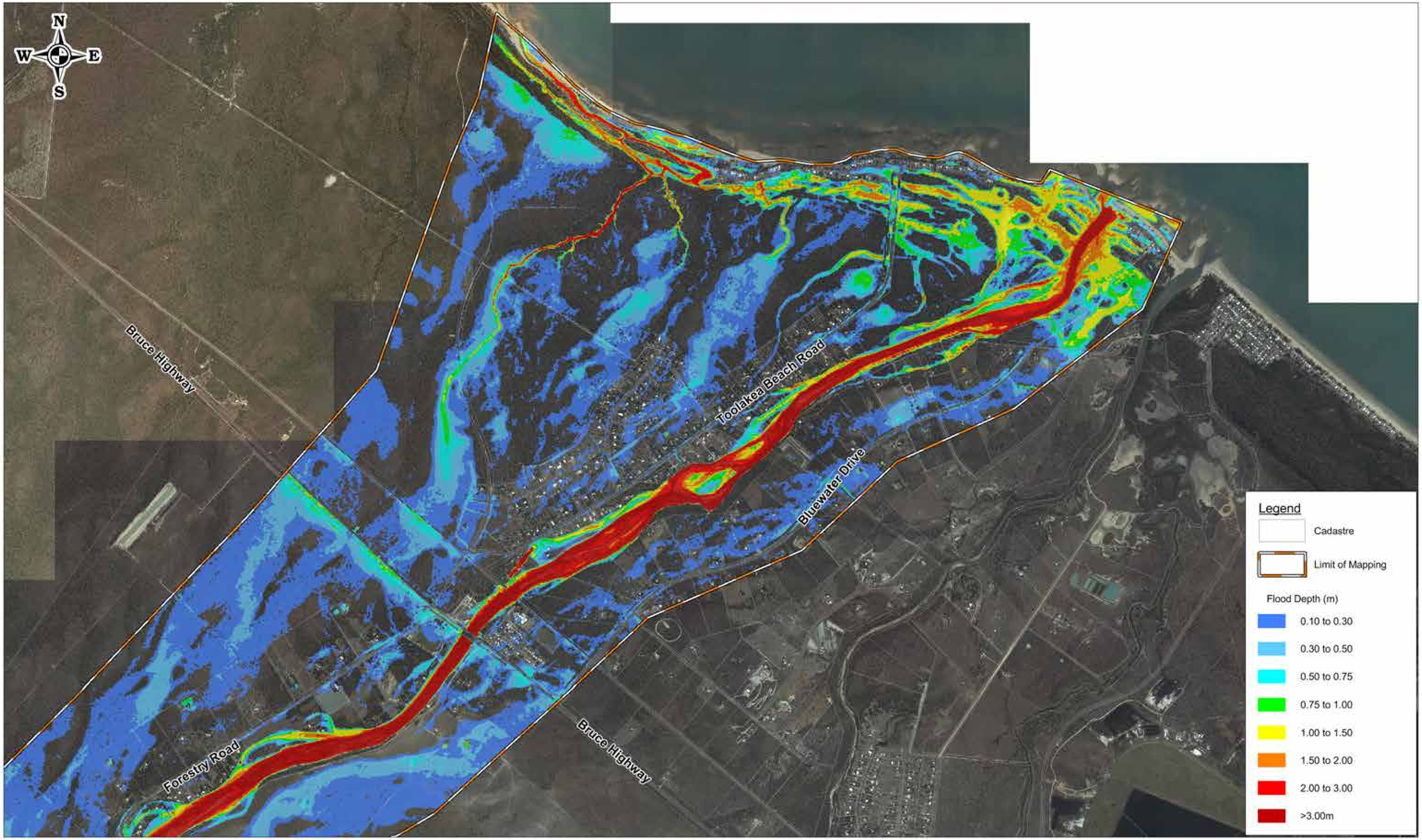
Bluewater Creek Flood Study

Appendix A41

Toolakea
50 Year ARI Peak Water Surface Level

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 17 May 2013

M:\Projects\M9300_Townsville City Council\M9300_001_Bluewater Creek Flood Study\Design\MapInfo\Figures



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ENGENY WATER MANAGEMENT

Townsville

0 500 1000
Scale in Meters (1:25,000 @ A3)

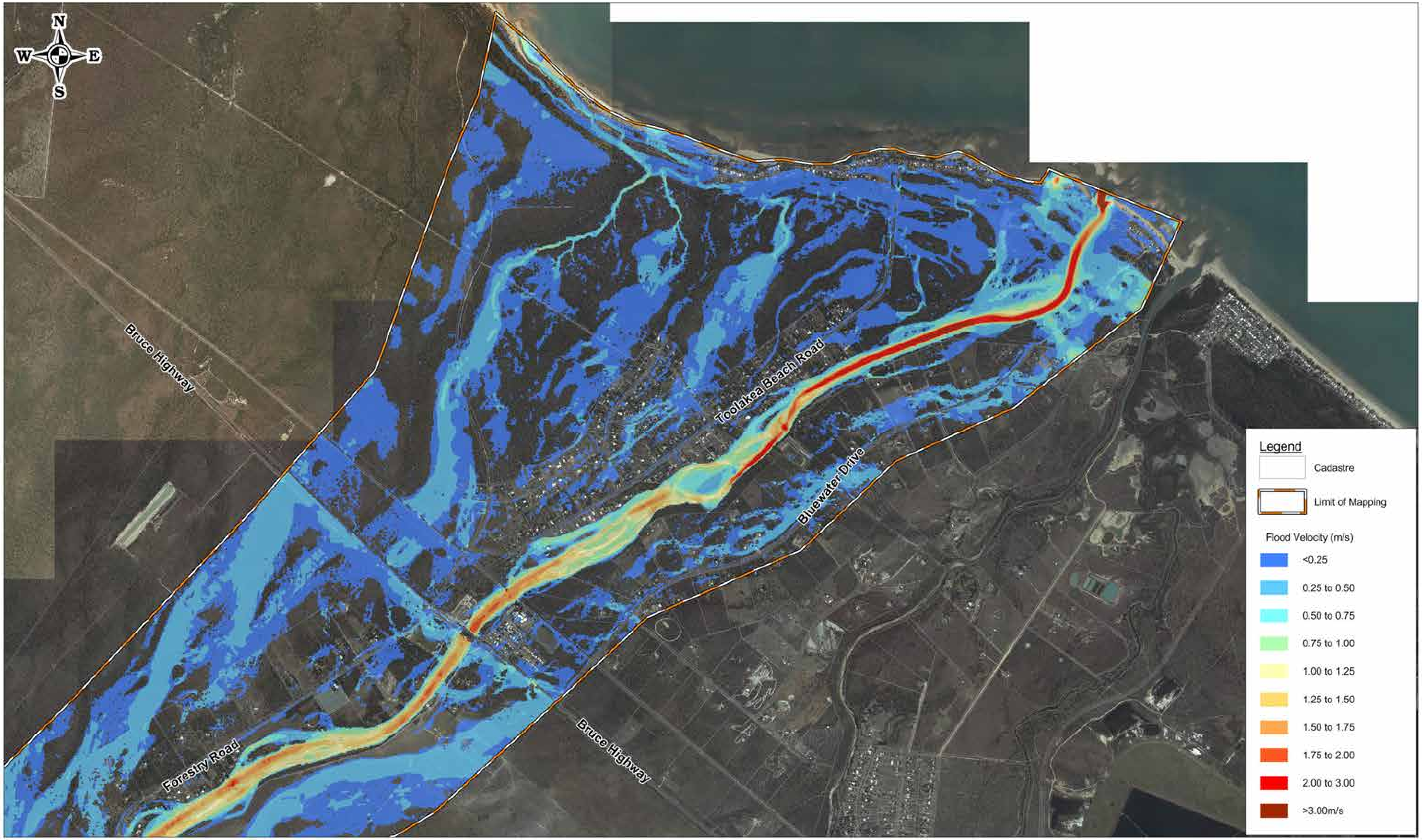
Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Bluewater Creek Flood Study

Appendix A42

Toolakea
50 Year ARI Peak Flood Depth

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 17 May 2013



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ENGENY WATER MANAGEMENT

Townsville

0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

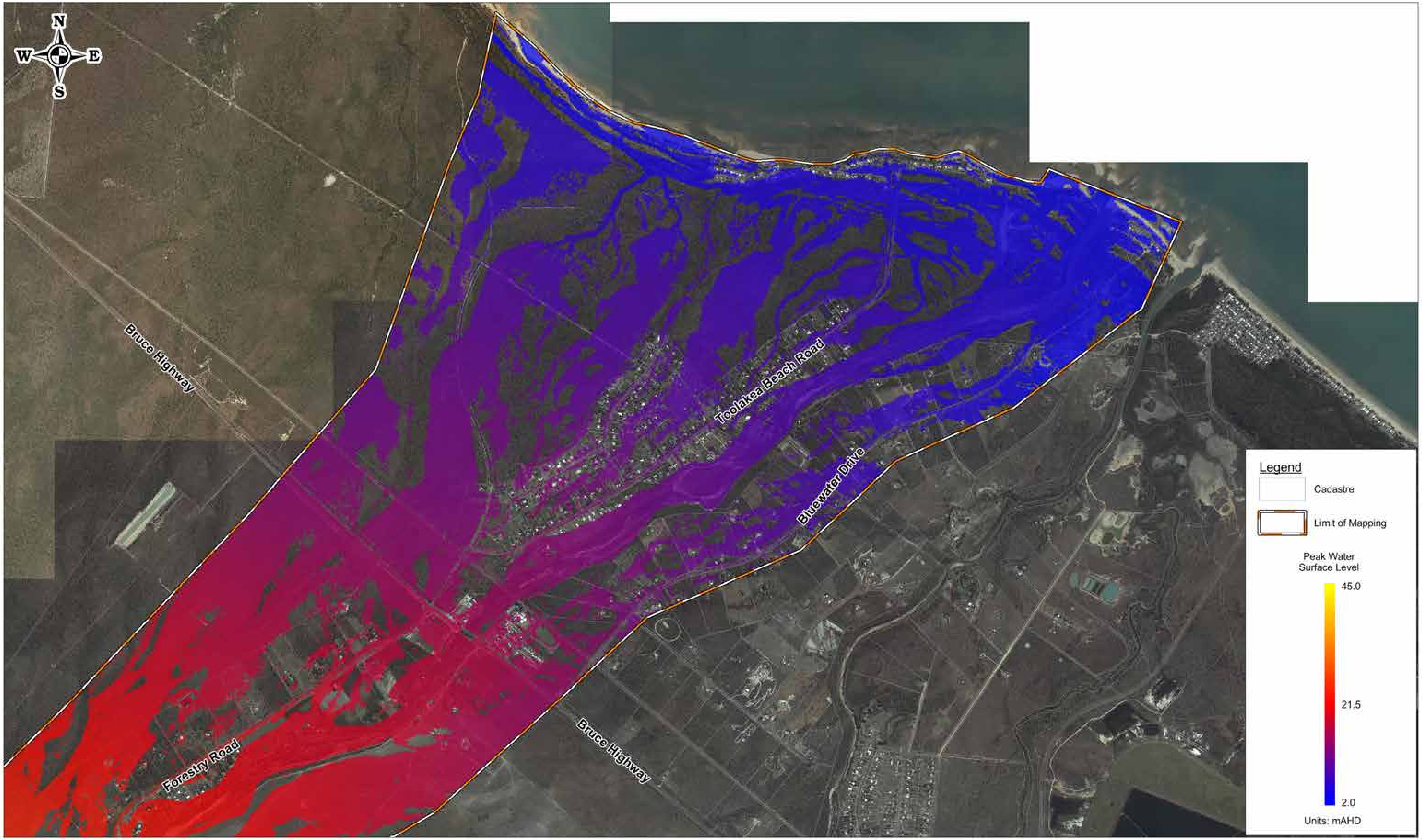
Bluewater Creek Flood Study

Appendix A43

Toolakea
50 Year ARI Peak Flood Velocity

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 17 May 2013

M:\Projects\M9300_Townsville City Council\M9300_001_Bluewater Creek Flood Study\Design\MapInfo\Figures



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ENGENY WATER MANAGEMENT

Townsville

0 500 1000
Scale in Meters (1:25,000 @ A3)

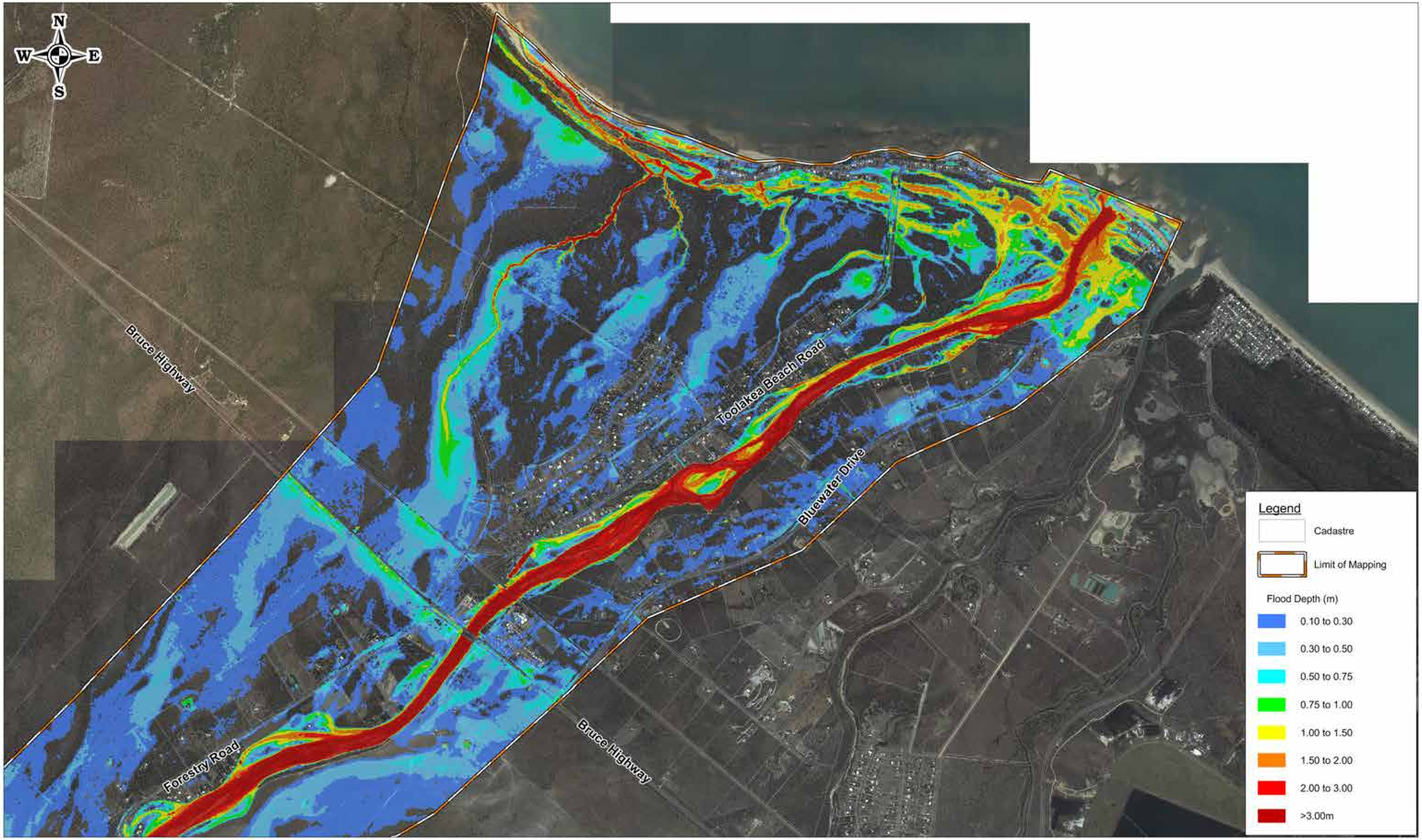
Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Bluewater Creek Flood Study

