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Captains Creek Flood Study

Base-line Flooding Assessment

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Client: Townsville City Council

ABN: 44 741 992 072

Prepared by

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Executive Summary

The Captains Creek Flood Study – Baseline Flooding Assessment has been completed as a component of Townsville City Council's (TCC) City Wide Flood Constraints Project. A detailed flood model has been developed to quantify the flood risk for the Captains Creek catchment, which includes the suburbs of:

- Rowes Bay
- Garbutt
- West End (parts of)
- Belgian Gardens (parts of).

A coupled two-dimensional / one-dimensional MIKE FLOOD hydraulic model was developed to provide detailed representation of key hydraulic controls within the Captains Creek catchment. The hydraulic model comprises of:

- a Digital Elevation Model (DEM) resolved to a 5 m grid
- open drains narrower than the 5 m grid resolution resolved as one-dimensional branches
- components of the underground drainage network with greater than 900 equivalent pipe diameter
- runoff hydrographs for each 5 m model grid cell within areas of low steepness
- point runoff hydrographs to represent flows at the outlet of steep catchments.

Verification of the model results was performed through comparison with calibrated overlapping flood models which were developed as part of TCC's City Wide Flood Constraints Project and through comparison with a previous study for the Garbutt area.

The flood model was used to assess design storm events for the 2, 5, 10, 20, 50, 100, 200 and 500 Average Recurrence Interval (ARI) as well as the Probable Maximum Flood (PMF) event.

The flood model results for the design storm events were used to:

- quantify the floodplain response with hydraulic grade lines and flow distributions for a variety of design events
- evaluate the potential flood impacts on residential properties
- identify emergency management considerations.

An assessment of the sensitivity of the hydraulic model outputs to climate change impacts and sea level rise was undertaken. It was found that for a 15% increase in rainfall intensity with 0.8 m sea level rise, an increase in flood depths of generally 10 – 50 mm is predicted with a higher increase of up to 250 mm in the Rowes Bay tidal flats and a particularly sensitive area at Heatley's Parade.

Two-dimensional mapping of the model outputs included water surface elevations, water depth and flow velocity envelopes for each of the design flood events. These maps are provided in Appendix A.

Table EX-1 provides a summary of the existing flooding constraints for the Captains Creek study area. This table includes indicative rainfalls for the design events to allow a broad comparison with real flood events.

The results of the study will enable TCC to identify flood hazard zones on the floodplain to inform flood overlay development for the new Townsville City Plan.

Table Ex-1 – Summary of Captains Creek Flood Study Results

Event	Indicative Rainfall	Properties Inundated[1]	Major Evacuation Route Closures	Flooding Description
2 year ARI	53 mm in 1 hour 70 mm in 2 hours 82 mm in 3 hours 96 mm in 4.5 hours 107 mm in 6 hours 125 mm in 9 hours 140 mm in 12 hours 166 mm in 18 hours 186 mm in 24 hours 242 mm in 48 hours 276 mm in 72 hours	148	Bundock Street Percy Street	- Flows contained mainly within the channel, break out flows occurring in the Melrose Park area and adjacent to the airport drain. - Floodplain inundation up to 1.5 m across the floodplain. - No significant impact predicted for residential areas (i.e. water depth generally below 0.3 m). - Velocities up to 1.5 m/s predicted across Bundock Street, and in Belgian Gardens.
5 year ARI	70 mm in 1 hour 93 mm in 2 hours 109 mm in 3 hours 127 mm in 4.5 hours 142 mm in 6 hours 166 mm in 9 hours 186 mm in 12 hours 223 mm in 18 hours 252 mm in 24 hours 336 mm in 48 hours 389 mm in 72 hours	213	Bundock Street Percy Street Old Common Road	- Floodplain inundation up to 2 m across the floodplain. - Properties near Melrose Park Channel, Percy Street inundated with water depths of up to 0.5 m. - Velocities up to 1.75 m/s predicted across Percy Street, Harold Street, Bundock Street, and in Belgian Gardens.

Event	Indicative Rainfall	Properties Inundated[1]	Major Evacuation Route Closures	Flooding Description
10 year ARI	81 mm in 1 hour 106 mm in 2 hours 125 mm in 3 hours 146 mm in 4.5 hours 163 mm in 6 hours 191 mm in 9 hours 214 mm in 12 hours 257 mm in 18 hours 293 mm in 24 hours 396 mm in 48 hours 462 mm in 72 hours	257	Bundock Street Percy Street Old Common Road	- Floodplain inundation up to 2 m across the floodplain. - Properties near Melrose Park Channel, Percy Street inundated with water depths of up to 0.5 m. - Properties in North Ward area inundated with water depths of up to 1 m. - Velocities up to 2 m/s predicted across Percy Street, Harold Street, Bundock Street, and in Belgian Gardens.
20 year ARI	94 mm in 1 hour 124 mm in 2 hours 146 mm in 3 hours 171 mm in 4.5 hours 190 mm in 6 hours 223 mm in 9 hours 250 mm in 12 hours 302 mm in 18 hours 348 mm in 24 hours 473 mm in 48 hours 554 mm in 72 hours	296	Bundock Street Percy Street Old Common Road Heatleys Parade	- Floodplain inundation up to 2 m across the floodplain. - Properties near Melrose Park Channel, Percy Street inundated with water depths of up to 0.75 m. - Properties in North Ward area inundated with water depths of up to 1 m. - Velocities up to 2 m/s predicted across Percy Street, Harold Street, Bundock Street, and in Belgian Gardens.
50 year ARI	112 mm in 1 hour 148 mm in 2 hours 174 mm in 3 hours 203 mm in 4.5 hours 227 mm in 6 hours 266 mm in 9 hours 298 mm in 12 hours 364 mm in 18 hours 420 mm in 24 hours 581 mm in 48 hours 683 mm in 72 hours	404	Bundock Street Percy Street Old Common Road Heatleys Parade	- Floodplain inundation up to 3 m across the floodplain. - Properties near Melrose Park Channel, Percy Street inundated with water depths of up to 0.75 m. - Properties in North Ward area inundated with water depths of up to 1 m. - Velocities up to 2 m/s predicted in Belgian Gardens. - Velocities of 2 m/s and higher predicted across Percy Street, Harold Street and Bundock Street.

Event	Indicative Rainfall	Properties Inundated[1]	Major Evacuation Route Closures	Flooding Description
100 year ARI	126 mm in 1 hour 166 mm in 2 hours 195 mm in 3 hours 230 mm in 4.5 hours 256 mm in 6 hours 300 mm in 9 hours 336 mm in 12 hours 412 mm in 18 hours 475 mm in 24 hours 662 mm in 48 hours 785 mm in 72 hours	448	Bundock Street Percy Street Old Common Road Heatleys Parade	- Increased floodplain inundation - Properties near Melrose Park Channel, Percy Street inundated with water depths of up to 0.75 m. - Increased inundation extent in Garbutt, Belgian Gardens, West End and North Ward properties. - Velocities up to 2 m/s predicted in Belgian Gardens. - Velocities of 2 m/s and higher predicted across Percy Street, Harold Street and Bundock Street.
200 year ARI	145 mm in 1 hour 190 mm in 2 hours 222 mm in 3 hours 288 mm in 4.5 hours 293 mm in 6 hours 344 mm in 9 hours 385 mm in 12 hours 475 mm in 18 hours 552 mm in 24 hours 773 mm in 48 hours 922 mm in 72 hours	461	Bundock Street Percy Street Old Common Road Heatleys Parade	- Properties near Melrose Park Channel, Percy Street inundated with water depths of up to 0.75 m. - Properties in North Ward area inundated with water depths of up to 1 m. - Velocities up to 2 m/s predicted in Belgian Gardens. - Velocities of 2 m/s and higher predicted across Percy Street, Harold Street and Bundock Street.
500 year ARI	170 mm in 1 hour 222 mm in 2 hours 261 mm in 3 hours 338 mm in 4.5 hours 342 mm in 6 hours 401 mm in 9 hours 451 mm in 12 hours 558 mm in 18 hours 650 mm in 24 hours 922 mm in 48 hours 1109 mm in 72 hours	535	Bundock Street Percy Street Old Common Road Heatleys Parade	- Properties near Melrose Park Channel, Percy Street inundated with water depths of up to 0.75 m. - Properties in North Ward area inundated with water depths of up to 1 m. - Velocities of 2 m/s and higher predicted across Percy Street, Bundock Street and in areas of Belgian Gardens. - Velocities up to 1.5 m/s predicted across Hugh Street.

Event	Indicative Rainfall	Properties Inundated[1]	Major Evacuation Route Closures	Flooding Description
PMF	430 mm in 1 hour 570 mm in 2 hours 651 mm in 3 hours 810 mm in 4.5 hours 828 mm in 6 hours 1536 mm in 24 hours 2808 mm in 72 hours	1010	Bundock Street Percy Street Old Common Road Heatleys Parade	- Significant inundation across the floodplain. - Increase in overflow. - Properties near Melrose Park Channel, Percy Street inundated with water depths of up to 1.5 m. - Properties in North Ward area inundated with water depths of up to 1.5 m. - Velocities of 2 m/s and higher predicted across Percy Street, Bundock Street and in areas of Belgian Gardens. - Velocities up to 1.75 m/s predicted across Hugh Street.

Notes:

[1] Number of inundated properties is assessed based on a minimum of 200 mm water depth covering at least 15% of the lot area for urban residential lots. This does not necessarily mean finished floor levels are exceeded. Floor level elevation data was not available for this study.

Glossary

AEP	Annual Exceedance Probability
AHD	Australian Height Datum (approximately equivalent to Mean Sea Level)
ARI	Average Recurrence Interval
AR&R	Australian Rainfall and Runoff
BoM	Bureau of Meteorology
DEM	Digital Elevation Model
DERM	Department of Environment and Resource Management
DFE	Defined Flood Event
DRAINS	A model for urban stormwater drainage system analysis and design
GDI	Garbutt Flooding and Drainage Investigation (Maunsell-AECOM 2008)
GTSMR	Generalised Tropical Storm Method Revised – Methodology for estimating the PMP
HAT	Highest Astronomical Tide – The highest level of water which can be predicted to occur under any combination of astronomical conditions.
HEC-RAS	A steady state 1D hydraulic model
Hydraulic model	A model used for assessing flood levels and velocities from inflows and topography
Hydrologic model	A model used for assessing catchment outflows from rainfall and catchment conditions
IFD	Intensity–Frequency-Duration
LiDAR	Light Detection and Ranging (Aerial Laser Survey)
LGAQ	Local Government Association of Queensland
MHWS	Mean High Water Springs – the average height of spring tide high water
MIKE11	Fully dynamic 1D hydraulic model
MIKE21	Fully dynamic 2D hydraulic model
MIKE FLOOD	Coupled 2D/1D hydraulic model combining MIKE11 and MIKE21
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
QUDM	Queensland Urban Drainage Manual
TFHAS	Townsville Flood Hazard Assessment Study (Maunsell-AECOM, 2005)
RCFS	Ross Creek Flood Study (TCC, 2013)
XP-RAFTS	An urban and rural runoff-routing hydrologic model

1.0 Introduction

1.1 Overview

AECOM Australia Pty Ltd (AECOM) was engaged to develop baseline hydrologic and hydraulic models for the Captains Creek catchment as a component of the Townsville City Council (TCC) City Wide Flood Constraints Project.

The City Wide Flood Constraints Project seeks to develop flood models to:

- define flood levels for most urban properties
- identify strategies for trunk stormwater and flood mitigation infrastructure for future capital investment
- provide a means of evaluating the impacts of future flood mitigation and development projects
- assess escape routes and flooding along major arterial roads to assist in disaster management processes.

The Captains Creek Flood Study builds on the previous Garbutt Drainage Investigation (Maunsell-AECOM, 2008) and augments overlapping studies by providing detailed hydrologic and hydraulic models for the Captains Creek catchment. The model extent for Captains Creek in relation to previous studies is shown in Figure 1-1.

1.2 Study Area

The focus area of this study is to the north-west of Townsville City and includes much of the urban areas of Rowes Bay, Belgian Gardens, Garbutt and parts of West End (Figure 1-2). The topography of the area is generally flat and low lying except for the eastern portion of the catchment which includes the very steep slopes of Castle Hill.

Land uses in the area include urbanised areas with commercial and residential land uses, the Townsville airport and RAAF Base Garbutt, and large undeveloped areas including the Rowes Bay tidal flats, which comprise a portion of the wetlands of the Townsville Town Common.

