Attachment 1 to Item 10.3.4.

Macdonald River, Colo River, Webbs Creek and Greens Creek Flood Study - Final Report

Date of meeting: 29 July 2025
Location: Council Chambers
Time: 6:30pm

Macdonald River, Colo River, Webbs Creek & Greens Creek

Flood Study Final

Hawkesbury City Council | RR-02-1382-03 | June 2025

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Document Control

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00	April 2024	Flood Study – Draft	OG / JV / DR	RST
01	December 2024	Flood Study – Final Draft	OG / JV / DR	RST/LCC
02	February 2025	Draft for Public Exhibition	OG	RST
03	27 June 2025	Final for Adoption	OG	RST

Prepared For: Hawkesbury City Council

Project Name: Combined Macdonald River, Colo River, Webbs Creek & Greens Creek Flood Study and Floodplain Risk Management Study and Plan

Rhelm Reference: J1382

Document Location: RR-02-1382-03 - Flood Study

Cover photo – photo of the Colo River near the Upper Colo Gauge, June 2020.

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Report Structure

The reporting for the Macdonald River, Colo River, Webbs Creek & Greens Creek Flood Study and Floodplain Risk Management Study and Plan has been presented in four key documents:

- **Flood Study** – establishes the flood behaviour and risk within the study area.
- **The Flood Risk Management Study** – details the assessments undertaken as part of the study.
- **The Flood Risk Management Plan** – presents an implementation strategy for Council to prioritise floodplain management options.
- **Map Compendium** – a set of A3 maps as referenced in the Flood Study, Flood Risk Management Study and Flood Risk Management Plan.
- **Map Compendium – Hawkesbury Driven Events**– A set of A3 maps showing flood depth, water level, velocity, and hazard associated with Hawkesbury-Nepean Valley flood events ranging from 2% AEP to the PMF. The modelling also assumes a 10% AEP catchment event for this mapping.

Foreword

The primary objective of the New South Wales (NSW) Government's Flood Prone Land Policy is to reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone property, and to reduce private and public losses resulting from floods, utilising ecologically positive methods wherever possible.

Through the NSW Department of Climate Change, Energy, the Environment and Water (DCCEEW) and the NSW State Emergency Service (SES), the NSW Government provides specialist technical assistance to local government on all flooding, flood risk management, flood emergency management and land-use planning matters.

The *NSW Flood Risk Management Manual* (NSW Government, 2023a) is provided to assist councils to meet their obligations through the preparation and implementation of flood risk management plans, through a staged process. **Figure F1**, taken from this manual, documents the process for plan preparation, implementation and review.

The *NSW Flood Risk Management Manual* (NSW Government, 2023a) is consistent with Australian Emergency Management Handbook 7: *Managing the floodplain: best practice in flood risk management in Australia* (AEM Handbook 7) (AIDR 2017).

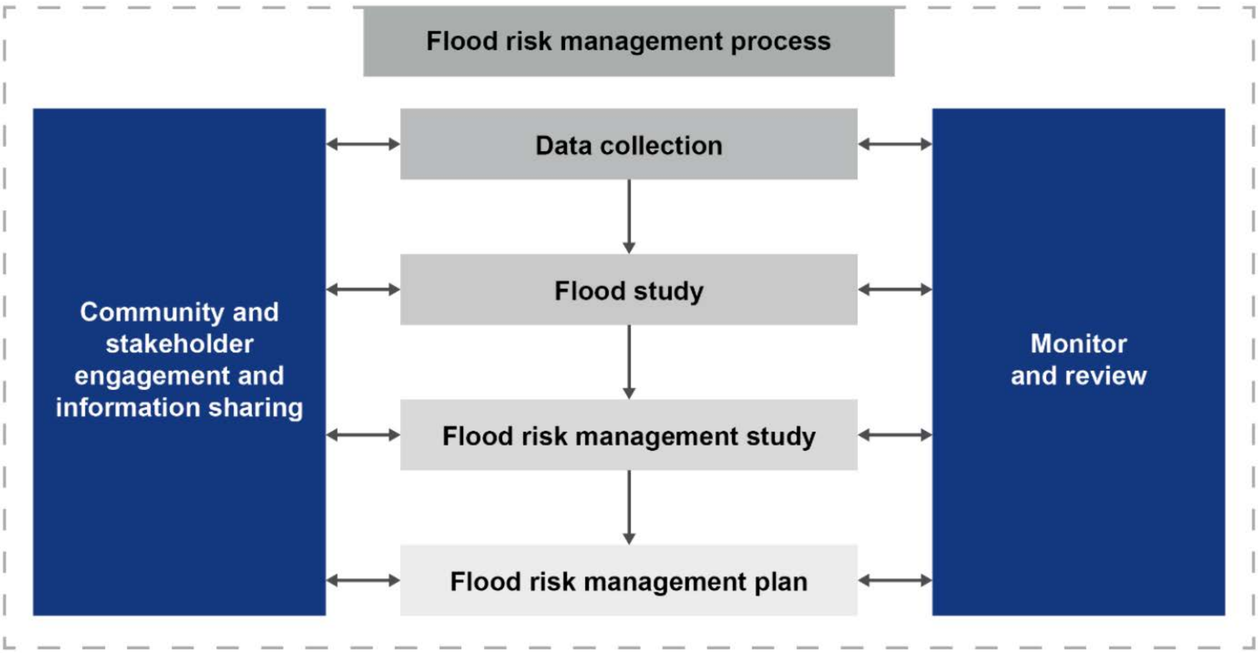

Figure F1. The Flood Risk Management Process (source: NSW Government, 2023a)

Executive Summary

The Macdonald River, Colo River, Webbs Creek and Greens Creek Flood Study has been prepared for Hawkesbury City Council (Council) to refine the understanding of flood risk in the study area.

Flooding is a known risk within the study area, affecting private and public property and access during and after flood events. The flooding of key crossings also restricts the response of emergency personnel during emergencies. Each catchment is also affected by backwater flooding from the Hawkesbury River, which can also exacerbate the isolation risk.

Study Area and Scope

The study area includes four catchments: the Macdonald River, Colo River, Webbs Creek, and Greens Creek. Each catchment discharges into the Hawkesbury River. The catchments within the study area are varied, with the Colo River covering 4,640 km², the Macdonald River 1,845 km², Webbs Creek 363 km², and Greens Creek 10 km².

The topography throughout the study area is predominantly steep, with the river flowing through valleys that are semi confined by sandstone. Due to the semi-confined valley topography, flood levels, particularly in the Colo and MacDonald Rivers, can reach significant heights.

This report is a flood study, which is a comprehensive technical investigation of existing flood behaviour. The overall objective of this study is to improve Council's understanding of flood behaviour and impacts, and better inform management of flood risk in the study area in consideration of the available information, and relevant standards and guidelines. The project will also assist Council with planning for future development and will provide flood information to the SES to enable them to progress their emergency management planning for the region

Engagement

Stakeholder engagement was undertaken throughout the flood study. This involved:

- Engaging agency and industry stakeholders to obtain details of historical flooding, survey data and other relevant data sets.
- Initial community engagement has been undertaken through the mail-out of a letter and questionnaire to residents in the study area. The letter also provided a link to a Your-Hawkesbury-Your-Say project page and an online copy of the survey. A community drop-in session was also held. The purpose of the initial community engagement was to raise awareness of the study and flood risk in the catchment, obtain observations and experiences of recent flooding to assist in model calibration, and understand community experiencing due and after flood evets. The drop in sessions also provided an opportunity to seek community input on potential flood mitigation measures to be investigated in the Flood Risk Management Study and Plan.

Hydrological and Hydraulic Modelling

Flood modelling has been undertaken using a combination of hydrological and hydraulic models. Hydrological modelling was undertaken for the study area using WBNM, and catchment flooding was modelled in TUFLOW. Both models extend to the outlet of the Hawkesbury River.

Historical flood data was available from rainfall, stream gauges and flood marks. Sufficient data was available for the Colo and Macdonald catchments to allow a calibration of both the hydrological and hydraulic models against historical events from 1978, 2020, March 2022 and July 2022.

The hydrological and hydraulic models were analysed for the Probable Maximum Flood (PMF), 1 in 2000 AEP, 1 in 1000 AEP, 1 in 500 AEP, 1 in 200 AEP , 1% AEP, 2% AEP, 10% AEP and 20% AEP events. The design events are based on ARR2019 methods. For the Macdonald and Colo Rivers, the design events have also been calibrated using flood frequency analysis

Design events were modelling in using 2D hydraulic models. The incised catchments limit the variation in flood extent across events, but the topography results in significant increases in flood depths especially for rarer events. PMF presents flood levels significantly higher than the 1% AEP event—up to 10 metres in some cases—accompanied by extreme depths and velocities. While rare, these conditions necessitate careful consideration in flood risk management to address the potential impacts of catastrophic flooding.

Hydraulic Model Sensitivity

The sensitivity of the hydraulic model to roughness, inflows, downstream boundary conditions, blockage and climate change were assessed in the TUFLOW model.

The results showed that the Macdonald and Colo models are more sensitive to changes in roughness and the predicted impacts of climate change than the Webbs Creek and Green Creek models. This was due to the significantly higher flows within the confined Colo and Macdonald Rivers valleys.

Each model was relatively sensitive to changes in the downstream boundary level, particularly in the lower 1-5 km of each watercourse. For Greens Creek in particular, backwater flooding from the Hawkesbury River is the dominate flooding mechanism.

The models were insensitive to blockage assumptions. Minor changes of less than 10 cm occurred in the vicinity of some bridges. This was due to the capacity of the crossing being negligible compared to the capacity of the river channel at the peak of the flood events.