Appendix A44

Toolakea
100 Year ARI Peak Water Surface Level

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 17 May 2013



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ENGENY WATER MANAGEMENT

Townsville

0 500 1000
Scale in Meters (1:25,000 @ A3)

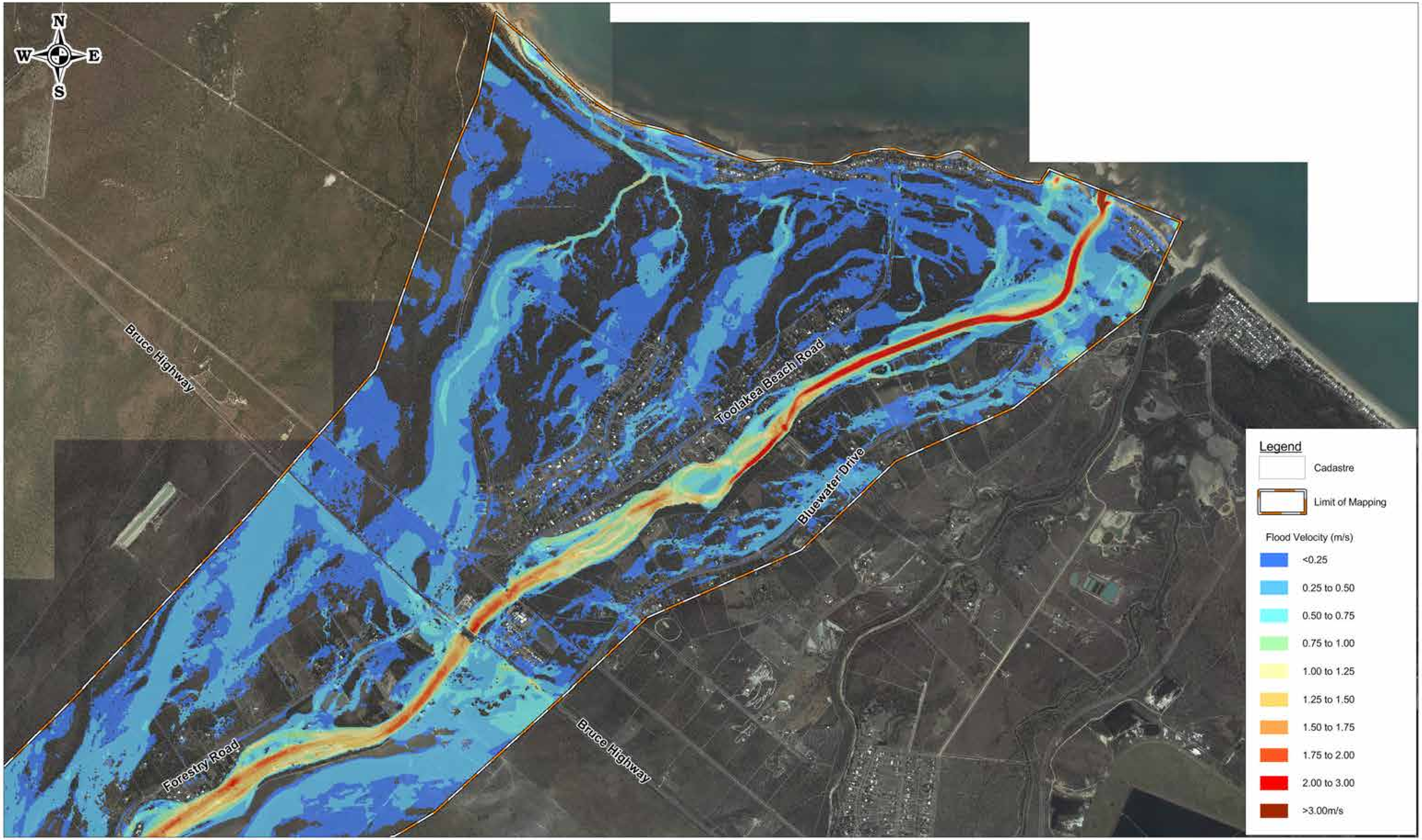
Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Bluewater Creek Flood Study

Appendix A45

Toolakea
100 Year ARI Peak Flood Depth

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 20 May 2013



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0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Bluewater Creek Flood Study

Appendix A46

Toolakea
100 Year ARI Peak Flood Velocity

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 20 May 2013

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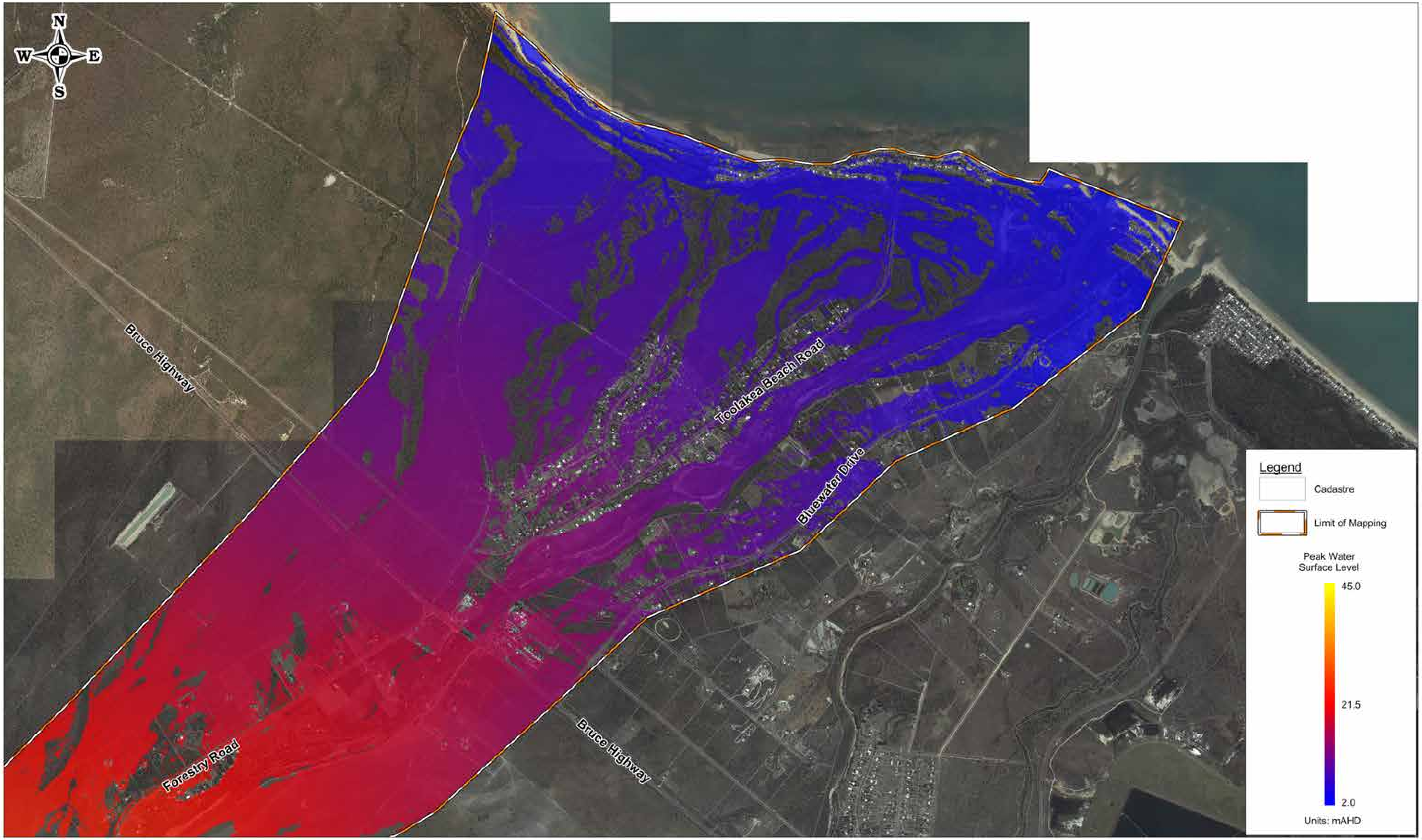

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ENGENY WATER MANAGEMENT

Townsville

0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

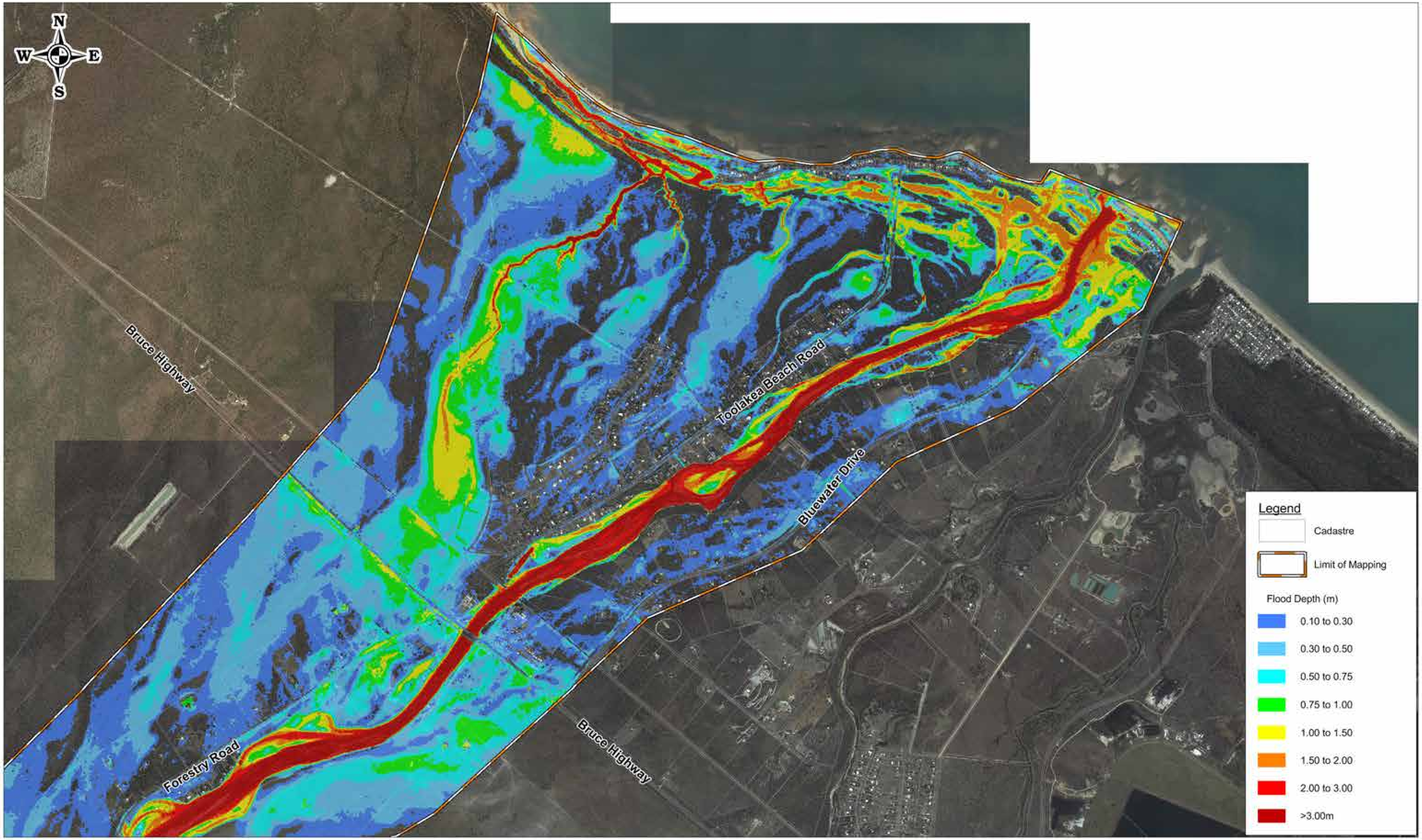
Bluewater Creek Flood Study

Appendix A47

Toolakea
500 Year ARI Peak Water Surface Level

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 27 May 2013

M:\Projects\M9300_Townsville City Council\M9300_001_Bluewater Creek Flood Study\Design\MapInfo\Figures



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Townsville

0 500 1000
Scale in Meters (1:25,000 @ A3)