The main watercourse in the study area is Captains Creek, which includes the Rowes Bay Canal that supports a network of pipe drainage systems and open channels. Major flow paths within the network are the Melrose Park Channel and Airport Drains which convey flows from the suburb of Garbutt (north of Ingham Road), parts of the suburb of West End and the majority of Belgian Gardens to the Rowes Bay Canal (Figure 1-2).

The canal has levee banks along its lower reaches and is the outlet for overflows from The Lakes detention basin system on Woolcock Street during major flood events. A narrow concrete drain to the north west of Garbutt drains areas adjacent to the Airport and some parts of western Garbutt. The airport drain joins the Rowes Bay Canal upstream of the Townsville Cemetery. Old areas of Belgian Gardens with concrete drainage channels drain towards the Rowes Bay Canal.

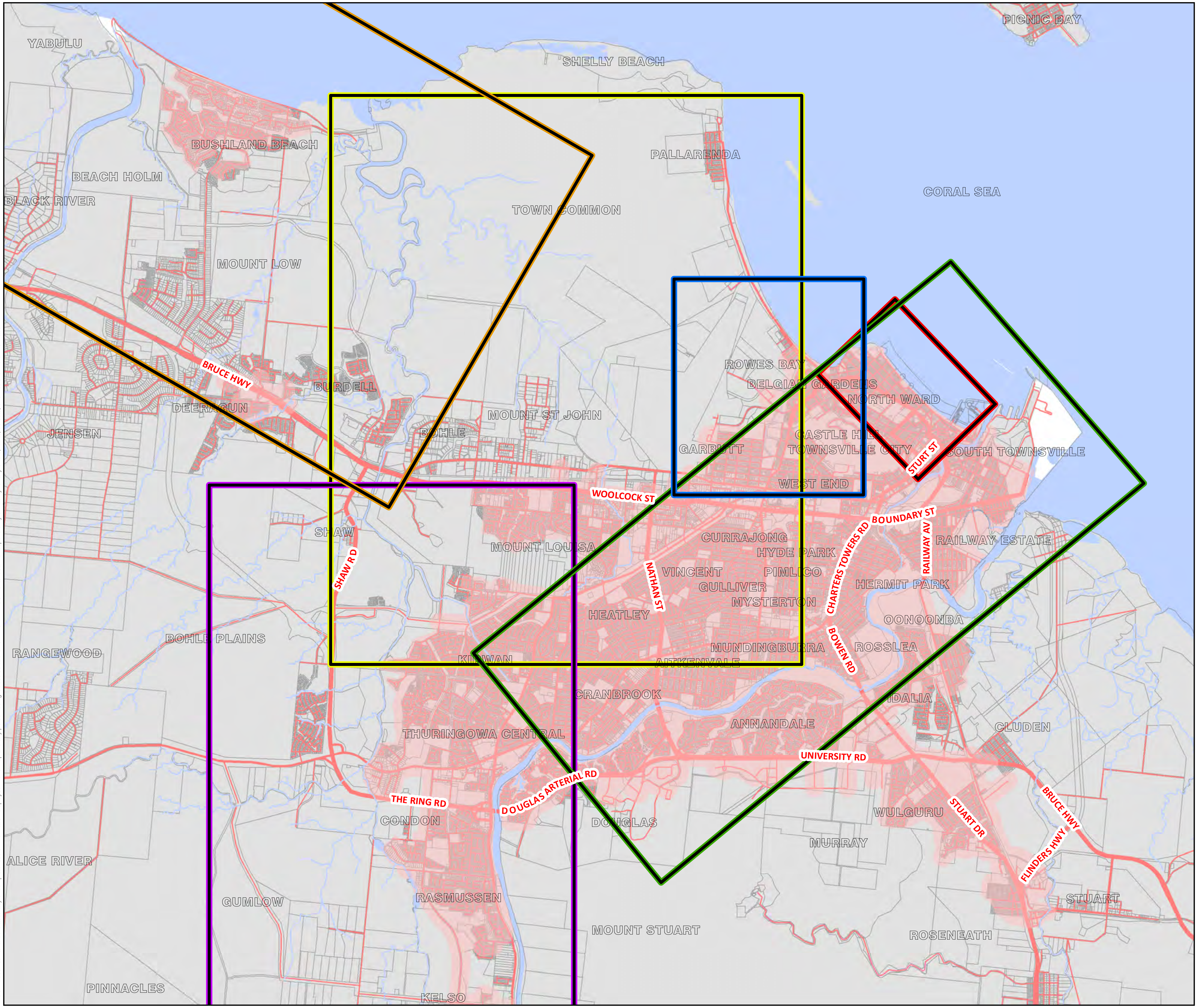
The mouth of the creek has undergone significant scour. The abutments of the Captains Creek bridge at Heatleys Parade have recently undergone major repair works following scour from recent flood events (Appendix D, photo 1).

The creek itself is low lying and subject to tidal inundation. A tidal gate was installed in the Rowes Bay Canal at Evans Street to control surge events and catchment outflows (Appendix D, photo 2).

1.3 Scope of Works

The scope of work for the *Captains Creek Flood Study* included:

- collation and review of available data including previous models relevant to the study and a site visit to verify the existing catchment conditions
- review of XP-RAFTS hydrologic models within the study area to confirm catchment delineations and derive inflow hydrographs for the 2, 5, 10, 20, 50, 100, 200 and 500 year ARI storm events and the Probable Maximum Precipitation (PMP) event
- develop direct rainfall (Rain-on-Grid) hydrographs to represent localised runoff within urbanised areas



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CAPTAINS CREEK FLOOD STUDY
Townsville Citywide Flood Constraints Model Extents

Figure 1-1

LEGEND

- Captain's Creek Model Extent
- Ross Creek Model Extent
- North Ward Model Extent
- Lower Bohle/Stony Creek Model Extent
- Middle Bohle Model Extent
- Louisa Creek Model Extent
- Built-up Area
- Local Roads
- Minor Roads
- Main Roads
- Highways
- Qld_Localities
- Watercourse

0 500 1,000 2,000
Metres

1:75,000 (when printed at A3)

N

Coordinate System: GDA 1994 MGA Zone 55

Data sources:
© 2012 (data source)
(additional data)

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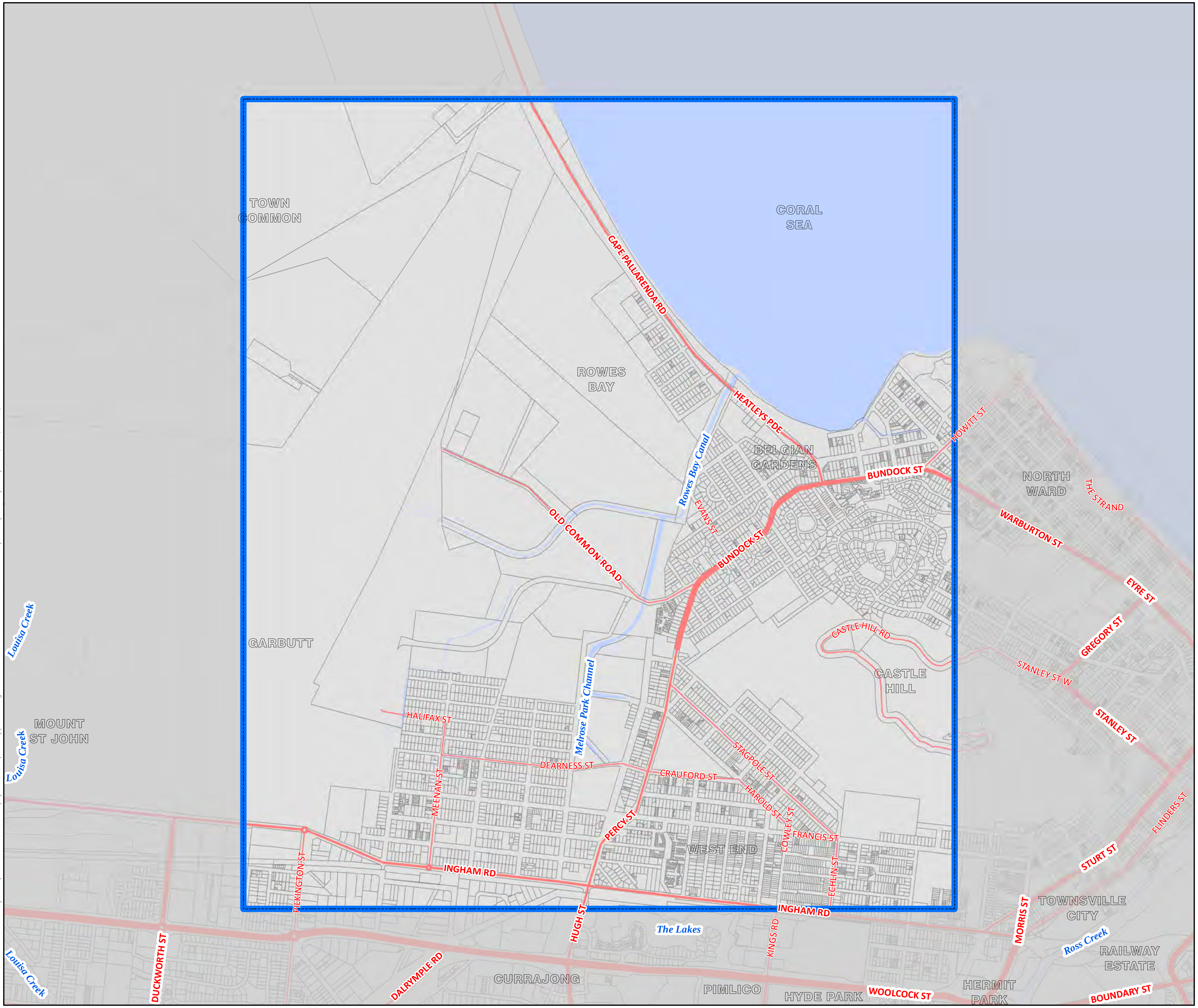
CAPTAINS CREEK FLOOD STUDY

Locality Map

Figure 1-2



LEGEND

- Watercourse
- Property Boundaries
- Captains Creek Model Extent

0 100 200 400 600

Metres

1:20,000 (when printed at A3)

N

Coordinate System: GDA 1994 MGA Zone 55

Data sources:
Road, Rail, Localities - StreetPro© 2010
Contours - Derived from 30m DEM, QLD Gov 2010
Imagery - QLD Gov 2010

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- develop a MIKE FLOOD hydraulic model within the study area to determine base-case flood extents, velocity and depth of flow for the 2, 5, 10, 20, 50, 100, 200 and 500 year ARI storm events and Probable Maximum Flood (PMF)
- determine peak flood envelope for the 50 year and 100 year ARI storm events under existing conditions based on analysis of a range of storm durations including the 1, 2, 3, 4.5, 6, 9, 12, 18, 24, 48 and 72 hour durations
- determine peak flood envelope for the 2, 5, 10, 20, 200, 500 year ARI storm events and the PMF under existing conditions based on the critical storm durations as determined by the analysis of 50 year and 100 year ARI storm events
- assess the sensitivity of the study area to the projected impacts of climate change and sea level rise
- assess sensitivity of the model to Manning's roughness.

1.4 Study Approach

The assessment of the Captains Creek area builds on previous flood studies in the vicinity. Where needed, existing hydrologic and hydraulic models have been updated and refined in accordance with *the Preparation of Flood Studies and Reports – Guidelines* (TCC, 2010) to account for significant changes.

The hydraulic model developed includes culverts, bridges and stormwater pipes with a cross sectional area equivalent or greater than that of a 900 mm diameter pipe. Modelling these structures facilitates the representation of flow through the existing drainage infrastructure and results in a more robust understanding of flooding across the study area.

Inflow boundary conditions were derived using inflow hydrographs from XP-RAFTS hydrologic models for Captains Creek and North Ward catchments (developed by TCC). Discharge hydrographs for the Lakes overflows were taken from the Ross Creek hydraulic model (developed by TCC). A combination of XP-RAFTS local source points and Rain-on-Grid net precipitation was adopted to represent runoff.

An open ocean boundary was used for the downstream boundary condition to account for tailwater levels associated with Mean High Water Springs and predicted future Sea Level Rise conditions.

