

# Woolshed Creek Flood Study





## Woolshed Creek Flood Study

Prepared for  
ACT Planning and Land Authority

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## Executive Summary

AECOM has been engaged by ACT Procurement Solutions on behalf of ACT Planning and Land Authority (ACTPLA) to undertake the Majura Valley Engineering Services Feasibility Study. As part of the study AECOM has undertaken the Woolshed Creek Flood Study to identify the floodplain constraints for development within the investigation areas.

The objective of this study is to identify the Woolshed Creek peak flood flows and flood inundation extent for the 100 year Average Recurrence Interval (ARI) flood event within the investigation areas. This report provides information on the peak flows at key nodal points in the Majura Valley catchment and flood levels for Woolshed Creek in the study area. Woolshed Creek flood inundation extents have been calculated and are presented for the 100 year ARI flood event.

An XP-RAFTS rainfall-runoff model was used to estimate the catchment discharges for the 10 year, 20 year and 100 year ARI pre and post development storm events for numerous storm durations. A HEC-RAS hydraulic model was used to estimate the peak flood levels in Woolshed Creek for each design flood event.

The proposed Majura Parkway extending for approximately 11.5 kilometres from the Federal Highway to the Monaro Highway is expected to be constructed in the near future through the Majura Valley. There is also potential for a Very High Speed Train (VHST) service to be constructed between Sydney, Canberra and Melbourne with a proposed alignment bisecting the study area, adjacent to the route of the Majura Parkway. These potential developments may have an impact on existing Woolshed Creek peak flood levels and the potential developable area within Investigation Area C.

The conclusions and recommendations from this flood study include:

- The study areas in the Majura Valley are not affected by the 100 year ARI Molonglo River peak flood level.
- The width of the Woolshed Creek 100 year ARI flood inundation extent varies between 50 m to 250 m.
- As the proposed development areas will have a storm water drainage system with roads, pits and pipes and lined floodway's, the peak flow values for individual sub-catchments may be higher than the calculated discharges from the XP- RAFTS modelling for individual sub-catchments with a shorter time of concentration. Detailed catchment studies should be carried out for specific development scenarios and retarding basins should be designed in the detailed design stages of the proposed development to attenuate post development flows to pre development flows.
- Detailed field survey should be carried out to 250 m either side of the entire creek down to the Molonglo River and the Majura Parkway embankment should be incorporated into the terrain model. Rural catchment rainfall losses and stream Manning's roughness parameters should be reviewed in conjunction with any future modelling. Bridge details should be surveyed to facilitate future hydraulic modelling of all structures along Woolshed Creek. Further investigations should be undertaken on filling the existing erosion gullies and localised flood plains to increase the developable areas.
- Due to the complex nature of flow paths and floodplain storage that will occur when the channel capacity is exceeded, more accurate results will be achieved through two dimensional hydraulic modelling of Woolshed Creek.
- TaMS have advised that a flood study of Pialligo Brook (located within Investigation Area D) is currently being undertaken. The Pialligo Brook flood study should be reviewed and used to update Woolshed Creek sub-catchment delineation and catchment parameters if necessary when the results of the study are made available.

## 1.0 Introduction

### 1.1 Background

AECOM has been engaged by ACT Procurement Solutions on behalf of ACT Planning and Land Authority (ACTPLA) to undertake the Majura Valley Engineering Services Feasibility Study. As a part of the study AECOM has undertaken the Woolshed Creek Flood Study to identify the floodplain constraints for development within the investigation areas.

The investigation areas are located either side of Woolshed Creek in the Majura Valley. The Woolshed Creek catchment plan and the investigation areas are presented on Figure 1.

### 1.2 Study Objectives

The objective of this study is to identify the inundation extent of flooding in the investigation area as follows:

- Develop an XP-RAFTS rainfall-runoff model for the Majura Valley catchment.
- Calculate and tabulate design flood discharges in Woolshed Creek for the 10 year, 20 year and 100 year ARI events pre and post development scenarios at key nodal points.
- Develop a HEC-RAS hydraulic model of Woolshed Creek.
- Determine the 100 year ARI peak flood flows, flood inundation extent, depth and prepare flood maps of Woolshed Creek.

This report outlines the review of previous studies and discusses the tasks undertaken to achieve the above objectives.

### 1.3 Design Standards

TaMS' Design Standards for Urban Infrastructure (DSUI) were a key reference for the stormwater aspects of this study. The information regarding rainfall loss rates and surface run-off routing (Tables 1.6 and 1.7, page 1-13 of DSUI) which were used as modelling parameters in XP-RAFTS.

## 2.0 Available Information

### 2.1 Previous Studies

A number of previous studies have been undertaken in the Majura Valley catchment:

- The most relevant to the present study is the Majura Precinct Flood Study by GHD in 1998. The objective of the GHD study was to identify and document the extent of flooding in the area to be developed for the Majura Precinct and in particular the Environmental Technology Development Zone (ETDZ). The ETDZ is comprised of areas along the western side of Majura Road and in the Southern area of the Majura Valley. XP-RAFTS was used for catchment modelling in the Majura Valley and HEC-RAS software was used for hydraulic flood modelling of Woolshed Creek. The GHD study concluded the following:
  - The peak 100 year ARI flow at the confluence with the Molonglo River was calculated as 265 m<sup>3</sup>/s.
  - The 100 year ARI flood level in the Molonglo River was found to have no impact on the nominal ETDZ sites.
  - The 100 year ARI flood inundation extent along Woolshed Creek was found to vary between 160 m and 330 m wide.
- A number of studies have been undertaken and are underway in the Molonglo River Catchment. The recent Ecwise 2000 hydrology study and the current Molonglo River Hydrology and Scrivener Dam Safety Review are most relevant to this study. The Molonglo River Hydrology and Scrivener Dam Safety Review will produce flood mapping for the Molonglo River downstream from Yass Road but was not available for this study. The information provided by ACTPLA from the Ecwise 2000 study was used to determine peak flood levels in the Molonglo River for the 100 year ARI flood event.

## 2.2 Investigation Inputs

### 2.2.1 Cadastral Information and Aerial Photos

Cadastral information, Aerial photos (2009) and 2 m contours were obtained from ACTPLA for the study area. This information was used to define the sub-catchment boundaries in the Majura Valley catchment, interpret physical features and land use, and as a background for flood modelling results.

### 2.2.2 Field Survey

Field survey was undertaken to determine cross sections along Woolshed Creek as Woolshed Creek is not adequately represented by 2 m contours of the catchment. The field survey was conducted using GPS along Woolshed Creek from Majura Road to Fairbairn Avenue (length of approximately 8100 m). Cross section survey of Woolshed Creek was carried out 20 m from the top of the bank on both sides of the creek at 50 m intervals for a total of 75 sections.

## 3.0 Study Area Features

### 3.1 Catchments Characteristics

The Majura catchment is defined by the topography from the Federal Highway to the Molonglo River and by the hills on either side of Woolshed Creek. The total catchment area of Woolshed Creek to Fairbairn Road is approximately 6450 ha. The catchment is mostly undeveloped broad acre land use zone with some areas of pine plantation and modified land for cultivation. The lower catchment comprises the Canberra Airport which includes an employment centre and retail outlets.

The catchment slope is steep along the Mount Majura and Mount Ainslie boundary and flat in the valley. The average catchment slopes are in the range of 5 to 20% in the vicinity of Mount Majura and Mount Ainslie and 1 to 2% in the valley along both sides of Woolshed Creek.

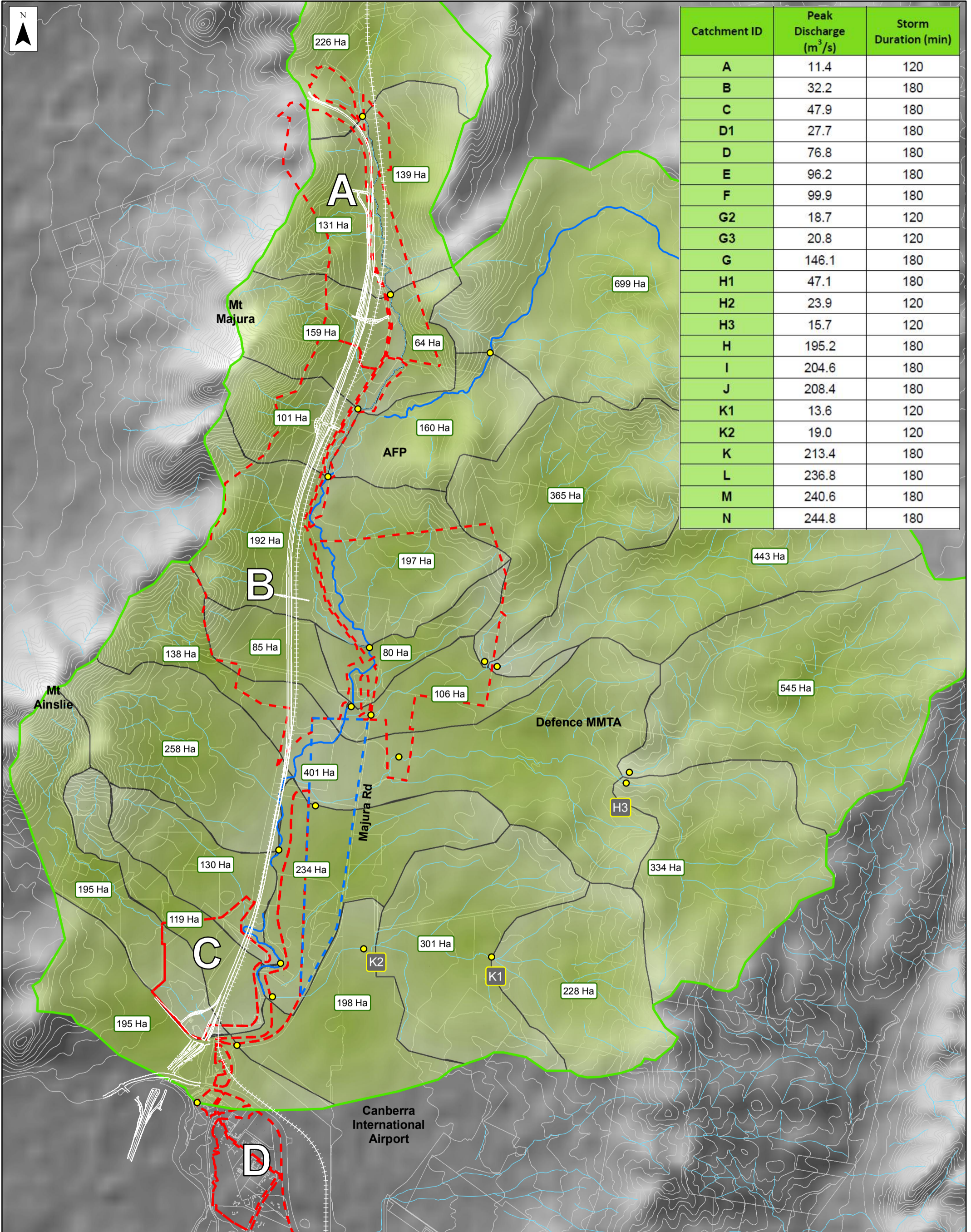
There are several creeks and tributaries in the catchment. Woolshed Creek is the main creek in the Majura Valley catchment running from the Federal Highway in the north to the Molonglo River in the south near Majura Road.

The investigation areas are located either side of Woolshed Creek in the Majura Valley. The Woolshed Creek catchment plan and the investigation areas are presented on Figure 1.

The Pialligo Brook catchment (located within investigation Area D) collects stormwater runoff from within the Canberra Airport and downstream residential developments before flowing into the Molonglo River just upstream of the confluence between the Molonglo River and Woolshed Creek. The Canberra Airport Summarised Water Management Plan (Canberra Airport, 2009) identifies that the passenger terminal facility, the General Aviation Precinct, the former and new fuel depot and runway system are contained within the Pialligo Brook catchment. Stormwater collected in the airport is discharged to either Woolshed Creek, Pialligo Brook or to the Molonglo River by a network of open grassed swales with some closed drains and detention basins. The proportion of the Pialligo Brook catchment that is diverted to Woolshed Creek has been estimated using the 2 m contours and aerial photography of the Majura Valley.

