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Rural Area Flood Study
Ropes, Reedy & Eastern Creeks
Final Report

Prepared for Fairfield City Council

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November 2013

Rural Area Flood Study

Ropes, Reedy and Eastern Creeks

Final Report

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Title :	Rural Area Flood Study Final Report
Author :	Joel Leister & Dexter Reynolds
Synopsis :	This report documents the methodology and results from the rural area flood study for Reedy Creek, Eastern Creek and Ropes Creek.

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EXECUTIVE SUMMARY

Fairfield City Council (FCC) commissioned BMT WBM Pty Ltd (BMT WBM) to undertake a flood study of three distinct yet adjoining catchments (Reedy Creek, Ropes Creek and Eastern Creek) as part of the Rural Area Flood Study. The study was undertaken in a manner consistent with the requirements of the NSW's Government's Floodplain Development Manual (NSW Government, 2005) and State Government's Flood Prone Land Policy.

The Reedy, Ropes and Eastern Creek systems consist of approximately 12 km of open channel of varying capacity and a series of small and large structures to convey flow beneath roads and access tracks. The catchments comprise a total area of approximately 22.5 square kilometres. The catchments are predominately used for farming and grazing, although there are two large quarries located at the downstream ends of both Reedy and Eastern Creeks.

The Reedy Creek catchment contains two well defined tributaries that have a confluence close to the downstream boundary; the Sydney Water Pipeline. Both branches are well incised open channels with little in the way of a broader floodplain.

The Ropes Creek catchment also contains two well defined tributaries which have a confluence at the downstream boundary forming the mapping limit of the study. Due to the nature of the catchment, both branches are well defined open channels with only a small area of floodplain near the outlet of the catchment.

The Eastern Creek catchment is formed from a single creek system. Whilst the creek alignment is relatively well vegetated, the surrounding floodplain has been extensively cleared. The creek itself is well defined and located in the base of the valley.

The flood study involved the development of a TUFLOW hydraulic model to simulate the flood behaviour of the study catchments. A direct rainfall modelling approach was adopted for this study. The developed TUFLOW model was set up to include the natural creek system as a 1D stream network dynamically linked to the 2D domain to ensure accurate representation of the channel conveyance and to ensure that the floodplain flow was modelled in two dimensions. The TUFLOW model was used to derive flood levels and flood extents for the 20, 50, 100, 500 and 2000 year ARI flood events as well as the Probable Maximum Flood.

The flood modelling results have demonstrated the following flood behaviour:

- Flooding within the Reedy Creek catchment is generally contained within the channels, the exception is between Horsley Road and Burnley Road where overbank flooding is observed in the 1 in 20 year ARI and larger flood events. In all modelled events, Horsley Road and Burnley Road (the two key east-west roads through the catchment) are cut by floodwaters.

- Flooding in the Ropes Creek catchment is generally well contained within the depression and valleys of the creek system during all modelled flood events. There are some noticeable areas of overbank flooding downstream of Selkirk Avenue and between Elizabeth Drive and Selkirk Avenue in the 1 in 20 year ARI flood event. The overbank flooding becomes more pronounced along the western arm of Ropes Creek as the modelled flood events increases in rarity, however, the eastern arm remains relatively well confined.

- Flooding in the Eastern Creek catchment is relatively well confined, with the exception of the overbank flooding which is evident downstream of Chandos Road in all modelled flood events. The two main roads through the catchment, Chandos Road and The Horsley Drive, remain free from flooding for all events up to and including the 1 in 100 year ARI flood event. Overbank flooding between Horsley Drive and Chandos Road is evident in the 1 in 100 year ARI flood event.

The Interim Flood Risk Precinct Mapping has been developed based upon the flood modelling results. The High Flood Risk Precinct identifies regions of excessively high flood depth, flow velocity, or some combination of both. The Medium and Low Flood Risk Precincts follow the same extents as the 100 year ARI and PMF event flood extents respectively.

Using the flood modelling results developed as part of this study, FCC can identify those properties in the study area affected by flooding from Reedy, Ropes and Eastern Creeks and update the Section 149 Notations for these properties as required.

The results and outcomes from this study can be used as a basis for the development of management strategies in the subsequent Rural Area Floodplain Risk Management Study

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1 INTRODUCTION

1.1 Background

Fairfield City Council (FCC) commissioned BMT WBM Pty Ltd (BMT WBM) to undertake a flood study of three distinct yet adjoining catchments (Reedy Creek, Ropes Creek and Eastern Creek) as part of the Rural Area Flood Study. The study was undertaken in a manner consistent with the requirements of the NSW Flood Prone Land Policy and the process described in the NSW Government's Floodplain Development Manual (NSW Government, 2005).

Fairfield LGA covers an area of approximately 102.5 square kilometres, and includes two major river catchments, The Georges River Catchment and the Hawkesbury Nepean Catchment. The three catchments included as part of the Rural Area Flood Study are subcatchments of the Hawkesbury Nepean Catchment.

1.2 Study Area

The study area is divided into three distinct catchments; Reedy Creek, Ropes Creek and Eastern Creek and covers the extents as shown in Figure 1-1. The study area is limited by the catchment extents to the East and South, by the Sydney Water Supply pipeline, and Blacktown LGA boundary to the North and the Fairfield/Penrith LGA boundary to the West.

The three creek catchments (Ropes Creek, Reedy Creek and Eastern Creek) are located in a predominantly rural area in the western portion of the Fairfield Local Government Area (LGA). The creeks themselves are part of the South Creek catchment, which in turn is part of the Hawkesbury-Nepean River catchment.

The creek systems consist of approximately 12 km of open channel of varying capacity and a series of culvert and bridges to convey flow beneath roads and access tracks. The three catchments comprise an area of approximately 22.5 square kilometres. The Reedy Creek and Ropes Creek catchments are zoned as Rural Landscape or Primary Production Small Lots, whilst the Eastern Creek catchment is predominately zoned as 'Western Sydney Parklands" and are predominately used for farming and grazing. However, the catchments also include zones of rural residential living. The study area includes two large quarries located at the downstream ends of both Reedy and Eastern Creeks in the suburbs of Horsley Park and Cecil Park and a large number of farm dams located throughout the catchments

The Reedy Creek catchment (Figure 1-1) contains two well defined tributaries that have a confluence close to the downstream boundary. Both branches are well incised channels with little in the way of a broad floodplain.

The Ropes Creek catchment (Figure 1-1) also contains two well defined tributaries which converge at the downstream boundary forming the mapping limit of the study. Due to the nature of the catchment, both branches are well defined channels with only a small area of floodplain near the outlet of the catchment.

The Eastern Creek catchment (Figure 1-1) is formed from a single creek system. Whilst the creek alignment is relatively well vegetated, the surrounding floodplain has been extensively cleared. The creek itself is well defined within the floodplain.

The creeks within the study catchment were generally fairly narrow (often less than 5 metres in width) and there was evidence along the creeks of old creek alignments that created numerous ponds and depressions alongside the creek itself.

All three catchments (Reedy Creek, Ropes Creek and Eastern Creek) have been extensively cleared of vegetation away from the waterways for agricultural activities to take place within the catchment. Catchment slopes along the main waterways are generally less than 1%, especially in the lower reaches. However, slopes of up to 10% are evident in the upper parts of the catchment away from the main creek alignment. Based on the CSIRO soils data, the catchments predominately consist of hard acidic red soils, with hard neutral and acidic yellow mottled soils likely to be present in the valleys. Ironside gravel is also likely to occur within these soil types.

1.3 History of Flooding

The Reedy Creek, Ropes Creek and Eastern Creek catchments have been subject to regular flooding and a continuous history of studies since 1957 (refer to section 2.1 for details). Records of flooding in the Ropes Creek catchment go back to at least 1949.

Information provided by Council indicates that major flooding occurred in the catchments in August 1986 and April 1988, however, there are no stream gauges located within the creek systems to record the historic flows of the study catchments.

1.4 Purpose of the Study

This current study aims to determine the mainstream flooding conditions, including flood levels, flow rates and flood risk, in the study area in an integrated manner, in line with the previous studies recently undertaken for FCC and in line with the NSW Floodplain Development Manual.

Subsequently, FCC intends to use the latest flood information from this study to update the Section 149 Certificates for the flood affected properties within the study area. As per the floodplain management framework set out in the Floodplain Development Manual 2005, this Flood Study is part of a process that subsequently involves the undertaking of a Floodplain Risk Management Study and development of a Floodplain Risk Management Plan. The Flood Study will be used as the basis for developing a Floodplain Risk Management Study and Plan for the Flood prone land within the study area, in which the end result of the process will be the development of management measures so future flood risk can be managed, reduced or eliminated.

The floodplain for this Study is considered as all land that is potentially at risk from flooding up to the Probable Maximum Flood (PMF), as defined in the Floodplain Development Manual (NSW Government, 2005). Consequently, a number of flood events, up to, and including the PMF are required to be assessed as part of this Study

1.5 Key Objectives

The key objectives of this study are to:

1. Develop a digital terrain model (DTM) for the study area based upon aerial laser survey (LiDAR) of the entire Fairfield LGA provided by FCC.

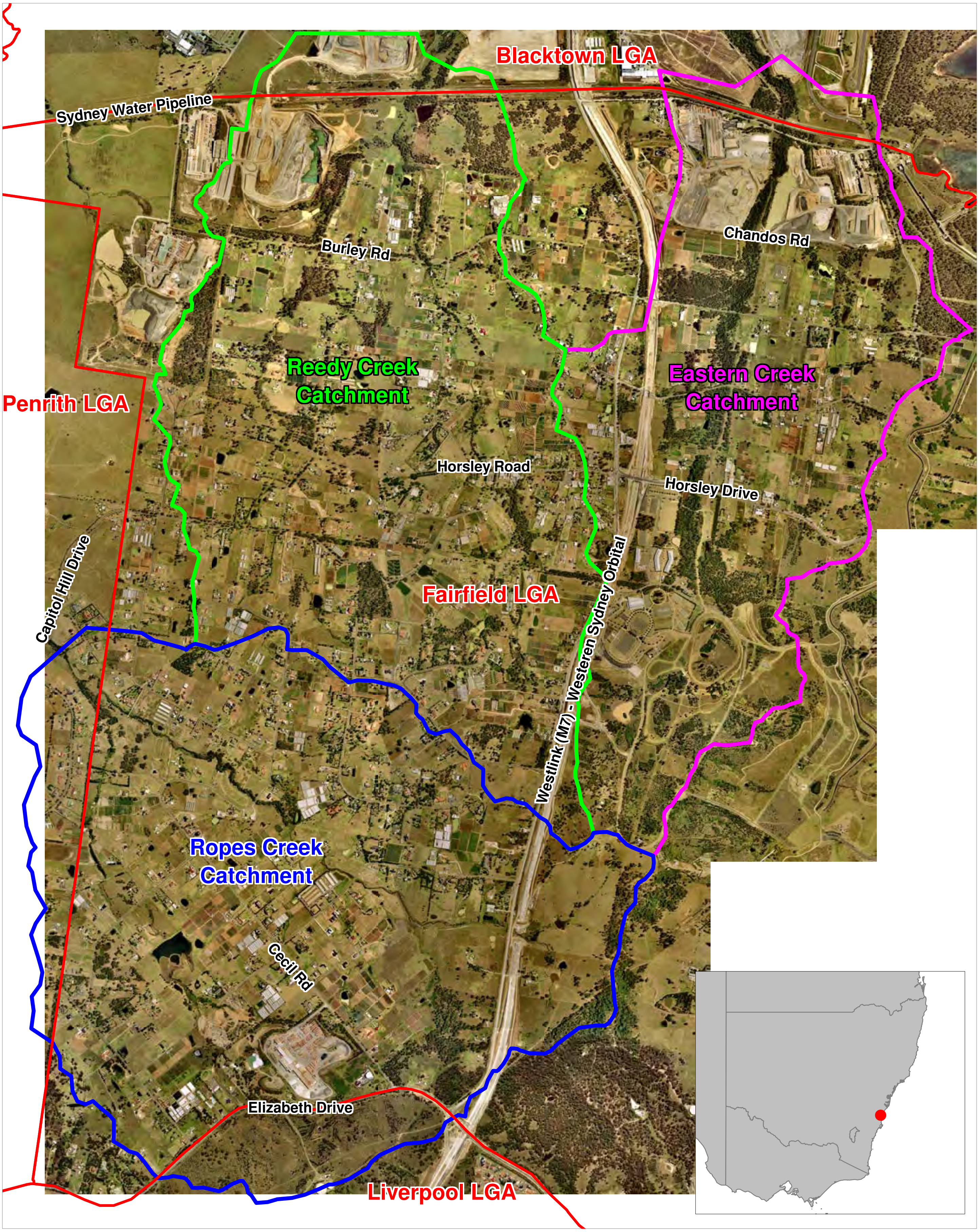
2. Develop a direct rainfall TUFLOW model hydraulic model for each of the three catchments included in the study area.

3. Compare the direct rainfall TUFLOW model to the traditional modelling approach of applying the outputs from a rainfall-runoff model (RAFTS) to the hydraulic model.

4. Undertake a sensitivity analysis to determine the influence on the flooding behaviour of parameter selection and the impact of blocked drainage structures.

5. Define the nature and extent of flood behaviour for selected design events up and including the PMF by providing information on flood level, velocity and distribution of floodwaters across the floodplain.

6. Produce a report, including flood behaviour mapping and flood risk precinct mapping, detailing the methodology and results from the above tasks.



Title:

Fairfield Rural Area Flood Study
Locality Map

Figure: **1 - 1**

Rev: **C**

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2 AVAILABLE DATA

2.1 Previous Studies

There have been a number of studies that are of relevance to the Rural Area Flood Study that have been previously undertaken. These studies are summarised below:

- Willing & Partners (1991) undertook a Floodplain Management Study for South Creek, covering areas west of Wallgrove Rd. The overall objective was to develop a floodplain management plan in accordance with the Floodplain Development Manual (NSW Government 2005). The principal requirement was to identify and assess works and measures aimed at reducing the impact and losses relating to flooding and water quality. Hydrologic and hydraulic analyses, using Department of Water Resources (DWR) models, were undertaken to evaluate water quantity and quality management strategies for the catchment.

- Dalland & Lucas (1991) prepared a Catchment Management Plan for the Horsley Park Residential Development Area. The main objectives of the study were to identify drainage reserves and flood affected areas and prepare design guidelines and conceptual designs for future drainage systems.

- The Department of Water Resources (1992) completed the Eastern Creek Flood Study which estimated 100-year discharges, velocities and levels for Eastern Creek downstream of the Sydney Water Supply Pipeline.

- Fairfield City Council (1994) undertook the Eastern Creek, Ropes Creek and Reedy Creek Flood Study. This flood study was used to define the flood behaviour within the study catchments. Since this modelling was undertaken, new techniques and data have become available that can improve the understanding of the flood behaviour within the catchments. Improving the understanding of the flood behaviour within the study catchments is a key reason why the current study is being undertaken.

- Fairfield Consulting Services (2006a) prepared a Review of Flooding Constraints in Horsley Village Area. This report was commissioned by council's City Outcomes Department to gain a better understanding of the flooding constraints and ecological impacts of any proposed changes around the Horsley Village area.

- Fairfield Consulting Services (2006b), at the request of City Outcomes Department, undertook a localised flood study of Reedy Creek in the Horsley Village area, and the floodplain was mapped up to the 100-year ARI flood extent.

- Patterson Britton & Partners (2007) issued a Draft Report related to the Update and Review of South Creek Flood Study using RMA-2 computer software. This study includes the lower reaches of Ropes Creek (however, it does not include the modelling of the section of Ropes Creek included in the current study).

In addition to the studies listed above, Fairfield City Council had developed an XP-RAFTS hydrologic model of the Reedy Creek catchment. The extent of this model was limited to the Reedy Creek study area and did not include either Eastern or Ropes Creeks.

The previous studies were used to provide background data for the current study and give context to the current study. The flood modelling undertaken as part of the current study utilises methods and techniques which are different to those adopted in previous studies. Consequently, direct comparisons of the previous studies to the current study have not been undertaken.

2.2 Topographic Survey

2.2.1 Airborne Laser Survey

FCC provided BMT WBM with topographic data from airborne laser survey (LiDAR) that had been flown over the entire Fairfield LGA in 2003. A Digital Terrain Model (DTM) was created by creating a triangular irregular network (TIN) from the LiDAR points using the computer package Vertical Mapper. The TIN was then converted into a raster format DTM. The DTM covers the entirety of the three catchments included in this study.

Within the flood mapping area the sampling resolution for the DTM is 1.0m. Previous studies undertaken by BMT WBM have shown that this level of detail is well suited to simulating the topography of rural environments for hydraulic modelling.

The DTM used in the TUFLOW hydraulic models is presented in Figure 2-1 (Reedy Creek), Figure 2-2 (Ropes Creek) and Figure 2-3 (Eastern Creek).

2.2.2 Ground Survey

Additional field survey was undertaken by FCC surveyors between July and November 2009 to improve the definition of the waterways in each of the three study catchments. Field survey was also utilised to capture detailed data of drainage structures and features that were not reliably captured by the LiDAR data. The additional field survey was not built into the DTM, rather it was directly included in the hydraulic models.

FCC surveyors captured 207 cross sections along Reedy Creek, 142 cross sections along Ropes Creek and 115 cross sections along Eastern Creek. In addition, 31 structures along Reedy Creek, 20 structures along Ropes Creek and 22 structures along Eastern Creek were surveyed. These structures included culverts, bridges and weirs; and including details of the Sydney Water Pipeline.

Survey of the hydraulic structures within the study catchments of Reedy, Ropes and Eastern Creeks was also collected during the collection of cross section survey. The structure survey generally included details of invert and obvert levels, soffit levels, deck levels, details of piers and details of railings (where present).

Digital copies of the ground survey that was undertaken as part of the Rural Area Flood Study have been provided to FCC as part of the data handover DVD.

2.3 GIS Data

All relevant data for the drainage systems was provided by FCC. The data was comprehensively reviewed to identify any significant data gaps (including missing structure data) and to gain a complete understanding of issues within the study area. Data gaps that were identified were filled based on the information collected by FCC surveyors (refer to Section 2.2.2)

Additional project related GIS data was sourced from Council's GIS system. In particular, the following data were supplied:

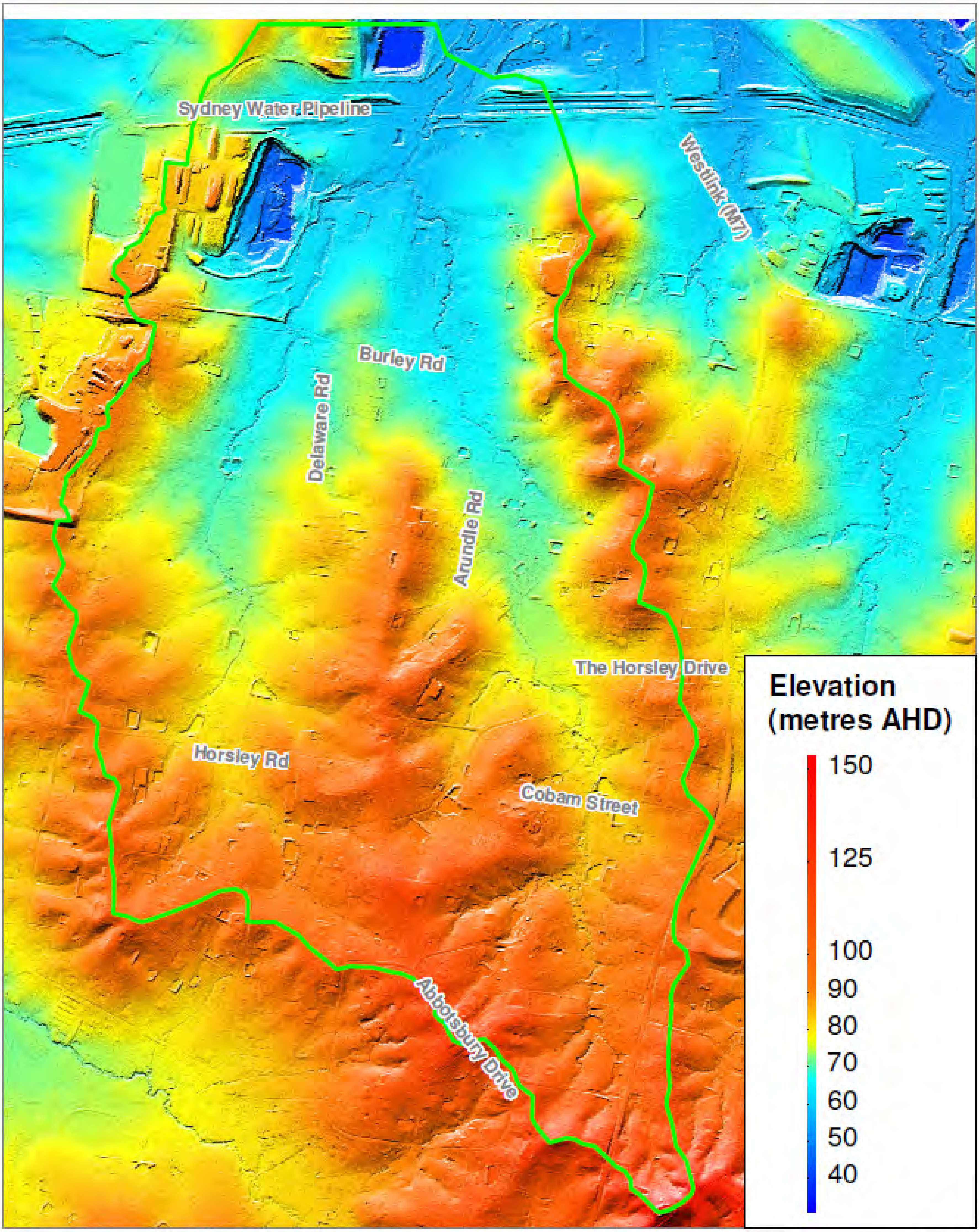
- cadastral information over the study area;
- planning scheme zones over the catchment (LEP 1994); and
- aerial photography (2005).

2.4 Site Inspection

Following commissioning of the study, an inception meeting was held between FCC representatives and BMT WBM project staff (Michael Turnley). During this meeting background data was supplied, project documentation was exchanged and the scope of works was discussed and approved. BMT WBM project staff undertook a site inspection at this time to determine site specific data, including Manning's 'n' values for the catchments and identify any structures that would require additional survey. Structures identified as requiring additional survey were included in the survey undertaken by FCC surveyors (as described in Section 2.2.2).

2.5 Summary

The data that has been collected and discussed in the previous sections is of sufficient quality to undertake the flood modelling required to understand the flooding behaviour of the Reedy Creek, Ropes Creek and Eastern Creek catchments and to achieve the objectives of the Study.



Title:

Reedy Creek
Digital Terrain Model

Figure: **2 - 1**

Rev: **A**

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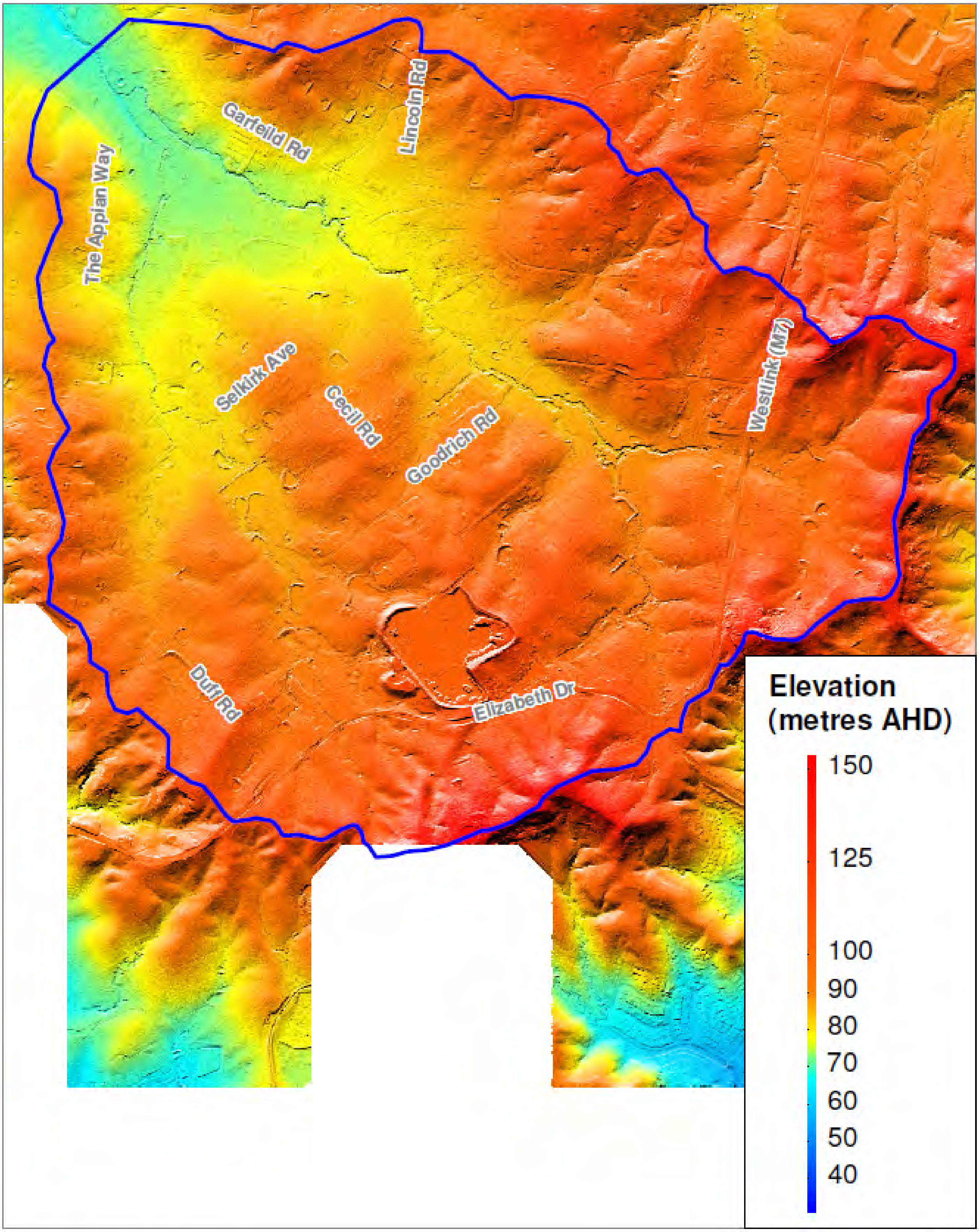

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Ropes Creek
Digital Terrain Model

Figure: 2 - 2

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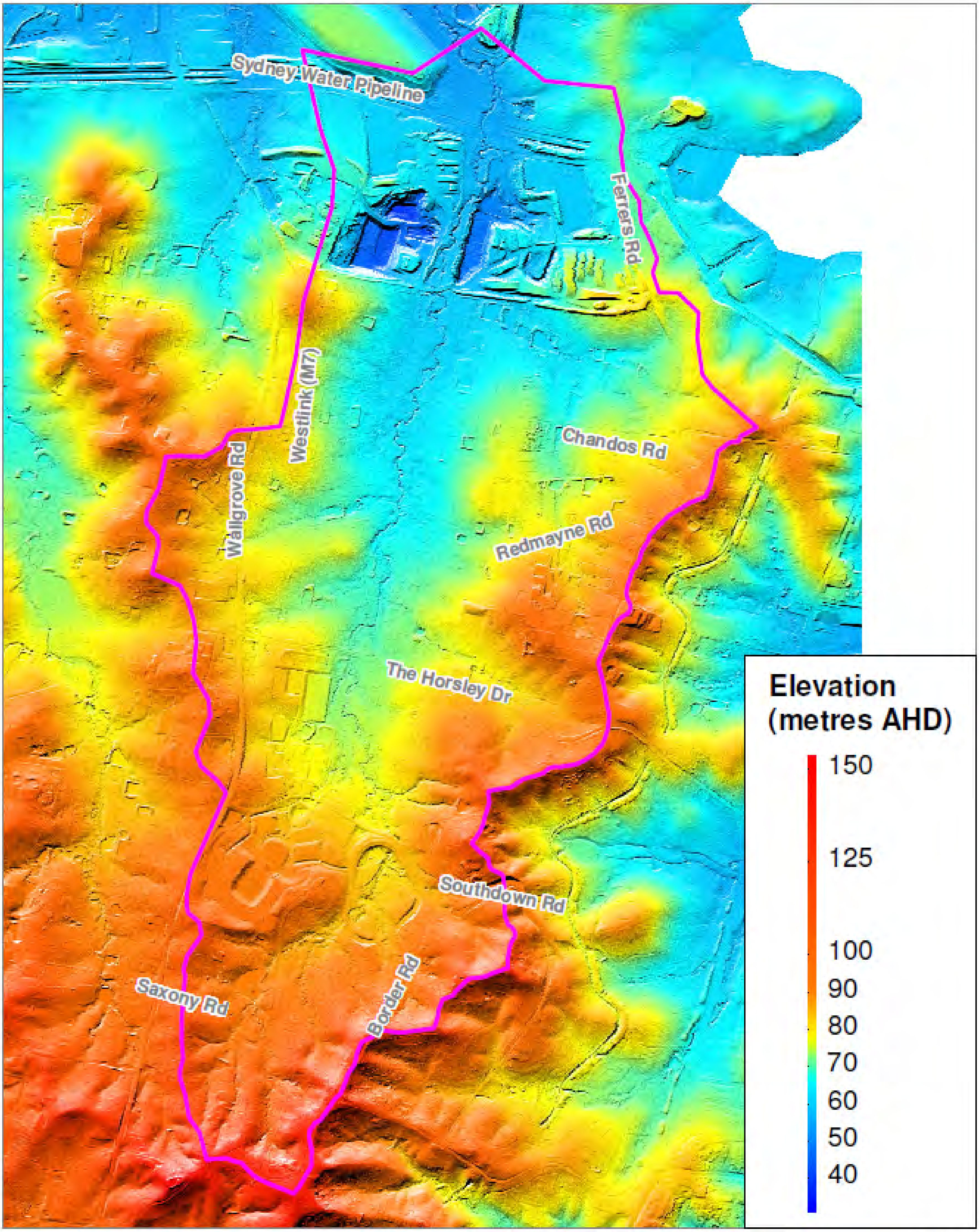

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Eastern Creek Digital Terrain Model	**2 - 3**	**A**

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3 HYDROLOGIC MODELLING

The modelling approach adopted for this study was to apply the rainfall directly to the hydraulic model. Consequently, there is no hydrologic model to provide inflow boundaries for the hydraulic model. With the direct rainfall modelling approach, all the rainfall losses were processed by TUFLOW prior to application of the boundaries to the hydraulic model, and routing was undertaken by the hydraulic model.

Direct rainfall modelling was adopted for this study as it would provide detailed flood modelling and flood behaviour mapping for not only the main creeks within the catchment, but also all the tributaries within the study area.

Direct rainfall modelling is a relatively new feature of hydraulic modelling and it is still being tested on a number of catchments to ensure it is reliably representing the flood behaviour of a given catchment. Therefore, it is recommended that the results from a direct rainfall model be calibrated against a gauge station within the catchment or compared to the traditional modelling approach of using a rainfall-runoff model to provide boundaries to the hydraulic model.

In the case of the Rural Area Flood Study, a RAFTS model that has previously been developed for the Reedy Creek catchment was used to apply boundaries to the Reedy Creek TUFLOW model. This traditional model was used as a comparison with the direct rainfall model. The calibration process is documented in a latter section of this report.

3.1 Direct Rainfall Modelling

3.1.1 Up to 100 year ARI Rainfall

FCC provided BMT WBM with rainfall intensities (mm/hr) for the various durations and return periods under investigation. The Intensity Frequency Duration (IFD) values provided were based on a location (33.875 °S 150.925°E) issued on April 1997 by Hydrometeorological Advisory Service. The IFD intensities were converted into hyetographs using the standard distributions for each rainfall event as described in Australian Rainfall and Runoff (1987).

3.1.2 500y, 2000y ARI and PMP Rainfall

The Bureau of Meteorology has developed a number of methods to determine the Probable Maximum Precipitation (PMP). For the study catchments, the appropriate methods were the Generalised Short Duration Method (GSDM) for events up to and including the 6 hour duration; and the Generalised Southeast Australia Method (GSAM) for rainfall durations between 24 and 96 hours. For events between the 6 and 24 hour durations, the rainfall intensity for the given duration is determined by interpolation for rainfall intensities derived from both GSDM and GSAM methodologies.

The 500 year ARI was calculated in accordance with the procedures described in section 1.6, Book 2 (Design Rainfall Considerations), Australian Rainfall and Runoff (1987).