1.5 Available Data

1.5.1 Spatial Data

TCC provided the following data for the study:

- topography data in the form of contours and XYZ tiles at 1 metre (m) spacing based on 2009 LiDAR survey (Captains Creek model)
- aerial photography flown in 2011 with pixel sizes of 0.125 m (used for assigning fraction impervious values and hydraulic roughness within the flood model)
- digital cadastral database containing property boundaries (TCC, October 2012). It is understood that there has not been significant greenfield development within the study area that has occurred since this date.
- structure information for various bridges and culverts identified within the extents of the models
- stormwater network for the urban areas within the modelling extents (TCC, October 2012).

A site inspection was performed to confirm existing structure details and following the identification of several key structures and waterways which were not included in any previous and overlapping studies, additional as-built drawings and topographical survey were provided by TCC to confirm the dimensions of these structures for the purpose of this study as well as a survey of narrow channels without design drawings following data gap analysis.

1.5.2 Historical Rainfall and Stream Gauging Records

Historical rainfall gauges in the vicinity of the Captains Creek study area include the Townsville Aero meteorological rainfall pluviometer (operated by the Bureau of Meteorology, station number 032040). The Townsville Airport flood pluvio (operated by TCC, station number 532031) and the Garbutt ALERT gauge (operated by TCC, station number 532106) have recently been installed and will provide useful data for future flood events.

1.6 Previous Reports

There are a number of previous and in preparation flood/drainage assessments completed by AECOM (formerly Maunsell) and others within and around the study area (Refer Figure 1-1).

- **Townsville Flood Hazard Assessment Study, Maunsell-AECOM (2005)**

The *Townsville Flood Hazard Assessment Study* (2005) was undertaken by Schlencker Mapping Pty Ltd (Phase 1) and AECOM (Phase 2 and 3) on behalf the Townsville City Council. The purpose of this study was to undertake a Disaster Risk Management Study specific to flooding and storm surge for Townsville and Magnetic Island. A comprehensive flood study was carried out which included the development of 1-D and 2-D hydraulic models to produce inundation maps for the design flood events ranging from the 2 year ARI storm event to the PMF. A preliminary assessment of storm tide inundation was performed assuming a constant storm tide level.

- **Garbutt Drainage Investigation, Maunsell-AECOM (2008)**

The *Garbutt Drainage Investigation* (2008) was a refinement of the *Townsville Flood Hazard Study* (2008) within areas of Garbutt, Belgian Gardens, West End and Rowes Bay. Hydrologic (XP-RAFTS and DRAINS) and a 5 m grid hydraulic model (MIKE FLOOD) were developed.

Overflows to the Captains Creek catchment from the Lakes II area were included, however these were taken from the Townsville Flood Hazard Assessment Study (2005) and were limited to the 6 hour duration event.

Results predicted approximately 249 lots in Garbutt area to be affected by flood waters in the 50 year ARI. Several options for reducing flooding in the area were tested and recommendations for infrastructure improvements were made, conceptually designed and costed for the 50 year ARI design flood event. It is noted that none of the identified mitigation works have been constructed to date.

The results from the Garbutt Drainage Investigation have been compared when reviewing the results of this study.

- **North Ward Flood Study, TCC (2011)**

The *North Ward Flood Study* assessed flooding for the North Ward area as part of the *TCC City Wide Flood Constraints Project*. A hydrological model for the North Ward catchment was developed using XP-RAFTS. A MIKE FLOOD hydraulic model was built based on TCC's LiDAR topography flown in 2009 and major culverts, open channel drains and the underground stormwater system were included in the model using the 1 D MIKE 11 and MIKE URBAN elements.

- **Blakey's Crossing (Louisa Creek) Flood Modelling, AECOM (2013)**

Flood modelling was undertaken as part of the *Blakey's Crossing Upgrade Project* for the hydraulic design of Blakey's Crossing. The model overlaps the area of interest of the Captains Creek model.

- **Captains Creek Flood Study (Intermediate Modelling), AECOM (2013)**

The modelling undertaken as part of the *Captains Creek Flood Study (Intermediate Modelling)* represented an intermediate step in the development of this study. The current study extends the intermediate modelling by further refining the hydraulic model to include underground drainage as well as direct effective rainfall.

- **Ross Creek Flood Study, TCC (2013)**

The *Ross Creek Flood Study* assessed flooding for the portions of the Townsville Floodplain that drain to Ross Creek building on a number of previous flood assessments carried out in the vicinity as part of the TCC *City Wide Flood Constraints Project*. A MIKE FLOOD hydraulic model was built based on LiDAR aerial survey flown in 2009. Major culverts, open channel drains and the underground stormwater system were included in the model using 1 D MIKE 11 and MIKE URBAN elements. The *Ross Creek Flood Study* hydraulic model was calibrated to three rainfall events: January 1998, February 2002 and January 2009.

Flows from the *Ross Creek Flood Study* hydraulic model were applied to the *Captains Creek Flood Study* model to represent overflows from the Lakes II.

- **Louisa Creek Flood Study (In preparation), AECOM (2014)**

The modelling undertaken as part of the *Blakey's Crossing Upgrade Hydraulic Modelling Study* is currently being refined as part of the development of the *Louisa Creek Flood Study*. The current study extends the intermediate modelling by further refining the hydraulic model to include underground drainage as well as direct effective rainfall.

2.0 Hydrological Assessment

2.1 Overview

The hydrology for the Captains Creek Flood Study was obtained from XP-RAFTS hydrologic models developed by TCC based on the previously completed *Garbutt Drainage Flood Study* (AECOM, 2008) and was reviewed by AECOM and used as a basis for this study.

The location and extent of model catchments in relation to the study area is shown in Figure 2-1. For this study the loss factors were adopted based on TCC guidelines *Preparation of Flood Studies and Reports – Guidelines* (TCC, 2010). For the pervious areas within the model the initial loss of 25 mm and continuing loss 2.5 mm/h were used whereas, for the impervious areas within the model the initial loss of 0 mm and continuing loss of 1 mm/h were adopted. Overland flow roughness coefficients varied from 0.015 to 0.070. The roughness coefficients and initial and continuing loss values were based on values determined based on calibrated models developed for the *Townsville Flood Hazard Assessment Study* (Maunsell, 2005).

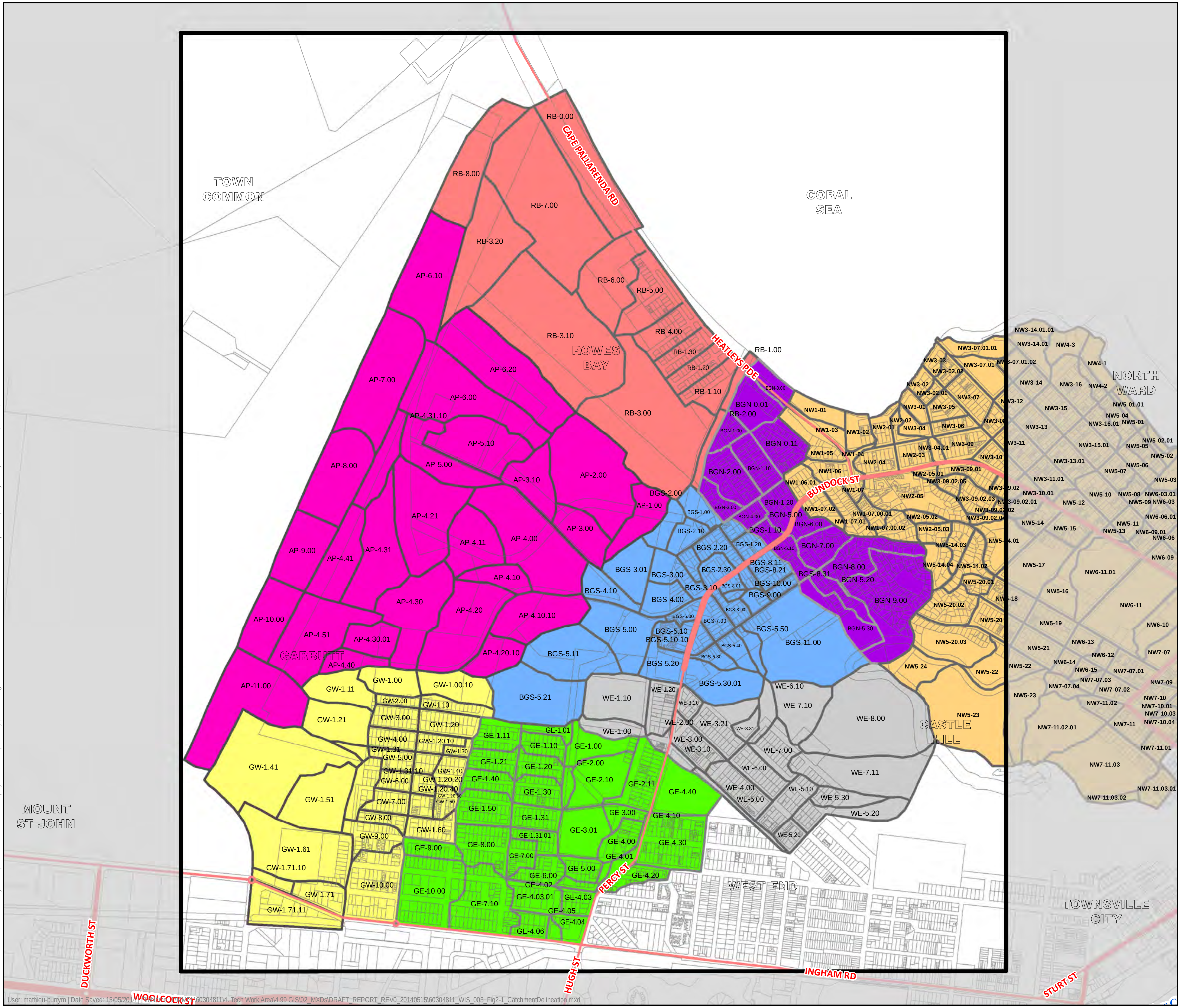
Two methods were used to represent rainfall runoff within the hydraulic model used for this study. They were:

- direct precipitation (Rain-on-Grid) which was used across the more urbanised and relatively flat catchments
- the rainfall-runoff hydrological modelling approach (XP-RAFTS) which was generally applied across rural as well as steep sub-catchments.

CAPTAINS CREEK FLOOD STUDY

Catchment Delineation

Figure 2-1



LEGEND

- Waterways
- Airport Catchments
- North Ward Catchments
- Belgian Gardens North Catchments
- Belgian Gardens South Catchments
- Garbutt East Catchments
- Garbutt West Catchments
- Rowes Bay Catchments
- West End Catchments

0 100 200 400 600

Metres

1:17,000 (when printed at A3)

Coordinate System: GDA 1994 MGA Zone 55

Data sources:
Road, Rail, Localities - StreetPro© 2010
Contours - Derived from 30m DEM, QLD Gov 2010
Imagery - QLD Gov 2010

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2.2 Design Rainfall

Intensity Frequency Duration (IFD) input parameters specific for the study area were determined from Volume 2 of the *Australian Rainfall and Runoff* report (AR&R, 1987). The values are summarised in Table 2-1. Standard techniques from AR&R were used to determine rainfall intensities for the durations assessed and for ARI's up to the 100 year event. For rainfall events greater than 100 year ARI but less than 1000 year ARI, extrapolation of AR&R rainfall estimation method has been undertaken. The values obtained are summarised in Table 2-2.

Table 2-1 IFD Input Parameters for the Townsville Area

Parameter	Value
Latitude (degree South)	19.2667
Longitude (degree East)	146.816
Zone	3
2 year ARI, 1-hour Intensity (mm/h)	53.7
2 year ARI, 12-hour Intensity (mm/h)	11.71
2 year ARI, 72-hour Intensity (mm/h)	3.85
50 year ARI, 1-hour Intensity (mm/h)	110.5
50 year ARI, 12-hour Intensity (mm/h)	24.5
50 year ARI, 72-hour Intensity (mm/h)	9.34
Skewness (G)	0.06
Geographic Factor (F2)	3.93
Geographic Factor (F50)	17.1

Table 2-2 Design Rainfall Intensities (mm/h)

Duration (hours)	Average Recurrence Interval (year)							
	2	5	10	20	50	100	200	500
1	53	70	81	94	112	126	145	170
2	35.2	46.5	53	62	74	83	95	111
3	27.4	36.3	41.6	48.6	58	65	74	87
4.5	21.4	28.2	32.4	37.9	45.2	51	64	75
6	17.9	23.7	27.2	31.7	37.9	42.6	48.9	57
9	13.9	18.4	21.2	24.8	29.6	33.3	38.2	44.6
12	11.7	15.5	17.8	20.8	24.8	28	32.1	37.6
18	9.2	12.4	14.3	16.8	20.2	22.9	26.4	31
24	7.76	10.5	12.2	14.5	17.5	19.8	23	27.1
48	5.05	7.01	8.26	9.86	12.1	13.8	16.1	19.2
72	3.83	5.4	6.41	7.7	9.49	10.9	12.8	15.4

2.3 Extreme Rainfall Events

Various methods can be used to estimate extreme rainfall. The Generalised Short Duration Method (GSDM) and the Generalised Tropical Storm Method (GTSM) were used to estimate the Probable Maximum Precipitation (PMP) for this study. The rainfall intensity for the extreme (PMP) events assessed in this study are summarised in Table 2-3.