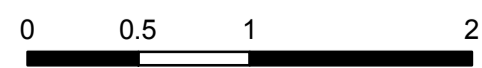
The downstream extent of the Woolshed Creek HEC-RAS model is located at Fairbairn Avenue. It is anticipated that stormwater runoff from the major airport developments such as the terminal facility and the general Aviation Precinct will discharge into Pialligo Brook or the Molonglo River.





Catchment ID	Peak Discharge (m <sup>3</sup> /s)	Storm Duration (min)
A	11.4	120
B	32.2	180
C	47.9	180
D1	27.7	180
D	76.8	180
E	96.2	180
F	99.9	180
G2	18.7	120
G3	20.8	120
G	146.1	180
H1	47.1	180
H2	23.9	120
H3	15.7	120
H	195.2	180
I	204.6	180
J	208.4	180
K1	13.6	120
K2	19.0	120
K	213.4	180
L	236.8	180
M	240.6	180
N	244.8	180

- **A** Stormwater Sub-catchment ID
- Woolshed Creek Catchment
- 560.5m (Molonglo River 100 Year Floodline)
- Woolshed Creek
- Water Course
- Stormwater Sub-catchment
- Investigation Area Boundary
- National Land
- Contour (10m)
- Proposed Majura Parkway & VHST Route





## 3.2 Floodplain Features and Hydraulic Behaviour of Woolshed Creek

Woolshed Creek has a narrow channel with sharp bends and a broad floodplain in many areas within the Majura Valley. The hydraulic response to flooding is influenced by the following:

- Majura Road Bridge (HEC-RAS chainage 5375 m) – The 18.3 m single span bridge with 5.3 m vertical clearance.
- Fairbairn Avenue Bridge (HEC-RAS chainage 105 m) – The 18.0 m mid Pier Bridge with 4.0 m vertical clearance.
- Pialligo Avenue Bridge (not included in the HEC-RAS model extent) – The 52.0 m Bridge with 3.9 m vertical clearance.
- Molonglo River Tail Water Level – Woolshed Creek peak flood levels are not influenced by Molonglo River tail water levels.
- The study areas in the Majura Valley are not affected by the Molonglo River 100 year ARI peak flood level. The Ecowise 2000 hydrology study identified Molonglo River peak flood levels between 559.17 m and 559.72 m AHD for the 100 year ARI event in the proximity of the Woolshed Creek and Molonglo River confluence. This was based on flood levels at cross sections 65 and 66 in the Ecowise study.

Woolshed Creek has limited channel capacity with an average width of 25 m at the top of the bank. There are erosion gullies and isolated pond areas found nearby the Creek. When the channel capacity is exceeded, the flood water overtops the bank and flows through the erosion gullies into floodplain storage.

## 4.0 Hydrologic Modelling

### 4.1 Sub Catchments

The 2 m contours and cadastre information provided by ACTPLA were used to define the sub catchment boundaries. Nodal points were established along Woolshed Creek to obtain design flow hydrographs.

It is understood that Aerial laser Survey (ALS) of the Molonglo River catchment has been undertaken for the Molonglo River and Hydrology and Scrivener Dam Safety Review. The Molonglo catchment ALS data was not provided to AECOM for this study since ACT Procurement Solutions advised that the ALS data did not cover the full extent of Woolshed Creek.

### 4.2 Model Parameters

The XP-RAFTS 2009 rainfall-runoff model was used to estimate the catchment discharges for the 10 year, 20 year and 100 year ARI design storm event for numerous storm durations. The data required to generate the hydrographs in individual sub catchments is:

- Catchments area
- Average vectored slope
- Surface roughness
- Degree of urbanisation
- Loss rates
- Observed or design rainfall
- Australian Rainfall and Runoff (AR&R) temporal patterns

Modelling parameters input into XP-RAFTS included the following:

- A 5% impervious area was assumed for most of the rural sub catchments with a surface roughness value of 0.05.

- The impervious area assumptions for the urban catchments were determined based on the existing developments and probable developable areas calculated in every sub catchments with a surface roughness value of 0.015.
- The initial and continuous rainfall loss model with 15 mm initial loss and 5 mm/hr continuous loss was adopted in rural catchments. For comparison purposes these parameters are based on those used in previous flood studies for Woolshed Creek.
- The Australian Representative Basins Model (ARBM) and the values for ARBM loss model recommended in TaMS' Design Standards for Urban Infrastructure is used in existing urban catchments and Investigation Areas. The surface roughness values of 0.04 and 0.015 are used in sub-catchment areas for permeable and impermeable areas respectively.
- The Intensity-Frequency-Duration (IFD) data recommended in TaMS' Design Standards for Urban Infrastructure was used for design rainfall.
- An average velocity of 1.5 m/s was adopted to estimate lag time between sub-catchments. Maximum velocities from Woolshed Creek were used to verify this velocity wherever applicable. The average velocity was selected based on the longitudinal grade of the channel.
- A 12D digital terrain model was used to calculate the vectored slopes in sub catchments and entered into XP-RAFTS.
- AR&R design temporal pattern Zone 2 was used in XP-RAFTS.

## 4.3 Flow Estimation Results

### 4.3.1 Existing Conditions

The Woolshed Creek catchment was divided into 29 sub catchments (See Figure 1). The 10 year, 20 year and 100 year ARI peak flows were determined in individual sub catchments for a range of storm event durations. The peak flows estimated from XP-RAFTS for the existing catchments are summarised in Table 1. The critical design storm duration for Woolshed Creek sub catchments is generally three hours for the 100 year ARI design event.

It was not possible to calibrate the XP-RAFTS rainfall-runoff model to historic flood events or do a statistical Flood Frequency Analysis (FFA) of historic flood events as there are no rainfall or stream gauges located within the Woolshed Creek catchment.

Table 1 Peak Sub-catchment Discharges–Existing Condition

Catchment ID	Peak Discharge (m <sup>3</sup> /s)		
	10 year ARI	20 year ARI	100 year ARI
A	4.6	6.5	11.4
B	13.8	19.6	32.2
C	21.1	29.9	47.9
D1	11.0	16.3	27.7
D	33.1	46.7	76.8
E	41.2	58.4	96.2
F	42.8	60.7	99.9
G2	7.7	10.7	18.7
G3	8.6	12.2	20.8
G	60.9	87.2	146.1
H1	18.9	27.4	47.0
H2	9.7	14.1	23.8
H3	6.4	9.2	15.6
H	79.8	114.8	195.2

Catchment ID	Peak Discharge (m <sup>3</sup> /s)		
	10 year ARI	20 year ARI	100 year ARI
I	89.3	120.6	204.6
J	85.6	123.0	208.4
K1	5.4	7.8	13.6
K2	7.6	10.7	18.9
K	87.2	125.4	213.4
L	98.9	139.0	236.8
M	101.0	141.7	240.6
N	104.1	145.9	244.8

#### 4.3.2 Comparison with Previous Studies

Table 2 compares the XP-RAFTS results from this study with values obtained in the 1998 study by GHD.

Table 2 XP-RAFTS Results Comparison

Description	100 year ARI Peak Flood Discharge (m <sup>3</sup> /s)
XP-RAFTS (AECOM 2010)	245
XP-RAFTS (GHD 1998)*	265

\*A vectored slope value between 1 to 15%, and a percentage impervious area of 0 to 3% was used.

The 100 year ARI discharge at the downstream end of the Woolshed Creek catchment was found to be 20 m<sup>3</sup>/s (7.5%) less than was determined in the 1998 GHD study. This difference is within the usual range of differences that can be expected in hydrological modelling. The possible reasons for this difference include vectored slope, percentage of imperviousness, lag time and sub-catchment delineation.

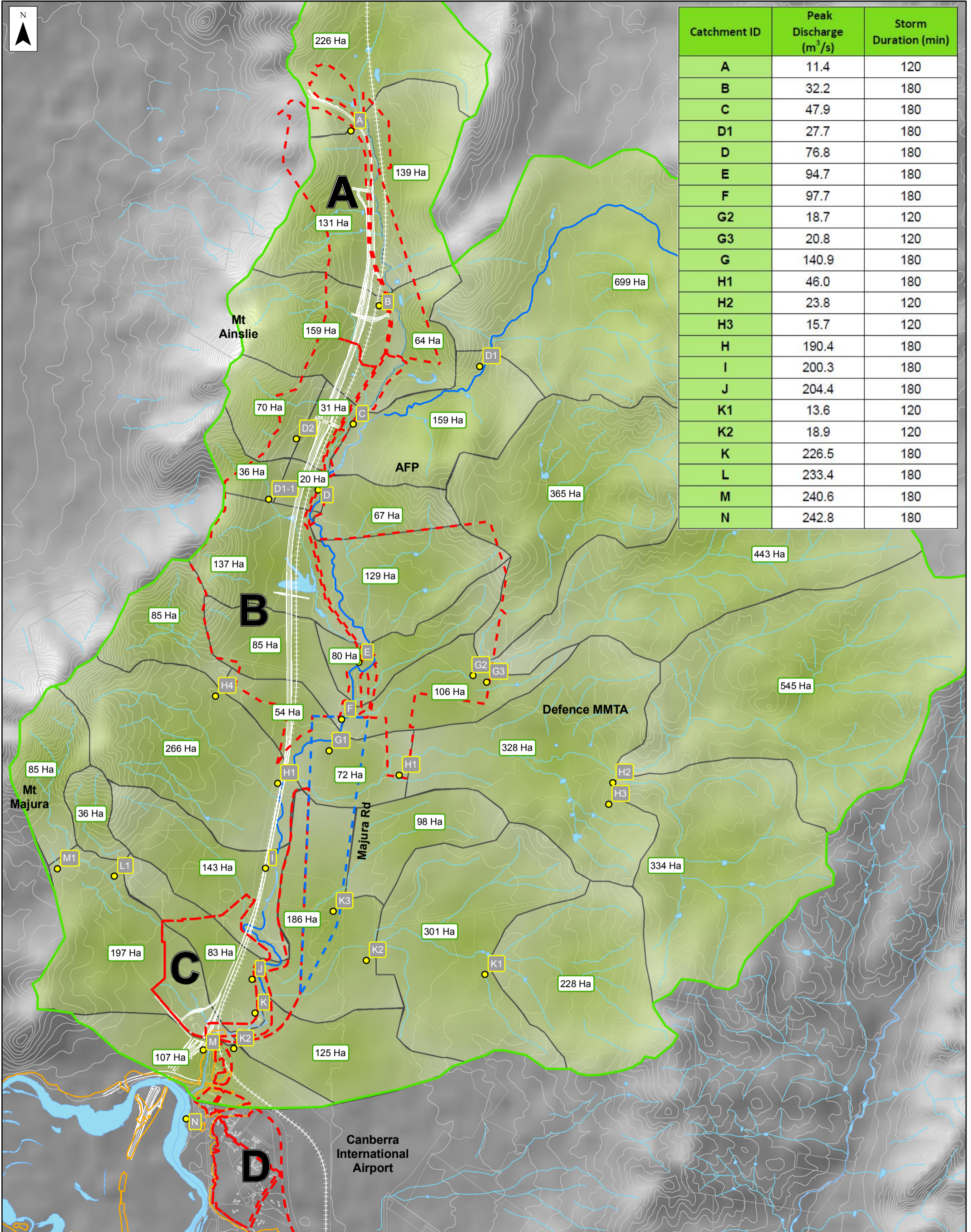
#### 4.3.3 Developed Conditions

The ARBM rainfall loss model parameters recommended in the ACT Urban Services guidelines were used in sub catchments that comprise the investigation study area. It has been assumed that 60 percent of the developable land in these precincts will have a 90 percent impermeable percentage. Surface roughness values of 0.04 and 0.015 were used in developed sub-catchment areas for permeable and impermeable areas respectively as per the TaMS guidelines.

The developed scenario catchment plan and the Investigation Areas are presented on Figure 2. The peak flows estimated from the XP-RAFTS model for the developed condition catchments are presented in Table 3. The critical storm duration in Woolshed Creek for the 100 year ARI flood event developed scenario is generally three hours.

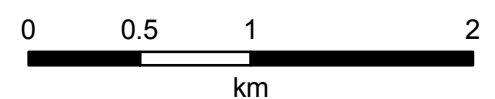
The XP-RAFTS output files for existing and developed conditions are presented in Appendix A.