The 2000 year ARI events were interpolated using the graphical methodology outlined in AR&R and the aforementioned rainfall methods. For each of the storm durations the 50, 100, 500 year and PMP rainfall depths were plotted on a log graph and a curve was fitted to the resultant points, the 2000 year ARI rainfall depth was then read from the graph. For the purposes of the plots, the PMP was calculated to be a 1,000,000 year ARI event as outlined in section 1.5, Book 6 (Estimation of Large and Extreme Floods), Australian Rainfall and Runoff (1997).

The GSDM temporal pattern was assigned to the 500 and 2000 year ARI as AR&R does not recommend using the same temporal pattern that is used for smaller events (events between 30 year ARI and 100 year ARI). This is important to note as the GSDM temporal pattern is smoother, without the rainfall burst that the standard AR&R temporal patterns exhibit. Figure 3-1 below illustrates the difference between the two temporal patterns, the vertical (y) axis shows the percentage of total rainfall not rainfall depth in mm. The large burst in the AR&R temporal pattern can result in an increased localised flood extent in the upper parts of a catchment. This burst may result in the seemingly illogical case of the 100 year ARI event producing a greater flood extent than a 2000 year ARI event in this localised area. Further down the catchment the 2000 year ARI event will result in a greater extent than the 100 year ARI event.

For further explanation refer to The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method (2003) and Australian Rainfall and Runoff (1987).

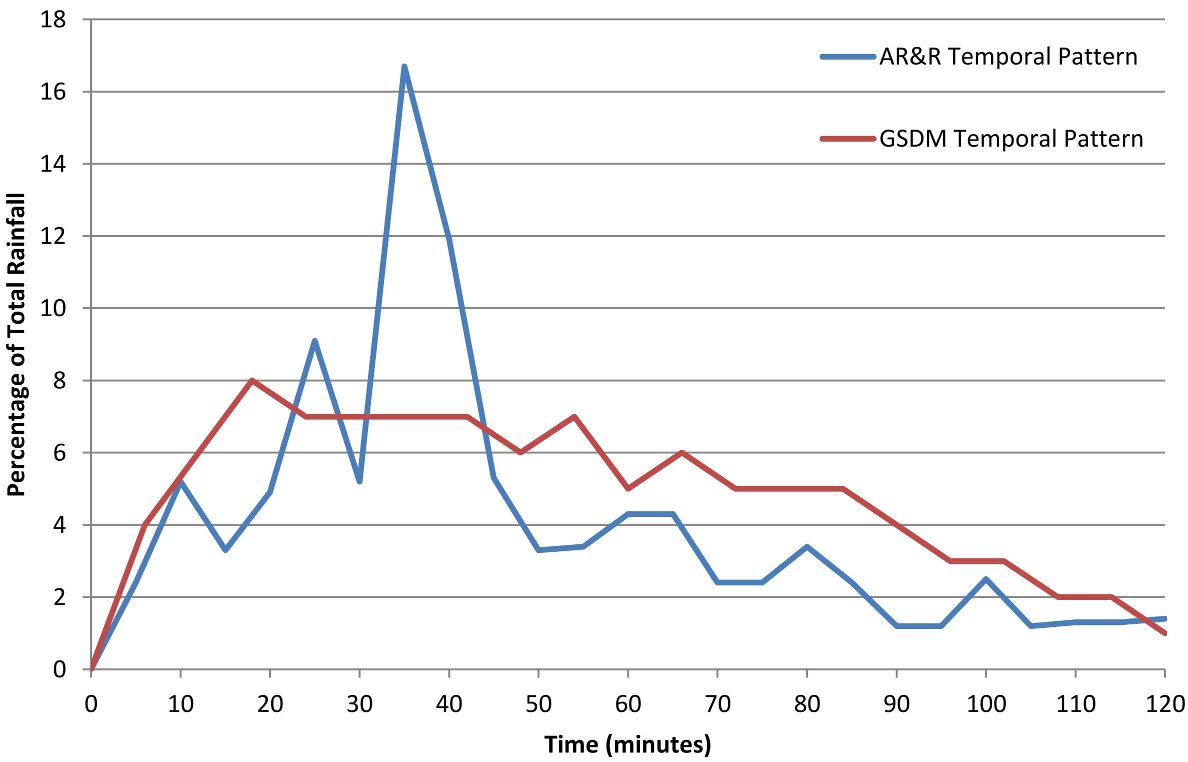


Figure 3-1 Temporal Pattern Comparison (2 hour duration)

3.1.3 Summary

A summary of the calculated rainfall depths for each event are detailed in Table 3-1. Table 3-1 does not include rainfall depths for all modelled events, and has been presented to give an indication as to how the rainfall depth varies between storm duration and storm frequency.

Table 3-1 Summary of Rainfall Depths (mm)

		Duration (hours)					
		2	3	6	9	12	18
ARI	20	69.9	81.0	105.5	123.6	138.6	163.3
	50	80.7	94.5	123.8	145.5	163.7	193.7
	100	89.4	104.8	137.6	162.1	182.5	216.7
	500	115.7	134.3	172.8	200.0		
	2000	150.9	176.7	231.8	265.6		
	PMF	483.4	570.0	742.8			

4 HYDRAULIC MODELLING

4.1 Development of Hydraulic Model

Individual hydraulic models of Reedy, Ropes and Eastern Creek were developed in the hydrodynamic modelling package, TUFLOW. TUFLOW is a fully 2D hydraulic modelling package with the ability to dynamically nest 1D elements. For Reedy, Ropes and Eastern Creeks, the overland flow paths and storages were modelled in the 2D domain, whilst the open channel flow (where cross sections were available) and structures were modelled as 1D elements, dynamically linked to the 2D domain.

The final TUFLOW models were run using TUFLOW version 2012-05-AE-iDP-w64. The TUFLOW manual recommends that direct rainfall models are run using the double precision version of TUFLOW due to the increased precision of the calculations required when determining extremely shallow water flow, a situation that occurs in direct rainfall models.

4.2 1D Domain Setup

The 1D model network can provide more refined model results for creeks that are too small to be accurately modelled into the 2D domain. The location of 1D network within the Reedy, Ropes and Eastern Creek catchments was determined based on the DEM and aerial photography, however, the representation of the 1D network was based upon the survey information. In each catchment, the 1D network consisted of natural open channels, hydraulic structures (bridges and culverts) and weirs (to model the flow when the bridges and culverts were overtopped).

The streams and channels represented in the modelling include:

- **Reedy Creek** – Reedy Creek (West) downstream of Horsley Road and Reedy Creek (East) downstream of Barbaro Lane
- **Ropes Creek** – Ropes Creek (West) from the storage upstream of Selkirk Avenue and Ropes Creek (East) downstream of Wallgrove Road
- **Eastern Creek** – Eastern Creek from upstream of Horsley Drive

The 1D elements including the open channels, pipe culverts and bridges were modelled using the survey data collected by the FCC surveyors. These were modelled as 1D components dynamically linked to the 2D domain so as to allow an interchange of water between domains.

Figure 4-1, Figure 4-2 and Figure 4-3 shows the TUFLOW model setup for Reedy, Ropes and Eastern Creeks respectively, including the locations of the embedded 1D network.

4.3 2D Domain Setup

The 2D model domains cover the entirety of the Ropes Creek, Reedy Creek and Eastern Creek catchments as shown in Figure 4-1, Figure 4-2 and Figure 4-3 respectively. The geometry of the 2D models was established by constructing a uniform grid of square elements. One of the key considerations in establishing a 2D hydraulic model relates to the selection of an appropriate grid element size. Element size affects the resolution, or degree of accuracy, of the representation of the physical properties of the study area as well as the size of the computer model and its resulting run times. Selecting a very small grid element size will result in both a higher resolution, however, the increase model resolution results in significantly longer model run times.

In adopting the element size for the Rural Area Flood Study, the above issues were considered in conjunction with the final objectives of the study. Given the size of the study area, run times could be kept to an acceptable length using a small grid element size of 5 m. A 5 m element size over the study area provided a good definition of land shape, key hydraulic controls and waterways (that were not already modelled in the 1D network). This grid size is also consistent with previous mainstream flood studies undertaken within the Fairfield LGA.

The modelled catchments of Reedy, Ropes and Eastern Creeks contain a large number of farm dams and storages that have the potential for significant attenuation of flood flows within the catchment. Each of these farm dams and storages has been included in the TUFLOW model based upon the terrain information captured from the DEM only. As a consequence, the embankment heights of the dams and storages may not be accurately represented in the TUFLOW model, however, the potential impact of this is negated by the assumed initial conditions (refer to Section 4.7).

Whilst the study catchments are predominately rural, a number a building exist within the catchment. These buildings have not been explicitly modelled within the 2D domain, rather they have been represented using the hydraulic model roughness. This approach is considered appropriate in rural areas where flows will not be significantly impacted by the presence of buildings.

4.4 Model Hydraulic Roughness

The initial hydraulic roughness (Manning's 'n' value) for the various land uses within the Reedy, Ropes and Eastern Creek catchments were based upon accepted industry values. However, the final adopted values were determined based upon the comparisons between the results of the direct rainfall model and the RAFTS-TUFLOW model (as discussed further in Section 4.10). The values were adjusted within reasonable bounds and the values adopted for the study, along with their justification are detailed in Section 4.10.

4.5 Hydraulic Structures

The collected survey information (Section 2.2.2) was used to include various structures (bridges and culverts) in the hydraulic model.

Bridges and culverts were always modelled as 1D elements, and where a roadway was present over the structure, a weir was used representing the flow over the road. The weir was represented using either the available survey information or road levels derived from the DEM. Where bridge railings (either as guard rails or pedestrian hand rails) were present, they included in the representation of the structure within the 1D model. Under existing conditions, these railing were modelled as a 50% blockage to the flow (based upon the available survey information for a number of the structures throughout the catchment)

4.6 Quarries

There are quarries located close to the downstream extents of both the Reedy Creek and Eastern Creek catchments (located adjacent to the Sydney Water Pipeline). In previous iteration of the modelling, these quarries were included in the hydraulic model, resulting in large volumes of water ponded in the base of the quarry.

Following discussion with FCC, it was decided that for the final modelling, these quarries should be removed from the topography to represent the catchments as if the quarries no longer exist. This was achieved by interpolating the terrain levels from around the boundary of the relevant lots to 'fill' the quarry in. The adopted terrain levels were based off the existing terrain surrounding the quarry as determined by the LiDAR data. Whilst this has removed the storage from the model, the underlying terrain is not reflective of the likely ground surface once the quarry site has been remediated. Consequently the mapping in these regions has not been shown to reflect the uncertainty of the flood extents and flood hazard in these regions following the removal of the quarry. The flood extents and flood hazard in the regions upstream of the quarries are unlikely to be significantly impacted by the removal of the quarries. However, it is recommended that the hydraulic models are re-run to confirm the flood extents and flood hazards once the ground surfaces in these areas have been determined.

4.7 Initial Conditions

The rural nature of the study catchments means that a large number of farm dams are present within each of the three catchments. When a large number of dams exist, there is potential for significant attenuation of flood flows to occur.

All the farm dams within the three study catchments were modelled with an initial water level. This water level, equivalent to the lowest point in the dam wall, meant that any additional water that fell on, or flowed into the dam, would result in the dam overflowing. This approach to the representation of the farm dams is considered conservative as it assumes no storage is available in any of the farm dams.

4.8 Design Events

The 20, 50 and 100 year ARI design storm events were modelled in TUFLOW for a number of storm durations: 2 hour, 3 hour, 6 hour, 9 hour, 12 hour and 18 hour. The 500 and 2000 year ARI design storm events modelled for the 2 hour, 3 hour, 6 hour and 9 hour durations. The PMP events modelled were for the 30 minute, 1 hour, 2 hour, 4 hour and 6 hour durations. The critical storm duration varied across the catchment and hence a variety of storm durations were modelled to ensure the maximum flood heights across the entire catchment are captured. Generally, the 9 hour storm duration was critical across the majority of the catchments.

Due to the different temporal patterns used for events of 100 year ARI or less, and the 500 year ARI and greater, it can be noted that in the upper most branches of the reach the smaller events may at times produce a greater flood extent than the larger less frequent events. This is discussed in detail in Section 3.1.2.

4.9 Boundary Conditions

4.9.1 Inflow Hydrographs

The direct rainfall modelling approach does not require individual inflow boundaries to be applied at discreet locations throughout the hydraulic model. Rather, a rainfall hyetograph is applied across the entire model domain. The rainfall hyetographs were developed using the methods described in Section 3 and applied using the temporal patterns as defined in Australian Rainfall and Runoff (IE Aust 1987).

4.9.2 Rainfall Losses

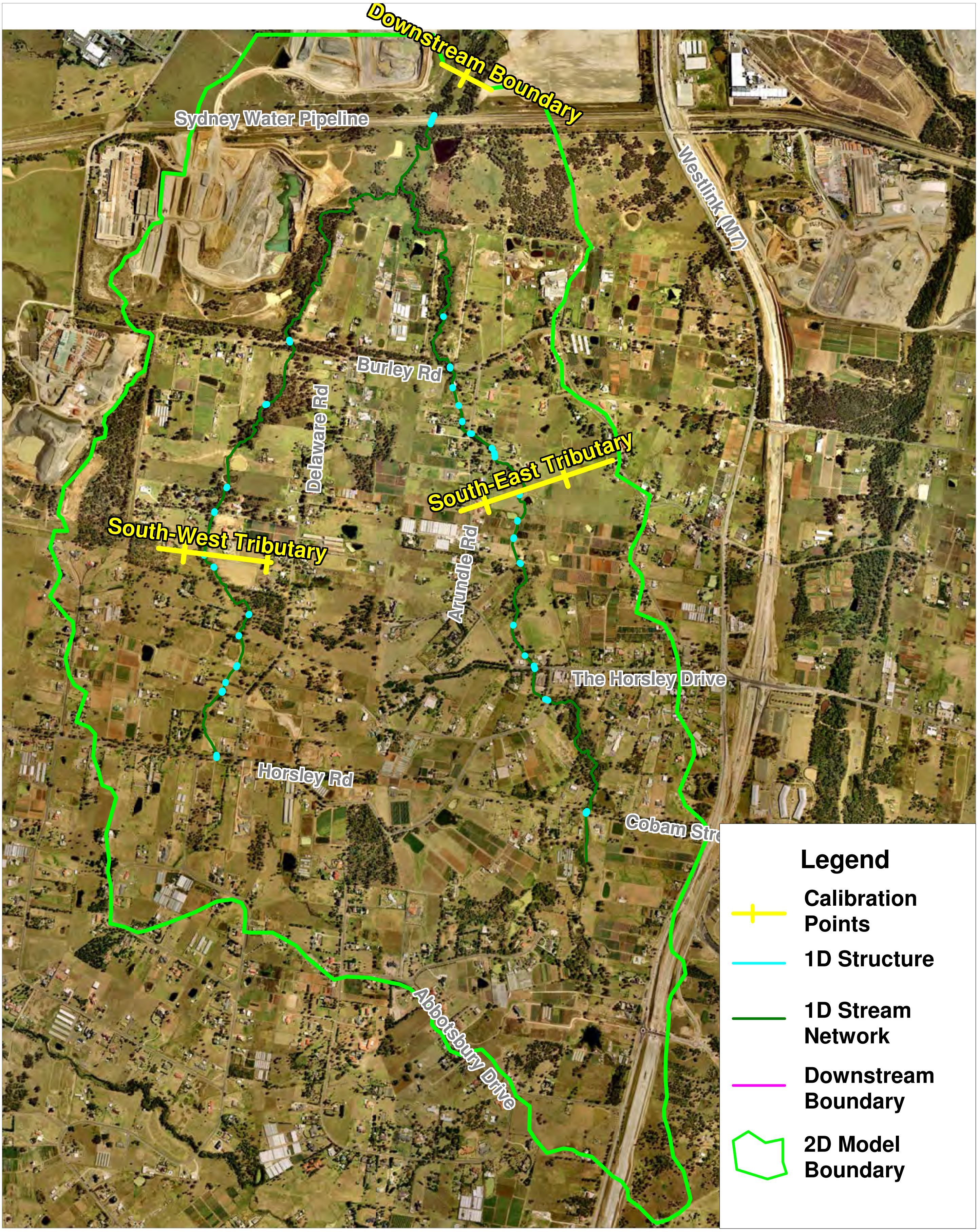
The direct rainfall modelling approach allows for different initial loss and continuing loss values to be applied to each different land use type within the hydraulic model. The adopted initial loss and continuing loss values were adjusted as part of the comparison process to ensure that the direct rainfall model was able to replicate the performance of the traditional modelling approach. The adopted loss values are presented in Section 4.10.3.

4.9.3 Downstream Boundary Conditions

Stage-discharge boundaries (or rating curves) were used as the downstream boundaries in each of the three TUFLOW models. TUFLOW automatically generated the stage-discharge relationship based upon a user defined slope. This calculation is based upon a Manning's flow calculation which uses the underlying model roughness in conjunction with the elevations of the hydraulic model at the location of the downstream boundary to determine the stage-discharge relationship for the defined slope at the boundary location. The adopted slopes were consistent with the ground slopes at the downstream extent of the model.

The downstream boundaries were located away from the area of interest to ensure that boundary effects did not influence the flood mapping. The Reedy Creek and Ropes Creek downstream boundaries are located 200 metres downstream, whilst the Eastern Creek downstream boundary is located 300 metres downstream of the area that is to be flood mapped.

The Sydney Water Pipeline located at the downstream extent of the Eastern Creek catchment has not been included in the modelling as only the details of the piers have been surveyed. Not including the Sydney Water Pipeline may result in underestimating flood levels (and therefore flood hazard) in the region immediately upstream of the pipeline. However, this region is currently occupied by a quarry and, as discussed in Section 4.6, detailed mapping has not been provided in this area.



Title:

Reedy Creek TUFLOW Model

Figure: 4-1

Rev: A

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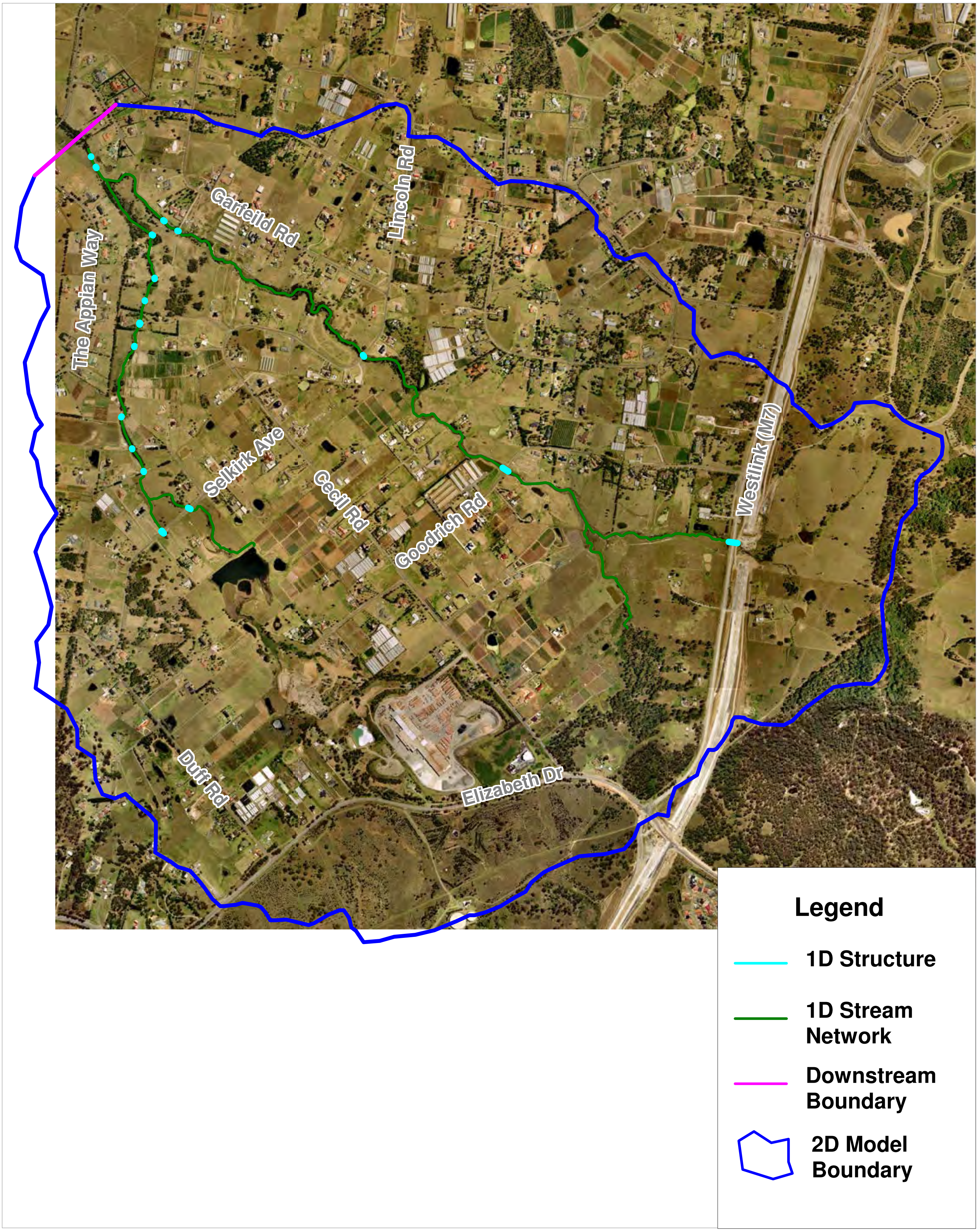

Title:

Ropes Creek TUFLOW Model

Figure: 4-2

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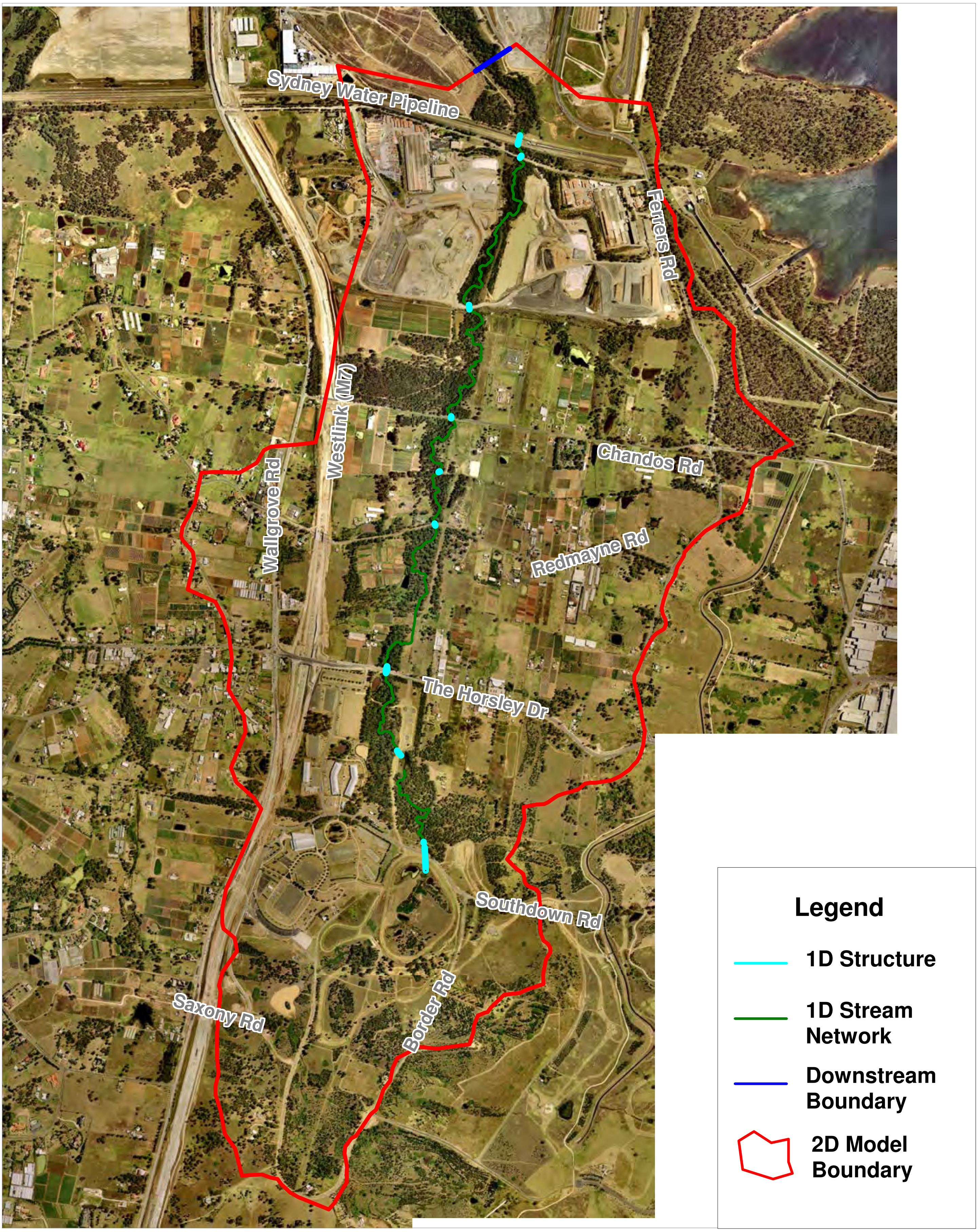

Title:

Eastern Creek TUFLOW Model

Figure: 4-3

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4.10 Comparison with the Direct Rainfall Model

4.10.1 Background

Direct rainfall modelling is a relatively new feature of hydraulic modelling therefore, it is recommended that the results from a direct rainfall model be calibrated against a gauge station within the catchment or calibrated to the traditional modelling approach of using a rainfall-runoff model to provide boundaries to the hydraulic model.

Calibrating a model to gauge data is the preferred method; unfortunately no gauge data is available for the Rope, Reedy or Eastern Creek catchments. Therefore it was necessary to resort to comparing to a more traditional hydrologic model.

In the case of the Rural Area Flood Study, a RAFTS model that has previously been developed by FCC for the Reedy Creek catchment was used to apply boundaries to the Reedy Creek TUFLOW model. This 'traditional' model was used as a comparison to the direct rainfall model. The comparison process is documented below.

4.10.2 Traditional Hydrologic/Hydraulic Model

Using a hydrologic model to generate runoff hydrographs and applying those hydrographs as boundaries to a hydraulic model is referred to as a 'traditional' modelling approach. This approach has been historically used in flood modelling and mapping projects. It is well understood, has been verified by numerous studies and consequently the approach is justifiable and defendable. A traditional model is therefore considered a sound basis for comparing and calibrating a direct rainfall model.

For Reedy Creek, an XP-RAFTS hydrologic model was used to simulate the rainfall-runoff processes within the catchment. The RAFTS model used for the calibration was provided by FCC. BMT WBM undertook a brief review of the hydrologic model to ensure that it was 'fit for purpose'. This review did not include the checking of sub-catchment delineation, impervious and pervious catchment areas or the adopted routing parameters. BMT WBM determined that the provided model was 'fit for purpose' and was subsequently used in the calibration process.

The resulting runoff hydrographs generated by RAFTS for each local sub catchment were applied as inflow boundaries to the TUFLOW model at locations throughout the catchment. The results from this traditional model were then used to calibrate the direct rainfall model using the methodology outlined in Section 4.10.3.

4.10.3 Methodology

The process of comparing the direct rainfall model to the traditional model was carried out in a logical and systematic way. The results of the traditional model at the downstream boundary and at selected locations upstream were extracted to provide a comparison to the results from the direct rainfall model at these locations. Model parameters were adjusted within reasonable bounds to improve the comparison between the models where appropriate. This approach is consistent with previous direct rainfall studies and the current advice detailed in the draft chapter of Australian Rainfall and Runoff – Chapter 15 2D Modelling of Urban and Rural Floodplains which recommends comparison between the direct rainfall model and alternative models (the traditional approach) in lieu of calibration (stream gauge) data.

Two benchmarks were selected to ensure that the model was calibrated correctly; peak flow and total model volume. Additionally, the timing of the peaks was compared to check the timing of peak flows throughout the catchment. Whilst comparing the outflow volume can be useful, it does not take into account floodwaters that may have ponded in depressions and de-facto storages throughout the model. The total model volume takes into account the floodwater volume left in the model at the completion of the simulation.

Six parameters were varied during the calibration process. These were the Initial and Continuing Loss, and the four parameters devoted to varying Manning's 'n' roughness with flow depth (the Manning's 'n' values for a given depth and the depths themselves).

Initial and Continuing Losses (mm/hr), are losses associated with initial wetting of soil and infiltration/evaporation respectively as well as interception and depression losses. The initial and continuing losses are set in the direct rainfall TUFLOW model according to the underlying land use. The average initial and continual loss for each sub-catchment (used in the RAFTS model) and those applied to the various land uses within the direct rainfall model were compared to ensure consistency. Where differences between the applied initial and continuing losses applied to the RAFTS and the direct rainfall model were significant, the values were reviewed and updated as appropriate to ensure agreement. This process was undertaken to ensure an appropriate comparison could be made between the RAFTS based hydraulic model and the direct rainfall model.

For Manning's 'n'; two different Manning's roughness values can be stipulated, an initial Manning's for shallow water depths and a value as flood depths increase. Due to the nature of a direct rainfall model it is important to vary the Manning's roughness with water depth. Typically in a rural environment the initial roughness is higher for shallow floodwaters and decreases as the depth increases. For instance, low flood depths through grass are rough, however once flood depths are at a greater height than the grass the roughness drops until the grass is pushed over by the flood waters and the roughness drops even further. A key to the planning layer (FCC LEP 1994) land use and descriptions of each is listed below in Table 4-1 and the adopted parameters based on the results of the model calibration are listed in Table 4-2.

Table 4-1 LEP (1994) Description

Land use	Land use description
Tag Key from LEP = 1(a)	Farm land including farm houses, roads and associated infrastructure
Tag Key from LEP = 1(b)	Quarry
Tag Key from LEP = 1(v)	Commercial
Tag Key from LEP = 5(a)	Pipeline easement and associated infrastructure
Tag Key from LEP = 5(b)	Sealed road and verge
Tag Key from LEP = 5(c)	Sealed road and verge
Tag Key from LEP = 6(a)	Sports ground
Tag Key from LEP = 6(d)	Farm land including farm houses, roads and associated infrastructure
Tag Key from LEP = SREP 31	Farm land including farm houses, roads and associated infrastructure

Table 4-2 Adopted Manning's 'n' Coefficients and Hydrological Loss Values

Land use	Lower Depth (m)	Lower 'n'	Upper Depth (m)	Upper 'n'	Initial Loss (mm)	Continuing Loss (mm/hr)
Agriculture	0.1	0.300	0.2	0.050	11.5	2.5
Forest / High Density Veg	0.1	0.300	0.2	0.160	11.5	2.5
Forest and Grassland / Medium Veg	0.1	0.300	0.2	0.110	11.5	2.5
Grassland / No Veg	0.1	0.300	0.2	0.050	10.0	2.0
Grazing / Low Veg	0.1	0.300	0.2	0.035	11.5	2.5
Transport	0.1	0.030	0.2	0.025	2.0	0.5
Commercial	0.1	0.075	0.2	0.250	2.0	0.5
Natural Waterway / Lake	0.1	0.025	0.2	0.045	12.0	2.5
Quarry	0.1	0.030	0.2	0.050	5.0	2.5
Waterway – No/Low Veg	0.1	0.300	0.2	0.045	11.5	2.5
Waterway – Med. Veg	0.1	0.300	0.2	0.055	11.5	2.5
Waterway – High Veg	0.1	0.300	0.2	0.080	11.5	2.5
Tag Key from LEP = 1(a)	0.1	0.300	0.2	0.085	11.5	2.5
Tag Key from LEP = 1(b)	0.1	0.030	0.2	0.050	5.0	2.5
Tag Key from LEP = 1(v)	0.1	0.075	0.2	0.200	2.0	1.0
Tag Key from LEP = 5(a)	0.1	0.300	0.2	0.050	11.5	2.5
Tag Key from LEP = 5(b)	0.1	0.030	0.2	0.025	2.0	0.5
Tag Key from LEP = 5(c)	0.1	0.030	0.2	0.025	2.0	0.5
Tag Key from LEP = 6(a)	0.1	0.300	0.2	0.050	11.5	2.5
Tag Key from LEP = 6(d)	0.1	0.300	0.2	0.080	11.5	2.5
Tag Key from LEP = SREP 31	0.1	0.300	0.2	0.080	11.5	2.5

4.10.4 Comparison

Nine permutations were performed varying the six parameters (either increasing or decreasing the values by a percentage value) detailed above before a final set of parameters were deemed satisfactory.