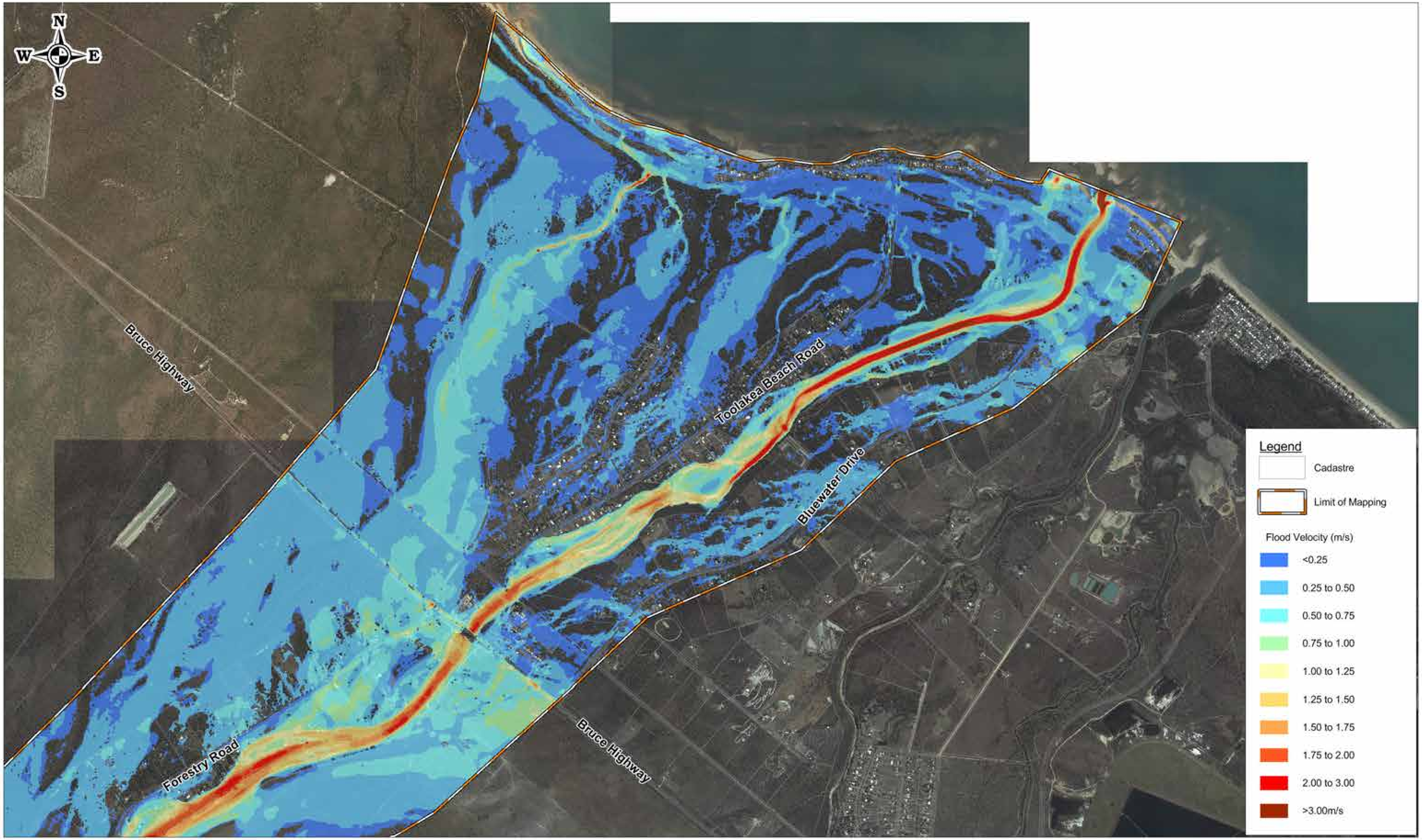
Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Bluewater Creek Flood Study

Appendix A48

Toolakea
500 Year ARI Peak Flood Depth

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 27 May 2013



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ENGENY WATER MANAGEMENT

Townsville

0 500 1000

Scale in Meters (1:25,000 @ A3)

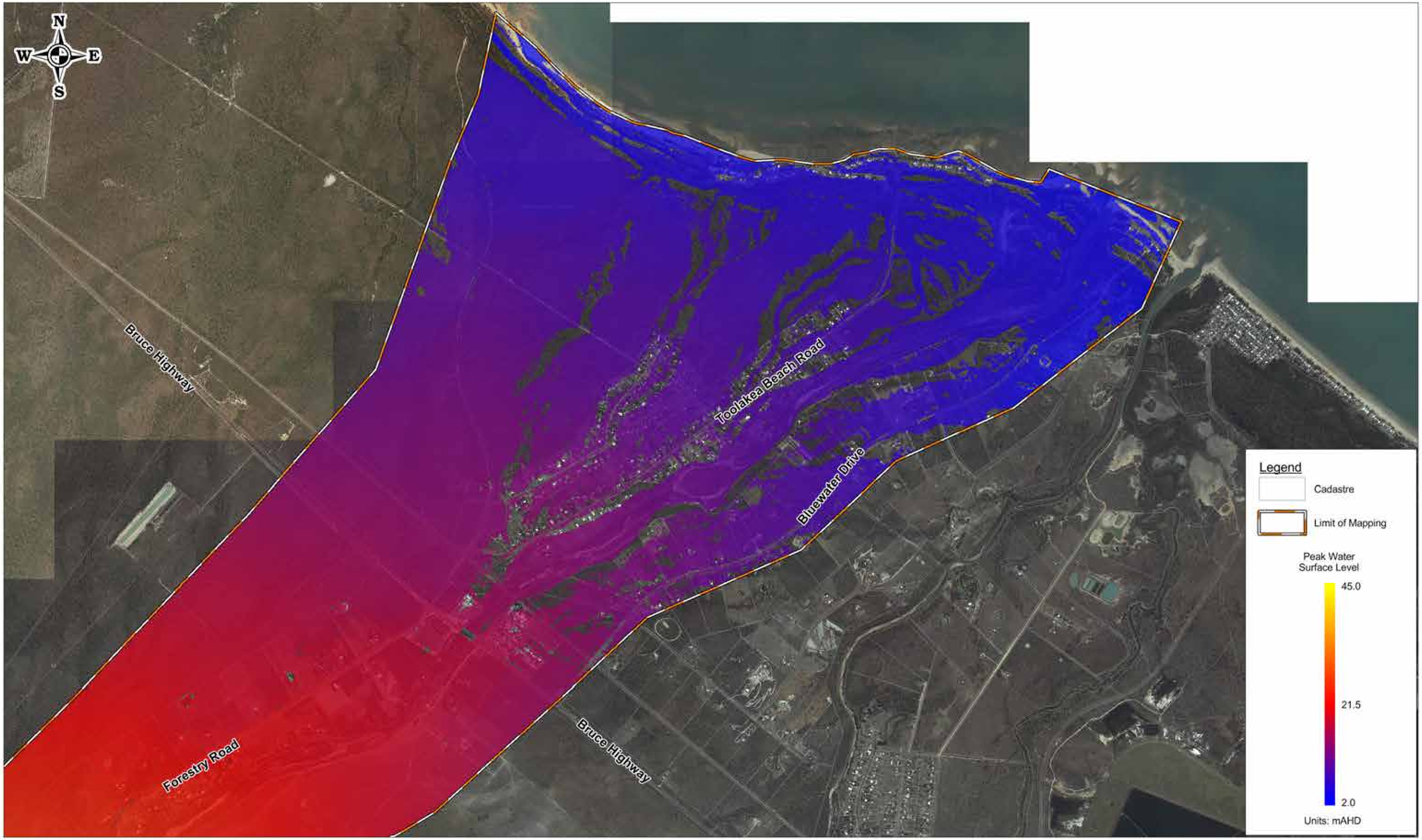
Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Bluewater Creek Flood Study

Appendix A49

Toolakea
500 Year ARI Peak Flood Velocity

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 27 May 2013



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ENGENY WATER MANAGEMENT

Townsville

0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

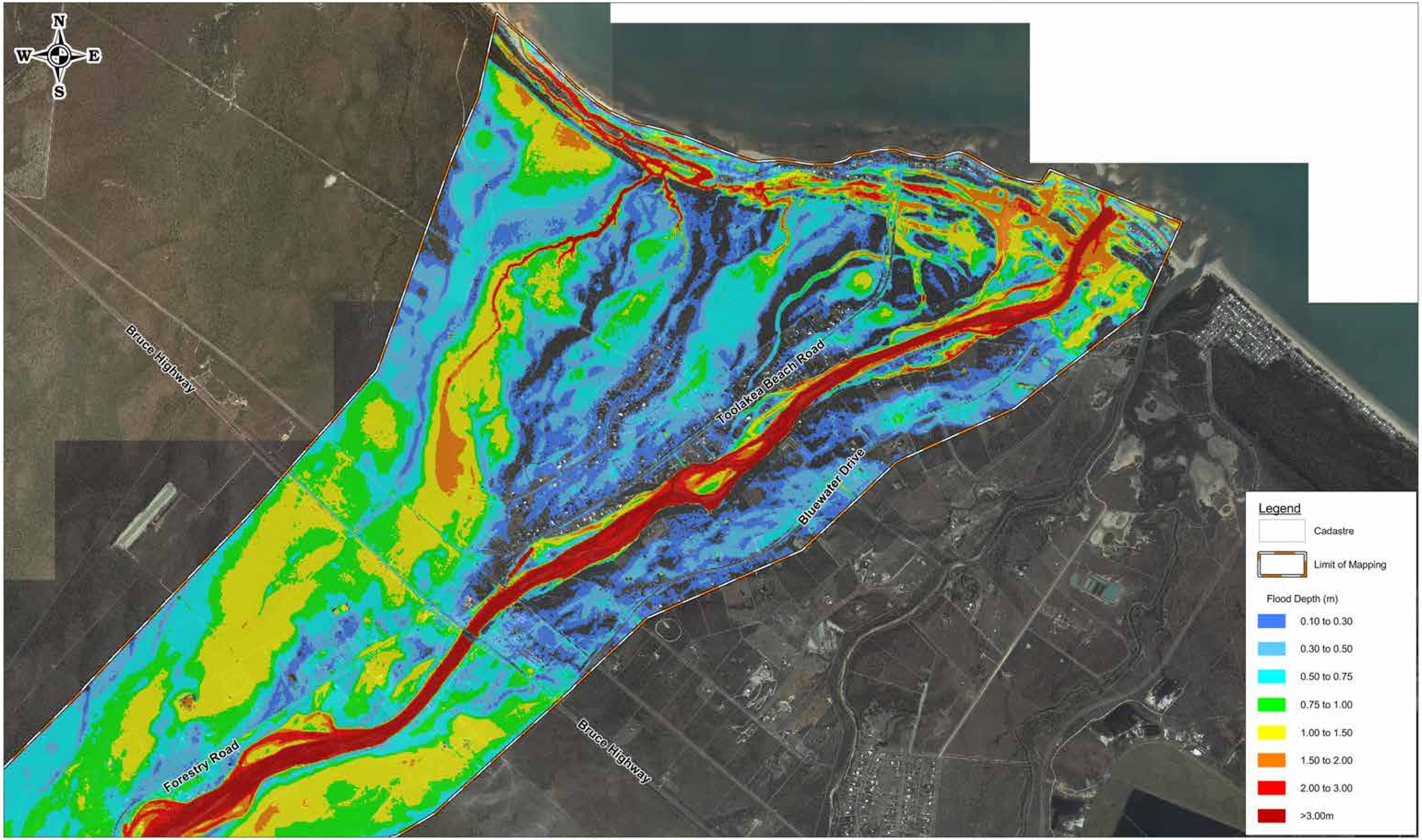
Bluewater Creek Flood Study

Appendix A50

Toolakea
PMF Peak Water Surface Level

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 17 May 2013

M:\Projects\M9300_Townsville City Council\M9300_001_Bluewater Creek Flood Study\Design\MapInfo\Figures



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ENGENY WATER MANAGEMENT

Townsville

0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

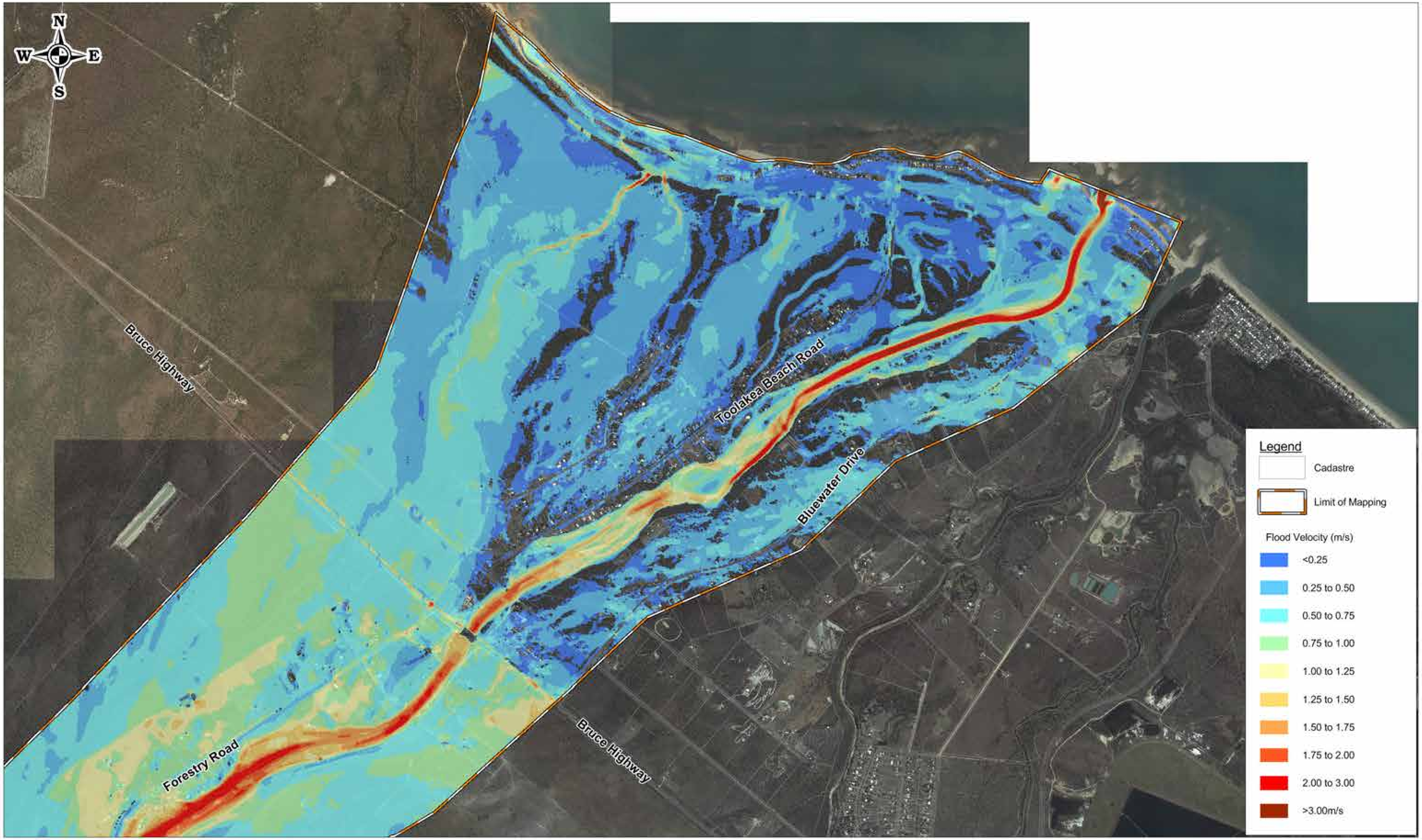
Bluewater Creek Flood Study

Appendix A51

Toolakea
PMF Peak Flood Depth

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 17 May 2013

M:\Projects\M9300_Townsville City Council\M9300_001_Bluewater Creek Flood Study\Design\MapInfo\Figures