Table 2-3 Extreme Rainfall Events Intensity (mm/h)

Duration (h)	Captains Creek
	PMP
2	285
24	65

2.4 RAFTS Verification

An order of magnitude verification of the TCC XP-RAFTS model was undertaken by comparing peak flow discharges with the Rational Method at selected sub-catchment outlets for the 50 year ARI 24 hour duration storm event (Table 2-4).

The Rational Method is a method for calculating peak flow according to a simplified hydrologic equation as described in *Australian Rainfall and Runoff* (1987). The two different methods results were in agreement by plus or minus 16 percent, which is considered acceptable for these types of calculations.

Table 2-4 Peak Flow Comparison (50 year ARI 24 hour duration storm event)

Location	XP-RAFTS Peak Flow (m^3/s)	Rational Method Peak Flow (m^3/s)	Percent Difference
TWE-4.00	29.4	26.0	12%
TWE-4.00	7.3	7.9	-9%
TBGS-7.00	13.2	12.9	2%
TGW-1.31	26.8	26.2	2%
TGE-6.00	10.6	11.2	-6%
TGE-6.00	4.0	3.4	16%
TGW-1.10	6.0	6.3	-4%
TGW-1.10	2.2	1.9	14%
TAP-4.11	12.9	11.9	8%
TAP-4.11	3.3	3.6	-9%
TRB-3.00	19.9	16.8	16%
TRB-3.00	5.3	5.0	5%

2.5 Rain-on-Grid Method – Local Runoff

Rain-on-Grid is a method for directly applying net precipitation to a hydraulic model. It involves applying the rainfall directly on the two-dimensional grid which minimises the need for hydrologic modelling using lumped rainfall-routing software like XP-RAFTS, RORB, etc.

This method is particularly advantageous in ungauged urbanised catchments such as Captains Creek. For this reason rain-on-grid was applied within the model grid to simulate the local runoff generated. It must be noted, however, that this method is not recommended for steep areas and therefore the extent of application across the hydraulic model has been limited to relatively flat areas. For steep areas, such as the slopes of Castle Hill inflows were applied to the model based on the XP-RAFTS model. Further details regarding the extents of the application of the rain-on-grid method are provided along with the description of the hydraulic model setup in Section 3.3.

Two-dimensional rainfall excess time series for each ARI and duration were created to represent the local net precipitation for the study area. This rainfall excess was calculated by applying initial and continuing losses to the design rainfall for two extreme scenarios (i.e. pervious and impervious) to represent infiltration and storage of runoff in surface depressions. Initial and continuous loss values of 25 mm / 2.5 mm/h and 0 mm / 1 mm/h were applied to the pervious and impervious areas respectively for the Captains Creek model.

For design events between the 2 year ARI and 500 year ARI, temporal patterns were applied based on AR&R, Volume 2. For events greater than the 500 year ARI, with a duration of less than 6 hours, the Generalised Short Duration Method (GSDM) temporal pattern was applied. For longer duration rare events, duration specific temporal patterns were applied based on the Generalised Tropical Storm Method.

An imperviousness map for the base case scenario was created using TCC's property boundary dataset (see Figure 2-2). This dataset contains suitable descriptors that allow the separation between vacant land, vacant land intended for residential use, residential dwelling, parks, commercial and industrial lands, etc. To determine the imperviousness percentage an average house size to land parcel ratio was used. For all other parcels such as parks, crown land, etc., an imperviousness value was applied based on typical values for the type of land in the area identified from aerial imagery (2011). This process of creating the imperviousness map was performed using the ArcGIS software package.

With the Rain-on-Grid methodology adopted for this study and not all culverts included in the hydraulic models, localised flooding within the study area is common. As this project seeks to assess the major flow paths within the study area, this localised flooding may not represent the true localised drainage condition but can be used as a guide to identify potential inundation issues.

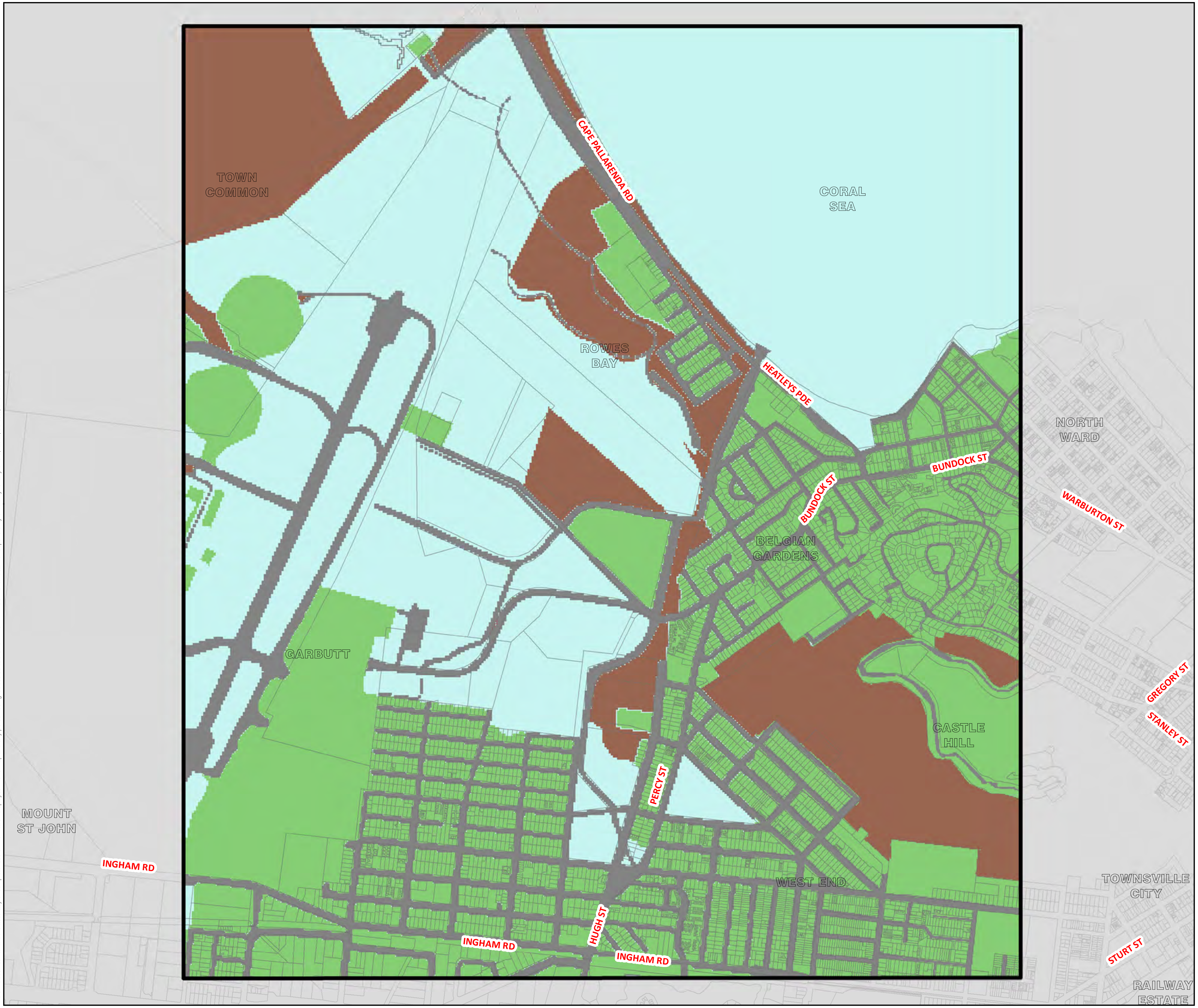
2.6 The Lakes

Inflow hydrographs from overtopping of the Lakes were directly calculated using two-dimensional MIKE FLOOD models as part of the *Ross Creek Flood Study, Base-line Flooding Assessment* (TCC, 2013). The inflow hydrographs were provided to AECOM by TCC, which were incorporated into the hydraulic model as an inflow source point. Further details regarding the locations of application of inflow source points are provided along with the description of the hydraulic model setup in Section 3.3.

CAPTAINS CREEK FLOOD STUDY

Imperviousness Map

Figure 2-2



Impervious Fraction (%)

- 0 - 10% Impervious
- 10 - 20% Impervious
- 20 - 30% Impervious
- 30 - 40% Impervious
- 40 - 50% Impervious
- 50 - 60% Impervious
- 60 - 70% Impervious
- 70 - 80% Impervious
- 80 - 90% Impervious
- 90 - 100% Impervious

0 100 200 400 600

Metres

1:17,000 (when printed at A3)

N

Coordinate System: GDA 1994 MGA Zone 55

Data sources:
Road, Rail, Localities - StreetPro© 2010
Property Boundary - QLD Gov 2013
Imagery - QLD Gov 2010
Elevation - TCC 2013

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3.0 Hydraulic Assessment

3.1 Overview

MIKE FLOOD was used as the platform to construct a dynamically linked hydraulic model for the Captains Creek area to assess flooding for the base case. The Captains Creek model extent is shown in Figure 1-1 along with those for previous overlapping studies undertaken as part of the C*itywide Flood Constraints Project.*

An overview of the model setup and key parameters is provided in Table 3-1.

3.2 MIKE FLOOD Hydraulic Model

MIKE FLOOD is a numerical hydraulic model developed by the Danish Hydraulic Institute (DHI). The model dynamically couples the one-dimensional MIKE URBAN pipe hydraulics and one-dimensional MIKE 11 elements (culverts, bridges and open channels) with the two-dimensional overland flow model MIKE 21. Outputs from MIKE FLOOD include GIS compatible maps of flood extents, water depth, water level, flow and velocities.

3.2.1 MIKE 11

MIKE 11 is a software package used for one-dimensional simulation of flows, water quality and sediment transport in estuaries, rivers, irrigation systems, channels and other water bodies. The model is typically used to assess one-dimensional flows through structures such as bridges and culverts. It also enables simulation of complex river systems where one-dimensional flow predominates.

3.2.2 MIKE 21

MIKE 21 is a software package used for two-dimensional simulation of flow distribution based on water and ground levels at each time step of a model run. The two-dimensional model provides a more accurate determination of the extent, magnitude and direction of the flood flows than MIKE 11, without the need to pre-determine the flow path.

3.2.3 MIKE URBAN

MIKE URBAN is a software package used for one-dimensional simulation of sanitary or storm drain sewers as well as water distribution systems that couples with MIKE 11 and MIKE 21. This software package can be used to analyse a range of parameters including water quality, rainfall runoff and infiltration.

Table 3-1 Captains Creek Model Setup Overview

Parameter	Information
Completion Date	2014
Return Periods Assessed (ARI)	2, 5, 10, 20, 50, 100, 200, 500, PMF
Hydrologic Modelling Approach	XP-RAFTS, Rain-on-Grid
IFD Input Parameters	Based on Volume 2 of AR&R 1987 (refer Table 2-1).
Hydraulic Modelling Approach	MIKE 21, MIKE 11, MIKE URBAN
Model Extent	Refer Figure 1-1.
Grid size	5 m
Digital Elevation Model (year flown)	2009
Roughness	Spatially varying standard values compliant with AR&R and TCC guidelines (refer to Table 3-2, Figure 3-3).
Eddy Viscosity	Constant, velocity based value of 2 m^2/s.
Model Calibration	No calibration data available.
Model Verification	Verification against Garbutt Drainage Flood Study (Maunsell-AECOM, 2008), Louisa Creek Flood Study (AECOM, 2014)
Upstream Model Boundary	Lakes overflows extracted from Ross Creek Flood Study (TCC, 2013) hydraulic model.
Inflows	Rain-on-grid in flat and urbanised catchments. All other inflows obtained from XP-Rafts models.
Downstream Model Boundary	Tidal Boundary (constant MHWS)
Hydraulic Model Time Step	0.25 s
Hydraulic Model Flooding and Drying Depth	0.015 m and 0.002 m respectively
Sensitivity Analysis	Climate Change with Sea Level Rise, Roughness, Highest Astronomical Tide.

