DOUGLAS AND ANNANDALE FLOOD STUDY

BASELINE FLOODING ASSESSMENT

Volume 1

FEBRUARY 2014

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Executive Summary

The *Douglas and Annandale Flood Study – Baseline Flooding Assessment* has been undertaken as part of Townsville City Council's City Wide Flood Constraints Project. This study builds on previous hydrologic analysis projects done for the Townsville City Council (TCC) and incorporates the latest Light Detection and Ranging (LiDAR) topographic data to form up to date hydrologic and hydraulic flood models for Douglas and Annandale. The study area covers Douglas and Annandale suburbs, their catchments and a 10km reach of the Ross River.

The study has developed a MIKE FLOOD coupled two-dimensional / one-dimensional hydraulic model. The model has been primarily verified to the Ross River model result of 100 year ARI event. The model represents in fine-scale resolution the topography and drainage systems of Douglas and Annandale areas, including:

- a digital elevation model resolved to a 10m grid;
- the larger components of the underground drainage network (greater than 900 mm diameter equivalent diameter);
- open drains narrower that the 10m grid resolution using one-dimensional branches; and
- application of rainfall directly on the model grid.

The calibrated flood model has been used to assess design storm flood events for the 2, 5, 10, 20, 50, 100, 200 and 500 Year Average Recurrence Intervals (ARI) as well as the Probable Maximum Precipitation flood event. The 100 Year and 50 Year design storm events have been run for a range of storm durations in order to assess the critical duration event for all points of the floodplain.

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

- quantify the floodplain hydraulic response with hydraulic grade lines and flow distributions;
- evaluate the potential impact on residential properties;
- identify flood hazard zones on the floodplain;
- inform flood overlay development for the new City Plan; and
- identify emergency management considerations.

The base-line flood maps for all the design flood events have been developed focussing on the area of interest. **Table E-1** provides a summary of the flooding results for Douglas and Annandale areas. Within the **Table E-1** indicative rainfall for the design events have been provided so that real events can easily be evaluated against the results of this study.

The impact of Highest Astronomical Tide (HAT) on flood levels has been assessed. The assessment shows that the flood levels in the Ross River at the downstream of Aplin Weir increases due to the impact of HAT. The impact of HAT on flood levels is insignificant on the other parts of the river and the study area.

An assessment for the potential for climate change to impact on flooding has been undertaken, accounting for a 0.8 m sea level rise and 15% increase in rainfall intensities. The model result shows that the flood levels increase up to 0.3 m around Verhoven Drive in Douglas area and increase up to 0.1 m near the intersection of Masuda Street and Fardon Street in Annandale due to climate change.

Table E-1: Summary of Douglas and Annandale Flooding Results

Event	Indicative Rainfall	Properties Inundated		Major Evacuation Route Closures	Emergency Management Issues	Flooding Description
		Douglas	Annandale			
2 Y ARI	63mm in 1.5 hours 83mm in 3 hours 277mm in 72 hours	0	1	-	-	Flooding is contained to drainage reserves and roads, lake, playground, flow paths and parks, with some inundation in a lot, particularly in Annandale.
5 Y ARI	83mm in 1.5 hours 110mm in 3 hours 392mm in 72 hours	4	4	-	-	Flooding is generally contained to drainage reserves and roads, playground, parking lots, lake and flow paths, with some inundation of residential lots, particularly 4 lots in Douglas and 4 lots in Annandale.
10 Y ARI	95mm in 1.5 hours 125mm in 3 hours 467mm in 72 hours	11	4	-	-	Flooding is generally contained to drainage reserves and roads, playground, parking lots, lakes and flow paths, with some inundation of residential lots, particularly 11 lots in Douglas and 4 lots in Annandale. Most of the inundated properties in Douglas are located around Verhoeven Drive.
20 Y ARI	111mm in 1.5 hour 146mm in 3 hours 562mm in 72 hours	28	6	-	-	Flooded areas becoming more widespread and connected, flooding is mainly contained to drainage reserves and roads, playground, parking lots, lakes and flow paths, with some inundation of residential lots, particularly 28 lots in Douglas and 6 lots in Annandale. Most of inundation takes place at Verhoeven Drive in Douglas and at the intersection of Masuada Street and Fardon Street in Annandale.
50 Y ARI	111mm in 1 hour 132mm in 1.5 hours 148mm in 2 hours 174mm in 3 hours 229mm in 6 hours 301mm in 12 hours 368mm in 18 hours 424mm in 24 hours 692mm in 72 hours	49	15	• Army Dam Bridge on University Road; • Cross-drainage at Ring Road near Douglas bio-retention Basin;	-	Flooding is largely contained to drainage reserves and roads, playground, lakes and flow paths except few localized areas in Douglas and Annandale, where widespread areas of interconnected flooding with significant flood depths are found. Significant number of residential lots is inundated in Douglas around Verhoeven Drive. Significant flood depth is found on few sections of major roads like Angus Smith Drive in Douglas and Yolanda Drive, Annandale Drive, Macarthur Drive and Glendale Drive in Annandale.

Table E-1: Summary of Douglas and Annandale Flooding Results (continued)

Event	Indicative Rainfall	Properties Inundated		Major Evacuation Route Closures	Emergency Management Issues	Flooding Description
		Douglas	Annandale			
100 Y ARI	125mm in 1 hour 148mm in 1.5 hours 166mm in 2 hours 195mm in 3 hours 257mm in 6 hours 338mm in 12 hours 416mm in 18 hours 481mm in 24 hours 796mm in 72 hours	65	15	• Army Dam Bridge on University Road; • Cross-drainage on Ring Road near Curtin Place; and • Cross-drainage at Ring Road near Douglas bio-retention Basin.	-	Flooding is largely contained to drainage reserves and roads, playground, lakes and flow paths except a few localized areas in Douglas and Annandale, where widespread areas of interconnected flooding with significant flood depths are found. The localized flooding areas are found around Verhoeven Drive in Douglas and at the intersection of Masuada Street and Fardon Street and Hoya Court in Annandale. A significant number of residential lots are inundated in Douglas around Verhoeven Drive. Significant flood depths are found on a few sections of major roads like Angus Smith Drive, Freshwater Drive and Riverside Boulevard in Douglas and Yolanda Drive, Annandale Drive, Macarthur Drive and Glendale Drive in Annandale.
200 Y ARI	165mm in 1.5 hours 217mm in 3 hours 905mm in 72 hours	72	18	• Army Dam Bridge on University Road; • Cross-drainage on Ring Road near Curtin Place; • Cross-drainage at Ring Road near Douglas bio-retention Basin; and • Cross-drainage point near Ring Road Bridge.	-	Flooding is mostly contained to drainage reserves and roads, playground, lakes and flow paths except a few localized areas in Douglas and Annandale, where widespread areas of interconnected flooding with significant flood depths are found. The localized flooding areas are found around Verhoeven Drive in Douglas. A significant number of residential lots are inundated in Douglas around Verhoeven Drive. Significant flood depths are found on the major roads like Angus Smith Drive, Freshwater Drive and Riverside Boulevard in Douglas and Yolanda Drive, Macarthur Drive and Glendale Drive in Annandale.

Table E-1: Summary of Douglas and Annandale Flooding Results (continued)

Event	Indicative Rainfall	Properties Inundated		Major Evacuation Route Closures	Emergency Management Issues	Flooding Description
		Douglas	Annandale			
500 Y ARI	187mm in 1.5 hours 248mm in 3 hours 1058mm in 72 hours	81	46	• Army Dam Bridge on University Road; • Intersection of Ring Road and Angus Smith Drive; • Cross-drainage on Ring Road near Curtin Place; • Cross-drainage at Ring Road near Douglas bio-retention Basin; and • Cross-drainage point near Ring Road Bridge.	River Gardens Community Centre inundated.	Flooding is mostly contained to drainage reserves and roads, playground, lakes and flow paths except few localized areas in Douglas and Annandale, where widespread areas of interconnected flooding with significant flood depths are found. The localized flooding areas are found around Verhoeven Drive in Douglas. Significant number of residential lots is inundated in Douglas around Verhoeven Drive. Significant flood depth is found on the major roads like Angus Smith Drive, Freshwater Drive and Riverside Boulevard in Douglas and Yolanda Drive, Macarthur Drive and Glendale Drive in Annandale.
PMP	394mm (Inner Ellipse) and 295mm (Outer Ellipse) in 1.5 hours; 279mm (Inner Ellipse) and 205mm (Outer Ellipse) in 3 hours; and 2520mm in 72 hours.	771	1855	• Army Dam Bridge on University Road; • University Creek Bridge on University Road; • University Road in front of Palmetum; • Intersection of Ring Road and Angus Smith Drive; • Cross-drainage on Ring Road near Curtin Place; • Cross-drainage at Ring Road near Douglas bio-retention Basin; and • Cross-drainage point near Ring Road Bridge.	Annandale State Primary School, Annandale Community Centre, Riverside Gardens Community Centre, James Cook University and Lavarack Barracks inundated.	Significant widespread flooding in both Douglas and Annandale. A total of approximately 771 and 1855 residential properties are inundated in Douglas and Annandale respectively. Numerous commercial premises, educational institutions and public utilities are also flooded due to this event. Flood affected properties are located mostly beside the right bank of the Ross River, both sides of the drainage paths /surface drains, the University Creek and the Army Dam Creek and locally flooded areas.

Glossary

AEP	Annual Exceedance Proability
AHD	Australian Height Datum
ARI	Average Recurrence Interval
AR&R	Australian Rainfall and Runoff
AVM	Average Variability Method
BoM	Bureau of Meteorology
CL	Continuous Loss of Rainfall in impervious/pervious layer
DEM	Digital Elevation Model
DERM	Department of Environment and Resource Management
DFE	Defined Flood Event
DTMR	Department of Transport and Main Roads
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.
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
IL	Initial Loss of Rainfall in impervious/pervious layer
IPCC	Intergovernmental Panel on Climate Change
LiDAR	Light Detection and Ranging (Aerial Laser Survey)
LGAQ	Local Government Association of Queensland
MHWS	Mean High Water Springs – the average height of the high waters of spring tides
MIKE11	Fully dynamic 1D hydraulic model
MIKE21	Fully dynamic 2D hydraulic model

MIKE FLOOD	Coupled 2D/1D hydraulic model combining MIKE11 and MIKE21
Pluviometer	Automated sampling device for measuring rainfall variability in short time periods
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
QUDM	Queensland Urban Drainage Manual
RCBC	Reinforced Concrete Box Culvert
RCPC	Reinforced Concrete Pipe Culvert
TCC	Townsville City Council
TFHAS	Townsville Flood Hazard Assessment Study (Maunsell, 2005)
XP-RAFTS	An urban and rural runoff-routing hydrologic model

1.0 Introduction

1.1 Overview

The *Douglas and Annandale Flood Study – Baseline Flooding Assessment* has been undertaken as part of Townsville City Council's City Wide Flood Constraints Project. The project seeks to develop up to date flood models for the city of Townsville at scales suitable for:

- defining flood levels for most urban properties;
- identifying the flood hazard overlay for the planning scheme;
- evaluating future flood mitigation projects; and
- assisting the disaster management process.

This study builds on previous hydrologic analysis projects done for the Townsville City Council and incorporates the latest Light Detection and Ranging (LiDAR) topographic data as well as hydrographic survey to form up to date hydrologic and hydraulic flood models for Douglas and Annandale.

1.2 Study Area

Douglas and Annandale suburbs are the main focus of the present study. The study area is shown in **Figure 1.1** and it includes Douglas and Annandale areas, their catchments and part of the Ross River (i.e. about 10 km).

The study area is bounded by the Ross River at the northern side and western side,Mount Stuart at the southern side and the Murray Sporting complex at the eastern side. The eastern extent of this study area has been considered up to Murray sporting complex.

The catchment of the study area extends up to the northern and the western sides of the Mount Stuart and discharges to the Ross River. Stormwater runoff in Douglas and Annandale areas is conveyed in a formalised drainage system comprising flow path/ unlined open drain and underground pipe flow through developed urban areas. The slope of the Douglas area is steeper than the Annandale area.

The Ross River is the main watercourse in the study area and its flow is regulated by the Ross River Dam. The Ross River travels about 26 km from the Dam before it discharges to Cleveland Bay. Initially it flows northwards approximately 10 km from the Dam and then it turns to northeast direction at Douglas area and travels further 16 km. The present study represents the 10 km of the Ross River adjacent to Douglas and Annandale.

The following hydraulic structures are located in the river within the study area:

- *Black Weir* – located approximately 11 km downstream of Ross River Dam and 15 km upstream of the mouth, near the suburbs of Kirwan and Douglas;
- *Gleesons Weir* – located approximately 12 km downstream of Ross River Dam near the suburbs of Cranbrook and Douglas; and

- *Aplins Weir* – located approximately 16 km downstream of Ross River Dam and 10 km upstream of the mouth, near the suburbs of Mundingburra and Annandale.
- *Ring Road bridge*- located approximately 9.5 km downstream of the dam and 16.5 km upstream of the Ross River mouth, connecting the suburbs of Condon and Douglas; and
- *Nathan Street bridge*- located approximately 14.5 km downstream of the dam connecting the suburbs of Cranbrook/Aitkenvale and Douglas/Annandale.

The above mentioned three weirs create permanent water bodies within the river around Douglas and Annandale areas. The lower reach of the Ross River downstream of Aplins Weir is tidal.

1.3 Scope of Works

The scope of works for this *Baseline Flooding Assessment* includes:

- review of previous engineering reports and data;
- compilation and analysis of relevant data including rainfall, stream gauging, construction drawings, topographic survey and hydrographic survey;
- identification of data gaps and collection of data through survey;
- identification of a suitable approach for hydrologic and hydraulic modelling;
- development and verification of Douglas-Annandale hydraulic model; and
- review and detailing the base-line flooding determined for the study area.

DOUGLAS & ANNANDALE FLOOD STUDY
Study Area

Figure 1-1

LEGEND

- ModelDomain
- Rain on Grid
- Suburbs

SCALE: 1:25,000 @A3

250 125 0 250 500 750 Metres

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1.4 Study Approach

The hydraulic model developed for Douglas and Annandale suburbs is a three-way coupled MIKE FLOOD model representing two-dimensional floodplain topography, one-dimensional flow paths and structures and trunk underground drainage. The model has been verified with the Ross River model result of 100 year ARI event as well as other overlapped model results at its eastern boundary. Verification confirmed the model parameters. Following verification the model has been run for 100 and 50 years ARI events for a range of durations to establish the critical storm duration across the floodplain.

A XP-RAFTS hydrologic model of Douglas and Annandale areas has been used to represent the flows from the upper catchment draining into the study area in combination with the "Rain on Grid" approach to represent a majority of the local rain within the bounds of the hydraulic model.

Results of the model are intended to be used for floodplain planning and evaluation of flood mitigation works for future investigations.

The report has been prepared in two volumes:

- Volume 1 (this Volume) – provides the majority of the report including methodology and discussion of results; and
- Volume 2 – provides the flood map results from the study.

2.0 Available Data

2.1 Topographic and Bathymetric Data

An accurate representation of topography and bathymetry is a key to any hydrologic and hydraulic investigation. In this study, topographic and bathymetric data collected from different sources have been used for appropriate representation of topography and bathymetry of the study area. The main datasets and sources used in this study are as follows:

Topographic data

- Townsville City Council obtained LiDAR from a joint government agency project, with capture around September/October 2009;
- Crest level data of highways, roads and streets obtained from Townsville City Council database; and
- Crest level data of Ring Road, University Road and Angus Smith Drive obtained from Department of Transport and Main Roads (DTMR).

Bathymetric Data

- Underwater survey data of the Ross River obtained from Townsville Flood Hazard Assessment Study (*Maunsell, 2005*); and
- Cross-sections obtained from MIKE 11 model setup of Townsville Flood Hazard Assessment Study:
  - *Douglas:* Surface drains between Ashburton Place and Grande Parade, Surface drain beside Southern Cross Circuit and drain beside Regatta Crescent; and
  - *Annandale:* Palmetum Drain, University Creek and downstream part of Annandale Drain).

Figure 2-1 shows the extent of the topographic and bathymetric datasets.

2.2 Structure Information

Hydraulic structures such as culverts and bridges are critical to flooding hydraulics and accurate representation is important in hydraulic modelling. In this study all the hydraulic structure information has been collected from the following sources:

- *Ross River Flood Model*- present study area overlaps the Ross River model at Douglas and Annandale areas and it covers about 10 km reach of the Ross River; all the hydraulic structures in the 10km river reach have been considered;
- *DTMR Drawings*- all the cross-drainage structures in Ring Road and University Road;
- *Townsville City Council Database*- surface and sub-surface drainage structures; and
- *Field survey*- missing structures' information.

DOUGLAS & ANNANDALE FLOOD STUDY
Data

Figure 2-1

LEGEND

Ross River

Drainage Paths

Topography (LiDAR)

Streets

City of Townsville

SCALE: 1:25,000 @A3

250 125 0 250 500 750 Metres

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2.3 Ross River Flows and Water Levels for Design Storms

Boundary conditions for the Douglas-Annandale model have been taken from flood studies previously completed as part of the City Wide Flood Constraints project. In the hydraulic model, the open-boundary flows and water levels in the Ross River for different ARI have been either extracted from the existing model results or generated from the existing XP-RAFTS model developed for the downstream part of the Ross River. The existing model results used in this study for generation of model boundaries are provided in Table 2.1.

Table 2-1 Model boundaries

ARI (Year)	Design Storm Duration (hr)	Ross River Model		XP-RAFTS Model (RossRiverDs)	Ross Creek Model
		Flow at U/S Boundary	Water Level at D/S Boundary	Flow at U/S Boundary	Water Level at D/S Boundary
All	72	√	√	-	-
All	Rest	-	-	√	√

2.4 Aerial Photography

Townsville City Council's aerial photography captured in July 2009 has been used for assigning fraction impervious and hydraulic roughness within the flood models.

2.5 Previous Flooding Reports

Townsville Flood Hazard Assessment Study

Townsville City Council commissioned Maunsell to undertake the *Townsville Flood Hazard Assessment Study* as part of the Natural Disaster Risk Management Studies Program. The Study was completed in 2005 and involved 3 phases:

- Phase 1 – Data Acquisition;
- Phase 2 – Flood Hazard Assessment; and
- Phase 3 – Vulnerability Assessment and Risk Analysis.

The flood modelling was completed for Phase 2 of the report. The study includes Annandale and part of Douglas areas. The study focused on local catchment flooding.

The runoff/ routing model XP-RAFTS was used to simulate the hydrological response of the local catchments of Townsville.

The hydraulic assessment developed a MIKE11 model for flood events up to the 20 Year ARI, while a MIKE21 model was developed for the flood events greater than and including the 50 Year ARI. To simplify the computational requirements of the project, only the 2 hour and 6 hour storm durations were assessed.

Data acquired for the *Townsville Flood Hazard Assessment Study* has been used in the development of the hydraulic model under present study.

Ross River Flood Study – Base Line Flooding Assessment
The Ross River Flood Study – Baseline Flooding Assessment was carried out as an initial part of Townsville City Council's City Wide Flood Constraints Project in January 2013.

The study examined catchment flows from the entire Ross River catchment- both upstream and downstream of the dam. It considered all the hydraulic structures in the Ross River (i.e. Dam, bridges and weirs). The hydraulics of the floodplain downstream of the dam were analysed using a MIKE FLOOD hydraulic model. The MIKE FLOOD, coupled 2D/1D model was used to represent the hydraulics of the river channel and floodplain downstream of the dam. The grid resolution of the 2D model was 30mX30m.

The main sources of topographic data were: LiDAR 2009 and hydrographic survey data of the freshwater reaches (2001) and the lower estuarine reaches of the Ross River (2010).

The model considered boundaries at Ross River Dam (as inflow to the model), Cleveland Bay, Bohle River Estuary and Louisa Creek Estuary. It incorporated following sub-catchments as source points:

- Ross River Downstream;
- Douglas/Annandale;
- Gordon Creek; and Stuart Creek.

In the model, major structures on the Ross River were represented as one-dimensional elements. Other bridge structures on overflow paths away from the channel of Ross River were not included in the model. Similarly, pipe drainage networks draining portions of the floodplain to the River were not modelled.

The Ross River Model was calibrated with 3 historical events (Dec 2010, Jan 2009 and Feb 2007) and it established 72 hour as the critical storm duration for the Ross River.

Design flood assessment reviewed the 2, 5, 10, 20, 50, 100, 200, 500, 1000 and 2000 Year Average Recurrence Interval (ARI) floods, in addition to Probable Maximum Flood (PMF).

The flood modelling results were used to assess a range of issues including:

- Floodplain hydraulic mechanisms;
- Approximate numbers of residential properties impacted by Ross River flooding;
- Overflows from the main river channel for given frequency floods;
- Hazard zones within the floodplain;
- Floodplain planning considerations;
- Emergency management including flood warning and prediction, road closures and flood immunity of key emergency management sites;
- Impacts on flooding of climate change.

The present study area overlaps the Ross River model at Douglas and Annandale areas covering about 10 km reach of the Ross River.

Hydraulic Study of the Discovery Rise Development – James Cook University

SMEC Australia, commissioned by James Cook University (JCU), carried out hydrologic, hydraulic and preliminary water quality modelling to determine the impact of the proposed JCU development and outline available mitigation measure to minimise impacts. The study focussed on the watercourses covering the university site in Douglas.

In the study two design events were adopted and modelled: 50 Year ARI and 100 Year ARI flood events. Hydrologic models were developed using XP-RAFTS software for each catchment for both existing and future conditions accounting for the proposed discovery rise development were assessed. A hydraulic model was developed using MIKE 11 software to assess the impact of the development.

The relevant key findings from the investigation are mentioned below:

- For the University Creek, draining most of the site and discharging to the Ross River - all state-controlled road crossing within the University Creek catchment have the capacity to pass up to the 100 Year ARI event for both the events;
- For the other un-named Creeks , draining the northern and north-western edges of the JCU site and discharging to the Ross River -
    - the state-controlled road crossings of the Ring Road and Angus Smith Drive for un-named creeks are capable of passing the 100 year ARI events without overtopping the road shoulder level for both the existing and future scenarios; and
    - the state-controlled road crossings of Angus Smith Drive (Structure No. 6B and 6C) in catchment of unnamed creek 3 cannot pass the 50 year ARI event without overtopping the road crest in the future scenario.

3.0 Hydrological Assessment

3.1 Catchment Overview

The catchment of the study area is located at the northern side of the Mount Stuart and it covers the suburbs of Douglas, Annandale and part of Murray. The northern slope of Mount Stuart drains to the Ross River through the drainage paths within the urban areas including James Cook University. The area on the north foothills of Mount Stuart is urbanised made-up of largely residential areas, with some commercial and parkland. The total area of the Douglas and Annandale catchments is approximately 27.24 km^2.

3.2 Hydrological Modelling Software

XP-RAFTS

The hydrologic modelling software XP-RAFTS calculates catchment flows from rainfall based on Laurenson's non-linear routing method. The model is able to predict flows for catchments containing both urban and rural land uses accounting for surface roughness, catchment slope, soil infiltration and depression storage losses. It is well suited to the study area due to the need for detailed sub-catchment definition and representation of both rural and urban areas combined.

The Douglas-Annandale XP-RAFTS model was developed as part of work for the City Wide Flood Constraints project and is presented in **AppendixA**. A previously developed XP-RAFTS model for the downstream reaches of Ross River has also been used (Ross River Flood Study 2013). The Douglas-Annandale model has been used to generate flows at the source points in the hydraulic model while the Ross River model has been used to generate flows in the Ross River.

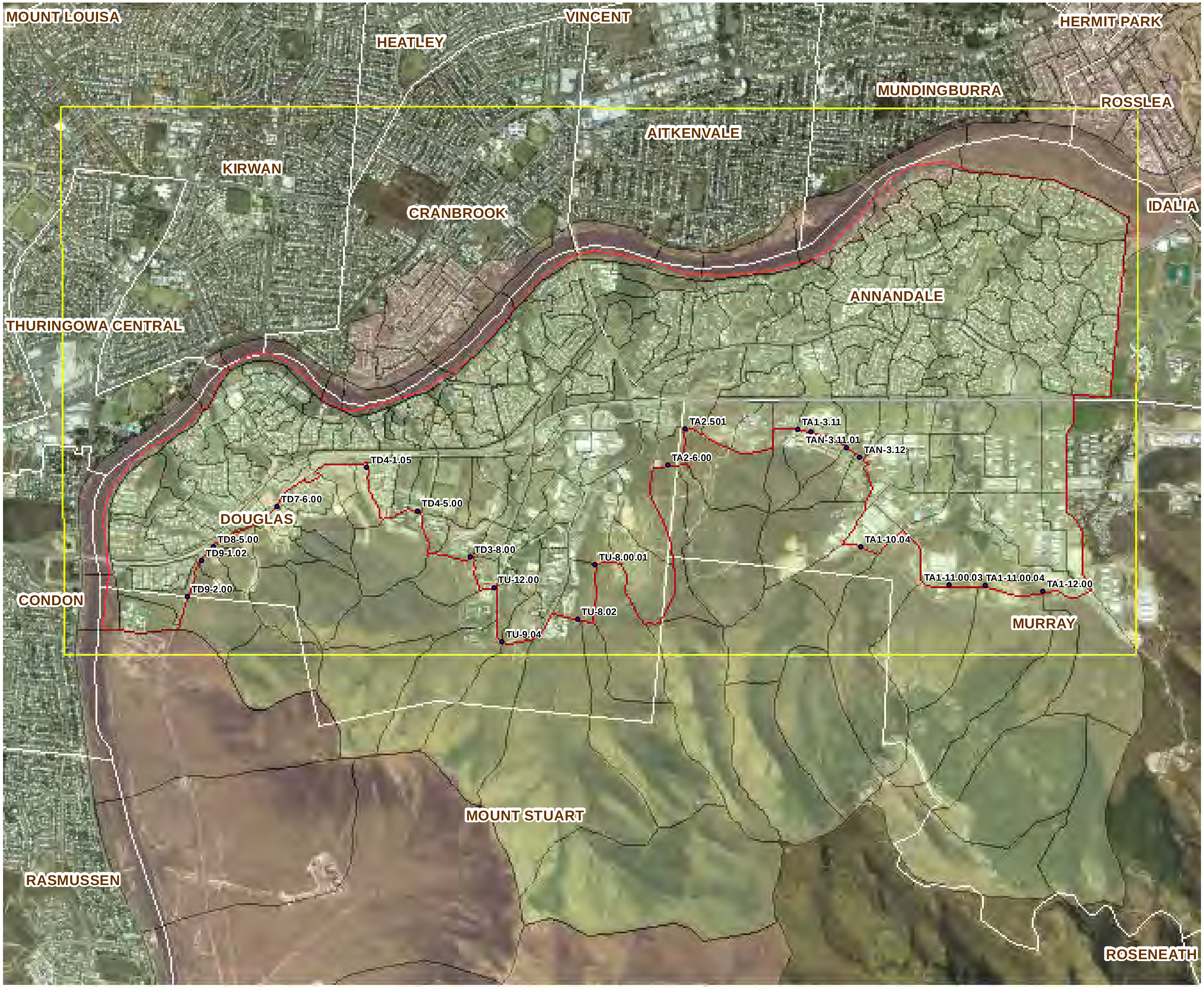
"Rain on Grid" Approach

The "Rain on Grid" approach has been used in this study. It involves directly applying rainfall excess to the two-dimensional grid of the MIKE FLOOD model. Rainfall excess is the rainfall less initial and continuing losses associated with surface depression storage and infiltration.

3.3 Catchment Delineation and Sub-Catchment Parameters

In the Douglas-Annandale XP-RAFTS model the catchment was divided into 242 sub-catchments. The catchment delineation was based on the 2009 LiDAR, aerial photograph, stormwater infrastructure GIS layers and cadastral boundaries. **Figure 3-1** shows an overview of the sub-catchments delineation of the Douglas-Annandale area adapted for this study.

Sub-catchment parameters for the Douglas-Annandale hydrological model were determined from topographic data, aerial photography, cadastral and site information. The adopted sub-catchment parameters are presented in **Appendix A.**



DOUGLAS & ANNANDALE FLOOD STUDY
Catchment Overview

Figure 3-1

LEGEND

- Douglas-Annandale
- RossRiver_DS
- Sources
- ModelDomain
- Rain on Grid
- Suburbs

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City of Townsville

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3.4 Design Rainfall

Design rainfall for the Douglas-Annandale catchment has been developed from the Intensity Frequency Duration (IFD) methods outlined in Australian Rainfall and Runoff (1998) using catchment specific IFD input parameters. The IFD input parameters adopted are provided in **Table 3-1**. The resulting IFD rainfall intensities for Douglas-Annandale are provided in **Table 3-2**.

Table 3-1 Douglas-Annandale IFD Input Data*

Parameter	Value
Latitude	19.322 Deg S
Longitude	146.765 Deg E
2 Year, 1 Hour Intensity	53.82 mm/h
2 Year, 12 Hour Intensity	11.92 mm/h
2 Year, 72 Hour Intensity	3.87 mm/h
50 Year, 1 Hour Intensity	110.12 mm/h
50 Year, 12 Hour Intensity	24.8 mm/h
50 Year, 72 Hour Intensity	9.48 mm/h
Skewness (G)	0.05
Geographical Factor (F2)	3.93
Geographical Factor (F50)	17.08

***** *These parameters are kept similar to the Ross Creek Flood Study as both locations are very close to each other.*

Table 3-2 Douglas-Annandale IFD Rainfall Data

Storm Duration	Rainfall Intensity (mm/h) for Given ARI								
	1Y	2Y	5Y	10Y	20Y	50Y	100Y	200Y	500Y
5 min	115.47	149.70	195.51	222.87	258.76	306.49	343.23	381.04	432.56
6 min	109.14	141.51	184.87	210.78	244.75	289.94	324.73	360.53	409.33
10 min	91.54	118.73	155.26	177.10	205.74	243.84	273.19	303.40	344.58
15 min	78.22	101.49	132.83	151.59	176.16	208.87	234.08	260.03	295.42
20 min	69.33	89.98	117.84	134.53	156.38	185.48	207.91	231.00	262.51
30 min	57.81	75.05	98.39	112.38	130.69	155.09	173.90	193.28	219.72
45 min	47.64	61.87	81.19	92.79	107.96	128.18	143.78	159.85	181.79
1 hour	41.28	53.64	70.44	80.54	93.74	111.34	124.92	138.91	158.02
1.5 hour	32.48	42.21	55.50	63.49	73.93	87.85	98.61	109.69	124.83
2 hour	27.30	35.49	46.69	53.44	62.25	74.01	83.08	92.45	105.24
3 hour	21.31	27.71	36.51	41.80	48.72	57.95	65.09	72.45	82.51
4.5 hour	16.61	21.62	28.51	32.66	38.09	45.33	50.93	56.71	64.61
6 hour	13.93	18.13	23.92	27.42	31.99	38.09	42.80	47.67	54.33
9 hour	10.87	14.15	18.70	21.45	25.03	29.82	33.53	37.35	42.59
12 hour	9.12	11.88	15.71	18.03	21.04	25.08	28.20	31.43	35.85
18 hour	7.14	9.35	12.54	14.50	17.04	20.45	23.11	25.87	29.66
24 hour	5.99	7.87	10.67	12.41	14.64	17.66	20.03	22.49	25.88
30 hour	5.21	6.87	9.39	10.96	12.99	15.73	17.88	20.13	23.24
36 hour	4.64	6.14	8.44	9.89	11.75	14.28	16.27	18.36	21.24
48 hour	3.84	5.10	7.09	8.36	9.98	12.19	13.95	15.79	18.35
72 hour	2.89	3.85	5.45	6.48	7.80	9.61	11.05	12.57	14.70

Probable Maximum Precipitation

Estimates of the Probable Maximum Precipitation (PMP) have been made for a range of storm durations. The Generalised Short Duration Method (GSDM) has been used for storm events up to 6 hours, while the Generalised Tropical Storm Method - Revised (GTSMR) has been used for storm events longer than 24 hours.

3.5 Rainfall Loss Values

Rainfall loss values for the design events have been determined based on model verification. A summary of the loss values determined from the calibration is as follows:

- Impervious – 1 mm IL and 0 mm CL;
- Pervious – 25 mm IL and 2.5 mm CL.