Catchment ID	Peak Discharge (m <sup>3</sup> /s)	Storm Duration (min)
A	11.4	120
B	32.2	180
C	47.9	180
D1	27.7	180
D	76.8	180
E	94.7	180
F	97.7	180
G2	18.7	120
G3	20.8	120
G	140.9	180
H1	46.0	180
H2	23.8	120
H3	15.7	120
H	190.4	180
I	200.3	180
J	204.4	180
K1	13.6	120
K2	18.9	120
K	226.5	180
L	233.4	180
M	240.6	180
N	242.8	180

- A Stormwater Sub-catchment ID
- 560.5m (Molonglo River 100 Year Floodline)
- Stormwater Sub-catchment
- Woolshed Creek Catchment
- Woolshed Creek
- Water Course
- National Land
- Investigation Area Boundary
- Contours (10m)
- Proposed Majura Parkway & VHST Route



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Table 3 Peak Sub-catchment Discharges –Developed Condition

Catchment ID	Area (ha)	Vectored Slope (%)	Peak Discharge (m <sup>3</sup> /s)		
			10 year ARI	20 year ARI	100 year ARI
A	226.75	2.2	4.6	6.5	11.4
B1	131.15	6.0	4.8	6.9	11.5
B2	163.70	8.0	6.5	9.4	15.7
B	-	-	13.8	19.6	32.2
C1	158.73	6.5	5.8	8.3	13.9
C2	63.80	4.0	2.3	3.2	5.4
C	-	-	21.1	29.9	47.9
D1	699.24	2.3	11.0	16.3	27.7
D2	101.05	11.5	5.0	7.3	12.6
D3	159.74	0.8	12.9	19.1	32.8
D	-	-	32.9	46.3	76.5
E1	191.65	2.5	25.8	30.7	39.0
E2	197.50	2.6	4.5	5.0	11.1
E	-	-	41.6	57.9	94.7
F	80.33	1.9	43.2	59.9	99.9
G1	105.85	0.7	16.7	23.2	43.0
G2	365.30	2.9	5.8	8.2	18.7
G3	442.65	2.6	8.6	12.2	20.8
G	-	-	61.0	85.1	140.9
H1	400.60	0.5	18.6	26.9	46.0
H2	544.80	2.5	9.7	14.1	23.9
H3	333.60	2.3	6.4	9.2	15.7
H4	138.60	3.0	2.0	2.8	10.4
H	-	-	80.7	113.2	190.4
I	258.20	3.0	84.5	118.6	200.3
J	130.45	1.4	86.7	121.3	204.4
K2	300.65	0.5	7.6	10.7	19.0
K1	228.04	3.2	5.4	7.8	13.6
K	233.52	0.5	95.3	134.8	226.5
L	118.66	1.5	102.1	104.9	233.4
M	194.70	2.7	107.5	147.4	240.6
N	195.12	2.5	105.1	149.8	242.80

The comparison table for pre and post development at key nodal points is summarised in Table 4.

Table 4 Peak Sub-catchment Discharge Comparison –Existing and Developed Conditions at Key Nodal Points

Catchment ID	10 year ARI Peak Discharge (m <sup>3</sup> /s)		20 year ARI Peak Discharge (m <sup>3</sup> /s)		100 year ARI Peak Discharge (m <sup>3</sup> /s)	
	Existing	Developed	Existing	Developed	Existing	Developed
A	4.6	4.6	6.5	6.5	11.4	11.4
B	13.8	13.8	19.6	19.6	32.2	32.2
C	21.1	21.1	29.9	29.9	47.9	47.9
D	33.1	32.9	46.7	46.3	76.8	76.8
E	41.2	<b>41.6</b>	58.4	57.9	96.2	94.7
F	42.8	<b>43.2</b>	60.7	59.9	99.9	97.7
G	60.9	<b>61.0</b>	87.2	85.1	146.1	141.0
H	79.8	<b>80.7</b>	114.8	113.2	195.2	190.5
I	89.3	84.5	120.6	118.6	204.6	200.3
J	85.6	<b>86.7</b>	123.0	121.3	208.4	204.4
K	87.2	<b>95.3</b>	125.4	<b>134.8</b>	213.4	<b>226.5</b>
L	98.9	<b>102.1</b>	139.0	104.9	236.8	233.4
M	101.0	<b>107.5</b>	141.7	<b>147.4</b>	240.6	240.6
N	104.1	<b>109.4</b>	145.9	<b>149.8</b>	244.8	242.8

Due to the difference in response time between the larger undeveloped upstream catchments and developed regions along Woolshed Creek, the peak flow from the developed areas will reach the creek before the peak flow from upstream catchments and therefore may reduce Woolshed Creek peak flood discharges further downstream. This is illustrated by the 100 year ARI flow hydrograph for existing and developed condition that show a slight reduction in peak flows (Refer Table 3, Table 4, Figure 3 and Figure 5).

The existing condition 100 year ARI peak flows were adopted in the HEC-RAS model of Woolshed Creek as the peak flows are generally reduced under developed conditions. Existing condition 10 year and 20 year ARI peak flows were also used in HEC-RAS for consistency when comparing peak flood levels.

#### 4.3.4 Retarding Basins

Water Sensitive Urban Design and stormwater detention for the potential development scenarios located within the Investigation Areas are discussed in more detailed in the Appendix on Water Sensitive Urban Design in the Majura Valley Engineering Feasibility and Flood Study report prepared by AECOM. It is anticipated that the proposed WSUD measures will provide both stormwater treatment and detention. Indicative stormwater detention areas are presented in the Majura Valley Engineering Feasibility and Flood Study report however stormwater detention basins were not included in the post development XP-RAFTS model as there was insufficient data available to include the detention basins in XP-RAFTS (such as development scenario, development density and possible attenuation provided by Majura Parkway) and basin sizing was outside the scope of services for this study.

The Territorial and Municipal Services (TaMS) Design Standards for Urban Infrastructure requires that post development flows do not exceed pre development flows from development areas. This criterion will apply to each development sub-catchment. It is also necessary to address local sub-catchment flooding, erosion and to reduce stormwater infrastructure costs further downstream.

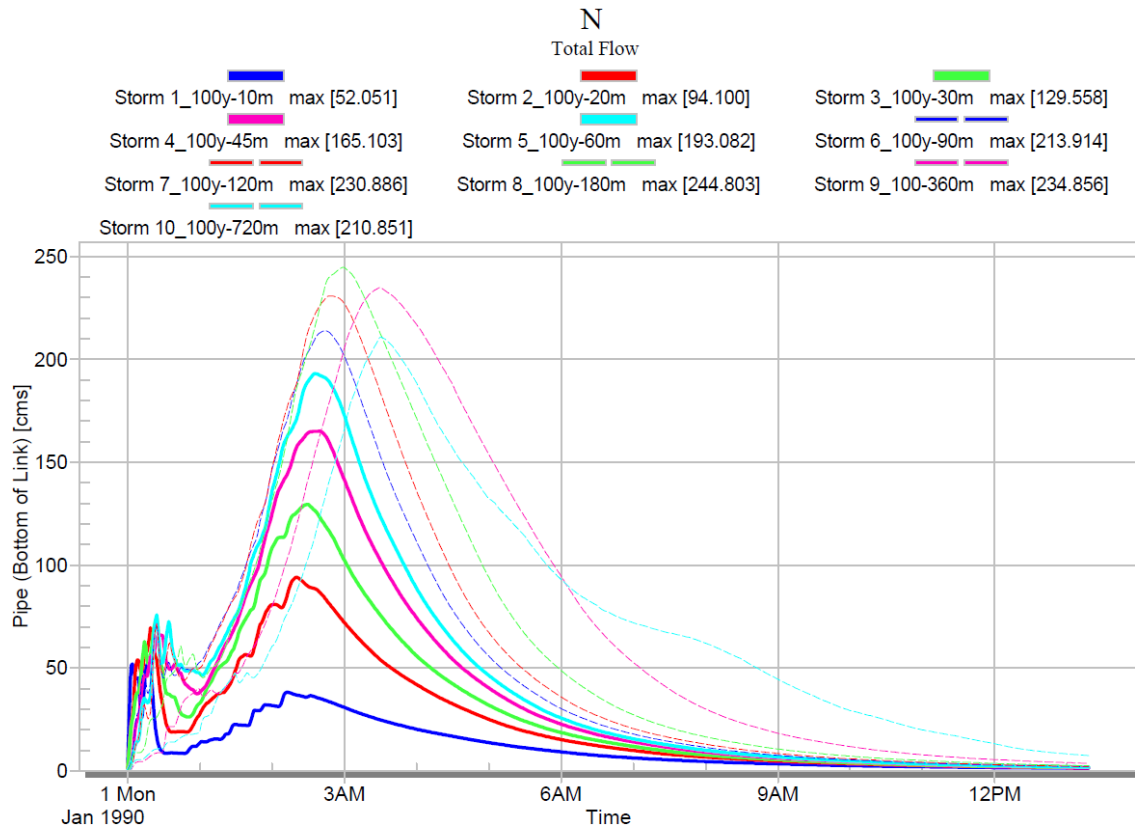


Figure 3 Existing Condition Flow Characteristic for 100 year ARI at Node N

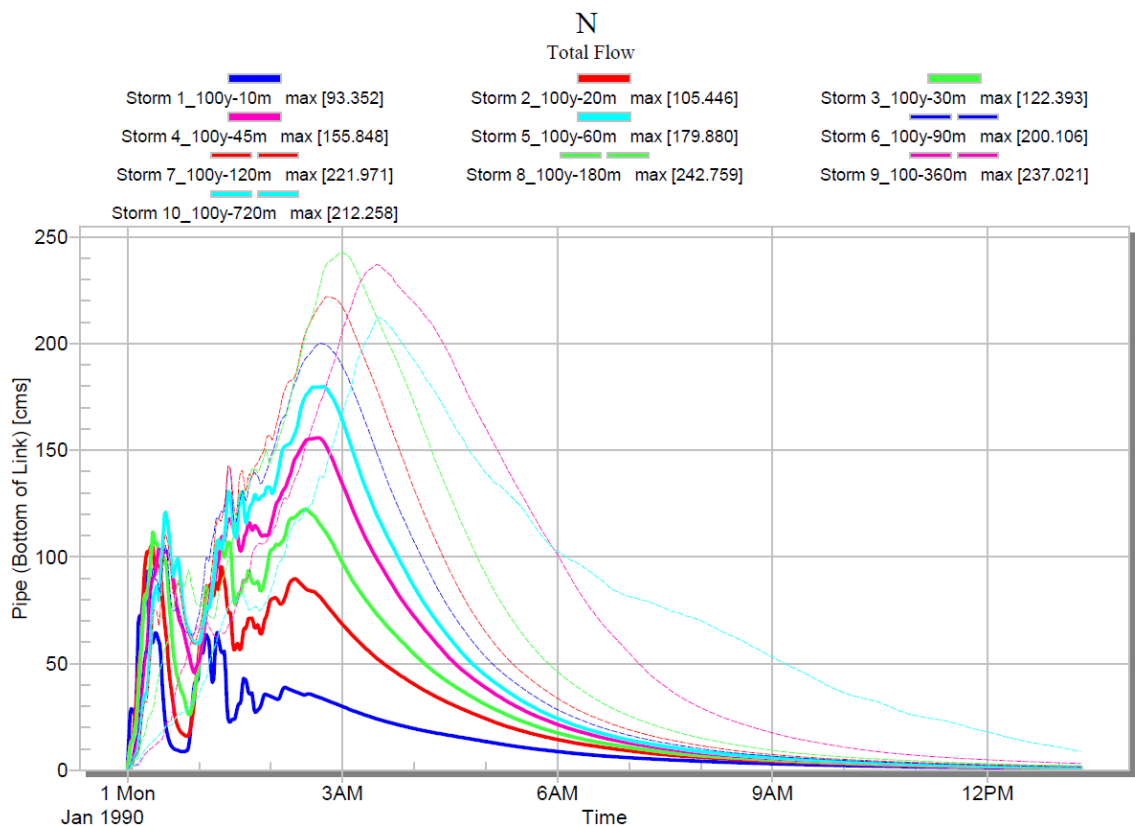


Figure 4 Developed Condition Flow Characteristic for 100 year ARI at Node N

## 5.0 Hydraulic Modelling

### 5.1 Digital Terrain Model (DTM) Development

The 2 m contours provided by ACTPLA and the field survey was used to create a three dimensional Digital Terrain Model (DTM) of Woolshed Creek in 12D. However, there are level differences in field survey cross sectional data and the 2m contours. There are low points and erosion gullies in the Woolshed Creek floodplain that are not represented in the 2m contours. Some interpolation at the interface of survey data sets was undertaken.