3.3 Model Development

3.3.1 Model Geometry

A 5 metre grid Digital Elevation Model (DEM) was developed to represent the topography of the Captains Creek catchment. The topography was derived from 1 m resolution aerial Light Detection and Ranging (LiDAR) survey which was flown in 2009 and supplied by TCC for the purposes of this study.

The DEM generally represents the average elevation over each 5 m grid cell area (Figure 3-1), however key hydraulic controls such as road crown levels and creek invert levels were manually refined in the MIKE 21 topographic grid to ensure that the overland flow regime was adequately represented.

Hydraulic structures with a cross-sectional waterway area equivalent or in excess of that of a 900 mm diameter pipe were included in the model. Smaller structures were considered likely to make less than 0.1 m difference in water level and hence were generally omitted from the hydraulic model.

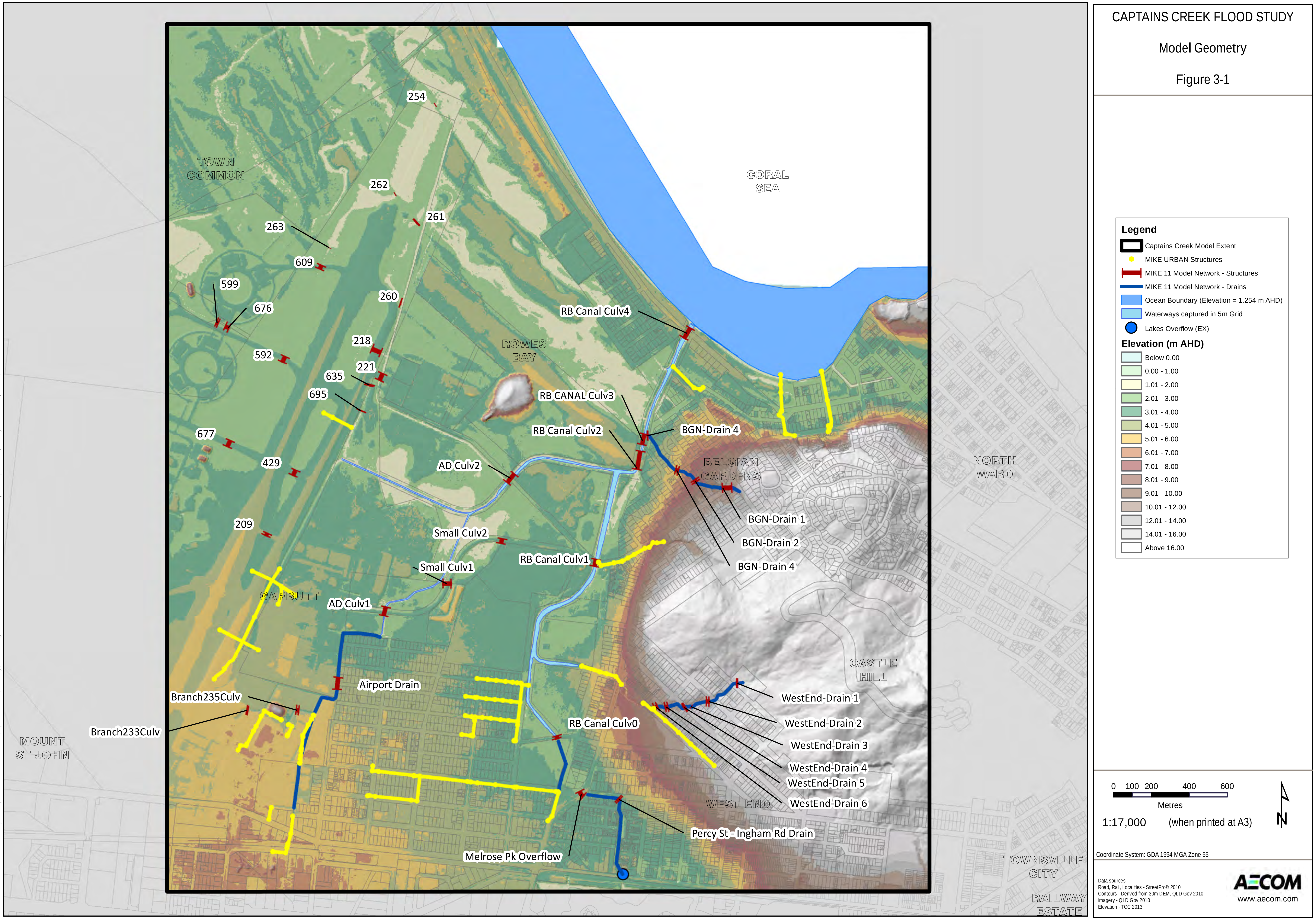
Hydraulic structures within the study area were represented using either the 1D MIKE 11 model or MIKE URBAN elements that were dynamically coupled into the 2D MIKE 21 grid. All major bridges and culverts within the model were represented in the MIKE 11 model. Full details of the structures modelled using MIKE 11 are summarised in Appendix B and illustrated in Figure 3-1. Major underground drainage within the model is generally represented using the MIKE URBAN model as shown in Figure 3-1.

Some narrow channels and drains were deemed too small to be resolved by the 5 m grid resolution and were therefore modelled as one-dimensional channels which were laterally linked to the 2D overland flow model. These included the Percy St – Ingham Road Drain, Melrose Park Overflow, the Airport Drain and the Chubb St - Belgian Gardens drain as shown in Figure 3-1 (refer also to Appendix D, photos 3 and 4).

CAPTAINS CREEK FLOOD STUDY

Model Geometry

Figure 3-1



0 100 200 400 600

Metres

1:17,000 (when printed at A3)

N

Coordinate System: GDA 1994 MGA Zone 55

Data sources:
Road, Rail, Localities - StreetPro© 2010
Contours - Derived from 30m DEM, QLD Gov 2010
Imagery - QLD Gov 2010
Elevation - TCC 2013

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3.3.2 Boundary Conditions

Based on a review of the outputs from the *Ross Creek Flood Study*, *North Ward Flood Study* and the *Louisa Creek Flood Study*, runoff inflows in the West End area east of Percy Street and the Garbutt Area south of Ingham Road were not included.

Runoff hydrographs were obtained from the XP-RAFTS hydrologic model and applied as source points within the MIKE 21 grid for steep areas. Several catchment inflow hydrographs were also input into the MIKE 11 and MIKE URBAN network geometry representing catchments which outlet within flow paths defined in the MIKE 11 network. Rain-on-grid was applied across the more urbanised and relatively flat areas of the model extent. The locations of all boundary conditions for this model can be seen in Figure 3-2.

A single inflow was input into MIKE 11 to represent surcharge to the study area from The Lakes drainage system according to the refinement developed by TCC (Figure 3-2).

A tidal boundary has been applied at Cleveland Bay as a constant water depth equivalent to the Mean High Water Springs (MHWS) level of 1.254 metres AHD based on Queensland Tide Tables (2014).

3.3.3 Roughness

A spatially varying roughness map was developed based on aerial photography of the study area (Figure 3-3). Due to the adoption of the rain-on-grid approach for overland flow this mapping was significantly more refined than the previous roughness mapping for the *Garbutt Drainage Investigation* (Maunsell-AECOM 2008).

A summary of the roughness values adopted for varying land uses is shown in Table 3-2. The roughness values were broadly consistent with those adopted for the Louisa Creek Flood Study, which was calibrated to the 2014 flood event and verified to the 1998 flood event.

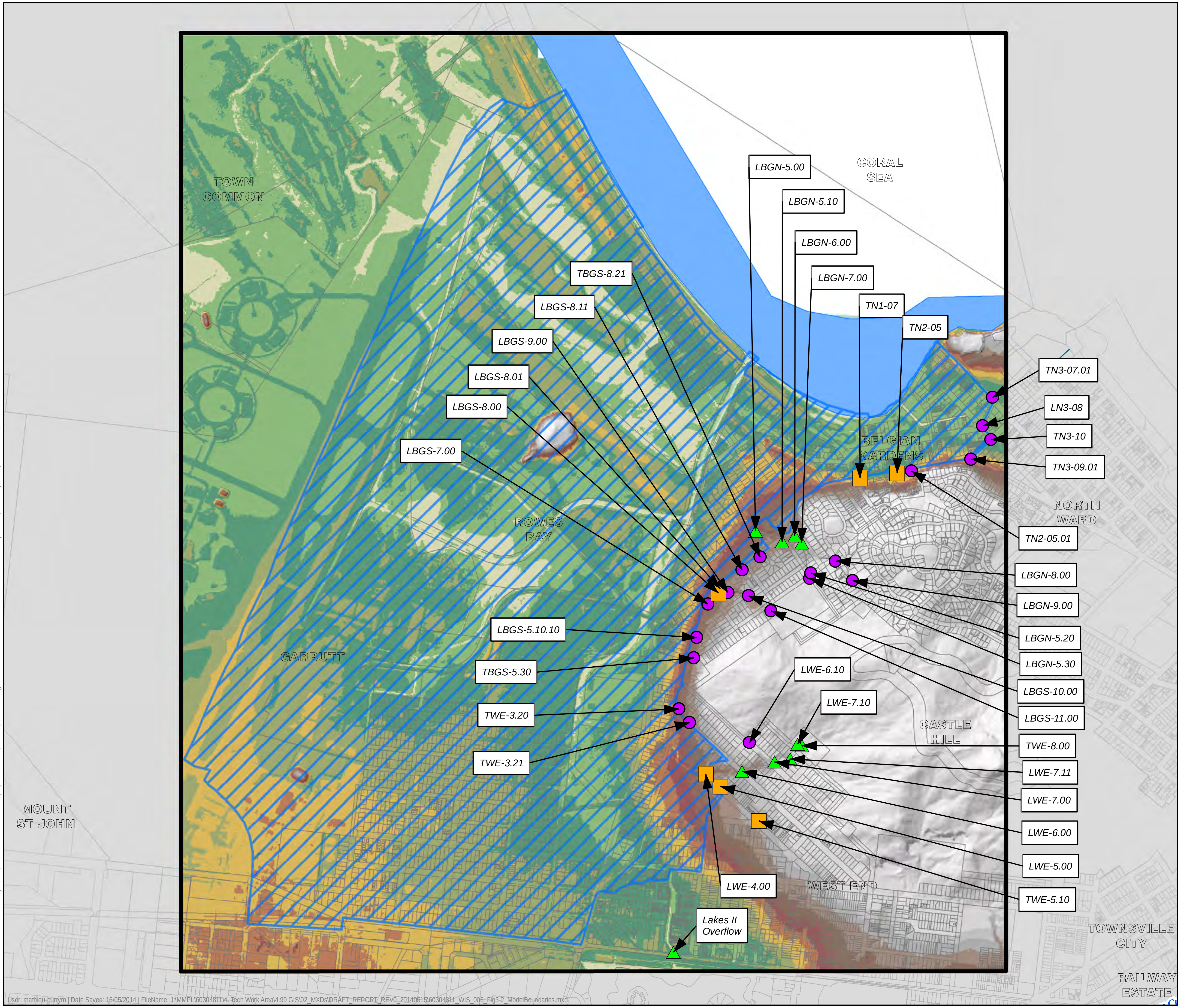
Table 3-2 Roughness Values and Associated Land Uses

Roughness Zone	Manning's n
Roads	0.020
Major Natural Water Courses	0.025
Open Space	0.030
Vegetated Floodplain	0.040
Pond/Sea	0.050
Urban Development	0.055

CAPTAINS CREEK FLOOD STUDY

MIKE FLOOD Model Boundaries

Figure 3-2



Legend

- Captains Creek Model Extent
- Rain On Grid Extent
- Ocean Boundary (Elevation = 1.254 m AHD)
- Mike 11 Inflow Source Points
- Mike 21 Inflow Source Points
- Mike Urban Inflow Source Points

Elevation (m AHD)