3.6 Hydrologic Results

Although the rainfall within the bounds of the hydraulic model has been represented with the "Rain on Grid", the local/ total sub-catchment flows from upstream in the local catchments were generated using the existing XP-RAFTS model and incorporated in the MIKE FLOOD model as sources. The hydrologic model results at these sources are presented in **Table 3-3**.

Table 3-3 Douglas-Annandale XP-RAFTS Design Flood Flows

Suburb	Sub-catchment ID	Peak Flood Flows (m3/s)								
		2Y	5Y	10Y	20Y	50Y	100Y	200Y	500Y	PMF
Douglas	TD9-2.00	5.3	9.1	11.3	14.7	18.0	21.4	24.5	28.8	58.6
Douglas	TD9-1.02	0.5	0.9	1.1	1.4	1.6	1.7	2.0	2.4	4.6
Douglas	TD8-5.00	1.3	2.3	2.9	3.6	4.0	4.6	5.0	5.8	12.2
Douglas	TD7-6.00	8.3	13.3	17.6	22.8	27.2	31.5	35.7	41.3	86.6
Douglas	TD4-1.05	1.6	2.8	3.5	4.3	4.8	5.5	6.1	7.3	15.0
Douglas	TD4-5.00	2.6	4.3	5.8	7.5	9.0	10.4	11.9	13.9	28.9
Douglas	TD3-8.00	1.5	2.7	3.4	4.4	5.2	6.0	6.6	7.7	22.2
Douglas	TU-12.00	11.1	19.6	24.6	30.6	37.9	41.6	48.0	58.2	145.2
Douglas	TU-9.04	4.1	7.3	9.0	12.0	14.9	17.7	20.4	24.0	68.9
Douglas	TU-8.02	21.8	37.7	48.0	62.8	75.7	88.3	100.0	118.7	426.8
Douglas	TU-8.00.01	3.0	5.2	6.6	8.4	10.5	12.6	14.8	17.5	50.9
Douglas	TA2-6.00	9.9	17.0	22.1	28.9	35.7	42.0	47.5	54.3	175.6
Murray	TA2-5.01	2.3	4.0	5.0	6.7	8.2	9.8	11.3	13.5	38.9
Murray	TA1-3.11	1.0	1.8	2.3	2.9	3.4	3.9	4.4	5.1	15.0
Murray	TA1-3.10.02	1.1	1.8	2.3	2.9	3.5	4.2	4.8	5.8	16.2
Murray	TAN-3.11.01	1.0	1.7	2.2	2.8	3.3	3.8	4.3	4.9	14.5
Murray	TAN-3.12	3.8	6.5	8.4	10.7	13.0	15.2	17.4	20.5	59.7
Murray	TA1-10.04	12.9	22.9	29.7	38.6	47.6	56.6	64.8	76.0	239.0
Murray	TA1-11.0002	5.3	8.9	11.4	14.7	18.3	21.9	25.4	30.3	98.3
Murray	TA1-11.0003	4.0	6.9	8.7	11.1	13.9	16.9	19.5	23.5	71.1
Murray	TA1-11.0004	5.1	8.7	11.1	14.4	18.0	21.2	24.7	29.5	95.1
Murray	TA1-12.00	19.5	33.1	41.4	54.8	69.7	82.6	94.3	110.4	289.5

4.0 Hydraulic Assessment

4.1 Floodplain Overview

The Douglas and Annandale areas are located between the floodplain of the Ross River and Mount Stuart foothills with both being established urbanised areas. Two highways (i.e. Townsville Ring Road and University Road) cross the study area. The Ring Road passes through Douglas and the University Road separates Annandale from Murray. There are many cross-drainage structures, surface drains and underground pipe drains in the floodplain that are facilitating stormwater runoff through Douglas and Annandale suburbs. The major surface flow paths for stormwater conveyance are:

- *University Creek*- which drains stormwater runoff from James Cook University and Townsville Hospital areas into the Ross River. It crosses the Ring Road and University Road.
- *Army Dam Creek*- which drains stormwater runoff from the Lavarack Barracks area in Murray to the Ross River through Annandale. It crosses University Road and Macarthur.

4.2 MIKE FLOOD

MIKE FLOOD is a dynamically linked 3-way hydraulic modelling package, which couples the 1D river hydraulics model, MIKE11 and the 1D sub-surface drainage model, MIKE URBAN with the 2D surface water model, MIKE21. MIKE FLOOD can be used to simulate:

- coincident river and storm surge flooding in coastal areas;
- the detailed flooding patterns on floodplains in terms of flow velocities and water levels;
- water exchange between channels, canals, sub-surface drainage and adjacent floodplains, ponds, reservoirs, etc.; and
- flood waves in channels and on flood plains associated with a dam failure.

The MIKE21 2D component of the MIKE FLOOD model has been used to adequately represent the complex 2D hydraulics of the floodplain. The MIKE11 1D component of the MIKE FLOOD model has been used to provide a more accurate representation of the hydraulics of structures (such as culverts, weirs and bridges) and narrow open channels. The MIKE URBAN 1D component of the MIKE FLOOD model has been used to represent sub-surface drainage that has the potential to impact on flood levels. Sub-surface drainage generally larger than or equal to the equivalent waterway area of 900 mm diameter pipe has been considered to have the potential to impact on flood levels.

4.3 Model Setup

Topographic Grid
The MIKE FLOOD model developed for the Douglas and Annandale areas is based on a 10 m topographic grid and it covers an area of 30 km^2 (7.68 kmX3.91 km). The model set-up is shown in **Figure 4-1**. The topographic grid for the flood plains of Douglas and Annandale are based on the LiDAR data of 2009 and it has been updated with the crest level data of highways, roads and streets. The bathymetry of the Ross River is based on underwater survey data obtained as part of the *Townsville Flood Hazard Assessment Study*.

Boundary Conditions
There are two main open boundaries in the model. The upstream boundary which has been defined as an inflow time series is located immediately upstream of the Ring Road Bridge. The downstream boundary defined as a water level time series is located immediately upstream of Bowen Bridge. The inflow and the water level data in the Ross River for different design events have been extracted from the existing model results (refer to **Section 2.3**).

The locations of the model boundaries are shown in **Figure 4-1**.

Rain on Grid
The application of rainfall excess directly to the MIKE FLOOD 2D grid is limited to flat portions of the study area to ensure model stability. The extent of the “Rain on Grid” area is shown in **Figure 4-1**. The rainfall excess has been applied in the MIKE FLOOD 2D grid with a spatial distribution representing the impervious areas within study area. The impervious areas have been identified from a detailed review of aerial photography and zoning information. The spatial distribution of impervious areas is shown in **Figure 4-2**.

In this study the rainfall loss values have been determined based on verification and match the findings of Gordon Creek Flood Study, which overlaps at Annandale suburbs. The loss values adopted for the design flood events are:

- initial loss - 25mm; and
- continuing loss 2.5 mm/h.

The derivation of the design rainfall applied using “Rain on Grid” is provided in **Section 3.4**.

Source Points
Inflows from the surrounding sub-catchments outside “Rain on Grid” area have been included in MIKE FLOOD model as sources (shown in **Figure 4-1**). The Douglas-Annandale XP-RAFTS model has been run for different design storms in order to obtain flows at different source points.

DOUGLAS & ANNANDALE FLOOD STUDY
Model Setup

Figure 4-1

LEGEND

- MIKE URBAN Nodes
- MIKE URBAN Links
- MIKE 11 Branches
- Sources
- Rain On Grid
- Model Domain

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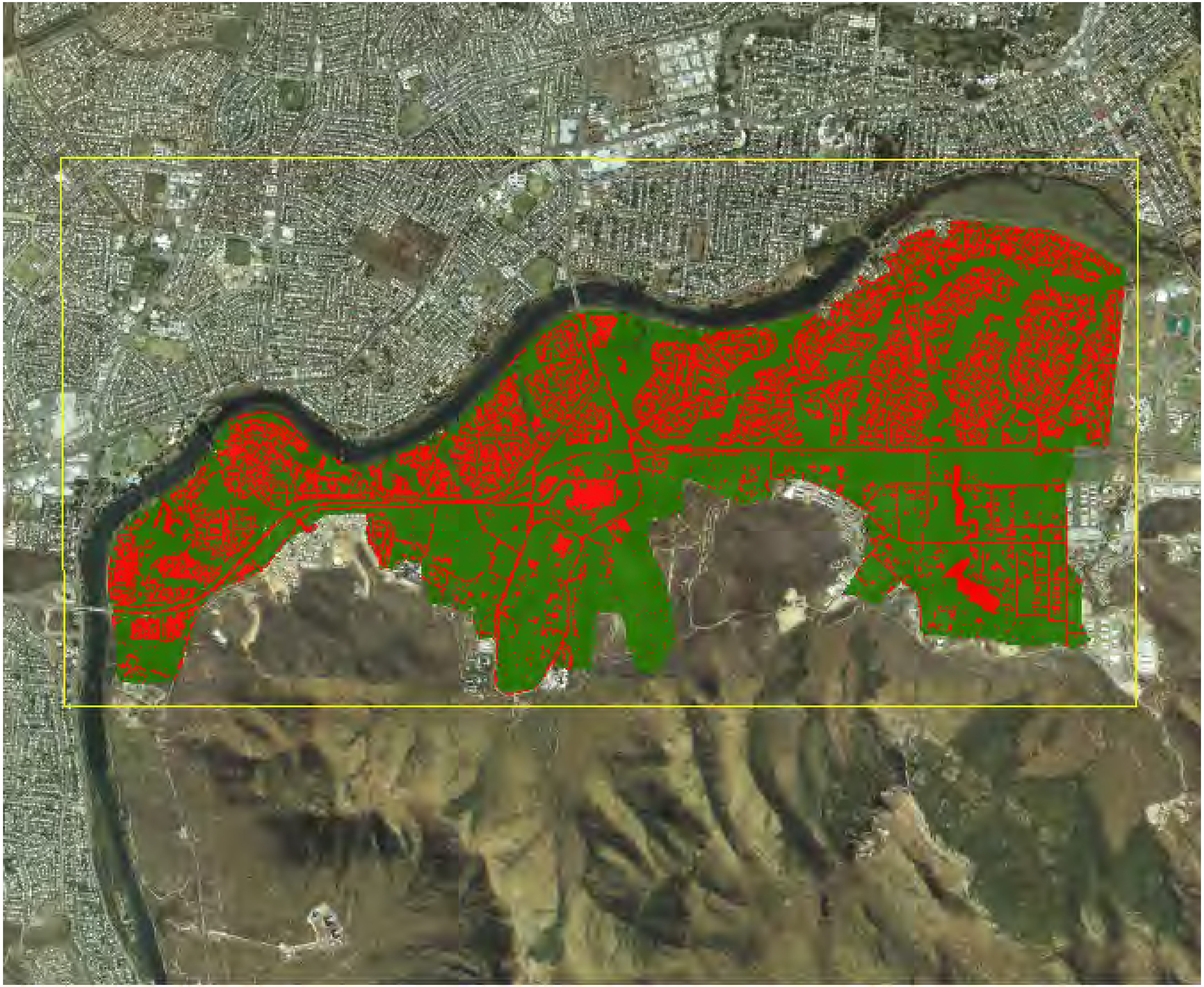

DOUGLAS & ANNANDALE FLOOD STUDY
Fraction Impervious

Figure 4-2

LEGEND

Impervious Assignment

- Impervious
- Pervious
- Model Domain

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Hydraulic Structures

All of the major hydraulic structures built on the Ross River and on the floodplain have been represented as one-dimensional elements in the model by either:

- representing the structure as an implicit coupled structure;
- representing the structure as an explicit coupled structure; or
- representing the structure within a 1-dimensional branch that was laterally coupled immediately upstream and downstream of the structure.

The main structures represented include:

In the Ross River

- Ring Road Bridge;
- Black Weir;
- Gleesons Weir;
- Nathan Street Bridge; and
- Aplins Weir.

In Douglas Area

- University Creek Bridge at Ring Road;
- Cross-drainage structures in Ring Road: 6 nos. RCBC and 3 nos. RCPC;
- Pedestrian Underpass at Ring Road (2.4m x 2.4m RCBC);
- Wildlife Corridor at Ring Road (3/2.4m x 2.1m RCBC and 1.8m x 1.8m RCBC);
- Cross-drainage structures in Angus Smith Drive (12 nos.):
- Culverts in floodplain (10 nos RCBC and 2 nos. RCPC);

In Annandale and its Surrounding Area

- Army Dam Creek Bridge allowing drainage from Murray to Annandale across University Road;
- University Creek Bridge allowing drainage from Douglas to Annandale across University Road;
- Pedestrian Underpass at University Road (2.4 m x 2.4 m RCBC);
- Cross-drainage structures in University Road: 8 nos. RCBC and 3 nos. RCPC;
- Culverts in floodplain (6 nos. RCBC and 4 nos. RCPC);

Details of the culverts, bridges and weirs represented within the Douglas-Annandale model are provided in **Appendix B**.

Narrow Flow Paths

Surface flow paths that are too narrow to be represented with the MIKE21 topographic grid component of the MIKE FLOOD model have been represented using MIKE11 branches. Overflows from the MIKE11 branches have been transferred to the MIKE21 topographic grid of the broader floodplain via lateral couples.

In Douglas-Annandale model, the narrow flow paths represented by MIKE11 branches are:

Douglas Area

- *Haven Place Drain:* an unlined open drain beside Haven Place;
- *Ashburton Place Drain:* an unlined open drain beside Ashburton Place;
- *Creekwood Way Drain:* an unlined open drain, which is draining overland and sub-surface stormwater flow of Creekwood Way and surrounding area;

- *Grande Parade Drain:* an unlined open drain beside Grande Parade, which is connected with a cross-drain at Ring Road and Angus Smith Drive and draining overland stormwater flow coming from the opposite side of Angus Smith Drive;
- *Swan Court Drain:* an unlined open drain, which is draining overland stormwater flow from surrounding area and also from the opposite side of Angus Smith Drive; and
- *Regatta Crescent Drain:* an unlined open drain beside Regatta Crescent, which is draining overland stormwater flow from surrounding area and also from the opposite side of Angus Smith Drive;

Annandale Area

- *Palmetum Drain:* an unlined open drain at Palmetum, which is draining both University Creek and overland and sub-surface flow at Verhoeven Drive of Douglas;
- *Army Dam Creek:* draining stormwater runoff from surrounding area at Murray and Annandale
- *Yolanda Drive Drain:* an unlined open drain beside Yolanda Drive;
- *Glendale Drive Drain;* and
- *Marabou Drive Drain:* an unlined open drain beside Marabou Drive.

Cross sections for the narrow flow path drains have been obtained from TFHAS. The locations of the narrow flow path branches represented within MIKE11 are shown in **Figure 4-1**.

Underground Drainage

Components of the underground drainage network that have potential to impact on surface flood levels have been represented using the MIKE URBAN component of the MIKE FLOOD model. Following an assessment of the conveyance within a typical street cross-section, with typical grades experienced in Townsville, it was identified that underground drainage with a cross-sectional area equal to a 900mm diameter pipe or greater was able to impact flood levels within the street cross-section by 10mm or greater. Generally only sections of the underground drainage, where the pipe cross-sectional area is greater than the equivalent of a 900mm pipe have been represented.

Figure 4-1 shows the general layout of the underground drainage network represented in the MIKE FLOOD model. Details of the underground drainage network represented in the MIKE FLOOD model are provided in **Appendix C**. Information to specify levels and dimensions of the network have been sourced from Council's corporate GIS database.

Hydraulic Roughness

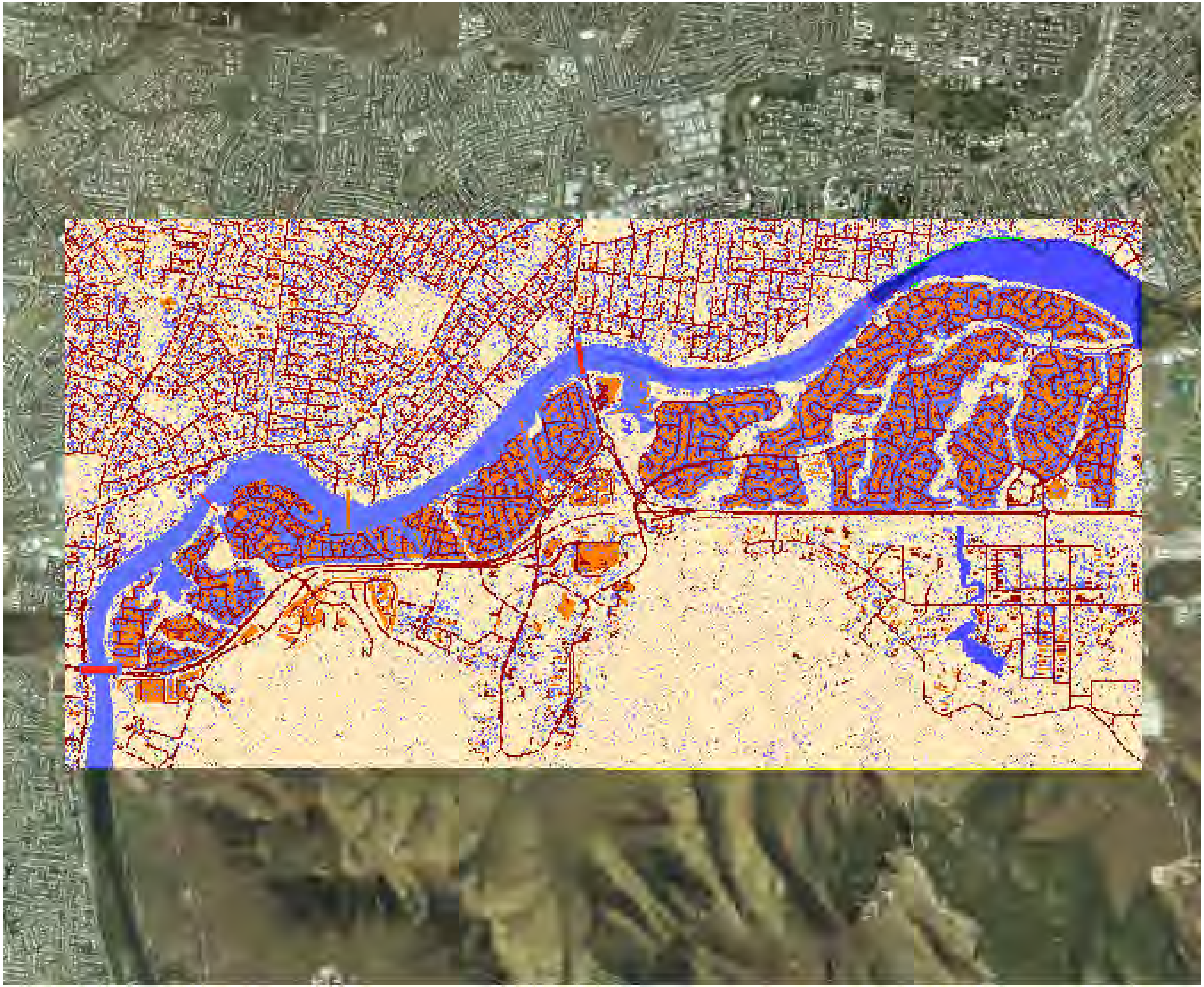
In this study land-use data, aerial photography and site assessment have been analysed and represented in the model as hydraulic roughness. The hydraulic roughness within the model is specified as Manning's 'n' values and its values have been determined based on previous studies and literature and finalised during model verification process. The roughness distribution map adopted within the MIKE21 component of the MIKE FLOOD model are shown in **Figure 4-3**. The specific roughness values adopted for different land-use are detailed in Table 4.1.

Table 4-1 Adopted Roughness Values in MIKE 21 Model

Land-use	*Roughness (Manning's n)*
Road crests	0.02
Flood plains having cleared land with tree stumps (no sprouts), pasture (no brush) or cultivated areas (no crop)	0.03
Urban area having buildings and fences	0.08
Unlined open drains having sluggish reaches, weedy and deep pools	0.08
Bridges and Weirs	0.1
The Ross River:	
- Riverbed less than 0 m AHD	0.015
- Riverbed between 0m and 2m AHD	0.025
- Riverbed greater than 2m AHD	0.05

Eddy Viscosity

The eddy viscosity parameter describes the degree of turbulence that exists at scales smaller than the model grid scale of 10m. Turbulence on the horizontal plan with a scale larger than 10m can be represented by flows in the model from one grid cell to the next. In this study eddy viscosity has been considered 9 for the Ross River and 2 for floodplain. The values of eddy viscosity were confirmed through model verification.



DOUGLAS & ANNANDALE FLOOD STUDY
MIKE 21 Roughness

Figure 4-3

LEGEND

Manning's n

- 0.018
- 0.02
- 0.025
- .0303
- .035
- 0.05
- 0.08
- 0.1

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Flow Couples

Several types of coupling can be used to simultaneously represent 2D floodplain flows (based on MIKE 21 model) with, 1D channel flows (based on MIKE 11 model) and 1D pipe flows (based on MIKE URBAN model) and also for transferring flow between models. The following is a general description of the couple types adopted within the MIKE FLOOD model setup:

- *Standard Couple* – representing flow transfer between MIKE21 and MIKE11 where one or more MIKE21 cells are linked to the end of a MIKE11 branch (either upstream or downstream end). This type of couple is useful for connecting a detailed MIKE21 grid into a broader MIKE 11 network, or to connect an internal MIKE11 branch/structure (with an extent of more than a grid cell) inside the MIKE 21 grid.
- *Lateral Couple* – representing flow transfer between MIKE21 and MIKE11 where a string of MIKE21 cells are laterally linked to MIKE11 for either a section of a branch or an entire branch. This type of couple is useful for simulating overflow from a channel onto a flood plain.
- *Structure Couple* – representing flow transfer between MIKE21 and MIKE11 where a structure is represented in MIKE11. The structure couple takes the flow terms from a structure in MIKE11 and inserts them directly into the momentum equations of MIKE21.
- *Zero Flow Couple* – prevent flow through a series of MIKE21 cells. These zero flow couples have been used in conjunction with standard couples, when the standard couples are used for structure branches. These couples ensure all flow travels through the MIKE11 branch.
- *River / Urban Couple* – representing flow transfer between MIKE11 and MIKE URBAN where a chainage in MIKE11 and a Node in MIKE URBAN are linked. This kind of couple is used for representing outlets from the underground drainage network. Flow can travel both ways through this couple depending on the head difference in MIKE11 and MIKE URBAN.
- *Urban Outlet Couple* – representing flow transfer between MIKE21 and MIKE URBAN where a MIKE21 cell and a Node in MIKE URBAN are linked. This kind of couple is used for representing outlets from the underground drainage network. Flow can travel both ways through this couple depending on the head difference in MIKE21 and MIKE URBAN.
- *Urban Inlet Couple* – representing flow transfer between MIKE21 and MIKE URBAN where a MIKE21 cell and a Node in MIKE URBAN are linked. This kind of couple is used for representing inlets to the underground drainage network. Flow can travel both ways through this couple depending on the head difference in MIKE21 and MIKE URBAN.

The MIKE FLOOD model has a total 204 couples comprising:

- 102 standard couples;
- 9 lateral couples;
- 11 structure couples;
- 4 zero flow couples; and
- 78 urban inlet/outlet couples.

4.4 Model Verification

The MIKE FLOOD model of Douglas and Annandale has been verified to the Ross River model result of 100 year ARI event (72 hour storm duration) as there was no available data for directly calibrating the MIKE FLOOD model. The Ross River Model was previously calibrated with 3 historical events (Dec 2010, Jan 2009 and Feb 2007). Inflow and the water level time series data for the verification event were obtained from the results of the Ross River Model and applied to the open boundaries

Sources of the bathymetric and topographic data for both the models are same although the Ross River model was built on 30m x 30m grid resolution and the present model has been built on 10m x 10m grid resolution.

All the structures' information in the Ross River (within the present model domain) have been taken from Ross River Model and incorporated in the present model as MIKE 11 branches.

In the present model the rainfall losses have been adopted as follows:

Table 4-1 Rainfall Losses

Loss Type	Pervious	Impervious
Initial	25 mm	1mm
Continuing	2.5 mm/h	0mm/h

Figure 4-4 shows the comparison of hydraulic grade lines between the Ross River Model and the Douglas-Annandale Model. It shows very good agreement at the downstream of Black Weir but the upstream water level difference is about 250 mm. There is a difference in the coupling method for Black Weir between the two models (standard coupling was used in Ross River Model and structure coupling is used in Douglas-Annandale Model) which is thought to be part of the reason for the difference in flood levels along with the boundary influence in the Douglas-Annandale Model.

In this verification process the model parameters like Manning's 'n' and eddy viscosity have been varied to get the best match as discussed in section 4.3.

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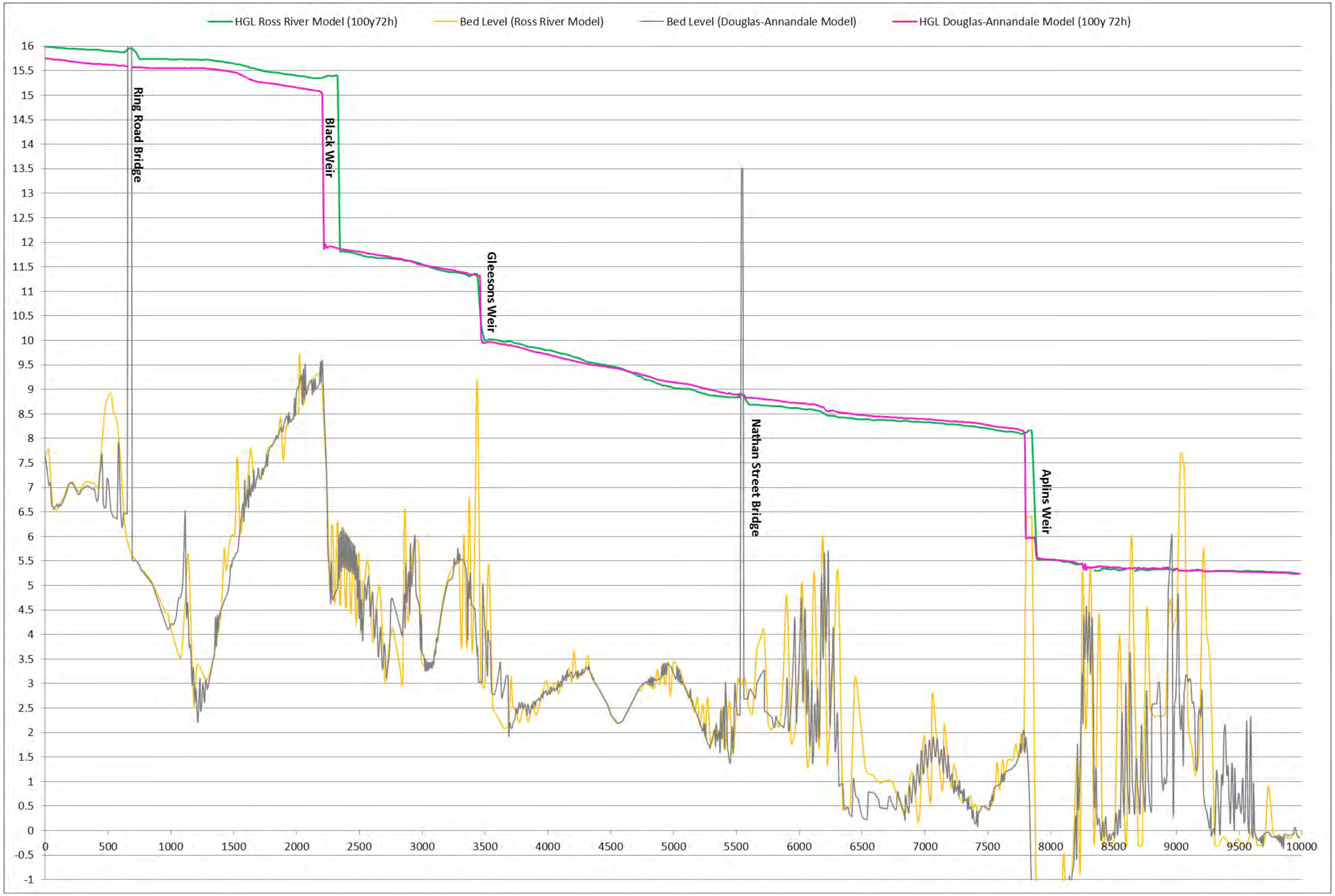
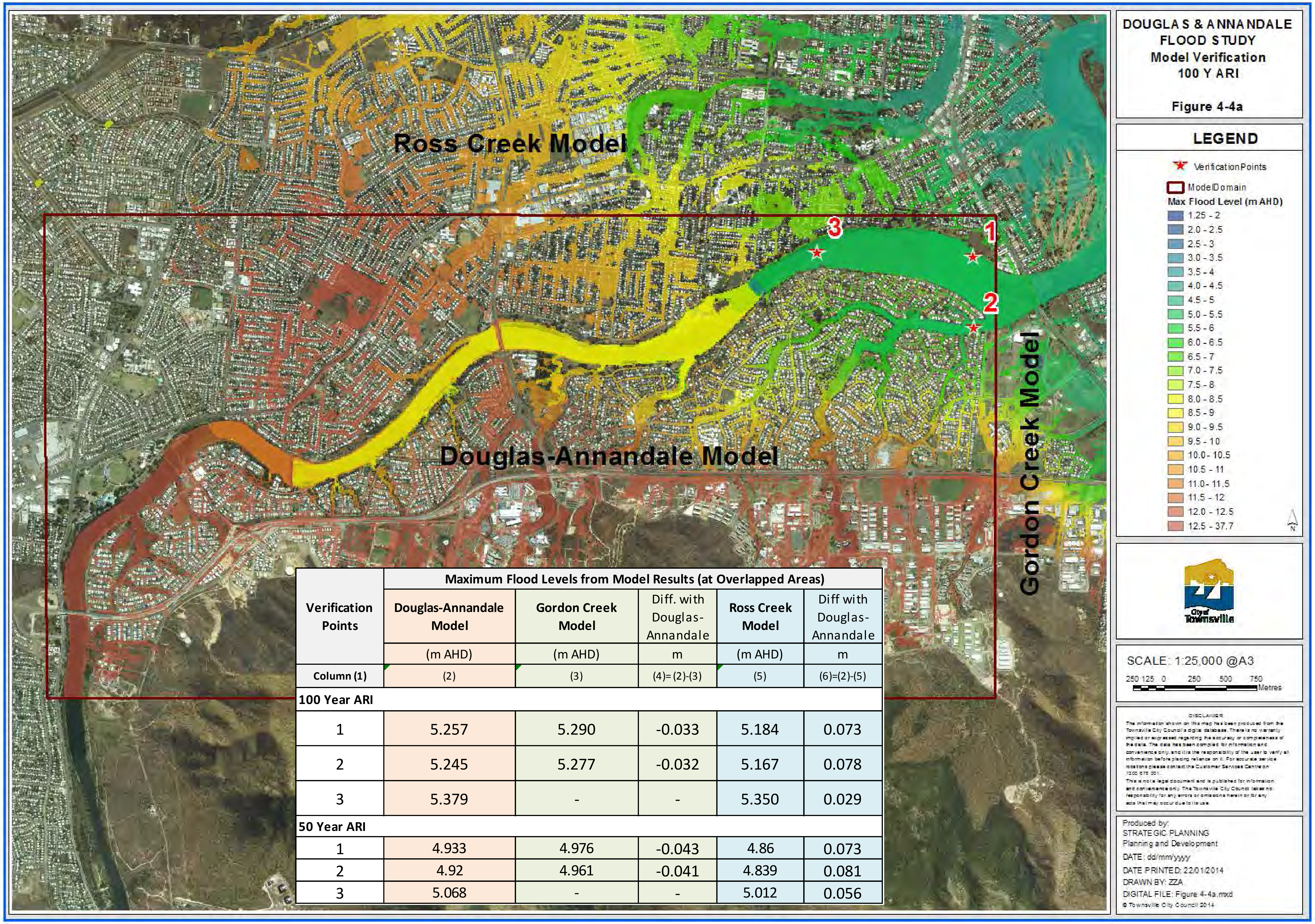


Figure 4-4 Comparison of Hydraulic Grade Lines between Ross River Model and Douglas-Annandale Model



Verification Points	Maximum Flood Levels from Model Results (at Overlapped Areas)				
	Douglas-Annandale Model	Gordon Creek Model	Diff. with Douglas-Annandale	Ross Creek Model	Diff with Douglas-Annandale
	(m AHD)	(m AHD)	m	(m AHD)	m
Column (1)	(2)	(3)	(4)= (2)-(3)	(5)	(6)=(2)-(5)
100 Year ARI					
1	5.257	5.290	-0.033	5.184	0.073
2	5.245	5.277	-0.032	5.167	0.078
3	5.379	-	-	5.350	0.029
50 Year ARI					
1	4.933	4.976	-0.043	4.86	0.073
2	4.92	4.961	-0.041	4.839	0.081
3	5.068	-	-	5.012	0.056

The Douglas-Annandale MIKE FLOOD model overlaps the Ross Creek Model and the Gordon Creek Model at its northern and eastern boundaries respectively. The model results have been verified with the model results of Ross Creek and Gordon Creek at the overlapped areas. **Figure 4-4a** shows the comparison of model results (i.e. maximum flood level in 100 Year ARI) with Ross Creek model and Gordon Creek model at overlapped areas. The comparison result shows that the difference between the Douglas-Annandale model and Ross Creek model varies with in the range of 0.016 to 0.078 m along the overlapped area at the three verification points. A difference between Douglas-Annandale model and Gordon Creek model varies from 0.032 to 0.090 at the two comparison points along the overlapped area. Similar results have been found for 50 Year ARI event (presented in the inbuilt table of Figure 4-4a).