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ENGENY WATER MANAGEMENT

Townsville

0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Bluewater Creek Flood Study

Appendix A52

Toolakea
PMF Peak Flood Velocity

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 20 May 2013

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Townsville

0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Bluewater Creek Flood Study

Appendix A53

Toolakea
50 Year ARI Highest Astromonical Tide Scenario
Flood Depth Difference

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 17 May 2013

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0 500 1000

Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Bluewater Creek Flood Study

Appendix A54

Toolakea
100 Year ARI Highest Astromonical Tide Scenario
Flood Depth Difference

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 17 May 2013

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Townsville

0 500 1000
Scale in Meters (1:25,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Bluewater Creek Flood Study

Appendix A55

Toolakea
50 Year ARI Climate Change Scenario
Flood Depth Difference

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 17 May 2013

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0 500 1000
Scale in Meters (1:25,000 @ A3)

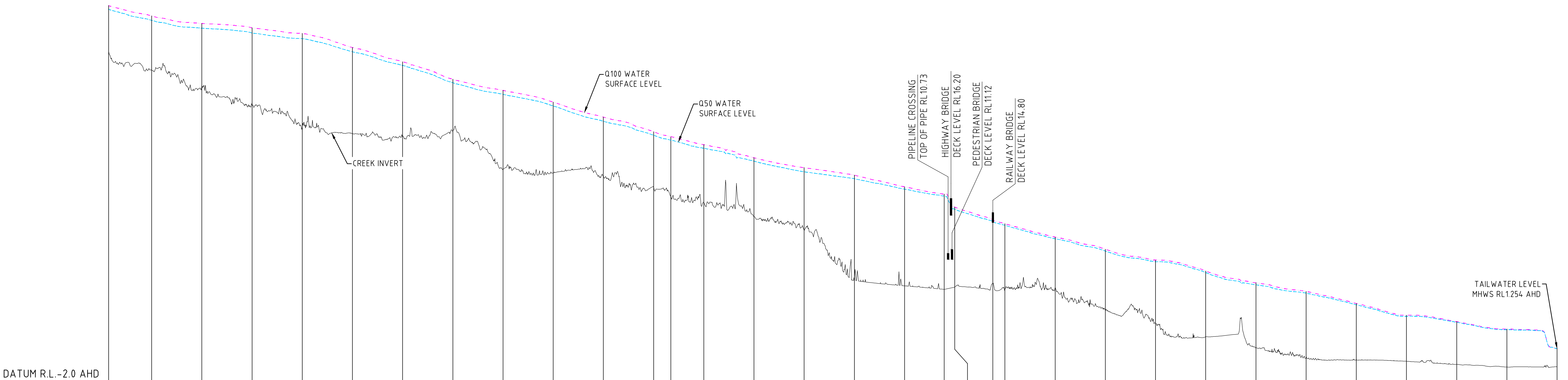
Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Bluewater Creek Flood Study

Appendix A56

Toolakea
100 Year ARI Climate Change Scenario
Flood Depth Difference

Job Number: M9300_001
Revision: 0
Drawn: JNA
Date: 20 May 2013



DATUM R.L.-2.0 AHD

Q100 WSL	35.4	34.367	33.615	33.18	32.623	31.228	29.799	28.071	26.955	25.787	24.296
Q50 WSL	35.04	33.929	33.147	32.666	32.099	30.8	29.437	27.725	26.563	25.407	23.882
CREEK BED LEVEL	30.824	28.969	27.361	25.510	23.329	22.640	22.365	22.887	19.098	18.737	18.376
CHAINAGE	14429	14000	13500	13000	12500	12000	11500	11000	10500	10000	9500

Q100 WSL	22.833	22.351	21.546	20.256	19.26	18.516	17.351	16.605	15.343	14.023	13.678
Q50 WSL	22.483	22.001	21.184	19.91	18.854	18.16	17.123	16.393	15.128	13.845	13.517
CREEK BED LEVEL	17.327	16.408	15.796	14.398	13.054	8.143	7.497	7.167	7.389	7.741	7.141
CHAINAGE	9000	8830	8500	8000	7500	7000	6500	6104	6000	5620	5500

Q100 WSL	12.347	11.142	10.062	8.977	7.795	6.943	5.744	4.572	3.939	3.19	1.262
Q50 WSL	12.176	10.957	9.900	8.816	7.592	6.769	5.608	4.461	3.869	3.128	1.262
CREEK BED LEVEL	7.274	5.124	3.753	2.433	1.328	0.333	0.129	-0.016	-0.328	-0.590	-0.563
CHAINAGE	5000	4500	4000	3500	3000	2500	2000	1500	1000	500	0

BLUEWATER CREEK LONGITUDINAL SECTION

SCALE 1 : 20000 HORIZ. 1 : 200 VERT.

PLAN

SCALE 1 : 20000

SCALE 1:20000 (HORIZONTAL) (A1)
0 200 400 600 800 1000m
0 2 4 6 8 10m
SCALE 1:200 (VERTICAL) (A1)
SCALE BEFORE REDUCTION

REV	DATE	REVISION DESCRIPTION	ORIG	CKD	ENG
0	07/06/2013	ISSUED TO CLIENT	PA		

DESIGNED: DATE:
DESIGN CHECK: DATE:
DRAWN: PA DATE:
DRAWING CHECK: DATE:
SCALE: A1 ORIGINAL
DOC. NUMBER | DOCUMENT TITLE
REFERENCE DOCUMENTS

ENGENY WATER MANAGEMENT
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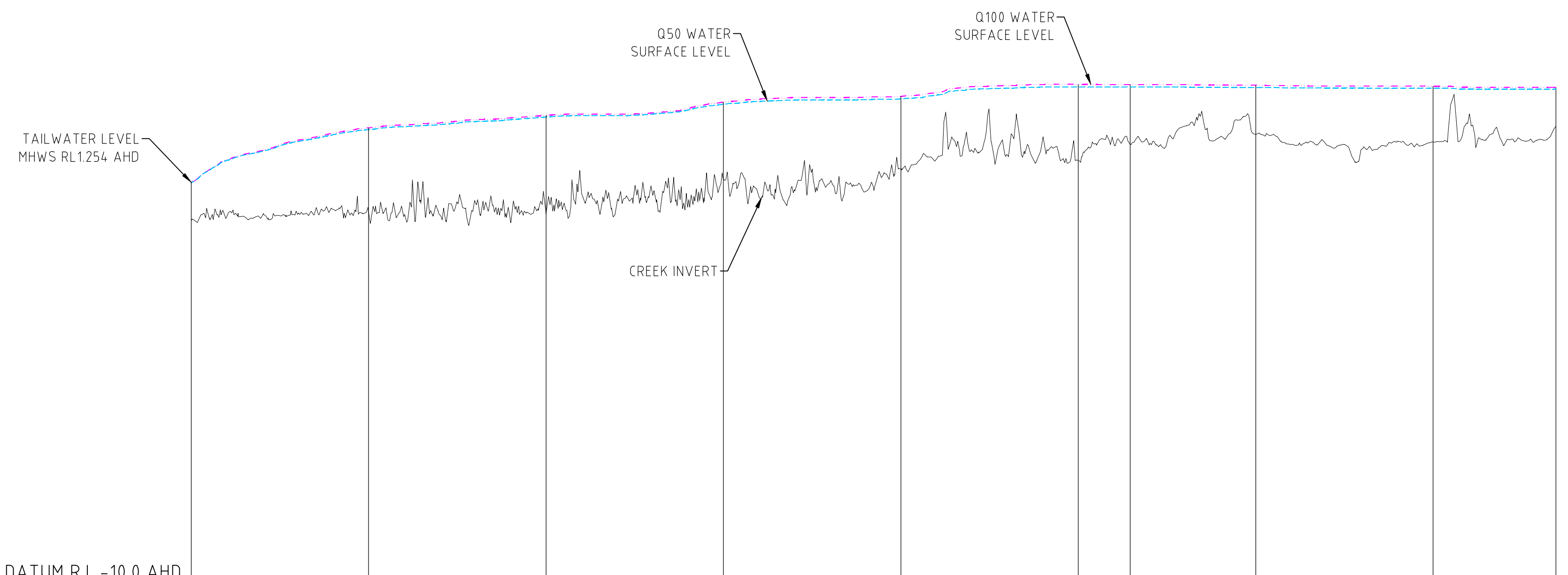
PREPARED FOR:
Townsville

TOWNSVILLE CITY COUNCIL
BLUEWATER CREEK FLOOD STUDY
BLUEWATER CREEK
LONGITUDINAL PROFILE

DRAWING NO: M9300-001-APPENDIX A57 REV: 0

Plot Date: 29 May 2013 - 10:15 AM Plotted by: ---- Cad File No: M:\Projects\M9300_Townsville City Council\M9300_001_Bluewater Creek Flood Study\Design\AutoCAD\Drawings\M9300-001-SK001-SK002.dwg



DATUM R.L.-10.0 AHD

Q100 WSL	1.334	2.868	3.221	3.591	3.755	4.091	4.087	4.066	4.039	4.008
Q50 WSL	1.33	2.819	3.173	3.532	3.684	4.019	4.0163	4.001	3.984	3.954
CREEK BED LEVEL	0.254	0.507	0.448	1.430	1.698	1.957	2.400	2.686	2.468	2.909
CHAINAGE	0	500	1000	1500	2000	2500	2650	3000	3500	3846.116

FERN GULLY LONGITUDINAL SECTION

SCALE 1 : 10000 HORIZ. 1 : 100 VERT.

PLAN

SCALE 1 : 10000

SCALE 1:10000 (HORIZONTAL) (A1)
0 100 200 300 400 500m
0 1 2 3 4 5m
SCALE 1:100 (VERTICAL) (A1)
SCALE BEFORE REDUCTION

REV	DATE	REVISION DESCRIPTION	ORIG	CKD	ENG
0	07/06/2013	ISSUED TO CLIENT	PA		

DESIGNED: DATE:
DESIGN CHECK: DATE:
DRAWN: DATE:
DRAWING CHECK: DATE:
SCALE: A1 ORIGINAL
DOC. NUMBER DOCUMENT TITLE
REFERENCE DOCUMENTS

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PREPARED FOR:
Townsville

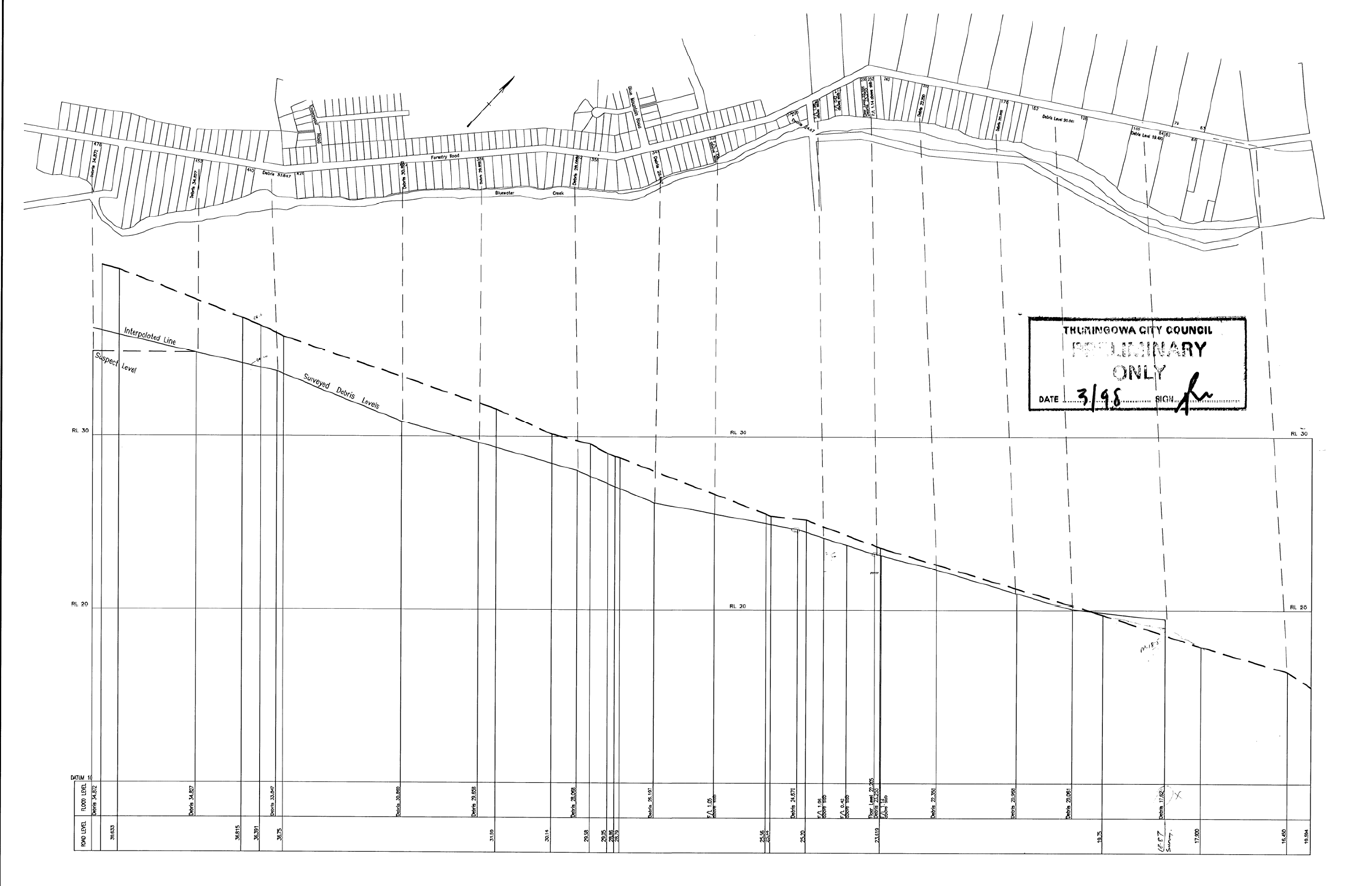
TOWNSVILLE CITY COUNCIL
BLUEWATER CREEK FLOOD STUDY
FERN GULLY
LONGITUDINAL PROFILE

DRAWING NO: M9300-001-APPENDIX A58 REV: 0

Plot Date: 29 May 2013 - 10:15 AM Plotted by: ---- Cad File No: M:\Projects\M9300_Townsville City Council\M9300_001_Bluewater Creek Flood Study\Design\AutoCAD\Drawings\M9300-001-SK001-SK002.dwg

Appendix B

1998 Surveyed Debris Levels



No.	DATE	DESCRIPTION	AP'D
A	24/2/1998	ORIGINAL ISSUE	

REVISIONS

NOTES :

Full Size A1

0 100 200 300 400 500m
Horizontal

0 1 2 3 4 5m
Vertical

CITY OF THURINGOWA

ASSOCIATED DRAWINGS:

REF. B.M.