- Below 0.00
- 0.00 - 1.00
- 1.01 - 2.00
- 2.01 - 3.00
- 3.01 - 4.00
- 4.01 - 5.00
- 5.01 - 6.00
- 6.01 - 7.00
- 7.01 - 8.00
- 8.01 - 9.00
- 9.01 - 10.00
- 10.01 - 12.00
- 12.01 - 14.00
- 14.01 - 16.00
- Above 16.00

0 100 200 400 600
Metres

1:17,000 (when printed at A3)

Coordinate System: GDA 1994 MGA Zone 55

Data sources:
Road, Rail, Localities - StreetPro© 2010
Contours - Derived from 30m DEM, QLD Gov 2010
Imagery - QLD Gov 2010
Elevation - TCC 2013

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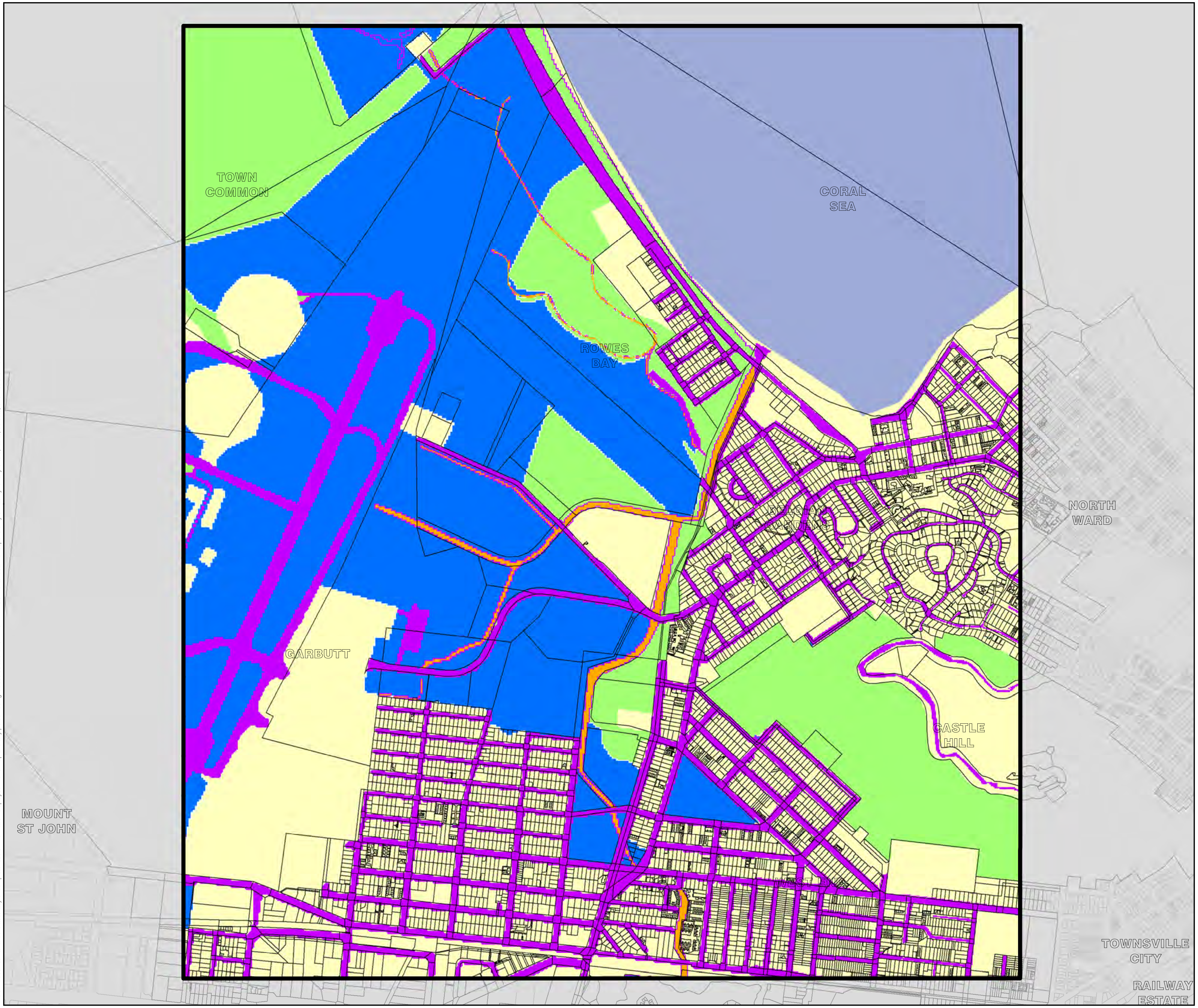
CAPTAINS CREEK FLOOD STUDY

Roughness Map

Figure 3-3



Manning's n

	Manning's n
Magenta	0.02
Orange	0.025
Blue	0.03
Green	0.04
Grey-blue	0.05
Pale yellow	0.055

0 100 200 400 600

Metres

1:17,000 (when printed at A3)

N

Coordinate System: GDA 1994 MGA Zone 55

Data sources:
Road, Rail, Localities - StreetPro© 2010
Contours - Derived from 30m DEM, QLD Gov 2010
Imagery - QLD Gov 2010
Elevation - TCC 2013

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3.4 Model Checking and Verification

3.4.1 Model Calibration

Unfortunately no recent calibration data was available for the Captains Creek catchment to facilitate calibration of the model and assess the model outputs for real events. It is noted that an ALERT stream gauge has recently been installed in the Captains Creek area. It is recommended that should significant flood information becomes available it is used to calibrate the model in future.

However, extensive checking of the results was undertaken to provide confidence in the results and understand model sensitivity to assumed hydraulic parameters such as roughness. Further description regarding the roughness sensitivity analysis is provided in Section 4.3.

3.4.2 Verification against previous and overlapping studies

Results of the model for this study were compared to the MIKE FLOOD results from the *Garbutt Drainage Investigation* (Maunsell-AECOM, 2008) to verify model topography and other input parameters.

Differences in topography between the 2008 study are shown in Figure 3-4. A general increase in the land surface elevations in the order of 100-400 mm is observed across many of the major flood storage areas across the floodplain, including the Rowes Bay tidal flats and rural and adjacent to the Townsville Airport. A similar increase is observed within some of the urbanised lots in the Garbutt area. Increases of above 500 mm are shown at number of locations of known recent development such as the Cleveland Youth Detention Centre site and the Northern Australian Aerospace Centre of Excellence (NAACEX) site, and also within the Townsville RAAF base.

The difference in water surface elevation shown in Figure 3-5, shows a consistent increase in water surface as compared with the 2008 study results. The increase is partially because of a change in topography and also because of increases in discharges associated with the TCC updated hydrology and the inclusion of overflows from the Lakes detention system. The difference shown in Cleveland Bay is due to an update in downstream boundary condition from 1.21 to 1.254 metres AHD.

Table 3-3 gives a comparison of the peak discharges at the cross section locations as shown in Figure 3-5. The 50 year ARI (24 hour duration) flows in the Captains Creek model at these locations are compared to the Garbutt Drainage Flood Study as well the peak total flow from the XP-RAFTS model.

Table 3-3 Discharge Comparison

Location	Captains Creek Modelled Discharge (m^3/s)	GDFS Modelled Discharge (m^3/s)	Percent Difference
1	22.5	22.0	2 %
2	23.2	21.5	8 %
3	20.5	21.5	-5%
4	4.6	5.1	-10%

The result shown in Figure 3-5 were also plotted as a long section profile along the Captains Creek channel, along with the hydraulic grade line profile from the overlapping *Blakey's Crossing Hydraulic Modelling*, these results are provided in Appendix C.

The assessment of the 50 year ARI 24 hour duration design run for Captains Creek showed that overall the model produced as part of this study predicted higher water levels than the *Garbutt Drainage Flood Study* model, this difference is explained by the revised hydrology, inclusion of Lakes overflows, and the inclusion more recent topography data. Model sensitivity testing confirmed that the higher levels predicted by the Captains Creek model as compared to the *Blakeys Crossing* model are explained by the inclusion of the Lakes overflows in the Captains Creek model.

3.4.3 Verification against recent flood events

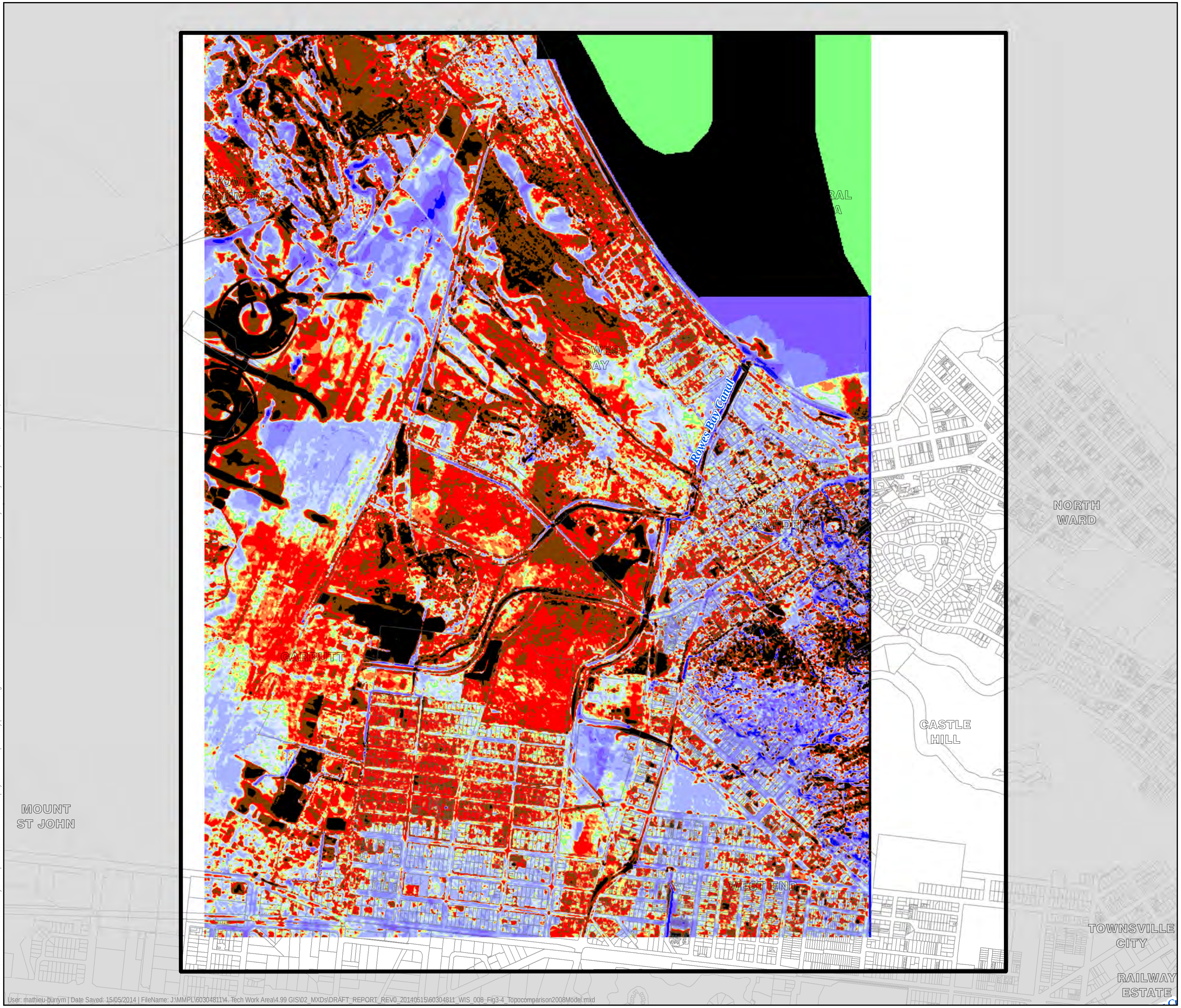
Based on recorded rainfall totals at the recently installed Garbutt ALERT gauge and the Townsville Airport gauge, the rainfall associated with Cyclone Ita in April 2014 was close to a 5 year ARI rainfall event for the Captains

Creek catchment. Site inspections and observations around the Garbutt area close to the time of the peak runoff from this rainfall event were consistent with the model predictions for a 5 year ARI flood event.

A number of photographs were taken (Appendix D, Photos 7-12). These photos show the observed inundation of Dearness St at the Melrose Park drain crossing, water on the road at Percy St near Crauford St and at Hugh St south of Dearness St, as well as inundation along Douglas St.