4.5 Design Flood Assessment

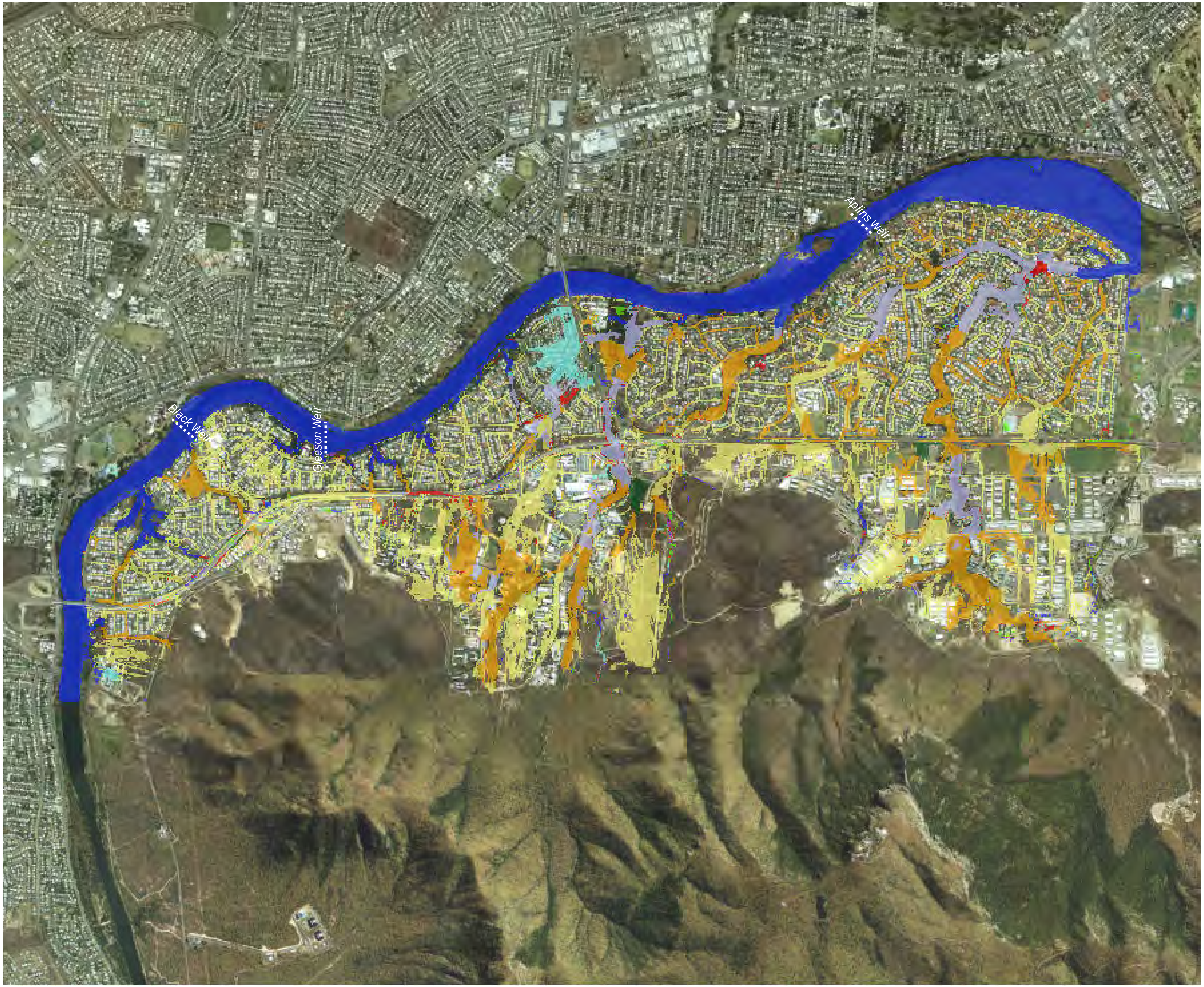
Following verification of the hydraulic model, the model has been updated to represent design flood events, by ensuring the topography and underground network represent 2011 conditions.

Initially the 100 Year and the 50 Year ARIs were run for a range of storm durations to establish critical durations across the floodplain. **Figure 4-5** and **Figure 4-6** show the critical flood durations for 100 Year and 50 Year ARI events respectively. The results show that 72-hour duration is critical in the River and the outfalls of drainage channels but there is no definite critical storm duration for the flood plain. Both events show that critical storm durations for different areas of Douglas and Annandale flood plains are 1 hour, 1.5 hours, 2 hours, 3 hours and 24 hours.

In order to reduce the number of critical storm durations for Douglas and Annandale flood plains, the flood levels for different storm durations have been compared. Results show that the flood levels of 1.5-hour storm duration event are very close to the flood levels of 1-hour and 2-hour storm duration events and the flood levels of 3-hour storm duration event is very close to 24-hour storm duration levels. For this reason, only three storm durations (i.e. 1.5 hours, 3 hours and 72 hours) have been adapted for rest of the design runs including 200 Year ARI, 500 Year ARI and Probable Maximum Flood (PMF).

Flood maps generated based on model results are provided in **Appendix D**, for water depths, flood levels and flow velocities. For all storm frequencies the flood map results are based on the critical flood envelope from all storm durations. Given the “Rain on Grid” approach has all cells within the model wet areas with depths of less than 0.1m have not been shown as inundated.

Detailed discussion of the flood model results are provided in subsequent chapters.



DOUGLAS & ANNANDALE FLOOD STUDY
Critical Duration (100 Y)

Figure 4-5

LEGEND

Critical Duration (Hour)

- 1h
- 1.5h
- 2h
- 3h
- 6h
- 12h
- 18h
- 24h
- 72h

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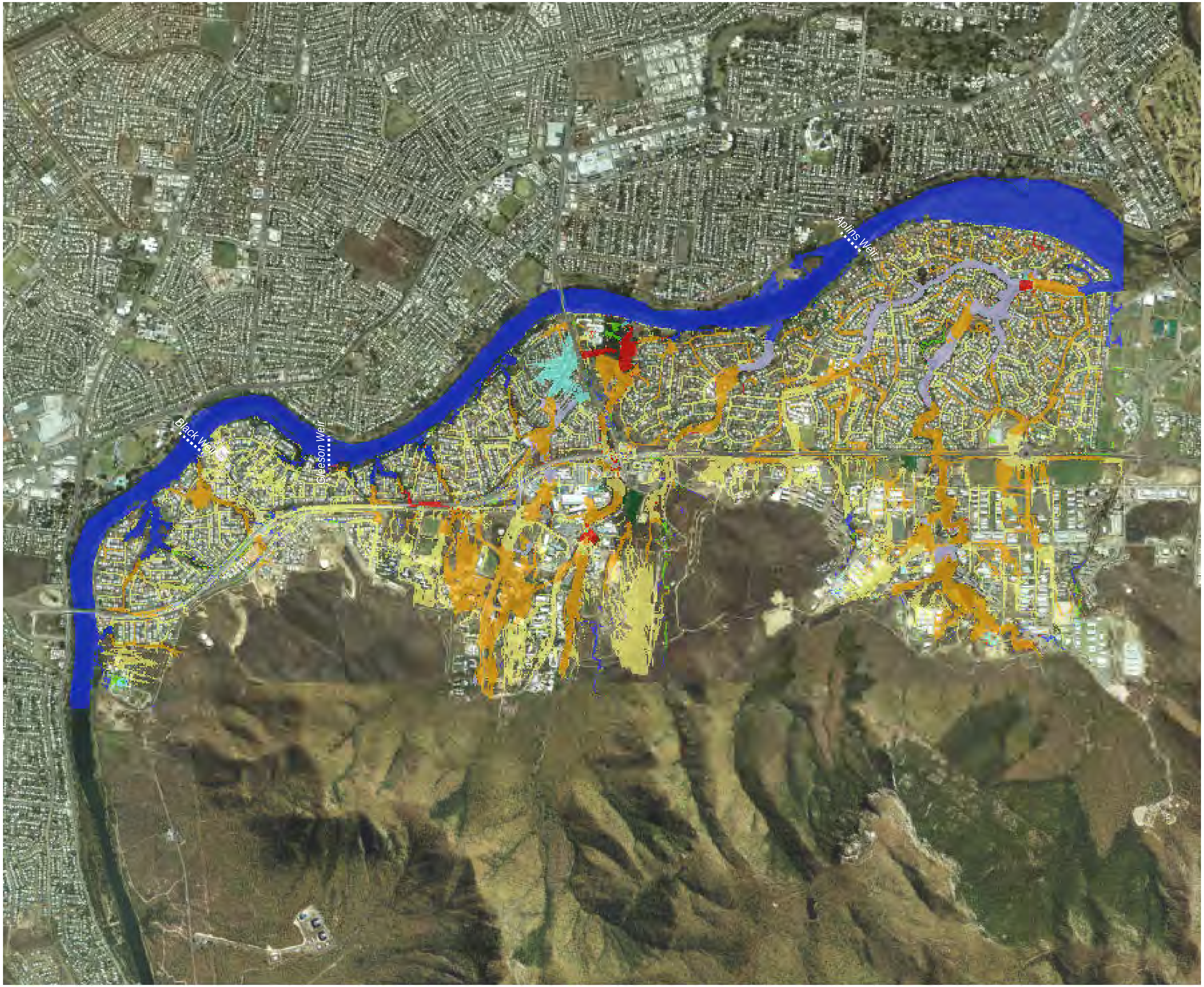
DOUGLAS & ANNANDALE FLOOD STUDY
Critical Duration (50 Y)

Figure 4-6



LEGEND

Critical Duration (Hour)

- 1h
- 1.5h
- 2h
- 3h
- 6h
- 12h
- 18h
- 24h
- 72h

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5.0 Baseline Flooding Summary

5.1 Description of Flooding Results

The base-line flood maps for the design flood events have been provided in **Appendix-D** focussing on West Douglas, East Douglas, West Annandale, East Annandale and Murray areas. The maps have been prepared for water depths, flood levels and flow velocities of the following flood events:

- 2 Year ARI;
- 5 Year ARI;
- 10 Year ARI;
- 20 Year ARI;
- 50 Year ARI;
- 100 Year ARI;
- 200 Year ARI;
- 500 Year ARI; and
- Probable Maximum Flood.

Descriptions of the flooding for the various design events are provided in the following sections for discrete areas of the floodplain. Where numbers of inundated residential properties are provided, they are on the basis of 0.20 m water depth within the lot, which does not mean floor levels are exceeded (though in some cases they may be when floor levels are less 0.20 m above the ground). To undertake a comparison to floor levels would require survey of all floor levels within the study area.

Douglas

Figure 5-1 and **Figure 5-2** outline the key drainage features of West Douglas and East Douglas respectively. There are eleven distinct flow paths in Douglas, which are draining stormwater runoff from different parts of Douglas area into the Ross River. Three of them are draining stormwater into the Ross River through a lake, which is located at upstream of Black Weir. Another flow path is draining water into the Ross River immediately upstream of Black Weir. Their tailwater levels are influenced by the level of Black Weir. Another flow path is located immediately upstream of Gleeson Weir, which is draining only a small local catchment. The remaining flow paths are draining to the Ross River downstream of Gleeson Weir and their tailwater levels are influenced by the Aplins Weir's level.

A summary of the Key flooding issues for different ARI flood events in Douglas has been provided in **Table 5-1** based on the flood maps of **Appendix D**.

Table 5-1 Douglas Area Flooding Issues

Event	Description
2 Year ARI	Generally the critical duration event is: • 1.5 hours in the residential area; • 3 hours in the flow paths; and • 72 hours in the Ross River and lake. Flooding is contained to drainage reserves and roads,, lake, playground, flow paths and parks.

Event	Description
	Inundation of major roads includes: *Freshwater Drive* • up to 0.27m of water at the intersection with Cockatoo Circuit *Different Sections of Riverside Boulevard* • up to 0.29m of water at the roundabout intersection with Riverbend Drive near Hermitage Place; • up to 0.3m of water at the intersection with Siris Place; • up to 0.3m of water at the roundabout intersection with Columbia Way; • up to 0.34m of water at the roundabout intersection with Logan Street; *Different Sections of Verhoeven Drive* • up to 0.41m of water at the intersection with Brent Street; • up to 0.43m of water at the intersection with Fenner Street; • up to 0.56m of water on the intersection with Keesing Road; *Internal Roads* • up to 0.470 m of water on the intersection of Sheerwater Parade and Riverwalk Way. • up to 0.442 m of water on the intersection of Regatta Crescent and Scholars Place; and • up to 0.360 m of water on the intersection of Regatta Crescent and Yale Close. Flow velocities are generally under 0.5m/s.
5 Year ARI	Generally the critical duration event is: • 1.5 to 3 hours in the residential area and the flow paths but the dominant critical duration for the residential area and the flow paths are 1.5 hours and 3 hours respectively ; and • 72 hours in the Ross River and lake. Flooding is generally contained to drainage reserves and roads, playground, lake and flow paths. Three properties close to the intersection of Verhoeven Drive and Fenner Street and one property at Waterlily Circuit get inundated. There is also a wide spread inundation on the playground near Freshwater Drive and the parking lots of James Cook University (JCU). Inundation of major roads includes: *Angus Smith Drive* • up to 0.2 m of water over the section between Riverside Boulevard intersection and University Road intersection. Maximum inundation is found near the intersection with Richardson Street; *Freshwater Drive* • up to 0.27m of water at the intersection with Cockatoo Circuit; *Different Sections of Riverside Boulevard* • up to 0.29m of water at the roundabout intersection with Riverbend Drive near Hermitage Place; • up to 0.3m of water at the intersection with Siris Place; • up to 0.3m of water at the roundabout intersection with Columbia Way; • up to 0.34m of water at the roundabout intersection with Logan Street; *Different Sections of Verhoeven Drive* • up to 0.59m of water at the intersection with Brent Street; • up to 0.58m of water at the intersection with Fenner Street; • up to 0.58m of water on the intersection with Keesing Road; *Internal Roads* • up to 0.470 m of water on the intersection of Sheerwater Parade and Riverwalk Way. • up to 0.442 m of water on the intersection of Regatta Crescent and Scholars

<table>
<tr><th>Event</th><th>Description</th></tr>
<tr><td></td><td>Place; and
up to 0.360 m of water on the intersection of Regatta Crescent and Yale Close. Flow velocities are generally under 0.5m/s. </td></tr>
<tr><td>10 Year ARI</td><td> Generally the critical duration event is: 1.5 to 3 hours in the residential area and the flow paths but the dominant critical duration for the residential area and the flow paths are 1.5 hours and 3 hours respectively ; and
72 hours in the Ross River and lake. Flooding is generally contained to drainage reserves and roads, playground, lake and flow paths except a localized area at Verhoeven Drive. Eleven properties are inundated in Douglas where ten properties are located at the Verhoeven Drive. There is also a widespread inundation on the playground near Freshwater Drive and parking lots in James Cook University (JCU). Inundation of major roads includes:
Different Sections of Angus Smith Drive up to 0.24 m of water over the section between Riverside Boulevard intersection and University Road intersection. Maximum inundation is found near the intersection with Richardson Street; Freshwater Drive up to 0.3m of water at the intersection with Cockatoo Circuit; Different Sections of Riverside Boulevard up to 0.34m of water at the roundabout intersection with Riverbend Drive near Hermitage Place;
up to 0.3m of water at the intersection with Siris Place;
up to 0.2m of water at the roundabout intersection with Creekwood Way;
up to 0.37m of water at the roundabout intersection with Columbia Way and Regatta Crescent;
up to 0.37m of water at the roundabout intersection with Logan Street; Different Sections of Verhoeven Drive up to 0.79m of water at the intersection with Brent Street;
up to 0.86m of water at the intersection with Fenner Street;
up to 0.6m of water on the intersection with Keesing Road; Internal Roads up to 0.47 m of water on the intersection of Sheerwater Parade and Riverwalk Way.
up to 0.47 m of water on the intersection of Regatta Crescent and Scholars Place; and
up to 0.47 m of water on the intersection of Regatta Crescent and Yale Close. Flow velocities are generally under 0.5m/s, however there are higher velocities in Angus Smith Drive (~1 m/s) in between the intersections with Riverside Boulevard and Tennants Street, Freshwater Drive (~0.68 m/s), Columbia Way (~1.0 m/s), Regatta Crescent (~1.1 m/s) and in Verhoeven Drive (~0.8 m/s) between the intersections with Kissing Road and Cilento Crescent. </td></tr>
</table>

20 Year ARI

Generally the critical duration event is:

- 1.5 to 3 hours in the residential area and the flow paths; and
- 72 hours in the Ross River and lake.

Flooding is mainly contained to drainage reserves and roads, playground, lake and flow paths except the localized area at Verhoeven Drive. Flooding in the localized area spreads further and inundates 27 residential lots around Verhoeven Drive. In total 28 residential lots get inundated due to this event. There is also a widespread inundation on the playground near Freshwater Drive and the parking lots in James Cook University (JCU).

Inundation of major roads includes:

Angus Smith Drive

- up to 0.32 m of water over the section between Riverside Boulevard intersection and University Road intersection;

Freshwater Drive

- up to 0.32m of water at the intersection with Cockatoo Circuit;

Different Sections of Riverside Boulevard

- up to 0.36m of water at the roundabout intersection with Riverbend Drive near Hermitage Place;
- up to 0.34m of water at the intersection with Siris Place;
- up to 0.38m of water at the roundabout intersection with Creekwood Way;
- up to 0.38m of water at the roundabout intersection with Columbia Way and Regatta Crescent;
- up to 0.38m of water at the roundabout intersection with Logan Street;

Different Sections of Verhoeven Drive

- up to 1.0m of water at the intersection with Brent Street;
- up to 1.0m of water at the intersection with Fenner Street;
- up to 0.6m of water on the intersection with Keesing Road;

Internal Roads

- up to 0.48 m of water on the intersection of Sheerwater Parade and Riverwalk Way.
- up to 0.48 m of water on the intersection of Regatta Crescent and Scholars Place; and
- up to 0.5 m of water on the intersection of Regatta Crescent and Yale Close.

Flow velocities are generally under 0.5m/s, however there are higher velocities in Angus Smith Drive (~1.3 m/s) in between the intersections with Riverside Boulevard and Tennants Street, Freshwater Drive (~0.8 m/s), Columbia Way (~1.1 m/s), Regatta Crescent (~1.1 m/s) and in Verhoeven Drive (~0.87 m/s) between the intersections with Kissing Road and Cilento Crescent.

50 Year ARI

Generally the critical duration event is:

- 1 to 1.5 hours in the residential area and the flow paths; and
- 72 hours in the Ross River and lake.

Flooding is largely contained to drainage reserves and roads, playground, lakes and flow paths except a localized area around Verhoeven Drive, where widespread areas of interconnected flooding with significant flood depths are found. Flooding in this localized area spreads further and inundates 48 residential lots around the intersection of Fenner Street and Verhoeven Drive. In total 49 residential lots get inundated due to this event. Inundation on the playground near Freshwater Drive and the parking lots and streets in James Cook University (JCU) spreads further.

Inundation of major roads includes:

Angus Smith Drive

- up to 0.34m of water over the section between Riverside Boulevard intersection and University Road intersection;

Freshwater Drive

- up to 0.37m of water at the intersection with Cockatoo Circuit;

Different Sections of Riverside Boulevard

- up to 0.4m of water at the roundabout intersection with Riverbend Drive near Hermitage Place;
- up to 0.36m of water at the intersection with Siris Place;
- up to 0.42m of water at the roundabout intersection with Creekwood Way;
- up to 0.44m of water at the roundabout intersection with Columbia Way and Regatta Crescent;
- up to 0.41m of water at the roundabout intersection with Logan Street;

Different Sections of Verhoeven Drive

- up to 1.3m of water at the intersection with Brent Street;
- up to 1.3m of water at the intersection with Fenner Street;
- up to 0.64m of water on the intersection with Keesing Road;

Internal Roads

- up to 0.49 m of water on the intersection of Sheerwater Parade and Riverwalk Way.
- up to 0.49 m of water on the intersection of Regatta Crescent and Scholars Place; and
- up to 0.52 m of water on the intersection of Regatta Crescent and Yale Close.

Flow velocities are generally under 0.5m/s, however there are higher velocities in Angus Smith Drive (~1.5 m/s) in between the intersections with Riverside Boulevard and Tennants Street, Freshwater Drive (~0.85 m/s), Columbia Way (~1.7 m/s), Regatta Crescent (~1.5 m/s) and in Verhoeven Drive (~0.9 m/s) between the intersections with Kissing Road and Cilento Crescent.

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100 Year ARI

Generally the critical duration event is:

- 1 to 1.5 hours in the residential area and the flow paths; and
- 72 hours in the Ross River and lake.

Flooding is largely contained to drainage reserves and roads, playground, lakes and flow paths except a localized area around Verhoeven Drive, where widespread areas of interconnected flooding with significant flood depths are found. Flooding in this localized area spreads further and inundates 64 residential lots around the intersection of Fenner Street and Verhoeven Drive. In total 65 residential lots get inundated due to this event. Inundation on the playground near Freshwater Drive and the parking lots and streets in James Cook University (JCU) spreads further.

Inundation of major roads includes:

Angus Smith Drive

- up to 0.37m of water over the section between Riverside Boulevard intersection and University Road intersection;

Freshwater Drive

- up to 0.38m of water at the intersection with Cockatoo Circuit;

Different Sections of Riverside Boulevard

- up to 0.4m of water at the roundabout intersection with Riverbend Drive near Hermitage Place;
- up to 0.37m of water at the intersection with Siris Place;
- up to 0.5m of water at the roundabout intersection with Creekwood Way;
- up to 0.5m of water at the roundabout intersection with Columbia Way and Regatta Crescent;
- up to 0.42m of water at the roundabout intersection with Logan Street;

Different Sections of Verhoeven Drive

- up to 1.4m of water at the intersection with Brent Street;
- up to 1.5m of water at the intersection with Fenner Street;
- up to 0.65m of water on the intersection with Keesing Road;

Internal Roads

- up to 0.5 m of water on the intersection of Sheerwater Parade and Riverwalk Way.
- up to 0.5 m of water on the intersection of Regatta Crescent and Scholars Place; and
- up to 0.55 m of water on the intersection of Regatta Crescent and Yale Close.

Flow velocities are generally under 0.5m/s, however there are higher velocities in Angus Smith Drive (~1.6 m/s) in between the intersections with Riverside Boulevard and Tennants Street, Freshwater Drive (~1.0 m/s), Columbia Way (~1.7 m/s), Regatta Crescent (~1.6 m/s) and in Verhoeven Drive (~1.0 m/s) between the intersections with Kissing Road and Cilento Crescent.

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200 Year ARI

Generally the critical duration event is:

- 1.5 to 3 hours in the residential area and the flow paths; and
- 72 hours in the Ross River and lake.

Flooding is mostly contained to drainage reserves and roads, playground, lakes and flow paths excepts localized area around Verhoeven Drive, where widespread areas of interconnected flooding with significant flood depths are found. Flooding in the localized area spreads further and inundates 71 residential lots around the intersection of Fenner Street and Verhoeven Drive. In total 72 residential lots get inundated due to this event. Inundation on the playground near Freshwater Drive and the parking lots and streets in James Cook University (JCU) spreads further.

Inundation of major roads includes:

Angus Smith Drive

- up to 0.5m of water over the section between Riverside Boulevard intersection and University Road intersection;

Freshwater Drive

- up to 0.42m of water at the intersection with Cockatoo Circuit;

Different Sections of Riverside Boulevard

- up to 0.4m of water at the roundabout intersection with Riverbend Drive near Hermitage Place;
- up to 0.37m of water at the intersection with Siris Place;
- up to 0.5m of water at the roundabout intersection with Creekwood Way;
- up to 0.5m of water at the roundabout intersection with Columbia Way and Regatta Crescent;
- up to 0.42m of water at the roundabout intersection with Logan Street;

Different Sections of Verhoeven Drive

- up to 1.5m of water at the intersection with Brent Street;
- up to 1.6m of water at the intersection with Fenner Street;
- up to 0.69m of water on the intersection with Keesing Road;

Internal Roads

- up to 0.5 m of water on the intersection of Sheerwater Parade and Riverwalk Way.
- up to 0.5 m of water on the intersection of Regatta Crescent and Scholars Place; and
- up to 0.55 m of water on the intersection of Regatta Crescent and Yale Close.

Flow velocities are generally under 0.5m/s, however there are higher velocities in Angus Smith Drive (~1.61 m/s) in between the intersections with Riverside Boulevard and Tennants Street, Freshwater Drive (~1.0 m/s), Columbia Way (~1.72 m/s), Regatta Crescent (~1.6 m/s) and in Verhoeven Drive (~1.0 m/s) between the intersections with Kissing Road and Cilento Crescent.

500 Year ARI	Generally the critical duration event is: • 1.5 to 3 hours in the residential area and the flow paths; and • 72 hours in the Ross River and lake. Flooding is mostly contained to drainage reserves and roads, playground, lake and flow paths except the localized area around Verhoeven Drive. Flooding in the localized area spreads further and inundates 78 residential lots around the intersection of Fenner Street and Verhoeven Drive. In total 81 residential lots get inundated due to this event. Inundation on the playground near Freshwater Drive and the parking lots and streets in James Cook University (JCU) spreads further. Inundation of major roads includes: *Angus Smith Drive* • up to 0.52m of water over the section between Riverside Boulevard intersection and University Road intersection; *Freshwater Drive* • up to 0.43m of water at the intersection with Cockatoo Circuit; *Different Sections of Riverside Boulevard* • up to 0.4m of water at the roundabout intersection with Riverbend Drive near Hermitage Place; • up to 0.7m of water at the intersection with Siris Place; • up to 0.6m of water at the roundabout intersection with Creekwood Way; • up to 0.5m of water at the roundabout intersection with Columbia Way and Regatta Crescent; • up to 0.43m of water at the roundabout intersection with Logan Street; *Different Sections of Verhoeven Drive* • up to 1.6m of water at the intersection with Brent Street; • up to 1.62m of water at the intersection with Fenner Street; • up to 0.74m of water on the intersection with Keesing Road; *Internal Roads* • up to 0.52 m of water on the intersection of Sheerwater Parade and Riverwalk Way. • up to 0.55 m of water on the Regatta Crescent; and • up to 0.56 m of water on the intersection of Regatta Crescent and Yale Close. Flow velocities are generally under 0.5m/s, however there are higher velocities in Angus Smith Drive (~1.65 m/s) in between the intersections with Riverside Boulevard and Tennants Street, Freshwater Drive (~1.0 m/s), Columbia Way (~1.79 m/s), Regatta Crescent (~1.61 m/s) and in Verhoeven Drive (~1.0 m/s) near the intersections with Kissing Road.

PMF	Generally the critical duration event is: • 1.5 hours in the inland residential area and 72 hours in the riverside residential area, flow paths and lakes (due to the overflow from the Ross River); and • 72 hours in the Ross River and lake. There is a significant widespread flooding with depths up to 2.4m. A total of approximately 771 residential properties are inundated. Numerous commercial premises, educational institutions and public utilities are also flooded due to this event. Inundation of major roads includes: *Angus Smith Drive* • up to 0.6m of water over the section between Riverside Boulevard intersection and University Road intersection; *Freshwater Drive* • up to 2.0m of water in between the intersections with Sheerwater Parade and Warbler Crescent; *Different Sections of Riverside Boulevard* • up to 2.3m of water near the intersection with Carallia Place; • up to 3.2m of water at the intersection with Siris Place; • up to 1.4m of water at the roundabout intersection with Creekwood Way; • up to 2.3m of water at the roundabout intersection with Columbia Way and Regatta Crescent; • up to 0.62m of water at the roundabout intersection with Logan Street; *Different Sections of Verhoeven Drive* • up to 2.2m of water at the intersection with Brent Street; • up to 2.4m of water at the intersection with Fenner Street; • up to 1.4m of water on the intersection with Keesing Road; *Internal Roads* • up to 1.7m of water on the intersection of Sheerwater Parade and Riverwalk Way. • up to 2.6 m of water on Regatta Crescent; and • up to 2.5 m of water on the intersection of Regatta Crescent and Yale Close. Flow velocities are generally under 0.75m/s, however there are higher velocities in Angus Smith Drive (~1.9 m/s) in between the intersections with Riverside Boulevard and Tennants Street, Freshwater Drive (~2.2 m/s), Columbia Way (~1.9 m/s), Regatta Crescent (~2.5 m/s) and in Verhoeven Drive (~1.3 m/s) near the intersections with Kissing Road.