Conclusion

This report provides a comprehensive technical investigation of flood behaviour that provides the main technical foundation for the development of a robust flood risk management study and plan.

The data developed as part of the study provides a better understanding of the flood behaviour and risks across the full range of flood events. It involved consideration of the local flood history, available flood data, and the development of hydrologic and hydraulic models that are calibrated and verified against historic flood events.

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Map Compendium

Map Number	Description	Map Number	Description
RG-00-001-1	Calibration July 2022 Colo River	RG-00-306	1 in 200 AEP Hazard
RG-00-001-2	Calibration July 2022 MacDonald River	RG-00-307	1 in 500 AEP Hazard
RG-00-002-1	Calibration March 2022 Colo River	RG-00-308	1 in 1000 AEP Hazard
RG-00-002-2	Calibration March 2022 MacDonald River	RG-00-309	1 in 2000 Hazard
RG-00-003-1	Calibration February 2020 Colo River	RG-00-310	PMF Hazard
RG-00-003-2	Calibration February 2020 MacDonald River		
RG-00-004-1	Calibration March 1978 Colo River	RG-00-401	1% AEP Flood Function
RG-00-004-2	Calibration March 1978 MacDonald River	RG-00-402	1 in 200 AEP (0.5% chance per year) Flood Function
		RG-00-403	1 in 500 AEP (0.2% chance per year) Flood Function
RG-00-101	20% AEP Peak Depth and Level	RG-00-404	PMF Flood Function
RG-00-102	10% AEP Peak Depth and Level		
RG-00-103	5% AEP Peak Depth and Level	RG-00-501	20% AEP High Blockage Sensitivity
RG-00-104	2% AEP Peak Depth and Level	RG-00-502	1% AEP High Blockage Sensitivity
RG-00-105	1% AEP Peak Depth and Level	RG-00-503	20% AEP Low Blockage Sensitivity
RG-00-106	1 in 200 AEP Peak Depth and Level	RG-00-504	1% AEP Low Blockage Sensitivity
RG-00-107	1 in 500 AEP) Peak Depth and Level	RG-00-505	20% AEP High Roughness Sensitivity
RG-00-108	1 in 1000 AEP Peak Depth and Level	RG-00-506	1% AEP High Roughness Sensitivity
RG-00-109	1 in 2000 AEP Peak Depth and Level	RG-00-507	20% AEP Low Roughness Sensitivity
RG-00-110	PMF Peak Depth and Level	RG-00-508	1% AEP Low Roughness Sensitivity
RG-00-201	20% AEP Peak Velocity	RG-00-601	1% AEP Climate Change 2050 SSP3
RG-00-202	10% AEP Peak Velocity	RG-00-602	1% AEP Climate Change 2100 SSP3
RG-00-203	5% AEP Peak Velocity		
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RG-00-301	20% AEP Peak Hazard	RG-00-901	Emergency Management Classification of Communities
RG-00-302	10% AEP Peak Hazard		
RG-00-303	5% AEP Peak Hazard		
RG-00-304	2% AEP Peak Hazard		
RG-00-305	1% AEP Peak Hazard		

Map Compendium – Hawkesbury Driven Events

Map Number	Description	Map Number	Description
RG-00-001-1	Calibration July 2022 Colo River	RG-00-306	1 in 200 AEP Hazard
RG-00-001-2	Calibration July 2022 MacDonald River	RG-00-307	1 in 500 AEP Hazard
RG-00-002-1	Calibration March 2022 Colo River	RG-00-308	1 in 1000 AEP Hazard
RG-00-002-2	Calibration March 2022 MacDonald River	RG-00-309	1 in 2000 Hazard
RG-00-003-1	Calibration February 2020 Colo River	RG-00-310	PMF Hazard
RG-00-003-2	Calibration February 2020 MacDonald River		
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RG-00-203	5% AEP Peak Velocity		
RG-00-204	2% AEP Peak Velocity	RG-00-701	Building Flooding
RG-00-205	1% AEP Peak Velocity	RG-00-702	Road Crossings
RG-00-206	1 in 200 AEP Velocity	RG-00-703	Infrastructure and Facilities
RG-00-207	1 in 500 AEP Velocity		
RG-00-208	1 in 1000 AEP Velocity	RG-00-801	Zoning
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RG-00-303	5% AEP Peak Hazard		
RG-00-304	2% AEP Peak Hazard		
RG-00-305	1% AEP Peak Hazard		

Glossary

The following glossary was adapted from the NSW Flood Risk Management Manual (NSW Government, 2023a).

Term	Description	Context for use/additional information
Annual exceedance probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage	AEP is generally the preferred terminology. ARI is the historical way of describing a flood event; for example, a 1% AEP flood has a 1% or 1 in 100 chance of being reached or exceeded in any given year
Australian Height Datum (AHD)	A common national surface level datum often used as a referenced level for ground, floor and flood levels	0.0m AHD corresponds approximately to mean sea level
Average recurrence interval (ARI)	The long-term average number of years between the occurrence of a flood equal to or larger in size than the selected event	ARI is the historical way of describing a flood event. AEP is generally the preferred terminology; for example a 100-year ARI flood that has 1 in 100 chance of being reached or exceeded in any given year. It is equivalent to a 1% AEP flood
Catchment	The area of land draining to a specific location	It includes the catchment of the primary waterway as well as any tributary streams and flowpaths
Defined flood event (DFE)	The flood event selected as a general standard for the management of flooding to development	Used to define the flood planning levels
Design flood	Design floods are hypothetical floods used for planning and floodplain management investigations. They are based on having a probability of occurrence specified as Annual Exceedance Probability (AEP) expressed as a percentage.	The design flood may be considered the flood mitigation standard for works or planning. For example, a levee may be designed to exclude a 2% AEP flood, which means that floods rarer than this may breech the structure and impact upon the protected area. In this case, the 2% AEP flood would not equate to the crest level of the levee, because this generally has a freeboard allowance, but it may be the level of the spillway to allow for controlled levee overtopping
Development	May be treated differently depending on the following categorisation: **infill development**: the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under current land zoning **new development:** development of a completely different nature to that associated with the former landuse (e.g. the urban subdivision of a previously rural area)	New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power Redevelopment generally does not require either rezoning or major extensions to urban services

Term	Description	Context for use/additional information
	redevelopment: rebuilding in an area (e.g. as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale)	
Flood	A natural phenomenon that occurs when water covers land that is normally dry. It may result from coastal inundation (excluding tsunamis) or catchment flooding, or a combination of both	Flooding results from relatively high stream flow that overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flowpaths associated with major drainage, and/or oceanic inundation resulting from superelevated ocean level
Flood awareness	An appreciation of the likely effects of flooding, and a knowledge of the relevant flood warning, response and evacuation procedures facilitating prompt and effective community response to a flood threat	In communities with a low degree of flood awareness, flood warnings may be ignored or misunderstood, and residents confused about what they should do, when to evacuate, what to take with them and where to go
Flood education	Seeks to provide information to raise awareness of flooding so as to enable individuals to understand how to manage themselves and their property in response to flood warnings	It can support a state of flood readiness
Flood evacuation	The movement of people from a place of danger to a place of relative safety, and their eventual return	People are usually evacuated to areas outside of flood prone land with access to adequate community support Livestock may be relocated to areas outside of the influence of flooding
Flood fringe areas	That part of the flood extents for the event remaining after the flood function areas of floodway and flood storage areas have been defined	
Flood function	The flood related functions of floodways, flood storage and flood fringe within the floodplain	Flood function is equivalent to hydraulic categorisation
Flood hazard	A flood that has the potential to cause harm or conditions with the potential to result in loss of life, injury and economic loss	The degree of hazard varies with the severity of flooding and is affected by flood behaviour (extent, depth, velocity, isolation, etc.)
Flood impact and risk assessment	A study to assess flood behaviour, constraints and risk, understand off-site flood impacts on property and the community resulting from the development, and flood risks to the development and its users	These studies are generally undertaken for development and are to be prepared by a suitably qualified engineer experienced in hydrological and hydraulic analysis for flood risk management
Flood plan (local or state)	A subplan of an emergency plan that deals specifically with flooding; they can exist at state, zone and local levels	The NSW Government develops flood plans as a legislative responsibility to determine how best to respond to floods. These community-based plans describe the risk to the community, outline agency roles and responsibilities, the agreed community

Term	Description	Context for use/additional information
		emergency response strategy and how floods will be managed. The relevant plan within the study area is the Hawkesbury-Nepean Valley Sub-Plan.
Flood planning area (FPA)	The combination of the flood level from the DFE and freeboard selected for FRM purposes	Different FPLs may apply to different types of development. Determining the FPL for typical residential development should generally start with a DFE of the 1% AEP flood plus an appropriate freeboard (typically 0.5 metres). This assists in determining the FPA
Flood planning levels (FPLs)	Flood planning levels selected for planning purposes are derived from a combination of the adopted flood level plus freeboard, as determined in floodplain management studies and incorporated in floodplain risk management plans. Selection should be based on an understanding of the full range of flood behaviour and the associated flood risk. It should also consider the social, economic and ecological consequences associated with floods of different severities. Different FPLs may be appropriate for different categories of land use and for different flood plans.	The concept of FPLs supersedes the "standard flood event". As FPLs do not necessarily extend to the limits of flood prone land, floodplain risk management plans may apply to flood prone land beyond that defined by the FPLs.
Flood prone land	Land susceptible to inundation by the probable maximum flood (PMF) event. Under the merit policy, the flood prone definition should not be seen as necessarily precluding development. Floodplain Risk Management Plans should encompass all flood prone land (i.e. the entire floodplain).	
Flood prone land	Land susceptible to flooding by the PMF event	Flood prone land is also known as the floodplain, flood liable land and flood affected land
Flood storage areas	Areas of the floodplain that are outside floodways which generally provide for temporary storage of floodwaters during the passage of a flood and where flood behaviour is sensitive to changes that impact on temporary storage of water during a flood.	See also flood function, floodways and flood fringe areas
Floodplain	Land susceptible to flooding by the PMF event.	See the definition of flood prone land
Floodways	Areas of the floodplain which generally convey a significant discharge of water during floods and are sensitive to changes that impact flow conveyance. They often align with naturally defined channels.	See also flood function, floodways and flood fringe areas Floodways are sometimes known as flow conveyance areas