LEVEL DATUM: AHD	DESIGNED:
FIELD BOOK:	DRAWN:
LEVEL BOOK: LB24 p1-5&10	CHECKED:
PLOTTED:	

CITY OF THURINGOWA

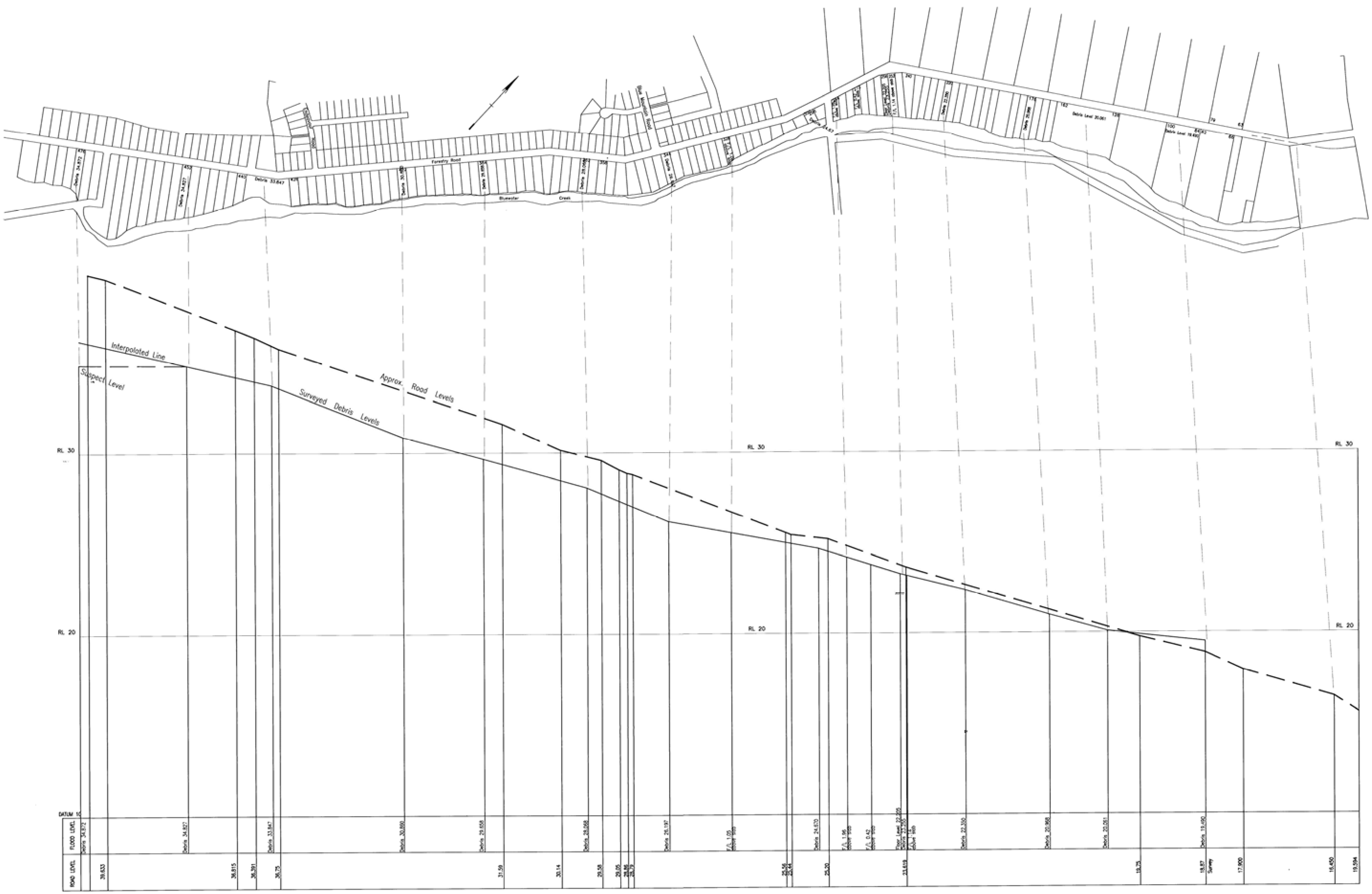
86 Thuringowa Drive, Thuringowa Central, QLD. 4817
Phone (077) 738411 Fax (077) 732936

Engineer Approved: Date:

D.E.S. Approved: Date:

FORESTRY ROAD – BLUEWATER
JANUARY 10 FLOOD – Ex Cyclone SID
FLOOD DEBRIS LEVELS
PLAN AND LONG SECTION

SHEET 1 OF 1 | 12056 | A



No.	DATE	DESCRIPTION	AP'D
B	6/1998	ROAD SURVEY LEVEL ADDED & DEBRIS LEVEL CORRECTED	MAL
A	24/2/1998	ORIGINAL ISSUE	

REVISIONS

NOTES :

Full Size A1

0 100 200 300 400 500m Horizontal

0 1 2 3 4 5m Vertical

ASSOCIATED DRAWINGS:

REF. B.M.

LEVEL DATUM: AHD

FIELD BOOK:

LEVEL BOOK: LB24 p1-5&10

PLOTTED:

DESIGNED:

DRAWN:

CHECKED:

CITY OF THURINGOWA

86 Thuringowa Drive, Thuringowa Central, QLD. 4817

Phone (077) 738411 Fax (077) 732936

Engineer Approved: Date:

D.E.S. Approved: Date:

FORESTRY ROAD – BLUEWATER
JANUARY 10 FLOOD – Ex Cyclone SID
FLOOD DEBRIS LEVELS
PLAN AND LONG SECTION

SHEET 1 OF 1

12056

B

Appendix C

DNRM Bluewater Creek Gauging Station Rating Curve Development

GAUGING STATION DETAILS

GS 117003A Bluewater Ck at Bluewater

Bluewater Ck is a small coastal catchment, arising in the ranges, with a catchment area of 86 km² at GS 117003A. There are no major dams on the system. The channel is lightly treed with rocky lower banks. AMTD = 6.4 km.

Flow is mostly confined at the recorder site. During investigations in 1972 Bluewater Pastoral Co. confirmed that all floods in the past 30 years had been confined to the channel. On 10.01.98 117003A peaked at 9.726m ght, breaking out on the left bank over Forestry Rd and leaving debris at the base of the recorder. The previous highest flood peak was 7.68m ght in 1997.

Control

The control is comprised of uneven rock fragments and is reasonably sensitive and stable. On several occasions, the control has been interfered with by children building rock dams across the stream bed.

The stream bed and banks are the controlling features for medium and high flows.

Quality of Flow Records

Flow records are based on rated height data. Height data is considered good with very few periods of derived data.

Rating

There are sufficient gaugings up to about 60 cumecs but Bluewater Ck has only been gauged to 116.005 cumecs at 3.95m ght. Only one gauging, at 102 cumecs, exists between 60 and 116 cumecs.

In 1972 a Myers Rating of 60 000 cusecs max flood (1699 cumecs) at RL = 114.3 – (9.3+10.00) = RL 95.0 ht was calculated, yielding a velocity of 8 ft/sec (2.44m/s).

The medium and high stage rating is based on Mannings, using the surveyed slope = 0.00092, and an estimated n value of 0.035. Using the surveyed cross section at the cableway site, a discharge of 520 cumecs at 6.60m ght was calculated in 1982. The rating was later extended to 6.8m at 540 cumecs after the 1991 flood and 7.75m at 800 cumecs after the 1994 flood. These rating points appear consistent with Mannings, using the variables listed above.

The rating was extended to 1650 cumecs at 10.000m ght after the 1998 flood exceeded the rating curve for the site. It appears to be a straight line extension from the slope of the curve between 6.8m and 7.75m ght, which does not take into account the overbank flow which was observed by the Thuringowa City Council during the 1998 flood event, or the surveyed flood slope of 0.0033 from this event.

Other Comments

The peak height at 117003A exceeds all surveyed cross sections by at least 0.555m.

11.03.1979 pk = 6.00m ght flood slope surveyed on Left Bank (800m) 0.00092

10.01.1998 pk = 9.73m ght flood slope surveyed on Left Bank 0.0033

Myers Formula

$Q = 10000\ A^{0.5}$

Q = peak flow feet/sec
A = catchment Area mi^2

Appendix D

Structure Details

Branch	ID	Culvert Center (X)	lvert Center	Upstream Invert	Downstream Invert	Length	Manning's n	No. of Culverts	Geometry Type	Diameter (m)	Width (m)	Height (m)
Branch5	1	448266.465	7875455.5	35.989	36.002	11	0.013	2	Rectangular		0.9	0.45
Branch6	21	448279.695	7875982.3	33.275	33.281	11	0.013	2	Rectangular		1.2	0.6
Branch7	2	448807.825	7876390.9	30.503	30.449	11	0.013	3	Rectangular		1.2	0.4
Branch8	3	449039.325	7876243.7	31.554	31.541	12	0.013	2	Rectangular		1.2	0.6
Branch9	4	449387.02	7876631.4	29.454	29.493	12	0.013	2	Rectangular		1.2	0.45
Branch10	5	449320.275	7877407.8	26.223	26.185	16	0.013	1	Rectangular		1.5	0.6
Branch11	6	449446.925	7877384.9	25.464	25.406	15	0.013	4	Circular	1.05		
Branch12	7	450397.225	7878012.3	23.829	23.764	12	0.013	1	Rectangular		1.2	0.3
Branch13	8	450398.38	7878015.5	23.536	23.697	12	0.013	1	Rectangular		1.2	0.45
Branch14	9	451947.27	7879259.2	17.533	17.29	10	0.013	1	Rectangular		1.2	0.6
Branch15	10	452719.875	7879842.3	13.989	13.882	13	0.013	2	Rectangular		1.2	0.3
Branch16	11	452919.405	7880150.4	12.466	12.426	10	0.013	2	Rectangular		1.2	0.6
Branch17	13	453982.135	7880861.4	10.333	10.166	11	0.013	5	Rectangular		1.2	0.45
Branch18	14	454117.645	7880677.7	10.798	10.547	13	0.013	1	Rectangular		0.75	0.375
Branch19	22	448819.445	7876000.1	32.9	32.75	13	0.013	2	Rectangular		1.2	0.6
Branch20	23	449285.195	7876992.8	28.453	28.387	13	0.013	1	Rectangular		1.2	0.375
Branch21	26	448708.33	7877202.4	26.558	26.495	18	0.013	4	Rectangular		2.4	0.9
Branch22	24	449281.845	7877296.1	26.4	26.383	14	0.013	2	Rectangular		1.2	0.75
Branch23	25	449784.935	7877192.8	27	26.9	12	0.013	9	Rectangular		1.2	0.45
Branch24	50	452238.615	7879387.6	16.592	16.572	30	0.013	3	Rectangular		1.2	0.375
Branch25	27	452745.64	7879778	14.748	14.391	23	0.013	1	Circular	0.45		
Branch26	28	452720.9	7879796.6	14.629	13.951	24	0.013	2	Circular	0.75		
Branch27	29	452641.345	7879859.9	14.34	13.97	22	0.013	3	Circular	0.45		
Branch28	30	452472.605	7880011.5	13.511	13.392	16	0.013	1	Circular	0.45		
Branch29	31	452385.83	7880094.1	13.077	12.899	20	0.013	3	Rectangular		1.2	0.45
Branch29	51	452385.83	7880094.1	13.077	12.899	20	0.013	2	Rectangular		1.5	0.45
Branch30	32	452321.82	7880155.7	13.321	13.071	17	0.013	1	Circular	0.375		
Branch31	33	452249.825	7880229.6	13.482	13.22	25	0.013	1	Circular	0.375		
Branch32	12	452942.52	7880172.8	12.828	12.822	16	0.013	1	Rectangular		1.2	0.45
Branch33	34	452930.755	7880181.4	12.731	12.703	13	0.013	1	Rectangular		1.2	0.45
Branch34	35	452969.095	7880215.6	12.168	12.15	14	0.013	3	Rectangular		1.2	0.3
Branch35	36	452660.89	7880410.7	11.853	11.781	10	0.013	2	Rectangular		0.6	0.45
Branch36	37	452631.35	7880434.7	11.829	11.918	10	0.013	1	Rectangular		0.6	0.45
Branch37	38	452624.145	7880441.3	12.09	11.971	10	0.013	1	Rectangular		1.2	0.45
Branch38	39	452610.595	7880452.8	11.811	11.776	10	0.013	1	Rectangular		1.2	0.45
Branch39	40	452592.43	7880467.1	11.9	11.811	10	0.013	1	Rectangular		0.6	0.45
Branch40	41	452575.245	7880481.8	11.93	11.829	10	0.013	1	Rectangular		0.6	0.45
Branch41	42	452565.52	7880490.3	11.948	11.787	10	0.013	1	Rectangular		0.6	0.45
Branch42	43	452557.205	7880496.9	11.942	11.948	10	0.013	1	Rectangular		0.6	0.45
Branch43	44	452547.09	7880504.8	12.162	12.162	10	0.013	1	Rectangular		0.6	0.45
Branch44	45	453096.74	7880460.7	11.971	11.883	12	0.013	3	Rectangular		1.2	0.3
Branch45	46	453112.47	7880532.2	11.609	11.668	16	0.013	2	Rectangular		0.9	0.3
Branch46	47	453623.97	7880755.4	11.413	11.318	12	0.013	2	Rectangular		1.2	0.3
Branch47	48	453904.57	7880920.3	10.64	10.533	15	0.013	2	Rectangular		1.2	0.3