DOUGLAS & ANNANDALE FLOOD STUDY
Figure 5-1

West Douglas

LEGEND

Drainage Flow Direction

Underground Drainage

Suburbs

100 Y ARI Water Depth (m)

- 0.01 - 0.3
- 0.3 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- 3 - 25

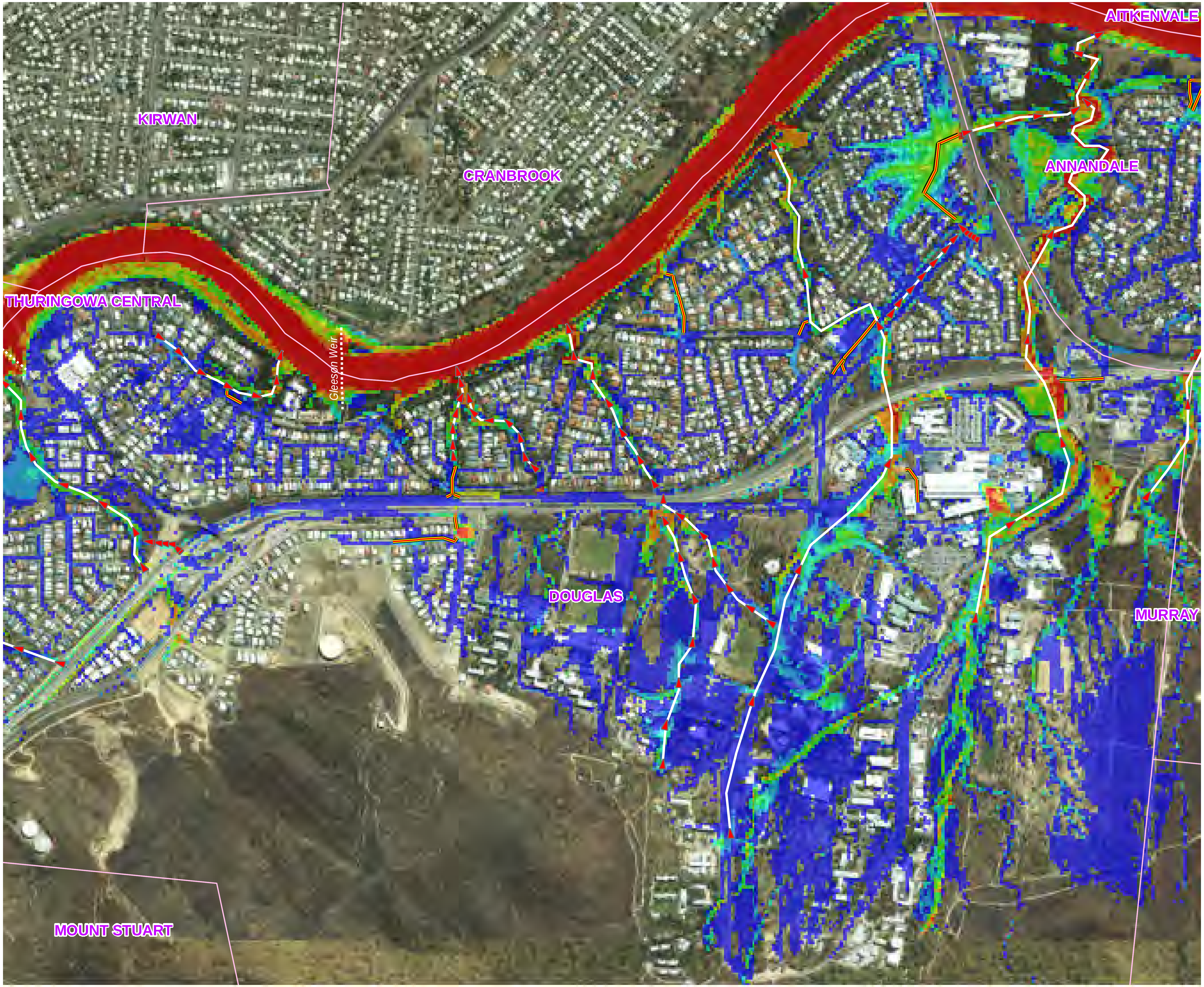
N

City of Townsville

SCALE: 1:10,000 @A3

100 50 0 100 200 300 Metres

Produced by:
STRATEGIC PLANNING
Planning and Development
DATE: dd/mm/yyyy
DATE PRINTED: 23/07/2014
DRAWN BY: ZZA
DIGITAL FILE: Figure5-1_5-4.mxd



DOUGLAS & ANNANDALE FLOOD STUDY
Figure 5-2

East Douglas

LEGEND

Drainage Flow Direction

Underground Drainage

Suburbs

100 Y ARI Water Depth (m)

- 0.01 - 0.3
- 0.3 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- 3 - 25

N

City of Townsville

SCALE: 1:10,000 @A3

100 50 0 100 200 300 Metres

Produced by:
STRATEGIC PLANNING
Planning and Development
DATE: dd/mm/yyyy
DATE PRINTED: 23/07/2014
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Annandale

Figure 5-3 and **Figure 5-4** outline the key drainage features of West Annandale and East Annandale respectively. There are six distinct drainage flow paths in Annandale area, where four drain stormwater runoff from both Annandale and Murray areas and rest drain Douglas and Annandale.

A summary of the key flooding issues within Annandale relative to the ARI of floods is provided in **Table 5-2** following inspection of the flood mapping as presented in Appendix D.

Table 5-2 Annandale Area Flooding Issues

Event	Description
2 Year ARI	Generally the critical duration event is: • 1.5 hours in the residential area; • 3 hours in the flow paths; and • 72 hours in the Ross River. Flooding is contained to drainage reserves and roads, except 1 residential lot which gets inundated by maximum of 0.350 m water depth near Hoya Court. Limited areas get flooded are: • at Palmetum; • at Marabou Drive park; • at park near intersection of River Park Drive and Glendale Drive; and • at car park of Annandale Shopping Centre. Inundation of major roads includes: *Yolanda Drive* • 0.1m of water near the intersection with Casuarina Drive but most of the road is flood free; *Annandale Drive* • up to 0.3m of water near the intersection with Indigo Crescent; *Macarthur Drive* • up to 0.46m of water in between Wave Hill Drive intersections but most of the road is flood free; *Different Sections of Glendale Drive* • up to 1.4 m of water at the flow path near the intersection with River Park Drive; • 0.2m water near the intersection with Hazelwood Court; *Internal Roads* • 0.4m water over Cypress Drive near the intersection with river Park Drive; • 0.4m water over Eucalyptus Avenue near the intersection with Myrtle Court; and • 0.67 m water over Fardon Street near the intersection with Masuda Street. Flow velocities are generally under 0.5m/s, however there are higher velocities in William Angliss Drive (up to 0.7m/s), Glendale Drive (up to 1.4 m/s at flow path) and Marabou Drive near the intersection with Cargillea Avenue (~0.7m/s)

5 Year ARI	Generally the critical duration event is: • 1.5 hours in the residential area, the parks and the car park of Annandale Shopping Centre; • 3 hours in the flow paths; and • 72 hours in the Ross River. Flooding is generally contained to drainage reserves and roads, except four residential lots get inundated by some extent. One near the intersection of Masuada Street and Fardon Street, one at the Hoya Court, one at the Indigo Crescent and one at Marigold court. Localized flooding is found at Palmetum, Marabou Drive park, the park near intersection of River Park Drive and Glendale Drive and the car park of Annandale Shopping Centre. Inundation of major roads includes: *Yolanda Drive* • up to 0.2m of water near the intersection with Casuarina Drive but most of the road is flood free; *Different Sections of Annandale Drive* • up to 0.3m of water near the intersection with Macarthur Drive; • up to 0.33m of water near the intersection with Indigo Crescent *Macarthur Drive* • up to 0.48m of water in between Wave Hill Drive intersections but most of the road is flood free; *Different Sections of Glendale Drive* • up to 1.9 m of water at the flow path near the intersection with River Park Drive; • 0.32m water near the intersection with Hazelwood Court; *Internal Roads* • up to 0.75 m of water over Fardon Street near the intersection with Masuda Street; • up to 0.6m of water over Hoya Court near inundated property; • up to 0.4m of water over Cypress Drive near the intersection with River Park Drive; and • up to 0.44m of water over Eucalyptus Avenue near the intersection with Myrtle Court. Flow velocities are generally under 0.5m/s, however there are higher velocities in Yolanda Drive (up to 0.7m/s), Glendale Drive (up to 1.7 m/s on the flow path near the intersection with River Park Drive) and in William Angliss Drive (up to 0.7 m/s)
10 Year ARI	Generally the critical duration event is: • 1.5 hours in the residential area, the parks and the car park of Annandale Shopping Centre; • 3 hours in the flow paths; and • 72 hours in the Ross River. Flooding is generally contained to drainage reserves and roads, except 4 residential lots get inundated. One near the intersection of Masuada Street and Fardon Street, one at the Hoya Court, one at the Indigo Crescent and one at Marigold court. Localized flooding is found at Palmetum, Marabou Drive park, park near the intersection of River Park Drive and Glendale Drive and at car park of Annandale Shopping Centre. Inundation of major roads includes: *Yolanda Drive* • up to 0.29m of water near the intersection with Casuarina Drive but most of the road is flood free;

Different Sections of Annandale Drive

- up to 0.34m of water near the intersection with Macarthur Drive;
- up to 0.42m of water near the intersection with Indigo Crescent

Macarthur Drive

- up to 0.5m of water in between Wave Hill Drive intersections but most of the road is flood free;

Different Sections of Glendale Drive

- up to 2.1 m of water at the flow path near the intersection with River Park Drive;
- up to 0.4m of water near the intersection with Hazelwood Court;

Internal Roads

- up to 0.8 m of water over Fardon Street near the intersection with Masuda Street;
- up to 0.5m of water over Masuda Street near the intersection with Fardon Street;
- up to 0.6m of water over Hoya Court near inundated property;
- up to 0.7 m of water over Boronia Drive close to intersection with Tibouchina Street;
- up to 0.48m of water over Cypress Drive near the intersection with River Park Drive; and
- up to 0.48m of water over Eucalyptus Avenue near the intersection with Myrtle Court.

Flow velocities are generally under 0.5m/s, however there are higher velocities in Masuda Street (up to 1.2 m/s), Fardon Street (up to 1.3 m/s), Yolanda Drive (up to 0.77m/s), Glendale Drive (up to 1.7 m/s on the flow path near the intersection with River Park Drive) and in William Angliss Drive (up to 0.9 m/s)

20 Year ARI

Generally the critical duration event is:

- 1.5 hours and 3 hours in the residential area, the flow paths, the parks and the car park of Annandale Shopping Centre; and
- 72 hours in the Ross River.

Flooding is mainly contained to drainage reserves and roads, except 6 residential lots get inundated. Three of them are located near the intersection of Masuada Street and Fardon Street, one at the Hoya Court, one at the Indigo Crescent and one at Marigold court.
Localized flooding is found at Palmetum, Marabou Drive park, park near the intersection of River Park Drive and Glendale Drive and at car park of Annandale Shopping Centre.

Inundation of major roads includes:

Yolanda Drive

- up to 0.3m of water near the intersection with Casuarina Drive;

Different Sections of Annandale Drive

- up to 0.36m of water near the intersection with Macarthur Drive;
- up to 0.44m of water near the intersection with Indigo Crescent

Macarthur Drive

- up to 0.5m of water in between Wave Hill Drive intersections but most of the road is flood free;

Different Sections of Glendale Drive

- up to 2.4 m of water at the flow path near the intersection with River Park Drive;
- up to 0.4m of water near the intersection with Hazelwood Court;

Internal Roads

- up to 0.86 m of water over Fardon Street near the intersection with Masuda Street;
- up to 0.75m of water over Masuda Street near the intersection with Fardon Street;
- up to 0.63m of water over Hoya Court near inundated property;

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up to 0.75 m of water over Boronia Drive close to intersection with Tibouchina Street;
up to 0.5m of water over Cypress Drive near the intersection with River Park Drive; and
up to 0.5m of water over Eucalyptus Avenue near the intersection with Myrtle Court.

Flow velocities are generally under 0.5m/s, however there are higher velocities in Masuda Street (up to 1.3 m/s), Fardon Street (up to 1.4 m/s), Yolanda Drive (up to 1.25m/s), Glendale Drive (up to 1.8 m/s on the flow path near the intersection with River Park Drive) and in William Angliss Drive (up to 1.0 m/s)
</td></tr>
<tr><td>50 Year ARI</td><td>
Generally the critical duration event is:

1 to 1.5 hours in the residential area and the car park of Annandale Shopping Centre;
1 to 2 hours in the flow paths;
1.5 to 3 hours in the Palmetum; and
72 hours in the Ross River and the outfalls of the flow paths.

Flooding is largely contained to drainage reserves and roads, except 15 residential lots get inundated. Five of them are located near the intersection of Masuada Street and Fardon Street. Localized flooding is found at Palmetum, Marabou Drive park, park near the intersection of River Park Drive and Glendale Drive and at car park of Annandale Shopping Centre.

Inundation of major roads includes:

Yolanda Drive

up to 0.33m of water near the intersection with Casuarina Drive;

Different Sections of Annandale Drive

up to 0.46m of water near the intersection with Macarthur Drive;
up to 0.42m of water near the intersection with Indigo Crescent

Macarthur Drive

up to 0.52m of water in between Wave Hill Drive intersections;

Different Sections of Glendale Drive

up to 2.7 m of water at the flow path near the intersection with River Park Drive;
up to 0.47m of water near the intersection with Hazelwood Court;

Internal Roads

up to 0.89 m of water over Fardon Street near the intersection with Masuda Street;
up to 0.78m of water over Masuda Street near the intersection with Fardon Street;
up to 0.64m of water over Hoya Court near inundated property;
up to 0.77 m of water over Boronia Drive close to intersection with Tibouchina Street;
up to 0.52m of water over Cypress Drive near the intersection with River Park Drive; and
up to 0.54m of water over Eucalyptus Avenue near the intersection with Myrtle Court.

Flow velocities are generally under 0.5m/s, however there are higher velocities in Masuda Street (up to 1.38 m/s), Fardon Street (up to 1.5 m/s), Yolanda Drive (up to 1.4m/s), Glendale Drive (up to 1.9 m/s on the flow path near the intersection with River Park Drive) and in William Angliss Drive (up to 1.1 m/s)
</td></tr>
</table>

100 Year ARI	Generally the critical duration event is: • 1 to 1.5 hours in the residential area and the car park of Annandale Shopping Centre; • 1 to 2 hours in the flow paths; • 1.5 to 2 hours in the Palmetum; and • 72 hours in the Ross River and the outfalls of the flow paths. Flooding is largely contained to drainage reserves and roads, except 15 residential lots get inundated. Five of them are located near the intersection of Masuada Street and Fardon Street. Localized flooding is found at Palmetum, Marabou Drive park, park near the intersection of River Park Drive and Glendale Drive and at car park of Annandale Shopping Centre. Inundation of major roads includes: *Yolanda Drive* • up to 0.4m of water near the intersection with Oleander Street; *Different Sections of Annandale Drive* • up to 0.5m of water near the intersection with Macarthur Drive; • up to 0.44m of water near the intersection with Indigo Crescent *Macarthur Drive* • up to 0.53m of water in between Wave Hill Drive intersections; *Different Sections of Glendale Drive* • up to 2.8 m of water at the flow path near the intersection with River Park Drive; • up to 0.49m of water near the intersection with Hazelwood Court; *Internal Roads* • up to 0.9 m of water over Fardon Street near the intersection with Masuda Street; • up to 0.85m of water over Masuda Street near the intersection with Fardon Street; • up to 0.65m of water over Hoya Court near inundated property; • up to 0.8 m of water over Boronia Drive close to intersection with Tibouchina Street; • up to 0.54m of water over Cypress Drive near the intersection with River Park Drive; • up to 0.56m of water over Eucalyptus Avenue near the intersection with Myrtle Court; and • up to 0.5m of water over Marigold Court. Flow velocities are generally under 0.5m/s, however there are higher velocities in Masuda Street (up to 1.4 m/s), Fardon Street (up to 1.6 m/s), Yolanda Drive (up to 1.45m/s), Glendale Drive (up to 1.9 m/s on the flow path near the intersection with River Park Drive) and in William Angliss Drive (up to 1.17 m/s)
200 Year ARI	Generally the critical duration event is: • 1.5 hours in the residential area, flow paths, Palmetum and the car park of Annandale Shopping Centre; and • 72 hours in the Ross River and the outfalls of the flow paths. Flooding is mostly contained to drainage reserves and roads, except 18 residential lots get inundated. Five of them are located near the intersection of Masuada Street and Fardon Street. Localized flooding is found at Palmetum, Marabou Drive park, park near the intersection of River Park Drive and Glendale Drive and at car park of Annandale Shopping Centre. Inundation of major roads includes: *Yolanda Drive* • up to 0.42m of water near the intersection with Oleander Street;

	Different Sections of Annandale Drive • up to 0.53m of water near the intersection with Macarthur Drive; • up to 0.46m of water near the intersection with Indigo Crescent *Macarthur Drive* • up to 0.54m of water in between Wave Hill Drive intersections; *Different Sections of Glendale Drive* • up to 3 m of water at the flow path near the intersection with River Park Drive; • up to 0.5m of water near the intersection with Hazelwood Court; *Internal Roads* • up to 0.95 m of water over Fardon Street near the intersection with Masuda Street; • up to 0.88m of water over Masuda Street near the intersection with Fardon Street; • up to 0.65m of water over Hoya Court near inundated property; • up to 0.82m of water over Boronia Drive close to intersection with Tibouchina Street; • up to 0.55m of water over Cypress Drive near the intersection with River Park Drive; • up to 0.58m of water over Eucalyptus Avenue near the intersection with Myrtle Court; and • up to 0.52m of water over Marigold Court. Flow velocities are generally under 0.5m/s, however there are higher velocities in Masuda Street (up to 1.5 m/s), Fardon Street (up to 1.7 m/s), Yolanda Drive (up to 1.45m/s), Glendale Drive (up to 1.7 m/s on the flow path near the intersection with River Park Drive) and in William Angliss Drive (up to 1.2 m/s)
500 Year ARI	Generally the critical duration event is: • 1.5 hours in the inland residential area and the car park of Annandale Shopping Centre; • 3 hours in the downstream part of the Ross River and Annandale Drain and their surrounding residential area; and • 72 hours in the Ross River and the residential area beside the Ross River. Flooding is mostly contained to drainage reserves and roads, except 46 residential lots get inundated. Nine of them are located at the Jacaranda Crescent and five of the inundated properties are located near the intersection of Masuada Street and Fardon Street. Localized flooding is found at Palmetum, Marabou Drive park, park near the intersection of River Park Drive and Glendale Drive and at car park of Annandale Shopping Centre. Inundation of major roads includes: *Yolanda Drive* • up to 0.5m of water near the intersection with Oleander Street; *Different Sections of Annandale Drive* • up to 0.55m of water near the intersection with Macarthur Drive; • up to 0.47m of water near the intersection with Indigo Crescent *Macarthur Drive* • up to 0.55m of water in between Wave Hill Drive intersections; *Different Sections of Glendale Drive* • up to 3.2 m of water at the flow path near the intersection with River Park Drive; • up to 0.52m of water near the intersection with Hazelwood Court; *Internal Roads* • up to 1.0m of water over Fardon Street near the intersection with Masuda Street; • up to 0.9m of water over Masuda Street near the intersection with Fardon Street; • up to 0.66m of water over Hoya Court near inundated property;

- up to 0.84m of water over Boronia Drive close to intersection with Tibouchina Street;
- up to 0.57m of water over Cypress Drive near the intersection with River Park Drive;
- up to 0.6m of water over Eucalyptus Avenue near the intersection with Myrtle Court; and
- up to 0.57m of water over Marigold Court.

Flow velocities are generally under 0.75m/s, however there are higher velocities in Masuda Street (up to 1.6 m/s), Fardon Street (up to 1.8 m/s), Yolanda Drive (up to 1.45m/s), Glendale Drive (up to 1.54 m/s on the flow path near the intersection with River Park Drive) and in William Angliss Drive (up to 1.3 m/s).

PMF

Generally the critical duration event is:

- 1.5 hours in the residential area, flow paths, Palmetum and the car park of Annandale Shopping Centre; and
- 72 hours in the Ross River and the outfalls of the flow paths.

There is a significant widespread flooding with depths up to 2.3m. A total of approximately 1855 residential properties are inundated. Numerous commercial premises, educational institutions and public utilities are also flooded due to this event.

Inundation of major roads includes:

Yolanda Drive

- up to 1.4m of water near the intersection with Oleander Street;

Different Sections of Annandale Drive

- up to 1.3m of water near the intersection with Macarthur Drive;
- up to 1.1m of water near the intersection with Indigo Crescent

Macarthur Drive

- up to 1.0m of water in between Wave Hill Drive intersections;

Different Sections of Glendale Drive

- up to 3.7 m of water at the flow path near the intersection with River Park Drive;
- up to 0.6m of water near the intersection with Hazelwood Court;

Inundation of Internal Roads:

- up to 2.3m of water over Fardon Street near the intersection with Masuda Street;
- up to 2.2m of water over Masuda Street near the intersection with Fardon Street;
- up to 1.0m of water over Hoya Court near inundated property;
- up to 1.9m of water over Boronia Drive close to intersection with Tibouchina Street;
- up to 1.1m of water over Cypress Drive near the intersection with River Park Drive;
- up to 1.6m of water over Eucalyptus Avenue near the intersection with Myrtle Court; and
- up to 0.8m of water over Marigold Court.

Flow velocities are generally under 0.75m/s, however there are higher velocities in Masuda Street (up to 2.5 m/s), Fardon Street (up to 2.9 m/s), Yolanda Drive (up to 2.4 m/s), Glendale Drive (up to 1.72 m/s on the flow path near the intersection with River Park Drive) and in William Angliss Drive (up to 2.2 m/s).

DOUGLAS & ANNANDALE FLOOD STUDY
Figure 5-3

West Annandale

LEGEND

Drainage Flow Direction

Underground Drainage

Suburbs

100 Y ARI Water Depth (m)

- 0.01 - 0.3
- 0.3 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- 3 - 25

N

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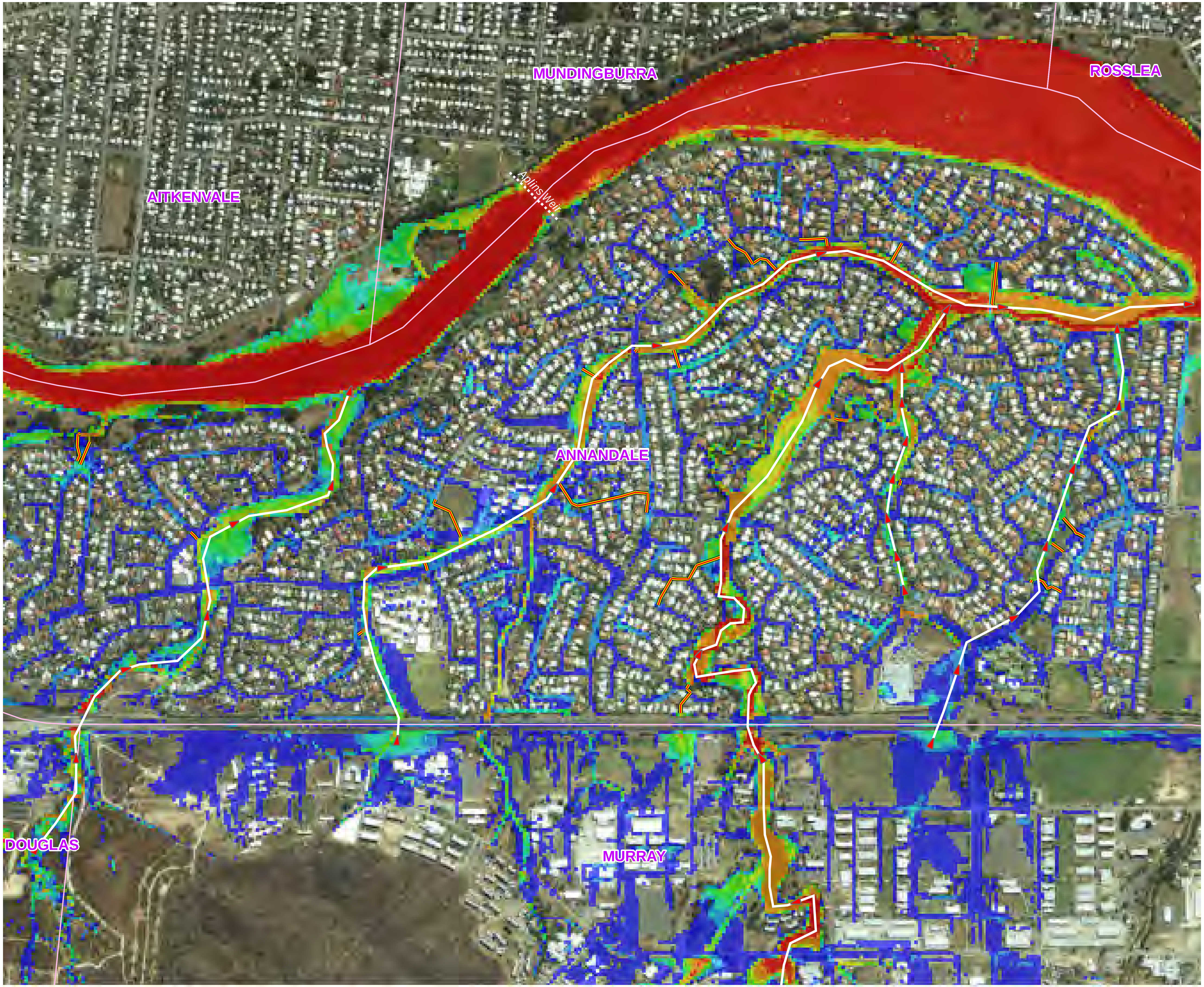
DOUGLAS & ANNANDALE FLOOD STUDY
Figure 5-4

East Annandale



LEGEND

Drainage Flow Direction

Underground Drainage

Suburbs

100 Y ARI Water Depth (m)

- 0.01 - 0.3
- 0.3 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- 3 - 25

N

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5.2 Hydraulic Grade Line

There are many flow paths/ open drains in the Douglas and Annandale areas. Here, only the major flow paths have been considered for hydraulic grade line analysis. There are six major flow paths in Annandale and Douglas as shown in **Figure 5-5**. The six major flow paths are:

In Annandale

- Army Dam Creek;
- Glendale Drive Flow Path;
- Yolanda Drive Drain; and
- Marabou Drive Drain.

In Douglas

- University Creek; and
- Regatta Crescent Drain.

Flood model results have been used to derive the hydraulic grade lines for the major flow paths within the study area. Long-sections showing these hydraulic grade lines are provided in **Appendix E**. Note that the chainages for all flow paths start at the upstream end of the branches shown in **Figure 5-5**.

Review of the hydraulic grade-line results identifies the following issues:

Army Dam Creek
The headwaters of Army Dam Creek originated in Murray on the northern foothills of Mount Stuart before it crosses University Road and Macarthur Drive and discharges into Annandale Drain.

The greatest head-losses have been found across:

- Army Dam Bridge at University Road; and
- Culvert at Macarthur Drive;

Both the bridge and the culvert have flood immunity greater than 500 Year ARI.

Glendale Drive Flow Path
The hydraulic grade lines for the Glendale Drive Flow Path shows significant head losses across sub-surface drain at William Angliss Drive and culvert at Glendale Drive near Tandamus Court and at its outfall at Annandale Drain. It also shows that the culvert at Glendale Drive near Tandamus Court has flood immunity in between the 50 Year ARI and 100 Year ARI.

Yolanda Drive Drain
The hydraulic grade lines show that significant head losses at Annandale Drive RCB culverts. The RCB culvert at Annandale Drive has flood immunity more than 50 Year ARI but it overflows at 100 Year ARI. The other RCB culvert at Glendale Drive near River Park Drive has flood immunity less than 2 Year ARI.

Marabou Drive Drain

There are significant head-losses across University Road, Yolanda Drive and Marabou Drive. Flood Immunities of the major crossings are:

- Culvert at University Road - greater than PMP;
- Culvert at Yolanda Drive – 50 Year ARI; and
- Culvert at Marabou Drive – less than 2 Year ARI.

University Creek

The headwaters of University Creek originate in the northern foothills of Mount Stuart near James Cook University (JCU) before it travels through Douglas and Annandale to discharge to the Ross River. University creek crosses Discovery Drive and University Road. Before its fall to the Ross River it merges to Palmetum Drain.

The hydraulic grade lines show significant head-losses across all the major crossings.

Flood Immunities of the major crossings are:

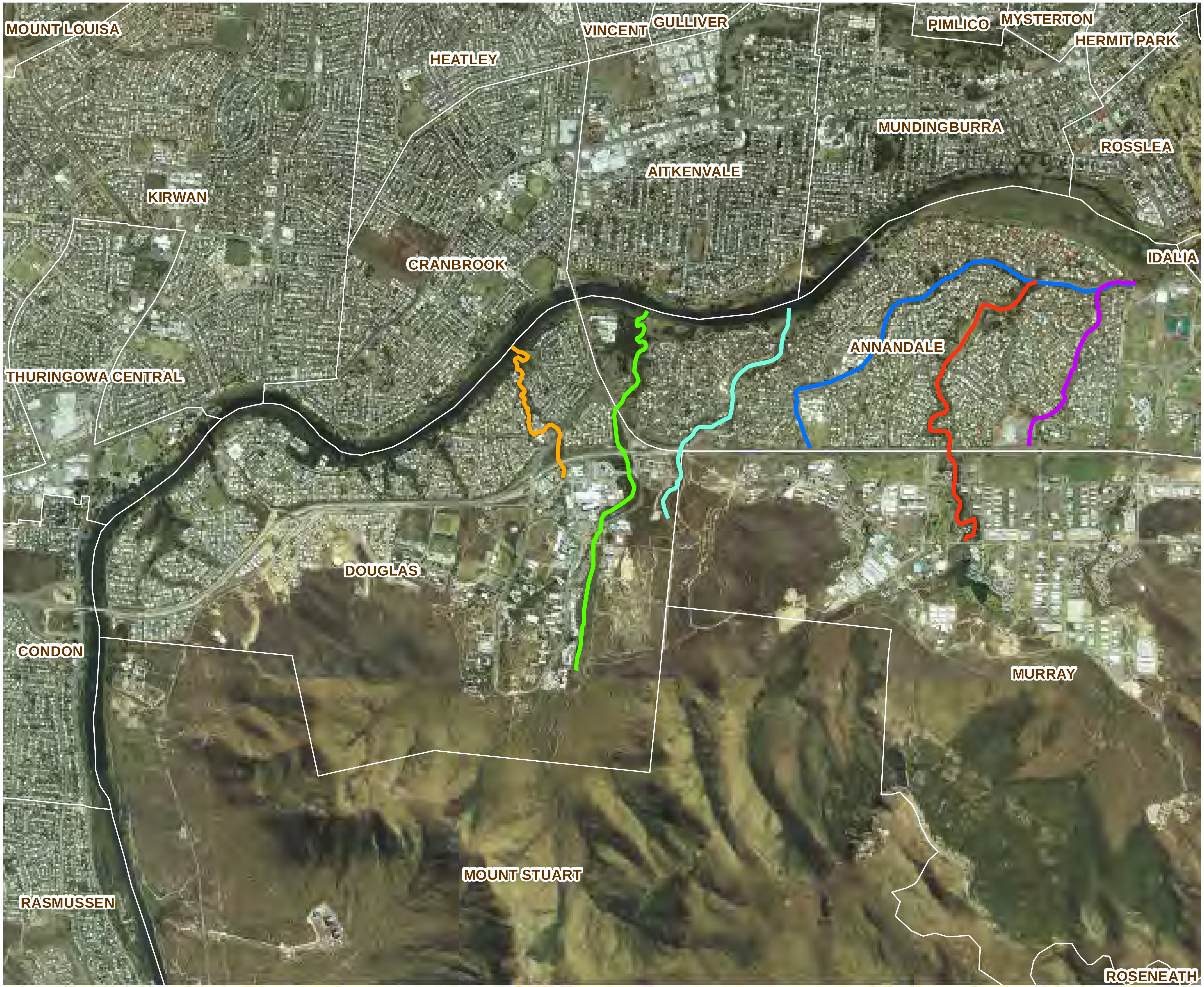
- Culvert at Discovery Drive at JCU area – 5 Year ARI;
- Culvert at Discovery Drive at Townsville Hospital area – 10 Year ARI; and
- University Creek Bridge – 500 Year ARI.

Regatta Crescent Drain

The hydraulic grade lines show significant head-losses across Ring Road crossing and Angus Smith Drive crossing.

Flood Immunities of the major crossings are:

- Culvert at Ring Road – greater than PMF; and
- Culvert at Angus Smith Drive – 2 Year ARI.