The final parameters selected resulted in both targets (Peak Discharge at the Outlet and Total Model Volume) being within +/-10% when comparing all modelled durations. Comparing flood levels between the two models would not be an appropriate comparison due to the direct rainfall model distributing the water more widely throughout the hydraulic model resulting in additional ponded water throughout the catchment, which would render level comparisons difficult to make. Total volume in the TUFLOW direct rainfall model is typically within +/-2% of the RAFTS TUFLOW model. The 9 hour event had been previously determined to be the critical event within the catchment and therefore more emphasis was placed on getting the calibration 'right' for this event. The 9 hour event was shown to have the total volume and outlet peak discharge comparisons within 1%.

In addition to ensuring that volumes and peaks were similar between the two modelling approaches it is important to consider the shape of the hydrographs at the downstream boundary. Comparisons of the hydrographs for each of the 100 year ARI events are presented in Appendix B, whilst the hydrograph for the critical 9 hour storm duration is shown in Figure 4-4. Generally the shapes of the hydrographs are well represented, although the entire hydrograph has experienced a time shift. This is due to the additional time taken in the direct rainfall model for the water to flow from the catchment as water is applied away from the main creek alignment.

Table 4-3 Results at Downstream Outlet – 100 Year ARI

Model Run	Criterion	2hr	3hr	6hr	9hr	12hr	18hr
RAFTS - TUFLOW	Total Volume (m^3)	605500	721100	959300	1122400	1257100	1484600
	Outlet Peak Discharge (m^3/s)	60.3	62.4	67.1	77.9	67.3	50.5
Final Calibration	*Total Volume (m^3)*	*628100*	*737700*	*960500*	*1108200*	*1229000*	*1410200*
	Outlet Peak Discharge (m^3/s)	*65.3*	*63.1*	*68.5*	*78.9*	*69.8*	*50.2*

Table 4-4 Comparison of Results at Downstream Outlet – 100 Year ARI

Model Run	Criterion	2hr	3hr	6hr	9hr	12hr	18hr
Final Calibration	*Total Volume (m^3)*	*4%*	*2%*	*0%*	*-1%*	*-2%*	*-5%*
	Outlet Peak Discharge (m^3/s)	*8%*	*1%*	*2%*	*1%*	*4%*	*-1%*

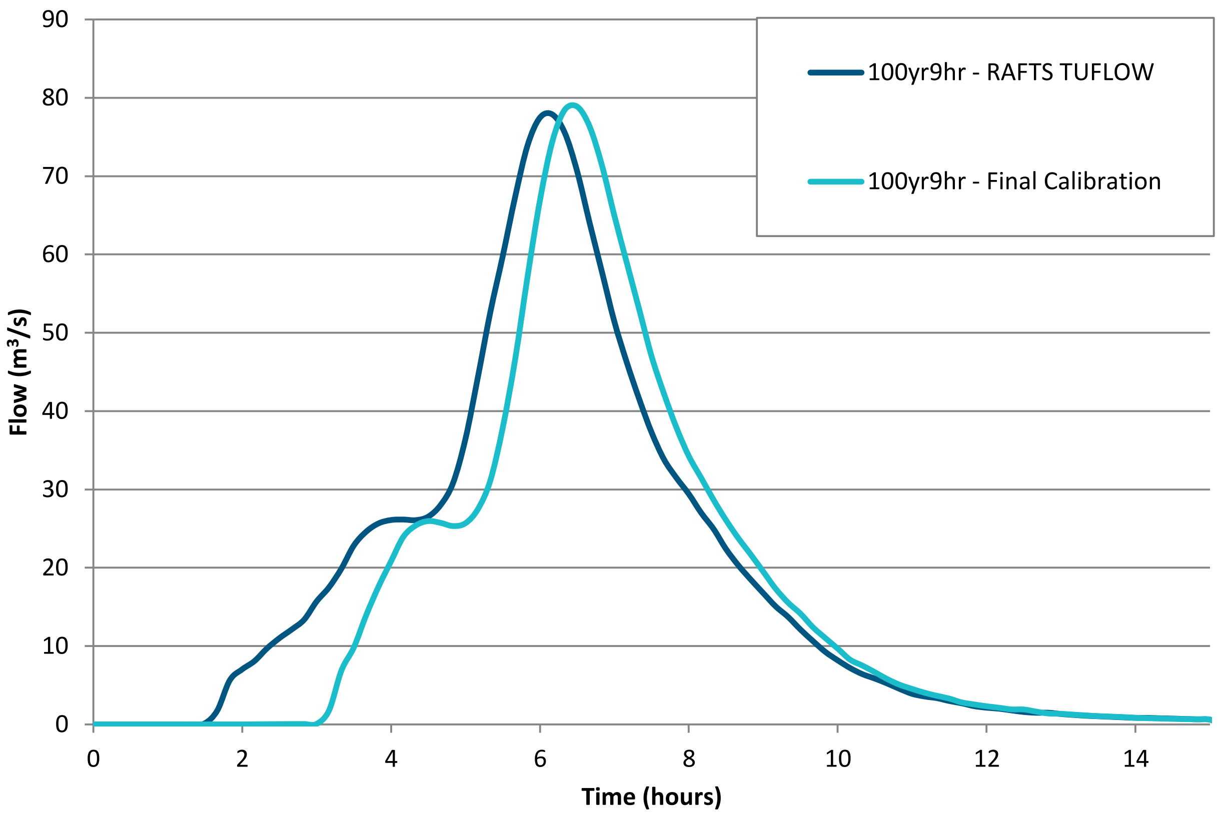

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Figure 4-4 Downstream Hydrographs – 100 Year ARI 9 Hour Duration

In addition to ensuring calibration at the outlet of the catchment, it is important to ensure calibration farther upstream. Two additional locations where chosen where comparisons were made to ensure an accurate flow and volume representation of the direct rainfall model. Both locations are situated approximately halfway up each of the two tributaries and were selected as representative of mid-way up the catchment. These are illustrated in Figure 4-1. Table 4-5 and Table 4-6 summarise the peak flow comparisons at these locations.

Overall the final results are similar to those found at the downstream boundary. The south-east tributary was found to have a final calibration peak flow typically +/-2% of the RAFTS TUFLOW model run. The south-west tributary had a slightly larger variation in peak flow over the range of events; however the peak storm (6hr at this location) was within +/-1%. Flood volume at these intermediary locations has not been considered as volume throughout the entire model has already been determined to be within acceptable bounds.

In addition to ensuring that the peak flows were similar, as with the outlet, it is important to consider the shape, if not timing, of the hydrographs at each location Comparisons of the hydrographs for each of the 100 year ARI events are presented in Appendix B, whilst the hydrograph for the critical 9 hour storm duration is shown in Figure 4-5 and Figure 4-6. Generally the final calibration model hydrographs are similar to the RAFTS TUFLOW model results.

Table 4-5 Comparison of Results at south-east Tributary – 100 Year ARI

Model Run		2hr	3hr	6hr	9hr	12hr	18hr
RAFTS - TUFLOW	Peak Flow (m^3/s)	15.1	16.1	18.2	22.5	19.6	13.8
Final Calibration		*14.8 (-2%)*	*15.3 (-5%)*	*17.5 (-4%)*	*22.5 (0%)*	*19.5 (-1%)*	*12.8 (-7%)*

Table 4-6 Comparison of Results at south-west Tributary – 100 Year ARI

Model Run		2hr	3hr	6hr	9hr	12hr	18hr
RAFTS - TUFLOW	Peak Flow (m^3/s)	14.8	13.5	15.0	14.1	12.2	8.9
Final Calibration		*16.0 (8%)*	*13.7 (1%)*	*15.2 (2%)*	*14.3 (2%)*	*13.1 (8%)*	*7.9 (-12%)*

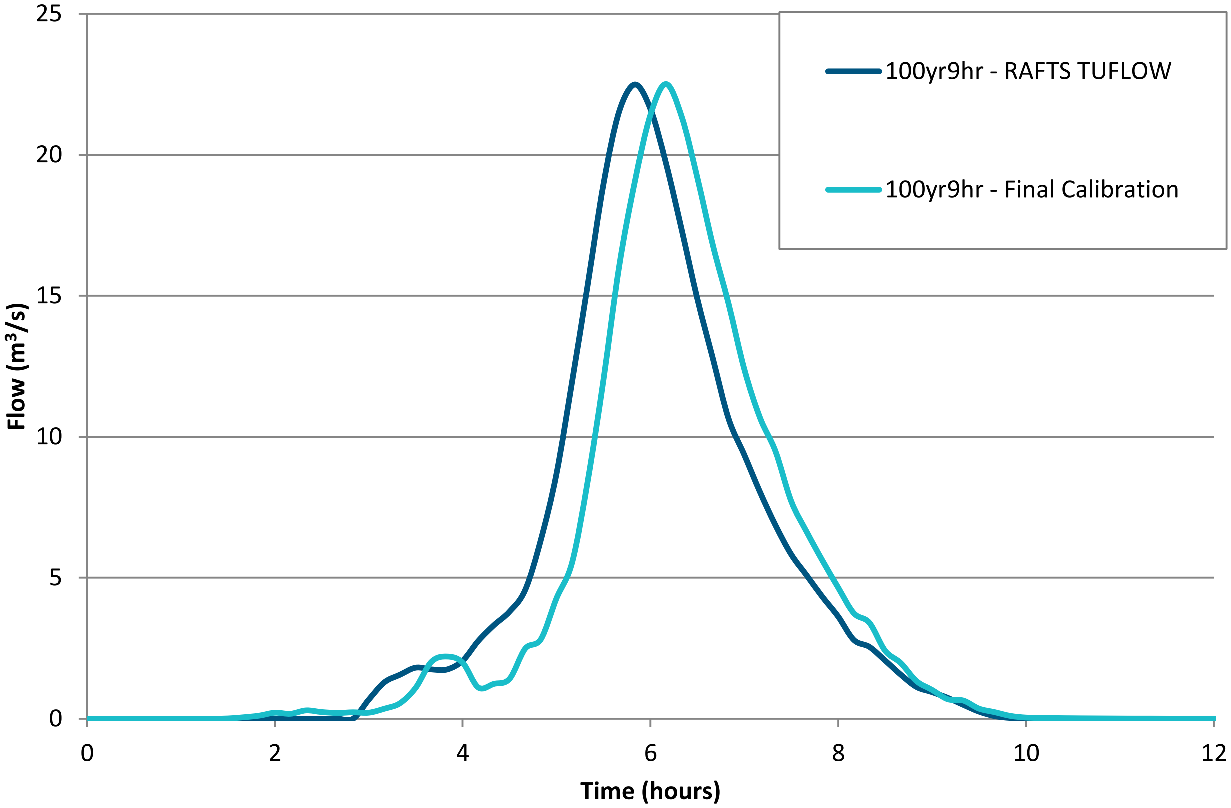


Figure 4-5 South-east Tributary Hydrographs – 100 Year ARI 9 Hour Duration

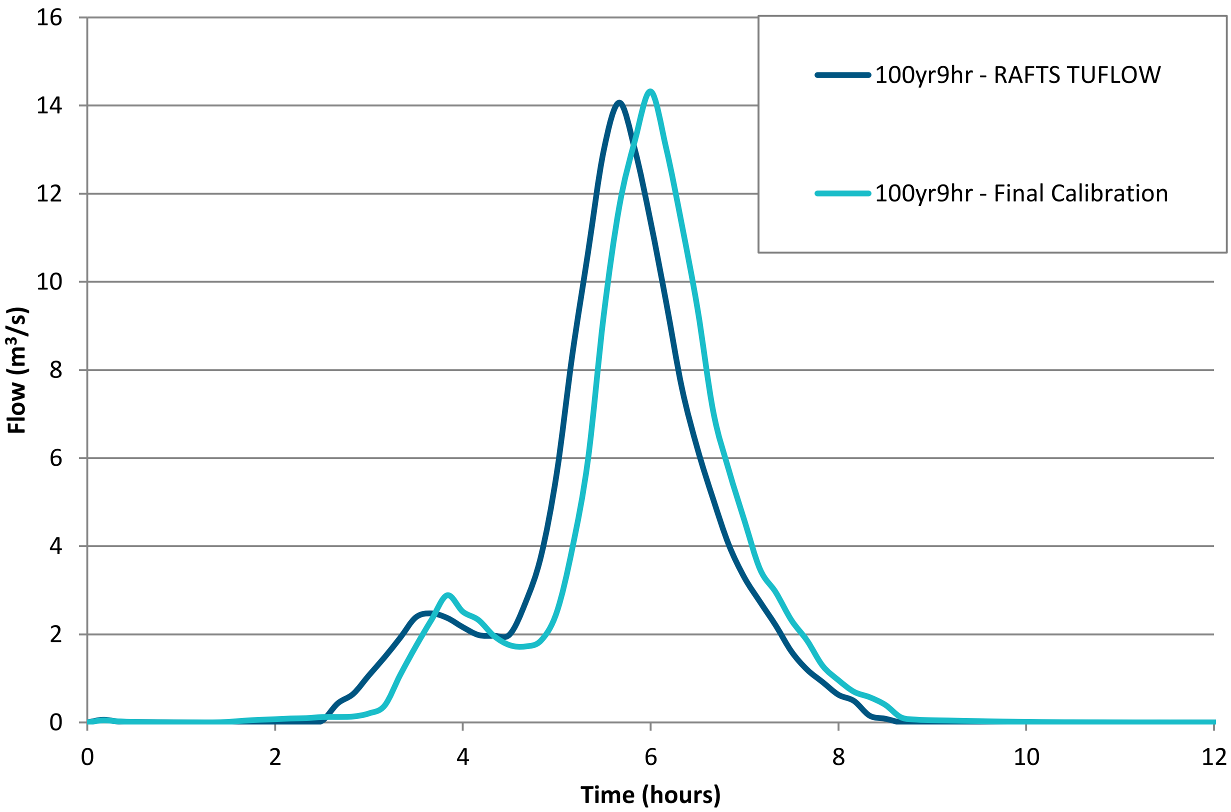


Figure 4-6 South-west Tributary Hydrographs – 100 Year ARI 9 Hour Duration

4.10.5 Summary

The Reedy Creek direct rainfall model has been calibrated to the traditional modelling approach (applying hydrologic model inputs onto a hydraulic model) through the adjustment of parameters including initial loss, continuing loss and Manning's 'n'. The parameters that have been adopted through the comparison process result in the direct rainfall model of Reedy Creek being able to generate peak flows and flood volumes at the catchment outlet and at two intermediate points that are comparable to a traditional model of the same catchment.

Hydrologic models of Ropes Creek and Eastern Creek were not available at the commencement of the study to enable a similar process to be undertaken for these systems. However, the parameters derived for Reddy Creek can be adopted for both Eastern Creek and Ropes Creek because the catchment have near identical hydrologic conditions.

5 FLOOD MODELLING RESULTS

This section provides a brief overview of the floodplain mapping process used in the investigation. TUFLOW was used to produce geo-referenced datasets defining peak water depths and levels throughout the model domain. The peak flood level from each of the modelled durations was selected for each computational cell to generate an envelope of peak flood level and peak flood depth. The data were imported into GIS to generate a digital model of the flood surface and flood depth. Flood depths and flood extents with height contours have been mapped for this final stage of the project.

5.1 Design Events

The 20, 50 and 100 year ARI design storm events were modelled in TUFLOW for a number of storm durations: 2 hour, 3 hour, 6 hour, 9 hour, 12 hour and 18 hour. The 500 and 2000 year ARI design storm events modelled for the 2 hour, 3 hour, 6 hour and 9 hour durations. Generally, the 9 hour storm duration was critical across the majority of the catchments.

The PMP events modelled were for the 30 minute, 1 hour, 2 hour, 4 hour and 6 hour durations (calculated using the GSDM approach). The critical storm duration varied across the catchment and hence a variety of storm durations were modelled to ensure the maximum flood heights across the entire catchment are captured. PMP events calculated using the GSAM approach (duration of 24 hours to 96 hours) were shown to not to be critical within the study catchments.

Due to the different temporal patterns used for events of 100 year ARI or less, and the 500 year ARI and greater, it can be noted that in the upper most branches of the reach the smaller events may at times produce a greater flood extent than the larger less frequent events. This is discussed in detail in Section 3.1.2.

5.2 Flood Mapping Methodology

The flood mapping was undertaken based on a procedure recommended by John Maddocks (FloodMit Pty Ltd) and utilised by FCC on the Wetherill Park Flood Mapping project. This mapping procedure will initially remove all flood depths less than 0.15 metres. 0.15 metres has been adopted as flood depths lower than 0.15 metres generally will not enter a property (assuming a minimum slab depth of 0.15 metres as per the Building Code of Australia specifications) and is consistent with previous studies undertaken for Council (including the Canley Corridor Flood Study).

A process is then undertaken to include selected areas of flooding with depths less than 0.15 metres in the flood mapping to ‘connect’ the flood mapping together and ensure a continual flood extent throughout the catchment.

5.3 Discussion of Design Flood Behaviour

The following sections discuss the design flood behaviour for each of the three study catchments. As detailed previously, the farm dams within the three catchments are assumed to be full at the commencement of the flood event (Section 4.7) and the flood mapping has not been shown in the area currently occupied by the quarries at the downstream end of the Reedy Creek and Eastern Creek catchments (as discussed in Section 4.6).

5.3.1 Reedy Creek

The flood depth maps for Reedy Creek are presented in Figure 5-1 to Figure 5-5 for the 20 year, 50 year, 100 year, 500 year and 2000 year ARI flood events, as well as for the PMP flood event.

Generally, flow is contained within the channels; the exception is between The Horsley Drive and Burley Road where overbank flooding is observed in the 20 year ARI and greater flood events. In all modelled events, both Burley Road and The Horsley Drive (the two key east-west roads through the catchment) are cut by floodwaters. Flooding of Cobham Street, Horsley Road and Arundel Road also occurs during the 20 year ARI flood event. Flooding of these roads increases in both width and depth as the rarity of the flood event increases.

The flood mapping shows flooding in and around the Horsley Village Shops (at the corner of The Horsley Drive and Horsley Road). The flooding is generally shallow during the 20 year ARI flood event (less than 0.25 metres) and is confined to the western section of the shopping precinct. The culvert underneath Horsley Road appears to be undersized, possibly increasing the flooding that is occurring in the local area.

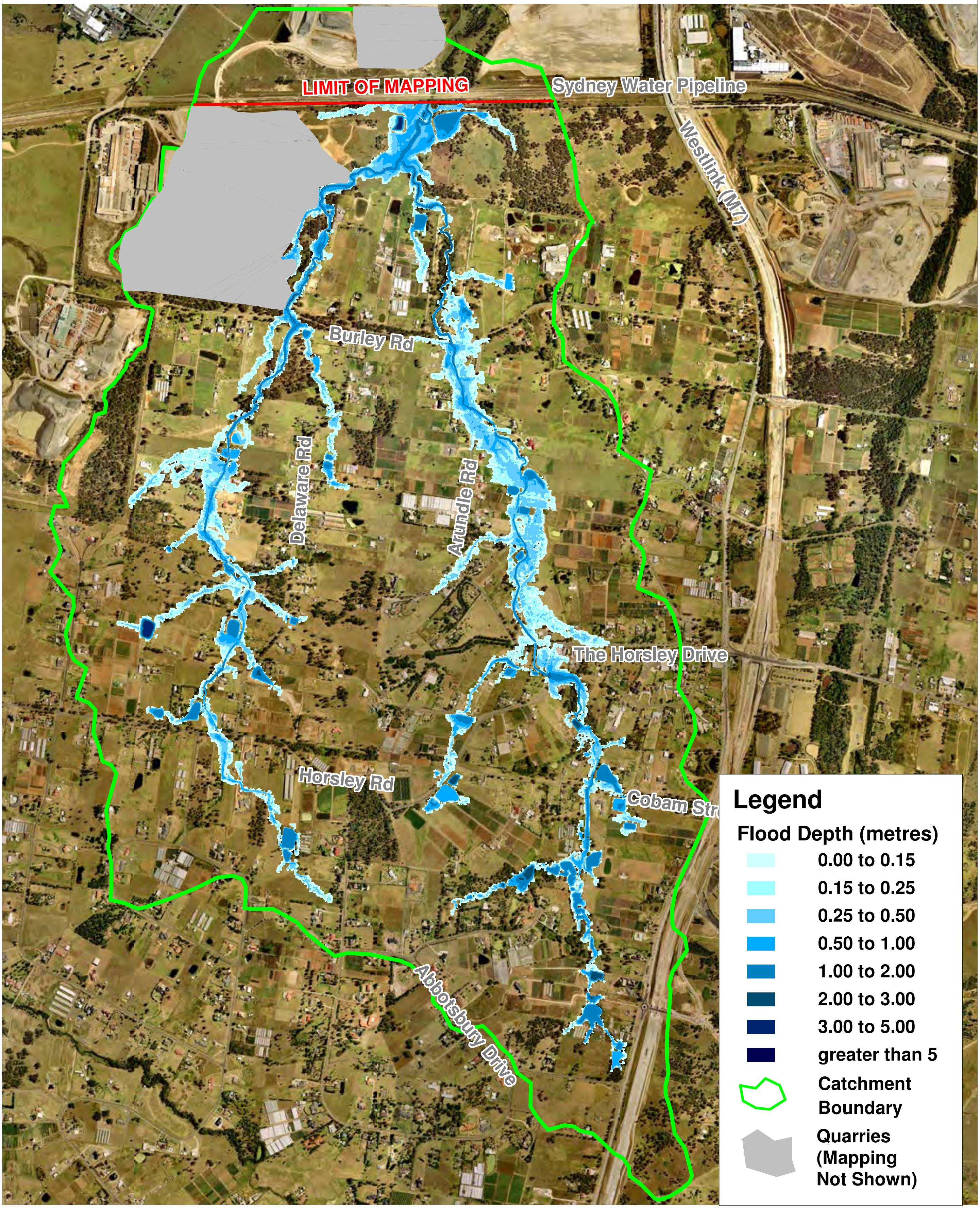
There are no significant flow breakouts from natural depressions. As the modelled floods increased in rarity, the flood extents and flood depths increased. No new flow paths become evident in the extremely rare events, indicating that the valley and depressions are well defined and able to contain the flood water.

5.3.1.1 Comparison to Previous Mapping

A comparison was made between the 100 year ARI flood extent and flood heights calculated as part of this study to those previous adopted by Council based upon the 1994 study of Reedy Creek, Ropes Creek and Eastern Creek.

This comparison has shown that the current mapping includes a number of tributaries of Reedy Creek that were previously not mapped. Additionally the current mapping extends further up the catchment than the previous mapping. However, in the areas where the overlap occurs, there is generally good agreement between the flood extents of the current study and those of the previous study (FCC, 1994). An obvious exception to this is along the eastern arm of Reedy Creek just upstream from the quarries where the current modelling shows a significantly more confined flood extent than the extent previously developed. A comparison of the flood levels shows that the current 100 year ARI flood levels are typically lower than the flood levels of the previous study by between 200 and 300 millimetres.

These comparison results are not unexpected. The flood levels in the direct rainfall model will typically be lower due to the inflow boundaries being more widely applied throughout the catchment rather than concentrated along the main creek alignment. This application of the boundaries is also likely to has reduced the peak flow along the main creek as floodwaters get caught in various natural storages throughout the catchment, resulting in some areas where the flood extents based on the current modelling as smaller than those previously derived



Title:

Reedy Creek
20 Year ARI Flood Depth

Figure: **5-1**

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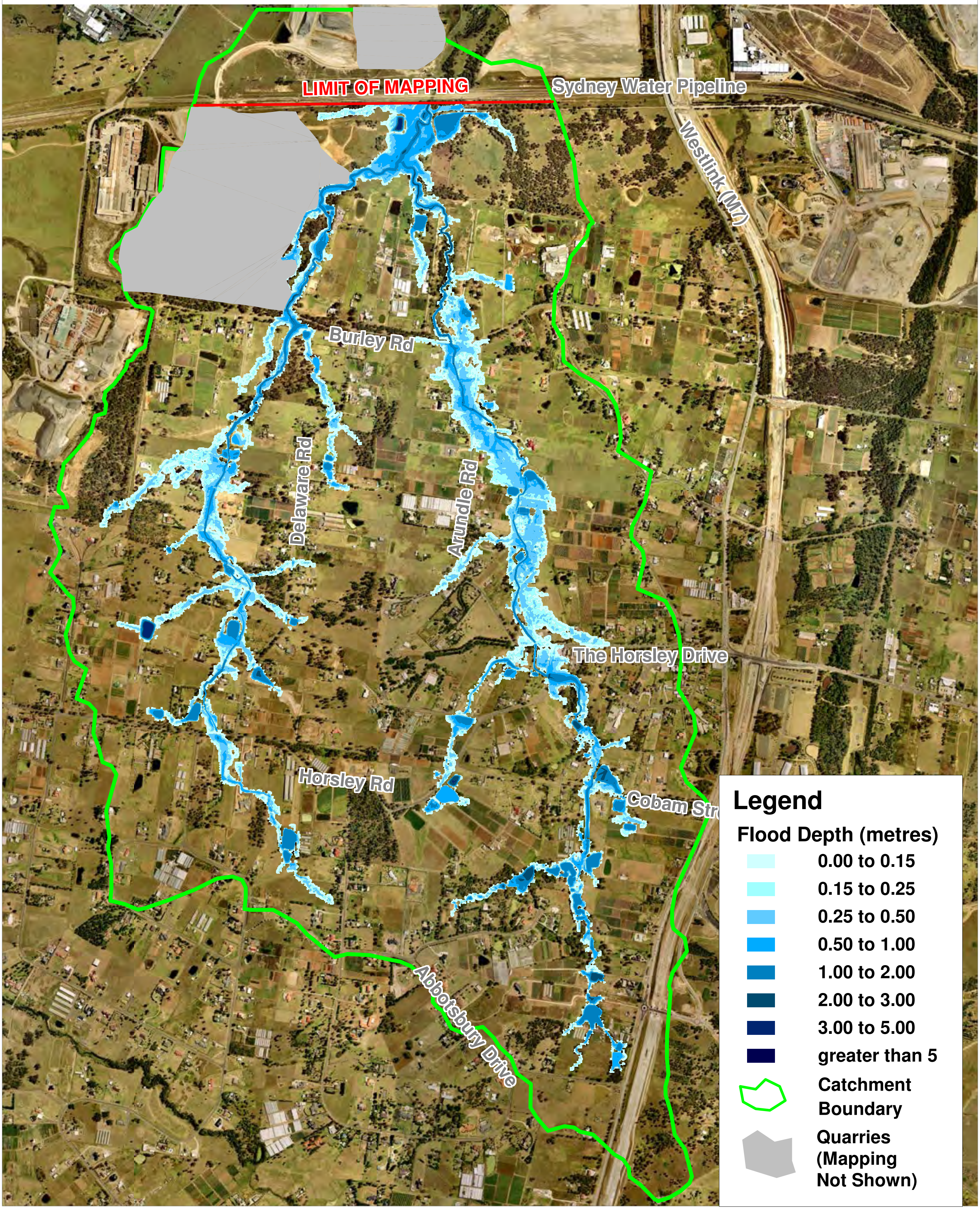

Title:

Reedy Creek
50 Year ARI Flood Depth

Figure: **5-2**

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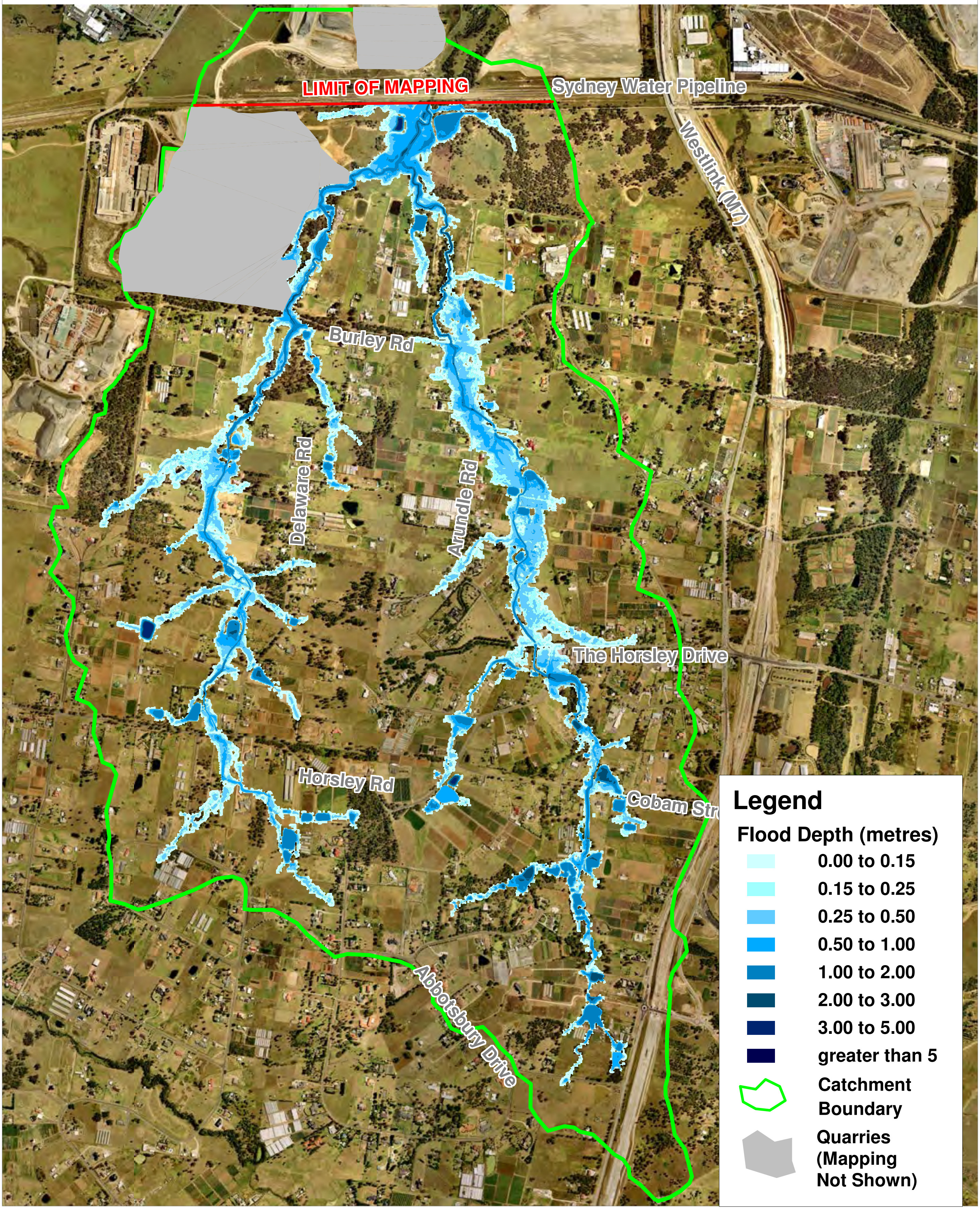

Title:

Reedy Creek
100 Year ARI Flood Depth

Figure: **5-3**

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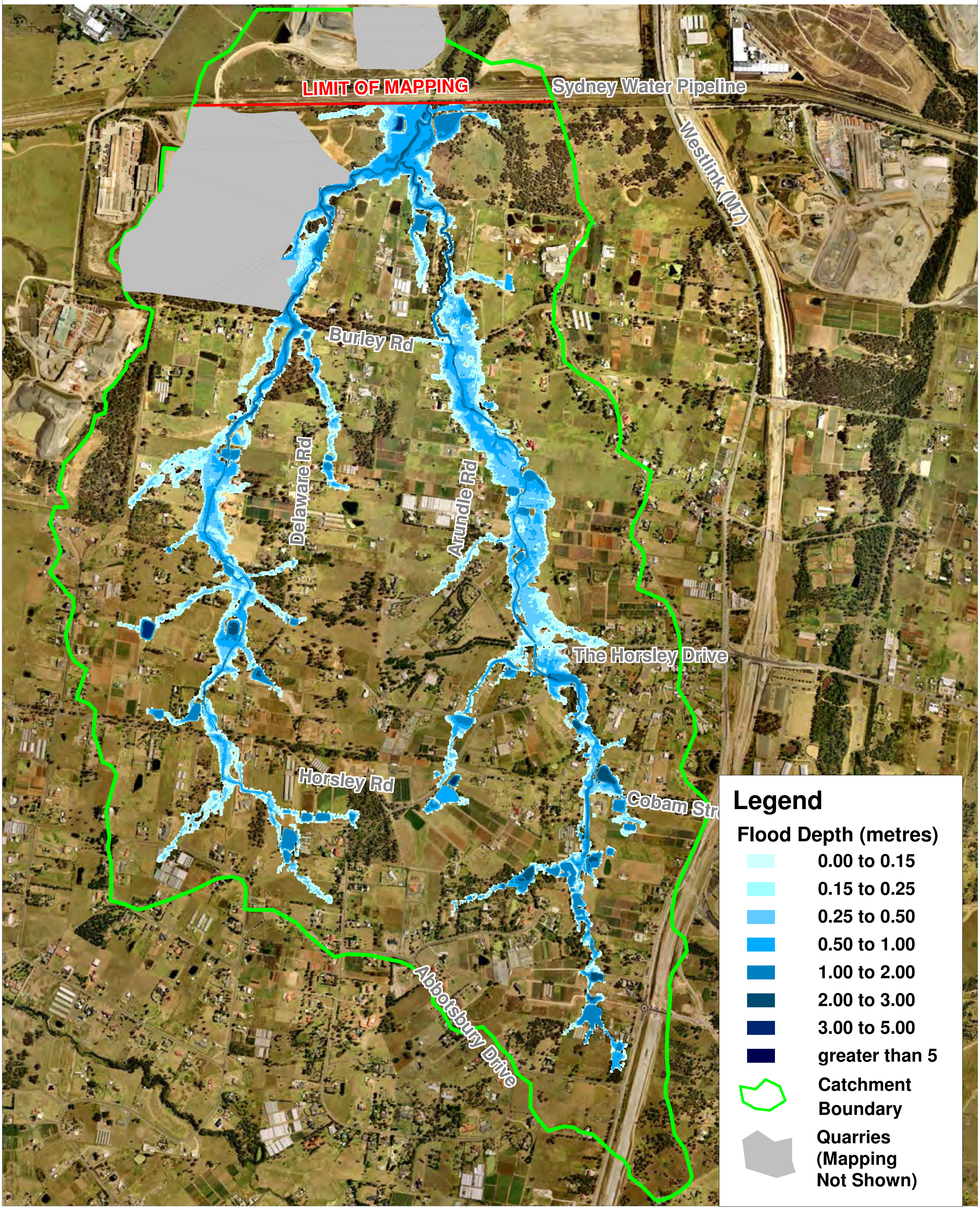

Title:

Reedy Creek
500 Year ARI Flood Depth

Figure: **5-4**

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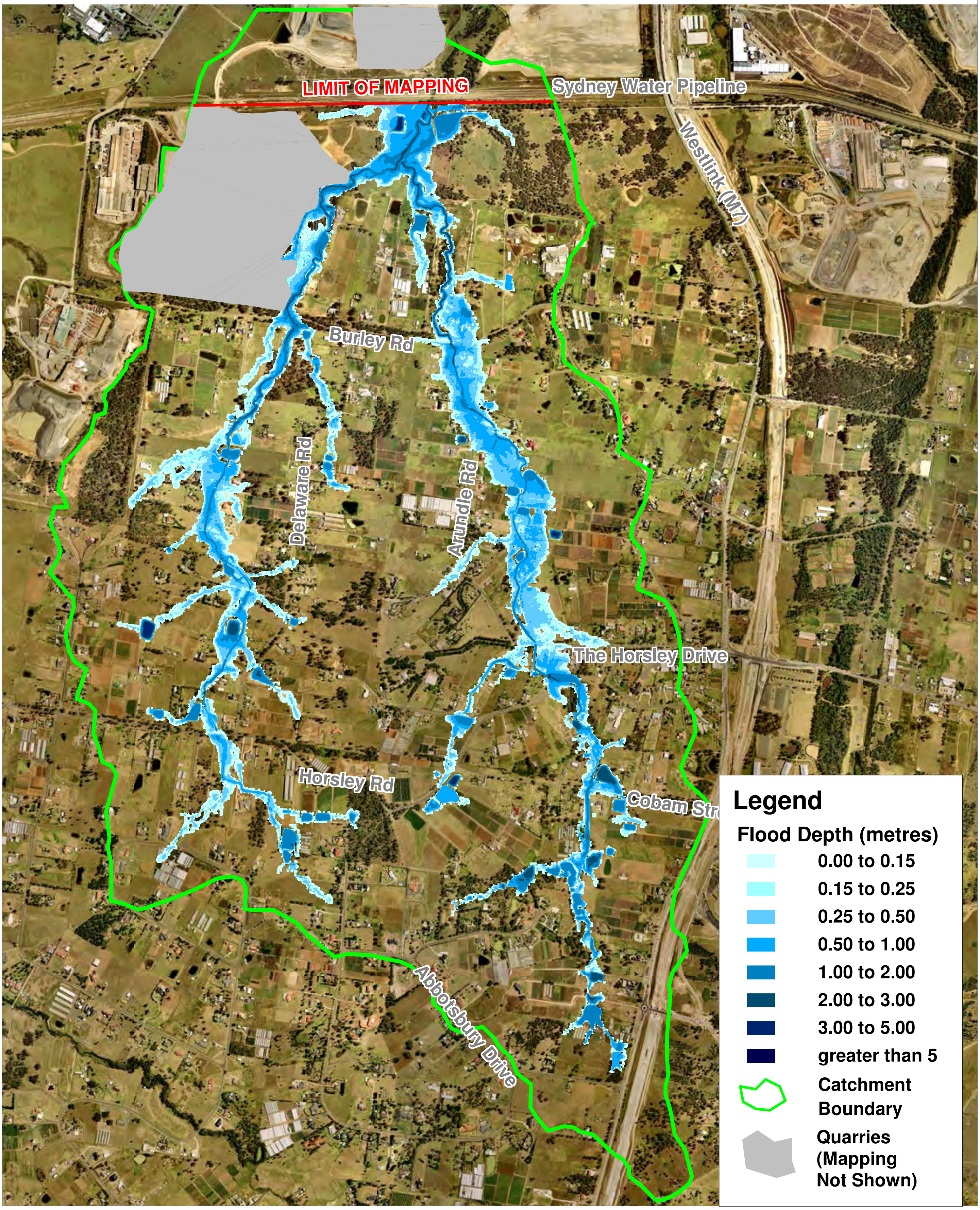

Title:

Reedy Creek
2000 Year ARI Flood Depth

Figure: **5-5**

Rev: **B**

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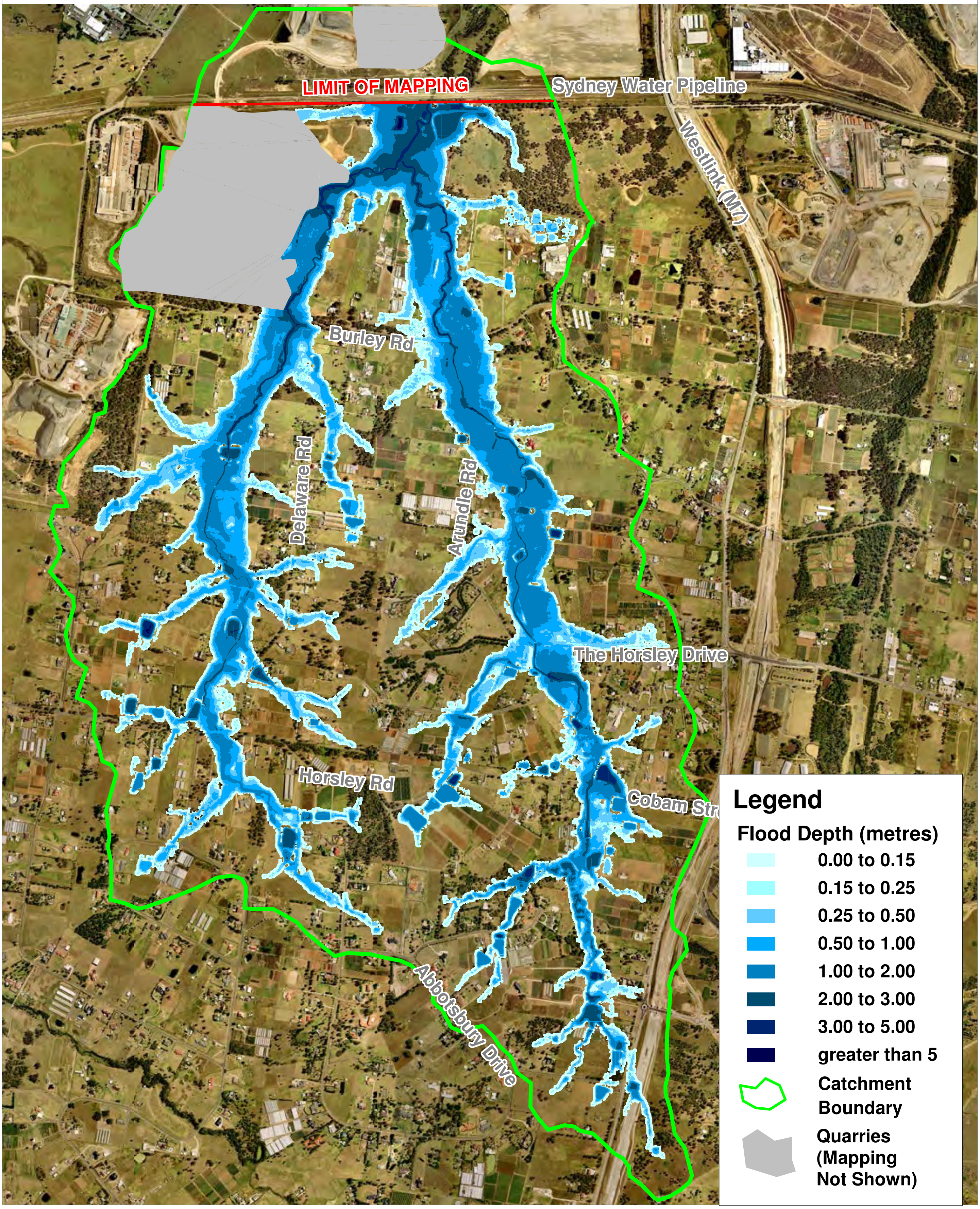

Title:

Reedy Creek
PMP Flood Depth

Figure: **5-6**

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5.3.2 Ropes Creek

The flood depth maps for Ropes Creek are presented in Figure 5-7 to Figure 5-12 for the 20 year, 50 year, 100 year, 500 year and 2000 year ARI flood events, as well as for the PMP flood event.

In a similar vein to Reedy Creek, the flooding of the eastern tributary of Ropes Creek is generally well contained within the depression and valleys of the creek system during all modelled flood events. However, there are some noticeable areas of overbank flooding downstream of Selkirk Avenue and between Elizabeth Drive and Selkirk Avenue in the 20 year ARI flood event. The overbank flooding becomes more pronounced along the western arm of Ropes Creek as the modelled flood events increases in rarity, however, the eastern arm remains relatively well confined.

Flooding is shown in all events in the vicinity of the M7 Motorway (upstream of Wallgrove Road). The M7 is elevated in this region, with the flooding shown expected to occur underneath the M7 bridge, which crosses both Ropes Creek and Villiers Road. For flood events up to and including the 100 year ARI flood event, flooding of the M7 is unlikely to occur due to the height of the bridge over the surrounding floodplain.

A number of roads are cut during the 20 year ARI flood events, including Goodrich Road, Selkirk Avenue and Lincoln Road (in numerous locations). Flood depths and flood widths across these roads increase as the modelled design event becomes rarer. During the 20 year ARI flood events, flood depths across the key roads within the Ropes Creek catchment are generally less than 0.15 metres. However, flood depths of up to 0.5 metres are observed along Goodrich Road and Selkirk Road during the 100 Year ARI flood event. Whilst a number of roads across the catchment are flooded, it does not appear that undersized culverts or bridges are having a significant impact on the flooding in the local area. However, these structures would need to be increased in size if the road levels were to be increased.

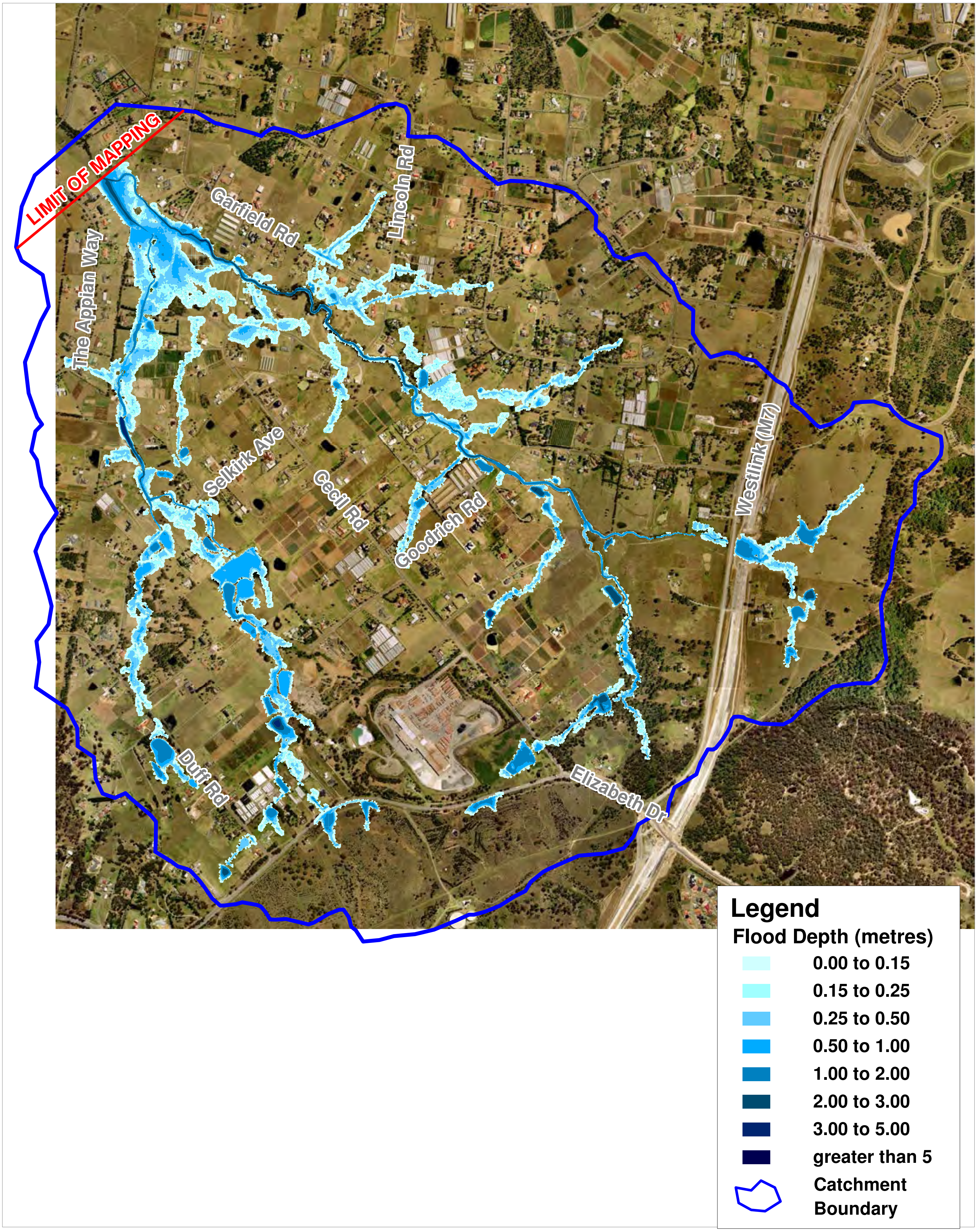
There are no significant flow breakouts from natural depressions. As the modelled floods increased in rarity, the flood extents and flood depths increased. No new flow paths become evident in the extremely rare events, indicating that the valley and depressions are well defined and able to contain the flood water.

5.3.2.1 Comparison to Previous Mapping

A comparison was made between the 100 year ARI flood extent and flood heights calculated as part of this study to those previous adopted by Council based upon the 1994 study of Reedy Creek, Ropes Creek and Eastern Creek.

This comparison has shown that the current mapping includes a number of tributaries of Ropes Creek that were previously not mapped. Additionally the current mapping extends further up the catchment than the previous mapping. However, in the areas where the overlap occurs, there is reasonable agreement between the flood extents of the current study and those of the previous study (FCC, 1994). However, there are a number of quite noticeable exceptions where the current modelling has generated a flood extent smaller than the previous modelling. This is particularly noticeable along the east arm of Ropes Creek. A comparison of the flood levels shows that the current 100 year ARI flood levels are typically lower than the flood levels of the previous study by between 200 and 300 millimetres.

These comparison results are not unexpected. The flood levels in the direct rainfall model will typically be lower due to the inflow boundaries being more widely applied throughout the catchment rather than concentrated along the main creek alignment. This application of the boundaries is also likely to has reduced the peak flow along the main creek as floodwaters get caught in various natural storages throughout the catchment, resulting in some areas where the flood extents based on the current modelling as smaller than those previously derived



Title:

Ropes Creek
20 Year ARI Flood Depth

Figure: **5-7**

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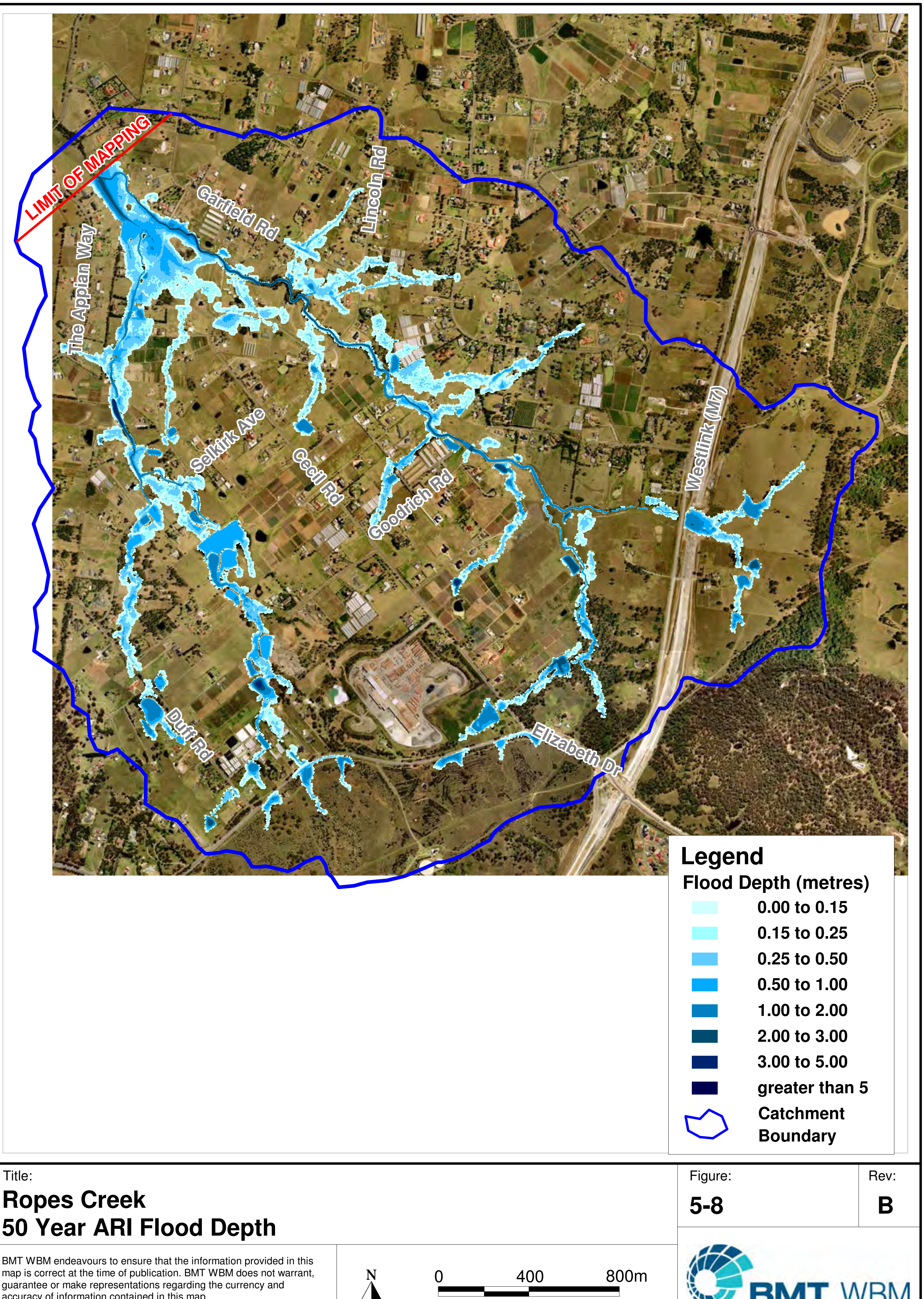

Title:

Ropes Creek
50 Year ARI Flood Depth

Figure: 5-8

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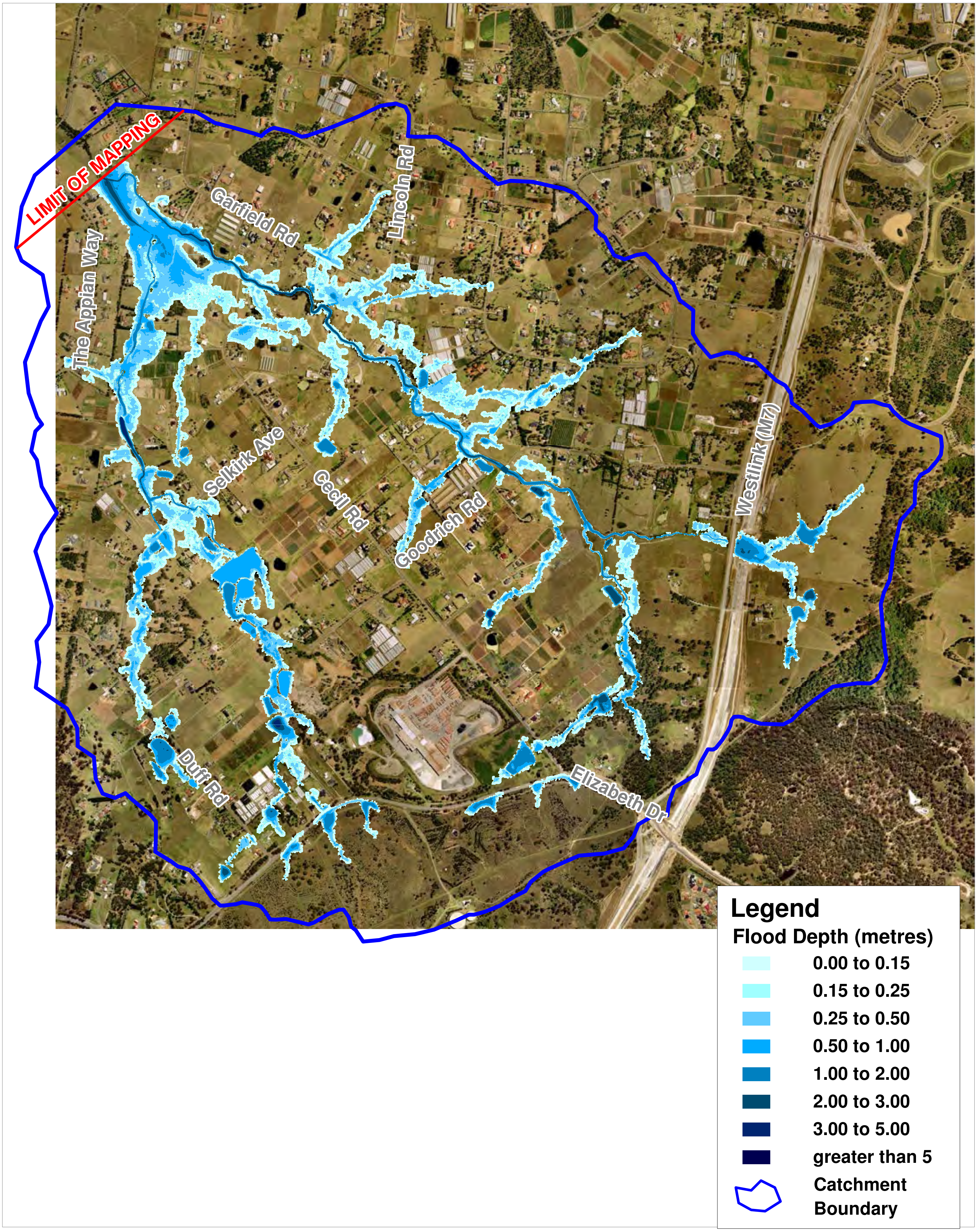

Title:

Ropes Creek
100 Year ARI Flood Depth

Figure: **5-9**

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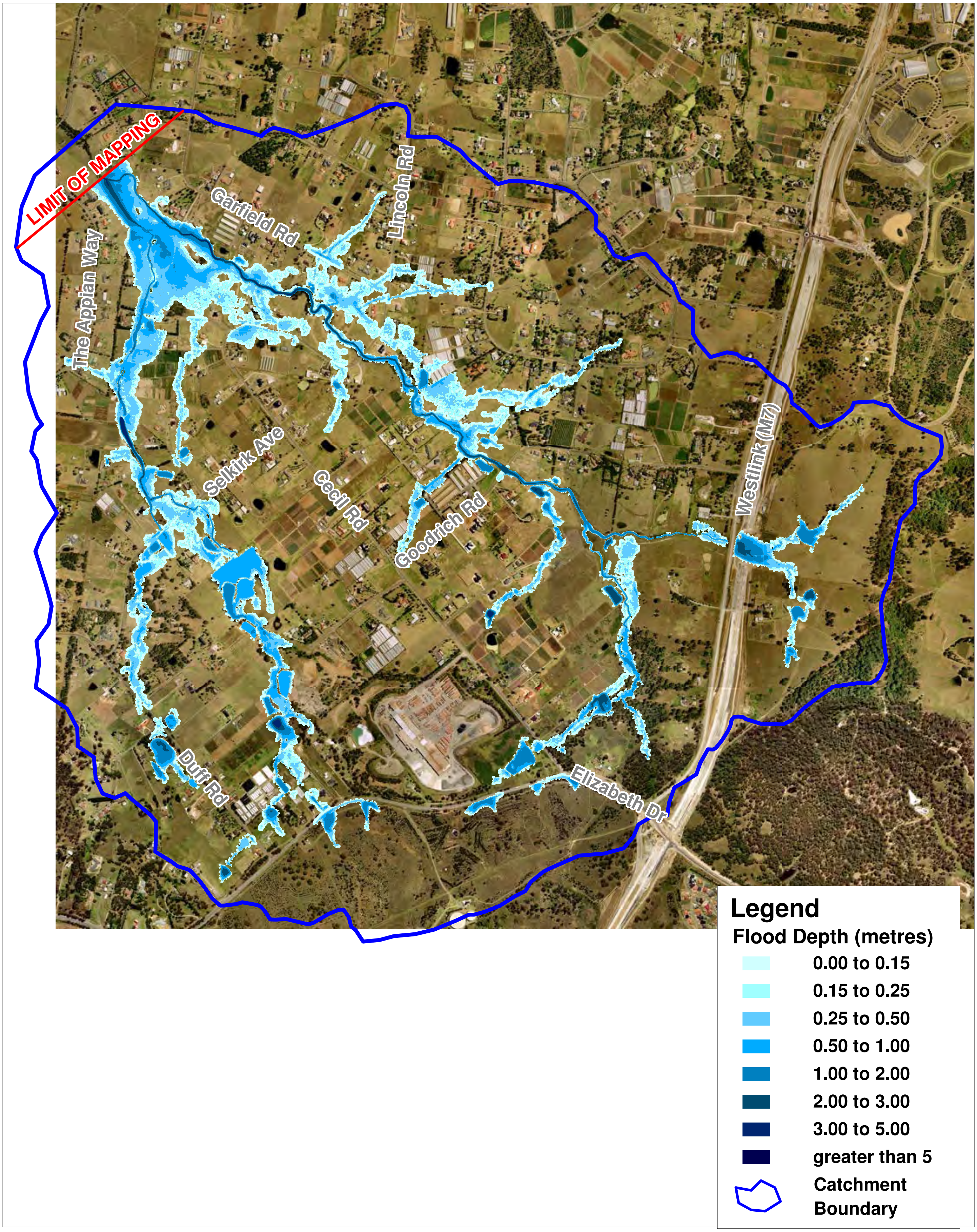

Title:

Ropes Creek
500 Year ARI Flood Depth

Figure: **5-10**

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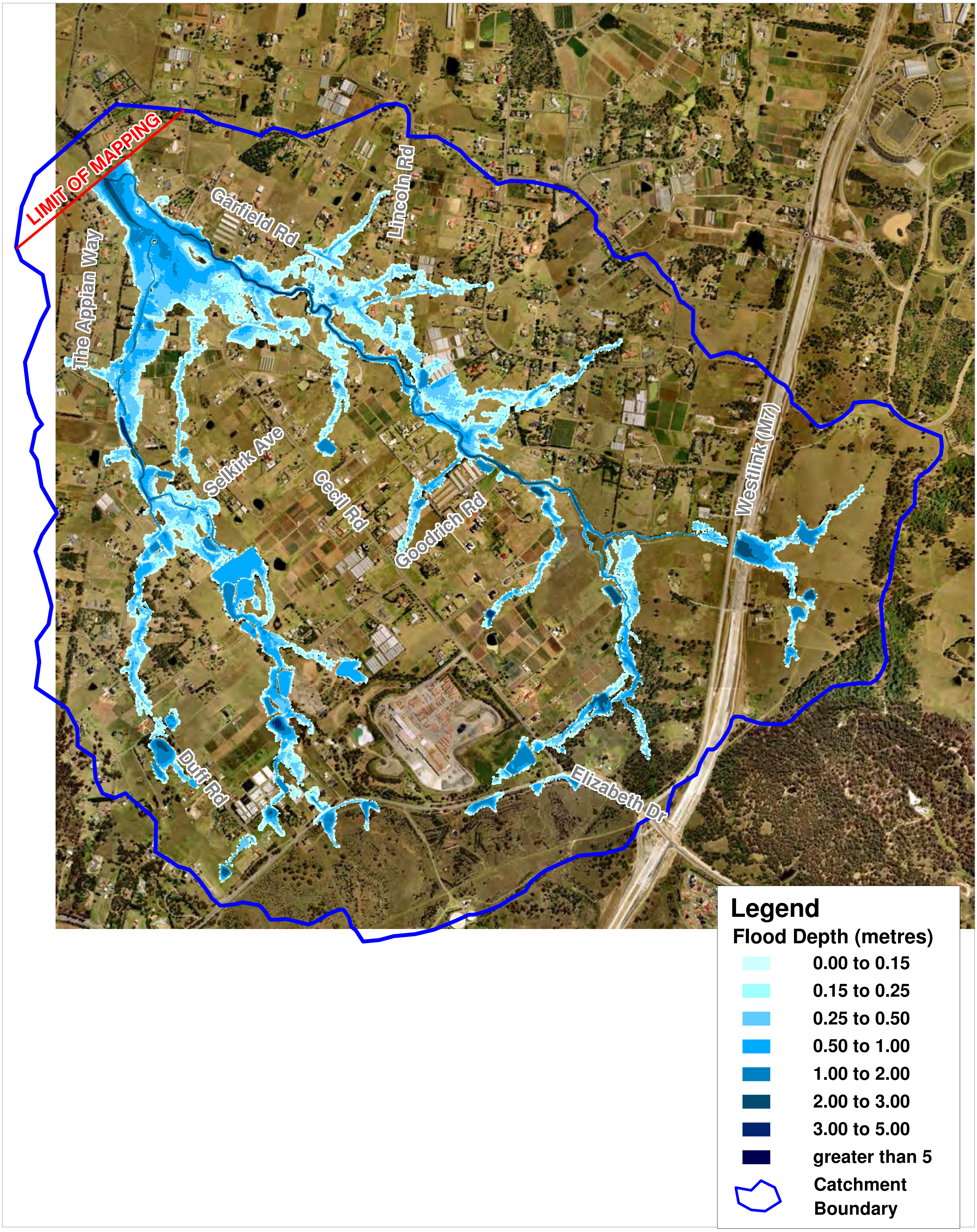

Title:

Ropes Creek
2000 Year ARI Flood Depth

Figure: 5-11

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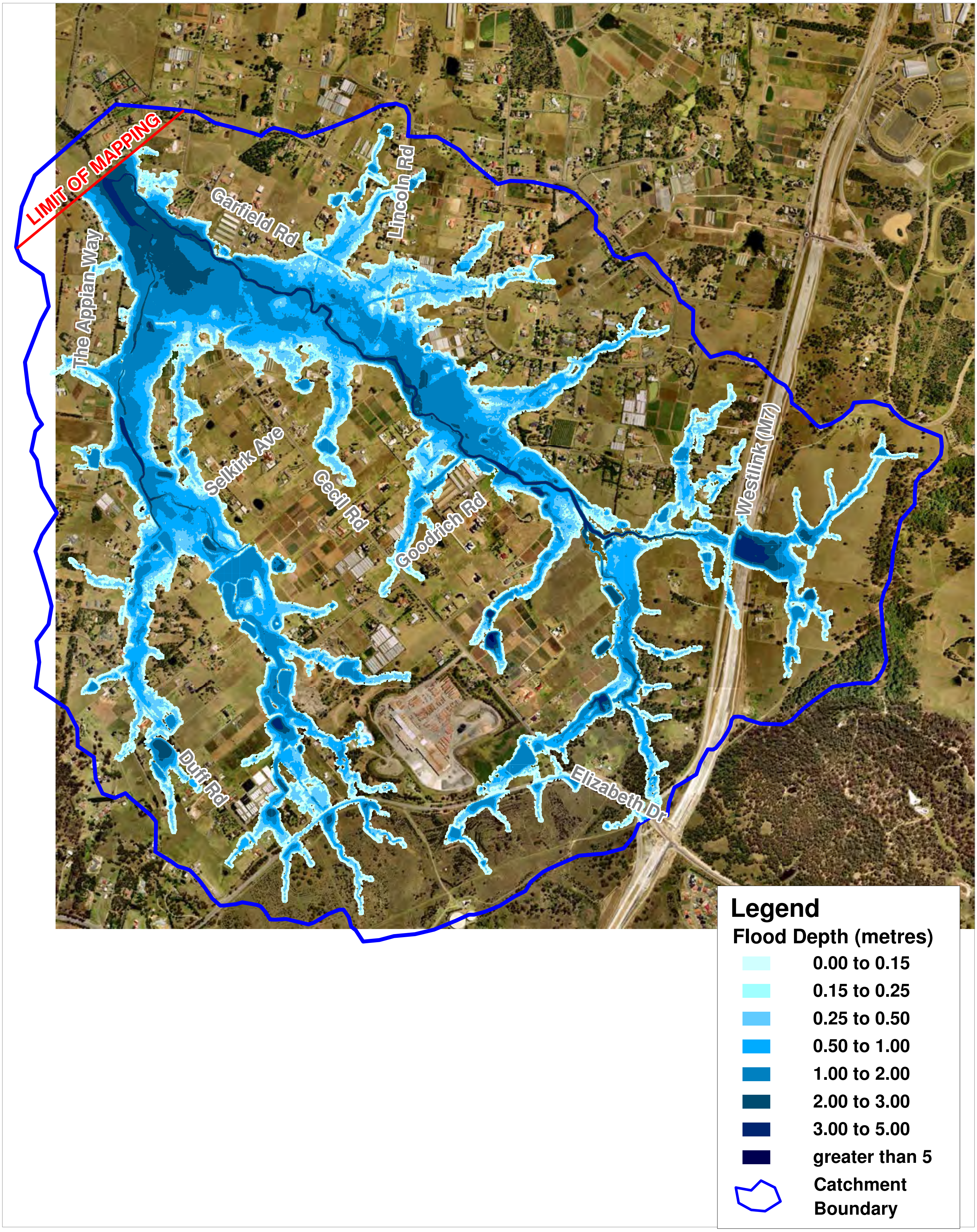

Title:

Ropes Creek
PMP Flood Depth

Figure: 5-12

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5.3.3 Eastern Creek

The flood depth maps for Eastern Creek are presented in Figure 5-13 to Figure 5-18 for the 20 year, 50 year, 100 year, 500 year and 2000 year ARI flood events, as well as for the PMP flood event.