Term	Description	Context for use/additional information
Freeboard	A factor of safety typically used in relation to the setting of minimum floor levels or levee crest levels	Freeboard aims to provide reasonable certainty that the risk exposure selected in deciding on a specific event for development controls or mitigation works is achieved. Freeboards for development controls and mitigation works will differ. In addition, freeboards for development control may vary with the type of flooding and with the type of development
Gauging height	The height of a flood level at a particular water level gauge site related to a specified datum	The datum may or may not be the AHD
Hazard	A source of potential harm or conditions that may result in loss of life, injury and economic loss due to flooding	
Hydraulics	The study of water flow in waterways and flow paths; in particular, the evaluation of flow parameters such as water level and velocity	
Hydrology	The study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods	
Merit-based approach	Weighs social, economic, ecological and cultural impacts of land-use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and wellbeing of the state's rivers and floodplains	The merit approach operates at two levels. At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk, which are formulated into council plans, policy, and environmental planning instruments. At a site-specific level, it involves consideration of the merits of a development consistent with council LEPs, DCPs and local FRM policies, and consistent with FRM plans
Probability	A statistical measure of the expected chance of a flood	For example AEP
Probable maximum flood (PMF)	The largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation (PMP), and where applicable, snow melt, coupled with the worst flood producing catchment conditions	This is equivalent to the probable maximum precipitation flood in Australian Rainfall and Runoff (ARR). The PMF in ARR is used for estimating dam design floods
Risk	'The effect of uncertainty on objectives' (ISO 2018)	See also flood risk. Note 4 of the definition in ISO31000:2018 also states that 'risk is usually expressed in terms of risk sources, potential events, their consequences and their likelihood'

Term	Description	Context for use/additional information
Stage	Equivalent to water level; measured with reference to a specified datum	Measurement may relate to AHD, a local datum or a local water level gauge
Velocity	The speed of floodwaters, measured in metres per second (m/s)	

Abbreviations

1D	One Dimensional
2D	Two Dimensional
AHD	Australian Height Datum
ARI	Average Recurrence Interval
ARR	Australian Rainfall and Runoff
ARR87	Australian Rainfall and Runoff 1987
ARR2019	Australian Rainfall and Runoff 2019
BoM	Bureau of Meteorology
DCCEEW	Department of Climate Change, Energy, the Environment and Water
DCP	Development Control Plan
DEM	Digital Elevation Model
DPE	Department of Planning and Environment
DPIE	Department of Planning, Industry and Environment
FPL	Flood Planning Level
FRMP	Flood Risk Management Plan
FRMS	Flood Risk Management Study
FPRMSP	Flood Risk Management Study & Plan
ha	Hectare
IFD	Intensity Frequency Duration
km^2	Square kilometres
LEP	Local Environment Plan
LGA	Local Government Area
LiDAR	Light Detection and Ranging
m	metre
m^2	Square metres
m^3	Cubic metres
mAHD	metres to Australian Height Datum
mm	millimetres
m/s	metres per second
NSW	New South Wales
OEH	Office of Environment and Heritage (NSW)
OEM	Office of Emergency Management
PMF	Probable Maximum Flood
RMS	Roads and Maritime Services
SES	State Emergency Service (NSW)
SSP	Shared Socioeconomic Pathway

1 Introduction

The Combined Macdonald River, Colo River, Webbs Creek and Greens Creek Flood Study and Flood Risk Management Study and Plan (FRMSP) has been prepared for the Hawkesbury City Council (Council) in accordance with the New South Wales (NSW) Flood Prone Land Policy and the Flood Risk Management Manual (NSW Government, 2023a) and its supporting guidelines.

The Flood Study is a comprehensive technical investigation of flood behaviour that provides the main technical foundation for the development of a robust FRMSP.

The outcome of the project is a FRMSP that identifies and evaluates potential measures to reduce the flood risk and associated damages in Macdonald River, Colo River, Webbs Creek & Greens Creek catchments. The options considered in the FRMSP will include an assessment of flood warning, evacuation and isolation within the study area. The FRMSP will also be used to inform strategic planning and development assessment throughout the study area.

1.1 Project Objectives

The overall objective of this study is to improve the understanding of flood behaviour and impacts to inform the management of flood risk in the study area.

The project incorporates three key components:

- **The Flood Study.** The flood study defines flood behaviour to better inform flood risk management. The flood study considers available information, previous studies and relevant standards and guidelines including Australian Rainfall and Runoff (2019) and the latest climate change guidance.
- **Flood Risk Management Study.** The FRMS will evaluate a range of measures (including emergency response, property modification and flood modification measures) to address the flood risk and inform the development of a Floodplain Risk Management Plan.
- **Flood Risk Management Plan.** The FRMP will provide a strategic level plan for Council to manage the flood risk in the study areas moving into the future.

The overall project will provide an understanding of, and information on, flood behaviour and associated risk and may inform:

- relevant government information systems;
- government and strategic decision makers on flood risk;
- the community and key stakeholders on flood risk;
- emergency management planning for existing and future development;
- flood risk management planning for existing and future development;
- selection of practical, feasible and economic measures for treatment of risk;
- decisions on insurance pricing;
- development of a floodplain risk management plan; and
- development of a prioritised implementation strategy.

2 Catchment Description

The study area incorporates four key catchments:

- Macdonald River (**Section 2.1**);
- Colo River (**Section 2.2**);
- Webbs Creek (**Section 2.3**); and,
- Greens Creek (**Section 2.4**).

An overview of the catchments and corresponding study areas is provided in **Figure 2-1**. Each catchment drains generally in a south easterly direction into the Hawkesbury River and is described in further detail below. The study areas cover the lower reaches of each catchment and encompass most of the developed and rural land relevant to the Hawkesbury City Council local government area (LGA).

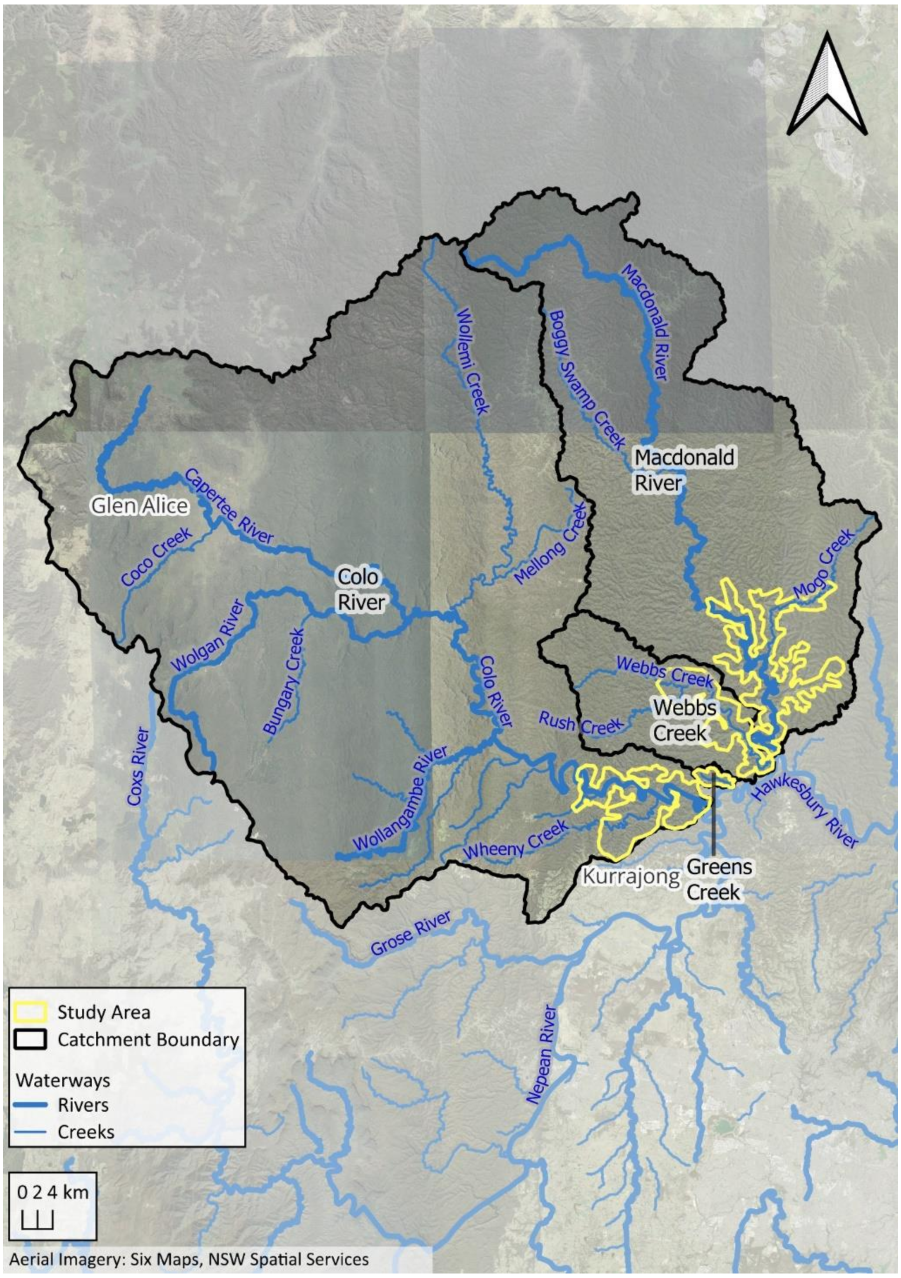

Figure 2-1 Study area

2.1 Macdonald River

The Macdonald River is a tributary of the Hawkesbury River and drains a catchment area of approximately 1,845 km^2 and a length of approximately 150 km. The Macdonald River channel has a dynamic nature that is geomorphologically very active. The catchment consists of steeply vegetated slopes up to elevations of around 800 m. The upper portions of the catchment consist predominantly of natural bushland. Downstream of the Mogo Creek confluence, the Macdonald River floodplain is constrained within a steep valley that is typically 300-500 m wide. The majority of development within the catchment consists of scattered free-standing dwellings located on rural acreages, typically zoned C4 – Environmental Living. St Albans is the only village within the catchment and has a population of around 300 people. The density of development increases in the downstream reaches of the valley. The highest concentration of residential development is located approximately 1-2km upstream of the Hawkesbury River junction, along the eastern side of the Macdonald River floodplain.