DOUGLAS & ANNANDALE FLOOD STUDY
HGL Locations

Figure 5-5

LEGEND

- GlendaleDrFlowPath
- ArmyDamCreek
- YolandaDrDrain
- MarabouDrDrain
- UniversityCreek
- RegattaCrescentDrain

N

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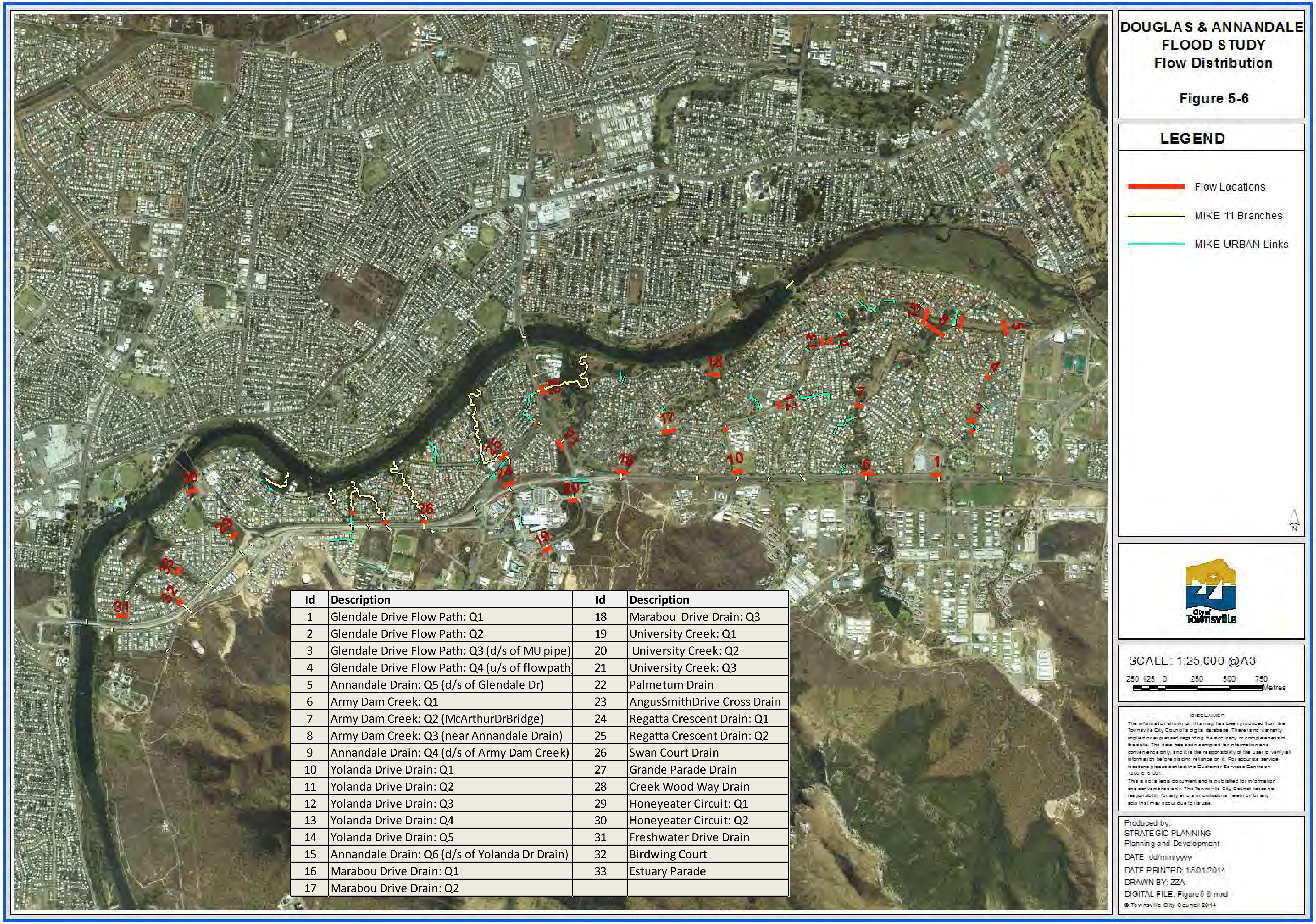
5.3 Flow Distributions

Flows at different locations of Douglas and Annandale floodplains have been calculated from the Douglas-Annandale model results. Maximum flows for the design flood events have been provided in **Table 5-3** at the locations shown in **Figure 5-6**. Note that the maximum flows provided here are the maximum of the peak flows for all duration storm events for the given ARIs. The peak flows for all storm durations have been presented in **Appendix-F**.

Table 5-3 Peak Flow Distribution Results

Locations	*Peak Flow (m^3/s)*								
	2 Y ARI	*5 Y ARI*	*10 Y ARI*	*20 Y ARI*	*50 Y ARI*	*100 Y ARI*	*200 Y ARI*	*500 Y ARI*	*PMF*
1	4.3	6.4	7.3	9.0	10.3	11.5	13.8	16.8	75.4
2	0.8	1.8	2.3	3.2	4.4	5.2	6.0	6.9	25.4
3	0.9	1.9	2.3	3.1	4.2	5.2	6.1	7.2	32.0
4	1.9	3.1	4.0	5.2	6.7	8.2	9.9	12.0	34.2
5	100.3	157.3	189.9	234.2	282.6	326.4	360.6	409.5	863.6
6	48.4	79.6	97.4	123.1	158.8	188.9	213.8	245.0	479.5
7	48.5	81.2	100.8	127.9	155.6	191.4	218.6	256.8	426.2
8	87.4	128.7	153.9	181.1	223.5	250.4	275.4	310.0	609.5
9	97.7	150.5	184.1	223.2	273.9	312.6	345.4	391.8	737.5
10	5.4	8.6	10.6	13.0	15.7	17.8	20.0	22.5	90.8
11	7.4	12.1	14.7	17.5	20.8	24.6	28.2	32.6	109.6
12	8.5	14.4	18.8	23.7	28.7	32.6	36.2	40.3	114.0
13	8.4	13.5	16.7	20.7	25.1	32.0	38.6	47.2	220.1
14	17.9	28.5	35.5	43.9	53.2	63.4	72.0	82.0	277.8
15	17.2	23.8	31.0	40.3	50.8	64.0	72.3	80.3	222.9
16	13.2	22.7	29.1	36.9	45.3	52.9	59.0	65.2	100.1
17	13.6	23.1	28.3	38.5	48.9	57.2	63.8	69.4	113.7
18	14.5	24.4	30.3	40.4	49.1	59.4	69.1	76.0	136.5
19	36.0	56.9	74.6	87.5	102.5	118.7	134.8	153.6	374.5
20	18.3	28.7	36.8	47.0	57.5	72.5	86.3	107.5	469.1
21	36.1	58.7	77.1	89.5	105.4	122.9	148.2	172.2	425.0
22	2.9	5.3	5.7	6.0	6.3	6.4	6.5	6.6	6.6
23	0.8	2.5	3.3	4.0	4.4	4.6	4.9	5.4	39.3
24	10.8	21.2	28.0	36.7	44.5	50.2	52.7	55.0	61.0
25	8.4	8.9	9.0	9.1	9.2	9.5	9.5	9.5	9.5
26	13.6	23.2	28.5	35.9	40.9	44.1	47.2	48.4	51.3
27	2.1	3.7	4.9	6.1	7.2	8.4	9.5	11.1	21.5
28	3.4	4.5	5.6	8.1	10.1	11.8	13.1	14.4	24.6
29	8.3	14.2	18.7	24.1	29.2	34.1	38.7	44.6	68.9
30	10.3	17.1	20.4	26.4	32.2	38.6	44.4	52.1	72.8
31	1.4	1.8	2.0	2.7	3.7	4.9	5.8	6.9	9.7
32	1.5	2.3	2.8	3.4	3.8	4.4	4.7	5.8	9.8
33	3.6	4.0	3.7	3.6	4.0	4.0	4.1	4.0	3.9



Id	Description	Id	Description
1	Glendale Drive Flow Path: Q1	18	Marabou Drive Drain: Q3
2	Glendale Drive Flow Path: Q2	19	University Creek: Q1
3	Glendale Drive Flow Path: Q3 (d/s of MU pipe)	20	University Creek: Q2
4	Glendale Drive Flow Path: Q4 (u/s of flowpath	21	University Creek: Q3
5	Annandale Drain: Q5 (d/s of Glendale Dr)	22	Palmetum Drain
6	Army Dam Creek: Q1	23	AngusSmithDrive Cross Drain
7	Army Dam Creek: Q2 (McArthurDrBridge)	24	Regatta Crescent Drain: Q1
8	Army Dam Creek: Q3 (near Annandale Drain)	25	Regatta Crescent Drain: Q2
9	Annandale Drain: Q4 (d/s of Army Dam Creek)	26	Swan Court Drain
10	Yolanda Drive Drain: Q1	27	Grande Parade Drain
11	Yolanda Drive Drain: Q2	28	Creek Wood Way Drain
12	Yolanda Drive Drain: Q3	29	Honeyeater Circuit: Q1
13	Yolanda Drive Drain: Q4	30	Honeyeater Circuit: Q2
14	Yolanda Drive Drain: Q5	31	Freshwater Drive Drain
15	Annandale Drain: Q6 (d/s of Yolanda Dr Drain)	32	Birdwing Court
16	Marabou Drive Drain: Q1	33	Estuary Parade
17	Marabou Drive Drain: Q2		

5.4 Impact on Residential Properties

A summary of the numbers of residential properties impacted by flooding within Douglas and Annandale areas is provided in **Table 5-4**. The numbers of inundated residential properties have been assessed based on 0.20 m water depth within the lot, which does not mean floor levels are exceeded (though in some cases they may be when floor levels are less 0.20 m above the ground). To undertake a comparison to floor levels would require survey of all floor levels within the study area.

Table 5-4 Summary of Inundate Residential Properties

Suburb	Number of Impacted Properties								
	2 Y	5 Y	10 Y	20 Y	50 Y	100 Y	200 Y	500 Y	PMF
Douglas	0	4	11	28	49	65	72	81	771
Annandale	1	4	4	6	15	15	18	46	1855
Total	1	11	18	38	64	80	90	127	2626

5.5 Floodplain Hazard

The safety of people and potential for damage to property is dependent on both the depth of inundation and the velocity of the flood waters. Floodwaters that flow deep and swift are obviously more hazardous than those areas where flows are shallow and slow.

The degree of hazard varies across the floodplain in response to:

- flood severity;
- floodwater depth and velocity;
- rate of rise of floodwater;
- duration of flooding;
- evacuation capacity;
- population at risk;
- land-use;
- flood awareness; and
- warning time.

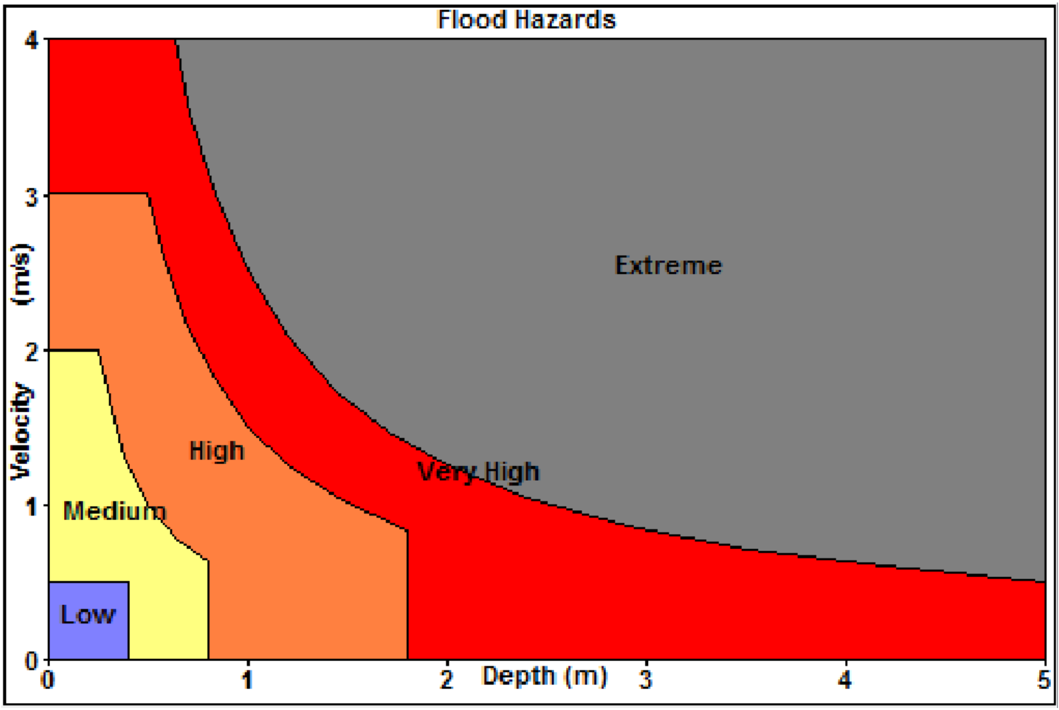
To assist with floodplain management it is necessary to determine the hazard and ensure land uses are suitably aligned. Five degrees of hazard have been adopted according to McConnell and Low (2000):

- **Low Hazard** – depth <0.4m and velocity <0.5m/s, suitable for cars;
- **Medium Hazard** – depth <0.8m, velocity <2m/s and velocity times depth <0.5, suitable for heavy vehicles and wading by able bodied adults;
- **High Hazard** – depth <1.8m, velocity <3m/s and velocity times depth <1.5, suitable for light construction (timber frame, brick veneer, etc.);

- **Very High Hazard** – velocity >0.5m/s and <4m/s with velocity times depth <2.5, suitable for heavy construction (steel frame, concrete, etc.); and
- **Extreme Hazard** – greater than very high, significant flow path development considered unsuitable and likely to significantly impact flood levels.

Prior to detailed assessment of floodplain hazard based on all the factors influencing hazard, preliminary assessment is often undertaken based on flood depth and velocity. **Figure 5-7** provides the basis for defining hazard as a function of depth and velocity as provided in McConnell and Low (2000).

Figure 5-7 Estimation of Flood Hazard



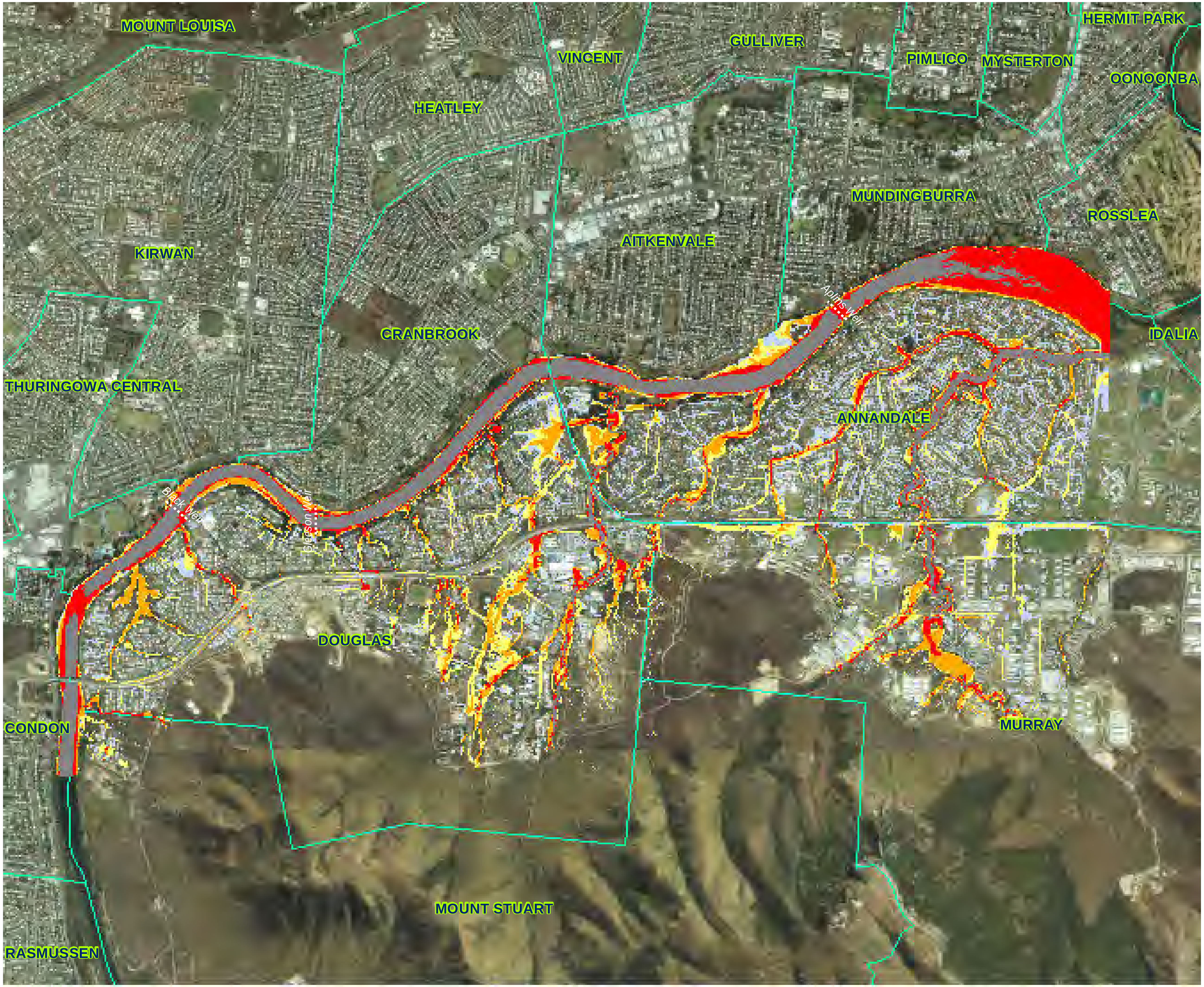
On the basis of the flood model results floodplain hazard has been mapped for the following events:

- **100 Year ARI** – representing the level of risk the *State Planning Policy - Mitigating the Adverse Impacts of Flood, Bushfire and Landslide (SPP 1/03)* requires for the Defined Flood Event, and also the first event modelled with significant overflows into residential areas;
- **500 Year ARI** – representing a rare event that is often used for design for critical infrastructure.
- **Probable Maximum Flood** – representing the extreme upper limit of flood hazard within the Douglas-Annandale floodplain.

Figures 5-8, **5-9** and **5-10** show the resulting floodplain hazard maps for the 100 Year ARI, 500 Year ARI and Probable Maximum Floods respectively. A summary of the number of residential properties within given hazard areas of the floodplain is provided in **Table 5-5**. The hazard category of a residential property has been determined based on the median cell value of that property.

Table 5-5 Floodplain Hazard Summary

Event	Number of Residential Properties					Location
	Low Hazard	Medium Hazard	High Hazard	Very High Hazard	Extreme Hazard	
100 Year ARI	**38**	**27**	**13**	**-**	**-**	**Douglas**
500 Year ARI	**69**	**50**	**19**	**-**	**-**	
PMF	**103**	**257**	**385**	**50**	**-**	
100 Year ARI	**62**	**7**	**-**	**-**	**-**	**Annandale**
500 Year ARI	**226**	**22**	**-**	**-**	**-**	
PMF	**526**	**1141**	**475**	**1**	**-**	



DOUGLAS & ANNANDALE FLOOD STUDY
100 Year ARI HAZARD

Figure 5-8

LEGEND

- Low Hazard
- Medium Hazard
- High Hazard
- Very High Hazard
- Extreme Hazard

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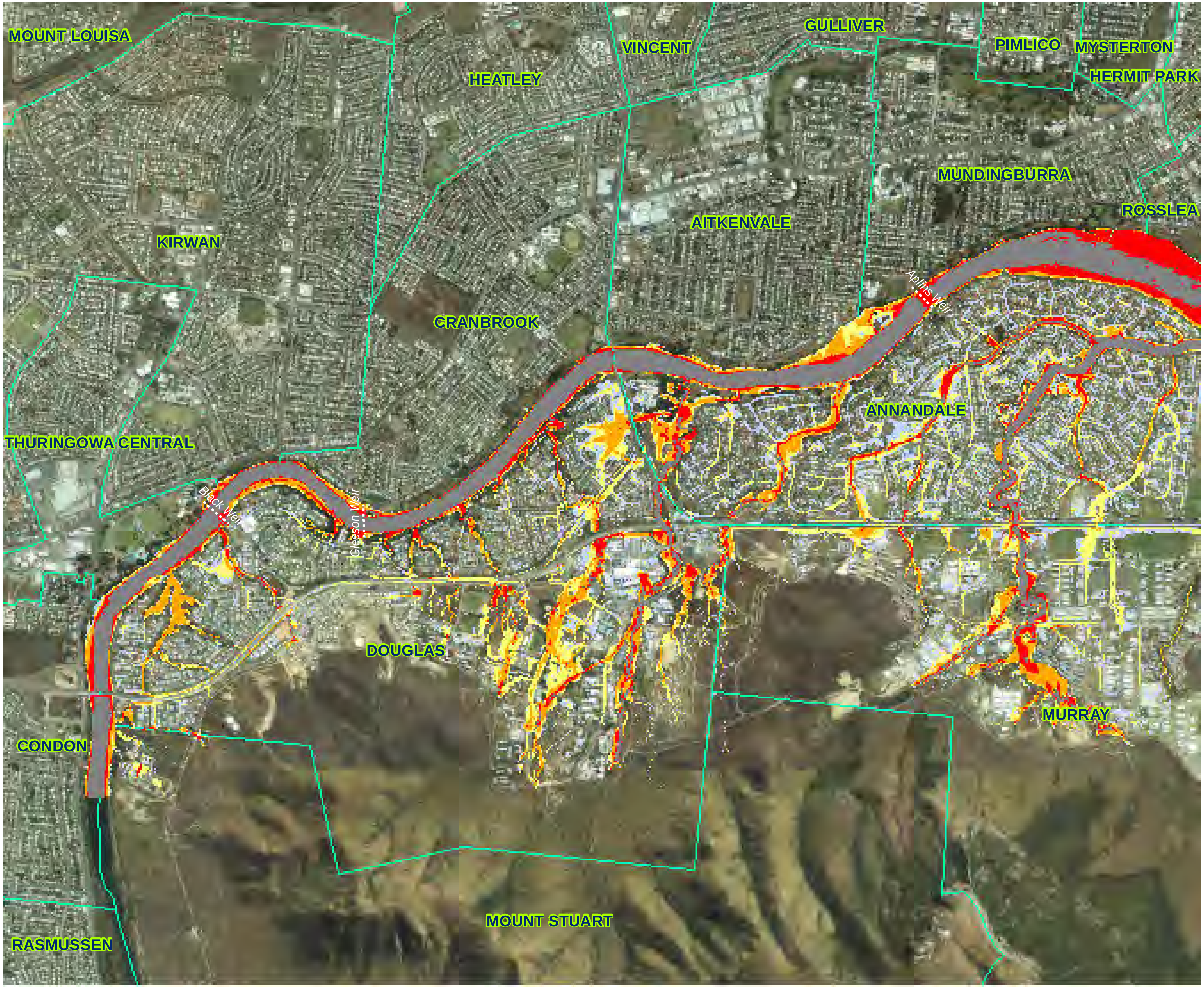
DOUGLAS & ANNANDALE FLOOD STUDY
500 Year ARI HAZARD

Figure 5-9



LEGEND

- Low Hazard
- Medium Hazard
- High Hazard
- Very High Hazard
- Extreme Hazard

N

SCALE: 1:25,000 @A3

250 125 0 250 500 750 Metres

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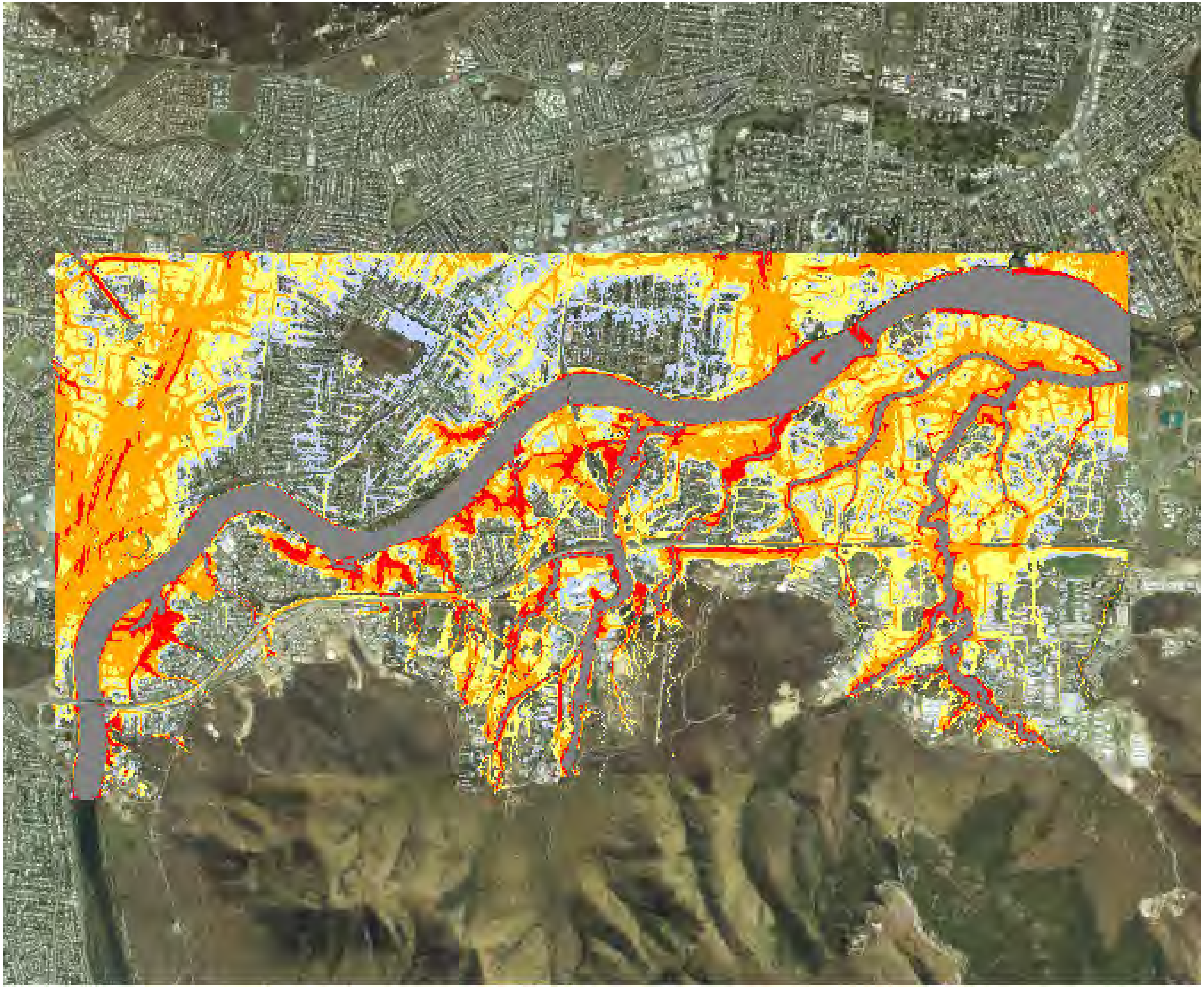

DOUGLAS & ANNANDALE FLOOD STUDY PMP HAZARD

Figure 5-10

LEGEND

- Low Hazard
- Medium Hazard
- High Hazard
- Very High Hazard
- Extreme Hazard

N

City of Townsville

SCALE: 1:25,000 @A3

250 125 0 250 500 750 Metres

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5.6 Floodplain Planning Considerations

Flood Hazard Overlay Mapping

The draft City Plan for Townsville City Council considers the 100 Year ARI (1% AEP) flood as the Defined Flood Event (DFE) for establishing floor levels based on "State Planning Policy 1/03- Mitigating the Adverse Impacts of Flood, Bushfire and Landslide". Flood Hazard Overlay maps have been prepared based on the following flood hazard criteria:

- Low Flood Hazard – areas of residual flood risk beyond the 100 Year ARI;
- Medium Flood Hazard – areas of shallower and slower moving flood waters in the 100 Year ARI as per the criteria in **Figure 5-11**;
- High Flood Hazard – areas of deeper and faster moving flood waters in the 100 Year ARI as per criteria in **Figure 5-11**.

These hazard maps differ from the previous hazard maps provided in Section 5-5 due to the different hazard criteria and flood probability.

Figure 5-11 Flood Hazard Overlay Definitions (Medium and High Hazard)

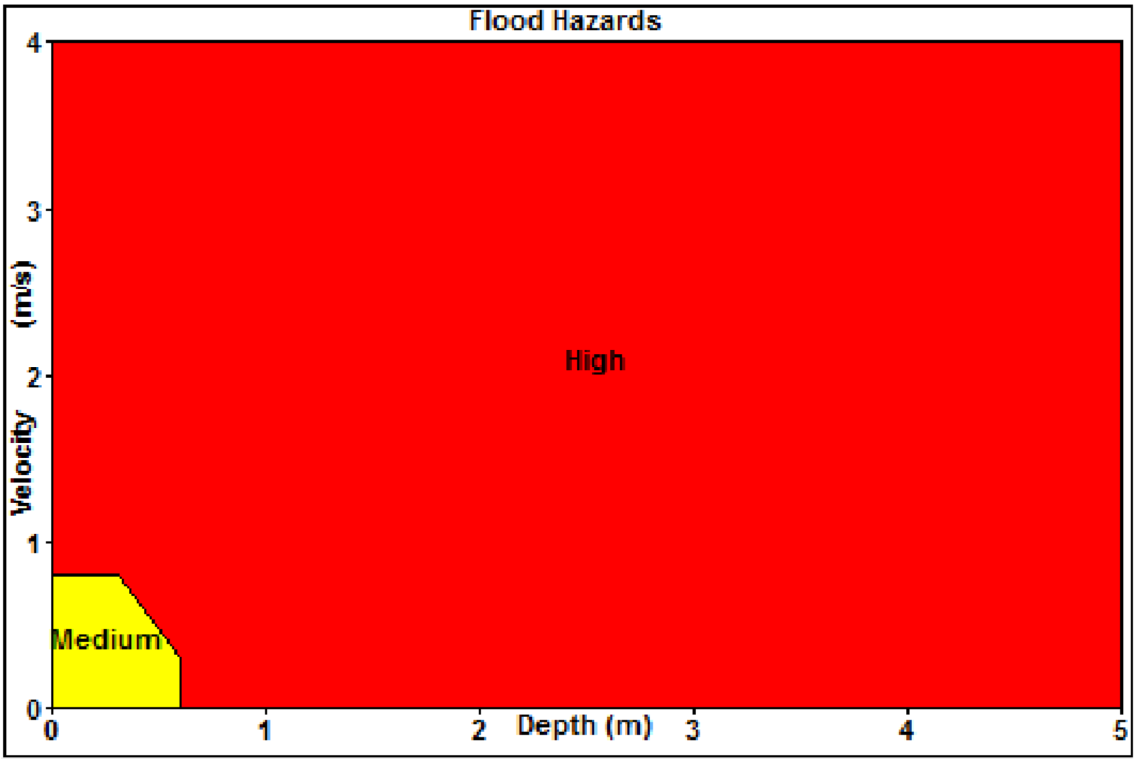
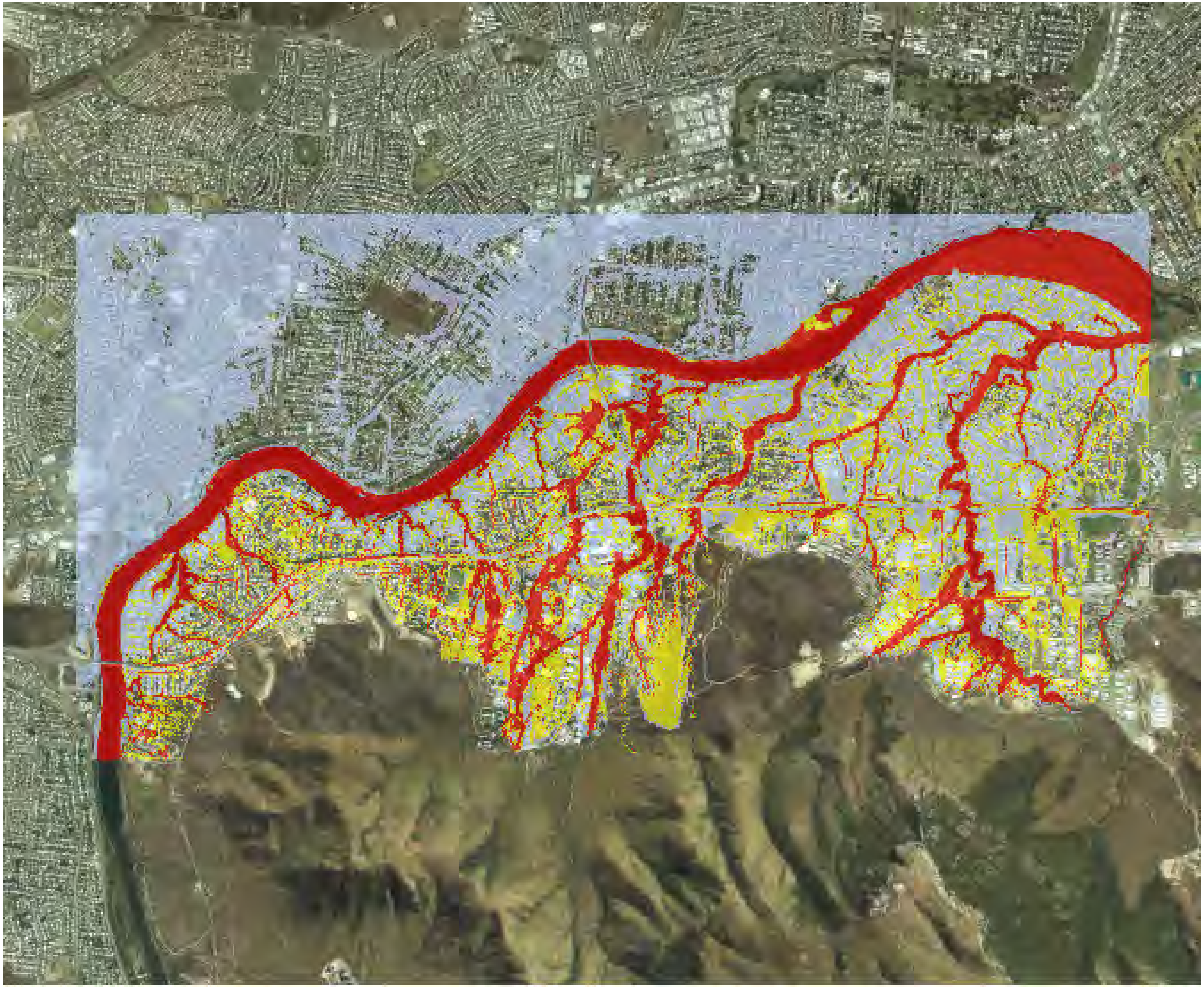


Figure 5-12 shows the flood hazard overlay map for the Douglas and Annandale area based on the above criteria.