The Woolshed Creek centre line was established from upstream of the Fairbairn Avenue Bridge. The chainage zero is approximately 15 m upstream from the road centre line. A 550m reach (Chainage 350 to 900 m) of Woolshed Creek was not surveyed due to the presence of water in the creek. The topography of this reach was interpolated between upstream and downstream sections in the field survey. Due to heavy rainfall, it was not possible to have the missing reach surveyed immediately and timing constraints required that the hydraulic modelling could not be delayed and therefore the HEC-RAS model was developed using the survey available at the time. Detailed survey in this reach should be undertaken and included into the HEC-RAS model in conjunction with modelling of the Majura Parkway embankment.

As discussed in Section 4.1, it is understood that Aerial laser Survey (ALS) of the Molonglo River catchment has been undertaken for the Molonglo River and Hydrology and Scrivener Dam Safety Review. The Molonglo catchment ALS data was not able to be provided to AECOM for this study.

It is noted that there was no detailed ground survey available at the downstream end of Woolshed Creek (in the vicinity of Fairbairn Road Bridge) for this study. This bridge was therefore included in the HEC-RAS model further upstream to ensure that the impact of Fairbairn Bridge on flooding in Woolshed Creek is represented as accurately as possible. It is noted that the 2 m interval ACTPLA contours and other topography sources such as 1:25,000 Series Topography maps do not have sufficient detail at the downstream end of Woolshed Creek.

### 5.2 HEC-RAS Parameters

The Manning's roughness coefficients and the contraction and expansion coefficients used in the HEC-RAS model are summarised in Table 5. Roughness parameters were selected based on aerial photography and site inspection. It is noted that the roughness parameters adopted represent current conditions and do not allow for changing land use along the creek corridor.

Table 5 HEC-RAS input Parameters

Parameter	Value
Manning's Value	
<ul style="list-style-type: none"> <li>• Left and Right Over Bank</li> <li>• Main Channel</li> </ul>	<p style="text-align: center;">0.04</p> <p style="text-align: center;">0.05</p>
Contraction Co-efficient	0.1
Expansion Co-efficient	0.3

### 5.3 Woolshed Creek Flood Levels

#### 5.3.1 Existing Conditions

The 10 year, 20 year and 100 year ARI peak flood levels in Woolshed Creek up to Fairbairn Avenue were estimated using the HEC-RAS hydraulic model. The existing condition flows from the XP-RAFTS model at key nodal points were input into HEC-RAS model and a steady state simulation was undertaken.

Mixed flow conditions with different downstream tail water conditions and upstream normal depth were used to calculate the design event peak flood levels.

A Woolshed Creek downstream grade of 0.006 m/m was used to create a rating curve at the model downstream extent. The normal depth calculation produced a tail water level of 559.7 m AHD, 560.0 m AHD and 560.50 m AHD for the 10 year, 20 year and 100 year ARI flood event just downstream of the Fairbairn Avenue Bridge.

It is noted that due to the difference in Woolshed Creek and Molonglo River catchment areas and the spatial variation of rainfall that a 100 year ARI flood in Woolshed Creek will not occur at the same time as a 100 year ARI flood in the Molonglo River. Flooding in the Molonglo River will be of a lower ARI than in Woolshed Creek and the difference in catchment response times will result in the Woolshed Creek peak flood discharge entering the Molonglo River before the Molonglo River flood peak reaches the confluence between the Molonglo River and Woolshed Creek. It is therefore not appropriate to use a 100 year ARI Molonglo River tail water level when modelling peak 100 year ARI flood levels in Woolshed Creek. For this study the Woolshed Creek tail water level was not set as a peak flood level in the Molonglo River but rather calculated using the Woolshed Creek channel grade to produce a rating curve. This approach assumes no influence from the Molonglo River.

Molonglo River 100 year ARI peak flood levels were obtained from the Ecwise 2000 hydrology study to assess the impact of Molonglo River flooding on the study areas in the Majura Valley. A Molonglo River 100 year ARI peak flood level of 559.17 m AHD has been calculated using data provided by ACTPLA. It is noted that the study areas in the Majura Valley are not inundated by 100 year ARI Molonglo River flood events.

The existing creek is narrow and meandering and has an average top width of 25m. The average creek depth from the top of the bank is approximately 2 m and during the 100 year ARI flood event this depth increases to 3m with a maximum top width of approximately 200 m. When Woolshed Creek flooding overtops the main channel the complex nature of the flow paths are best represented in a two dimensional or linked one dimensional / two dimensional hydraulic model. HEC-RAS is a one dimensional model and therefore may not accurately represent the flooding behaviour in Woolshed Creek for overbank flow.

The Majura Road and Fairbairn Avenue bridge crossings within the study area and the bridges have been modelled with the available bridge data. There was no detailed survey data available for the bridges along Woolshed Creek. As there is no cross sectional survey data available for Woolshed creek beyond Fairbairn Avenue, the Fairbairn Avenue Bridge has been included just upstream of its actual location to ensure any impacts on inundation extent and peak flood levels upstream of the bridge are incorporated into the model results.

The 10 year, 20 year and 100 year ARI peak flood levels in Woolshed Creek are summarised in Table 6 and the 10 year, 20 year and 100 year ARI peak flood level profile along Woolshed Creek is presented in Figure 6. The 100 year ARI flood inundation extent was mapped in GIS and is presented on Figure 5.

It was not possible to calibrate the HEC-RAS model to historic flood events as there are no stream gauges or debris points from historic flood event available.

It is noted that the HEC-RAS model has calculated Froude Numbers of 1.0 at a couple of sections along Woolshed Creek which correspond to locations with a steep channel gradient. A Froude Number of 1.0 indicates the presence of critical flow, a Froude Number < 1.0 indicates sub-critical flow and a Froude Number > 1.0 indicates supercritical flow conditions. The HEC-RAS model has not calculated the presence of any hydraulic jumps within the Woolshed Creek reach modelled for this study.

Table 6 Woolshed Creek Peak Flood Levels

Chainage(m)	Peak Flood Level (m AHD)			100 year ARI Flood Depth (m)	100 year ARI Inundation Top Width (m)
	10 year ARI	20 year ARI	100 year ARI		
100	559.7	560.0	560.5	3.4	65
400	561.8	562.4	563.5	4.2	85
800	562.8	563.0	564.0	3.5	125
1200	563.8	564.0	564.5	2.7	250
1600	565.5	565.8	566.0	3.6	105
2000	569.9	570.0	570.0	2.2	735
2400	570.7	570.8	571.0	2.7	150
2800	572.0	572.2	572.5	3.0	260
3200	573.0	573.1	573.5	2.9	165
3600	574.7	574.9	575.0	2.9	255
4000	576.3	576.7	576.5	3.5	180
4400	578.2	578.3	578.5	3.1	135
4800	579.8	580.2	580.5	3.0	100
5200	581.5	581.1	581.5	2.1	17
5600	584.3	584.7	585.5	4.6	110
6000	588.3	588.5	589.0	2.0	275
6400	591.9	592.2	592.5	2.2	175
6800	595.6	595.9	596.5	2.3	25
7200	599.7	599.8	600.0	1.4	100
7600	603.6	603.8	604.0	1.5	105
7700	604.1	604.3	604.5	1.4	55

Table 7 provides the river chainages linked to the XP-RAFTS node locations and HEC-RAS Output river station numbers.

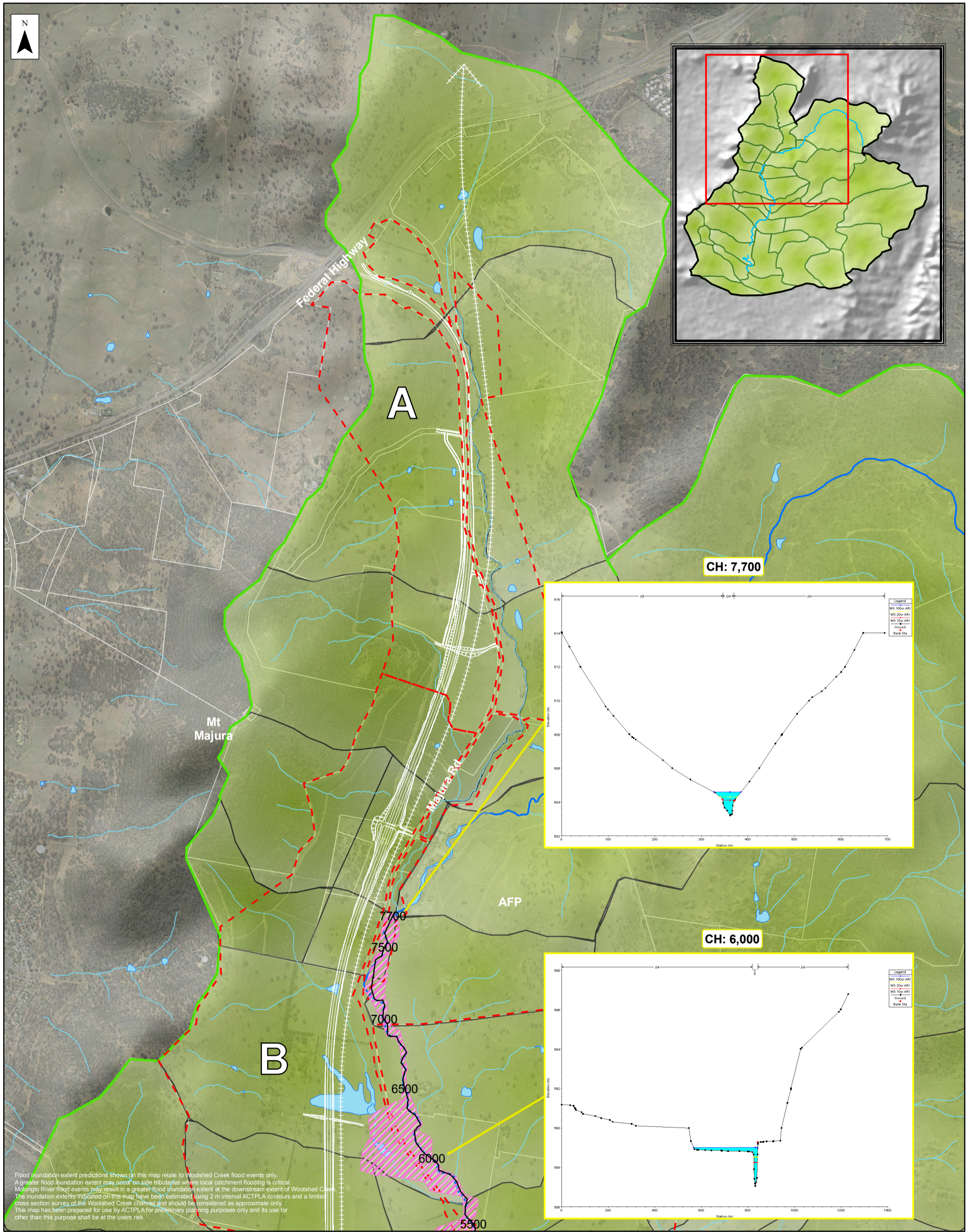
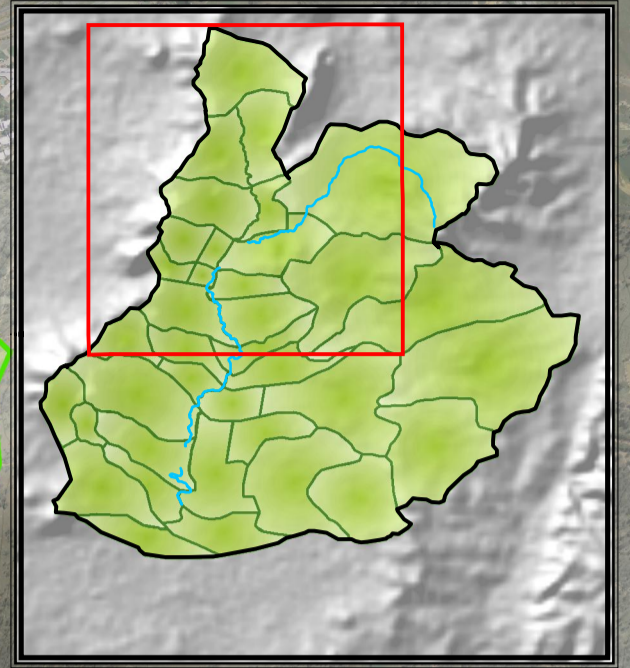
A sensitivity analysis has been undertaken for Manning's parameters on Woolshed Creek. A +/- 0.01 change in Manning's value results in a +/- 0.15 m change in Woolshed Creek peak flood levels.