Figure 2-2 Macdonald River at Higher Macdonald (18 February 2022)

Flooding within the valley is primarily a consequence of surface runoff generated in the upper reaches and from local catchments. The lower reaches of the Macdonald River are also affected by backwater effects from the Hawkesbury River. Significant recent flooding occurred in 2020, 2021, March 2022 and July 2022.

There is also an established history of flooding with significant events known to have occurred in 1978, 1964, 1949 and as far back as 1867.

2.2 Colo River

The Colo River begins at the confluence of the Wolgan River and the Capertee Rivers, north of Lithgow. The river flows eastwards and then south through a deep gorge in the northern Blue Mountains and ultimately flows into the Hawkesbury River at Lower Portland. The Colo River is approximately 97 km in length and has a catchment area of 4,640 km^2. A majority of the catchment is undeveloped. Within the study area, development consisting of scattered free-standing dwellings is located on rural acreages on land zoned C4 – Environmental Living. The study area also supports a significant ecotourism and outdoor education sector that at times supports large groups of tourists and school groups.

Figure 2-3 Colo River at Upper Colo Bridge (17 February 2022)

Flood behaviour in the Colo River catchment is comparable to the Macdonald River. Flooding results from surface runoff generated in the upper reaches and from local catchments. The lower reaches of the Colo River are also affected by backwater effects from the Hawkesbury River. The catchment has experienced significant recent flooding with major flooding recorded in 2020, 2021, March 2022 and July 2022. The March 2022 event was the largest recently recorded event.

2.3 Webbs Creek

Webbs Creek is approximately 40 km in length and has a catchment area of 363 km2. Webbs Creek flows generally south-east before reaching its confluence with the Hawkesbury River, around 500m upstream from the Webbs Creek Ferry crossing The lower reaches of Webbs Creek are tidal and subject to backwater effects from the Hawkesbury River when the Hawkesbury is in flood.

The majority of development within the Webbs Creek catchment is found in the lower portions of the catchment. The developed area consists of scattered free-standing dwellings located on land zoned C4 – Environmental Living. The remainder of the catchment is heavily vegetated bushland with steep slopes. The catchment also supports a significant ecotourism sector including outdoor retreats. There are no towns or villages in the catchment. There is limited information relating to historic flooding in the catchment.

Figure 2-4 Webbs Creek, looking upstream from Chaseling Road North Bridge (17 February 2022)

2.4 Greens Creek

Greens Creek is a small (6 km long) perennial watercourse located at Lower Portland, with a catchment area of 10 km2. The creek flows in general in the south-east direction to join the Hawkesbury River. Flooding in the catchment is dominated by backwater from the Hawkesbury River.

Development in the catchment includes low density rural residential properties within land zoned C4 – Environmental Living.

Figure 2-5 Greens Creek, looking upstream from Greens Road (17 February 2022)

3 Data Review

3.1 Previous Studies and Reports

Table 3-1 outlines the historic reports compiled for the study area and a summary of the relevance to this study. The studies were provided by Council or sourced from publicly available sources including the NSW SES flood data portal. A significant number of the studies have focussed on flooding behaviour and flood risk along the Hawkesbury-Nepean River including backwater effects along the Colo and Macdonald Rivers. The Lower Macdonald River Flood Study (Webb, McKeown & Associates, 2004) is the most recent study to specifically examine Macdonald River flooding. No previous studies have solely focussed on the flood behaviour of the Colo River, Greens Creek or Webbs Creek.

Table 3-1 Previous studies

Document	Relevance to Study
Lower Macdonald River Flood Study (Webb, McKeown & Associates, 2004)	The Lower Macdonald River Flood Study was prepared by Webb McKeown & Associates in 2004. A Watershed Bounded Network Model (WBNM) hydrologic model was established to represent the entire catchment draining to the Hawkesbury River. A MIKE-11 hydraulic model was created to represent the Lower Macdonald River downstream of the confluence with Womerah Creek. The lower reaches of Wrights Creek were also included in the hydraulic model. The hydrologic and hydraulic models were calibrated making use of available historical data to ensure that they reasonably simulated recorded historical floods. The models were calibrated to the March 1978 flood and verified against the August 1990 event. A flood frequency analysis was undertaken on the streamflow estimates obtained from the gauge located on the Macdonald River at St Albans. The adopted set of design flows were used to define inflow hydrographs to the hydraulic model. The calibration parameters from this report have informed the hydrological calibration for the current study. Comparisons are also made with the flood levels from this study (See **Section 6.3**).
Hawkesbury-Nepean River Flood Study (Rhelm CSS, 2024)	An investigation of flood behaviour for the Hawkesbury-Nepean River between Bents Basin and Brooklyn was undertaken using a WBNM hydrologic model and a TUFLOW hydraulic model, underpinned by a Monte Carlo framework. Further, a detailed investigation was undertaken on the joint probability of Colo and Macdonald River flooding with Hawkesbury River flooding. The Macdonald River, Colo River, Webbs Creek and Greens Creek are impacted by backwater flooding from the Hawkesbury-Nepean River. The Hawkesbury-Nepean River Flood Study has informed the downstream boundary conditions for this current study. Hydrologic and hydraulic model elements have been used in this investigation.
Hawkesbury Nepean Valley Regional Flood Study (WMA Water, 2019)	This flood study includes an investigation of flood behaviour for the Hawkesbury-Nepean River between Bents Basin and Brooklyn, using a RORB hydrologic model, RUBICON hydraulic model, Monte Carlo framework, and flood frequency analysis. This study has subsequently been updated in the Rhelm CSS (2024) study.

Document	Relevance to Study
Hawkesbury Floodplain Risk Management Study and Plan (Bewsher, 2012)	This FRMSP includes an investigation and assessment of flood behaviour and floodplain management options along the Hawksbury River within the Hawkesbury City Council LGA. The Bewsher (2012) study focusses on the Hawksbury River floodplain between Yarramundi and Sackville and is therefore upstream of the current study area. The Bewsher (2012) study identifies high priority flood measures related to community education, evacuation and land use planning that the current FRMS can build on for the Colo River, Macdonald River, Webbs Creek and Greens Creek catchments.
Hawkesbury Floodplain Risk Management Study and Plan Draft (WMA Water, 2025)	This study provides an update to Bewsher (2012) and is informed by the results of the Hawkesbury-Nepean River Flood Study (Rhelm CSS, 2024). The study was recently publicly exhibited and includes a range of flood mitigation options. The study also recommended the flood planning level be increased to the 200 year AEP to consider the impacts of climate change.

3.2 Survey Data

3.2.1 LiDAR

Several aerial survey data sets are available for the study area. These data sets are summarised in **Table 3-2**.

Table 3-2 Available LiDAR data and reported accuracy

Year	Source	Formats	Average Point Separation (m)	Horizontal Accuracy (m)	Vertical Accuracy (m)
2021	ELVIS website*	1 m DEM, Point cloud	Not reported	0.8 @ 95% confidence interval	0.3 @ 95% confidence interval
2010	ELVIS website*	30 m DEM,	Not reported	Not reported	Not reported

* ELVIS – Elevation and Depth – Foundation Spatial Data website (https://elevation.fsdf.org.au/).

The 2021 LiDAR is the most recent dataset and was used to define the floodplain ground levels.

Where floor level survey is not available, the ground levels represented by the 2021 LiDAR set were used to estimate floor levels for the surrounding urban development.

3.2.2 Existing Ground Survey

No ground survey was available within the study area.

3.2.3 Floor Level Survey

No floor level survey was available within the study area.

3.2.4 Additional Survey

Additional channel and structure survey was collected in August 2023 by BCE Ppatial to fill data gaps and provide representative channel cross sections to inform the hydraulic model. The survey details are provided in **Appendix A.**

3.3 Hydrologic Data

3.3.1 Rainfall Data

A number of agencies collect rainfall data within the study area, including:

- Bureau of Meteorology (BoM);
- Sydney Water Corporation (Sydney Water);
- Manly Hydraulics Laboratory (MHL); and
- WaterNSW.

As part of the Hawkesbury-Nepean River Flood Study (Rhelm CSS, 2024), rainfall data was compiled and processed from these agencies for the rainfall gauges throughout the catchment, as well as areas adjacent to the catchment. This included data sourced from the BoM rainfall database.