CAPTAINS CREEK FLOOD STUDY

Topography Comparison
(2013 model subtract 2008 model)
Figure 3-4



Ground Level Difference (m)

- Below -1
- -1 - -0.5
- -0.5 - -0.25
- -0.25 - -0.1
- -0.1 - -0.05
- -0.05 - -0.01
- -0.01 - 0.01
- 0.01 - 0.05
- 0.05 - 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- Above 0.5

0 100 200 400 600
Metres

1:17,000 (when printed at A3)

N

Coordinate System: GDA 1994 MGA Zone 55

Data sources:
Road, Rail, Localities - StreetPro© 2010
Property Boundary - QLD Gov 2013
Imagery - QLD Gov 2010
Elevation - TCC 2013

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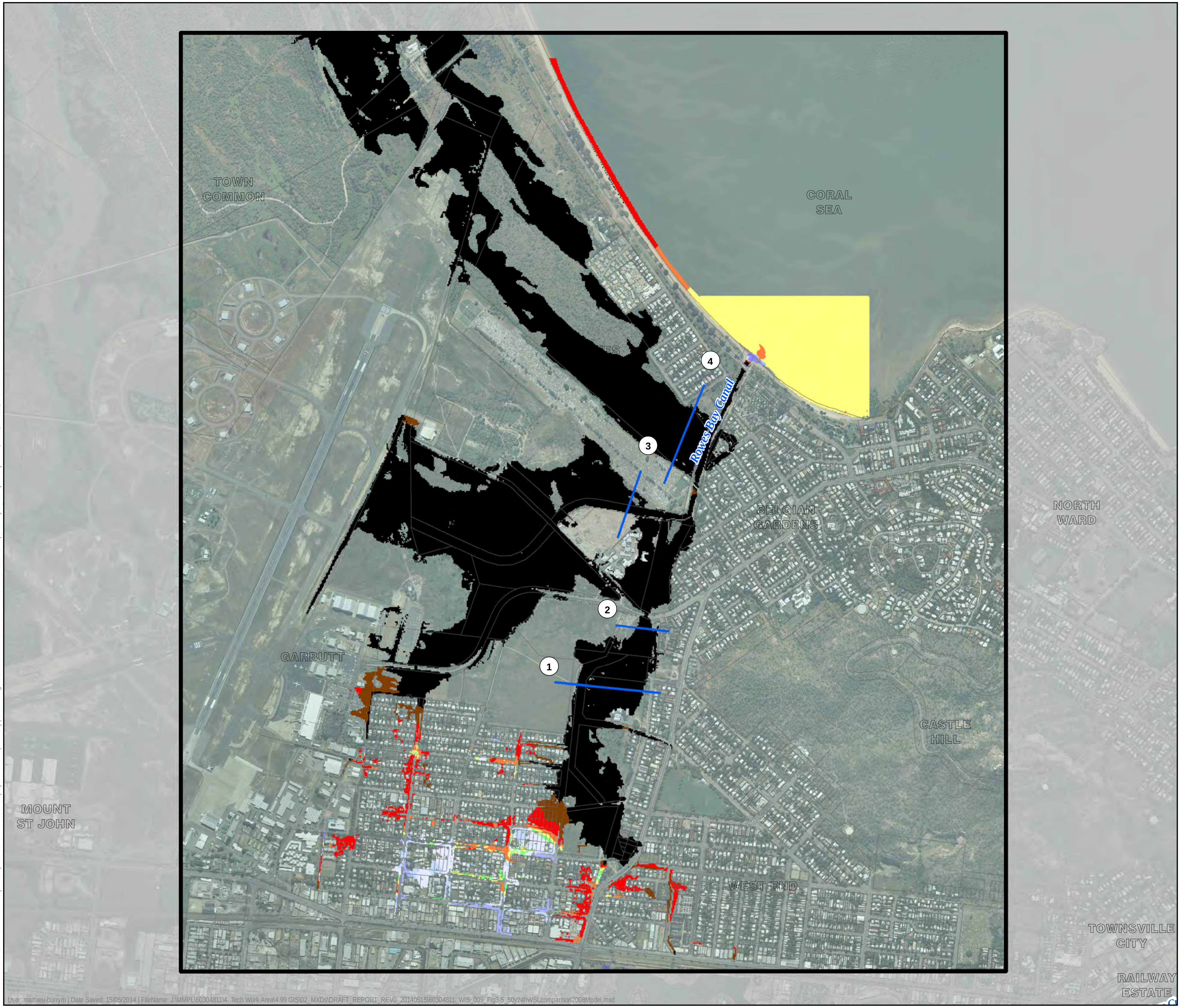
CAPTAINS CREEK FLOOD STUDY

Water Surface Elevation Comparison
(2013 model subtract 2008 model)
Figure 3-5



LEGEND

Discharge Location

Water Surface Elevation Difference (m)

- Below -1
- -1 - -0.5
- -0.5 - -0.25
- -0.25 - -0.1
- -0.1 - -0.05
- -0.05 - -0.01
- -0.01 - 0.01
- 0.01 - 0.05
- 0.05 - 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- Above 0.5

0 100 200 400 600
Metres

1:17,000 (when printed at A3)

N

Coordinate System: GDA 1994 MGA Zone 55

Data sources:
Road, Rail, Localities - StreetPro© 2010
Property Boundary - QLD Gov 2013
Imagery - QLD Gov 2010
Elevation - TCC 2013

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Results of the URBAN model for this study were also compared to the DRAINS results from the *Garbutt Drainage Investigation* (Maunsell-AECOM 2008). For selected URBAN nodes, the surcharge flow rates from the Mike Urban links were compared with the GDFS DRAINS results for the 50 year ARI 24 hour duration event, as shown in Table 3-4.

Table 3-4 Comparison of Surcharge Flow Rates from Mike Urban Links with Previous DRAINS Results (50 year ARI 24 hour duration event)

Manhole ID (Captains Creek Model)	Pit ID (GFDS)	GDFS DRAINS Peak Discharge (m^3/s)	Captains Creek Model URBAN Link Discharge (m^3/s)	Percent Difference (%)
RC-0088AB6U	PI91	0.33	0.31	-3.7
RC-0088A13U	PI104	0.37	0.21	-43.9
RC-0088A12U	PI97	0.29	0.33	14.7
RC-0088A6U	PI68	0.40	0.44	10.6
RC-0088AC3U	PI58	0.35	0.20	-41.4
RC-0050A15U	PI170	0.25	0.20	-18.4
RC-0050A13U	PI999	0.37	0.40	9.6
RC-0050A8U	PI138	1.18	0.90	-23.8

3.5 Design Flood Critical Duration Assessment

The critical duration for the 2, 5, 10, 20, 50, 100, 200 and 500 year ARI events was assessed by simulating the 1, 2, 3, 4.5, 6, 9, 12, 18, 24 and 48 durations for the 50 and 100 year ARI events. Figure 3-6 shows the 50 year ARI critical duration map for areas within the Captains Creek catchment and Figure 3-7 shows the 100 year ARI critical duration map.

The 1 and 24 hour durations were adopted as they were found to best represent the critical duration across the urban areas. Comparison of the 24 hour and 48 hour events showed only minor difference in water level of up to 50 mm in the Melrose Park drain. A more significant difference was observed in parts of the urbanised area of Garbutt.

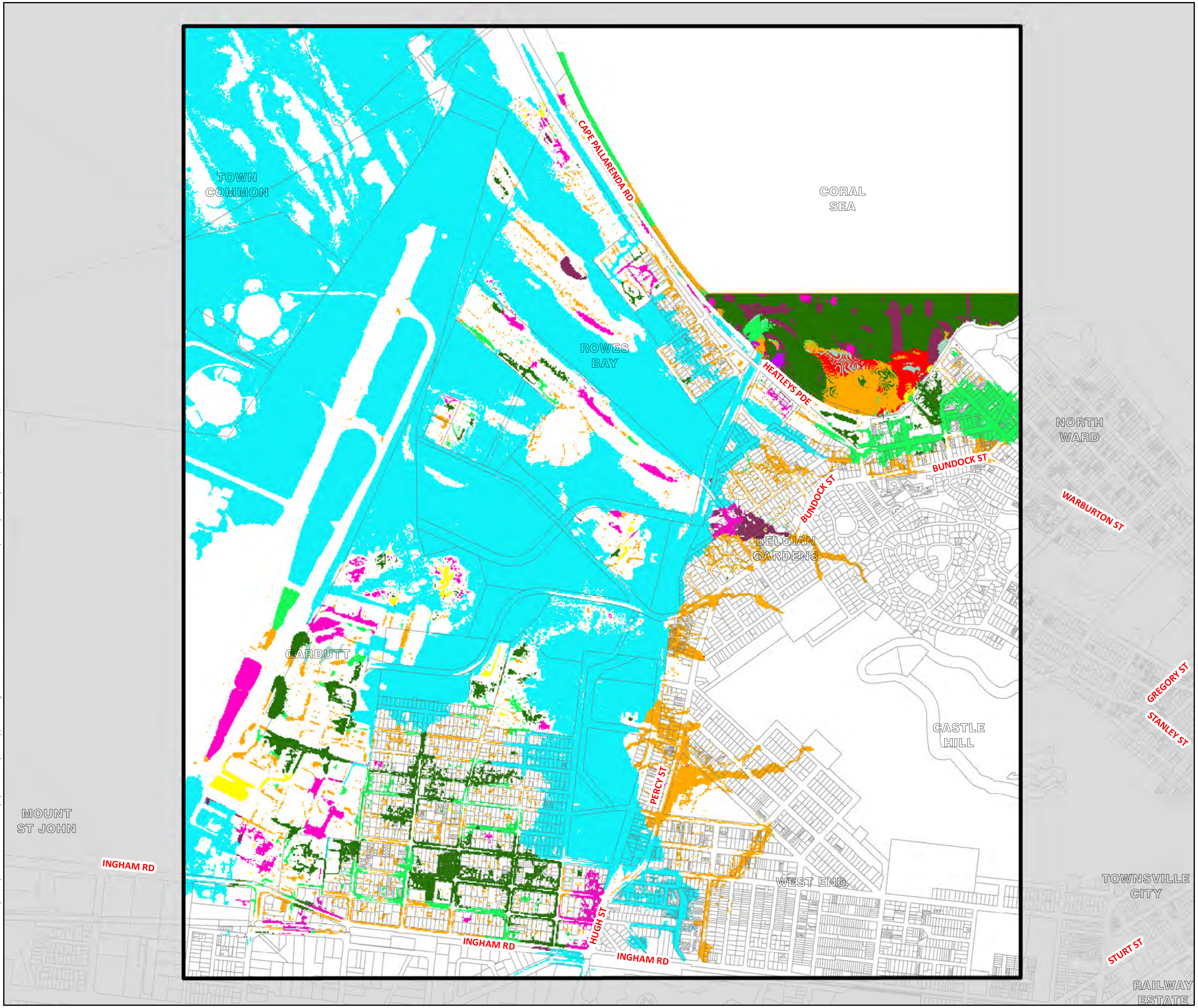
These critical durations were applied to the 2, 5, 10, 20, 200 and 500 year ARI events for both the Captains Creek model.

For PMP event the 2 hour and 24 hour storm durations were assessed for the Captains Creek study area.

Graphical displays of maximum water depth, surface elevation and flow velocity magnitude for each event modelled are provided in Appendix A.