Branch48	17	454539.975	7881370.2	7.738	7.667	11	0.013	8	Rectangular		1.2	0.45
Branch49	16	454401.355	7881550.2	8.395	8.412	11	0.013	4	Rectangular		1.2	0.3
Branch50	15	454320.995	7881595.6	8.338	8.264	13	0.013	1	Rectangular		0.6	0.3
Branch51	18	455993.895	7882306.7	3.693	3.577	12	0.013	2	Circular	1.2		
Branch52	19	456012.515	7882485.3	3.534	3.872	11	0.013	3	Circular	0.45		
Branch53	20	456035.545	7882703.9	2.216	2.501	11	0.013	1	Circular	0.9		
Branch54	49	456050.195	7882848.4	3.131	2.269	15	0.013	1	Circular	0.45		
Branch101	52	452560	7879930	14.2466	13.8489	15	0.013	1	Circular	0.375		
Branch102	53	452025	7880440	12.7924	12.5913	20	0.013	1	Circular	0.375		
Branch103	54	451870	7880580	12.4193	12.5191	18	0.013	1	Rectangular		1.38	0.375
Branch104	55	451715	7880720	12.0922	11.9018	16	0.013	1	Rectangular		1.38	0.375
Branch105	56	451670	7880760	12.6804	11.7605	16	0.013	2	Rectangular		1.38	0.375
Branch106	57	452055	7880915	11.63	11.3321	10	0.013	4	Rectangular		0.6	0.45
Branch107	58	452405	7880620	12.5191	12.2412	10	0.013	1	Rectangular		0.6	0.45

Bridge	X	Y	Soffit (m AHD)	Deck (m AHD)	Width (m)
BluewaterCk_Rail	453,273.88	7,879,896.63	13.8	14.78	4
BluewaterCk_Hwy	452,979.09	7,879,603.61	14.5	16.2	10.1
BluewaterCk_Pipe	452,959.17	7,879,583.60	10.12	10.73	2.5
Bluewater_Ped	452,988.05	7,879,609.72	10.52	11.12	3.5

Appendix E

Bluewater Creek List of Model Simulations

Townsville Flood Study List of Simulation

No.	ARI (yr)	Duration (hr)	Boundary	Value at Boundary
1	2011 Event	51	MHWS	1.254
2	1998 Event	120	MHWS	1.254
3	PMP	2	MHWS	1.254
4	PMP	6	MHWS	1.254
5	PMP	9	MHWS	1.254
6	PMP	12	MHWS	1.254
7	2	2	MHWS	1.254
8	2	9	MHWS	1.254
9	2	12	MHWS	1.254
10	2	36	MHWS	1.254
11	5	2	MHWS	1.254
12	5	9	MHWS	1.254
13	5	12	MHWS	1.254
14	5	36	MHWS	1.254
15	10	2	MHWS	1.254
16	10	9	MHWS	1.254
17	10	12	MHWS	1.254
18	10	36	MHWS	1.254
19	20	2	MHWS	1.254
20	20	9	MHWS	1.254
21	20	12	MHWS	1.254
22	20	24	MHWS	1.254
23	50	2	MHWS	1.254
24	50	9	MHWS	1.254
25	50	12	MHWS	1.254
26	50	24	MHWS	1.254
27	50	2	HAT	2.254
28	50	9	HAT	2.254
29	50	12	HAT	2.254
30	50	24	HAT	2.254
31	50 CC	2	(MHWS+0.8m) AND Rainfall Increase	2.054
32	50 CC	9	(MHWS+0.8m) AND Rainfall Increase	2.054
33	50 CC	12	(MHWS+0.8m) AND Rainfall Increase	2.054
34	50 CC	24	(MHWS+0.8m) AND Rainfall Increase	2.054
35	100	2	MHWS	1.254
36	100	9	MHWS	1.254
37	100	12	MHWS	1.254
38	100	24	MHWS	1.254
39	100	2	HAT	2.254
40	100	9	HAT	2.254
41	100	12	HAT	2.254
42	100	24	HAT	2.254
43	100 CC	2	(MHWS+0.8m) AND Rainfall Increase	2.054
44	100 CC	9	(MHWS+0.8m) AND Rainfall Increase	2.054
45	100 CC	12	(MHWS+0.8m) AND Rainfall Increase	2.054
46	100 CC	24	(MHWS+0.8m) AND Rainfall Increase	2.054
47	500	2	MHWS	1.254
48	500	9	MHWS	1.254
49	500	12	MHWS	1.254
50	500	24	MHWS	1.254

Townsville	above LAT	m AHD
MHWS	3.11	1.254
HAT	4.11	2.254
AHD	1.856	0

Semidiurnal Tidal Planes 2012

Height above Lowest Astronomical Tide

Place	Latitude South	Longitude East	Time Difference HW	LW	MHWS	MHWN	MLWN	MLWS	AHD	MSL	Ratio	Cons	HAT
Tidal Datum Epoch 1992 -2011			1	2	3	4	5	6	7	8	9	10	11
			H M	H M	m	m	m	m	m	m		m	m
Bugatti Reef	**20 05**	**150 18**	**Standard Port**		**2.6**	**2.0**	**1.1**	**0.5**		**1.56**			**3.5**
Rib Reef	18 28	146 52	-0 45	-0 45	2.8	1.9	1.4	0.6		1.68			3.6
Cato Island	23 15	155 32	-2 03	-2 03	1.6	1.3	0.7	0.3		0.99			2.2
Creal Reef	20 32	150 22	+0 20	+0 20	3.2	2.5	1.1	0.4		1.80			4.1
Shute Harbour	**20 17**	**148 47**	**Standard Port**		**3.30**	**2.57**	**1.27**	**0.54**	**1.907**	**1.92**	**1.00**	**0.00**	**4.33**
East Repulse Island	20 35	148 53	+0 15	+0 15	4.5	3.5	1.7	0.8		2.64			5.7
Lindeman Island	20 28	149 03	+0 06	+0 08	3.78	2.95	1.49	0.66		2.32	1.13	+0.05	4.94
Hamilton Island	20 21	148 57	+0 02	+0 02	3.80	2.97	1.51	0.68		2.10	1.13	+0.07	4.96
Abel Point (Airlie Beach)	20 16	148 43	-0 07	-0 06	3.00	2.34	1.16	0.49	1.75	1.75	0.91	0.00	3.94
Cid Harbour	20 15	148 55	-0 02	-0 02	3.3	2.5	1.3	0.5		1.87			4.2
Double Bay	20 11	148 38	-0 20	-0 20	3.0	2.4	1.2	0.6		1.77			3.9
Nara Inlet	20 10	148 54	-0 12	-0 12	3.26	2.55	1.29	0.58		1.89	0.97	+0.06	4.26
Hayman Island	20 04	148 53	-0 24	-0 24	3.3	2.6	1.3	0.6		1.93			4.3
Hook Island	20 04	148 56	-0 13	-0 13	2.9	2.3	1.1	0.5		1.69			3.8
Bowen	**20 01**	**148 15**	**Standard Port**		**2.83**	**2.21**	**1.31**	**0.67**	**1.776**	**1.76**	**1.00**	**0.00**	**3.73**
Abbot Point	**19 51**	**148 05**	**Standard Port**		**2.70**	**2.07**	**1.30**	**0.67**	**1.626**	**1.69**	**1.00**	**0.00**	**3.60**
Oyster Rocks (Burdekin River)	19 44	147 35	-0 03	+0 32	2.54	1.95	1.22	0.63		1.59	0.94	0.00	3.38
Townsville	**19 15**	**146 50**	**Standard Port**		**3.11**	**2.26**	**1.63**	**0.77**	**1.856**	**1.94**	**1.00**	**0.00**	**4.11**
Rocky Ponds Creek	19 50	147 39	+0 58	+1 14	2.47	1.93	1.23	0.70	1.41	1.50			3.38
Cape Ferguson	19 17	147 03	+0 00	-0 01	2.89	2.09	1.49	0.67	1.69	1.76	0.95	-0.06	3.84
Cape Pallarenda	19 11	146 47	+0 02	+0 03	3.10	2.24	1.61	0.75	1.88		1.01	0.00	4.10
Magnetic Island	19 09	146 52	+0 06	+0 02	3.01	2.17	1.57	0.75	1.84	1.91	0.96	0.00	3.98
Townsville Fairway Beacon	19 08	146 54	-0 04	-0 06	2.99	2.17	1.56	0.74		1.86	0.96	0.00	3.95
Britomart Reef	18 15	146 43	-0 15	-0 20	2.67	1.94	1.40	0.66		1.69	0.86	0.00	3.53
Goold Island	18 10	146 09	-0 02	-0 02	2.9	2.2	1.6	0.8		1.88			3.8
Dunk Island	17 56	146 08	-0 02	-0 02	2.8	2.1	1.5	0.8		1.79			3.6
Flinders Reef	17 43	148 27	-0 25	-0 15	2.31	1.72	1.28	0.69		1.48	0.69	+0.16	3.00

Appendix F

Bluewater Creek Semi-Diurnal Tidal Planes 2012

Semidiurnal Tidal Planes 2012

Height above Lowest Astronomical Tide

Place	Latitude	Longitude	Time Difference		MHWS	MHWN	MLWN	MLWS	AHD	MSL	Ratio	Cons	HAT
	South	East	HW	LW									
Tidal Datum Epoch 1992 -2011			1	2	3	4	5	6	7	8	9	10	11
			H M	H M	m	m	m	m	m	m		m	m
Gold Coast Seaway	27 57	153 25	Standard Port		1.42	1.13	0.39	0.11	0.760	0.76	1.00	0.00	1.91
North Coast New South Wales -													
Ballina (Richmond River)	28 53	153 35	+0 06	+0 06	1.4	1.1	0.5	0.2		0.80			1.9
Brunswick Heads	28 32	153 33	+0 07	+0 07	1.5	1.2	0.5	0.2		0.86			2.0
Kingscliff	28 16	153 35	+0 09	+0 09	1.4	1.1	0.4	0.2		0.76			1.9
Tweed River Breakwater	28 10	153 33	-0 04	+0 00	1.47	1.22	0.55	0.29	0.86	0.86	0.92	+0.04	1.91
Gold Coast Beaches -													
Snapper Rocks (Coolangatta)	28 10	153 33	-0 26	-0 15	1.64	1.32	0.49	0.20	0.98	0.97	1.10	0.00	2.11
Broadwater & Nerang River-													
Isle of Capri	28 00	153 25	+0 41	+0 56	1.17	0.90	0.28	0.08	0.59	0.67	0.72	+0.24	1.60
Gold Coast Bridge	27 59	153 25	+0 10	+0 20	1.51	1.23	0.51	0.24	0.79	0.83	0.97	+0.13	1.98
Grand Hotel Jetty	27 57	153 25	+0 16	+0 31	1.39	1.11	0.38	0.11	0.79	0.80	0.98	0.00	1.87
Nerang Township	28 00	153 20	+1 53	+2 39	1.08	0.87	0.17	0.03	0.48	0.58	0.78	0.00	1.49
Paradise Point	27 53	153 24	+1 01	+1 25	1.20	0.93	0.23	0.05	0.61	0.64	0.87	0.00	1.66
Runaway Bay	27 55	153 24	+0 31	+0 52	1.18	0.91	0.22	0.05	0.62	0.62	0.86	0.00	1.65
Coomera River (Saltwater Creek)	27 52	153 20	+1 44	+2 21	1.23	0.99	0.37	0.13	0.56	0.67	0.84	+0.04	1.64
Sanctuary Cove	27 51	153 22	+1 34	+2 06	1.23	0.99	0.37	0.13	0.56	0.67	0.84	+0.04	1.65
Couran Cove	27 49	153 25	+1 19	+1 20	1.34	1.06	0.35	0.09	0.78	0.76	0.96	-0.02	1.81
The Bedroom	27 46	153 26	+1 14	+1 06	1.34	1.06	0.35	0.09		0.76	0.96	-0.02	1.81
Brisbane Bar	27 22	153 10	Standard Port		2.17	1.78	0.76	0.37	1.243	1.27	1.00	0.00	2.73
Pimpama River (Kerkin Rd Weir)	27 48	153 20	+0 57	+1 27	1.36	1.05	0.30	0.15	0.60	0.73			1.78
Albert River -													
Junction Logan River	27 42	153 14	+1 22	+2 14	2.05	1.66	0.54	0.33	0.98	1.12			2.59
Pacific Highway Bridge	27 44	153 13	+1 37	+2 42	1.90	1.50	0.44	0.25	0.91	0.94			2.45
Wolffdene	27 47	153 11	+2 12		1.32	0.98			0.91				1.79
Logan River -													
Rocky Point (Mouth Logan River)	27 42	153 21	+0 40	+0 55	2.09	1.72	0.74	0.37	1.10	1.21	0.96	+0.01	2.63
Junction Albert River	27 42	153 14	+1 22	+2 14	2.05	1.66	0.54	0.33	0.98	1.12			2.59
Slacks Creek (Mouth)	27 40	153 10	+2 13	+3 05	1.79	1.45	0.40	0.21	0.82	0.96			2.27
Waterford	27 42	153 09	+2 39	+3 34	1.59	1.27	0.28	0.11	0.66	0.81			2.03
Brisbane River -													
Boat Passage	27 24	153 10	+0 10	+0 07	2.26	1.85	0.79	0.38	1.24	1.31	1.04	0.00	2.84
Pinkenba	27 26	153 07	+0 11	+0 16	2.26	1.85	0.79	0.38	1.24	1.27	1.04	0.00	2.84
Cairncross Dock	27 27	153 05	+0 18	+0 24	2.30	1.89	0.81	0.39	1.24	1.34	1.06	0.00	2.89
New Farm	27 28	153 03	+0 30	+0 35	2.30	1.89	0.81	0.39	1.24	1.34	1.06	0.00	2.89
Port Office (Edward St Ferry)	27 28	153 02	+0 35	+0 36	2.24	1.83	0.78	0.38	1.24	1.31	1.03	0.00	2.81
Tennyson (Long Pocket)	27 32	153 00	+1 00	+1 20	2.37	1.94	0.83	0.40	1.15		1.09	0.00	2.98
Indooroopilly	27 31	152 59	+1 20	+1 45	2.34	1.92	0.82	0.40	1.15		1.08	0.00	2.95
Seventeen Mile Rocks	27 33	152 58	+1 45	+2 00	2.32	1.90	0.81	0.40	1.05		1.07	0.00	2.92
Jindalee	27 32	152 56	+1 45	+2 00	2.32	1.90	0.81	0.40	1.05		1.07	0.00	2.92
Redbank	27 36	152 51	+2 45	+3 00	2.13	1.74	0.74	0.36	0.95		0.98	0.00	2.68
Moggill Ferry	27 35	152 52	+2 50	+3 10	2.13	1.74	0.74	0.36	0.95		0.98	0.00	2.68
Kholo Creek	27 32	152 51	+2 50	+3 17	1.87	1.45	0.40	0.21	0.69				2.46
Ipswich (Bremer River)	27 35	152 47	+3 00	+3 30	2.16	1.76	0.71	0.30	0.95		1.03	0.00	2.81
Moreton Bay Area -													
Woogoompah Island	27 47	153 24	+0 14	+0 02	1.50	1.23	0.52	0.26		0.82	0.69	-0.02	1.88
Jacobs Well	27 47	153 22	+0 28	+0 18	1.59	1.29	0.49	0.19	0.74	0.86	0.78	-0.10	2.03
The Bedroom	27 46	153 26											
Cabbage Tree Point	27 44	153 22	+0 30	+0 29	1.84	1.50	0.61	0.27	0.89	1.03	0.87	-0.05	2.33
Kalinga Bank	27 44	153 26	-0 34	-0 47	1.49	1.22	0.53	0.26		0.87	0.68	+0.01	1.87