Within the study area, there are 47 daily rainfall gauges operated by the BoM. There are eight sub daily gauges within the study area (discussed further in **Section 4.2**). **Figure 3-1** shows the location of the BoM daily rainfall gauges within the study area surrounding areas. The gauges are distributed in the upper and lower Macdonald and Colo River catchments. There are large areas within both catchments where there are no rainfall gauges. It should also be noted that not all gauges were operational for all historic events. There are no gauges in the Greens Creek or Webbs Creek catchments. For calibration and validation purposes, the processed rainfall data from Rhelm CSS (2024) was used. The processed data features the prioritisation of gauges based on proximity, data quality and length of record.

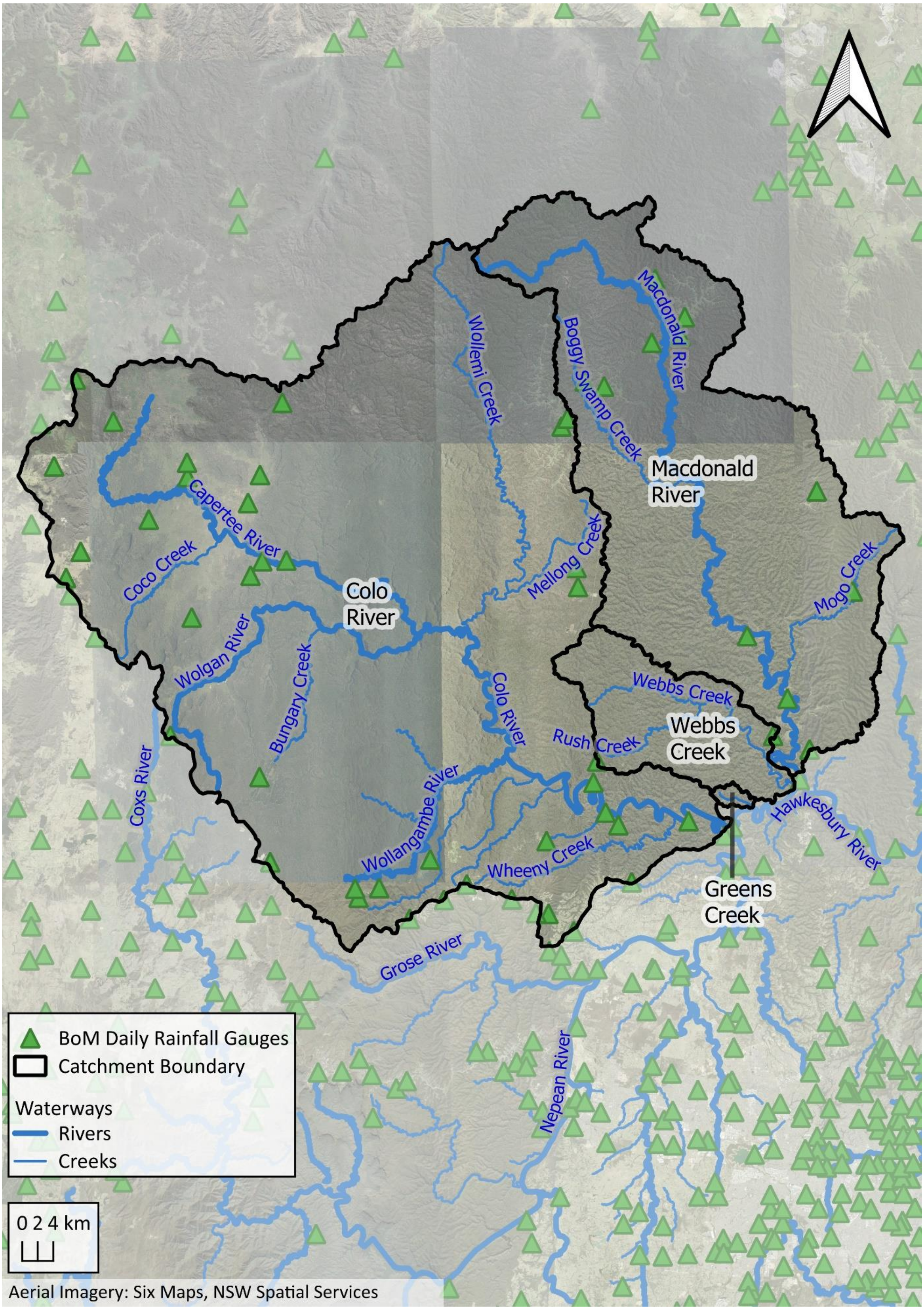

Figure 3-1 BoM daily rainfall gauges

3.3.2 Streamflow Data

Streamflow estimates are derived through a combination of recorded water levels at a location, and a rating curve that allows for the conversion of these water levels into a discharge estimate. Rating curves are derived from field measurements that are undertaken at the gauging location, estimating flows (also referred to as discharge) using current meters.

A key challenge for the derivation of rating curves is during high flows. These can be limited in terms of the ability to measure the flows at these higher flood events (together with these events being less frequent). This can lead to higher uncertainty for larger flow events. It is therefore important to ensure that gauges that are used for flow estimation have been "rated" at higher flow events to ensure that they are representative for flood events. Where they have not been rated, then alternative approaches, such as the use of hydraulic models, can be used to estimate an extrapolated the rating.

Figure 3-2 shows the locations of gauges within the study area. **Table 3-3** summarises the gauge operational information and whether they were operational during possible calibration events. **Table 3-4** summarises the maximum gauging and ratings for the key gauges in the study area from the gauge owner. Given uncertainties regarding the rating curves for the gauges relevant to the current study (Upper Colo and St Albans gauges), a rating curve review was conducted and this is reported in **Section 3.3.3**.

In addition to streamflow estimates, there are also several water level only gauges along the Hawkesbury River that may be used for setting downstream tail water conditions during the calibration and validation stage of the portion of the study (**Section 5.3).**

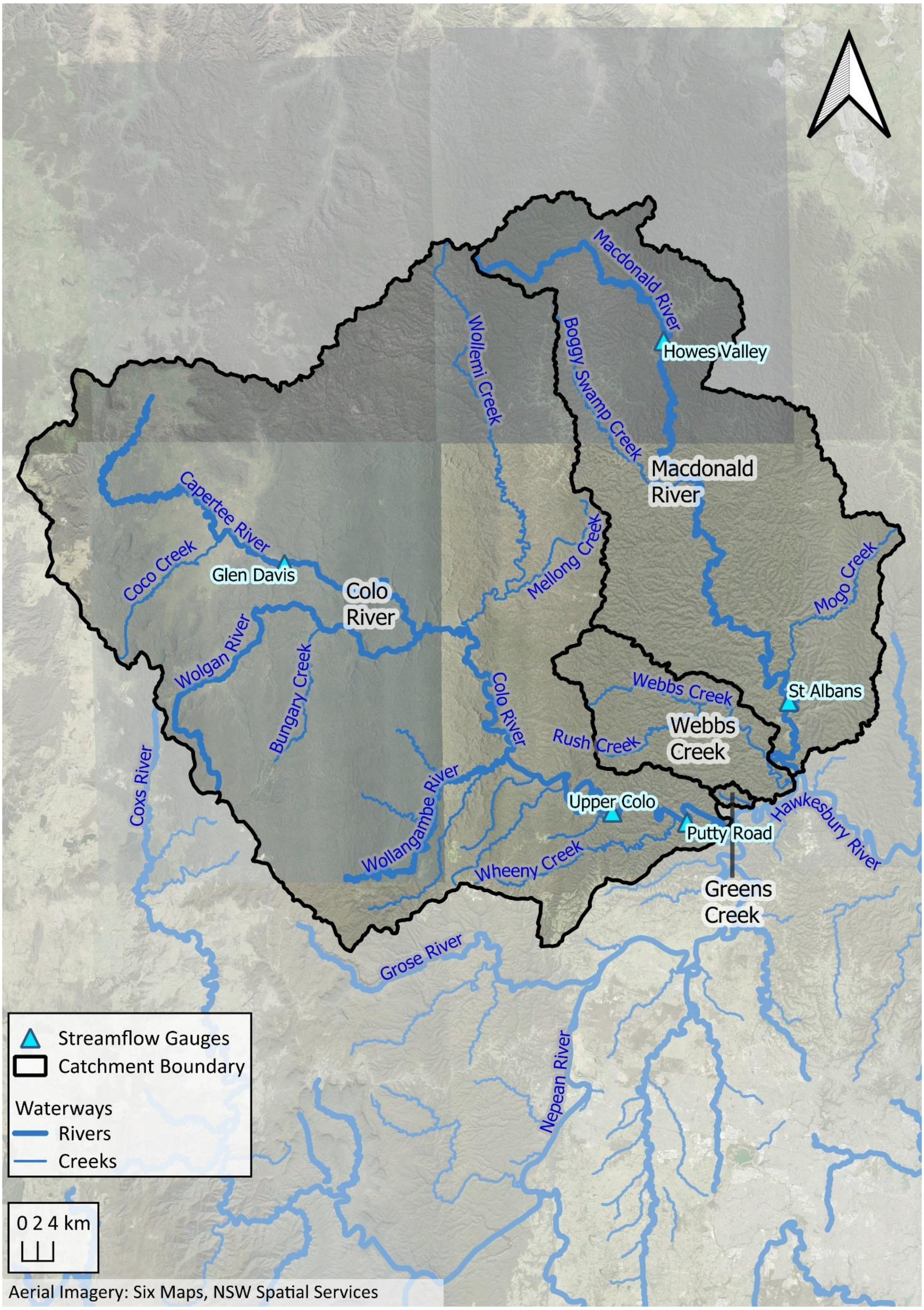

Figure 3-2 Flood gauges in the catchments

Table 3-3 Streamflow gauges within the catchment

Gauge ID (WaterNSW and Sydney Water or MHL)	Mar 1978	Aug 1986	Apr/ May 1988	Aug 1990	Aug 1998	Feb 2020	Mar 2022	July 2022
212290 / 563033; Upper Colo (Colo River)	✓	✓	✓	✓	✓	✓	✓	✓
212018 / NA; **Glen Davis (Capertee River)**	✓	✓	-	✓	✓	✓	✓	✓
212908 / NA; Putty Road (Colo River)[1]							✓	✓
212021 / 561036; Howes Valley (Macdonald River)	✓	✓	✓	✓	-	-	✓	✓
212228 / 061353; St Albans (Macdonald River)	✓	-	-	✓	✓	✓	✓	✓