Unlike Reedy Creek and Ropes Creek, there is overbank flooding along the length of Eastern Creek in all modelled flood events. The natural creek system has insufficient capacity to convey the flood events that are expected in the catchment, resulting in significant overbank flooding even in relatively frequent flood events (the 20 year ARI flood event). In a similar way to Ropes Creek, whilst some degree of ponding does occur behind the road embankments, it does not appear that the structures are particularly undersized. However, these drainage structures would need to be improved if the road level was to be increased to prevent particular roads from flooding.

Like the flood mapping for Ropes Creek, flooding is shown in all events in the vicinity of the M7 Motorway (downstream of Wallgrove Road). The M7 is elevated in this region, with the flooding shown expected to occur underneath the M7 bridge, which crosses both a tributary of Eastern Creek and Redmayne Road. For modelled flood events (including the PMP), the flood depths in this region (of up to 1 metre) are not going to result in flooding of the M7 due the height of the bridge over the surrounding floodplain.

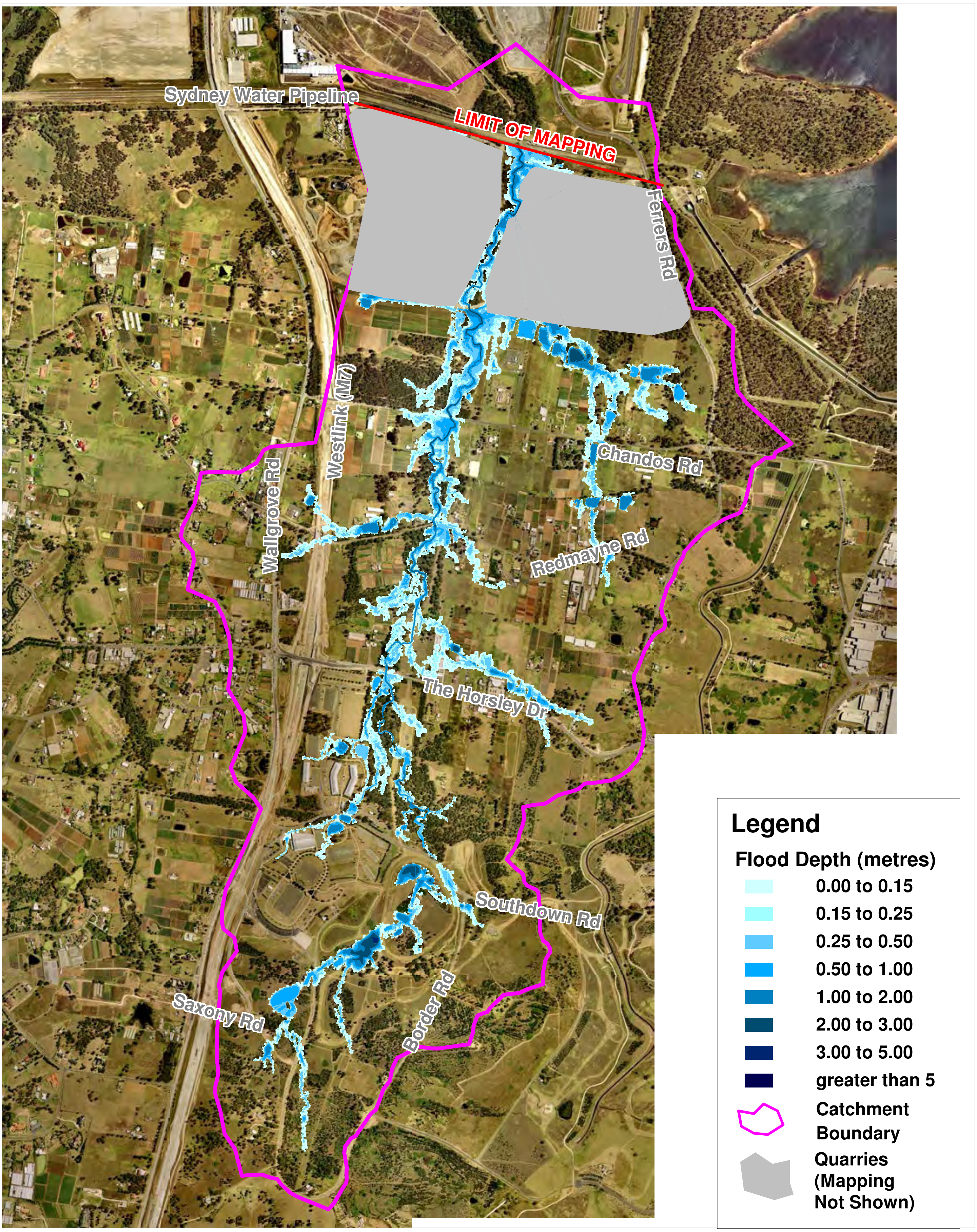
The three main roads through the catchment, Chandos Road, Redmayne Road and The Horsley Drive, are shown to be flooded during all modelled flood events. All three roads are likely to be cut by floodwaters at multiple locations during flood events equal to or greater than the 20 year ARI design flood, however, flood depths are likely to less than 0.15 metres during this event. Flood depths across roads within the Eastern Creek catchment are likely to be up to 0.50 metres during the 100 year ARI flood event.

5.3.3.1 Comparison to Previous Mapping

A comparison was made between the 100 year ARI flood extent and flood heights calculated as part of this study to those previous adopted by Council based upon the 1994 study of Reedy Creek, Ropes Creek and Eastern Creek.

This comparison has shown that the current mapping includes a number of tributaries of Eastern Creek that were previously not mapped. Additionally, the current mapping extends further up the catchment than the previous mapping. However, in the areas where the overlap occurs, there is generally good agreement between the flood extents of the current study and those of the previous study (FCC, 1994). There are a number of regions where the current flood extents are larger than those previously developed, however these regions are located close to locations where tributaries are joining Eastern Creek. A comparison of the flood levels shows that the current 100 year ARI flood levels are typically lower than the flood levels of the previous study by between 200 and 300 millimetres.

These comparison results are not unexpected. The flood levels in the direct rainfall model will typically be lower due to the inflow boundaries being more widely applied throughout the catchment rather than concentrated along the main creek alignment. This application of the boundaries is also likely to has reduced the peak flow along the main creek as floodwaters get caught in various natural storages throughout the catchment, resulting in some areas where the flood extents based on the current modelling as smaller than those previously derived.



Title:

Eastern Creek
20 Year ARI Flood Depth

Figure: **5-13**

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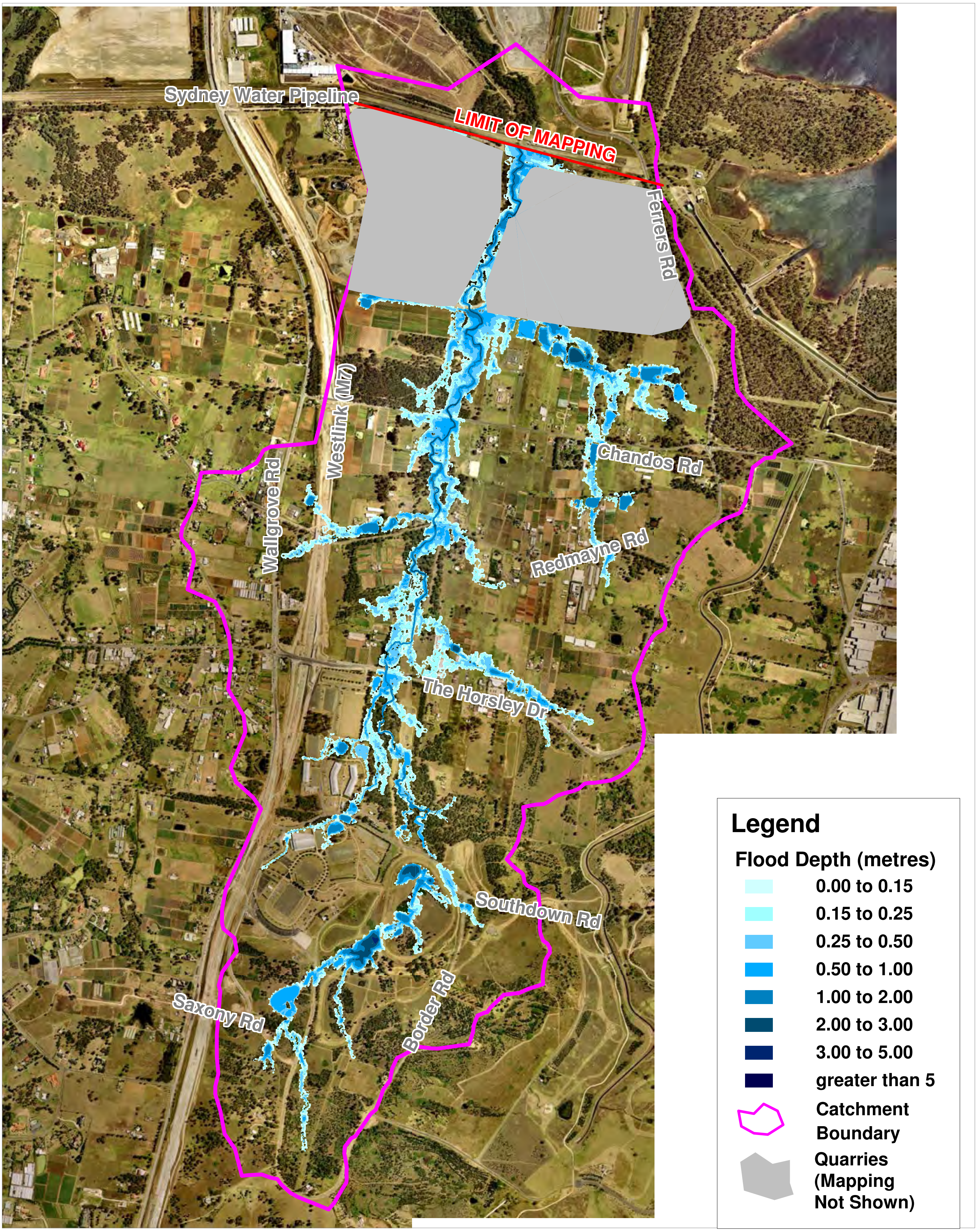

Title:

Eastern Creek
50 Year ARI Flood Depth

Figure: **5-14**

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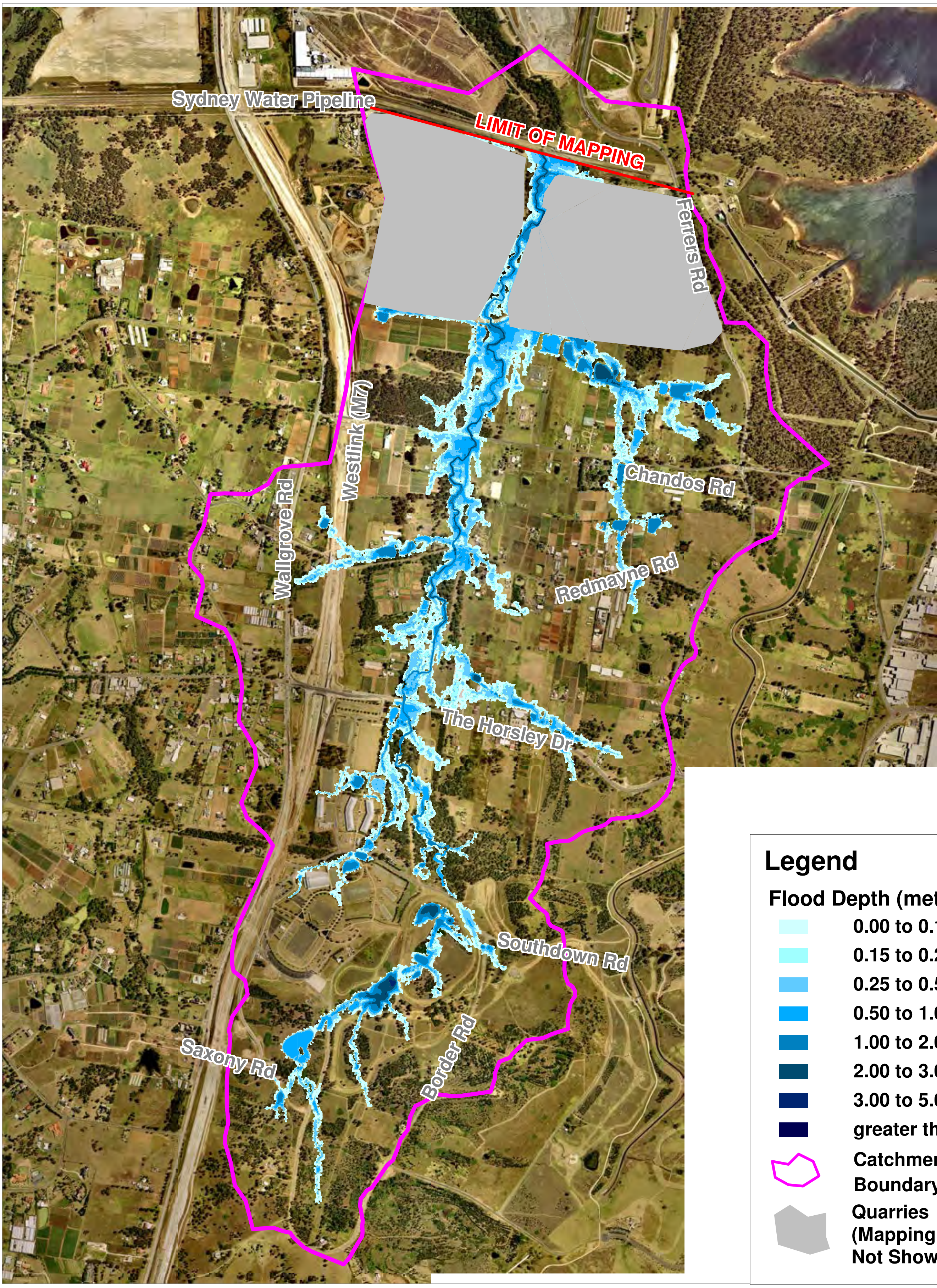

Legend

Flood Depth (metres)

- 0.00 to 0.15
- 0.15 to 0.25
- 0.25 to 0.50
- 0.50 to 1.00
- 1.00 to 2.00
- 2.00 to 3.00
- 3.00 to 5.00
- greater than 5
- Catchment Boundary
- Quarries (Mapping Not Shown)

Title:

Eastern Creek
100 Year ARI Flood Depth

Figure: **5-15**

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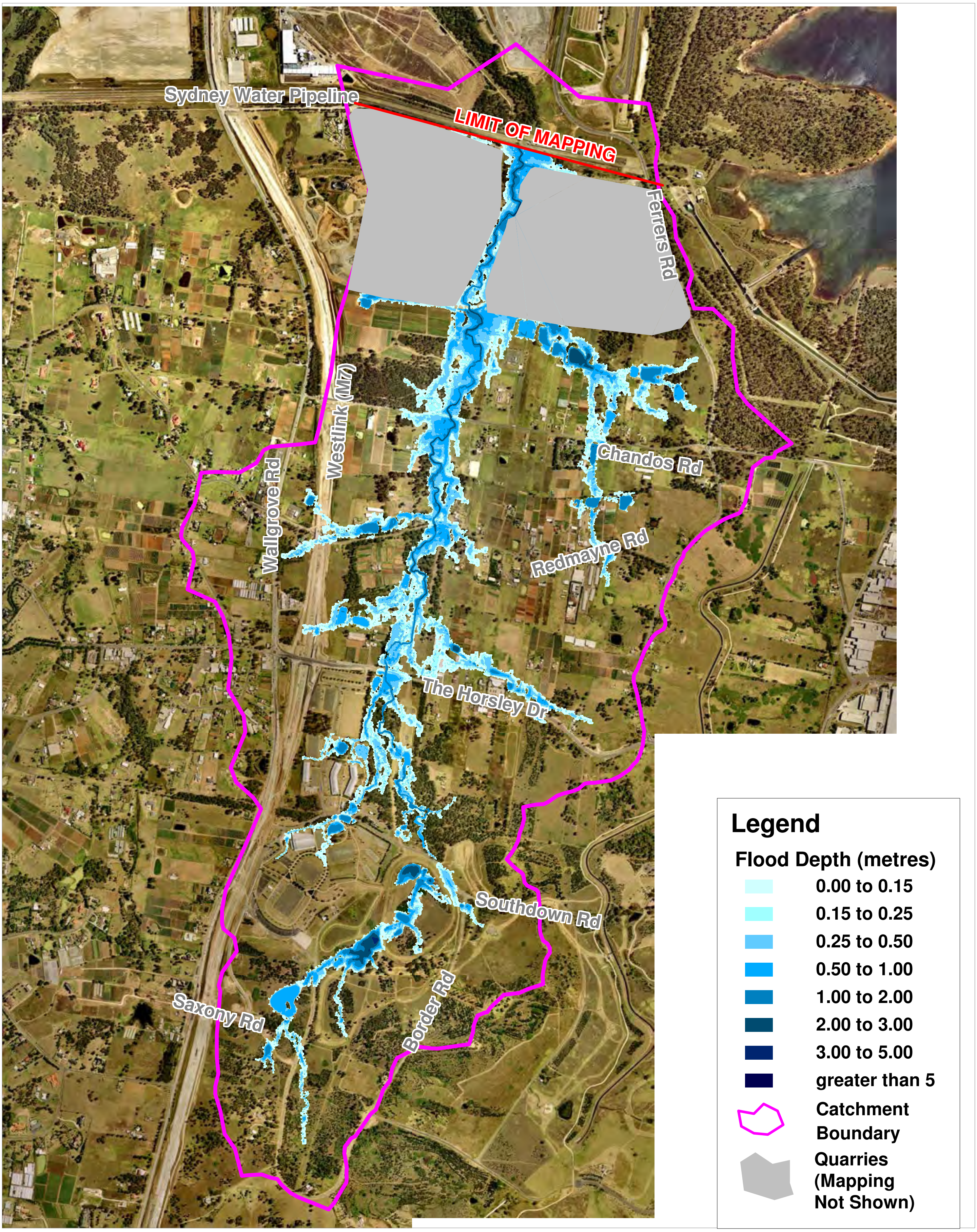

Title:

Eastern Creek
500 Year ARI Flood Depth

Figure: **5-16**

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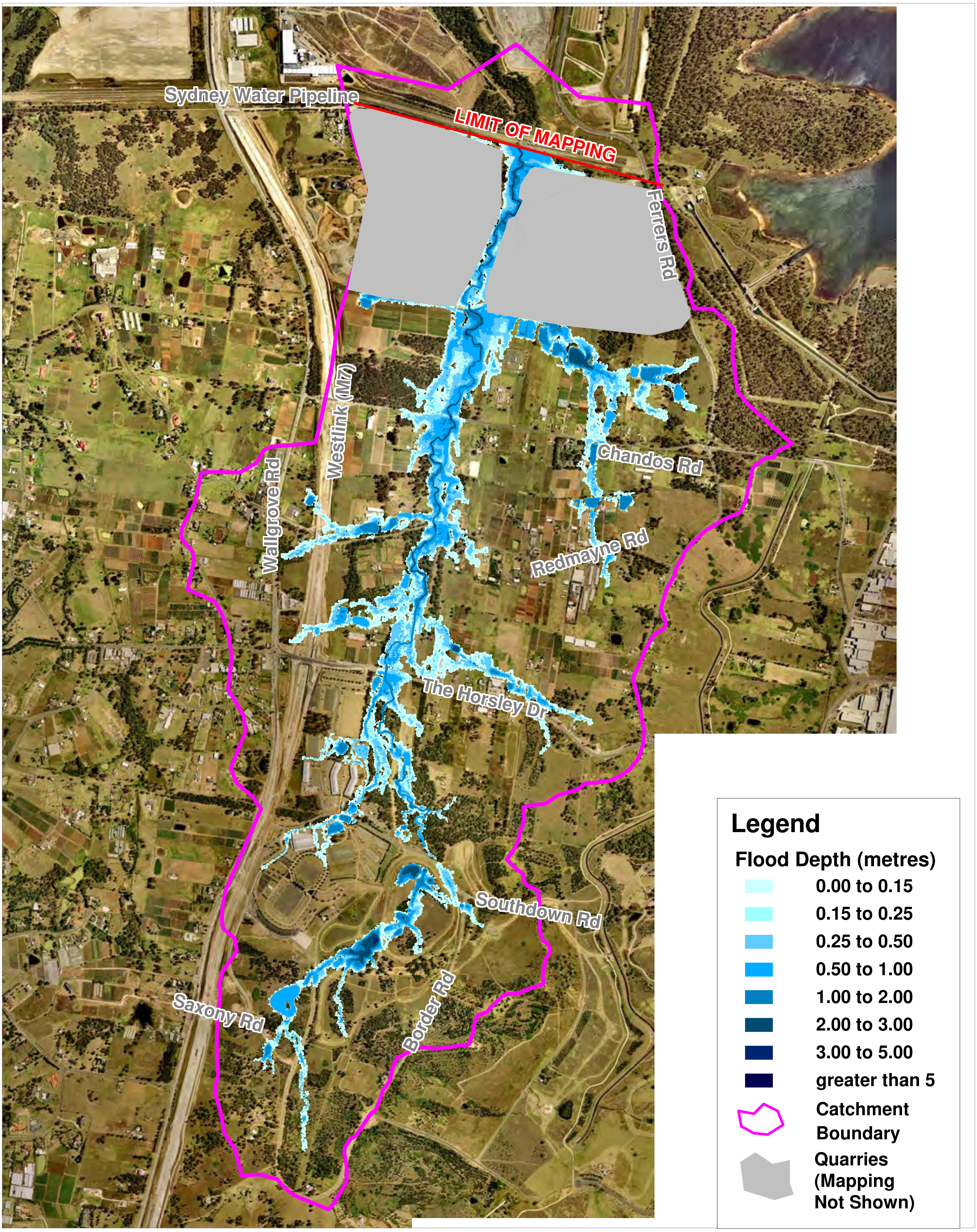

Title:
Eastern Creek
2000 Year ARI Flood Depth

Figure: **5-17**

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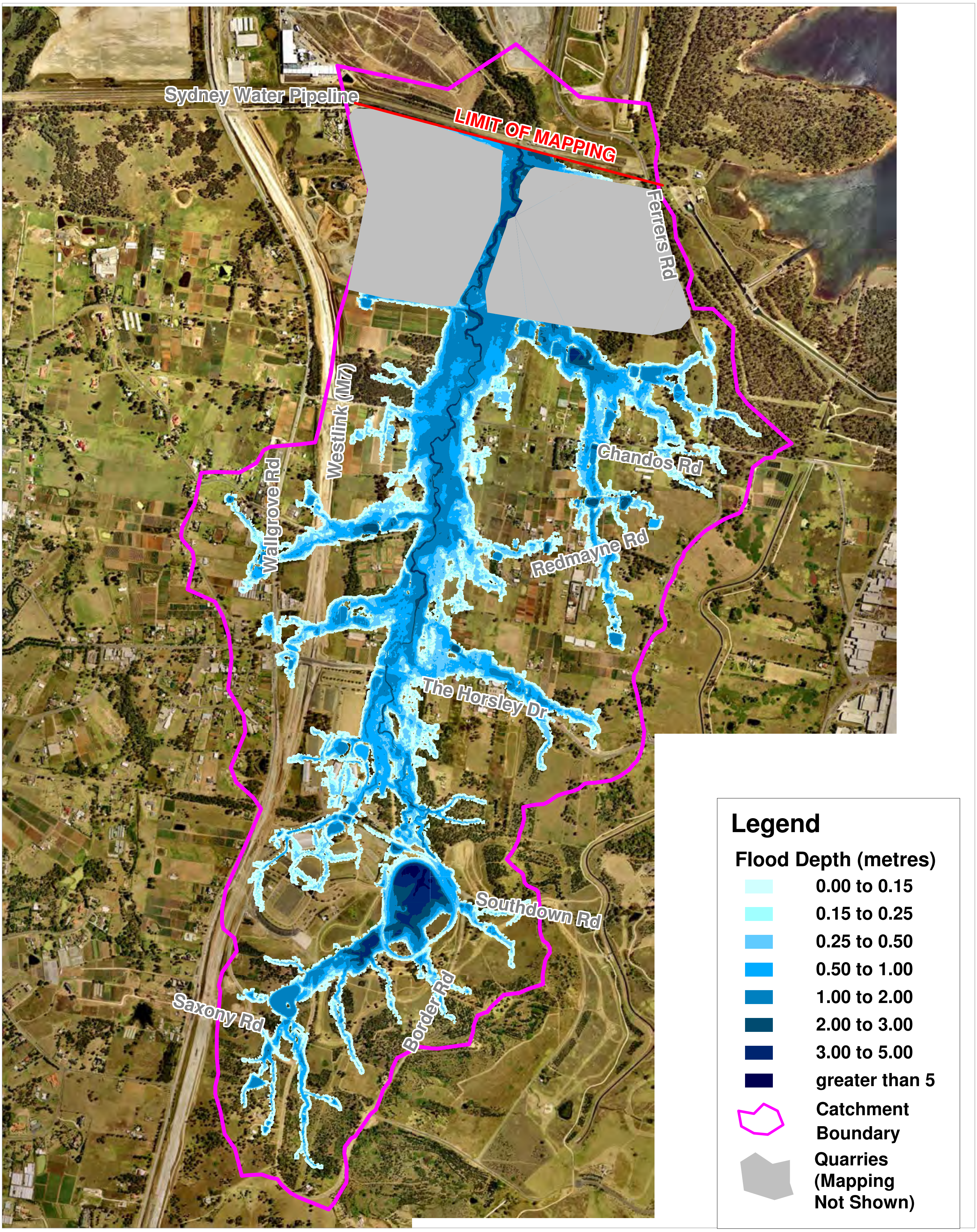

Title:

Eastern Creek PMP Flood Depth

Figure: **5-18**

Rev: **B**

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5.4 Flood Risk Precincts

Interim Flood Risk Precinct Mapping has been prepared for the Reedy, Ropes and Eastern Creek study areas. This mapping is based on the GIS mapping of the 100 year and PMF peak depth and velocity outputs from the TUFLOW hydraulic model. The Flood Risk Precinct Mapping is based upon the FCC Flood Risk Precinct categories described in Table 5-1 (as detailed in Chapter 11 of Council's DCP 2013).

Table 5-1 FCC Flood Risk Precincts

Risk Precinct	Description
High	The area of land below the 100 year ARI flood outline that is subject to high hydraulic hazard (for preparation of the draft flood risk precincts, this has been taken as the provisional 'High Hazard' zone from Figure L2 of Appendix L in the NSW Floodplain Development Manual)
Medium	Land below the 100 year ARI flood outline that is not in the High Risk Flood Precinct
Low	All other land within the floodplain (i.e.: within the extent of the PMF) but not identified within either High Risk or Medium Risk Precincts

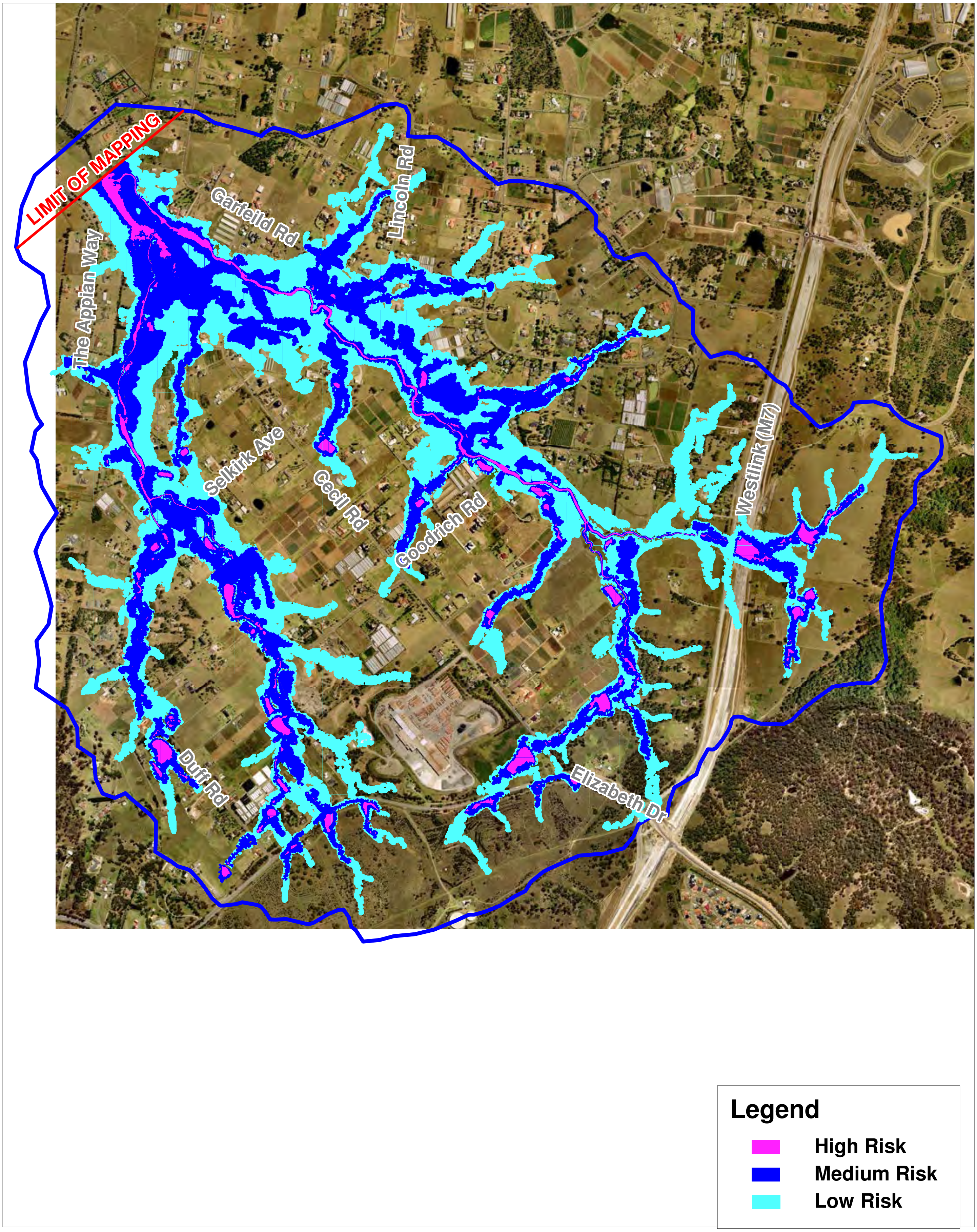
The Interim Flood Risk Precinct Maps are presented in Figure 5-19 (Reedy Creek), Figure 5-20 (Ropes Creek) and Figure 5-21 (Eastern Creek). These maps show the precinct outlines which are based upon the GIS analysis and interpretation of the developed flood extents. The Flood Risk Precinct Mapping has been labelled as "Interim" as the Precincts have not yet been reviewed as part of a floodplain risk management study process, and also, as evacuation planning considerations have not yet been included in the Precinct outlines

The High Risk Precinct highlights areas within the study area of excessively hazardous flood depth or flow velocity, or some combination of both. For the majority of the catchment, these areas of high flood risk are generally confined to the Reedy Creek, Ropes Creek and Eastern Creek channels. However, a large majority of the farm dams and storages within the respective catchments are also shown as being of high flood risk, primarily because of the flood depth.