Table 7 XP-RAFTS and HEC-RAS Output Summary

River Station/Chainage (m)	10 year ARI Peak Flood Level (m AHD)	20 year ARI Peak Flood Level (m AHD)	100 year ARI Peak Flood Level (m AHD)	100 year ARI Inundation Top Width (m)	XP-RAFTS Node
100.3	559.7	560.0	560.5	65	M
899.9	563.0	563.2	564.0	100	K
1499.1	565.0	565.2	565.5	90	J
2799.9	572.0	572.2	572.6	260	I
3700.2	575.0	575.1	575.4	315	H
4400.1	578.2	578.3	578.5	135	G
4800.1	579.8	580.2	580.4	100	F
5600	584.3	584.7	585.4	110	E
7699.5	604.1	604.3	604.5	55	D

The HEC-RAS output data for the 10 year, 20 year and 100 year ARI flood events are annexed in Appendix B.





Flood inundation extent predictions shown on this map relate to Woolshed Creek flood events only. A greater flood inundation extent may occur on-site in areas where local catchment flooding is critical. Molonglo River flood events may result in a greater flood inundation extent at the downstream extent of Woolshed Creek. The inundation extents indicated on this map have been estimated using 2 m interval ACTPLA contours and a limited cross section survey of the Woolshed Creek channel and should be considered as approximate only. This map has been prepared for use by ACTPLA for preliminary planning purposes only and its use for other than this purpose shall be at the users risk.

- 560.5m (Molonglo River 100 Year Floodline)
- Woolshed Creek
- Water Course
- 100 Year Floodline (AECOM, 2010)
- 100 Year Floodline (GHD, 1998)
- Woolshed Creek Control Line
- National Land
- Investigation Area Boundary
- Woolshed Creek Catchment
- Stormwater Sub-catchment
- Contour (10m)
- Proposed Majura Parkway & VHST Route

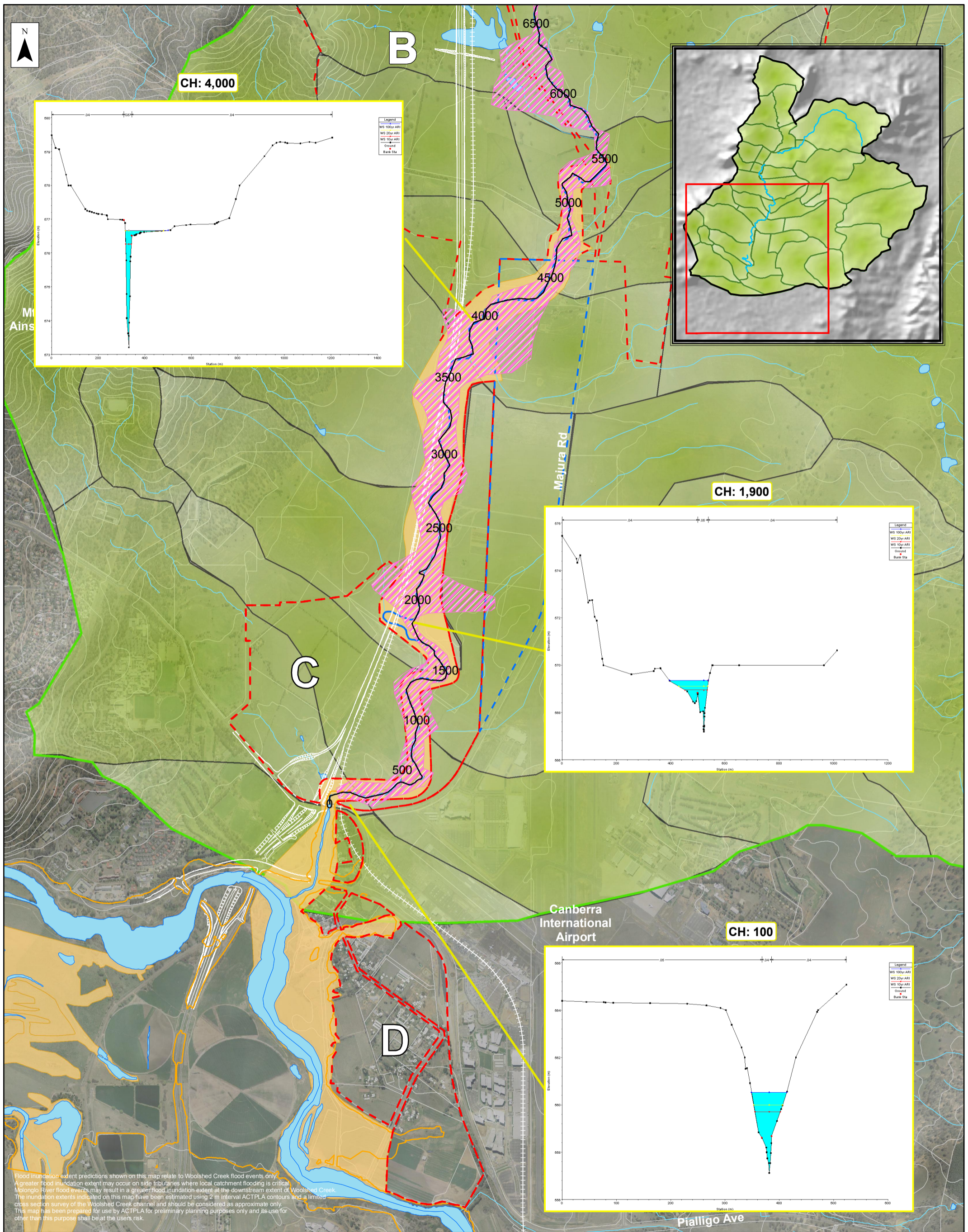
MAJURA VALLEY ENGINEERING FEASIBILITY STUDY  
**WOOLSHED CREEK FLOOD STUDY**  
 Source: ACTPLA (2009), SMEC (2009)

AUG 2010  
60143881

**3-A**

0 0.25 0.5 1  
km  
1:20,000 @ A3



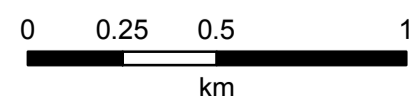


Flood inundation extent predictions shown on this map relate to Woolshed Creek flood events only. A greater flood inundation extent may occur on side tributaries where local catchment flooding is critical. Molonglo River flood events may result in a greater flood inundation extent at the downstream extent of Woolshed Creek. The inundation extents indicated on this map have been estimated using 2 m interval ACTPLA contours and a limited cross section survey of the Woolshed Creek channel and should be considered as approximate only. This map has been prepared for use by ACTPLA for preliminary planning purposes only and its use for other than this purpose shall be at the user's risk.

- 560.5m (Molonglo River 100 Year Floodline)
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MAJURA VALLEY ENGINEERING FEASIBILITY STUDY  
**WOOLSHED CREEK FLOOD STUDY**  
 Source: ACTPLA (2009), SMEC (2009)

AUG 2010  
 60143881



1:20,000 @ A3

**3-B**



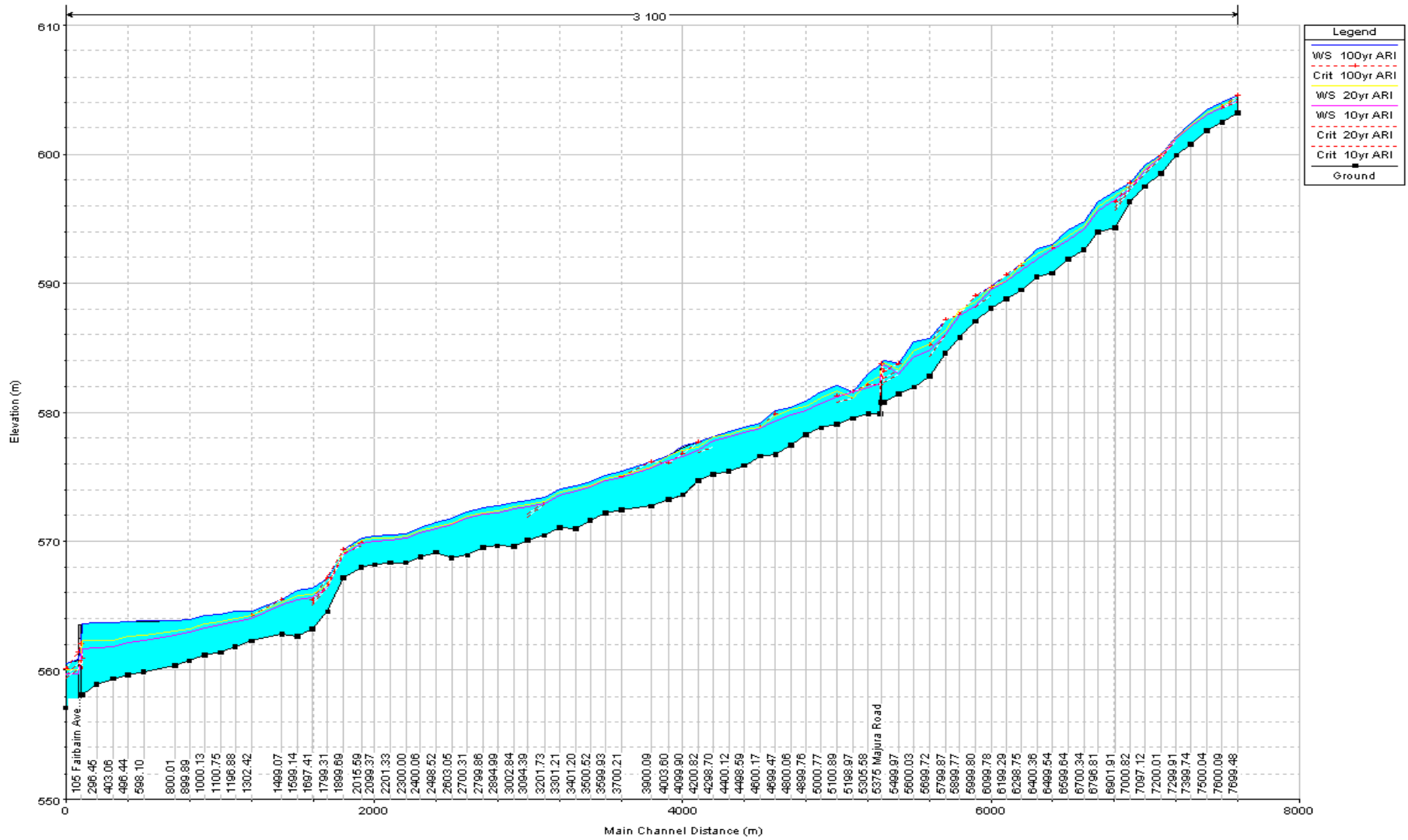


Figure 6 Woolshed Creek 100 year ARI Peak Flood Level Profile

### 5.3.2 Developed Conditions

The existing and developed peak flow discharges are similar with identical design storm durations. The stormwater detention system will be designed in the investigation areas to restrict post-development flows to predevelopment flows into Woolshed Creek.

It is noted that the flood inundation extent in the Majura Valley could be reduced with the inclusion of flood detention facilities within upper sub-catchments.

### 5.3.3 Comparison with Previous Studies

The flood extents in Woolshed Creek in the current study are narrower than the previous GHD 1998 study (Refer Figure 5). The reason for this difference includes:

- The cross sectional data used in the previous study HEC-RAS modelling were based on the survey taken at approximately 400 m intervals. The current HEC-RAS modelling is based on the survey carried out at 50 m interval cross sections and therefore the current study represents the Woolshed Creek geometry more accurately.
- The previous study was carried out along Woolshed Creek from the Molonglo River confluence to Majura Road (approximately 5760 m) upstream with the tail water level of 561.07 m AHD for 100 year ARI flood event. The current study was carried out from Fairbairn Avenue to upstream of Majura Road (approximately 7700 m) with the tail water level of 560.50 m AHD calculated from Normal Depth calculations. The current Ecwise 2000 hydrology study concluded that the Molonglo River 100 year ARI peak flood level in the close proximity of Woolshed Creek is between 559.17 m and 559.72 m AHD. It also indicated that the backwater effects of Molonglo River for the 100 year ARI flood event in Woolshed creek is within the creek.
- This study has a peak 100 year ARI discharge lower than used in the GHD study (refer Section 4.3.2).