[1] **The Putty Road gauge is manually operated and may not be useful for validation and calibration**

Table 3-4 Streamflow gauges – rating and gauging

ID	Gauge Name	Key Tributary	Max Rating	Max Gauging	Comments
212290	Upper Colo Station – Colo River	Colo River	19.20m; 5681 m^3/s [3830 m^3/s according to AWACS]	19.18m; 3824 m^3/s in March 1978	The 2019 Regional Flood Study notes that it malfunctioned during the 1986 flood event. It is noted that AWACS (1997) revised the rating curve for this gauge for higher flow events.
212018	Glen Davis – Capertee River	Capertee River	5.27m; 202.5 m^3/s	4.26m; 202.5 m^3/s in June 1978	The Capertee River at Glen Davis gauge is on an unstable sand bar and is subject to change during flood events.
212228	St Albans – Macdonald River	Macdonald River	7.00m; 766.2 m^3/s	5.91m; 510.4 m^3/s in March 1978	The Macdonald River at St Albans is sandy and subject to morphological changes. The dynamic nature of the Macdonald River may reduce the confidence in the gauge.
212021	Howes Valley – Macdonald River	Macdonald River	6.87m; 691 m^3/s	2.99m; 163.2 m^3/s in March 1978	This gauge is relatively high up in the catchment.

3.3.3 Rating Curve Data Review

A review of the rating curves at the Upper Colo Gauge on the Colo River and the St Albans Bridge Gauge on the Macdonald River was undertaken.

AWACS (1997) reviewed the rating curve at the Colo River at Upper Colo gauge. This review identified that for higher levels, the WaterNSW rating over-estimated the flows. AWACS (1997) therefore developed a revised rating curve for the gauge. The Upper Colo Gauge was also reviewed as part of the Hawkesbury-Nepean River Flood Study (Rhelm CSS 2024) based on a Mannings calculation and WaterNSW surveyed cross section of the channel. Rhelm CSS (2024) found the AWACS (1997) curve better matched the Mannings calculated curve than the WaterNSW rating. As a result, the AWACS (1997) curve was adopted for the Hawkesbury-Nepean River Flood Study.

For this study, a further review was undertaken using the TUFLOW hydraulic model. The TUFLOW rating was based on the stage-discharge relationship for the rising limb of the calibration and validation events (See **Section 5.3).** This approach minimised the effect of hysteresis to provide more confidence in the rating.

The Colo River at Upper Colo gauge and Macdonald River at St Albans gauge were assessed using the calibration models to compare the water level and flow across both gauges. Surveyed cross sections were collected at each gauge location to provide a greater level of confidence in the modelled stage-discharge relationship estimated from the model.

The Upper Colo rating curve review summary is provided in **Figure 3-3**. The review suggests a close alignment with the curve adopted by AWACS (1997). As a result of this finding, the AWACS (1997) rating curve was adopted by the current study for flow conversions between water level and flow at the Upper Colo water level gauge.

It is noted that there is uncertainty regarding the validity of the WaterNSW gauge zero relative to the Australian Height Datum. The survey cross-section collected at this location as a part of this study suggested that the bed level at the gauge was around 3.1 mAHD while the WaterNSW gauge zero level is around 1.47 mAHD. Through correspondence with WaterNSW, it was revealed that there is some uncertainty with the datum used for the WaterNSW cross section datum. It was considered that, for this analysis, the gauge zero level be increased by 1.5 m to better align with the survey in from this study. However, the calibration of the Colo River is based on the WaterNSW gauge zero level as there remains some uncertainty regarding the datum, cross section history and gauge location history. The hydraulic model calibration is discussed further in **Section 5.3.**

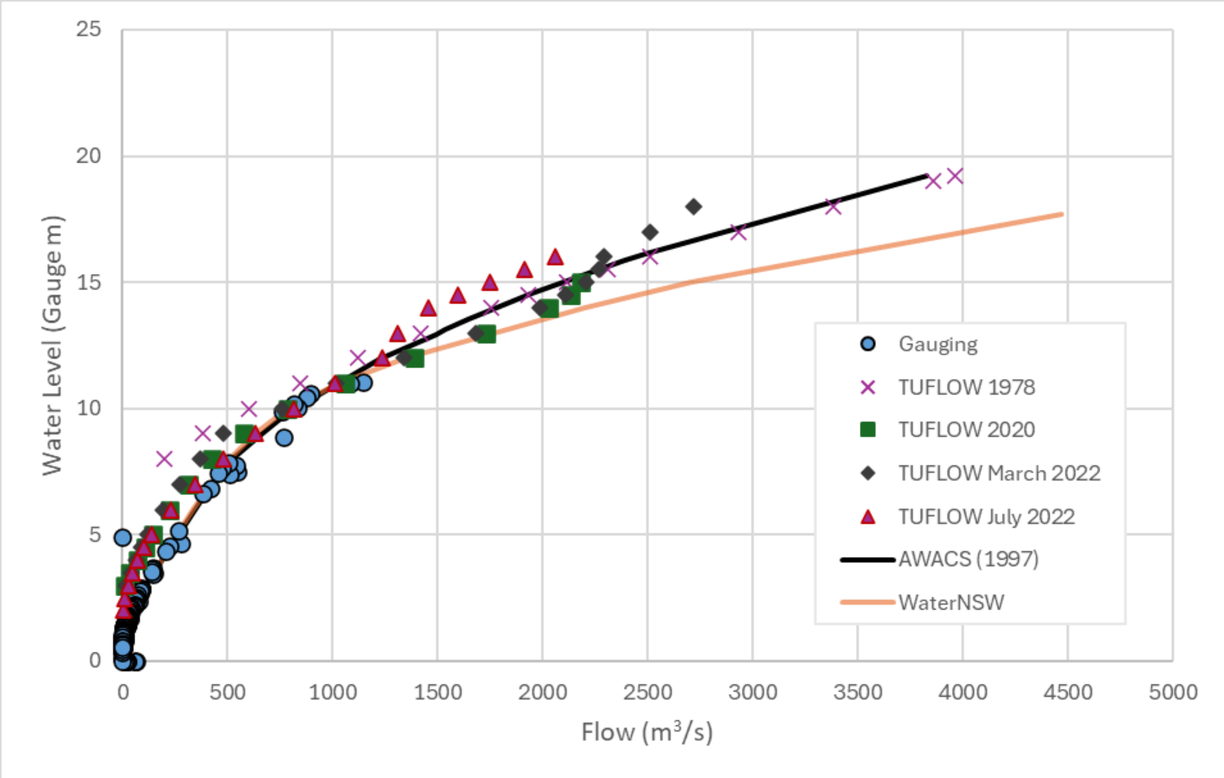

Figure 3-3 Colo River at Upper Colo Gauge rating curve review summary

For the St Albans gauge, the rating curve review is shown in **Figure 3-4**. The TUFLOW rating was based on the stage-discharge relationship for the rising limb of the calibration and validation events (See **Section 5.3).** This approach minimised the effect of hysteresis to provide more confidence in the rating. Each modelled stage-discharge relationship for each event was very similar and provides confidence in the rating adopted for this study. The WaterNSW rating shows higher flows at lower levels compared to the TUFLOW ratings. Given the close alignment of the TUFLOW rating, that is informed by 2D modelling and recent survey, this study has adopted a rating curve based on the TUFLOW results.

There is some potential uncertainty for this rating for larger events. As identified in Rhelm CSS (2024), for large Hawkesbury River flood events, there is a potential for some backwater effects which would influence the rating curve.