DOUGLAS & ANNANDALE FLOOD STUDY

Flood Hazard Overlay

Figure 5-12

LEGEND

Hazard Overlay

- Low
- Medium
- High

N

City of Townsville

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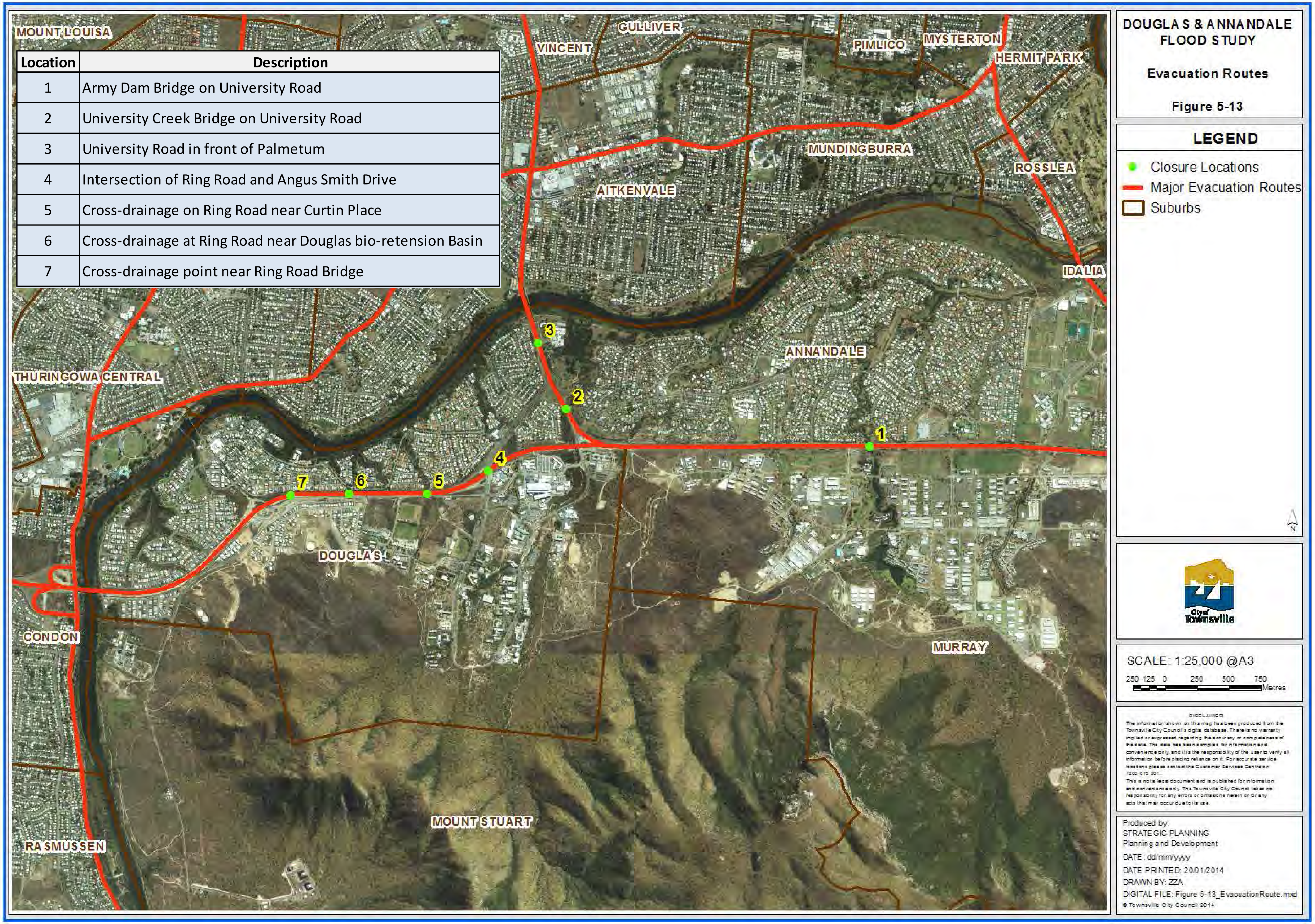
5.7 Emergency Management Considerations

Evacuation Route Closures

University Road and Ring Road are the main evacuation routes of Douglas and Annandale suburbs. **Figure 5-13** shows the locations where the major evacuation routes are closed under extreme flood event (i.e. PMP). Based on the flood study results the flood immunity of the evacuation routes is provided in **Table 5-6**. The evacuation routes have been assumed to be closed with flood depths greater than 200 mm. The following table shows that the major evacuation routes of Douglas and Annandale remain open in the flood events up to 200 Year ARI. The evacuation route remains closed at Army Dam Bridge location on University Road during 500 Year ARI.

Table 5-6 Major Evacuation Route Flood Immunity

Location	Description	Depth over Road (m)								
		2 Year ARI	5 Year ARI	10 Year ARI	20 Year ARI	50 Year ARI	100 Year ARI	200 Year ARI	500 Year ARI	PMP
1	Army Dam Bridge on University Road	-	-	-	-	0.10	0.15	0.19	0.56	0.67
2	University Creek Bridge on University Road	-	-	-	-	-	-	-	-	1.07
3	University Road in front of Palmetum	-	-	-	-	-	-	-	-	0.32
4	Intersection of Ring Road and Angus Smith Drive	-	-	-	-	-	-	-	0.10	0.42
5	Cross-drainage on Ring Road near Curtin Place	-	-	-	-	-	0.10	0.10	0.10	0.51
6	Cross-drainage at Ring Road near Douglas bio-retension Basin	-	-	-	-	0.10	0.11	0.11	0.12	0.33
7	Cross-drainage point near Ring Road Bridge	-	-	-	-	-	-	0.10	0.10	0.37



Location	Description
1	Army Dam Bridge on University Road
2	University Creek Bridge on University Road
3	University Road in front of Palmetum
4	Intersection of Ring Road and Angus Smith Drive
5	Cross-drainage on Ring Road near Curtin Place
6	Cross-drainage at Ring Road near Douglas bio-retension Basin
7	Cross-drainage point near Ring Road Bridge

Emergency Management Facilities

Emergency Management Facilities of Douglas and Annandale areas include:

- Medical Facilities;
- Major Public Transport; and
- Pre- and Post-impact Evacuation Centres.

All the information on these facilities available in Townsville City Council's database have been retrieved and overlaid on flood maps in order to assess the inundation depth at the facilities during different flood events. **Figure 5-14** shows the potential emergency management facilities within the study area. Among these emergency management facilities Townsville Hospital is the most important one. It is located at the centre of the study area and accessible both from Angus Smith Drive and Discovery Drive.

Flood depths at all the emergency management facilities has been derived from model results for different flood events and presented in **Table 5-7**. Given the flood depths indicated are only depths relative to lots' levels, they may not necessarily indicate whether the facilities themselves are inoperable as a result of flooding.

Model results show that:

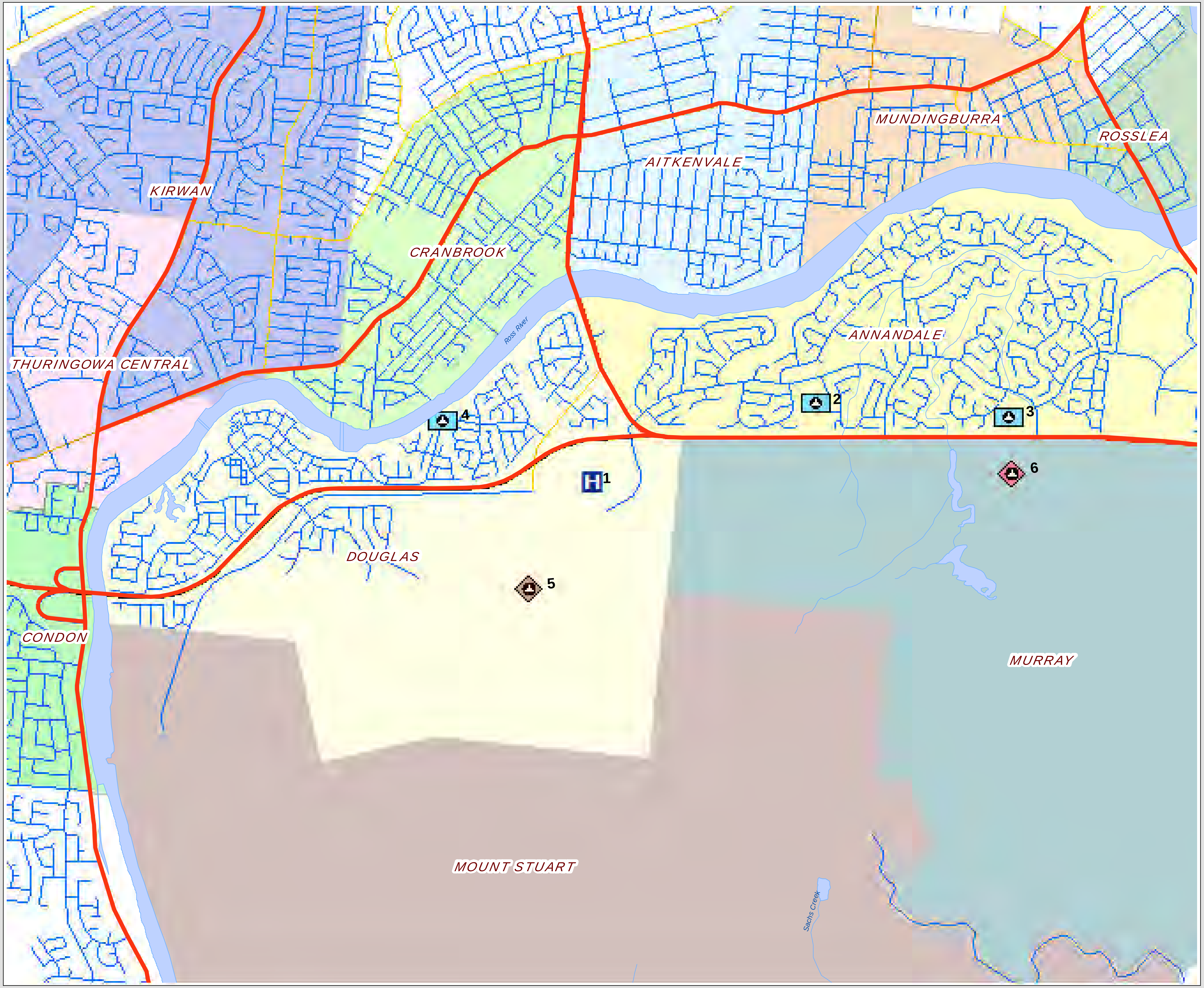
- most facilities with a major role in disaster management remains unaffected up to the large flood events (greater than 100 Year ARI); and
- Townsville Hospital remains flood free in all the flood events. In PMP event, the flood free area is reduced to main building area and two car parks but the accesses roads to the Hospital remain closed.

Table 5-7 Emergency Management Facility Flooding

Location	Description	Facility Type	Depth over Road (m)								
			2 Year ARI	5 Year ARI	10 Year ARI	20 Year ARI	50 Year ARI	100 Year ARI	200 Year ARI	500 Year ARI	PMP
1	Townsville Hospital	MEDICAL	-	-	-	-	-	-	-	-	-
2	Annandale State School	POST IMPACT	-	-	-	-	-	-	-	-	0.16
3	Annandale Community Centre	PRE IMPACT	-	-	-	-	-	-	-	-	0.18
4	Riverside Gardens Community Centre	PRE IMPACT	-	-	-	-	-	-	-	1.66	3.80
5	James Cook University	POST IMPACT	-	-	-	-	-	-	-	-	0.21
6	Lavarack Barracks	POST IMPACT	-	-	-	-	-	-	-	-	0.13

DOUGLAS & ANNANDALE FLOOD STUDY
Disaster Management

Figure 5-14



LEGEND

Evacuation Facilities

- MEDICAL
- POST IMPACT
- PRE IMPACT

Major Evacuation Route

SCALE: 1:25,000 @A3

250 125 0 250 500 750 Metres

DISCLAIMER

The information shown on this map has been produced from the Townsville City Council's digital database. There is no warranty implied or expressed regarding the accuracy or completeness of the data. The data has been compiled for information and convenience only, and it is the responsibility of the user to verify all information before placing reliance on it. For accurate service locations please contact the Customer Services Centre on 1300 878 001.

This is not a legal document and is published for information and convenience only. The Townsville City Council takes no responsibility for any errors or omissions herein or for any acts that may occur due to its use.

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5.8 Tailwater Conditions

For all the design storm events the MIKE FLOOD hydraulic model has adopted a fixed tail water condition at the MHWS tidal level (i.e. 1.254 m AHD) at the outfall of the Ross River. This is considered somewhat conservative as in reality a flood is likely to coincide with a tidal level within low and high tides across a tidal cycle.

In this study a higher sea-level has been reviewed in the light of impact on flood levels. The Highest Astronomical Tide (HAT) at the outfall of the Ross River is 2.254 m AHD. The impact due to the Highest Astronomical Tide (HAT) on 100 year ARI (3 hour duration) flood event has been assessed using Douglas-Annandale flood model. The impact of HAT on 100 year ARI 3 hour duration flood levels is presented in **Figure 5-15**.

The figure shows that the flood levels in the Ross River at the downstream of Aplin Weir increases due to the impact of HAT. The impact is insignificant on the other parts of the river and the study area.

DOUGLAS & ANNANDALE FLOOD STUDY 100 Y ARI & HAT

Figure 5-15

LEGEND

Water Level Difference (m)

- Previously Inundated
- < -1
- -1 - -0.5
- -0.5 - -0.3
- -0.3 - -0.1
- -0.1 - -0.05
- -0.05 - -0.01
- -0.01 - 0.01
- 0.01 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- > 1
- Now Inundated

N

City of Townsville

SCALE: 1:25,000 @A3

250 125 0 250 500 750 Metres

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DIGITAL FILE: Figure 5-15_HAT100y3h.mxd

6.0 Impact of Climate Change on Flooding

In this study, the impact of climate change on 100 year ARI flood event has been assessed based on model results. In the model runs, the climate change scenario incorporates both the sea level rise and the increased intensity of extreme rainfall.

The sea-level rise specified within the *Queensland Coastal Plan* of 0.8 m to allow for conditions in 2100 has been adopted. This value is consistent with advice from the *IPCC Fifth Assessment Report: Climate Change* (2013) and the range of projections within *Climate Change Projections for the Townsville Region* (Hennessy et al, 2008).

In a joint project between, Department of Environment and Resource Management (DERM), the Department of Infrastructure and Planning (DoIP) and the Local Government Association of Queensland (LGAQ), a review of the potential for climate change to alter extreme rainfall intensities has been completed. *Increasing Queensland's resilience to inland flooding in a changing climate* (DERM, 2010) provides recommendation for extreme rainfall intensities in the interim until a new revision of *Australian Rainfall and Runoff* addresses the issue. The Scientific Advisory Group (SAG) agreed that:

- an increase in rainfall intensity is likely;
- the available scientific literature indicates this increased rainfall intensity to be in the range of 3–10% per degree of global warming; and
- in the interim the SAG would consider a figure of a 5% increase in rainfall intensity per degree of global warming reasonable for informing policy development in the interim.

To evaluate the impact of sea-level rise and changes in extreme rainfall intensities on the flooding of Douglas and Annandale areas, the modelling was updated by:

- increasing rainfall intensities by 15% allowing for a 3ºC rise in temperature to 2100;
- re-calculating catchment runoff based on the new rainfall intensities;
- updating the rain on grid data based on the new rainfall intensities;
- applying the revised flows as boundary conditions and source points to the MIKE FLOOD model; and
- updating the tail water level to account for a 0.8 m rise in sea level to 2100.

Assessing the change in rainfall intensities relative to existing IFD data presented in **Table 3-3** suggest that:

- the climate change 100 Year ARI, 3 hour intensity of 74.85 mm/h is between the existing 200 and 500 Year ARI, 3 hour intensities; and
- the climate change 100 Year ARI, 72 hour intensity of 12.71 mm/h is between the existing 200 and 500 Year ARI, 72 hour intensities.

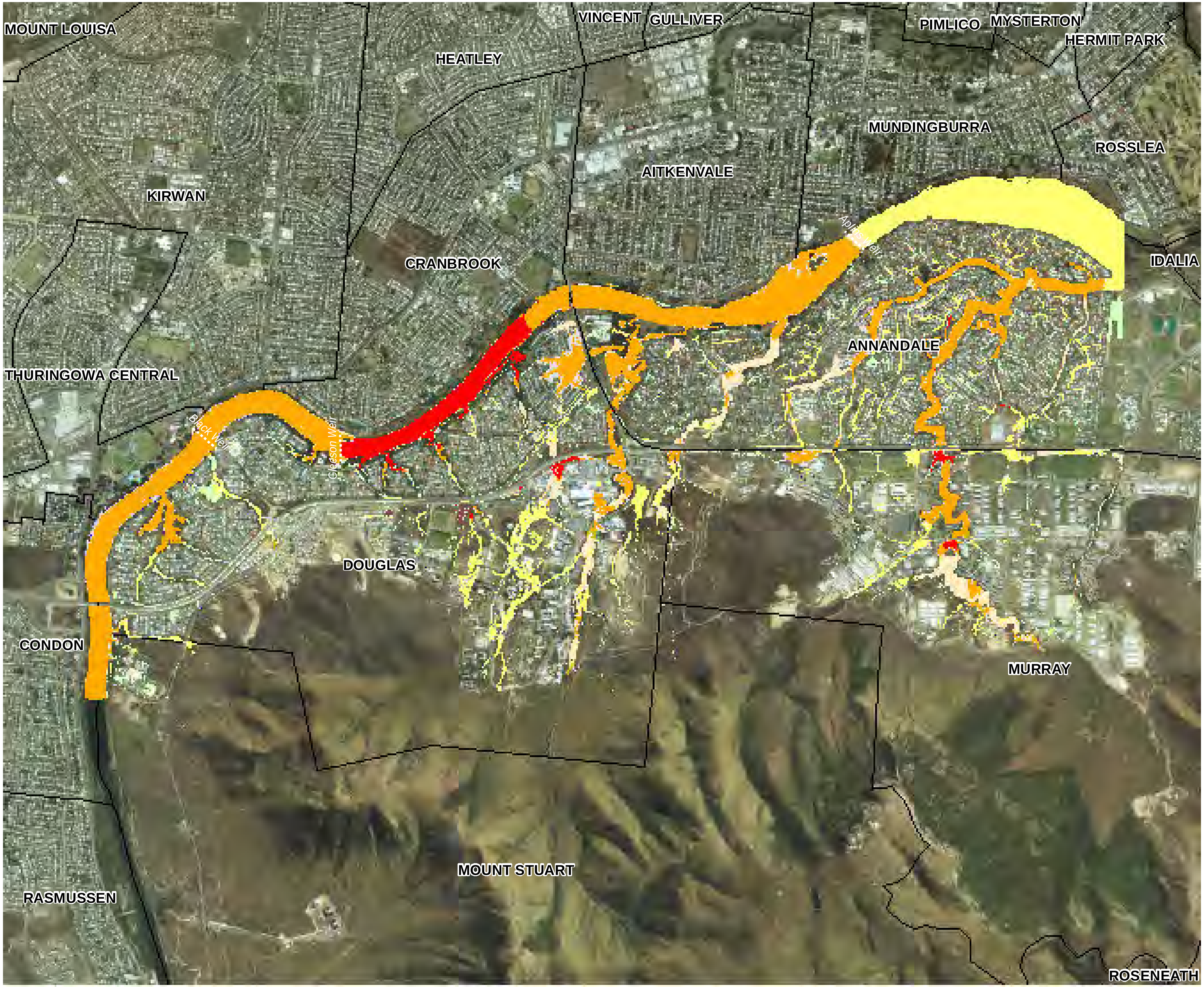
It should be noted that the following assumptions are implied in this methodology:

- initial and continuing rainfall losses remain unchanged from present conditions;
- rainfall temporal patterns remain unchanged from present conditions;
- catchment surface retardances remain unchanged from present conditions;
- channel and floodplain hydraulic roughness remains unchanged from present conditions; and
- fraction impervious remains unchanged from present conditions.

For all ARIs 72 hour and 3 hour storm durations have been found critical in the Ross River and in inland area respectively. The impact of climate change on the 100 year ARI flood levels has been assessed based on the two storm durations. **Figures 6-1** shows the changes in flood levels of 100 Year ARI flood event due to climate change.

Impact of climate change on 100 Year ARI flood levels:

- in total 71 properties are affected due to climate change in the study area, where 68 properties are in Douglas and 3 in Annandale;
- In Douglas, all of the affected properties are located around Verhoven Drive and there are increases in extent of inundation and flood levels at this location;
- flood level increases up to 0.3 m around Verhoven Drive due to climate change; and
- In Annandale the affected properties are located near the intersection of Masuda Street and Fardon Street, where flood level increases up to 0.1 m.



DOUGLAS & ANNANDALE FLOOD STUDY
100 Y ARI
CLIMATE CHANGE

Figure 6-1

LEGEND

Water Level Difference (m)

- Previously Inundated
- < -1
- -1 - -0.5
- -0.5 - -0.3
- -0.3 - -0.1
- -0.1 - -0.05
- -0.05 - -0.01
- -0.01 - 0.01
- 0.01 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- > 1
- Now Inundated

N

City of Townsville

SCALE: 1:25,000 @A3

250 125 0 250 500 750 Metres

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7.0 Summary and Conclusions

The *Douglas and Annandale Flood Study – Baseline Flooding Assessment* has been undertaken as part of Townsville City Council's City Wide Flood Constraints Project. This study builds on previous flood studies completed for Townsville City Council and incorporates the latest Light Detection and Ranging (LiDAR) topographic data as well as recent hydrographic survey to form up to date hydraulic flood model for Douglas and Annandale.

Within the study area, "Rain on Grid" approach has been used directly applying rainfall excess to the two-dimensional grid of MIKE FLOOD model, and has been supplemented with flows from XP-RAFTS models of Ross River and the local catchments of Mount Stuart foothills.

This study has developed a detailed flood model incorporating hydrologic and hydraulic assessment for quantifying the flood risk in Douglas and Annandale suburbs and its surrounding areas. The model has been calibrated with the Ross River model result of 100 year ARI event and verified with the other overlapped model results (i.e. Ross Creek Model and Gordon Creek Model) at its northern and eastern boundaries respectively. The model represents in fine-scale resolution the topography and drainage systems of Douglas and Annandale areas, including:

- a digital elevation model resolved to a 10m grid;
- the larger components of the underground drainage network (greater than 900 mm diameter equivalent diameter);
- open drains narrower that the 10m grid resolution using one-dimensional branches; and
- application of rainfall directly on the model grid.

The verified flood model has been used to assess design storm flood events for the 2, 5, 10, 20, 50, 100, 200 and 500 Year Average Recurrence Intervals (ARI) as well as the Probable Maximum Precipitation flood event. The 100 Year and 50 Year design storm events have been run for a range of storm durations in order to assess the critical duration event for all points of the floodplain.

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

- quantify the floodplain hydraulic response with hydraulic grade lines and flow distributions;
- evaluate the potential impact on residential properties;
- identify flood hazard zones on the floodplain;
- inform flood overlay development for the new City Plan; and
- identify emergency management considerations.

7.1 Floodplain Hydraulic Mechanisms

Floodplain hydraulic mechanisms in Douglas and Annandale have been examined in detailed in **Section 5.1**.

There are eleven distinct flow paths in Douglas, which are draining stormwater runoff from different parts of Douglas area into the Ross River. Three of them are draining stormwater into the Ross River through a lake, which is located at upstream of Black Weir. Another flow path is draining water into the Ross River immediately upstream of Black Weir. Their tailwater levels are influenced by the level of Black Weir. Another flow path is located immediately upstream of Gleeson Weir, which is draining only a small local catchment. The remaining flow paths are draining to the Ross River downstream of Gleeson Weir and their tailwater level is influenced by the Aplins Weir's level.

There are six distinct drainage flow paths in Annandale area, where four drain stormwater runoff from both Annandale and Murray areas and rest drain Douglas and Annandale.

7.2 Inundation of Residential Properties

The residential properties potentially inundated by flooding within Douglas and Annandale areas have been assessed for all the design flood events. The number of residential properties inundated by depths of greater than 0.2 m above ground level is provided in **Table 6.1**.

Table 6-1 Summary of Residential Property Inundation

Design Flood	Residential Properties Inundated	
	Douglas	Annandale
2 Year ARI	0	1
5 Year ARI	4	4
10 Year ARI	11	4
20 Year ARI	28	6
50 Year ARI	49	15
100 Year ARI	65	15
200 Year ARI	72	18
500 Year ARI	81	46
PMF	771	1855

7.3 Floodplain Hazard

Flood plain hazard has been characterised based on the function of flood depth and velocity. Five degrees of hazard have been adopted according to McConnell and Low (2000):

- **Low Hazard** – depth <0.4m and velocity <0.5m/s, suitable for cars;
- **Medium Hazard** – depth <0.8m, velocity <2m/s and velocity times depth <0.5, suitable for heavy vehicles and wading by able bodied adults;
- **High Hazard** – depth <1.8m, velocity <3m/s and velocity times depth <1.5, suitable for light construction (timber frame, brick veneer, etc.);
- **Very High Hazard** – velocity >0.5m/s and <4m/s with velocity times depth <2.5, suitable for heavy construction (steel frame, concrete, etc.); and
- **Extreme Hazard** – greater than very high, significant flow path development considered unsuitable and likely to significantly impact flood levels.

The floodplain hazard has been evaluated for the 100 Year ARI, 500 Year ARI and PMF events. The hazard mapping indicates that:

- Majority of the residential properties inundated in the 100 Year ARI are characterised by Low and Medium Hazard in Douglas (49% and 35% respectively) and by Low Hazard in Annandale (90%);
- Majority of the residential properties inundated in the 500 Year ARI are characterised by Low and Medium Hazard in Douglas (50% and 36% respectively) and by Low and Medium Hazard in Annandale (91% and 9%); and
- Majority of the residential properties inundated in the PMF are characterised by Medium and High Hazard in Douglas (32% and 48% respectively) with remaining properties in Very High and Low Hazard areas and by Medium and High Hazard in Annandale (53% and 22%) with remaining properties in Low Hazard area.

7.4 Floodplain Planning

The new City Plan for Townsville proposes to adopt the 100 Year ARI flood as the Defined Event and will adopt a Flood Overlay map comprising three hazard categories for flooding:

- Low flood hazard- areas of residential flood risk beyond the 100 Year ARI;
- Medium flood hazard- areas of shallower and slower moving flood waters in the 100 Year ARI; and
- High flood hazard- areas of deeper and faster moving flood waters in the 100 Year ARI.

The number of properties fall under different hazard categories in Douglas and Annandale areas are provided in **Table 6-2**.

Table 6-2 Number of properties under different hazard categories

Suburb	Low Flood Hazard Rating	Medium Flood Hazard Rating	High Flood Hazard Rating
Douglas	507	430	50
Annandale	1015	1211	89

7.5 Emergency Management

University Road and Ring Road are the main evacuation routes of Douglas and Annandale suburbs. Model result shows that the evacuation route remains closed (due to the flood depth greater than 200 mm) at seven locations in extreme flood condition (i.e. PMF). The closed locations are mentioned below:

- Army Dam Bridge on University Road;
- University Creek Bridge on University Road;
- University Road in front of Palmetum;
- Intersection of Ring Road and Angus Smith Drive;
- Cross-drainage point on Ring Road near Curtin Place;
- Cross-drainage point at Ring Road near Douglas bio-retension Basin; and
- Cross-drainage point near Ring Road Bridge.

The Army Dam Bridge on University Road also gets inundated in 500 Year ARI flood event.

Emergency Management Facilities of Douglas and Annandale areas include:

- Medical Facilities;
- Major Public Transport; and
- Pre- and Post-impact Evacuation Centres.

Model results show that:

- most facilities with a major role in disaster management remains unaffected up to the large flood events (greater than 100 Year ARI); and
- Townsville Hospital remains flood free in all the flood events. In PMP event, the flood free area is reduced to main building area and two car parks.

7.6 Impact of Higher Tides

The impact of Highest Astronomical Tide (i.e. 2.25 m AHD) on flood levels has been assessed using the Douglas-Annandale flood model. The model result shows that the flood levels in the Ross River at the downstream of Aplin Weir increases due to the impact of Highest Astronomical Tide. The impact of HAT on flood levels is insignificant on the other parts of the river and the study area.

7.7 Impact of Climate Change

The impact of climate change on 100 year ARI flood event has been assessed based on model results. To account for climate change conditions in 2100, the model was updated to:

- Include the sea level rise of 0.8 m on the Mean High Water Springs level to give a resulting sea level of 2.054 m AHD; and
- Increase rainfall intensities by 15% in accordance with Increasing Queensland resilience to inland flooding in a changing climate (DERM, 2010).

The model result shows that the flood extents and the flood levels increase around Verhoven Drive in Douglas area. Here, flood level increases up to 0.3 m due to climate change. In Annandale, flood level increases up to 0.1 m near the intersection of Masuda Street and Fardon Street.