CAPTAINS CREEK FLOOD STUDY

Critical Duration Assessment
50-year ARI
Figure 3-6



1:17,000 (when printed at A3)

Coordinate System: GDA 1994 MGA Zone 55

Data sources:
Road, Rail, Localities - StreetPro© 2010
Property Boundary - QLD Gov 2013
Imagery - QLD Gov 2010
Elevation - TCC 2013

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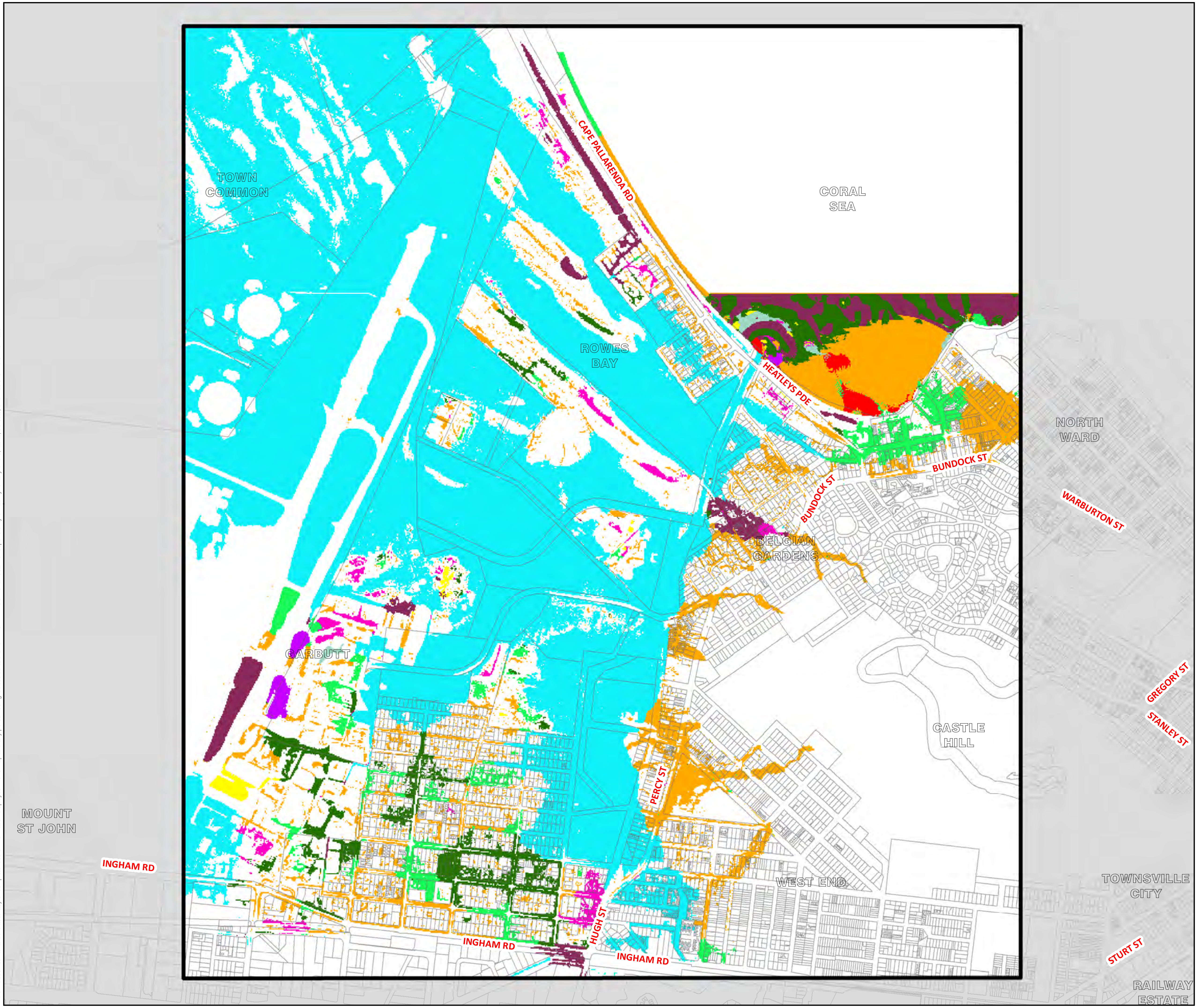
User: mathieu-burrym | Date Saved: 15/05/2014 | FileName: J:\MMPL\60304811\4. Tech Work Area\4.99 GIS\02_MXDs\DRAFT_REPORT_REV0_20140515\60304811_WIS_010_Fig3-6_CriticalDuration_50y.mxd

CAPTAINS CREEK FLOOD STUDY

Critical Duration Assessment
100-year ARI
Figure 3-7



Duration (hours)

- 1
- 2
- 3
- 4.5
- 6
- 9
- 12
- 18
- 24
- 48

0 100 200 400 600
Metres

1:17,000 (when printed at A3)

N

Coordinate System: GDA 1994 MGA Zone 55

Data sources:
Road, Rail, Localities - StreetPro© 2010
Property Boundary - QLD Gov 2013
Imagery - QLD Gov 2010
Elevation - TCC 2013

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4.0 Baseline Flooding Summary

4.1 Flooding across the Study Area – Summary

Base case flood maps for design ARI storms are provided in Appendix A. The maps show maximum water depth, surface elevation and flow velocity magnitude produced for the following storms:

- 2 year ARI
- 5 year ARI
- 10 year ARI
- 20 year ARI
- 50 year ARI
- 100 year ARI
- 200 year ARI
- 500 year ARI
- Probable Maximum Flood.

For mapping purposes the criteria adopted involves:

- including water depths greater than or equal to 0.1 m, or
- including water velocities greater than or equal to 0.3 m/s.

Therefore, only areas predicted to experience water depths lower than 0.1 m or water velocities lower than 0.3 m/s are shown as free from flooding in the mapping undertaken. This is in line with TCC's Flood Hazard Mapping Criteria.

To facilitate reading of flood modelling results, the majority of labels have been left out of the flood maps. The key areas mentioned in the assessment included in this section are shown in the locality map (Figure 1-2) and therefore it is recommended that this is used as a reference when reviewing the flood maps.

A summary description of the flooding for the various design events are provided in Table 4-1. Assessment for out of bank flow, ponding across developed areas and high velocities within channels has been undertaken for each ARI being assessed.

Table 4-1 Captains Creek – Flooding Assessment Summary

Event	Description	Map Ref
2 year ARI	- Flows contained mainly within the channel. - Floodplain inundation up to 1.5 m across the floodplain. - No significant impact predicted for residential areas (i.e. water depth generally below 0.3 m). - Velocities up to 1.75 m/s predicted across Bundock Street and in Belgian Gardens.	A1, A10 and A19
5 year ARI	- Floodplain inundation up to 2 m across the floodplain. - Properties near Melrose Park Channel, Percy Street inundated with water depths of up to 0.5 m. - Velocities up to 1.75 m/s predicted across Percy Street, Harold Street, Bundock Street and in Belgian Gardens.	A2, A11 and A20
10 year ARI	- Floodplain inundation up to 2 m across the floodplain. - Properties near Melrose Park Channel, Percy Street inundated with water depths of up to 0.5 m. - Properties in North Ward area inundated with water depths of up to 1 m. - Velocities up to 2 m/s predicted across Percy Street, Harold Street, Bundock Street, and in Belgian Gardens.	A3, A12 and A21

Event	Description	Map Ref
20 year ARI	- Floodplain inundation up to 2 m across the floodplain. - Properties near Melrose Park Channel, Percy Street inundated with water depths of up to 0.75 m. - Properties in North Ward area inundated with water depths of up to 1 m. - Velocities up to 2 m/s predicted across Percy Street, Harold Street, Bundock Street, and in Belgian Gardens.	A4, A13 and A22
50 year ARI	- Floodplain inundation up to 3 m across the floodplain. - Properties near Melrose Park Channel, Percy Street inundated with water depths of up to 0.75 m. - Properties in North Ward area inundated with water depths of up to 1 m. - Velocities up to 2 m/s predicted in Belgian Gardens. - Velocities of 2 m/s and higher predicted across Percy Street, Harold Street and Bundock Street.	A5, A14 and A23
100 year ARI	- Increased floodplain inundation - Properties near Melrose Park Channel, Percy Street inundated with water depths of up to 0.75 m. - Increased inundation extent in Garbutt, Belgian Gardens, West End and North Ward properties. - Velocities up to 2 m/s predicted in Belgian Gardens. - Velocities of 2 m/s and higher predicted across Percy Street, Harold Street and Bundock Street.	A6, A15 and A24
200 year ARI	- Properties near Melrose Park Channel, Percy Street inundated with water depths of up to 0.75 m. - Properties in North Ward area inundated with water depths of up to 1 m. - Velocities up to 2 m/s predicted in Belgian Gardens. - Velocities of 2 m/s and higher predicted across Percy Street, Harold Street and Bundock Street.	A7, A16 and A25
500 year ARI	- Properties near Melrose Park Channel, Percy Street inundated with water depths of up to 0.75 m. - Properties in North Ward area inundated with water depths of up to 1 m. - Velocities of 2 m/s and higher predicted across Percy Street, Harold Street, Bundock Street and in areas of Belgian Gardens. - Velocities up to 1.5 m/s predicted across Hugh Street.	A8, A17 and A26
PMF	- Significant inundation across the floodplain. - Increase in overflow. - Properties near Melrose Park Channel, Percy Street and in North Ward inundated with water depths of up to 1.5 m. - Velocities of 2 m/s and higher predicted across Percy Street, Harold Street, Bundock Street and in areas of Belgian Gardens. - Velocities up to 1.75 m/s predicted across Hugh Street.	A9, A18 and A27

4.2 Major Arterial Roads

There are various important roads across the Captains Creek area which if flooded would have an impact on the local residents of these communities. An indication of the maximum estimated water depth over these roads within the Captains Creek model extent is provided in Table 4-2.

Table 4-2 Flooding Depth Affecting Main Roads within the Captains Creek Section (m)

Description	Event (Year ARI)								PMF
	2	5	10	20	50	100	200	500	
Bundock Street/Bevan St	0.11	0.12	0.13	0.14	0.14	0.14	0.15	0.16	0.17
Bundock Street/Old Common Rd	0.15	0.20	0.21	0.23	0.25	0.26	0.30	0.32	0.39
Bundock Street/Taylor Street	0.13	0.14	0.14	0.15	0.17	0.20	0.25	0.35	0.45
Percy Street*	0.11	0.14	0.15	0.17	0.23	0.24	0.24*	0.24*	0.62
Dearness Street (at Melrose Park Channel)*	-	0.57	0.63	0.69	0.89	0.90	0.90*	0.90*	0.13
Heatleys Parade	-	-	-	0.23	0.29	0.38	0.43	0.50	0.78
Old Common Rd*	-	0.71	0.77	0.83	1.02	1.03	1.03*	1.03*	1.41

Note: For the purposes of the above table only water depths in excess of 0.1 m have been considered.
* The 200 and 500 year ARI water depths at this location obtained from the modelling were slightly lower than the 100 year ARI depths since the critical duration at this location (48 hours) was not run for the 200 and 500 year ARI. The same values as for the 100 year ARI event have therefore been quoted.

4.3 Sensitivity Analysis

4.3.1 Overview

The hydraulic model for Captains Creek was not calibrated due to the lack of stream gauge data within the model extent. A sensitivity analysis was undertaken to evaluate how sensitive the hydraulic model was to changes in surface roughness, tidal level and climate change with sea level rise. The sensitivity analysis was completed for the 50 year ARI and 100 year ARI 24 hour event and involved increasing and decreasing the modelled roughness by 10%.

4.3.2 Surface Roughness Sensitivity

The results of the roughness sensitivity analysis are shown in Figure 4-1 and Figure 4-2.

The following conclusions were reached from the analysis:

- an increase in roughness results in higher flood levels. Water levels increased by generally up to 50 mm in the Rowes Bay tidal flats with a negligible increase in the rest of the study area
- a decrease in roughness results in lower flood levels. Water levels reduced by generally up to 100 mm in the Rowes Bay tidal flats with negligible decrease in the rest of the study area.

4.3.3 Tidal Level Sensitivity

The sensitivity of the Captains Creek hydraulic model was assessed for changes in the boundary condition. Figure 4-3 and Figure 4-4 show results of the boundary sensitivity test for the 50 year and 100 year ARI 24 hour events respectively where the ocean boundary condition is increased to Highest Astronomical Tide (HAT).

The results show that if the ocean boundary is increased to HAT, it is predicted that generally a 10 – 50 mm increase in flood depths in the lower reaches of Captains Creek and the Rowes Bay tidal flats, but there is particularly sensitive area at Heatley's Parade.

4.3.4 Climate Change (with Sea Level Rise) Sensitivity

The impact of climate change was also assessed. Figure 4-5 and Figure 4-6 show results of the climate change sensitivity test for the 50 year and 100 year ARI 24 hour events respectively where the ocean boundary is increased by 0.8 m to allow for sea level rise and the rainfall intensity is increased by 15%.

The results of the climate change sensitivity analysis showed that the lower reaches of Captains Creek and the Rowes Bay tidal flats generally experiences an increase in flood depths of 10 – 50 mm with the highest increase of up to 250 mm in the Rowes Bay tidal flats and the lower reaches of Captains Creek. There is also a particularly sensitive area at Heatley's Parade which is predicted to experience an increase of up to 0.5 m.