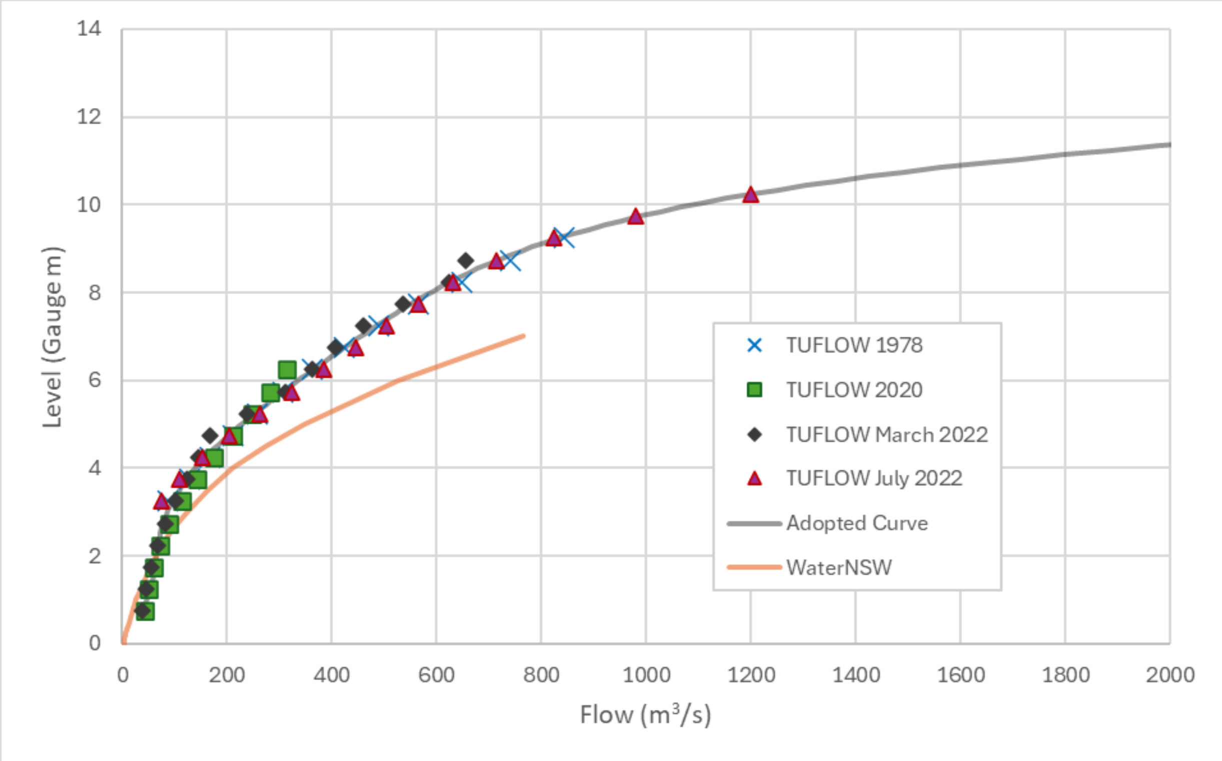

Figure 3-4 Macdonald River at St Albans Gauge rating curve review summary

3.4 Spatial Data

The following spatial data was provided by Council in shapefile and geodatabase format:

- building footprints captured from 1998 and 2016;
- cadastral boundaries;
- bridges and speedhumps;
- easements;
- land zoning;
- PMF and 1% AEP flood extents from historic studies;
- Council assets including bridges, culverts and roads;
- HLEP (2012) Land zoning; and
- Vegetation mapping (2018).

The 1% AEP and PMF flood extents provided are based on the:

- Macdonald River Flood Study (2004)
- 1978 Flood Extent for the Colo River; and
- Lower Hawkesbury Flood Study (AWACS, 1997)

3.5 Aerial Photography

Aerial photography from the following sources was used for this assessment:

- NSW SixMaps (https://maps.six.nsw.gov.au/); and

- Nearmap (https://www.nearmap.com/au/en).

The higher definition Nearmap was used where available, however Nearmap images do not cover the entire study area.

3.6 Local Policies and Emergency Management Plans

A variety of relevant planning documents, where available, were also reviewed and considered as part of the study. These documents are listed in **Table 3-5**.

Table 3-5 Local policies and plans

Document	Relevance to Study
Hawkesbury City Council Flood Policy (2020)	The flood policy sets out the controls for flood planning. Controls relate to flood function and flood hazard and are designed to apply a risk based approach to floodplain management. The Policy includes specific controls for new development, and for additions, alterations, intensification or redevelopment of existing uses. The existing policy excludes freeboard from the flood planning level. Typically, flood planning levels in NSW include a freeboard of 0.5m for mainstream flooding. This FRMS makes recommendations for a future flood related DCP chapter that will supersede the Flood Policy.
Hawkesbury City Council Local Environmental Plan 2012 (HLP 2012)	The LEP's existing flood related planning controls have been reviewed within the context of flood risk and planning within the study area (**Section 4**).
Hawkesbury City Council HDCP 2002)	The DCP's existing flood related planning controls have been reviewed within the context of flood risk and planning within the study area (**Section 4**).
Hawkesbury Nepean Valley Flood Emergency Plan (SES, 2020)	Special arrangements described in the Hawkesbury-Nepean Valley Flood Emergency Plan cover prevention and preparedness measures, the conduct of flood operations and the transition to recovery for floods in the Hawkesbury-Nepean Valley. The Plan covers the Colo River, Webbs Creek, Macdonald Rivers. Greens Creek is not mentioned in the Plan however evacuation is considered within the Webbs Creek and Colo Sectors, including the inundation of Greens Road. This study informs the flood classification within the study area and provide further information on the depth, timing and duration of flooding to inform future revisions of the HNFESP.

3.7 Guideline and Reference Documents

3.7.1 Australian Rainfall and Runoff

Australian Rainfall and Runoff is a national guidance document, originally published by The Institution of Engineers, Australia (e.g. 1987 Edition, Pilgrim (Ed)) and currently published by the Australian Government (through Geoscience Australia, Ball et al, 2019). The document has been used extensively as the basis for design flood estimation for flood studies.

The 2019 version of the document (Ball et al, 2019) provides a significant revision of the 1987 version and incorporated additional information such as:

- Updated intensity-frequency-duration IFD relationships (using rainfall data collected since the analysis for the 1987 version was conducted);
- Updated storm temporal patterns;
- Advice on blockage for structures such as culverts and bridges (not discussed in the 1987 version);
- Advice on climate change adjustments associated with emission-related projections; and
- Some of the specific parameters associated with the guideline are provided through the ARR Data Hub (http://data.arr-software.org/).

OEH (now DCCEEW) in January 2019 published a guidance on incorporating the updated Australian Rainfall and Runoff into flood studies in NSW. The Flood Risk Management Guide: Incorporating 2016 Australian Rainfall and Runoff in studies (OEH, 2019) is a key document in guiding the application of Australian Rainfall and Runoff. In particular, there is specific guidance related to rainfall losses that is of particular relevance to this assessment. For design flood modelling, the OEH guideline recommends the use of the mean temporal pattern within the 10 ensemble storms.

3.7.2 NSW Flood Risk Management Manual

DCCEEW is the custodian of the NSW Government's Flood Risk Management Manual (2023a), which is the key guiding document in the management of flood-prone land.

In addition to the Flood Risk Management Manual (NSW Government, 2023a), DCCEEW have issued a toolkit to support policy implementation. The manual replaces the Floodplain Development Manual (NSW Government, 2005) and provides guidelines covering a diverse range of topics including:

- Understanding flood behaviour;
- Assessing flood damage;
- Climate change;
- Other flood management concerns; and
- Supporting emergency management.

The guidelines can be found at http://www.environment.nsw.gov.au/topics/water/floodplains/floodplain-guidelines.

3.8 Site Inspection

A site inspection of the study area was undertaken by Rhelm and Catchment Simulation Solutions (CSS)) staff on 17 and 18 February 2022. On 17 February, the temperature was 35 degrees and there were evening storms in the area. On 18 February, the temperature was 32 degrees. The catchments had recorded 30-40 mm of rainfall in the proceeding 7 days. Flows were near average in the Colo and Macdonald Rivers at the time of the inspection.

Key locations inspected were:

- Colo River (17 February 2022)
  - Upper Colo bridge
  - Colo RFS Shed
  - Sumerset Outdoor Learning Centre
  - Bielany Camp Site
  - Wheeny Creek/Colo River Confluence
  - Putty Road Bridge

    - Greens Road Bridge – Lower Portland
    - Colo River/Hawkesbury River Confluence
- Greens Creek (17 February 2022)
    - Greens Creek at Greens Road
- Webbs Creek (17 February 2022)
    - Webbs Creek/Hawkesbury River Confluence
    - Chaseling Road N Bridge
    - Webbs Creek Road to DinkiDell Campsite
- MacDonald River (18 February 2022)
    - MacDonald River Village
    - MacDonald River/Wrights Creek Confluence
    - St Albans Bridge
    - St Albans RFS Station
    - St Albans Common – Mogo Creek
    - Macdonald River at Upper Macdonald
    - Macdonald River at Higher Macdonald

The site inspection provided an overview of the study area and an appreciation of key features affecting flood behaviour and evacuation constraints. Photographs of the site inspection are provided in **Appendix B**.

4 Hydrologic Model

Two computer models were developed to simulate flood behaviour across each of the four catchments:

- A hydrologic model was developed to simulate the transformation of rainfall into runoff across the catchment. The hydrologic model was developed using the WBNM software, and,
- A hydraulic model was developed to simulate how the runoff from the hydrologic model would be distributed/move across the catchment. The hydraulic model was developed using the TUFLOW software.

This section details the hydrologic model build, calibration and design event modelling, while Section 5 describes the hydraulic model

4.1 Model Development

The hydrological modelling was completed using the WBNM (Watershed Bounded Network Model) hydrological model (v2017_001c), and is based on the model that was developed for the Hawkesbury-Nepean River Flood Study (Rhelm CSS, 2024).

WBNM calculates runoff based on rainfall hyetographs. By dividing the catchment into sub-catchments, WBNM allows for the generation of hydrographs at various locations within the catchment, effectively modelling the spatial variability of rainfall and its associated losses. The model distinguishes between overland flow routing and channel routing, and can be applied in rural and urban catchments. The subcatchment delineation has been adapted from the Hawkesbury-Nepean River Flood Study (Rhelm CSS, 2024) and is based on available LiDAR information, with some updates undertaken in this study to align with the hydraulic modelling. The total subcatchments are shown in **Table 4-1**, and the subcatchment delineation is shown in **Figure 4-1**.

Details of the inputs and data sources common to each catchment are summarised in **Table 4-2**.