8.0 References

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14/ Hennessy et al, (2008) *Climate Change Projections for the Townsville Region*

15/ Department of Environment and Resource Management, (2010) *Queensland's resilience to inland flooding in a changing climate*

16/ IPCC Fifth Assessment Report, (2013) *Climate Change 2013 The Physical Science Basis*

Appendix A – Sub-Catchments of Douglas and Annandale

(Refer to Volume II also)

Sub-catchment ID	Pervious (1) / Impervious (2)	Total Area [ha]	Percentage Impervious [%]	Catchment Slope [%]	Catchment Mannings 'n' [n value]
U-8.03	1	123.70	0.1	15.00	0.08
	2	0.01	100	15.00	0.02
A2-7.00	1	54.62	0.1	15.00	0.08
	2	0.01	100	15.00	0.02
D8-1.00	1	4.70	0.1	6.27	0.08
	2	0.73	100	6.27	0.01
D2-1.01	1	2.99	0.1	3.07	0.06
	2	4.30	100	3.07	0.01
D3-8.00	1	12.29	0.1	15.00	0.07
	2	0.98	100	15.00	0.01
D4-5.00	1	23.10	0.1	15.00	0.07
	2	0.99	100	15.00	0.02
D5-1.00.01	1	1.18	0.1	5.00	0.06
	2	1.15	100	5.00	0.01
D6-3.00	1	2.79	0.1	5.54	0.06
	2	1.30	100	5.54	0.01
D7-8.00	1	19.36	0.1	15.00	0.07
	2	0.01	100	15.00	0.02
D9-3.00	1	27.87	0.1	15.00	0.07
	2	0.01	100	15.00	0.02
A1-1.02	1	3.74	0.1	3.04	0.07
	2	3.86	100	3.04	0.01
A1-1.00	1	8.98	0.1	5.52	0.06
	2	3.91	100	5.52	0.01
A1-1.00.01	1	2.29	0.1	1.42	0.07
	2	3.36	100	1.42	0.01
A1-2.01	1	2.11	0.1	1.27	0.07
	2	3.26	100	1.27	0.01
A1-2.00	1	3.73	0.1	2.55	0.06
	2	3.78	100	2.55	0.01
A1-3.00	1	3.73	0.1	3.62	0.06
	2	2.66	100	3.62	0.01
AN-3.13	1	25.51	0.1	15.00	0.08
	2	7.66	100	15.00	0.02
A1-3.01.01	1	1.89	0.1	1.25	0.07
	2	3.02	100	1.25	0.01
A1-3.01	1	2.04	0.1	4.72	0.06
	2	1.56	100	4.72	0.01
A1-3.02	1	1.15	0.1	6.95	0.06
	2	0.52	100	6.95	0.01
A1-3.02.02	1	2.25	0.1	1.37	0.07
	2	3.24	100	1.37	0.01
A1-3.02.01	1	1.22	0.1	1.29	0.07
	2	1.50	100	1.29	0.01
A1-3.03.01	1	0.74	0.1	2.06	0.06
	2	1.00	100	2.06	0.01

Sub-catchment ID	Pervious (1) / Impervious (2)	Total Area [ha]	Percentage Impervious [%]	Catchment Slope [%]	Catchment Mannings 'n' [n value]
A1-3.03.02	1	2.06	0.1	1.69	0.07
	2	3.15	100	1.69	0.01
A1-3.03	1	3.14	0.1	4.34	0.06
	2	1.81	100	4.34	0.01
A1-3.04	1	3.32	0.1	5.61	0.06
	2	1.92	100	5.61	0.01
A1-3.04.01	1	2.38	0.1	1.81	0.07
	2	3.69	100	1.81	0.01
A1-3.04.02	1	2.15	0.1	1.90	0.07
	2	3.31	100	1.90	0.01
A1-3.05	1	3.41	0.1	2.89	0.06
	2	3.33	100	2.89	0.01
A1-3.05.01	1	2.13	0.1	1.93	0.07
	2	3.41	100	1.93	0.01
A1-3.06	1	7.05	0.1	2.52	0.06
	2	7.66	100	2.52	0.01
A1-3.07.03	1	1.94	0.1	1.99	0.07
	2	2.79	100	1.99	0.01
A1-3.07.01	1	1.06	0.1	1.94	0.07
	2	1.60	100	1.94	0.01
A1-3.07.02	1	0.86	0.1	1.74	0.07
	2	1.44	100	1.74	0.01
A1-3.07	1	4.79	0.1	3.29	0.06
	2	2.51	100	3.29	0.01
A1-3.07.04	1	2.60	0.1	1.87	0.07
	2	3.81	100	1.87	0.01
A1-3.07.05	1	1.13	0.1	1.79	0.07
	2	1.75	100	1.79	0.01
A1-3.07.06	1	1.78	0.1	1.74	0.07
	2	2.74	100	1.74	0.01
A1-3.08	1	4.26	0.1	2.20	0.06
	2	5.46	100	2.20	0.01
A1-3.08.01	1	2.26	0.1	1.70	0.07
	2	1.99	100	1.70	0.01
A1-3.09	1	6.95	0.1	2.90	0.06
	2	3.23	100	2.90	0.02
A1-3.09.01	1	2.57	0.1	1.70	0.07
	2	3.91	100	1.70	0.01
A1-3.09.02	1	3.93	0.1	1.86	0.07
	2	5.17	100	1.86	0.01
A1-3.10	1	3.92	0.1	2.27	0.06
	2	4.13	100	2.27	0.02
A1-3.10.01	1	2.31	0.1	2.56	0.06
	2	2.21	100	2.56	0.02
A1-3.10.02	1	7.07	0.1	11.92	0.08
	2	2.96	100	11.92	0.02

Sub-catchment ID	Pervious (1) / Impervious (2)	Total Area [ha]	Percentage Impervious [%]	Catchment Slope [%]	Catchment Mannings 'n' [n value]
A1-3.09.03	1	4.55	0.1	2.26	0.06
	2	3.94	100	2.26	0.02
A1-3.09.04	1	7.19	0.1	1.43	0.06
	2	1.18	100	1.43	0.02
A1-3.11	1	7.90	0.1	15.00	0.08
	2	1.14	100	15.00	0.02
AN-3.08	1	2.83	0.1	2.04	0.06
	2	3.10	100	2.04	0.02
AN-3.08.01	1	2.49	0.1	1.92	0.07
	2	3.65	100	1.92	0.01
AN-3.09	1	4.33	0.1	2.53	0.07
	2	3.46	100	2.53	0.01
AN-3.10	1	0.68	0.1	2.63	0.05
	2	0.64	100	2.63	0.02
AN-3.11	1	7.21	0.1	2.84	0.06
	2	4.72	100	2.84	0.02
AN-3.12	1	2.84	0.1	9.08	0.06
	2	2.81	100	9.08	0.02
AN-3.10.01	1	4.28	0.1	1.92	0.06
	2	2.83	100	1.92	0.02
AN-3.10.02	1	5.06	0.1	2.31	0.06
	2	6.18	100	2.31	0.02
AN-3.11.01	1	7.67	0.1	15.00	0.08
	2	1.05	100	15.00	0.02
A1-4.00	1	4.90	0.1	4.35	0.06
	2	2.69	100	4.35	0.01
A1-4.01	1	3.34	0.1	5.16	0.06
	2	1.42	100	5.16	0.02
A1-4.02	1	2.24	0.1	3.07	0.07
	2	2.20	100	3.07	0.01
A1-4.02.01	1	2.77	0.1	1.71	0.07
	2	4.40	100	1.71	0.01
A1-4.01.01	1	1.71	0.1	1.43	0.07
	2	2.76	100	1.43	0.01
A1-4.03	1	2.86	0.1	2.70	0.07
	2	3.30	100	2.70	0.01
A1-4.04	1	4.54	0.1	2.29	0.06
	2	4.22	100	2.29	0.02
A1-4.04.01	1	4.75	0.1	1.71	0.06
	2	6.12	100	1.71	0.01
A1-4.05	1	14.01	0.1	1.39	0.06
	2	12.69	100	1.39	0.02
A1-4.06	1	7.55	0.1	1.31	0.06
	2	6.87	100	1.31	0.02
A1-4.07	1	5.98	0.1	1.85	0.06
	2	5.04	100	1.85	0.02

Sub-catchment ID	Pervious (1) / Impervious (2)	Total Area [ha]	Percentage Impervious [%]	Catchment Slope [%]	Catchment Mannings 'n' [n value]
A1-5.00	1	13.45	0.1	3.81	0.06
	2	7.91	100	3.81	0.01
A1-6.00	1	4.43	0.1	4.06	0.06
	2	3.23	100	4.06	0.02
A1-7.00	1	2.98	0.1	4.71	0.06
	2	2.04	100	4.71	0.01
A1-8.00	1	3.13	0.1	5.82	0.06
	2	1.38	100	5.82	0.02
A1-8.01	1	0.68	0.1	2.65	0.07
	2	1.11	100	2.65	0.01
A1-8.02	1	0.34	0.1	3.55	0.05
	2	0.01	100	3.55	0.02
A1-8.03	1	3.57	0.1	2.00	0.06
	2	2.50	100	2.00	0.02
A1-8.04	1	2.56	0.1	1.81	0.06
	2	3.13	100	1.81	0.02
A1-9.00	1	7.73	0.1	3.42	0.06
	2	5.36	100	3.42	0.02
A1-10.00	1	10.48	0.1	4.91	0.06
	2	7.97	100	4.91	0.02
A1-10.01	1	4.47	0.1	5.42	0.06
	2	2.68	100	5.42	0.02
A1-10.02	1	5.30	0.1	3.50	0.06
	2	5.44	100	3.50	0.02
A1-10.06	1	48.24	0.1	15.00	0.08
	2	0.01	100	15.00	0.02
A1-10.03	1	4.51	0.1	4.13	0.06
	2	4.44	100	4.13	0.02
A1-14.00	1	54.48	0.1	15.00	0.08
	2	2.17	100	15.00	0.02
A1-10.04	1	13.50	0.1	10.34	0.08
	2	3.27	100	10.34	0.02
A1-10.05	1	36.92	0.1	15.00	0.08
	2	0.14	100	15.00	0.02
A1-10.0501	1	50.09	0.1	15.00	0.08
	2	0.42	100	15.00	0.02
A1-11.0001	1	9.79	0.1	1.94	0.06
	2	11.97	100	1.94	0.02
A1-11.00	1	31.06	0.1	4.41	0.06
	2	24.04	100	4.41	0.02
A1-11.0002	1	61.32	0.1	15.00	0.08
	2	3.05	100	15.00	0.02
A1-11.0003	1	43.72	0.1	15.00	0.08
	2	2.81	100	15.00	0.02
A1-11.0004	1	61.81	0.1	15.00	0.08
	2	0.16	100	15.00	0.02

Sub-catchment ID	Pervious (1) / Impervious (2)	Total Area [ha]	Percentage Impervious [%]	Catchment Slope [%]	Catchment Mannings 'n' [n value]
A1-12.01	1	41.62	0.1	15.00	0.08
	2	0.01	100	15.00	0.02
A1-12.00	1	42.87	0.1	5.17	0.08
	2	0.01	100	5.17	0.02
A1-13.01	1	63.03	0.1	15.00	0.08
	2	0.01	100	15.00	0.02
A1-13.00	1	46.33	0.1	15.00	0.08
	2	0.40	100	15.00	0.02
A2-1.00	1	7.14	0.1	3.35	0.06
	2	3.57	100	3.35	0.01
A2-2.01	1	3.22	0.1	2.14	0.07
	2	4.99	100	2.14	0.01
A2-2.00	1	7.58	0.1	2.55	0.06
	2	5.28	100	2.55	0.01
A2-3.00	1	10.28	0.1	4.00	0.06
	2	5.72	100	4.00	0.02
A2-4.00	1	6.91	0.1	3.41	0.06
	2	0.89	100	3.41	0.02
A2-5.01	1	24.22	0.1	14.82	0.08
	2	0.08	100	14.82	0.02
A2-5.00	1	4.58	0.1	5.22	0.08
	2	0.18	100	5.22	0.02
A2-6.00	1	18.78	0.1	9.77	0.08
	2	0.12	100	9.77	0.02
A2-6.01	1	44.16	0.1	15.00	0.08
	2	0.00	100	15.00	0.02
U-1.00	1	6.01	0.1	5.91	0.06
	2	0.64	100	5.91	0.02
U-2.00	1	4.68	0.1	3.89	0.06
	2	3.42	100	3.89	0.02
U-1.01	1	2.98	0.1	2.32	0.07
	2	4.64	100	2.32	0.01
U-1.02	1	1.85	0.1	2.16	0.07
	2	2.83	100	2.16	0.01
U-1.03	1	3.01	0.1	2.67	0.06
	2	2.80	100	2.67	0.01
U-1.00.01	1	2.22	0.1	1.90	0.07
	2	1.86	100	1.90	0.01
U-3.00	1	4.47	0.1	6.19	0.06
	2	0.83	100	6.19	0.02
U-4.00	1	6.93	0.1	5.00	0.06
	2	3.53	100	5.00	0.02
U-4.01	1	4.89	0.1	4.64	0.06
	2	0.52	100	4.64	0.02
U-3.02	1	1.72	0.1	1.75	0.06
	2	2.66	100	1.75	0.01

Sub-catchment ID	Pervious (1) / Impervious (2)	Total Area [ha]	Percentage Impervious [%]	Catchment Slope [%]	Catchment Mannings 'n' [n value]
U-3.01	1	1.12	0.1	3.52	0.05
	2	0.68	100	3.52	0.02
U-3.05	1	0.82	0.1	2.06	0.05
	2	0.60	100	2.06	0.02
U-3.04	1	2.41	0.1	2.23	0.06
	2	3.54	100	2.23	0.01
U-3.03	1	1.94	0.1	1.76	0.06
	2	2.99	100	1.76	0.01
U-3.08	1	1.62	0.1	2.05	0.06
	2	2.40	100	2.05	0.01
U-3.07	1	0.53	0.1	2.48	0.06
	2	0.59	100	2.48	0.01
U-3.06	1	2.75	0.1	2.80	0.06
	2	2.52	100	2.80	0.01
U-5.00	1	2.95	0.1	11.31	0.08
	2	1.58	100	11.31	0.02
U-5.01	1	2.18	0.1	7.02	0.08
	2	0.01	100	7.02	0.02
U-6.00	1	5.29	0.1	6.40	0.08
	2	3.93	100	6.40	0.02
U-7.01	1	18.95	0.1	4.35	0.08
	2	1.81	100	4.35	0.02
U-7.00	1	6.76	0.1	5.97	0.08
	2	8.41	100	5.97	0.02
U-7.02	1	18.43	0.1	6.87	0.08
	2	0.07	100	6.87	0.02
U-8.00	1	13.71	0.1	3.82	0.08
	2	5.07	100	3.82	0.02
U-8.00.01	1	32.67	0.1	15.00	0.08
	2	0.01	100	15.00	0.02
U-13.00	1	40.61	0.1	15.00	0.07
	2	0.01	100	15.00	0.02
U-8.01	1	7.77	0.1	5.12	0.08
	2	1.83	100	5.12	0.02
U-8.02.01	1	57.37	0.1	15.00	0.08
	2	0.01	100	15.00	0.02
U-8.02	1	116.59	0.1	15.00	0.08
	2	1.29	100	15.00	0.02
U-9.00	1	2.61	0.1	3.61	0.08
	2	1.29	100	3.61	0.02
U-10.00	1	5.59	0.1	2.60	0.08
	2	2.56	100	2.60	0.02
U-11.00	1	4.67	0.1	3.93	0.08
	2	2.32	100	3.93	0.02
U-12.00	1	33.79	0.1	15.00	0.07
	2	2.18	100	15.00	0.01

Sub-catchment ID	Pervious (1) / Impervious (2)	Total Area [ha]	Percentage Impervious [%]	Catchment Slope [%]	Catchment Mannings 'n' [n value]
U-12.01	1	35.70	0.1	15.00	0.07
	2	1.38	100	15.00	0.01
U-9.01	1	5.10	0.1	2.50	0.08
	2	3.00	100	2.50	0.02
U-9.03	1	6.13	0.1	2.96	0.08
	2	2.64	100	2.96	0.02
U-9.02	1	1.13	0.1	2.38	0.08
	2	0.74	100	2.38	0.02
U-9.04	1	43.05	0.1	15.00	0.07
	2	0.22	100	15.00	0.02
D1-1.01	1	3.42	0.1	1.86	0.06
	2	2.63	100	1.86	0.01
D1-1.00	1	6.29	0.1	5.69	0.08
	2	3.83	100	5.69	0.02
D1-2.01	1	1.38	0.1	2.43	0.06
	2	1.79	100	2.43	0.01
D1-2.02	1	3.06	0.1	3.27	0.06
	2	4.87	100	3.27	0.01
D1-2.00	1	2.98	0.1	4.90	0.08
	2	2.51	100	4.90	0.02
D1-2.00.01	1	1.12	0.1	10.34	0.08
	2	0.43	100	10.34	0.02
D1-3.00	1	1.82	0.1	7.06	0.08
	2	0.50	100	7.06	0.02
D1-2.00.02	1	1.70	0.1	6.02	0.08
	2	1.78	100	6.02	0.02
D1-4.00	1	2.88	0.1	5.11	0.08
	2	2.90	100	5.11	0.02
D1-5.00	1	3.57	0.1	3.38	0.08
	2	6.76	100	3.38	0.02
D1-5.01	1	2.47	0.1	3.62	0.08
	2	0.58	100	3.62	0.02
D1-2.00.04	1	1.89	0.1	1.79	0.08
	2	0.23	100	1.79	0.02
D1-6.00	1	5.19	0.1	2.49	0.08
	2	2.91	100	2.49	0.02
D1-6.01	1	4.93	0.1	3.24	0.08
	2	2.40	90	3.24	0.02
D1-7.00	1	3.82	0.1	2.39	0.08
	2	2.26	100	2.39	0.02
D1-5.02	1	1.73	0.1	2.99	0.08
	2	0.58	100	2.99	0.02
D1-5.03	1	2.33	0.1	2.80	0.08
	2	1.55	100	2.80	0.02
D1-5.04	1	2.34	0.1	2.81	0.08
	2	1.17	100	2.81	0.02

Sub-catchment ID	Pervious (1) / Impervious (2)	Total Area [ha]	Percentage Impervious [%]	Catchment Slope [%]	Catchment Mannings 'n' [n value]
D1-2.00.03	1	3.39	0.1	7.42	0.05
	2	2.26	100	7.42	0.02
D2-2.00	1	2.80	0.1	4.11	0.06
	2	2.12	100	4.11	0.01
D2-1.00	1	2.27	0.1	4.27	0.06
	2	2.28	100	4.27	0.01
D3-1.00	1	1.16	0.1	8.13	0.08
	2	0.59	100	8.13	0.01
D3-1.01	1	1.23	0.1	3.05	0.06
	2	1.59	100	3.05	0.01
D3-2.00	1	2.34	0.1	4.99	0.08
	2	1.36	100	4.99	0.01
D3-2.01	1	0.47	0.1	3.57	0.06
	2	0.65	100	3.57	0.01
D3-3.01	1	1.42	0.1	3.75	0.06
	2	2.24	100	3.75	0.01
D3-3.00	1	2.89	0.1	5.75	0.08
	2	1.98	100	5.75	0.01
D3-4.00	1	1.95	0.1	3.79	0.05
	2	1.80	100	3.79	0.02
D3-5.00	1	11.28	0.1	4.81	0.07
	2	1.69	100	4.81	0.01
D3-6.00	1	7.69	0.1	4.30	0.08
	2	0.80	100	4.30	0.02
D3-6.01	1	3.74	0.1	4.04	0.08
	2	0.76	100	4.04	0.02
D3-5.01	1	2.69	0.1	11.45	0.07
	2	1.20	100	11.45	0.01
D3-7.00	1	4.52	0.1	7.25	0.07
	2	2.10	100	7.25	0.01
D4-1.02	1	1.25	0.1	3.18	0.06
	2	1.70	100	3.18	0.01
D4-1.00.01	1	0.47	0.1	2.31	0.06
	2	0.58	100	2.31	0.01
D4-1.01.01	1	0.39	0.1	4.18	0.06
	2	0.43	100	4.18	0.01
D4-1.01	1	1.00	0.1	13.35	0.06
	2	0.01	100	13.35	0.01
D4-1.00	1	1.26	0.1	9.70	0.08
	2	0.39	100	9.70	0.01
D4-2.00	1	2.12	0.1	6.15	0.08
	2	1.24	100	6.15	0.01
D4-1.04	1	3.75	0.1	7.63	0.07
	2	2.54	100	7.63	0.02
D4-1.06	1	3.80	0.1	15.00	0.07
	2	0.89	100	15.00	0.02

Sub-catchment ID	Pervious (1) / Impervious (2)	Total Area [ha]	Percentage Impervious [%]	Catchment Slope [%]	Catchment Mannings 'n' [n value]
D4-1.05	1	6.62	0.1	15.00	0.07
	2	0.56	100	15.00	0.02
D4-3.00	1	0.99	0.1	6.93	0.05
	2	0.99	100	6.93	0.02
D4-1.03	1	3.00	0.1	9.82	0.05
	2	3.00	100	9.82	0.02
D4-3.01	1	4.64	0.1	8.22	0.07
	2	1.01	100	8.22	0.01
D4-4.00	1	4.34	0.1	9.03	0.07
	2	0.93	100	9.03	0.01
D5-1.00	1	1.12	0.1	8.54	0.08
	2	0.70	100	8.54	0.01
D5-1.01	1	1.47	0.1	8.05	0.06
	2	2.14	100	8.05	0.01
D5-2.00	1	1.95	0.1	5.32	0.08
	2	2.01	100	5.32	0.01
D6-1.00.01	1	1.03	0.1	5.20	0.06
	2	1.43	100	5.20	0.01
D6-1.01.02	1	2.56	0.1	9.43	0.06
	2	2.09	100	9.43	0.01
D6-1.01.01	1	1.17	0.1	6.60	0.06
	2	1.35	100	6.60	0.01
D6-1.02	1	0.99	0.1	6.98	0.06
	2	1.31	100	6.98	0.01
D6-2.00	1	2.01	0.1	8.16	0.08
	2	0.54	100	8.16	0.01
D6-1.00	1	1.71	0.1	9.51	0.08
	2	0.30	100	9.51	0.01
D6-1.01	1	1.58	0.1	6.39	0.08
	2	0.65	100	6.39	0.01
D6-1.01.03	1	0.84	0.1	6.15	0.08
	2	0.64	100	6.15	0.01
D6-1.03.01	1	1.07	0.1	6.98	0.06
	2	1.36	100	6.98	0.01
D6-1.03	1	1.53	0.1	3.87	0.06
	2	2.24	100	3.87	0.01
D7-1.00	1	2.80	0.1	6.11	0.08
	2	1.29	100	6.11	0.02
D7-2.00	1	3.31	0.1	3.97	0.08
	2	0.47	100	3.97	0.02
D7-2.00.01	1	1.77	0.1	6.35	0.06
	2	2.71	100	6.35	0.02
D7-3.01	1	2.47	0.1	3.61	0.06
	2	3.31	100	3.61	0.02
D7-4.00	1	1.16	0.1	6.33	0.08
	2	0.73	100	6.33	0.02

Sub-catchment ID	Pervious (1) / Impervious (2)	Total Area [ha]	Percentage Impervious [%]	Catchment Slope [%]	Catchment Mannings 'n' [n value]
D7-4.01	1	0.97	0.1	11.28	0.06
	2	0.96	100	11.28	0.02
D7-3.00	1	3.60	0.1	7.99	0.08
	2	1.59	100	7.99	0.02
D7-4.02	1	1.06	0.1	8.48	0.05
	2	1.04	100	8.48	0.02
D7-5.00	1	3.41	0.1	6.13	0.07
	2	1.92	100	6.13	0.02
D7-6.02	1	4.74	0.1	9.80	0.07
	2	2.75	100	9.80	0.02
D7-6.01	1	8.89	0.1	15.00	0.07
	2	0.55	100	15.00	0.02
D7-6.00	1	2.35	0.1	7.35	0.07
	2	0.85	100	7.35	0.02
D7-6.00.01	1	6.24	0.1	15.00	0.07
	2	0.00	100	15.00	0.02
D7-7.01	1	15.32	0.1	15.00	0.07
	2	0.01	100	15.00	0.02
D7-7.00	1	8.38	0.1	15.00	0.07
	2	0.00	100	15.00	0.02
D8-1.00.01	1	2.59	0.1	3.11	0.06
	2	2.16	100	3.11	0.01
D8-1.00.03	1	3.28	0.1	4.21	0.06
	2	3.47	100	4.21	0.01
D8-1.00.02	1	7.46	0.1	3.37	0.08
	2	3.38	100	3.37	0.01
D8-1.01	1	4.24	0.1	5.48	0.08
	2	3.42	100	5.48	0.01
D8-3.00	1	5.21	0.1	4.58	0.08
	2	4.52	100	4.58	0.01
D8-2.01	1	4.75	0.1	3.56	0.06
	2	5.14	100	3.56	0.01
D8-2.00	1	3.79	0.1	4.87	0.08
	2	1.60	100	4.87	0.01
D8-4.00	1	0.60	0.1	8.25	0.07
	2	0.60	100	8.25	0.02
D8-1.02	1	1.76	0.1	5.20	0.07
	2	1.63	100	5.20	0.02
D8-6.00	1	2.95	0.1	14.49	0.07
	2	0.19	100	14.49	0.02
D8-5.00	1	6.44	0.1	15.00	0.07
	2	0.03	100	15.00	0.02
D9-1.02	1	3.56	0.1	15.00	0.07
	2	0.12	100	15.00	0.02
D9-1.01	1	1.48	0.1	8.78	0.07
	2	1.48	100	8.78	0.02

Sub-catchment ID	Pervious (1) / Impervious (2)	Total Area [ha]	Percentage Impervious [%]	Catchment Slope [%]	Catchment Mannings 'n' [n value]
D9-1.00.01	1	2.94	0.1	3.86	0.06
	2	3.81	100	3.86	0.01
D9-1.00	1	6.23	0.1	6.08	0.07
	2	1.34	100	6.08	0.02
D9-1.00.03	1	8.37	0.1	4.38	0.07
	2	0.53	100	4.38	0.02
D9-2.00	1	21.51	0.1	15.00	0.07
	2	0.09	100	15.00	0.02
D9-1.00.02	1	0.57	0.1	3.68	0.07
	2	0.66	100	3.68	0.02
A1-1.01	1	5.36	0.1	2.24	0.07
	2	6.22	100	2.24	0.01
A1-1.02.05	1	4.76	0.1	1.80	0.07
	2	4.34	100	1.80	0.01
A1-1.03	1	4.40	0.1	1.46	0.07
	2	4.55	100	1.46	0.01
A1-1.02.02	1	1.47	0.1	1.47	0.07
	2	2.36	100	1.47	0.01
A1-1.02.04	1	1.88	0.1	1.60	0.07
	2	2.87	100	1.60	0.01
A1-1.02.03	1	0.48	0.1	1.81	0.06
	2	0.19	100	1.81	0.01
A1-1.02.01	1	1.00	0.1	1.87	0.06
	2	1.51	100	1.87	0.01

Appendix B – Culvert and Bridge Details

(Refer to Volume II also)

Culvert Details

Branch	Chainage	ID	Upstream IL (m AHD)	Downstream IL (m AHD)	Length (m)	Manning's n	Number	Geometry	Diameter (m)	Width (m)	Height (m)
RCP1_ArmyDam	8.6	RCP_AD	11.633	11.446	17.2	0.015	9	Circular	1.83		
PalmetumDrain	10020	RCP1_PD1	8.238	7.668	38.083	0.015	2	Circular	1.5		
PalmetumDrain	10060	RCB1_PD1	7.671	7.695	3.565	0.015	1	Rectangular		0.9	1.2
RCB1_HoneySuckleDr	8.5	RCB1_HSD	5.873	5.747	16.8	0.015	1	Irregular, Level-Width Table	Channel Geometry Applied		
RCP2_YolandaDr	10	RCP2_YD	6.434	6.411	19.491	0.015	5	Circular	1.35		
RCB1_MarabouDrain	2	RCB1_MD	5.921	5.912	3.392	0.015	2	Rectangular		2.4	0.8
RCB1_UnivRd	18.5	RCB1_UR	11.86	11.67	37	0.015	6	Rectangular		1.2	0.45
RCB1_GlendaleDr	8	RCB1_GD	4.291	4.243	16	0.015	2	Rectangular		2.4	1.74
RCB1_McArthurDr	7.5	RCB1_MAD	6.1	5.5	15	0.015	6	Rectangular		3	3.2
RCB2_UnivRd	30	RCB2_UR	12.15	11.6	59.78	0.015	6	Rectangular		1.2	0.75
RCB3_UnivRd	19	RCB3_UR	10.2	9.8	37.82	0.015	1	Rectangular		3	1.8
RCP1_UnivRd	18	RCP1_UR	10.6	10	35.38	0.015	4	Circular	1.2		
RCB4_UnivRd	18.5	RCB4_UR	13.247	13.03	37	0.015	5	Rectangular		1.8	0.9
RCB6_UnivRd	26.5	RCB6_UR	11.835	11.078	54.413	0.015	2	Rectangular		2.1	2.1
RCB6_UnivRd	26.5	RCB6b_UR	13.436	12.953	44.68	0.015	1	Rectangular		2.4	2.4
RCB6_UnivRd	26.5	RCB6a_UR	11.9	11.2	54.9	0.015	1	Rectangular		2.4	2.1
RCB7_UnivRd	7.5	RCB7_UR	15.779	15.679	15	0.015	1	Rectangular		0.9	0.45
RCB8_UnivRd	16.5	RCB8_UR	11.847	11.228	33	0.015	2	Rectangular		0.75	0.3
RCB1_DiscoveryDr	17	RCB1_DD	12.4	12.3	34	0.015	7	Rectangular		3	2.6
RCB2_DiscoveryDr	10.5	RCB2_DD	16.973	16.903	20.945	0.015	3	Rectangular		3.7	3.07
RCP1_YolandaDr	10.5	RCP1_YD	8.059	8.059	19.658	0.015	5	Circular	1.67		
RCB1_AnnandaleDr	8	RCB1_AD	4.161	4.157	16	0.015	3	Rectangular		3	3
CrossDrain1_AngusSmithDr	8	RCP1_CD1_ASD	10.981	10.787	16	0.015	1	Circular	1.05		
CrossDrain1_AngusSmithDr	37	RCP2_CD1_ASD	10.736	10.765	26	0.013	1	Circular	1.05		
DougDrain6_ASDr	10011	RCP1_DD6_ASD	12.006	12	23.153	0.015	3	Circular	1.05		

Culvert Details

Branch	Chainage	ID	Upstream IL (m AHD)	Downstream IL (m AHD)	Length (m)	Manning's n	Number	Geometry	Diameter (m)	Width (m)	Height (m)
DougDrain6_ASDr	10045	RCP2_DD6_ASD	11.838	11.815	19.749	0.015	3	Circular	1.05		
CrossDrain2_RingRd	26	RCP1_CD2_RR	18	17.7	48.97	0.015	3	Circular	0.675		
CrossDrain2_RingRd	62	RCP2_CD2_RR	17.6	17.44	18.3	0.015	3	Circular	0.75		
RCP5_AngusSmithDr	12.5	RCP5_ASD	14.955	14.863	25	0.015	2	Circular	0.9		
DougDrain4a_ASDr	10038	RCB1_DD4a_ASD	12.381	12.01	76	0.015	1	Rectangular		2.4	2.4
DougDrain4a_ASDr	10112	RCB2_DD4a_ASD	11.482	11.275	25	0.015	1	Rectangular		2.4	2.4
CrossDrain3_RingRd	11	RCP1_CD3_RR	13.949	13.749	21.76	0.015	2	Circular	0.9		
CrossDrain4_RingRd	7	RCP1_CD4_RR	12.75	12.7	13	0.015	1	Circular	1.8		
CrossDrain4_RingRd	36.5	RCP2_CD4_RR	11.295	11.2	20.74	0.015	3	Circular	2.1		
RCB4_RingRd	23	RCB4_RR	23.332	23	46	0.015	3	Rectangular		2.4	2.1
RCP4_RingRoad	20	RCP4_RR	23.83	23.68	27.45	0.015	1	Circular	0.9		
RCP5_RingRoad	33	RCP5_RR	25.04	24.8	66	0.015	2	Circular	1.05		
CrossDrain1_RingRd	64	RCB1_CD1_RR	22.71	22.35	59.7	0.015	1	Rectangular		1.8	1.8
CrossDrain1_RingRd	11	RCB2_CD1_RR	27.272	27.061	22	0.015	2	Circular	1.2		
RCP12_AngusSmithDr	11	RCP12_ASD	25.552	25.499	22	0.015	2	Circular	0.9		
RCP13_AngusSmithDr	5.5	RCP13_ASD	23.334	23.056	11	0.015	3	Circular	1.5		
RCB2_FreshWaterDr	11.5	RCB2_FWD	25.75	25.65	23	0.015	3	Rectangular		1.2	0.45
RCB7_RingRd	5.5	RCB7_RR	18.98	18.9	11	0.015	2	Rectangular		1.8	0.75
RCB8_RingRd	5	RCB8_RR	18.52	18.47	10	0.015	2	Rectangular		1.5	0.75
RCB1_FreshWaterDr	13	RCB1_FWD	16.829	16.691	25.43	0.015	2	Rectangular		1.2	0.6
RCB1_SheerwaterPrd	15	RCB1_SWP	15.442	15.354	16.69	0.015	2	Rectangular		1.2	0.6
RCB4_FreshWaterDr	11	RCB4_FWD	14.5	14.4	22	0.015	2	Rectangular		1.2	2.1
RCB2_RiversideBvd	13.5	RCB2_RSB	11.555	11.046	27	0.015	1	Rectangular		1.5	0.6
DougDrain1_FWDr	11	RCB1_DD1_FWD	14.7	14.5	22	0.015	5	Rectangular		2.7	0.9
RCP3_DiscoveryDr	4	RCP3_DD	18.577	18.417	7.349	0.015	3	Circular	1.2		
RCB1_AngusSmithDr	18	RCB1_ASD	25.707	25.518	36	0.015	3	Rectangular		3.6	1.8
RCP7_RingRd	20	RCP7_RR	13.6	13.3	46.36	0.015	4	Circular	1.65		
DougDrain5_ASDr	10008	RCP1_DD5_ASD	12.66	12.58	16.57	0.015	4	Circular	1.65		
DougDrain5_ASDr	10040	RCP2_DD5_ASD	12.53	12.24	39.04	0.015	4	Circular	1.8		
CrossDrain3_RingRd	41.5	RCP2_CD3_RR	12.2	11.97	20.74	0.015	1	Circular	1.95		
DougDrain5_ASDr	10675	RCB1a_DD5_ASD	6.461	6.379	18.645	0.015	1	Irregular, Level-Width Table	Channel Geometry Applied		
RCP375_UnivRd	7.5	RCP375_UR	11.92	11.85	14.64	0.015	1	Circular	0.375		