Semidiurnal Tidal Planes 2012

Height above Lowest Astronomical Tide

Place	Latitude South	Longitude East	Time Difference HW	LW	MHWS	MHWN	MLWN	MLWS	AHD	MSL	Ratio	Cons	HAT
Tidal Datum Epoch 1992 -2011			1 H M	2 H M	3 m	4 m	5 m	6 m	7 m	8 m	9	10 m	11 m
Brisbane Bar continued													
Moreton Bay Area continued													
Oak Island	27 42	153 24	+0 15	-0 30	1.71	1.41	0.60	0.29		0.96	0.79	0.00	2.16
Koureyabba	27 42	153 24	+0 30	+0 06	1.76	1.44	0.62	0.30		1.00	0.81	0.00	2.21
Russell Island (Canaipa Point)	27 39	153 25	+0 31	+0 42	2.30	1.89	0.81	0.39	1.39	1.33	1.06	0.00	2.89
Macleay Island (Southern Jetty)	27 38	153 22	+0 30	+0 42	2.25	1.83	0.73	0.31	1.29	1.25	1.08	-0.09	2.86
Redland Bay	27 37	153 18	+0 30	+0 45	2.37	1.94	0.83	0.40	1.41	1.35	1.09	0.00	2.98
Victoria Point	27 35	153 19	+0 14	+0 18	2.38	1.97	0.91	0.50	1.41	1.39	1.04	+0.12	2.96
Macleay Island (Potts Point)	27 35	153 22	+0 15	+0 23	2.28	1.87	0.80	0.39		1.32	1.05	0.00	2.87
Toondah Harbour (Cleveland)	27 32	153 17	+0 13	+0 16	2.21	1.82	0.78	0.38	1.25	1.29	1.02	0.00	2.78
Cleveland Point	27 31	153 18	+0 13	+0 16	2.21	1.82	0.78	0.38	1.25	1.29	1.02	0.00	2.78
Peel Island	27 30	153 21	+0 10	+0 17	2.21	1.82	0.78	0.38		1.23	1.02	0.00	2.78
Dunwich	27 30	153 24	+0 11	+0 16	2.15	1.76	0.75	0.37	1.30	1.22	0.99	0.00	2.70
Raby Bay (Canals Entrance)	27 30	153 16	+0 02	+0 02	2.27	1.86	0.81	0.41	1.36	1.32	1.03	+0.03	2.84
Tingalpa Creek (Mouth)	27 28	153 13	+0 02	+0 06	2.34	1.92	0.82	0.40	1.29		1.08	0.00	2.95
Wellington Point	27 28	153 14	-0 06	-0 03	2.26	1.85	0.79	0.38	1.33	1.26	1.04	0.00	2.84
Lota	27 28	153 11	+0 02	+0 07	2.24	1.83	0.78	0.38	1.29	1.27	1.03	0.00	2.81
Huybers Light	27 27	153 15	+0 12	+0 03	2.17	1.78	0.76	0.37		1.26	1.00	0.00	2.73
Manly	27 27	153 11	+0 02	+0 07	2.24	1.83	0.78	0.38	1.29	1.27	1.03	0.00	2.81
D'Arcy Light	27 26	153 12	+0 02	+0 07	2.17	1.78	0.76	0.37		1.26	1.00	0.00	2.73
Rous Light	27 24	153 20	+0 09	+0 06	2.17	1.78	0.76	0.37		1.21	1.00	0.00	2.73
Amity Point	27 24	153 26	-0 40	-0 54	1.78	1.46	0.62	0.30	1.02	1.09	0.82	0.00	2.24
Saint Helena (South)	27 24	153 13	+0 00	+0 00	2.28	1.87	0.80	0.39		1.32	1.05	0.00	2.87
Nudgee Beach	27 21	153 06	+0 01	-0 01	2.08	1.71	0.73	0.36	1.31	1.19	0.96	0.00	2.62
Cabbage Tree Creek (Mouth)	27 20	153 06	+0 01	-0 01	2.08	1.71	0.73	0.36	1.31	1.19	0.96	0.00	2.62
Shorncliffe and Sandgate	27 20	153 05	+0 01	-0 01	2.08	1.71	0.73	0.36	1.31	1.19	0.96	0.00	2.62
Woody Point	27 16	153 06	+0 00	+0 02	2.06	1.69	0.72	0.35	1.23	1.15	0.95	0.00	2.59
Measured Mile-Rear Recip. Lead	27 15	153 15	-0 25	-0 23	2.04	1.67	0.71	0.35		1.14	0.94	0.00	2.57
Margate	27 15	153 07	+0 00	+0 02	2.06	1.69	0.72	0.35	1.23	1.15	0.95	0.00	2.59
Redcliffe	27 14	153 07	+0 00	+0 00	2.08	1.71	0.73	0.36		1.11	0.96	0.00	2.62
East Channel	27 14	153 20	-0 09	-0 13	2.06	1.69	0.72	0.35		1.20	0.95	0.00	2.59
Scarborough Boat Harbour	27 12	153 06	+0 05	+0 05	1.93	1.58	0.68	0.33	1.17	1.11	0.89	0.00	2.43
Tangalooma	27 11	153 22	-0 23	-0 27	2.00	1.65	0.73	0.38		1.15	0.90	+0.05	2.51
Beachmere(Caboolture River)	27 08	153 02	+0 06	+0 18	2.08	1.71	0.73	0.36	1.26	1.21	0.96	0.00	2.62
Bulwer Wrecks	27 05	153 22	-0 25	-0 30	1.76	1.44	0.62	0.30		1.02	0.81	0.00	2.21
North West Channel Fairway	26 51	153 09	-1 30	-1 40	1.63	1.34	0.57	0.28	0.99	0.95	0.75	0.00	2.05
North Pine River -													
Deepwater Bend	27 18	153 02	+0 13	+0 41	2.17	1.78	0.78	0.40	1.24	1.28	0.98	+0.04	2.72
Petrie	27 17	152 58	+0 24	+0 52	2.26	1.85	0.79	0.38	1.26	1.27	1.04	0.00	2.84
Pumicestone Passage-Bribie Is.													
Bribie Beacon (South Point)	27 06	153 09	-0 09	-0 13	1.91	1.57	0.69	0.36		1.09	0.86	+0.04	2.39
Bongaree	27 05	153 09	+0 00	-0 15	1.87	1.53	0.65	0.32	1.10	1.06	0.86	0.00	2.35
Woorim	27 05	153 12	-0 22	-0 34	1.71	1.41	0.60	0.29		0.93	0.79	0.00	2.16
Toorbul	27 02	153 06	+0 30	+0 20	1.95	1.60	0.68	0.33	1.10	1.13	0.90	0.00	2.46
Donnybrook	27 00	153 04	+1 00	+0 56	1.88	1.55	0.69	0.35	1.12	1.11	0.85	+0.04	2.36
Hussey Creek (Mouth)	26 56	153 04	+2 04	+2 56	1.35	1.04	0.40	0.32					1.80
The Skids	26 54	153 04	+1 48	+2 05	0.98	0.66	0.28	0.14	0.41	0.51			1.38
Halls Creek (Mouth) 'The Farm'	26 52	153 07	+0 47	+1 33	0.87	0.62			0.46	0.59			1.21
Golden Beach (Caloundra)	26 48	153 07	-0 53	-0 11	1.12	0.82	0.43	0.32	0.66	0.77			1.52

Semidiurnal Tidal Planes 2012

Height above Lowest Astronomical Tide

Place	Latitude	Longitude	Time Difference		MHWS	MHWN	MLWN	MLWS	AHD	MSL	Ratio	Cons	HAT
	South	East	HW	LW									
Tidal Datum Epoch 1992 -2011			1	2	3	4	5	6	7	8	9	10	11
			H M	H M	m	m	m	m	m	m		m	m
Mooloolaba	26 41	153 08	Standard Port		1.66	1.33	0.58	0.26	0.990	0.96	1.00	0.00	2.17
Caloundra Head	26 48	153 09	+0 00	+0 00	1.63	1.34	0.57	0.28	0.99	0.95			2.05
Parrearra (Mooloolah River)	26 43	153 07	+0 23	+0 44	1.67	1.23	0.55	0.20	0.93		0.94	0.00	2.21
Mooloolaba Beach	26 41	153 06	+0 00	+0 00	1.66	1.33	0.58	0.26	0.99	0.97	1.00	0.00	2.17
Maroochydore Beach	26 40	153 06	+0 00	+0 00	1.66	1.33	0.58	0.26	0.99	0.97	1.00	0.00	2.17
Coolum	26 31	153 06	+0 00	+0 00	1.66	1.33	0.58	0.26	0.99	0.97	1.00	0.00	2.17
Maroochy River -													
Picnic Point	26 39	153 05	+1 02	+1 52	0.93	0.65	0.27	0.13	0.46	0.52			1.36
David Low Bridge	26 38	153 03	+1 35	+2 27	0.90	0.66	0.30	0.19	0.44	0.53			1.28
Dunethin Rock	26 35	153 02	+2 09	+3 06	1.03	0.78	0.28	0.15	0.44	0.53			1.41
Junction North Maroochy River	26 34	152 58	+2 18	+3 12	1.15	0.88	0.34	0.22	0.49	0.60			1.57
Noosa Head	26 23	153 06	Standard Port		1.78	1.45	0.71	0.38	1.123	1.08	1.00	0.00	2.28
Noosa River -													
Munna Point	26 24	153 04	+0 42	+1 35	0.78	0.65	0.29	0.17	0.42	0.45	0.40	+0.13	1.10
Tewantin	26 24	153 02	+1 07	+1 49	0.61	0.53	0.28	0.20	0.34	0.38	0.31	+0.09	0.89
Noosa Beaches -													
Noosa Beach	26 23	153 05	+0 00	+0 00	1.78	1.45	0.71	0.38	1.12	1.06	1.00	0.00	2.28
Teewah Sands	26 16	153 04	+0 00	+0 00	1.78	1.45	0.71	0.38	1.12	1.06	1.00	0.00	2.28
Cooloola	26 11	153 04	+0 00	+0 00	1.78	1.45	0.71	0.38	1.12	1.06	1.00	0.00	2.28
Double Island Point	25 55	153 11	+0 00	+0 00	1.78	1.45	0.71	0.38	1.12	1.06	1.00	0.00	2.28
Rainbow Beach	25 54	153 05	+0 00	+0 00	1.78	1.45	0.71	0.38	1.12	1.06	1.00	0.00	2.28
Waddy Point (Fraser Island)	24 58	153 21	Standard Port		1.75	1.44	0.81	0.50	1.007	1.129	1.00	0.00	2.37
Wide Bay Bar (Ocean Side)	25 49	153 03	+0 00	+0 00									
Eurong	25 30	153 07	+0 00	+0 00									
Happy Valley	25 20	153 12	+0 00	+0 00									
Indian Head	25 00	153 22	+0 00	+0 00									
Orchid Beach	24 58	153 19	+0 00	+0 00									
Urangan	25 18	152 55	Standard Port		3.49	2.80	1.38	0.68	2.040	2.09	1.00	0.00	4.28
Kingfisher Bay	25 24	153 06	+0 11	+0 18	3.73	3.00	1.48	0.73		2.26	1.07	0.00	4.58
Bundaberg (Burnett Heads)	24 46	152 23	Standard Port		2.88	2.30	1.14	0.56	1.693	1.72	1.00	0.00	3.67
Great Sandy Strait -													
Tin Can Bay (Snapper Creek)	25 54	153 00	+0 44	-0 16	2.31	1.84	0.91	0.45	1.36	1.36	0.80	0.00	2.94
Elbow Point	25 48	153 01	+0 15	-0 03	2.14	1.71	0.85	0.42		1.28	0.74	0.01	2.73
Snout Point	25 42	152 59	+0 55	+0 29	2.34	1.86	0.92	0.45		1.39	0.81	0.00	2.97
Big Tuan	25 41	152 53	+0 55	+1 05	2.16	1.73	0.86	0.42	1.19	1.37	0.75	0.00	2.75
Boonooroo	25 39	152 54	+0 55	+1 05	2.16	1.73	0.86	0.42	1.19	1.37	0.75	0.00	2.75
Boonlye Point	25 34	152 56	+1 09	+0 57	3.14	2.51	1.24	0.61		1.89	1.09	0.00	4.00
Ungowa Jetty	25 30	152 59	+0 51	+0 49	3.83	3.06	1.52	0.74		2.39	1.33	0.00	4.88
Mary River -													
Bingham (River Heads)	25 26	152 55	+1 13	+1 11	3.70	3.05	1.19	0.64	2.17	2.17			4.60
Baumgarts	25 30	152 44	+2 00	+3 10	3.30	2.56	0.62	0.31	1.49				4.39
Maryborough	25 33	152 43	+1 57	+3 00	3.22	2.55	0.53	0.14	1.40				4.10
Copenhagen Bend	25 31	152 39	+2 46	+3 53	3.24	2.50	0.37	0.22	1.22				4.22
Barrage	25 37	152 37	+3 03	+5 09	2.92	2.24	0.18	0.09	0.86				3.79