As discussed in Section 5.3.1; due to the difference in Woolshed Creek and Molonglo River catchment areas and the spatial variation of rainfall that a 100 year ARI flood in Woolshed Creek will not occur at the same time as a 100 year ARI flood in the Molonglo River. Flooding in the Molonglo River will be of a lower ARI than in Woolshed Creek and the difference in catchment response times will result in the Woolshed Creek peak flood discharge entering the Molonglo River before the Molonglo River flood peak reaches the confluence between the Molonglo River and Woolshed Creek. It is therefore not appropriate to use a 100 year ARI Molonglo River tail water level when modelling peak 100 year ARI flood levels in Woolshed Creek. For this study the Woolshed Creek tail water level was not set as a peak flood level in the Molonglo River but rather calculated using the Woolshed Creek channel grade to produce a rating curve. This approach assumes no influence from the Molonglo River.

## 6.0 Majura Parkway and Very High Speed Train Developments

The Majura Parkway dual carriageway road extending for approximately 11.5 kilometres from Federal Highway to Monaro Highway is expected to be constructed in the near future through the Majura Valley. There is also potential for a Very High Speed Train (VHST) service to be constructed between Sydney, Canberra and Melbourne with a proposed alignment bisecting the study area, adjacent to the route of the Majura Parkway. These potential developments may have an impact on existing Woolshed Creek 100 year ARI peak flood levels and the potential developable area.

The Majura Parkway is located adjacent to Woolshed creek in Investigation Area C. The Majura Parkway road embankment details have not been incorporated into the hydraulic modelling in this flood study. The likely impact of the proposed Majura Parkway on flooding in Woolshed Creek could include increased peak flood levels and inundation extent along the eastern side of Woolshed Creek due to a reduction in Woolshed Creek floodplain storage. It is also possible that the Majura Parkway may attenuate inflows from the Mount Ainslie and Mount Majura sub-catchments which could increase flooding on the western side of the Majura Parkway unless hydraulic structures have an adequate capacity.

## 7.0 Further Investigation

- As the proposed development areas will have a storm water drainage system with roads, pits and pipes and lined floodway's, the peak flow values for individual sub-catchments may be higher than the calculated discharges from the XP- RAFTS modelling for individual sub-catchments with a shorter time of concentration. Detailed catchment studies should be carried out for specific development scenarios and retarding basins should be designed in the detailed design stages of the proposed development to attenuate post development flows to pre development flows.
- Detailed field survey should be carried out to 250 m either side of the entire creek up to Molonglo River and the Majura Parkway embankment should be incorporated into the terrain model. This will ensure that there is ground survey available in the location of Fairbairn Bridge. Rural catchment rainfall losses and stream Manning's roughness values should be reviewed in conjunction with any future modelling. Bridge details have to be surveyed to facilitate future hydraulic modelling. Further investigations have to be carried out on filling the existing erosion gullies and localised flood plains to increase the developable areas.
- Due to the complex nature of flows paths and floodplain storage that will occur when the channel capacity is exceeded, more accurate results will be achieved through two dimensional or linked one dimensional / two dimensional hydraulic modelling of Woolshed Creek. If there are any future plans to modify the existing creek geometry by removing the sharp bends to increase the developable area, one dimensional HEC-RAS modelling may be developed for the realigned Woolshed Creek.
- As previously discussed, a flood study of the Molonglo River is being undertaken by another consultant, and results were not available during the preparation of this report. ACTPLA advised that peak flood levels from a study by Ecowise in 2000 of the Molonglo River should be used. The impact of Molonglo River flooding on the study areas in the Majura Valley should be reviewed when the Molonglo study is complete.
- TaMS have advised that a flood study of Pialligo Brook (located within Investigation Area D) is currently being undertaken. The Pialligo Brook flood study should be reviewed and used to update Woolshed Creek sub-catchment delineation and catchment parameters if necessary when the results of the study are made available.



## Appendix A

# XP-RAFTS DATA



## Appendix A XP-RAFTS DATA

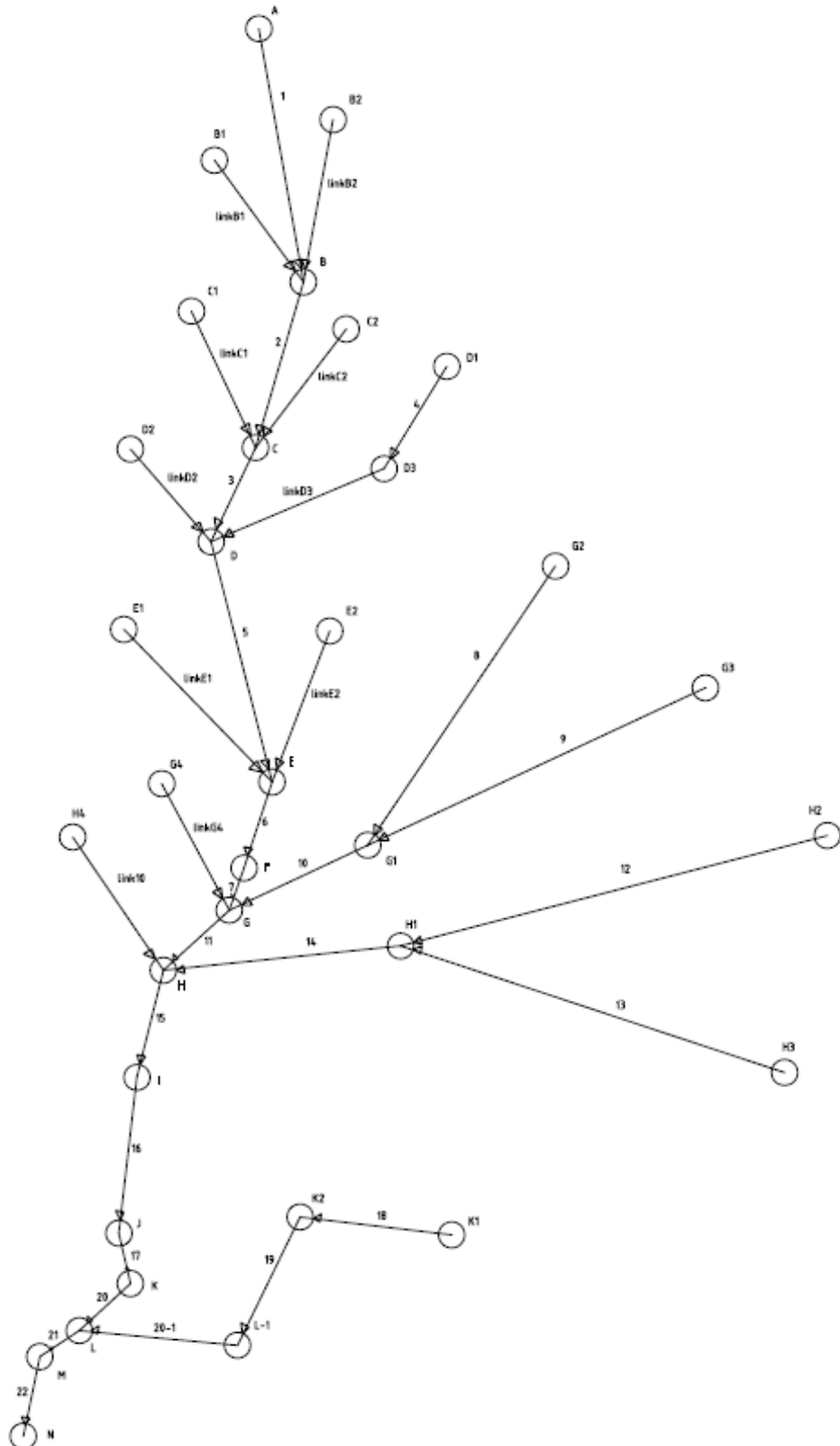


Figure 7 XP-RAFTS Model Layout – Existing Condition

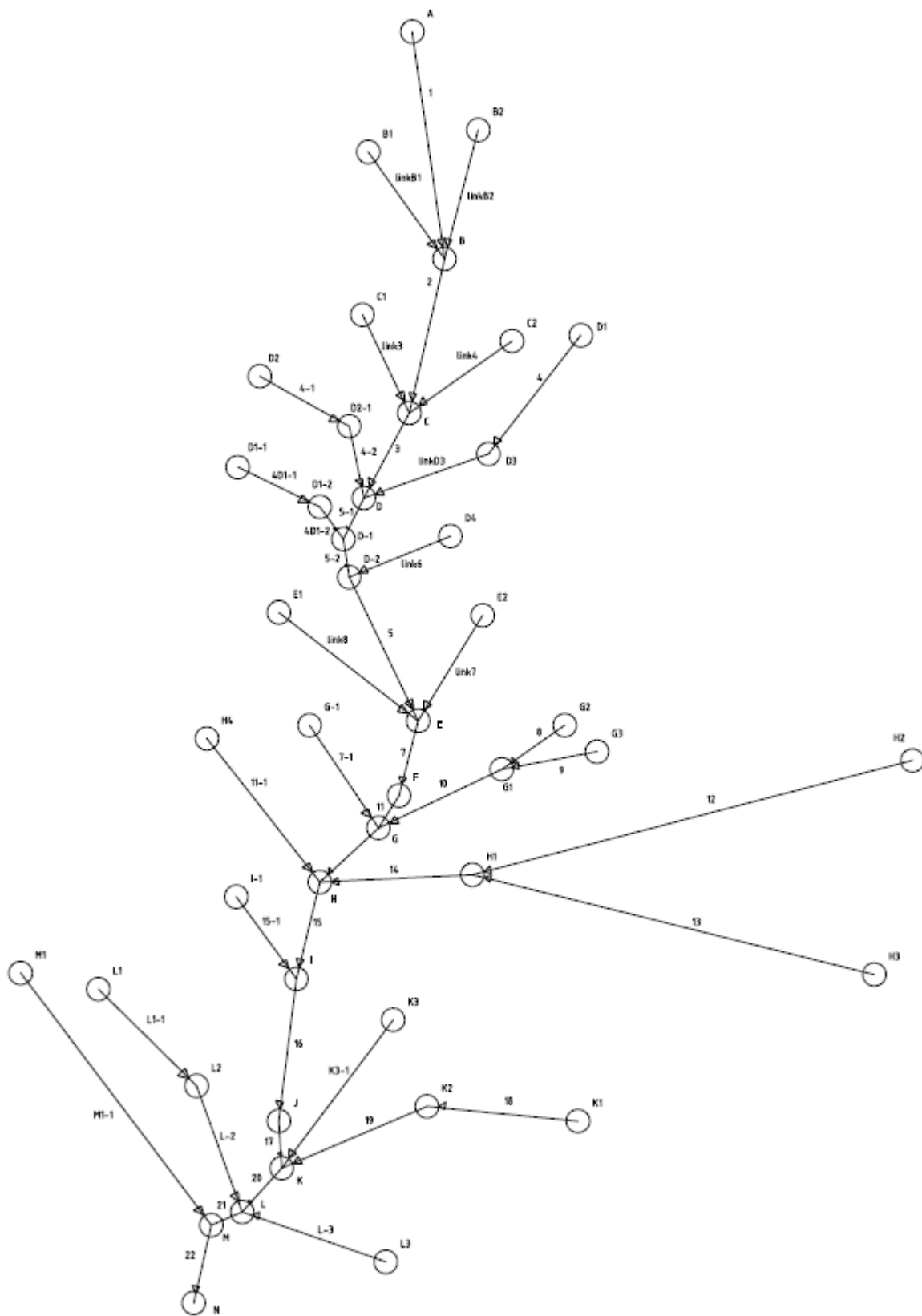


Figure 8 XP-RAFTS Model Layout – Developed Condition

## Appendix B

# HEC-RAS DATA



## Appendix B HEC-RAS DATA

Table 8 Detailed 100 year ARI HEC-RAS Output

NOTE: HEC-RAS river station changes are measured from 0 m at the downstream extent of the model.