The Medium and Low Flood Risk Precincts follow the same spatial extents as the 100 year ARI and PMF flood extents respectively.

The Interim Flood Risk Precinct Mapping indicates that a number of lots within each of the three catchments will be affected by the Low, Medium or High Risk Precincts. The number of properties has been detailed in Table 5-2 (Reedy Creek), Table 5-3 (Ropes Creek) and Table 5-4 (Eastern Creek). In each of these tables, a lot has only been counted once; even if it is affected by multiple floor risk precincts (the highest risk defines the risk precinct for the lot).

The Interim Flood Risk Precinct Mapping only identifies lots that will be impacted by the 1 in 100 year ARI flood event. Any buildings that are located on these lots may not necessarily be affected by above floor flooding. Whilst a large number of lots are shown to be impacted, a review of the flood mapping presented in Section 5.3, shows that the majority of buildings within the catchment are



Title:

Ropes Creek
Interim Flood Risk Precincts

Figure: 5-20

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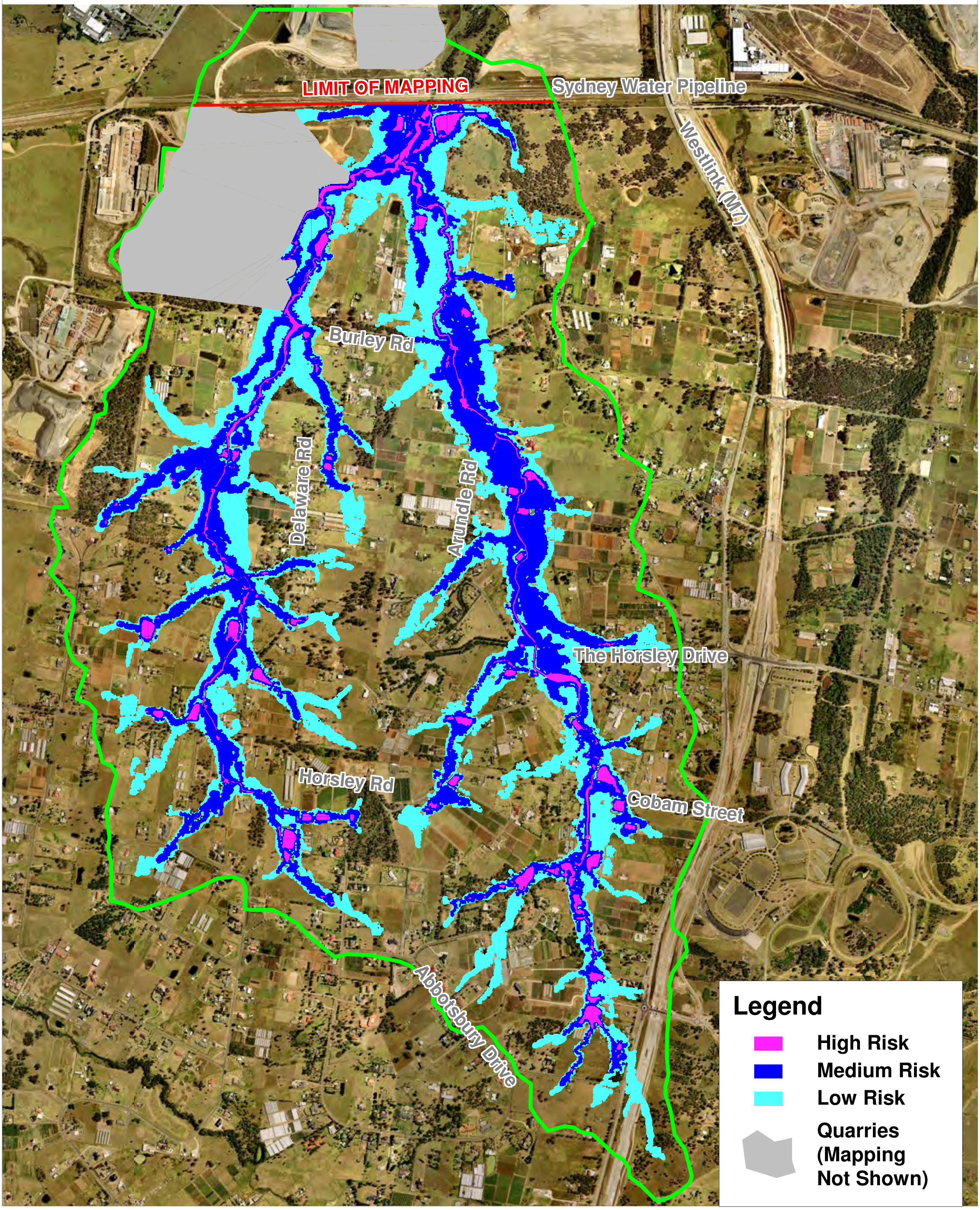

Title:

Reedy Creek
Interim Flood Risk Precincts

Figure: **5-19**

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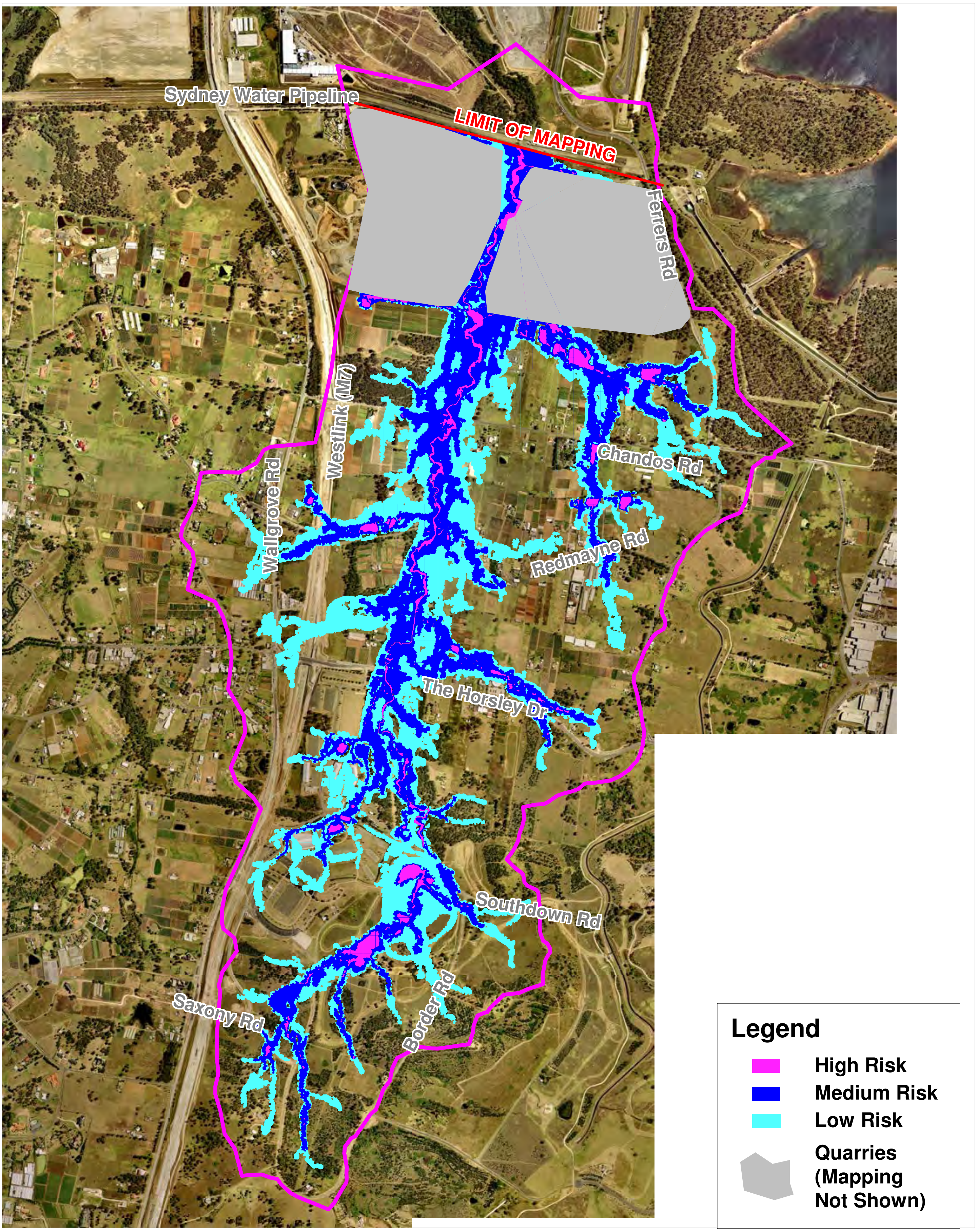

Title:

Eastern Creek
Interim Flood Risk Precincts

Figure: **5-21**

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Filepath : T:\M7198.MT.Fairfield\MapInfo\Figures\Final_Report\Fig_5-21_Eastern_Risk_RevB.WOR located away from the flood extent. Detailed floor level survey would be required to ascertain the exact number of buildings that are impacted by the prepared flood mapping.

Table 5-2 Reedy Creek – Lots affected by Interim Flood Risk Precinct Mapping

Risk Precinct	Number of Impacted Lots
High	155
Medium	57
Low	77
Total Lots within Catchment	***419***

Table 5-3 Ropes Creek – Lots affected by Interim Flood Risk Precinct Mapping

Risk Precinct	Number of Impacts Lots
High	157
Medium	40
Low	79
Total Lots within Catchment	***407***

Table 5-4 Eastern Creek – Lots affected by Interim Flood Risk Precinct Mapping

Risk Precinct	Number of Impacts Lots
High	88
Medium	30
Low	65
Total Lots within Catchment	***277***

Overall, a total of 748 lots (out of a total of 1103 lots within the three catchments) are affected across all three catchments by flooding of events up to and including the PMF.

5.5 Sensitivity Analysis

The sensitivity of the hydraulic model was tested by altering three input variable, as discussed with FCC, to gain an understanding of the effect of varying these parameters on the flood levels.

The analysis was undertaken to determine the sensitivity (or otherwise) of key input parameters to the hydraulic model to determine their relative impact on the flood mapping. A total of six (6) sensitivity scenarios were considered, with a summary of each scenario listed in Table 5-5. The sensitivity scenarios based around Manning's 'n' focussed on the key land use within each of the three catchments, grazing. Sensitivity testing other land uses would have only resulted in fairly minor changes to flood levels as they do not make up a large percentage of the catchment.

Table 5-5 Sensitivity Scenarios

Sensitivity Scenario	Parameter Tested	Percent Change in Parameter
1	Initial Loss	+20%
2	Initial Loss	-20%
3	Continuing Loss	+20%
4	Continuing Loss	-20%
5	Key Roughness – Grazing Land	+20%
6	Key Roughness – Grazing Land	-20%

A series of longitudinal plots have been presented for Reedy Creek (Figure 5-22 and Figure 5-23), Ropes Creek (Figure 5-24 and Figure 5-25) and Eastern Creek (Figure 5-26). These plots do not cover the entire longitudinal profile of the respective creeks; however, they show a 500 metre section of the profile to give an indication of how the flood level varies for each of the sensitivity scenarios described in Table 5-5.

For each of the three creeks, the sensitivity analysis showed that the flood levels are not overly sensitive to changes in the tested parameters (initial loss, continuing loss and Manning's 'n' for the grazing land).

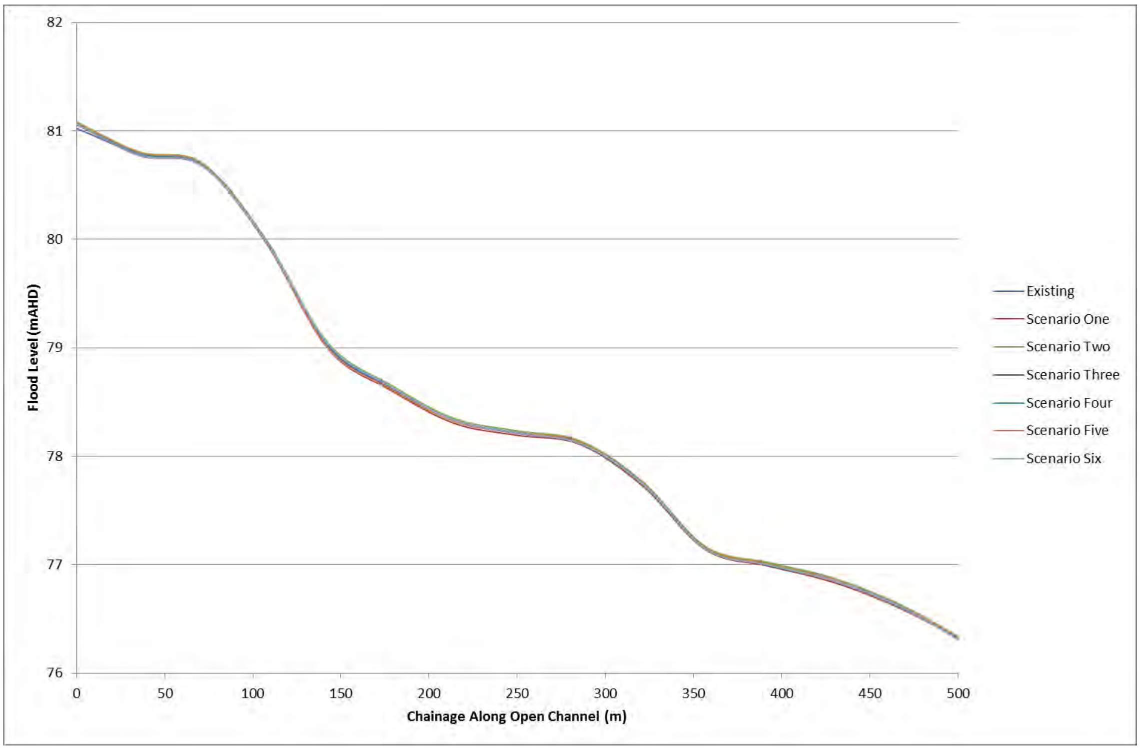

Figure 5-22 Longitudinal Profile along Reedy Creek (West)

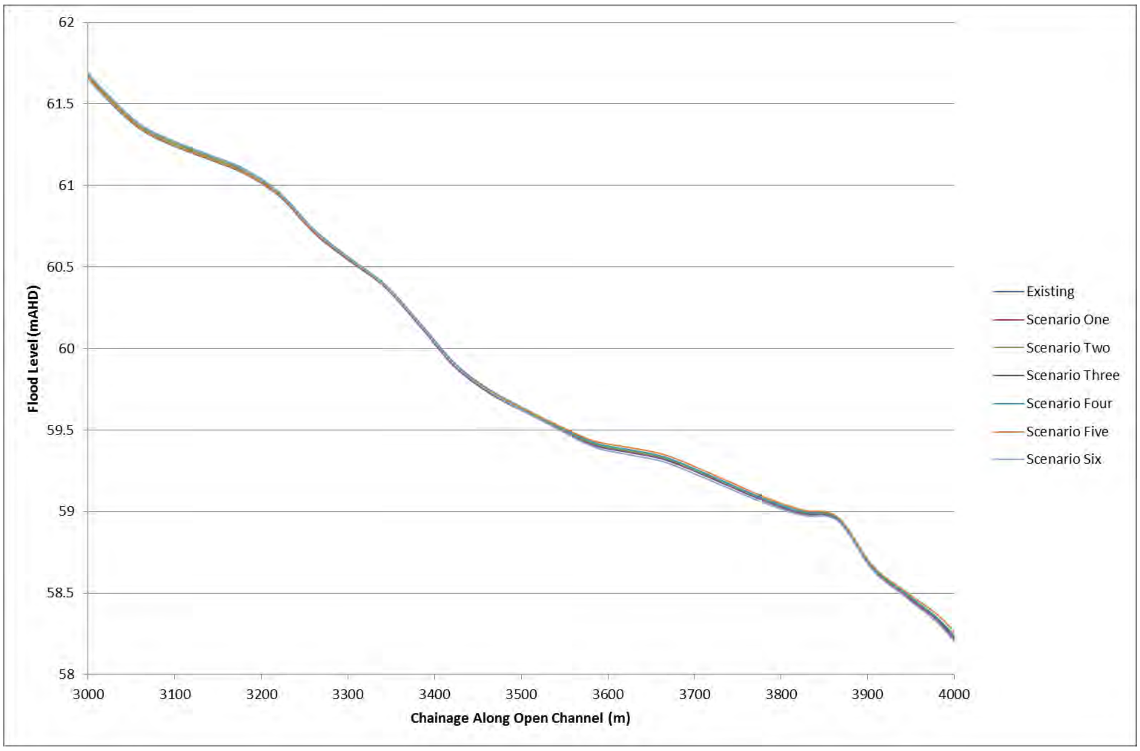

Figure 5-23 Longitudinal Profile along Reedy Creek (East)

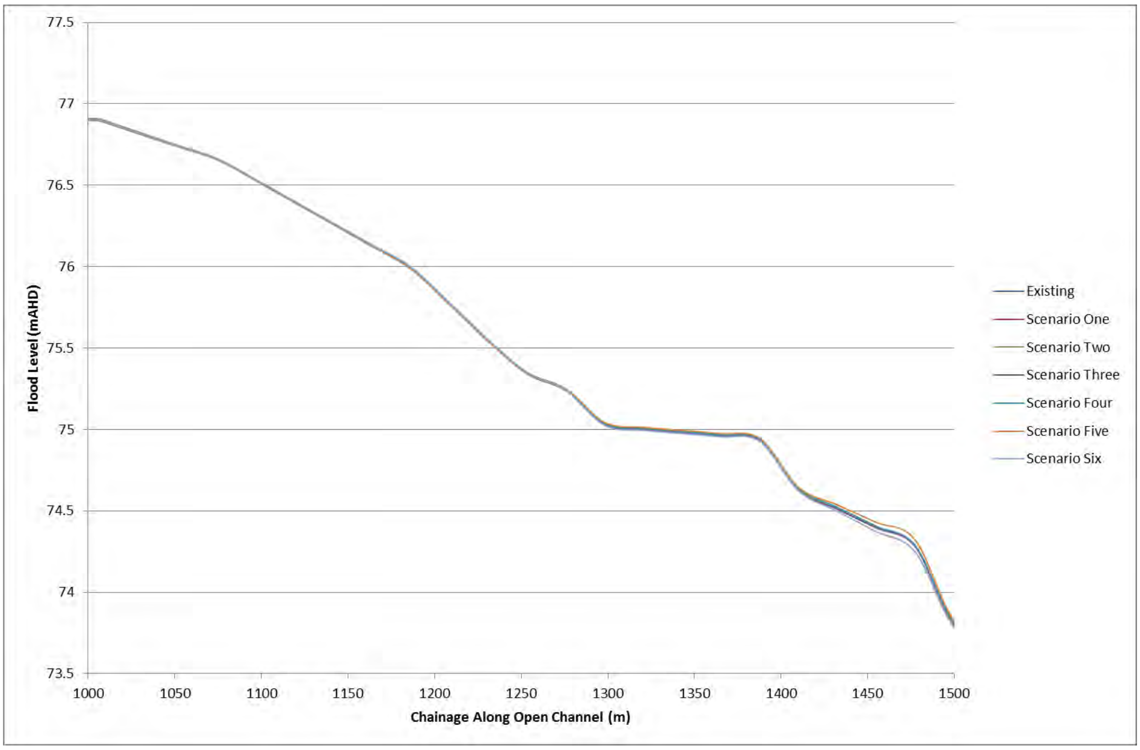

Figure 5-24 Longitudinal Profile along Ropes Creek (West)

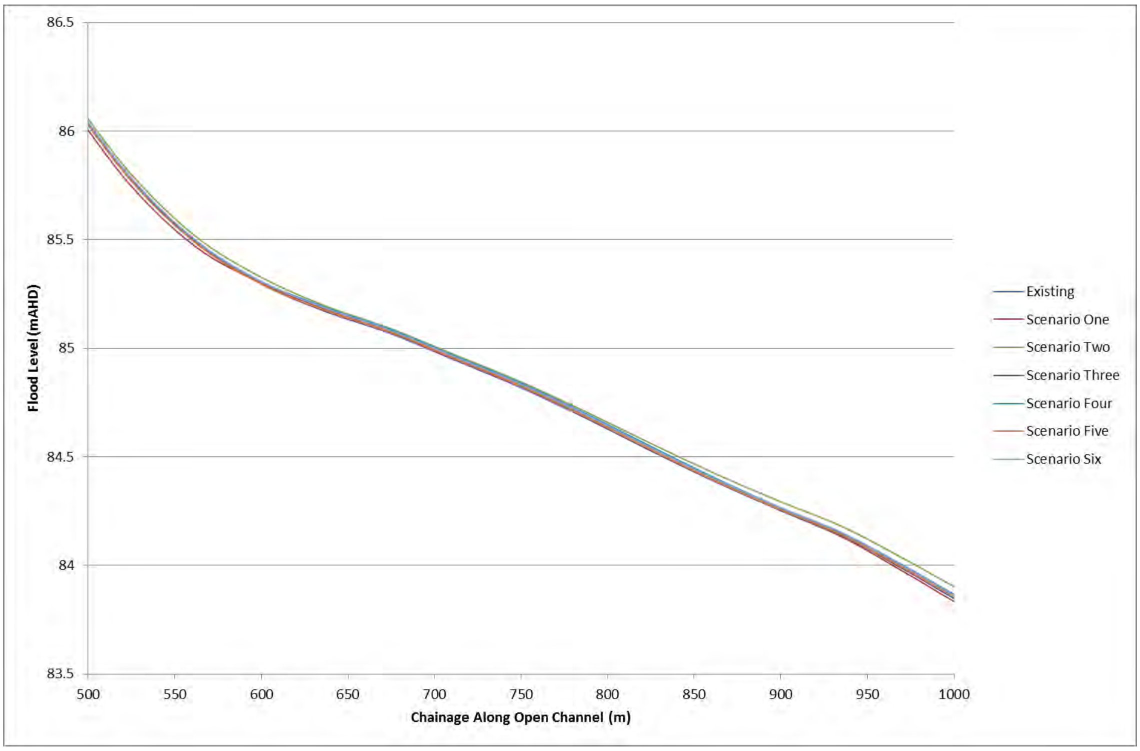

Figure 5-25 Longitudinal Profile along Ropes Creek (East)

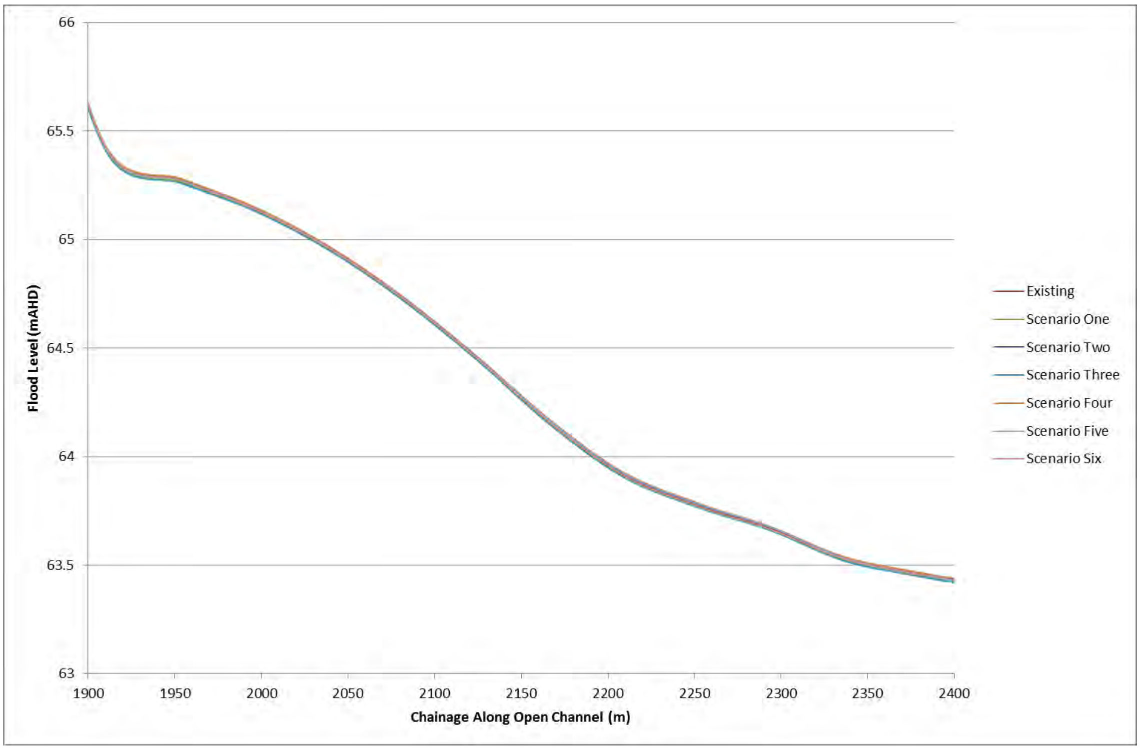

Figure 5-26 Longitudinal Profile along Eastern Creek

5.6 Blockage Analysis

Through discussion with FCC, it was agreed that the blockage scenario to test the sensitivity of culverts/bridges should consist of 100% blockage of all major waterway structures simultaneously (i.e. in a single model).100% blockage of structures is considered a worst case scenario, however, such structure blockage is likely during large flood events as observed during the 2007 Newcastle flood. 100% blockage was undertaken as the vast majority of the structures within each of the catchments were relatively small and the catchment is predominately rural. The impact of blockages was assessed on the relative impact on the existing conditions for each of the design events considered.

As would be expected, blocking the hydraulic structures within TUFLOW resulted in increased flood levels upstream of a structure. Downstream of the blocked structures typically show reduced water levels due to the water being held back behind the bridge/culvert headwall until overtopped.

For each public road crossing, a point upstream and downstream was used to interrogate the results to assess the impact on flood levels of blocking the structure. This was done for each ARI event. The results are shown in Table 5-6 through Table 5-8 for Reedy, Ropes and Eastern Creek respectively. Each table shows the existing conditions level in m AHD and the water level difference caused by blocking the structure.

As the flood event increases, the impact of the blocked structure will generally decrease. This is due to an increasing proportion of the floodwater by-passing the structure entirely. In large flood events, a small proportion of the water would pass through a culvert under the road when compared to the floodwaters flowing over the road. Therefore, the blockage of the structure has minimal impact. The greatest impacts of the blockage analysis are often seen in the smallest event (20 year ARI), as most of the floodwaters would have usually passed through the structures that have now been blocked.