Culvert Details

Branch	Chainage	ID	Upstream IL (m AHD)	Downstream IL (m AHD)	Length (m)	Manning's n	Number	Geometry	Diameter (m)	Width (m)	Height (m)
RCP375_UnivRd	27	RCP375a_UR	11.79	11.53	14.64	0.015	1	Circular	0.375		
RCB1_AnnanDrain	7.5	RCB_AD	0.868	0.825	15	0.015	2	Rectangular		2.7	1.2
RCP1_McArthurDr	14.5	RCP1_McAD	7.03	6.93	29	0.015	2	Circular	1.5		

Bridge Details

Name	Chainage (m)	Bridge ID	Type	Soffit (m AHD)	Deck (m AHD)	Width (m)
Nathan St	17	Nathan Street	FHWA WSPRO	11.5	13.5	34
Ring Road	20	Ring Road	FHWA WSPRO	23.164	25.9	14.2
ArmyDamBridge	5	Bridge1_UR	FHWA WSPRO	12.8	13.437	10
ArmyDamBridge	25	Bridge2_UR	FHWA WSPRO	12.8	13.437	10
UniversityCreek	5	Bridge1	FHWA WSPRO	14.05	14.7	9.97
UniversityCreek	27	Bridge2	FHWA WSPRO	14.05	14.7	9.97

Weir Details

Name	Chainage	Location	Type	Width	Height	Weir Coeff.	Weir Exp.
AplinsWeir	43	The Ross River	Weir Formula 1	144	6.39	2.18	1.7
GleesonsWeir	5	The Ross River	road Crested We	River Geometry applied			
BlacksWeir	5	The Ross River	Weir Formula 1	200	13.805	2	1.5

Appendix C – Underground Drainage Details

(Refer to Volume II also)

Link Details

Link ID	Type No	Conduit Type	Upstream Level (m AHD)	Downstream Level (m AHD)	Length (m)	Slope (m)	Diameter (m)	Width (m)	Height (m)
201309054	1	RCP	16.720	16.640	10.709	0.747	1.050		
201309051	1	RCP	17.390	17.290	25.397	0.394	0.900		
201309053	1	RCP	17.000	16.820	37.090	0.485	0.900		
201309052	1	RCP	17.260	17.090	38.731	0.439	0.900		
106273	1	RCP	3.340	1.130	80.100	2.759	0.900		
106893	1	RCP	4.140	4.100	10.821	0.370	0.900		
106894	1	RCP	4.100	4.060	12.113	0.330	0.900		
250728	1	RCP	0.980	0.823	6.337	2.478	0.900		
330447	1	RCP	16.860	16.820	90.045	0.044	0.900		
330452	1	RCP	16.820	16.750	37.075	0.189	0.900		
332058	1	RCP	12.997	12.946	20.078	0.254	1.050		
332067	1	RCP	12.820	12.700	22.188	0.541	0.900		
33754	1	RCP	8.020	7.015	70.144	1.433	1.200		
33778	1	RCP	7.790	7.680	10.000	1.100	0.900		
33782	1	RCP	7.870	7.790	16.808	0.476	0.900		
33853	1	RCP	7.210	7.120	10.131	0.888	0.900		
33925	1	RCP	6.240	6.200	13.046	0.307	0.900		
33927	1	RCP	6.290	6.260	14.421	0.208	0.900		
36568	1	RCP	4.450	4.338	49.887	0.225	0.900		
37112	1	RCP	7.260	6.930	71.800	0.446	0.900		
37114	1	RCP	7.790	7.350	45.200	0.973	0.900		
37122	1	RCP	7.870	7.810	48.580	0.124	0.900		
37124	1	RCP	7.980	7.880	64.445	0.155	0.900		
37126	1	RCP	8.130	8.010	21.205	0.566	0.900		
379810	1	RCP	12.300	11.700	15.409	3.894	0.900		
379823	1	RCP	12.350	11.700	17.959	3.619	1.950		
39737	1	RCP	5.200	5.100	2.500	4.001	1.050		
39739	1	RCP	5.310	5.300	1.000	1.000	0.900		
404654	1	RCP	16.910	16.427	49.017	0.985	1.050		
404656	1	RCP	16.427	16.150	19.554	1.417	1.050		
404660	1	RCP	16.150	15.890	9.736	2.671	1.200		
404680	1	RCP	15.850	15.520	65.162	0.506	1.200		
404690	1	RCP	15.500	15.330	33.130	0.513	1.350		
404712	1	RCP	15.330	15.160	12.731	1.335	1.500		
43723	1	RCP	4.450	4.408	50.694	0.099	1.050		
43731	1	RCP	4.700	4.600	11.122	0.899	0.900		
46188	1	RCP	8.920	8.860	23.902	0.251	1.500		
46190	1	RCP	8.810	8.760	45.399	0.110	1.500		
46200	1	RCP	8.717	8.680	15.400	0.195	1.500		
46202	1	RCP	8.597	8.559	12.404	0.322	1.500		
47273	1	RCP	6.300	6.200	5.999	1.667	0.900		
47275	1	RCP	6.500	6.300	34.138	0.586	0.900		
47281	1	RCP	6.800	6.500	27.856	1.077	0.900		
47287	1	RCP	7.040	6.800	18.032	1.331	0.900		
47911	1	RCP	3.580	3.320	18.871	1.378	1.050		
47913	1	RCP	3.640	3.610	26.775	0.112	1.050		
47925	1	RCP	3.750	3.720	12.549	0.239	1.050		
47929	1	RCP	3.780	3.750	24.458	0.123	1.050		
47931	1	RCP	3.870	3.830	32.959	0.121	1.050		
47937	1	RCP	4.250	4.050	31.329	0.638	0.900		
48022	1	RCP	6.820	6.610	78.637	0.267	0.900		
48024	1	RCP	7.050	6.880	50.888	0.334	0.900		
48030	1	RCP	7.250	7.080	14.504	1.172	0.900		
48076	1	RCP	4.820	4.810	5.917	0.169	1.050		
48381	1	RCP	10.800	10.730	13.091	0.535	0.900		
48383	1	RCP	10.890	10.820	37.409	0.187	0.900		
48444	1	RCP	11.910	11.890	32.080	0.062	1.200		
48446	1	RCP	12.000	11.930	47.645	0.147	1.200		
48448	1	RCP	12.360	12.050	72.952	0.425	1.200		
48450	1	RCP	12.860	12.530	40.350	0.818	1.050		
48452	1	RCP	12.950	12.860	18.435	0.488	0.900		
48929	1	RCP	5.690	5.650	7.602	0.526	0.900		
48931	1	RCP	5.720	5.710	0.999	1.001	0.900		

Node Details

MUID	Node Type	Invert Level (m AHD)	Ground Level (m AHD)	Eqv.Diameter (m)
0043A2U	Manhole/inlet	7.790	9.530	0.900
0043A3U	Manhole/inlet	7.870	9.447	0.900
0110A4U	Manhole/inlet	8.610	10.380	1.650
0110A6U	Manhole/inlet	9.000	10.550	1.050
0110A8U	Manhole/inlet	9.230	10.720	1.050
0193A2U	Manhole/inlet	8.020	9.285	1.200
0193B2U	Manhole/inlet	6.500	9.485	0.900
0193B3U	Manhole/inlet	6.804	9.270	0.900
0193B4U	Manhole/inlet	7.040	9.368	0.900
0193BG1U	Manhole/inlet	6.300	7.300	0.900
0323A3U	Manhole/inlet	6.290	8.356	0.900
0336A2U	Manhole/inlet	6.820	8.250	0.900
0336A3U	Manhole/inlet	7.050	8.690	0.900
0336A4U	Manhole/inlet	7.250	8.927	0.900
0339B10U	Manhole/inlet	6.280	8.290	0.900
0339B11U	Manhole/inlet	6.390	8.375	0.900
0339B4U	Manhole/inlet	5.720	7.699	0.900
0339B5U	Manhole/inlet	5.780	8.000	0.900
0339B9U	Manhole/inlet	6.210	8.529	0.900
0351A2U	Manhole/inlet	4.450	7.262	0.900
0364A02U	Manhole/inlet	4.100	6.549	0.900
0371A2U	Manhole/inlet	7.250	10.319	0.900
0371A3U	Manhole/inlet	7.790	10.219	0.900
0371A4U	Manhole/inlet	7.870	10.019	0.900
0371A5U	Manhole/inlet	7.980	10.179	0.900
0371A6U	Manhole/inlet	8.130	10.502	0.900
0374A2U	Manhole/inlet	5.200	7.410	1.050
0401A2U	Manhole/inlet	4.450	6.780	1.050
0401A3U	Manhole/inlet	4.700	6.778	0.900
0403A97U	Manhole/inlet	6.652	8.834	0.900
0404A1U	Manhole/inlet	5.060	7.010	1.050
0404AA1U	Manhole/inlet	5.070	7.140	0.900
0405A2U	Manhole/inlet	8.590	11.500	1.500
0405A3U	Manhole/inlet	8.710	11.730	1.500
0405A4U	Manhole/inlet	8.813	12.380	1.500
0408A3U	Manhole/inlet	3.580	6.420	1.050
0408A4U	Manhole/inlet	3.640	6.530	1.050
0408A5U	Manhole/inlet	3.750	6.610	1.050
0408A6U	Manhole/inlet	3.780	6.780	1.050
0408A7U	Manhole/inlet	3.870	6.720	1.050
0408A8U	Manhole/inlet	4.250	6.959	0.900
0436A102U	Manhole/inlet	10.800	12.660	0.900
0436A103U	Manhole/inlet	10.890	13.238	0.900
0436B4U	Manhole/inlet	8.240	10.900	0.900
0436B7U	Manhole/inlet	9.000	12.144	0.900
0437A102U	Manhole/inlet	11.890	14.755	1.200

Node Details

MUID	Node Type	Invert Level (m AHD)	Ground Level (m AHD)	Eqv.Diameter (m)
0437A103U	Manhole/inlet	12.000	14.840	1.200
0437AA2U	Manhole/inlet	12.950	15.775	0.900
0489A3U	Manhole/inlet	3.390	6.130	1.200
0489A4U	Manhole/inlet	3.769	6.190	0.900
0489A5U	Manhole/inlet	3.810	6.340	0.900
0491A2U	Manhole/inlet	3.430	6.118	0.900
0496A3U	Manhole/inlet	1.101	3.030	0.900
0496A4U	Manhole/inlet	3.342	5.682	0.900
0501A2U	Manhole/inlet	9.634	12.308	2.120
0501A3U	Manhole/inlet	10.140	12.810	1.350
0506A3U	Manhole/inlet	10.637	13.375	0.900
0507A3U	Manhole/inlet	6.050	8.070	1.650
0507C3U	Manhole/inlet	6.710	9.320	1.885
0507CB1U	Manhole/inlet	6.864	8.692	0.900
0507CB2U	Manhole/inlet	6.900	8.700	0.900
0507CB3U	Manhole/inlet	6.936	8.739	0.900
0755R4U	Manhole/inlet	15.500	18.213	1.350
0755R5U	Manhole/inlet	15.850	18.406	1.200
0755R6U	Manhole/inlet	16.146	18.421	1.200
0755R7U	Manhole/inlet	16.427	18.487	1.050
Hospital_MH1	Manhole/inlet	17.386	19.371	0.900
Hospital_MH3	Manhole/inlet	17.000	19.420	0.900
Hospital_MH4	Manhole/inlet	16.715	19.157	1.050
Hospital_MH2	Manhole/inlet	17.260	19.240	0.900
0755R3U	Manhole/inlet	15.330	17.960	1.500
0755H2U	Manhole/inlet	12.350	14.510	1.950
0755G2U	Manhole/inlet	12.300	14.425	0.900
0507CA1U	Manhole/inlet	6.760	8.938	1.050
0507C4U	Manhole/inlet	6.790	8.500	1.050
0507C2U	Manhole/inlet	6.690	8.990	1.885
0507B3U	Manhole/inlet	6.370	7.993	0.900
0507B2U	Manhole/inlet	6.325	8.067	0.900
0507A4U	Manhole/inlet	6.090	7.500	1.050
0507A2U	Manhole/inlet	6.000	7.810	1.650
0506B2U	Manhole/inlet	10.652	13.107	0.900
0506A2U	Manhole/inlet	10.501	12.900	0.900
0500AA1U	Manhole/inlet	4.290	6.570	0.900
0496A2U	Manhole/inlet	0.829	2.485	0.900
0491002	Manhole/inlet	2.570	5.985	0.900
0489A2U	Manhole/inlet	3.190	6.190	1.200
0437AA1U	Manhole/inlet	12.824	14.800	0.900
0437A106U	Manhole/inlet	12.997	15.375	1.050
0437A105U	Manhole/inlet	12.860	15.090	1.050
0437A104U	Manhole/inlet	12.360	15.060	1.200
0436B6U	Manhole/inlet	8.840	11.180	0.900
0436B5U	Manhole/inlet	8.670	11.030	0.900

Node Details

MUID	Node Type	Invert Level (m AHD)	Ground Level (m AHD)	Eqv.Diameter (m)
0436B3U	Manhole/inlet	8.150	10.850	0.900
0436B2U	Manhole/inlet	7.760	10.850	1.050
0415C3U	Manhole/inlet	16.860	18.458	0.900
0415C2U	Manhole/inlet	16.820	18.642	0.900
0408A2U	Manhole/inlet	3.240	6.420	1.050
0408002	Manhole/inlet	3.230	6.225	1.050
0404AAB1U	Manhole/inlet	5.300	7.029	0.900
0403AD1U	Manhole/inlet	7.100	8.832	0.900
0374AA1U	Manhole/inlet	5.310	7.410	0.900
0339B8U	Manhole/inlet	6.140	7.840	0.900
0339B7U	Manhole/inlet	6.080	7.810	0.900
0339B6U	Manhole/inlet	5.870	7.640	0.900
0339B3U	Manhole/inlet	5.690	7.490	0.900
0339B2U	Manhole/inlet	5.640	7.490	0.900
0324AA1U	Manhole/inlet	4.690	6.733	1.050
0323A2U	Manhole/inlet	6.240	8.290	0.900
0322C2U	Manhole/inlet	4.820	7.450	1.050
0110AG1U	Manhole/inlet	10.290	11.602	1.050
0047A2U	Manhole/inlet	7.210	9.189	0.900
00339002	Manhole/inlet	5.530	7.385	0.900
Hospital_Outlet	Outlet	16.637	17.790	1.050
0755R1D	Outlet	15.160	17.033	1.500
0755H1D	Outlet	11.700	13.750	1.950
0755G1D	Outlet	11.700	12.700	0.900
0507C1D	Outlet	6.630	7.950	1.885
0507B1D	Outlet	6.300	7.300	0.900
0507A1D	Outlet	5.970	7.120	1.650
0506B1D	Outlet	10.478	11.438	0.900
0506A1D	Outlet	9.992	10.952	0.900
0501A4U	Manhole/inlet	11.018	13.000	1.350
0501A1D	Outlet	9.582	11.000	2.120
0500AA1D	Outlet	4.234	5.230	0.900
0496A1D	Outlet	0.823	1.850	0.900
0491A1D	Outlet	2.300	3.500	0.900
0489A1D	Outlet	2.720	3.940	1.200
0437A101D	Outlet	11.890	13.190	1.200
0436B1D	Outlet	7.760	8.910	1.050
0436A101D	Outlet	10.730	11.700	0.900
0415C1D	Outlet	16.750	17.700	0.900
0408A1D	Outlet	3.200	4.350	1.050
0405A5U	Manhole/inlet	8.916	10.448	1.500
0405A1D	Outlet	8.559	10.800	1.500
0404A1D	Outlet	5.030	6.630	1.050
0403A96D	Outlet	6.640	7.650	0.900
0401A1D	Outlet	4.400	5.550	1.050
0374A1D	Outlet	5.100	6.200	1.050

Node Details

MUID	Node Type	Invert Level (m AHD)	Ground Level (m AHD)	Eqv.Diameter (m)
0371A1D	Outlet	6.930	7.950	0.900
0364AC1D	Outlet	4.060	5.110	0.900
0364A1D	Manhole/inlet	4.140	5.140	0.900
0351A1D	Outlet	4.340	5.340	0.900
0339B1D	Outlet	5.510	6.510	0.900
0336A1D	Outlet	6.610	7.610	0.900
0324A1D	Outlet	4.290	5.440	1.050
0323A1D	Outlet	6.200	7.200	0.900
0322C1D	Outlet	4.810	5.960	1.050
0193B1D	Outlet	6.200	7.200	0.900
0193A1D	Outlet	7.015	8.320	1.200
0110AG2U	Manhole/inlet	10.317	11.465	1.050
0110	Outlet	8.280	9.430	1.650
0047A1D	Outlet	7.120	8.120	0.900
0043A1D	Outlet	7.680	8.701	0.900
Node_9	Manhole/inlet	16.900	18.719	1.050
Node_17	Manhole/inlet	14.650	15.250	1.060
Node_18	Outlet	13.270	13.770	1.060

Link Details

Link ID	Type No	Conduit Type	Upstream Level (m AHD)	Downstream Level (m AHD)	Length (m)	Slope (m)	Diameter (m)	Width (m)	Height (m)
48933	1	RCP	5.780	5.750	18.084	0.166	0.900		
48937	1	RCP	5.870	5.810	27.937	0.215	0.900		
48939	1	RCP	6.080	5.890	76.369	0.249	0.900		
48941	1	RCP	6.140	6.110	22.652	0.132	0.900		
48943	1	RCP	6.210	6.170	42.543	0.094	0.900		
48945	1	RCP	6.280	6.240	36.876	0.108	0.900		
48947	1	RCP	6.390	6.320	55.481	0.126	0.900		
49115	1	RCP	4.690	4.290	54.044	0.740	1.050		
49270	1	RCP	9.000	8.690	75.898	0.408	1.050		
49272	1	RCP	9.000	8.690	75.739	0.409	1.050		
49292	1	RCP	9.230	9.020	75.606	0.278	1.050		
49294	1	RCP	9.230	9.020	75.879	0.277	1.050		
49295	1	RCP	10.290	9.230	77.979	1.359	1.050		
49297	1	RCP	10.320	10.300	41.191	0.049	1.050		
49657	1	RCP	5.260	5.210	14.350	0.348	0.900		
49665	1	RCP	5.060	5.030	3.675	0.816	1.050		
52303	1	RCP	8.560	8.240	16.390	1.952	0.900		
52305	1	RCP	8.150	8.120	7.360	0.408	0.900		
52307	1	RCP	7.980	7.760	13.709	1.605	1.050		
52412	1	RCP	3.810	3.790	16.553	0.121	0.900		
52418	1	RCP	3.770	3.390	60.337	0.630	0.900		
52422	1	RCP	3.390	3.199	7.058	2.706	1.200		
52424	1	RCP	3.190	2.729	15.372	2.999	1.200		
52528	1	RCP	6.900	6.640	7.100	3.662	0.900		
52662	1	RCP	8.840	8.700	66.108	0.212	0.900		
52666	1	RCP	9.010	8.890	47.209	0.254	0.900		
52786	1	RCP	8.670	8.590	39.890	0.201	0.900		
64338	1	RCP	10.140	9.630	32.951	1.548	1.350		
64339	1	RCP	10.140	9.630	32.577	1.566	1.350		
64340	1	RCP	11.018	10.157	41.875	2.056	1.350		
64341	1	RCP	11.018	10.157	41.775	2.061	1.350		
68862	1	RCP	10.500	9.990	12.417	4.107	0.900		
68877	1	RCP	10.650	10.480	26.207	0.649	0.900		
71527	3	RCP	6.000	5.970	48.447	0.062		1.650	1.050
71532	1	RCP	6.090	6.070	23.301	0.086	1.050		
71533	1	RCP	6.090	6.070	23.237	0.086	1.050		
71580	1	RCP	6.350	6.300	29.819	0.168	0.900		
71581	1	RCP	6.370	6.350	10.783	0.185	0.900		
72359	1	RCP	4.290	4.230	14.306	0.419	0.900		
72792	1	RCP	6.936	6.920	25.623	0.062	0.900		
72794	1	RCP	6.920	6.870	6.212	0.805	0.900		
72795	1	RCP	6.870	6.790	12.669	0.631	0.900		
72973	1	RCP	1.100	1.060	40.343	0.099	0.900		
73051	1	RCP	10.640	10.500	48.000	0.292	0.900		
74863	1	RCP	6.790	6.770	22.122	0.090	1.050		
74879	1	RCP	6.770	6.760	8.974	0.111	1.050		
Link_6	1	RCP	7.100	7.050	1.850	2.703	0.900		
Link_7	1	RCP	5.300	5.260	1.994	2.006	0.900		
47909	1	RCP	3.230	3.200	15.490	0.194	1.050		
Link_8	1	RCP	3.240	3.230	21.421	0.047	1.050		
Link_9	1	RCP	6.790	6.770	22.122	0.090	1.050		
Link_11	1	RCP	5.640	5.540	45.789	0.218	0.900		
48927	1	RCP	5.536	5.510	11.427	0.227	0.900		
Link_12	1	RCP	3.430	2.570	48.158	1.785	0.900		
52764	1	RCP	2.570	2.300	15.142	1.785	0.900		
Link_14	3	RCBC	8.610	8.280	61.167	0.540		1.650	1.050
Link_16	3	RCBC	6.710	6.690	9.410	0.213		1.885	1.200
Link_17	3	RCBC	6.690	6.630	7.575	0.792		1.885	1.200
Link_18	3	RCBC	6.050	6.030	9.513	0.210		1.650	1.050
Link_19	3	RCBC	9.630	9.580	5.256	0.951		2.120	1.350
Link_20	3	RCBC	14.650	13.270	32.205	4.285		1.060	0.450

Appendix D – Flood Maps

(Refer to Volume II)

Appendix E – Long Sections

(Refer to Volume II)

Appendix F – Peak Surface Flow Results

Locations	Storm Duration	Peak Flow (m^3/s)								
		2 Y ARI	5 Y ARI	10 Y ARI	20 Y ARI	50 Y ARI	100 Y ARI	200 Y ARI	500 Y ARI	PMF
1	1.5 h	4.3	6.41	7.32	9.04	10.34	11.46	13.78	16.8	75.4
	3h	3.96	6.01	6.9	7.95	9.42	10.99	12.28	13.95	53.44
	72h	1.71	2.38	2.97	3.67	4.1	4.78	5.48	6.36	7.21
2	1.5 h	0.805	1.739	2.34	3.17	4.35	5.23	6	6.92	25.4
	3h	0.839	1.84	2.3	3	3.65	4.47	5.09	6.35	18.3
	72h	0.377	0.528	0.68	0.94	1.12	1.44	1.79	2.28	2.84
3	1.5 h	0.943	1.81	2.3	3.08	4.22	5.17	6.06	7.18	31.95
	3h	0.948	1.87	2.34	2.98	3.64	4.42	5.12	6.44	22.2
	72h	0.494	0.67	0.82	1.12	1.29	1.58	1.93	2.41	2.96
4	1.5 h	0.28	3.09	3.99	5.2	6.67	8.21	9.88	11.99	34.2
	3h	1.87	3.11	3.95	4.92	5.86	2.13	8.37	10.64	26.4
	72h	1.85	1.95	2.1	2.38	2.44	2.93	3.48	4.19	4.74
5	1.5 h	81.54	136.3	173.84	212.4	282.6	326.38	360.6	409.45	863.6
	3h	100.26	157.25	189.9	234.2	274.08	320.7	355.6	401.6	740.2
	72h	81.09	114.97	134	156.7	174..22	190.02	214.3	206.5	484.2
6	1.5 h	41.47	74.6	92.6	123.05	158.79	188.85	213.8	244.95	479.5
	3h	48.35	79.6	97.4	121.56	146.08	175.6	201.95	132.09	439.6
	72h	31.52	47.02	56.87	69.98	79.12	88.94	106.31	124.09	172.99
7	1.5 h	45.4	81.2	100.5	124.63	155.58	191.36	218.6	256.82	426.2
	3h	48.5	80.2	100.8	127.85	148.82	178.7	206.3	238.11	405.2
	72h	33.65	48.7	59.74	73.74	81.4	93.7	109.2	128.34	175.38
8	1.5 h	73.1	119.2	139.7	178.34	223.45	250.4	275.4	310.01	609.5
	3h	87.4	128.7	153.89	181.11	209.2	246.99	268.63	301.7	554.04
	72h	67.99	96.3	110.06	127.85	139.45	150.37	169.91	150.39	286.87
9	1.5 h	79.4	136.5	167.1	210.7	273.85	311.9	345.4	391.81	737.5
	3h	97.7	150.5	184.14	223.15	260.74	312.64	339.5	382.96	686.07
	72h	76.5	110.9	129.04	151.8	168.17	182.7	207.08	197.63	454.84
10	1.5 h	5.42	8.58	10.5	13	15.66	17.84	19.97	22.53	90.75
	3h	4.99	8.48	10.62	12.5	13.63	15.9	17.06	19.18	77.25
	72h	1.9	3.1	3.76	4.61	5.14	5.99	6.96	8.29	9.33
11	1.5 h	7.35	12.08	14.66	17.25	20.83	24.64	28.23	32.55	109.64
	3h	6.94	11.24	14.06	17.48	19.25	22.16	24.02	27.06	95.89
	72h	2.6	4.11	5.13	6.38	7.13	8.4	9.7	11.44	14.66
12	1.5 h	8.5	14.35	18.82	23.71	28.67	32.64	36.16	40.33	113.98
	3h	8.36	14.38	17.39	21.05	24.81	30.09	33.8	38.9	100.6
	72h	4.35	5.56	7.014	8.9	10.07	11.97	13.95	16.64	89.85
13	1.5 h	7.85	13.45	16.7	20.58	25.11	31.96	38.6	47.15	220.14
	3h	8.4	13.09	16.4	20.68	23.72	29.82	34.52	42.64	197.45
	72h	5.1	6.29	7.9	9.8	11	12.94	15.01	18.03	174.4
14	1.5 h	16.7	28.53	35.5	43.5	53.2	63.38	71.995	81.98	277.78
	3h	17.9	27.9	34.85	43.93	49.9	59.16	64.53	74.51	258.98
	72h	11.96	14.12	16.9	21.06	23.68	27.9	32.4	38.82	240.18
15	1.5 h	13.3	20.1	27.21	35.99	50.8	61.68	72.33	80.257	222.89
	3h	14.2	23.8	30.95	40.33	49.51	63.97	69.265	79.52	201.76
	72h	17.2	19.8	21.16	25.13	28.94	32.75	37.95	46.38	211.57
16	1.5 h	12.8	22.7	29.1	36.86	45.33	52.85	59.03	65.23	100.08
	3h	13.2	22.4	28.4	36.11	41.76	50.94	54.78	61.11	95.16
	72h	8.4	11.8	13.52	16.44	18.37	21.3	24.76	29.18	43.24

Locations	Storm Duration	Peak Flow (m^3/s)								
		2 Y ARI	5 Y ARI	10 Y ARI	20 Y ARI	50 Y ARI	100 Y ARI	200 Y ARI	500 Y ARI	PMF
17	1.5 h	12.5	22.75	29.21	38.53	48.93	57.23	63.78	69.4	113.65
	3h	13.6	23.1	28.27	37.06	44.32	53.32	59.28	65.39	103.72
	72h	8.7	12.3	14.22	17.3	19.4	22.52	26.08	30.95	46.47
18	1.5 h	12.6	22.7	30.28	40.03	49.05	59.39	69.08	76.01	136.46
	3h	14.5	24.4	29.56	40.39	47.19	57.37	63.2	71.6	118.59
	72h	9.6	13.7	16.13	19.91	22.18	25.86	29.96	35.41	47.99
19	1.5 h	35.2	56.5	70.01	87.18	102.5	118.65	134.75	153.64	374.46
	3h	36	56.9	74.55	87.5	101.7	112.01	128.62	143.26	332.62
	72h	25.4	33.82	39.78	51.5	55.51	62.5	70.42	76.9	113.09
20	1.5 h	17.5	27.4	35.6	46.98	57.5	72.48	86.26	107.52	469.06
	3h	18.3	28.7	36.8	46.1	55.83	66.54	81.26	93.24	389.44
	72h	13.1	17.43	20.34	26.46	28.59	32.12	36.51	43.03	69.18
21	1.5 h	34.1	58.74	72.2	88.53	105.43	122.88	148.22	172.15	425.03
	3h	36.08	55.07	77.12	89.47	103.85	113.63	130.83	155.97	393.65
	72h	25.99	34.07	39.75	50.84	59.87	69.128	77.57	84.327	114.66
22	1.5 h	2.87	5.08	5.51	5.86	6.13	6.28	6.38	6.47	6.41
	3h	2.68	5.3	5.68	5.99	6.26	6.4	6.49	6.56	6.57
	72h	2.61	2.69	4.4	5.47	5.75	6.07	6.32	6.5	6.56
23	1.5 h	0.72	2.33	3.03	3.743	4.35	4.54	4.89	5.14	39.29
	3h	0.84	2.5	3.3	4	4.34	4.6	4.85	5.41	31.58
	72h	0.9	1.31	2.011	2.85	3.24	3.64	3.92	4.13	3.84
24	1.5 h	9.55	20.05	27.4	35.8	44.53	50.21	52.67	54.98	61.03
	3h	10.84	21.2	27.99	36.67	41.96	49.96	51.74	53.75	60.38
	72h	4.9	8.8	11.66	15.2	17.56	20.74	24.73	30.15	40.7
25	1.5 h	8.223	8.881	9.02	9.13	9.21	9.46	9.33	9.485	9.544
	3h	8.436	8.89	9.018	9.14	9.179	9.353	9.46	9.456	9.534
	72h	4.39	8.03	8.61	8.75	8.811	8.894	8.973	9.048	9.15
26	1.5 h	13.01	23.18	28.47	35.85	40.881	44.133	47.211	48.409	51.308
	3h	13.611	23.173	28.12	35.1	38.81	42.6	45.54	47.844	50.422
	72h	6.692	10.671	12.94	15.96	17.453	20.38	22.32	26.3	33.65
27	1.5 h	2.13	3.722	4.851	6.123	7.15	8.395	9.511	11.071	21.492
	3h	2.065	3.67	4.5	5.48	5.93	7.156	7.384	8.398	15.995
	72h	1.343	1.362	1.62	1.98	2.174	2.495	2.884	3.34	4.09
28	1.5 h	3.341	4.47	5.55	8.143	10.05	11.828	13.088	14.369	24.56
	3h	3.427	4.49	5.16	7.78	9.207	10.52	11.37	12.601	19.86
	72h	3.038	3.483	3.796	4.2	4.487	5.274	5.732	7.153	5.92
29	1.5 h	8.22	14.2	18.72	24.14	29.18	34.11	38.7	44.57	68.87
	3h	8.34	12.52	15.77	19.98	22.96	29.72	30.43	35.39	58.12
	72h	4.38	6.97	7.18	8.7	9.35	10.5	11.84	14.29	21.78
30	1.5 h	10.3	16.33	20.07	26.417	32.19	38.61	44.424	52.11	72.783
	3h	10.33	17.12	20.39	24.11	26.58	34.5	33.56	39.7	59.04
	72h	4.89	6.84	8.01	9.96	11.01	12.79	14.52	17.344	113.05
31	1.5 h	0.73	1.43	1.95	2.38	3.7264	4.935	5.84	6.86	9.67
	3h	0.84	1.35	2.03	2.71	3.18	4.3	4.07	4.81	6.08
	72h	1.43	1.75	1.81	1.77	1.84	1.82	1.856	2.19	2.54
32	1.5 h	1.45	2.34	2.83	3.4	3.83	4.3	4.74	5.758	9.82
	3h	1.3	2.24	2.66	3.11	3.33	4.35	4.16	4.71	8.88
	72h	0.62	0.75	1.15	1.36	1.48	1.66	1.88	2.19	2.88
33	1.5 h	1.14	3.53	3.44	3.41	1.716	1.96	3.73	3.63	3.66
	3h	3.55	4.01	3.68	3.58	3.896	3.99	3.87	3.95	3.83
	72h	3.5	3.71	3.29	3.22	3.97	4.02	4.08	3.7	3.88