River Sta (m)	Q Total (m3/s)	Min Ch El (m)	W.S. Elev (m)	Crit W.S. (m)	E.G. Elev (m)	E.G. Slope (m/m)	Vel Chnl (m/s)	Flow Area (m2)	Top Width (m)	Froude # Chl
7699.5	76.8	603.2	604.6	604.6	604.9	0.0	2.7	32.6	56.9	0.9
7600.1	76.8	602.5	604.0	603.7	604.1	0.0	1.4	68.1	106.9	0.4
7500.0	76.8	601.8	603.4		603.6	0.0	1.7	44.9	61.3	0.6
7399.7	76.8	600.8	602.4		602.6	0.0	1.7	43.5	85.0	0.7
7299.9	76.8	599.9	601.4		601.5	0.0	1.5	55.0	114.8	0.6
7200.0	76.8	598.5	600.0	599.9	600.1	0.0	2.0	42.3	98.0	0.8
7097.1	76.8	597.5	599.2		599.2	0.0	1.3	58.7	79.8	0.5
7000.8	76.8	596.4	597.8	597.8	598.3	0.0	3.0	26.1	29.7	1.0
6901.9	76.8	594.3	597.1	596.4	597.2	0.0	1.4	70.8	86.0	0.3
6796.8	76.8	594.0	596.4		596.7	0.0	2.7	28.8	24.6	0.8
6700.3	76.8	592.6	594.8		595.2	0.0	2.8	27.6	24.3	0.8
6599.6	76.8	591.9	594.1		594.3	0.0	1.8	41.7	26.8	0.5
6499.5	76.8	590.8	593.0	592.8	593.5	0.0	3.1	24.9	17.2	0.8
6400.4	76.8	590.5	592.7		592.8	0.0	1.5	76.1	174.5	0.4
6298.8	76.8	589.5	591.5	591.3	592.1	0.0	3.5	22.2	16.7	0.9
6199.3	76.8	588.8	590.6	590.6	590.8	0.0	1.8	66.8	279.1	0.6
6099.8	76.8	588.1	589.7	589.7	589.8	0.0	1.3	93.0	458.0	0.5
5999.8	76.8	587.1	589.0	589.0	589.1	0.0	1.9	67.8	275.2	0.6
5899.8	76.8	585.8	587.5	587.5	588.2	0.0	3.7	20.6	15.1	1.0
5799.9	96.2	584.5	587.2	587.2	587.4	0.0	2.1	69.9	176.9	0.5
5699.7	96.2	582.8	585.8	585.2	586.2	0.0	3.1	31.2	15.4	0.7
5600.0	96.2	581.9	585.4		585.5	0.0	1.6	73.5	109.9	0.4
5500.0	96.2	581.5	583.8	583.8	584.6	0.0	4.0	23.9	14.8	1.0
5402.5	96.2	580.8	584.0	583.2	584.1	0.0	1.7	78.7	118.6	0.4
5375.0	Bridge									
5305.6	96.2	579.9	583.0	582.2	583.3	0.0	2.5	42.7	93.2	0.6
5199.0	96.2	579.5	581.6	581.6	582.3	0.0	3.8	25.1	17.0	1.0
5100.9	96.2	579.1	582.1	581.3	582.3	0.0	2.3	49.3	74.8	0.5
5000.8	96.2	578.8	581.6		581.8	0.0	2.2	54.2	67.1	0.5
4899.8	96.2	578.3	580.8		581.1	0.0	2.4	41.4	43.1	0.7
4800.1	99.9	577.5	580.4		580.6	0.0	1.7	74.3	102.0	0.4
4699.5	99.9	576.8	580.1	579.9	580.2	0.0	1.7	84.8	153.4	0.4
4600.2	99.9	576.6	579.2	578.9	579.6	0.0	2.8	36.7	37.7	0.8
4498.6	99.9	575.9	578.9		579.0	0.0	1.4	93.2	115.8	0.3
4400.1	146.1	575.4	578.5		578.7	0.0	2.0	101.3	135.6	0.5
4298.7	146.1	575.2	578.1		578.3	0.0	2.2	112.6	218.5	0.5
4200.8	146.1	574.7	577.7	577.7	577.8	0.0	2.2	124.4	328.7	0.5
4099.9	146.1	573.6	577.3	576.8	577.4	0.0	1.2	224.7	430.2	0.3
4003.6	146.1	573.2	576.7	576.1	577.1	0.0	2.8	58.9	181.4	0.7
3900.1	146.1	572.7	576.2	576.2	576.3	0.0	2.0	139.5	554.3	0.5
3700.2	146.1	572.5	575.4	575.0	575.5	0.0	1.2	186.0	314.3	0.3
3599.9	195.2	572.2	575.2		575.3	0.0	1.5	182.3	253.7	0.4
3500.5	195.2	571.6	574.6		574.8	0.0	2.3	111.2	169.8	0.6
3401.2	195.2	570.9	574.3		574.4	0.0	1.4	211.8	289.8	0.3
3301.2	195.2	571.1	574.1		574.2	0.0	1.6	161.8	211.8	0.4
3201.7	195.2	570.5	573.4		573.6	0.0	2.9	107.3	165.1	0.6

River Sta	Q Total (m3/s)	Min Ch El (m)	W.S. Elev (m)	Crit W.S. (m)	E.G. Elev (m)	E.G. Slope (m/m)	Vel Chnl (m/s)	Flow Area (m2)	Top Width (m)	Froude # Chl
3094.4	195.2	570.1	573.2		573.2	0.0	1.5	189.0	199.2	0.3
3002.8	195.2	569.6	573.0		573.1	0.0	1.8	164.4	202.8	0.4
2895.0	195.2	569.6	572.7		572.8	0.0	1.6	195.0	250.6	0.3
2799.9	204.6	569.5	572.6		572.6	0.0	1.3	219.4	258.9	0.3
2700.3	204.6	568.9	572.3		572.4	0.0	1.8	164.4	209.5	0.4
2603.1	204.6	568.7	571.8		571.9	0.0	1.9	134.6	140.3	0.4
2498.5	204.6	569.2	571.5		571.6	0.0	1.7	149.3	155.3	0.4
2400.1	204.6	568.8	571.1		571.2	0.0	2.1	120.5	148.0	0.5
2300.0	204.6	568.4	570.6		570.8	0.0	2.1	123.9	156.1	0.5
2201.3	204.6	568.4	570.4		570.5	0.0	1.1	220.9	252.1	0.3
2099.4	204.6	568.2	570.4		570.4	0.0	0.8	341.7	457.7	0.2
2015.6	204.6	568.0	570.2	569.9	570.3	0.0	1.4	287.4	737.1	0.3
1899.7	204.6	567.2	569.4	569.4	569.7	0.0	2.8	86.8	143.9	0.9
1799.3	204.6	564.5	567.1	567.1	567.7	0.0	3.9	60.6	52.0	0.9
1697.4	204.6	563.2	566.4	565.5	566.4	0.0	1.4	168.5	114.8	0.3
1599.1	204.6	562.7	566.3		566.3	0.0	1.4	159.7	105.5	0.3
1499.1	208.4	562.8	565.5	565.5	566.0	0.0	3.3	73.8	89.7	0.8
1302.4	208.4	562.3	564.6	564.2	564.8	0.0	2.2	130.4	145.6	0.5
1196.9	208.4	561.8	564.5		564.6	0.0	1.1	250.0	248.1	0.2
1100.8	208.4	561.4	564.4		564.4	0.0	1.5	184.4	181.7	0.3
1000.1	208.4	561.2	564.3		564.3	0.0	1.2	243.1	209.3	0.2
899.9	236.8	560.8	564.0		564.1	0.0	2.0	144.7	99.8	0.4
800.0	236.8	560.4	563.9		564.0	0.0	1.4	205.6	125.8	0.3
598.1	236.8	559.9	563.8		563.8	0.0	1.0	301.1	178.7	0.2
496.4	236.8	559.7	563.8		563.8	0.0	1.0	268.2	130.5	0.2
403.1	236.8	559.3	563.6		563.7	0.0	1.6	177.2	86.6	0.3
296.5	240.6	558.9	563.6		563.7	0.0	0.8	360.4	150.1	0.1
202.2	240.6	558.1	563.6	560.9	563.6	0.0	1.0	304.0	119.1	0.1
105.0	Bridge									
100.3	240.6	557.1	560.5	560.2	560.9	0.0	3.2	90.5	64.2	0.7

Table 9 Detailed 20 year ARI HEC-RAS Output

River Sta	Q Total (m3/s)	Min Ch El (m)	W.S. Elev (m)	Crit W.S. (m)	E.G. Elev (m)	E.G. Slope (m/m)	Vel Chnl (m/s)	Flow Area (m2)	Top Width (m)	Froude # Chl
7699.5	46.7	603.2	604.3	604.3	604.6	0.0	2.5	19.1	35.7	1.0
7600.1	46.7	602.5	603.8	603.6	603.9	0.0	1.4	43.3	87.5	0.4
7500.0	46.7	601.8	603.2		603.3	0.0	1.4	33.3	43.8	0.5
7399.7	46.7	600.8	602.3		602.4	0.0	1.5	31.8	78.0	0.7
7299.9	46.7	599.9	601.2		601.3	0.0	1.3	39.0	100.5	0.6
7200.0	46.7	598.5	599.8	599.8	599.9	0.0	1.7	29.5	84.6	0.8
7097.1	46.7	597.5	598.9	598.7	599.0	0.0	1.2	38.8	67.3	0.5
7000.8	46.7	596.4	597.5	597.5	597.8	0.0	2.7	17.3	23.3	1.0
6901.9	46.7	594.3	596.7	595.9	596.8	0.0	1.5	39.3	74.0	0.4
6796.8	46.7	594.0	595.9		596.2	0.0	2.5	19.0	17.8	0.8
6700.3	46.7	592.6	594.4		594.7	0.0	2.4	19.3	20.3	0.8
6599.6	46.7	591.9	593.6		593.8	0.0	1.7	28.1	25.0	0.5
6499.5	46.7	590.8	592.9		593.1	0.0	2.1	22.7	16.3	0.6
6400.4	46.7	590.5	592.2		592.4	0.0	1.8	25.7	19.8	0.5
6298.8	46.7	589.5	591.4		591.7	0.0	2.1	21.8	16.2	0.6
6199.3	46.7	588.8	590.2	590.1	590.5	0.0	2.5	18.7	19.2	0.8
6099.8	46.7	588.1	589.7		589.7	0.0	1.1	66.4	445.1	0.4
5999.8	46.7	587.1	588.5	588.4	588.9	0.0	2.8	16.8	15.0	0.8
5899.8	46.7	585.8	587.9		588.0	0.0	1.2	48.7	132.6	0.4
5799.9	58.4	584.5	586.4	586.3	587.0	0.0	3.5	16.9	13.9	1.0
5699.7	58.4	582.8	585.3		585.6	0.0	2.4	24.3	13.9	0.6
5600.0	58.4	581.9	584.7		584.9	0.0	2.0	28.8	15.8	0.5
5500.0	58.4	581.5	583.3	583.3	583.9	0.0	3.6	16.5	13.0	1.0
5402.5	58.4	580.8	583.8	582.6	583.9	0.0	1.4	58.7	89.1	0.3
5375.0	Bridge									
5305.6	58.4	579.9	582.3		582.6	0.0	2.3	26.0	15.9	0.6
5199.0	58.4	579.5	581.1	581.1	581.7	0.0	3.4	17.1	14.6	1.0
5100.9	58.4	579.1	581.6	580.8	581.8	0.0	1.9	31.2	19.0	0.5
5000.8	58.4	578.8	581.1		581.3	0.0	2.0	28.7	20.4	0.5
4899.8	58.4	578.3	580.5		580.6	0.0	1.9	30.2	22.6	0.5
4800.1	60.7	577.5	580.2		580.3	0.0	1.3	51.2	81.8	0.3
4699.5	60.7	576.8	579.7		579.9	0.0	2.0	33.9	67.9	0.6
4600.2	60.7	576.6	578.9		579.1	0.0	2.1	29.0	24.8	0.6
4498.6	60.7	575.9	578.6		578.7	0.0	1.2	63.5	95.0	0.3
4400.1	87.2	575.4	578.3		578.4	0.0	1.7	70.9	119.2	0.4
4298.7	87.2	575.2	578.1	577.4	578.2	0.0	1.4	107.2	215.3	0.3
4200.8	87.2	574.7	577.2	576.9	577.7	0.0	3.2	28.3	32.0	0.8
4099.9	87.2	573.6	577.0		577.1	0.0	1.6	95.5	397.1	0.4
4003.6	87.2	573.2	576.7		576.8	0.0	1.7	56.3	162.9	0.4
3900.1	87.2	572.7	575.7	575.5	576.1	0.0	2.9	34.5	71.8	0.8
3700.2	87.2	572.5	575.1		575.2	0.0	1.2	108.0	221.3	0.3
3599.9	114.8	572.2	574.9		574.9	0.0	1.3	116.4	184.6	0.3
3500.5	114.8	571.6	574.4		574.5	0.0	2.0	74.7	133.7	0.6
3401.2	114.8	570.9	574.0		574.1	0.0	1.3	135.7	261.0	0.3
3301.2	114.8	571.1	573.8		573.9	0.0	1.4	109.9	177.0	0.4
3201.7	114.8	570.5	573.1	573.1	573.3	0.0	2.8	68.1	135.2	0.6
3094.4	114.8	570.1	572.9	572.2	572.9	0.0	1.3	131.2	161.1	0.3
3002.8	114.8	569.6	572.7		572.8	0.0	1.7	107.8	161.2	0.4