Table 5-6 Reedy Creek Blocked Structures Impact

Road Name	US or DS	20 Year ARI			50 Year ARI			100 Year ARI		
		Base Level	Blocked Level	Dif	Base Level	Blocked Level	Dif	Base Level	Blocked Level	Dif
Cobham St	US	83.05	82.51	-0.54	83.09	82.58	-0.51	83.13	82.66	-0.47
	DS	82.27	82.27	0.01	82.35	82.36	0.01	82.43	82.43	0.00
Horsley Rd	US	77.35	77.41	0.06	77.42	77.47	0.04	77.48	77.51	0.03
	DS	77.06	76.99	-0.06	77.11	77.06	-0.05	77.17	77.13	-0.04
Arundel Rd (north)	US	75.56	76.04	0.48	75.66	76.09	0.43	75.74	76.13	0.39
	DS	74.90	74.92	0.02	74.96	74.95	-0.01	74.99	74.98	-0.01
Arundel Rd (south)	US	67.26	67.30	0.04	67.34	67.36	0.03	67.39	67.42	0.03
	DS	67.00	67.04	0.03	67.08	67.09	0.02	67.13	67.15	0.02
Burley Rd	US	65.28	65.46	0.18	65.35	65.50	0.15	65.40	65.54	0.14
	DS	64.21	64.00	-0.20	64.32	64.11	-0.21	64.40	64.21	-0.19
Pipeline	US	58.16	58.48	0.32	58.24	58.55	0.31	58.32	58.61	0.29
	DS	57.85	57.67	-0.18	57.83	57.75	-0.08	57.88	57.80	-0.08
Burley Rd (west)	US	64.73	64.56	-0.17	64.80	64.66	-0.14	64.87	64.76	-0.11
	DS	64.23	64.25	0.02	64.33	64.35	0.02	64.43	64.46	0.02
Horsley Rd (west)	US	81.60	81.63	0.03	81.67	81.69	0.02	81.72	81.74	0.02
	DS	80.70	80.70	0.00	80.79	80.78	0.00	80.85	80.85	0.00

Road Name	US or DS	500 Year ARI			2000 Year ARI			PMP		
		Base Level	Blocked Level	Dif	Base Level	Blocked Level	Dif	Base Level	Blocked Level	Dif
Cobham St	US	83.20	82.81	-0.40	83.26	82.91	-0.35	84.06	84.04	-0.02
	DS	82.57	82.58	0.01	82.68	82.68	0.00	83.85	83.85	0.00
Horsley Rd	US	77.58	77.60	0.02	77.65	77.67	0.01	78.74	78.75	0.01
	DS	77.25	77.23	-0.02	77.31	77.29	-0.02	78.32	78.30	-0.02
Arundel Rd (north)	US	75.85	76.21	0.35	75.95	76.27	0.32	76.89	77.00	0.12
	DS	75.06	75.04	-0.02	75.11	75.09	-0.02	75.69	75.74	0.05
Arundel Rd (south)	US	67.48	67.51	0.03	67.57	67.59	0.02	68.59	68.60	0.01
	DS	67.21	67.23	0.02	67.30	67.31	0.01	68.31	68.30	0.00
Burley Rd	US	65.46	65.59	0.13	65.54	65.65	0.11	66.43	66.46	0.03
	DS	64.52	64.34	-0.19	64.68	64.47	-0.21	65.73	65.72	-0.01
Pipeline	US	58.40	58.71	0.30	58.49	58.79	0.29	60.04	60.18	0.14
	DS	57.99	57.90	-0.09	58.11	57.99	-0.12	59.46	59.44	-0.01
Burley Rd (west)	US	65.05	64.99	-0.07	65.21	65.09	-0.12	66.37	66.40	0.03
	DS	64.67	64.69	0.02	64.78	64.79	0.01	66.12	66.12	0.00
Horsley Rd (west)	US	81.76	81.77	0.01	81.80	81.81	0.01	82.54	82.53	-0.01
	DS	80.90	80.90	0.00	80.95	80.95	0.00	81.89	81.89	0.00

Table 5-7 Ropes Creek Blocked Structures Impact

Road Name	US or DS	20 Year ARI			50 Year ARI			100 Year ARI		
		Base Level	Blocked Level	Dif	Base Level	Blocked Level	Dif	Base Level	Blocked Level	Dif
Wallgrove Rd	US	96.50	98.96	2.46	96.70	99.03	2.33	96.87	99.05	2.18
	DS	94.41	94.19	-0.22	94.42	94.34	-0.08	94.45	94.37	-0.09
Goodrich Rd	US	83.32	84.32	1.00	83.49	84.37	0.88	83.71	84.42	0.71
	DS	83.03	82.77	-0.26	83.14	82.89	-0.25	83.28	83.03	-0.25
Lincoln Rd	US	78.24	79.83	1.59	78.37	79.88	1.52	78.51	79.94	1.43
	DS	78.10	77.87	-0.23	78.23	77.94	-0.28	78.37	78.10	-0.28
Selkirk Ave (west)	US	81.22	81.24	0.02	81.26	81.28	0.01	81.30	81.30	0.01
	DS	79.97	79.97	0.00	80.07	80.08	0.01	80.16	80.17	0.01
Selkirk Ave (east)	DS	81.06	81.17	0.10	81.13	81.20	0.07	81.17	81.22	0.05
	DS	80.24	80.14	-0.10	80.33	80.23	-0.09	80.38	80.30	-0.08

Road Name	US or DS	500 Year ARI			2000 Year ARI			PMP		
		Base Level	Blocked Level	Dif	Base Level	Blocked Level	Dif	Base Level	Blocked Level	Dif
Wallgrove Rd	US	97.21	99.05	1.83	97.46	99.08	1.63	99.48	99.59	0.11
	DS	94.49	94.36	-0.13	94.51	94.42	-0.10	95.26	95.26	0.00
Goodrich Rd	US	84.04	84.52	0.48	84.18	84.60	0.42	85.71	85.85	0.13
	DS	83.49	83.23	-0.26	83.61	83.37	-0.24	85.05	85.02	-0.02
Lincoln Rd	US	78.75	80.03	1.28	79.06	80.07	1.02	80.51	80.78	0.28
	DS	78.60	78.28	-0.32	78.75	78.42	-0.33	79.96	79.87	-0.09
Selkirk Ave (west)	US	81.30	81.30	0.00	81.33	81.33	0.00	81.87	81.85	-0.02
	DS	80.18	80.16	-0.02	80.25	80.24	-0.01	81.39	81.40	0.00
Selkirk Ave (east)	DS	81.21	81.25	0.04	81.24	81.27	0.03	81.85	81.84	-0.01
	DS	80.47	80.41	-0.07	80.56	80.51	-0.05	81.37	81.36	-0.01

Table 5-8 Eastern Creek Blocked Structures Impact

Road Name	US or DS	20 Year ARI			50 Year ARI			100 Year ARI		
		Base Level	Blocked Level	Dif	Base Level	Blocked Level	Dif	Base Level	Blocked Level	Dif
Southdown Rd	US	81.20	84.52	3.32	81.29	85.03	3.73	81.42	85.39	3.96
	DS	78.34	77.90	-0.44	78.43	77.91	-0.51	78.48	77.92	-0.56
The Horsley Drive	US	71.81	72.31	0.49	72.12	72.33	0.22	72.21	72.35	0.14
	DS	71.53	71.19	-0.34	71.64	71.24	-0.40	71.69	71.26	-0.43
Redmayne Rd	US	66.10	66.04	-0.06	66.23	66.09	-0.14	66.31	66.14	-0.17
	DS	65.37	65.28	-0.09	65.45	65.36	-0.09	65.53	65.41	-0.12
Chandos Rd	US	63.15	62.94	-0.22	63.23	63.04	-0.19	63.30	63.11	-0.19
	DS	62.59	62.53	-0.05	62.66	62.60	-0.06	62.75	62.66	-0.08
Pipeline	US	56.17	56.36	0.19	56.22	56.39	0.17	56.27	56.42	0.14
	DS	55.68	55.55	-0.13	55.73	55.61	-0.12	55.79	55.68	-0.12

Road Name	US or DS	500 Year ARI			2000 Year ARI			PMP		
		Base Level	Blocked Level	Dif	Base Level	Blocked Level	Dif	Base Level	Blocked Level	Dif
Southdown Rd	US	81.60	85.37	3.78	81.80	85.69	3.90	86.02	86.17	0.16
	DS	78.51	77.91	-0.60	78.55	77.94	-0.61	78.99	78.75	-0.24
The Horsley Drive	US	72.24	72.39	0.15	72.31	72.42	0.11	72.86	73.00	0.14
	DS	71.71	71.32	-0.39	71.76	71.36	-0.40	72.27	72.24	-0.02
Redmayne Rd	US	66.34	66.23	-0.12	66.41	66.28	-0.13	67.19	67.09	-0.10
	DS	65.57	65.53	-0.05	65.64	65.60	-0.04	66.66	66.63	-0.03
Chandos Rd	US	63.36	63.24	-0.12	63.42	63.31	-0.12	64.25	64.20	-0.05
	DS	62.81	62.78	-0.03	62.88	62.84	-0.04	63.72	63.69	-0.03
Pipeline	US	56.35	56.45	0.10	56.42	56.50	0.08	57.49	57.47	-0.02
	DS	55.88	55.80	-0.08	55.95	55.88	-0.08	57.20	57.13	-0.06

6 CONCLUSION AND RECOMMENDATIONS

6.1 Summary of Study Outcomes

The existing flood conditions of the Reedy, Ropes and Eastern Creek catchments were determined using a ‘direct rainfall’ TUFLOW hydraulic model The modelling included up to date topographic and survey information to define the waterways in each catchment as well as the various structures (culverts and bridges) that convey flow. The ‘direct rainfall’ TUFLOW model was calibrated to a traditional modelling approach of applying hydrographs from a hydrologic model (FCC’s XP-RAFTS model of Reedy Creek) to a TUFLOW model by the adjustment of initial and continuing losses and Manning’s ‘n’ values.

The flood inundation mapping has been presented in Section 5.3 for all modelled flood events. The Interim Flood Risk Precinct Mapping is presented in Section 5.4.

Across all three catchments (Reedy Creek, Ropes Creek and Eastern Creek), the Interim Flood Risk Mapping indicates that 400 lots are affected by the High Risk Precinct, 127 lots are affected by the Medium Risk Precinct and 221 lots are affected by the Low Risk Precinct. It is noted that an individual lot can contain areas of High, Medium and Low Risk.

The sensitivity analysis (Section 5.5) showed that the flood levels are not overly sensitive to changes (+/- 20%) in the key parameters (Initial Loss, Continuing Loss and Manning’s ‘n’ value for grazing land). Although not tested, the model would be sensitive to changes in land use, including an increased fraction imperviousness of the catchment as a result of development

The blockage analysis (Section 5.6) demonstrated that during the 100 year ARI flood event, 100% blockage of culverts and bridge structures did not have a significant impact on flood levels along the creek. Whilst there were localised impacts upstream (increased flood levels) and downstream (reduced flood levels), the impacts did not extend significantly beyond the structure. The impacts were worst in the more frequent events (20 Year ARI flood event) when compared to the rare flood events (greater than the 100 year ARI flood event)

6.2 Conclusions based on Study Outcomes

Based on the outcomes of the study, BMT WBM makes the following conclusions:

- Using the flood modelling results produced by this study, FCC can identify those properties in the study area affected by flooding from Reedy Creek, Ropes Creek and Eastern Creek and update the Section 149 certificates for these properties as required.
- The findings of this study can be used as a basis for the development of management strategies in the subsequent Rural Area Floodplain Risk Management Studies.

6.3 Recommendations based on Study Outcomes

Based on the outcomes of the study, BMT WBM makes the following recommendations:

- As part of any subsequent Floodplain Risk Management Studies, the Interim Flood Risk Precincts presented in this report should be reviewed to ensure the implications from any evacuation planning consideration or other relevant consideration are appropriately included in the Flood Risk Precinct Mapping.

7 REFERENCES

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APPENDIX A: HYDRAULIC MODEL COMPARISON HYDROGRAPHS

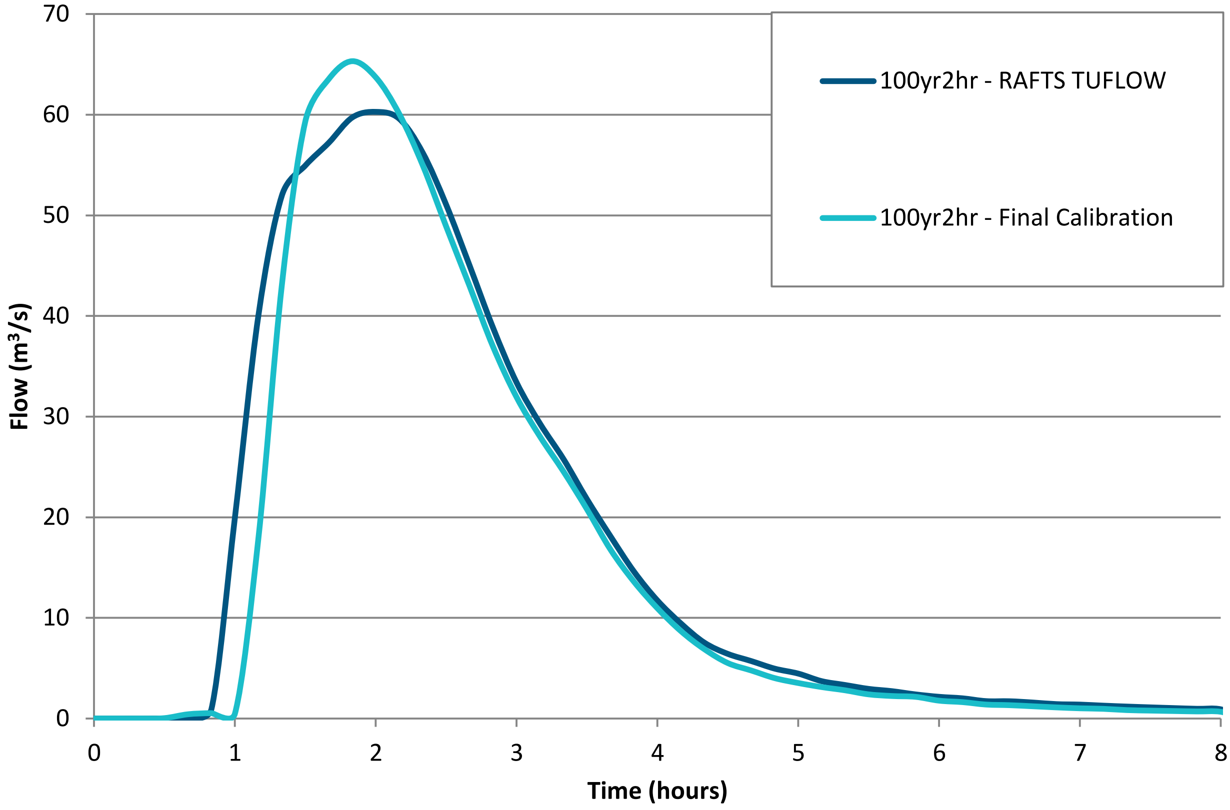

Figure 7-1 Downstream Hydrographs – 100 Year ARI 2 Hour Duration

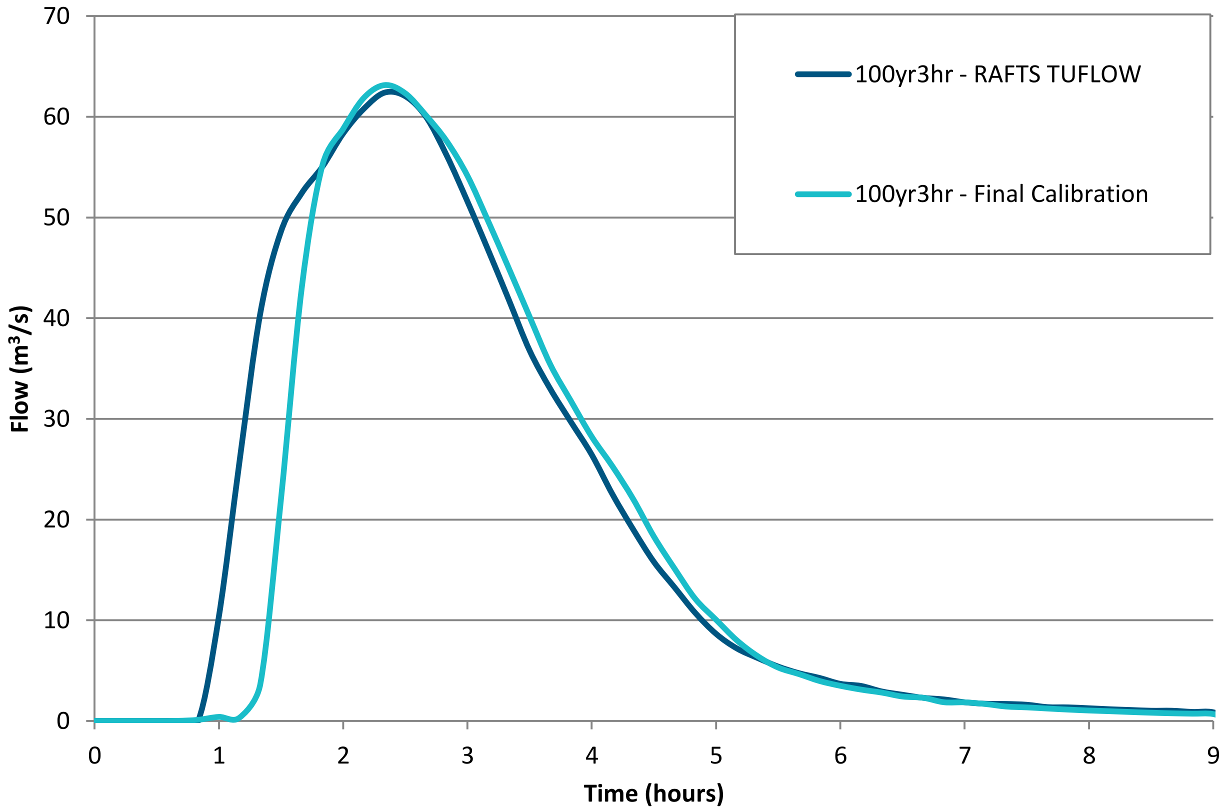

Figure 7-2 Downstream Hydrographs – 100 Year ARI 3 Hour Duration

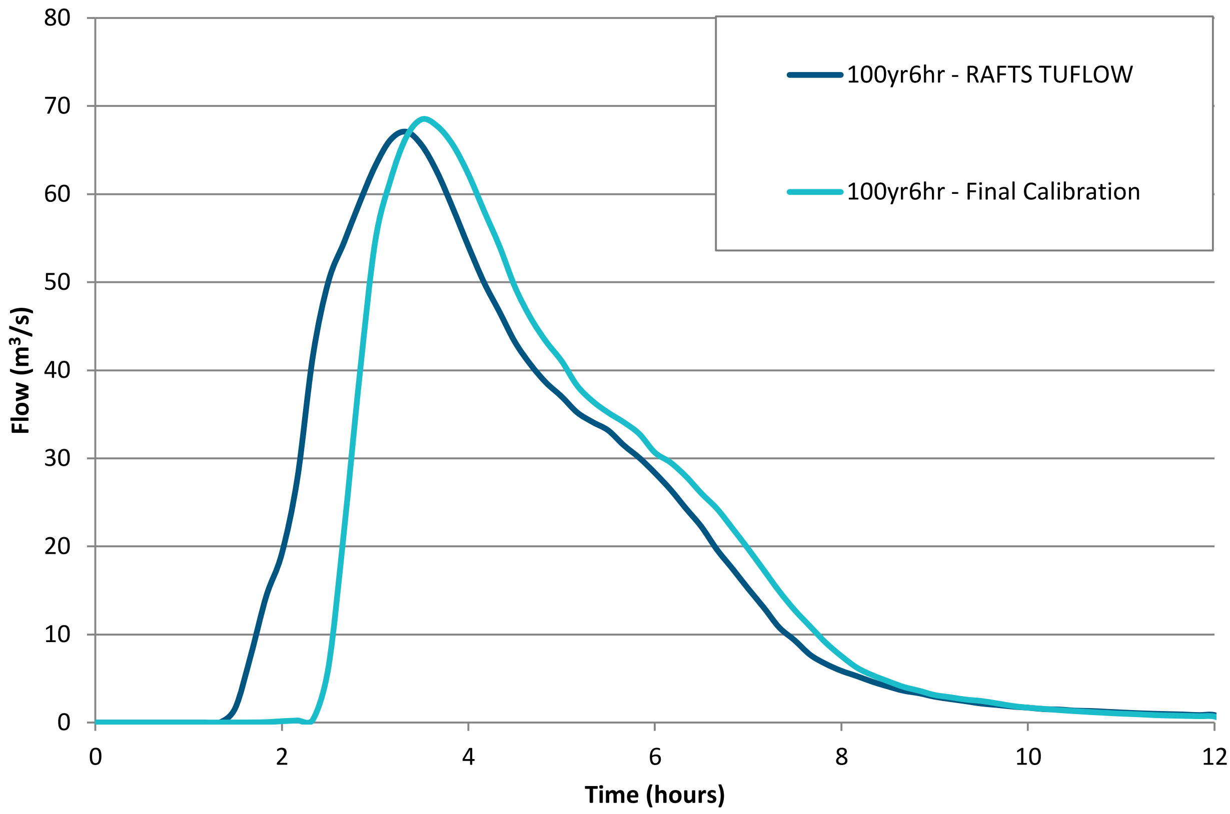

Figure 7-3 Downstream Hydrographs – 100 Year ARI 6 Hour Duration

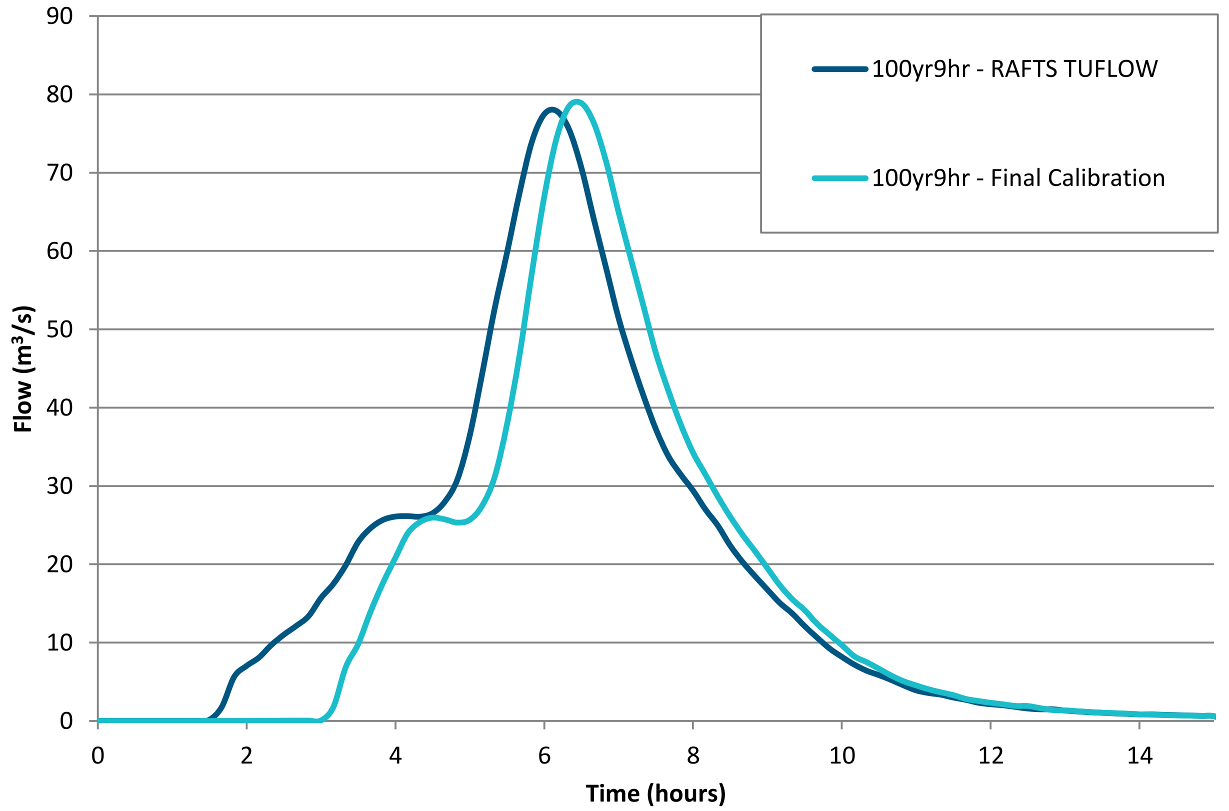

Figure 7-4 Downstream Hydrographs – 100 Year ARI 9 Hour Duration

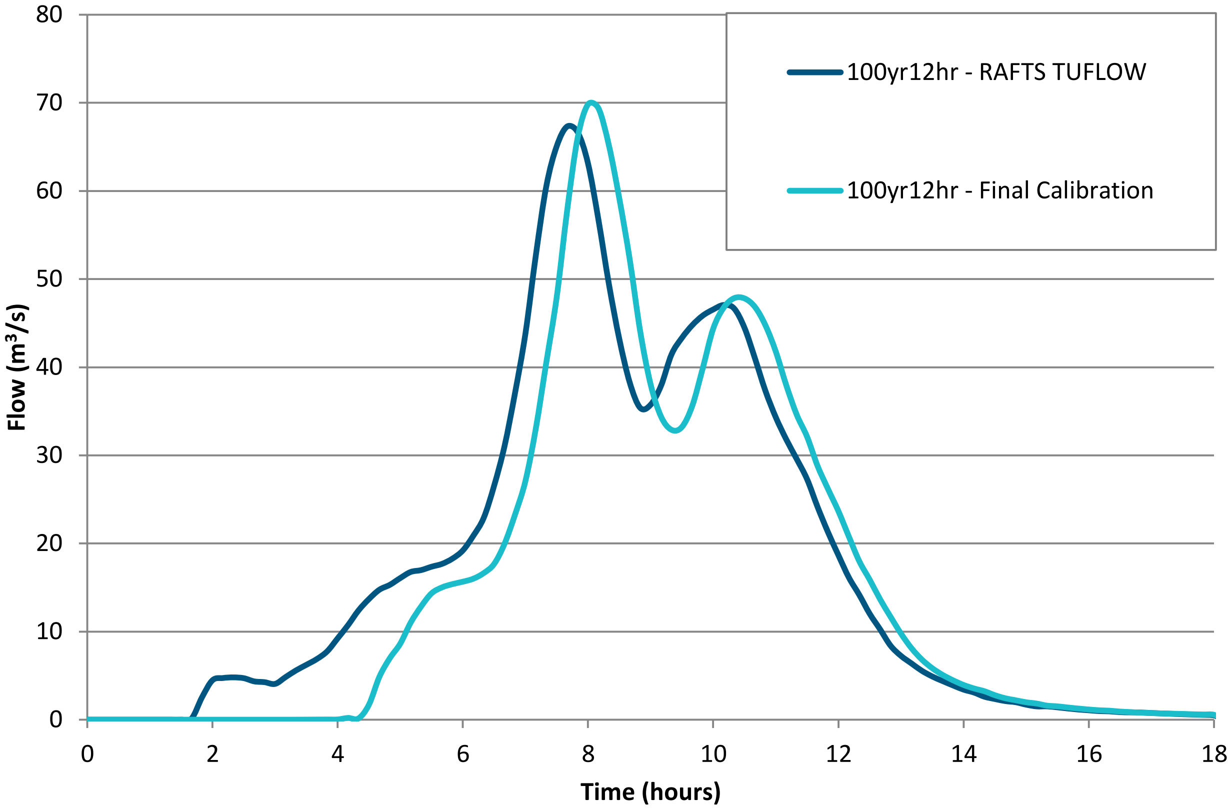

Figure 7-5 Downstream Hydrographs – 100 Year ARI 12 Hour Duration

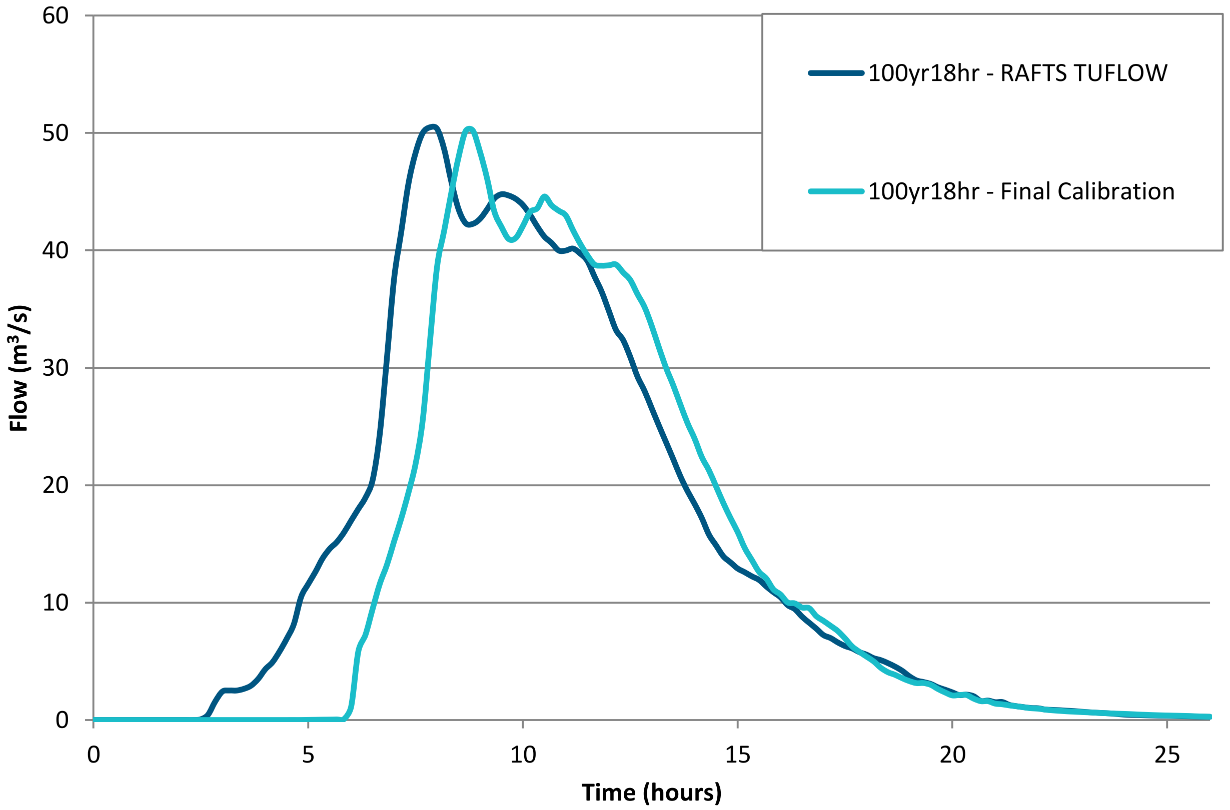

Figure 7-6 Downstream Hydrographs – 100 Year ARI 18 Hour Duration

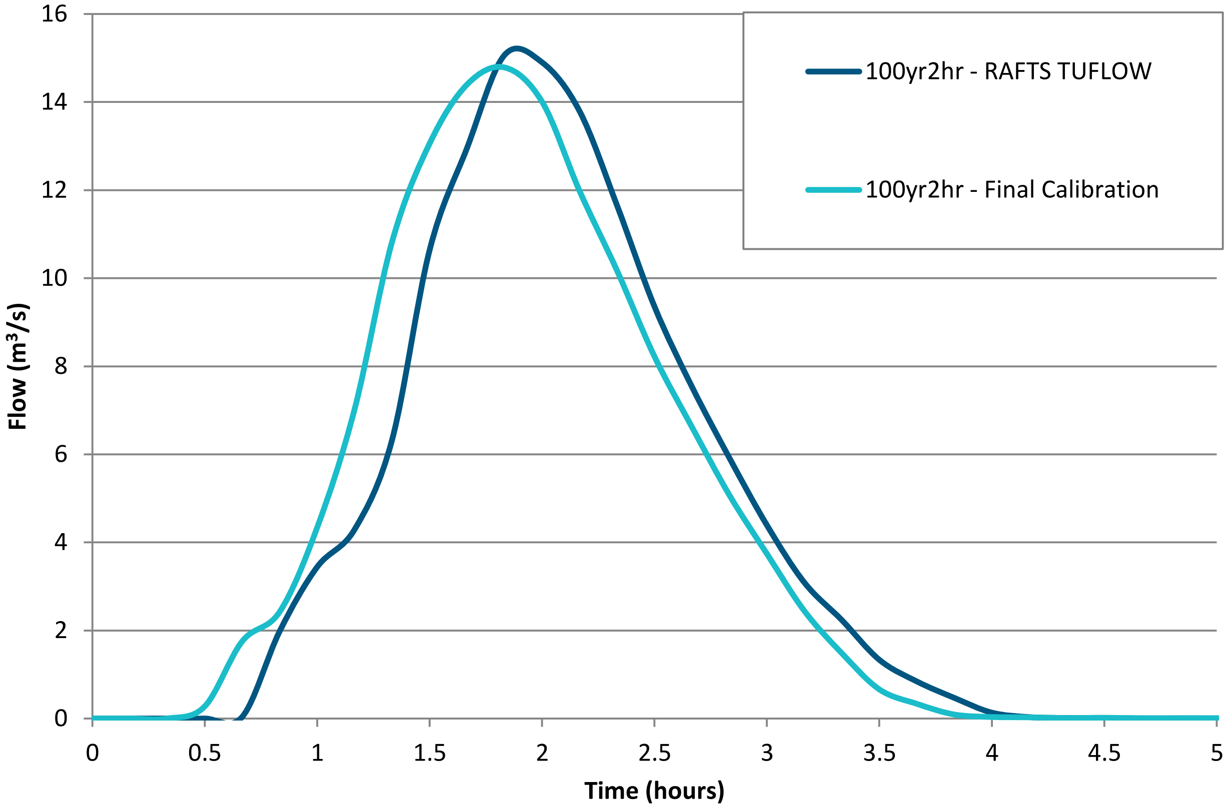

Figure 7-7 South-east Tributary Hydrographs – 100 Year ARI 2 Hour Duration

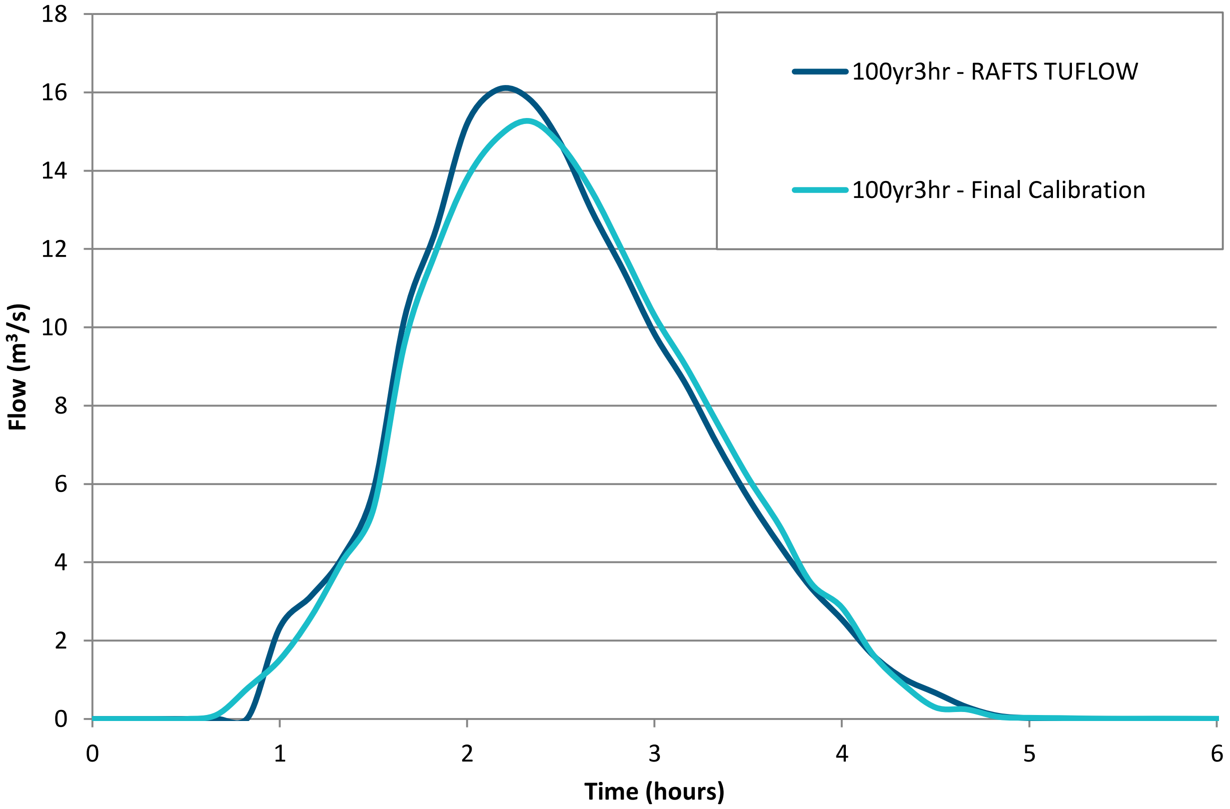

Figure 7-8 South-east Tributary Hydrographs – 100 Year ARI 3 Hour Duration

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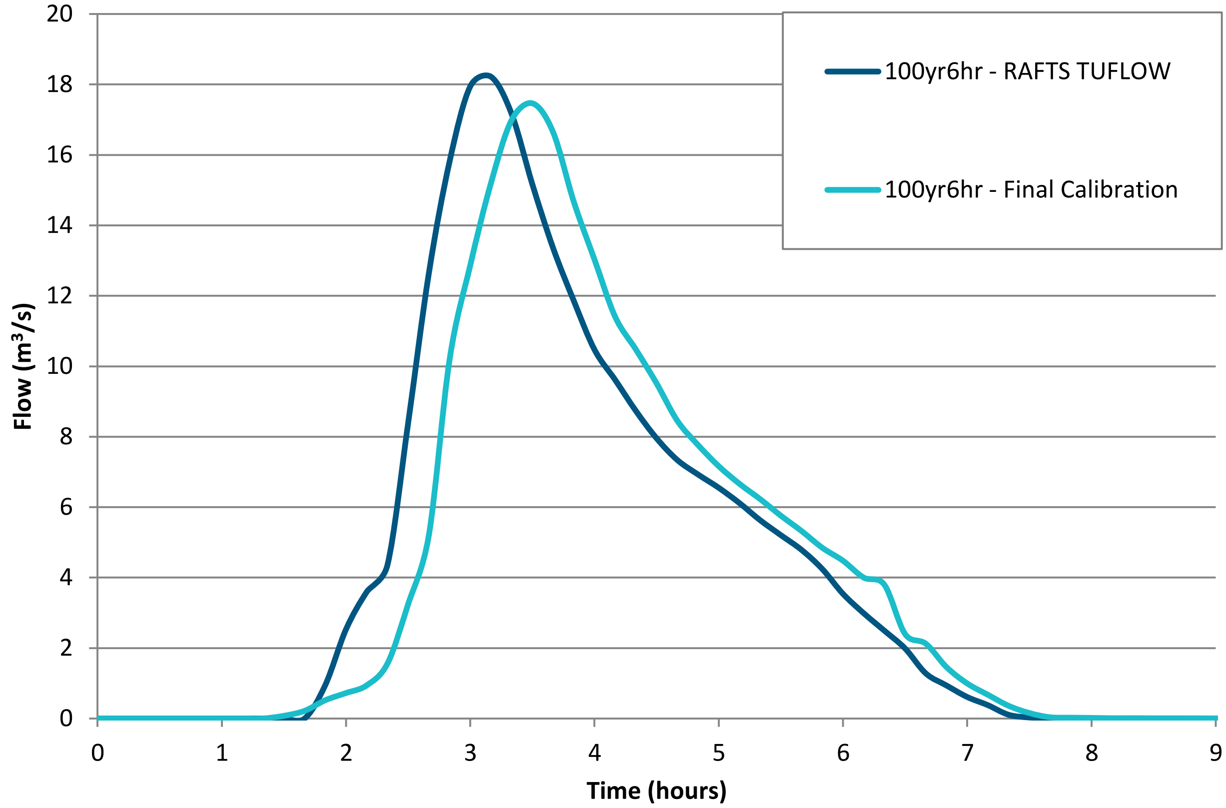