Semidiurnal Tidal Planes 2012

Height above Lowest Astronomical Tide

Place Tidal Datum Epoch 1992 -2011	Latitude South	Longitude East	Time Difference HW 1 H M	Time Difference LW 2 H M	MHWS 3 m	MHWN 4 m	MLWN 5 m	MLWS 6 m	AHD 7 m	MSL 8 m	Ratio 9	Cons 10 m	HAT 11 m
Bundaberg (Burnett Heads) cont.													
Hervey Bay -													
Point Vernon	25 15	152 48	-0 10	-0 10	3.23	2.58	1.28	0.63	1.89	1.90	1.12	0.00	4.11
Burrum Heads	25 11	152 37	+0 12	+0 30	3.05	2.42	1.17	0.54	1.82	1.78	1.08	-0.06	3.90
Woodgate (Theodolite Creek)	25 04	152 33	-0 15	-0 15	3.06	2.44	1.21	0.59	1.77	1.78	1.06	0.00	3.89
Wathumba Creek (Fraser Island)	24 58	153 14	-0 12	+0 36	3.03	2.43	1.18	0.55		1.86	1.06	0.00	3.88
Elliott River Entrance	24 55	152 30	-0 09	-0 09	2.96	2.35	1.13	0.52	1.70	1.73	1.05	-0.07	3.78
Burnett River (Town Reach)	24 52	152 21	+0 32	+0 57	3.17	2.53	1.25	0.62	1.79	1.83	1.10	0.00	4.04
Bargara	24 49	152 27	+0 00	+0 00	2.88	2.30	1.14	0.56	1.69	1.73	1.00	0.00	3.67
Kolan River (Booyan Bridge)	24 42	152 11	+0 23	+1 30	2.60	2.02	0.86	0.66	1.31	1.51	0.89	0.00	3.37
Baffle Creek (Winfield)	24 32	152 02	+1 05	+1 56	2.22	1.74	1.02	1.02	1.32	1.56			2.83
Lady Elliot Island	24 07	152 43	-0 19	-0 19	2.1	1.7	0.8	0.4		1.25			2.8
Gladstone	23 50	151 15	Standard Port		3.96	3.11	1.57	0.72	2.268	2.34	1.00	0.00	4.83
Seventeen Seventy	24 11	151 53	-0 35	-0 22	2.79	2.20	1.12	0.52	1.61	1.60	0.70	0.00	3.58
Pancake Creek	24 01	151 44	-0 35	-0 35	2.97	2.33	1.18	0.54		1.74	0.75	0.00	3.62
Clews Point	24 01	151 45	-0 45	-0 45	2.9	2.2	1.1	0.4		1.64			3.5
Lady Musgrave Island	23 55	152 23	-0 52	-0 52	2.2	1.7	0.9	0.4		1.30			2.9
Gatcombe Head	23 53	151 22	-0 17	-0 16	3.45	2.71	1.37	0.56		2.08	0.87	0.00	4.29
South Trees Wharf	23 51	151 19	-0 11	-0 10	3.80	2.99	1.51	0.69	2.21	2.20	0.96	0.00	4.63
Fishermans Landing	23 47	151 11	+0 15	+0 12	4.20	3.30	1.66	0.76	2.43	2.41	1.06	0.00	5.12
Graham Creek	23 45	151 11	+0 19	+0 10	4.34	3.41	1.72	0.79		2.58	1.10	0.00	5.30
The Narrows (Boat Creek)	23 39	151 06	+0 31	+0 26	4.58	3.59	1.79	0.79		2.68	1.17	-0.05	5.60
The Narrows (Ramsay Crossing)	23 38	151 05	+0 19	+0 22	5.08	4.01	2.07	1.00		3.01	1.26	0.09	6.17
Sea Hill	23 30	150 59	-0 01	-0 07	4.47	3.51	1.77	0.81		2.63	1.13	0.00	5.45
Polmaise Reef	23 34	151 39	-0 29	-0 29	3.0	2.3	1.1	0.4		1.71			3.7
Heron Island	23 27	151 55	-0 43	-0 38	2.68	2.11	1.01	0.42		1.44	0.70	0.00	3.30
Rockhampton	23 23	150 31	+1 23	+2 31	5.18	4.16	1.63	0.95	2.52	2.86			6.42
Tryon Island	23 14	151 46	-0 18	-0 18	2.9	2.2	1.1	0.4		1.63			3.6
Great Keppel Island	23 11	150 56	+0 05	+0 03	4.16	3.27	1.65	0.76		2.43	1.05	0.00	5.07
Cape Manifold	22 41	150 50	+0 17	+0 29	4.36	3.42	1.73	0.79		2.52	1.10	0.00	5.31
Port Clinton	22 32	150 45	+0 34	+0 34	4.3	3.3	1.6	0.5		2.44			5.2
Gannet Cay	21 59	152 28	-0 09	-0 09	2.1	1.6	0.8	0.4		1.23			2.8
Port Alma	23 35	150 52	Standard Port		4.93	3.83	1.98	0.88	2.854	2.90	1.00	0.00	5.98
Rosslyn Bay	23 10	150 48	Standard Port		4.23	3.24	1.60	0.62	2.360	2.42	1.00	0.00	5.14
Hay Point	21 16	149 18	Standard Port		5.80	4.48	2.25	0.94	3.340	3.37	1.00	0.00	7.14
Marquis Island	22 20	150 27	-0 26	-0 26	6.5	5.0	2.5	1.0		3.73			7.5
McEwen Islet	22 09	149 36	+0 24	+0 24	7.4	5.6	2.6	0.8		4.13			9.1
High Peak Island	21 57	150 41	-0 45	-0 45	4.8	3.7	1.8	0.7		2.75			5.9
Bell Cay	21 49	151 15	-0 58	-0 58	3.6	2.7	1.3	0.4		2.00			4.3
Middle Island (Percy Isles)	21 39	150 15	-0 14	-0 14	5.7	4.2	2.2	0.7		3.23			6.7
Cullen Islet	21 25	149 29	-0 03	-0 03	6.09	4.70	2.36	0.99		3.51	1.05	0.00	7.50
Penrith Island	21 00	149 54	-0 07	-0 07	4.6	3.5	1.6	0.5		2.56			5.6
Scawfell Island	20 52	149 37	-0 04	-0 04	4.4	3.4	1.7	0.6		2.51			5.4
Mackay Outer Harbour	21 06	149 14	Standard Port		5.29	4.07	1.96	0.74	2.941	3.02	1.00	0.00	6.58
Thirsty Sound	22 08	150 02	-0 26	-0 37	6.08	4.68	2.25	0.85		3.45	1.15	0.00	7.57
Keswick Island	20 55	149 26	-0 03	+0 04	4.71	3.62	1.74	0.66		2.69	0.89	0.00	5.86
Halliday Bay	20 54	148 59	+0 09	+0 23	5.03	3.73	1.69	0.56	2.63	2.65	0.92	0.00	6.14
Finlayson Point	20 53	148 56	+0 20	+0 20	5.40	4.15	2.00	0.75		3.07	1.02	0.00	6.71
Carlisle Island	20 47	149 17	+0 02	-0 02	4.44	3.42	1.65	0.62		2.53	0.84	0.00	5.53
Laguna Quays Marina	20 36	148 40	+0 30	+0 25	4.74	3.74	1.87	0.88	2.81	2.74	0.91	+0.02	6.30

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Tidal Datum Epoch 1992 -2011													
Bugatti Reef	20 05	150 18	Standard Port		2.6	2.0	1.1	0.5		1.56			3.5
Rib Reef	18 28	146 52	-0 45	-0 45	2.8	1.9	1.4	0.6		1.68			3.6
Cato Island	23 15	155 32	-2 03	-2 03	1.6	1.3	0.7	0.3		0.99			2.2
Creal Reef	20 32	150 22	+0 20	+0 20	3.2	2.5	1.1	0.4		1.80			4.1
Shute Harbour	20 17	148 47	Standard Port		3.30	2.57	1.27	0.54	1.907	1.92	1.00	0.00	4.33
East Repulse Island	20 35	148 53	+0 15	+0 15	4.5	3.5	1.7	0.8		2.64			5.7
Lindeman Island	20 28	149 03	+0 06	+0 08	3.78	2.95	1.49	0.66		2.32	1.13	+0.05	4.94
Hamilton Island	20 21	148 57	+0 02	+0 02	3.80	2.97	1.51	0.68		2.10	1.13	+0.07	4.96
Abel Point (Airlie Beach)	20 16	148 43	-0 07	-0 06	3.00	2.34	1.16	0.49	1.75	1.75	0.91	0.00	3.94
Cid Harbour	20 15	148 55	-0 02	-0 02	3.3	2.5	1.3	0.5		1.87			4.2
Double Bay	20 11	148 38	-0 20	-0 20	3.0	2.4	1.2	0.6		1.77			3.9
Nara Inlet	20 10	148 54	-0 12	-0 12	3.26	2.55	1.29	0.58		1.89	0.97	+0.06	4.26
Hayman Island	20 04	148 53	-0 24	-0 24	3.3	2.6	1.3	0.6		1.93			4.3
Hook Island	20 04	148 56	-0 13	-0 13	2.9	2.3	1.1	0.5		1.69			3.8
Bowen	20 01	148 15	Standard Port		2.83	2.21	1.31	0.67	1.776	1.76	1.00	0.00	3.73
Abbot Point	19 51	148 05	Standard Port		2.70	2.07	1.30	0.67	1.626	1.69	1.00	0.00	3.60
Oyster Rocks (Burdekin River)	19 44	147 35	-0 03	+0 32	2.54	1.95	1.22	0.63		1.59	0.94	0.00	3.38
Townsville	19 15	146 50	Standard Port		3.11	2.26	1.63	0.77	1.856	1.94	1.00	0.00	4.11
Rocky Ponds Creek	19 50	147 39	+0 58	+1 14	2.47	1.93	1.23	0.70	1.41	1.50			3.38
Cape Ferguson	19 17	147 03	+0 00	-0 01	2.89	2.09	1.49	0.67	1.69	1.76	0.95	-0.06	3.84
Cape Pallarenda	19 11	146 47	+0 02	+0 03	3.10	2.24	1.61	0.75	1.88		1.01	0.00	4.10
Magnetic Island	19 09	146 52	+0 06	+0 02	3.01	2.17	1.57	0.75	1.84	1.91	0.96	0.00	3.98
Townsville Fairway Beacon	19 08	146 54	-0 04	-0 06	2.99	2.17	1.56	0.74		1.86	0.96	0.00	3.95
Britomart Reef	18 15	146 43	-0 15	-0 20	2.67	1.94	1.40	0.66		1.69	0.86	0.00	3.53
Goold Island	18 10	146 09	-0 02	-0 02	2.9	2.2	1.6	0.8		1.88			3.8
Dunk Island	17 56	146 08	-0 02	-0 02	2.8	2.1	1.5	0.8		1.79			3.6
Flinders Reef	17 43	148 27	-0 25	-0 15	2.31	1.72	1.28	0.69		1.48	0.69	+0.16	3.00
Lucinda (Offshore)	18 31	146 23	Standard Port		2.98	2.18	1.60	0.80	1.844	1.89	1.00	0.00	3.96
Albino Rock	18 47	146 43	+0 01	+0 01	2.7	1.9	1.3	0.5		1.56			3.5
Cardwell	18 16	146 02	+0 01	-0 05	3.14	2.28	1.68	0.81	1.86	1.94	1.06	0.00	4.13
Mourilyan Harbour	17 36	146 07	Standard Port		2.65	1.98	1.49	0.83	1.729	1.74	1.00	0.00	3.50
Clump Point	17 51	146 06	+0 01	+0 01	2.72	2.01	1.49	0.79	1.68	1.73	1.06	-0.09	3.62
Nathan Reef	17 32	146 30	-0 07	-0 04	2.39	1.78	1.34	0.74		1.61	0.90	0.00	3.15
Innisfail	17 31	146 02	+0 25	+0 55	1.97	1.31	1.12	0.83	0.96	1.06	0.98	-0.63	2.80
Flying Fish Point	17 30	146 05	+0 05	+0 15	2.62	1.96	1.48	0.82	1.63	1.69	0.99	0.00	3.47
Peart Reef	17 29	146 25	-0 08	-0 02	2.51	1.86	1.49	0.83		1.64	0.95	0.00	3.47
Cairns	16 56	145 47	Standard Port		2.62	1.94	1.46	0.78	1.643	1.70	1.00	0.00	3.50
Saxon Reef	16 28	145 59	+0 17	+0 11	2.30	1.70	1.28	0.68			0.88	0.00	3.08
Low Islets	16 23	145 34	+0 00	+0 00	2.37	1.83	1.34	0.81		1.55	0.93	0.00	3.25
Cooktown	15 28	145 15	-0 02	+0 06	2.40	1.77	1.32	0.71	1.48	1.49	0.92	0.00	3.20
Cape Flattery	14 57	145 19	-0 10	-0 10	2.38	1.71	1.32	0.65		1.48	0.89	0.00	3.08
Morris Island	13 29	143 42	+0 14	+0 14	2.5	1.8	1.4	0.7		1.58			3.3
Portland Roads	12 36	143 25	+0 19	+0 08	2.62	1.94	1.46	0.78		1.63	1.00	0.00	3.50
Cape Grenville	11 58	143 16	+0 51	+0 51	2.6	1.8	1.3	0.5		1.53			3.3

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Tidal Datum Epoch 1992 -2011			1 H M	2 H M	3 m	4 m	5 m	6 m	7 m	8 m	9	10 m	11 m
Port Douglas	16 29	145 28	Standard Port		2.49	1.83	1.37	0.70	1.581	1.60	1.00	0.00	3.36
Leggatt Island	14 32	144 51	Standard Port							1.70	1.00	0.00	3.4
Normanby River	14 26	144 09	+0 05	+0 05	2.5	1.6	1.2	0.3		1.39			3.4
Flinders Island	14 10	144 14	+0 11	+0 11	2.5	1.7	1.4	0.6		1.52			3.3
Eden Reef	14 04	143 54	-0 10	-0 10	2.8	2.0	1.5	0.7		1.77			3.6
Pelican Island	13 55	143 50	+0 07	+0 07	3.0	2.2	1.7	0.9		1.93			3.9
Fife Island	13 39	143 43	+0 03	+0 03	2.6	1.8	1.4	0.7		1.63			3.3
Round Point	11 54	143 06	+0 42	+0 42	2.8	1.9	1.4	0.5		1.67			3.6
Hannibal Islands	11 36	142 56	+0 56	+0 56	3.0	2.1	1.5	0.6		1.78			3.8
Collette Reef	11 14	142 56	+0 34	+0 34	2.7	1.9	1.3	0.5		1.60			3.5

The secondary place time differences and tidal planes are based on short observation sets and are updated as new observations become available.

Appendix G

Bluewater Creek Annual Peak Flow Summary

Water Year	Stream Discharge (m^3/s)
1997	816.3414041
1999	419.0449939
2010	417.5533339
1996	390.238089
1993	319.0445539
2007	314.977472
1990	281.5673051
2004	268.9780442
2006	261.708667
2011	261.3578616
2008	255.0574255
1989	250.5330905
2009	247.9547758
1978	241.8389855
1980	239.1211527
2001	232.6593913
1975	213.004888
2000	201.3530757
1995	176.4712158
1982	175.7908658
1976	175.0366151
1983	143.0101582
2003	138.9075777
1988	137.9132843
1974	127.9660157
1977	116.9692001
1973	108.4978733
1991	106.6276181
1979	102.3116804
2005	53.63935071
1998	47.07043865
1985	45.01900843
1992	25.2309444
2002	18.40127332
1986	17.83755102
1981	9.791336625
1994	8.851986904
1987	3.155200784
1984	0.217516135
2012	0.115708998