River Sta	Q Total (m3/s)	Min Ch El (m)	W.S. Elev (m)	Crit W.S. (m)	E.G. Elev (m)	E.G. Slope (m/m)	Vel Chnl (m/s)	Flow Area (m2)	Top Width (m)	Froude # Chl
2895.0	114.8	569.6	572.4		572.5	0.0	1.5	122.4	190.5	0.3
2799.9	120.6	569.5	572.2		572.3	0.0	1.2	140.3	205.4	0.3
2700.3	120.6	568.9	571.9		572.0	0.0	1.7	101.4	146.4	0.4
2603.1	120.6	568.7	571.4		571.5	0.0	1.6	90.9	115.3	0.4
2498.5	120.6	569.2	571.1		571.2	0.0	1.4	104.4	125.7	0.4
2400.1	120.6	568.8	570.8		570.9	0.0	1.8	83.1	121.1	0.5
2300.0	120.6	568.4	570.4		570.5	0.0	1.7	90.9	142.6	0.5
2201.3	120.6	568.4	570.3		570.3	0.0	0.8	177.7	238.2	0.2
2099.4	120.6	568.2	570.2		570.2	0.0	0.6	276.4	417.1	0.2
2015.6	120.6	568.0	570.1	569.6	570.1	0.0	1.5	178.3	725.2	0.4
1899.7	120.6	567.2	569.1	569.1	569.4	0.0	2.5	55.4	106.4	0.9
1799.3	120.6	564.5	566.6	566.7	567.2	0.0	3.7	37.3	40.6	1.0
1697.4	120.6	563.2	565.9	565.2	566.0	0.0	1.2	117.3	101.7	0.3
1599.1	120.6	562.7	565.8		565.8	0.0	1.2	114.4	91.3	0.3
1499.1	123.0	562.8	565.2	564.9	565.6	0.0	2.6	50.2	68.3	0.7
1302.4	123.0	562.3	564.2		564.4	0.0	2.0	81.5	104.5	0.5
1196.9	123.0	561.8	564.0		564.1	0.0	1.2	140.0	183.7	0.3
1100.8	123.0	561.4	563.8		563.9	0.0	1.6	97.0	113.0	0.4
1000.1	123.0	561.2	563.6		563.7	0.0	1.2	131.0	142.6	0.3
899.9	139.0	560.8	563.2		563.4	0.0	2.2	78.1	73.1	0.5
800.0	139.0	560.4	563.0		563.1	0.0	1.6	109.3	91.7	0.3
598.1	139.0	559.9	562.7		562.8	0.0	1.3	134.6	124.9	0.3
496.4	139.0	559.7	562.6		562.7	0.0	1.1	139.1	95.7	0.2
403.1	139.0	559.3	562.4		562.5	0.0	1.9	85.4	56.8	0.4
296.5	141.7	558.9	562.4		562.4	0.0	0.9	188.2	116.6	0.2
202.2	141.7	558.1	562.3	560.4	562.3	0.0	1.0	170.1	87.1	0.2
105.0	Bridge									
100.3	141.7	557.1	560.0	559.7	560.3	0.0	2.6	60.9	53.0	0.7

Table 10 Detailed 10 year ARI HEC-RAS Output

River Sta	Q Total (m3/s)	Min Ch El (m)	W.S. Elev (m)	Crit W.S. (m)	E.G. Elev (m)	E.G. Slope (m/m)	Vel Chnl (m/s)	Flow Area (m2)	Top Width (m)	Froude # Chl
7699.5	33.1	603.2	604.1	604.1	604.4	0.0	2.4	14.1	25.5	1.0
7600.1	33.1	602.5	603.6	603.5	603.7	0.0	1.3	31.5	76.6	0.5
7500.0	33.1	601.8	603.0		603.1	0.0	1.2	26.9	40.7	0.5
7399.7	33.1	600.8	602.2		602.3	0.0	1.3	25.7	74.4	0.6
7299.9	33.1	599.9	601.1	601.0	601.2	0.0	1.2	30.8	94.3	0.6
7200.0	33.1	598.5	599.7	599.7	599.8	0.0	1.5	23.5	78.9	0.8
7097.1	33.1	597.5	598.7	598.5	598.8	0.0	1.2	29.4	60.5	0.5
7000.8	33.1	596.4	597.3	597.3	597.6	0.0	2.5	13.1	20.4	1.0
6901.9	33.1	594.3	596.5	595.6	596.6	0.0	1.5	23.2	25.4	0.4
6796.8	33.1	594.0	595.6		595.9	0.0	2.4	14.1	13.9	0.7
6700.3	33.1	592.6	594.2	594.0	594.5	0.0	2.1	15.6	18.2	0.7
6599.6	33.1	591.9	593.3		593.5	0.0	1.6	21.1	23.2	0.5
6499.5	33.1	590.8	592.6		592.7	0.0	1.8	18.3	15.2	0.5
6400.4	33.1	590.5	591.9		592.0	0.0	1.7	19.4	18.3	0.5
6298.8	33.1	589.5	591.0		591.2	0.0	2.0	16.2	13.1	0.6
6199.3	33.1	588.8	590.2		590.4	0.0	1.8	18.3	19.1	0.6
6099.8	33.1	588.1	589.6	589.1	589.6	0.0	1.2	34.5	137.9	0.5
5999.8	33.1	587.1	588.3	588.2	588.6	0.0	2.6	12.9	14.2	0.9
5899.8	33.1	585.8	587.5		587.7	0.0	1.6	20.3	15.1	0.5
5799.9	41.2	584.5	586.1	586.1	586.6	0.0	3.2	12.9	12.6	1.0
5699.7	41.2	582.8	584.9	584.3	585.1	0.0	2.2	18.8	12.7	0.6
5600.0	41.2	581.9	584.3		584.5	0.0	1.8	22.8	14.1	0.5
5500.0	41.2	581.5	583.0	583.0	583.5	0.0	3.3	12.7	12.0	1.0
5402.5	41.2	580.8	583.7	582.3	583.8	0.0	1.1	49.8	84.1	0.3
5375.0	Bridge									
5305.6	41.2	579.9	581.9		582.1	0.0	2.0	20.3	14.4	0.6
5199.0	41.2	579.5	581.6		581.7	0.0	1.6	25.1	17.0	0.4
5100.9	41.2	579.1	581.2		581.4	0.0	1.7	24.3	17.1	0.5
5000.8	41.2	578.8	580.7		580.9	0.0	1.8	23.0	15.7	0.5
4899.8	41.2	578.3	580.1		580.3	0.0	1.8	22.9	20.0	0.5
4800.1	42.8	577.5	579.8		579.9	0.0	1.2	35.3	22.0	0.3
4699.5	42.8	576.8	579.3		579.5	0.0	2.1	21.0	17.2	0.6
4600.2	42.8	576.6	578.7		578.9	0.0	1.7	24.8	20.2	0.5
4498.6	42.8	575.9	578.5		578.5	0.0	1.1	48.2	82.3	0.3
4400.1	60.9	575.4	578.2		578.3	0.0	1.5	54.9	109.5	0.4
4298.7	60.9	575.2	577.8	577.0	577.9	0.0	1.8	50.3	133.7	0.4
4200.8	60.9	574.7	577.0		577.4	0.0	2.5	24.5	15.7	0.6
4099.9	60.9	573.6	576.6		576.7	0.0	1.7	42.2	55.4	0.4
4003.6	60.9	573.2	576.3		576.4	0.0	1.5	39.8	24.0	0.4
3900.1	60.9	572.7	575.6		575.9	0.0	2.2	30.2	45.1	0.6
3700.2	60.9	572.5	575.0		575.0	0.0	1.2	73.6	173.5	0.3
3599.9	79.8	572.2	574.7		574.7	0.0	1.2	85.6	151.7	0.3
3500.5	79.8	571.6	574.2		574.3	0.0	1.8	55.8	110.5	0.5
3401.2	79.8	570.9	573.9		573.9	0.0	1.3	95.3	204.8	0.3
3301.2	79.8	571.1	573.6		573.7	0.0	1.3	81.8	155.0	0.4
3201.7	79.8	570.5	573.0	573.0	573.2	0.0	2.5	52.1	120.7	0.6
3094.4	79.8	570.1	572.7	571.9	572.7	0.0	1.1	103.0	137.6	0.3
3002.8	79.8	569.6	572.5		572.6	0.0	1.5	80.7	138.3	0.3
2895.0	79.8	569.6	572.2		572.3	0.0	1.4	93.1	164.2	0.3

River Sta	Q Total (m3/s)	Min Ch El (m)	W.S. Elev (m)	Crit W.S. (m)	E.G. Elev (m)	E.G. Slope (m/m)	Vel Chnl (m/s)	Flow Area (m2)	Top Width (m)	Froude # Chl
2799.9	89.3	569.5	572.0		572.1	0.0	1.2	108.0	179.0	0.3
2700.3	89.3	568.9	571.8		571.9	0.0	1.6	76.8	122.3	0.4
2603.1	89.3	568.7	571.3		571.4	0.0	1.5	72.3	102.9	0.4
2498.5	89.3	569.2	571.0		571.0	0.0	1.2	85.6	110.8	0.3
2400.1	89.3	568.8	570.7		570.8	0.0	1.6	68.4	107.5	0.5
2300.0	89.3	568.4	570.2		570.3	0.0	1.7	71.6	134.0	0.5
2201.3	89.3	568.4	570.1		570.1	0.0	0.8	140.0	225.4	0.2
2099.4	89.3	568.2	570.0		570.1	0.0	0.6	205.4	396.0	0.2
2015.6	89.3	568.0	569.9		569.9	0.0	1.3	99.7	216.2	0.4
1899.7	89.3	567.2	568.9	568.9	569.2	0.0	2.5	40.4	82.0	0.9
1799.3	89.3	564.5	566.4	566.5	566.9	0.0	3.3	30.0	36.3	0.9
1697.4	89.3	563.2	565.6	565.1	565.7	0.0	1.2	89.9	94.0	0.3
1599.1	89.3	562.7	565.5		565.5	0.0	1.1	88.7	82.2	0.3
1499.1	85.6	562.8	565.0	564.6	565.3	0.0	2.2	39.8	35.2	0.6
1302.4	85.6	562.3	564.0		564.1	0.0	1.8	61.6	90.0	0.5
1196.9	85.6	561.8	563.8		563.8	0.0	1.2	97.3	150.1	0.3
1100.8	85.6	561.4	563.5		563.6	0.0	1.4	71.3	87.5	0.4
1000.1	85.6	561.2	563.3		563.4	0.0	1.2	94.7	121.5	0.3
899.9	98.9	560.8	563.0		563.1	0.0	2.0	59.9	63.9	0.5
800.0	98.9	560.4	562.8		562.8	0.0	1.4	85.7	81.2	0.3
598.1	98.9	559.9	562.3		562.4	0.0	1.5	85.3	106.8	0.4
496.4	98.9	559.7	562.1		562.2	0.0	1.2	96.0	84.0	0.3
403.1	98.9	559.3	561.8		562.0	0.0	1.9	57.7	45.6	0.5
296.5	101.0	558.9	561.8		561.8	0.0	1.0	123.3	96.3	0.2
202.2	101.0	558.1	561.7	560.1	561.7	0.0	1.0	120.3	74.6	0.2
105.0	Bridge									
100.3	101.0	557.1	559.7	559.4	560.0	0.0	2.3	47.6	47.0	0.6