Figure 7-9 South-east Tributary Hydrographs – 100 Year ARI 6 Hour Duration

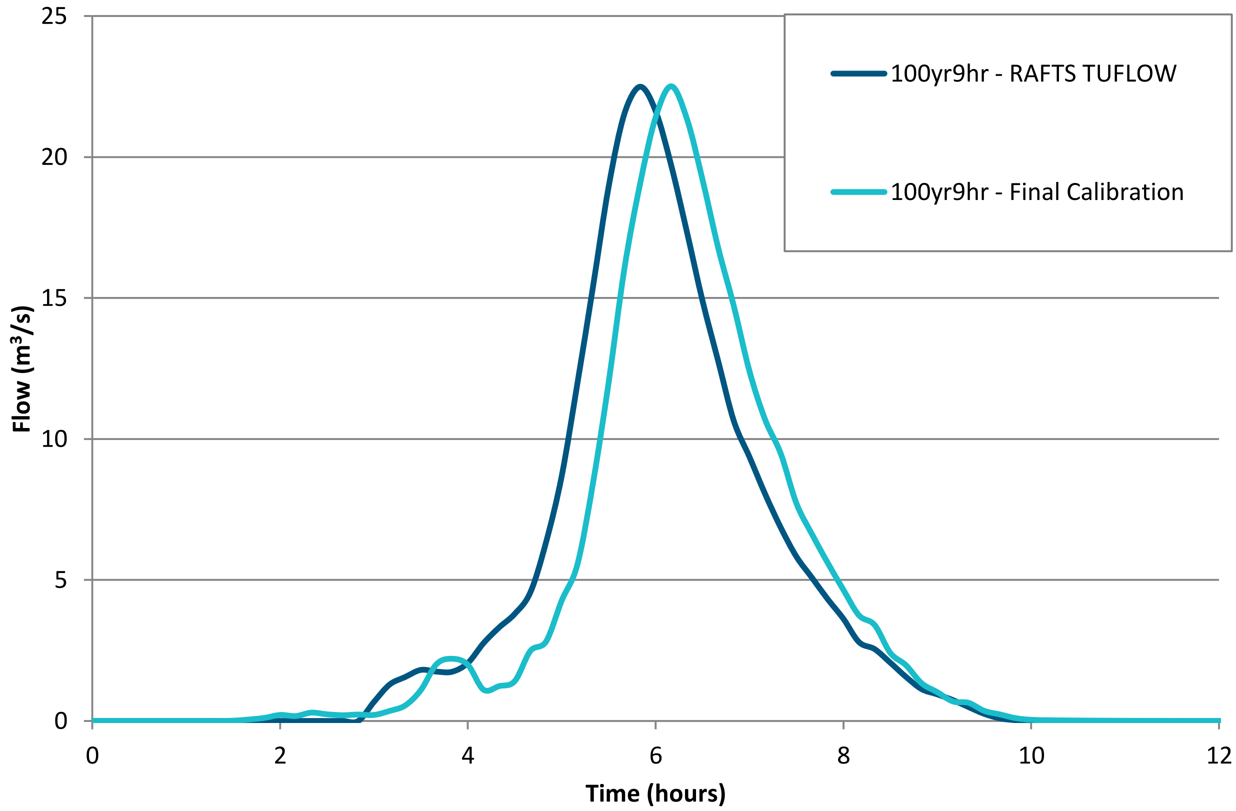

Figure 7-10 South-east Tributary Hydrographs – 100 Year ARI 9 Hour Duration

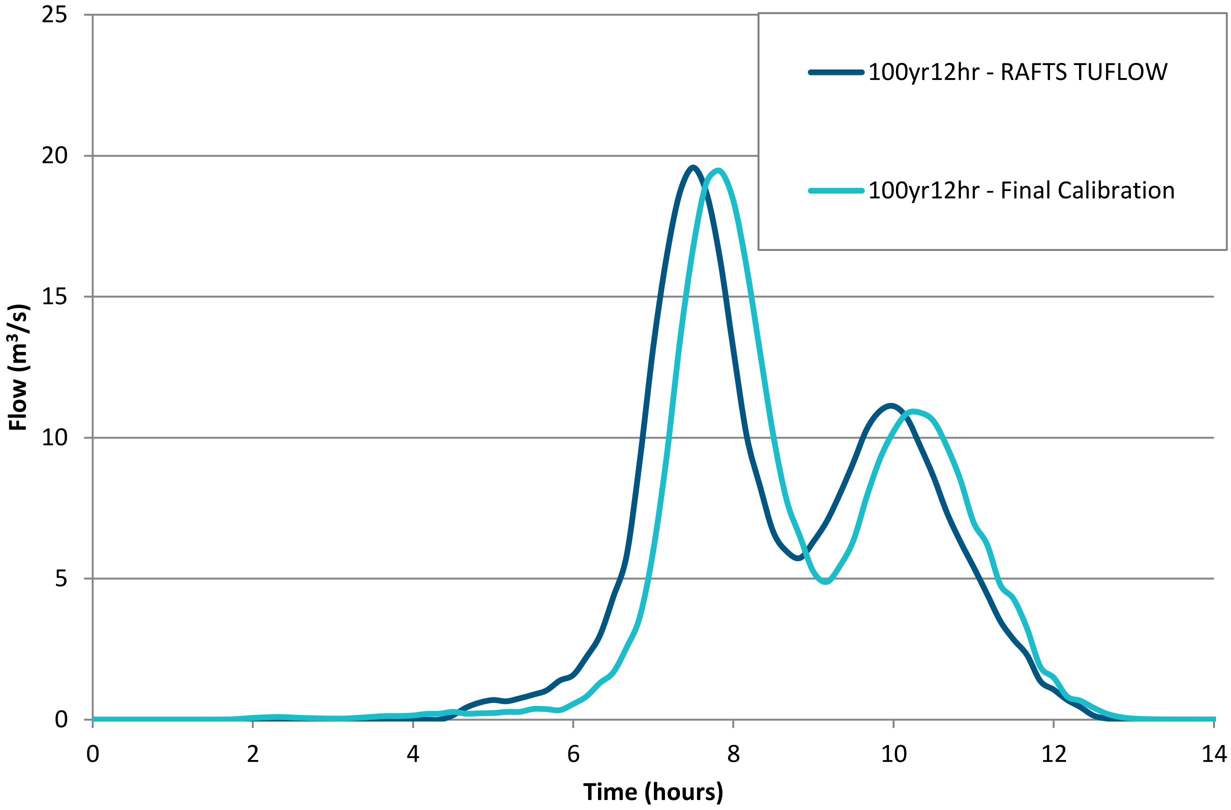

Figure 7-11 South-east Tributary Hydrographs – 100 Year ARI 12 Hour Duration

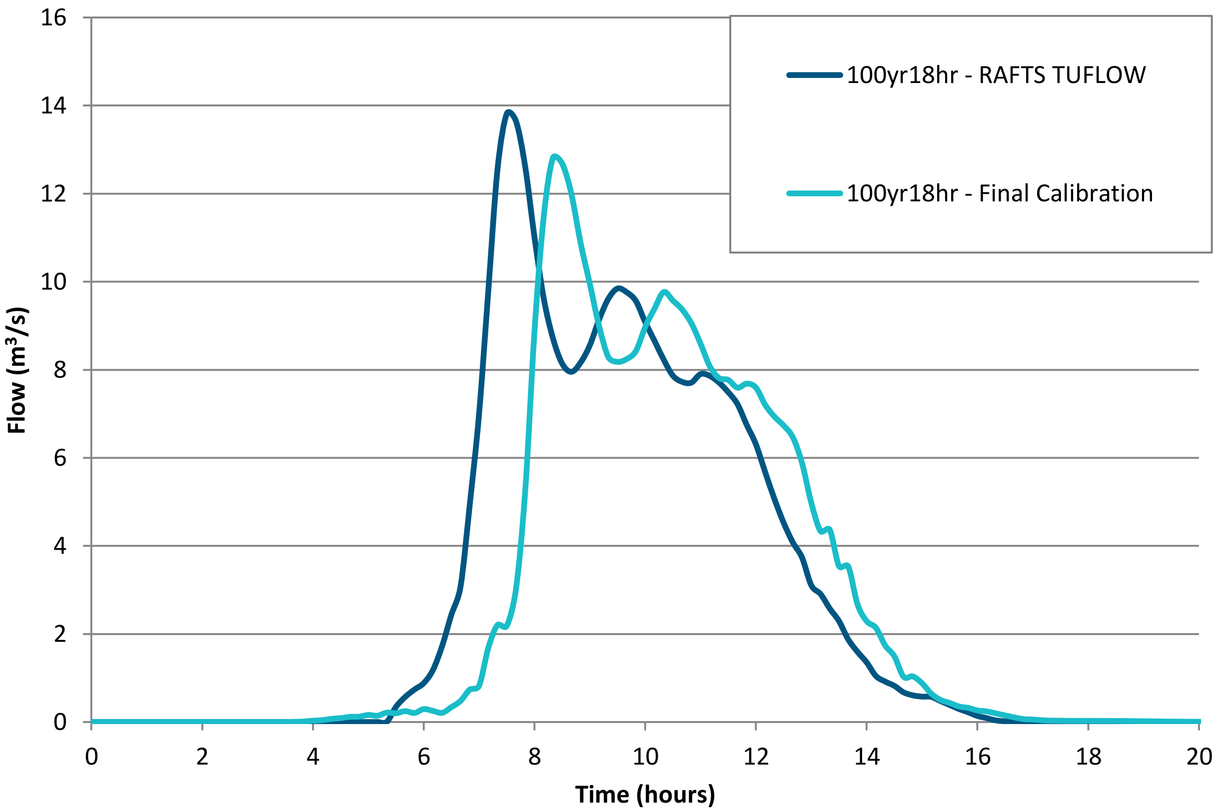

Figure 7-12 South-east Tributary Hydrographs – 100 Year ARI 18 Hour Duration

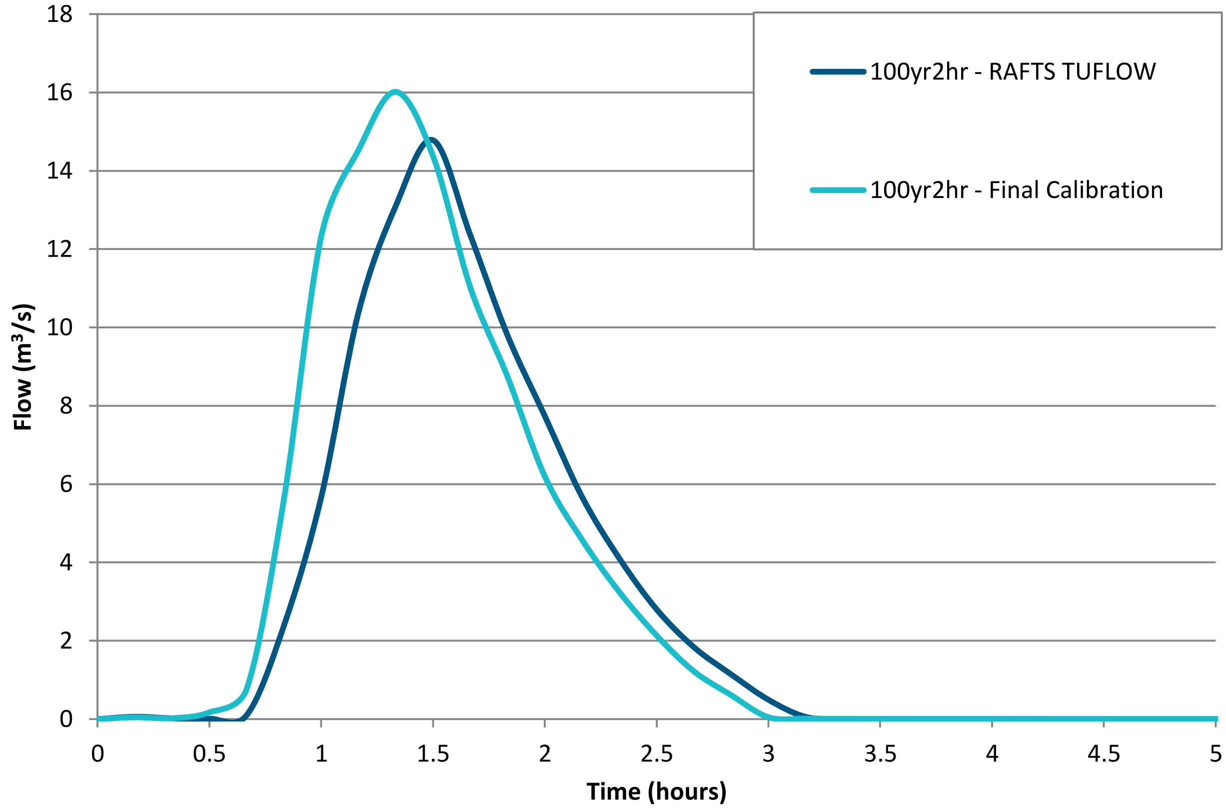

Figure 7-13 South-west Tributary Hydrographs – 100 Year ARI 2 Hour Duration

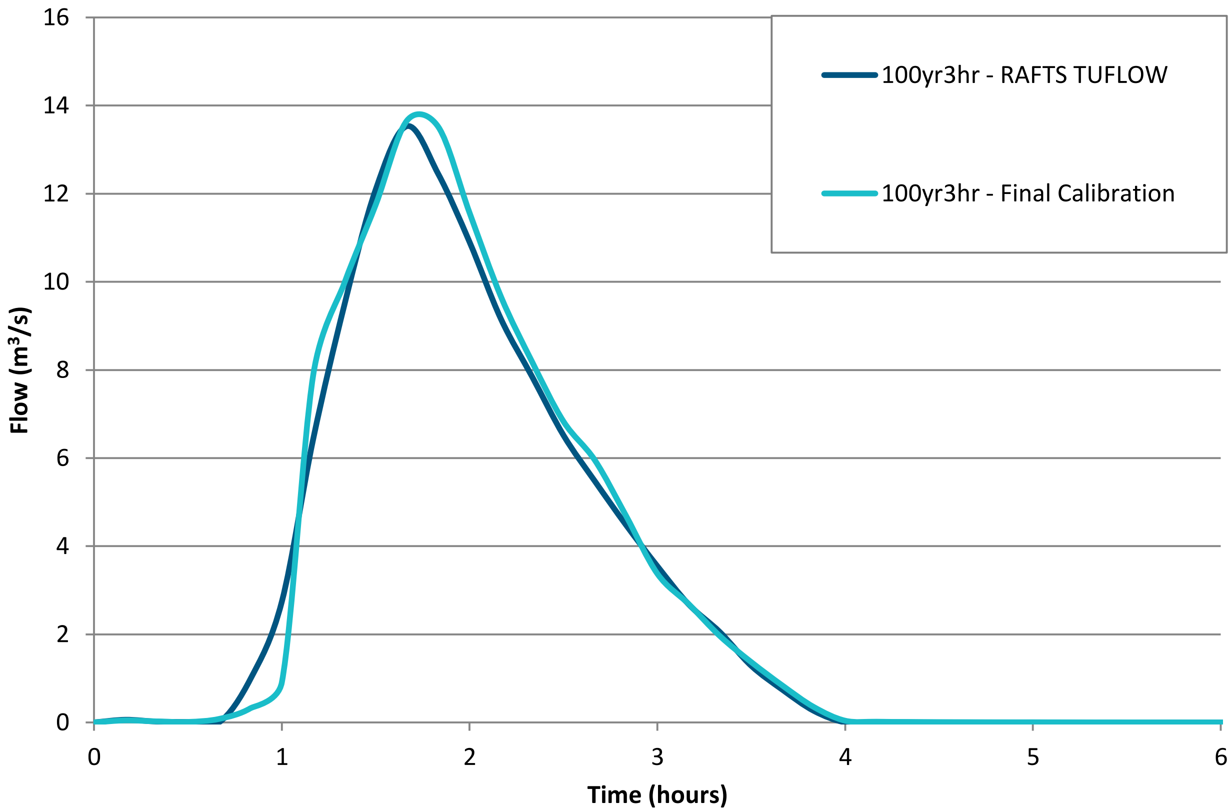

Figure 7-14 South-west Tributary Hydrographs – 100 Year ARI 3 Hour Duration

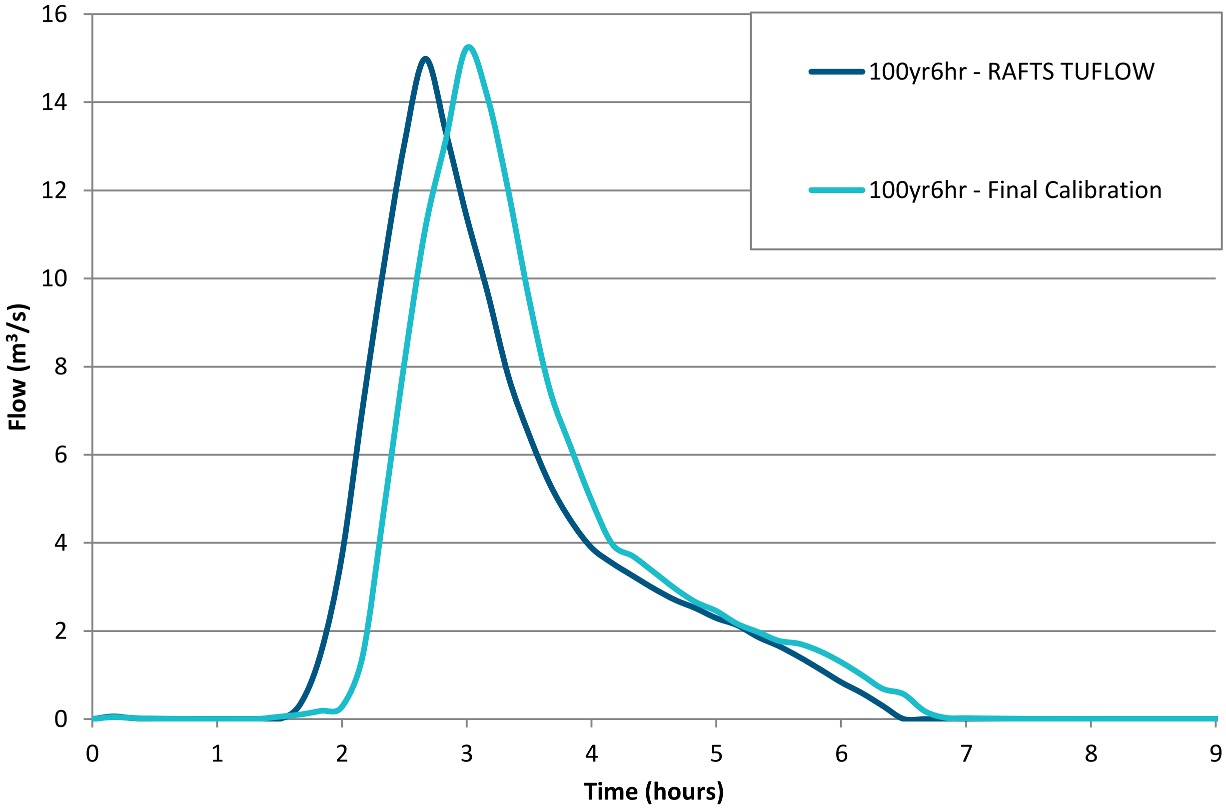

Figure 7-15 South-west Tributary Hydrographs – 100 Year ARI 6 Hour Duration

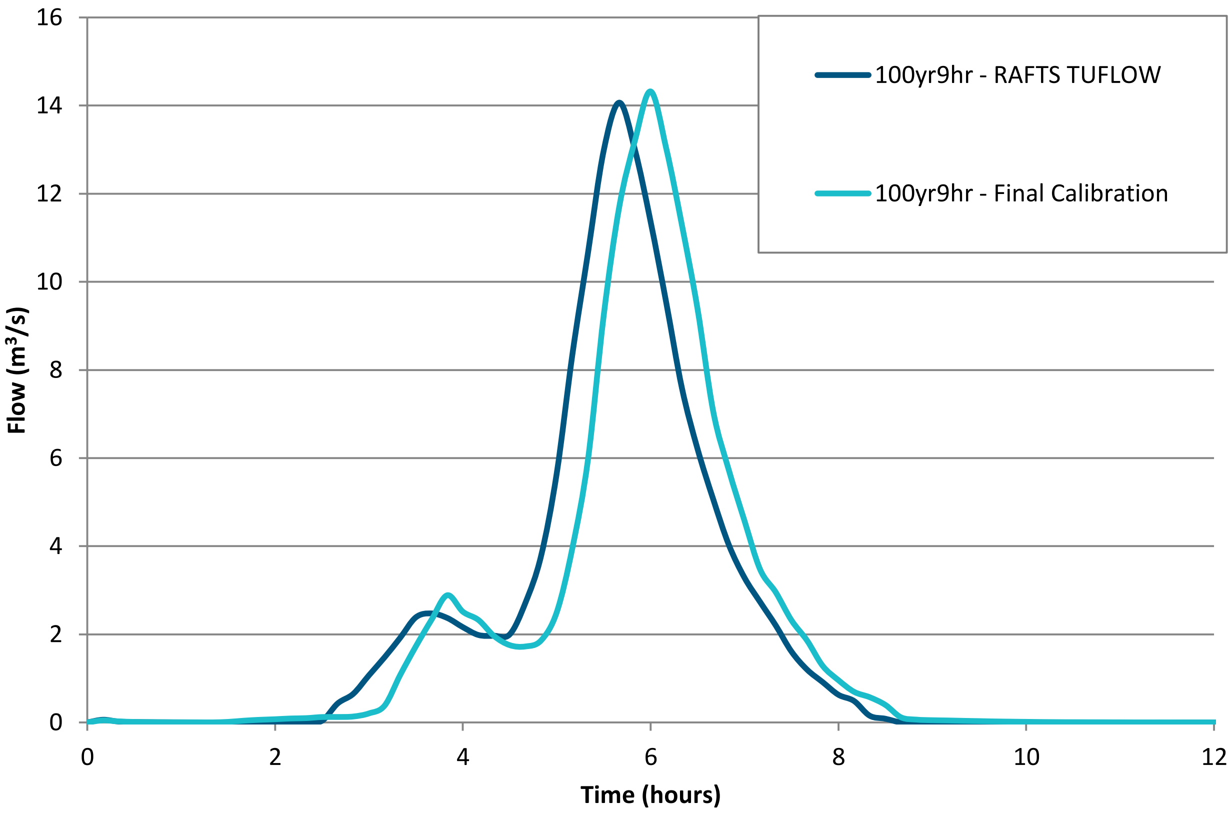

Figure 7-16 South-west Tributary Hydrographs – 100 Year ARI 9 Hour Duration

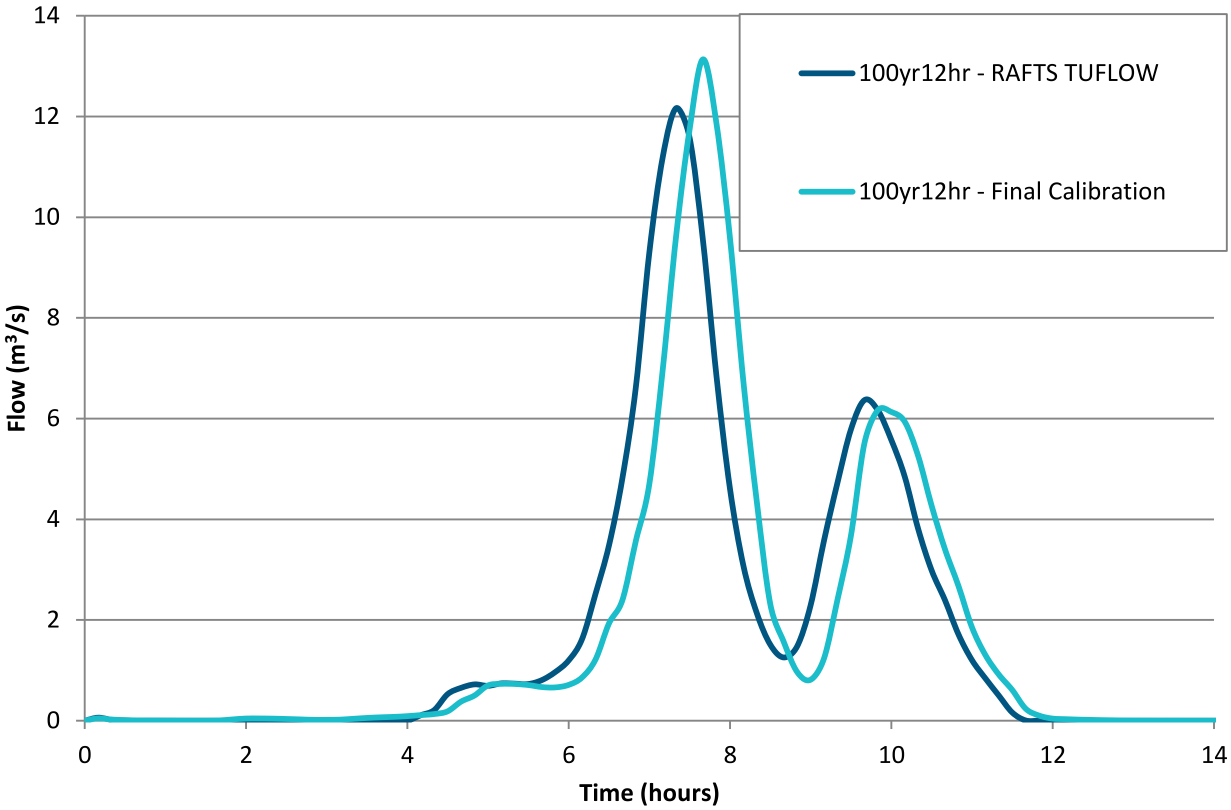

Figure 7-17 South-west Tributary Hydrographs – 100 Year ARI 12 Hour Duration

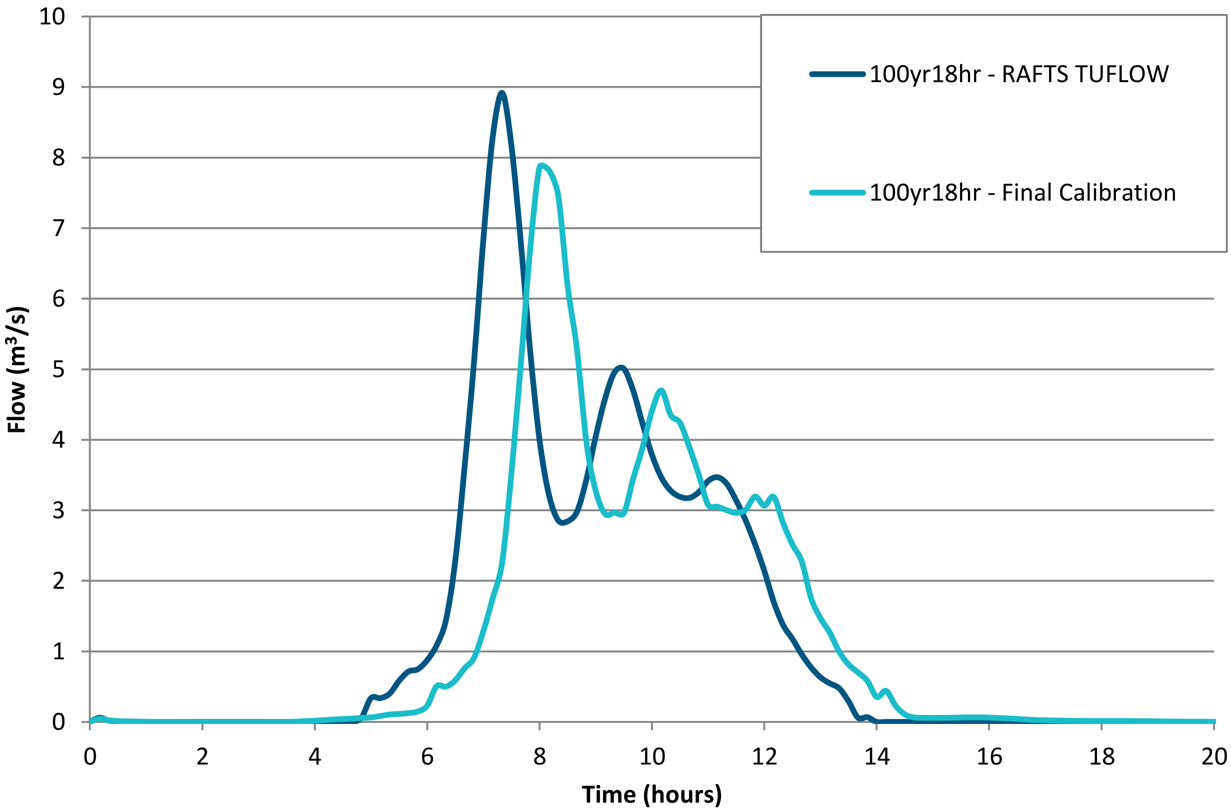

Figure 7-18 South-west Tributary Hydrographs – 100 Year ARI 18 Hour Duration

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