Table 4-1 Number of subcatchments for each catchment

Catchment	Number of Subcatchments
Colo River	252
Macdonald River	107
Greens Creek	5
Webbs Creek	19

Table 4-2 Hydrological model input data

Parameter	Data Source
Percentage impervious	Percentage impervious areas are largely a factor of development intensity. These areas can be quantified by rasterising point land-use classification data from LiDAR. This processing was completed for the Hawkesbury-Nepean River Flood Study (Rhelm CSS, 2024) and has been drawn upon for this study. Note that the impervious area percentage is very low as the catchments are largely undeveloped, and therefore this is not a significant parameter for this study.

Parameter	Data Source
Runoff routing	Routing refers to the transfer of flows from one subcatchment to another. WBNM manages this runoff through the catchment lag factor (model parameter, 'C'). The Hawkesbury-Nepean River Flood Study (Rhelm CSS, 2024) and the historical calibration process informed the selection of the 'C' parameter. A 'C' parameter of 1.55 was adopted for the Colo River catchment, and 1.9 was adopted for the Macdonald River and Webbs Creek catchments. Given catchment similarities, a 'C' parameter of 1.9 was adopted for Greens Creek. The impervious lag factor was set using the recommended value of 0.1
Rainfall losses	Under the new methodology set out in ARR2019, rainfall parameters for hydrological modelling are all available from the ARR Data Hub and should be adjusted per NSW government guidance (Incorporating 2016 Australian Rainfall and Runoff in Studies). Deviation from this approach is expected when better site-specific information is available. In the case of the Colo River and Macdonald River catchments, the data from the Hawkesbury-Nepean River Flood Study (2024) provided the most up to date information and supplemented available data from the ARR Data Hub. For the historical calibration events in the Colo and Macdonald River catchments, the Hawkesbury-Nepean River Flood Study (2024) values formed the starting point for the calibration process, though adjustments were made for individual historical events, as discussed below in **Section 4.2.** The design rainfall losses for the Colo and Macdonald River catchments differed from the historical event losses as a consequence of the Flood Frequency Analyses (FFA) that was undertaken. The FFA is discussed in **Section 4.3.** More information on the design event modelling process is found in **Section 4.4.** For the design rainfall losses in the Greens and Webbs Creek catchments, probability neutral burst losses from ARR Data Hub were adopted for the initial loss, while the continuing losses followed the values adopted for the Macdonald River catchment due to similar catchment conditions. For more design model information, refer to **Section 4.4.**
Rainfall intensities and hyetographs/ temporal patterns	Historical rainfall intensities and hyetographs were sourced from available rainfall gauge data (refer to **Section 3.3.1**). Design rainfall intensities and temporal patterns were taken from the ARR Data Hub and are discussed in **Section 4.4**. The intensities and temporal patterns for Probable Maximum Precipitation (PMP) modelling were dictated by the Generalised Southeast Australia Method (Colo, Macdonald and Webbs catchments) and Generalised Short Duration Method (Webbs and Greens catchments) approaches, as discussed in **Section 4.4**.
Areal reduction factors	The areal reduction factors for design rainfall modelling were taken from the ARR Data Hub and were varied for each model based on the relevant catchment area. See **Section 4.4** for more details.
Stream lag	The stream lag factor, 'F', is a WBNM-specific parameter that accounts for variation in flow velocity and lag times caused by stream channel roughness. As the four catchments are all natural catchments, the WBNM-recommended value of 1 (Boyd et al, 2017) was adopted for all subcatchments in the model.

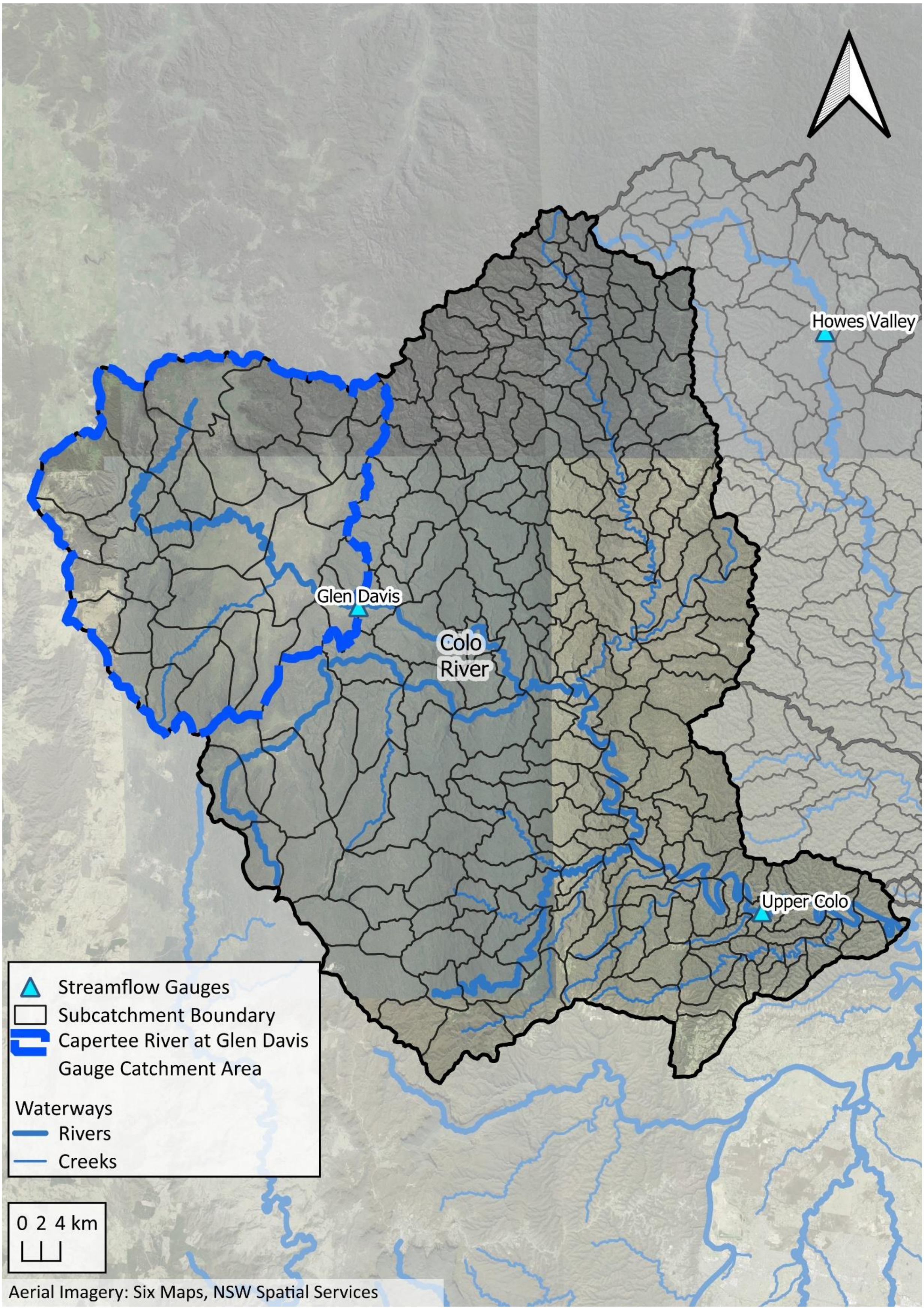

Figure 4-1 Subcatchment delineation for hydrological model

4.2 Calibration and Validation

Calibration of a hydrological model is important, as it ensures that model parameters are appropriate for a catchment. Four water level gauges were identified for the calibration of the hydrological model. These gauges provide useful historical snapshots for calibration of the Colo and Macdonald River catchments.

The Colo and Macdonald River hydrological models were calibrated to four historical flood events, namely:

- July 2022
- March 2022
- February 2020
- March 1978

Following a Flood Frequency Analysis (FFA) undertaken at the Upper Colo and St Albans gauges (refer to **Section 4.3.1** and **Section 4.3.2** respectively), the estimated AEP of the calibrated events is shown in **Table 4-3**.

Table 4-3 Estimated AEPs of historical calibration events

	Estimated AEP (1 in X Years)			
Catchment	March 1978	February 2020	March 2022	July 2022
Colo River	~80	10 – 20	30 – 40	10 – 20
Macdonald River	~20	2 – 5	10 – 20	~20

While accounts of larger floods with higher water levels exist, there is a lack of spatial and temporal rainfall data available for these events (e.g. the 1889 flood event in the Colo River). The selected calibration events include the 1978 flood, which was the largest flood event that occurred at the Upper Colo since gauge records started and the July 2022 event, which was the largest event that occurred at St Albans for the available gauge record.

To calibrate a model, consideration of the underlying historical data and model parameters is required. From the calibration process undertaken in the Hawkesbury-Nepean River Flood Study (2024), the processed historical data and catchment lag parameters were found to be reasonable for this study. Given the Hawkesbury-Nepean River Flood Study (2024) was primarily focussed on the flood behaviour of the Hawkesbury-Nepean River, fine-tuning of rainfall losses was undertaken to enhance the calibration outcomes for the Colo and Macdonald River catchments.

The calibration inputs and comparison with the gauge records are provided for the above events in the following sections.

4.2.1 Colo River Calibration

4.2.1.1 Catchment Context

The Colo River Catchment upstream of the Upper Colo gauge has a catchment area of around 4340km^2. A large majority of the catchment falls within national parks, with steep terrain and gorges.

There are two streamflow gauges in this catchment, Glen Davis and Upper Colo. The gauge locations are shown in **Figure 4-2.** The Glen Davis gauge is located in the upper portion of the catchment. The catchment characteristics upstream of the gauge is different to the majority of the catchment, with largely rural areas around the Glen Davis area draining to this point. The WaterNSW site report identifies that the river at this location is unstable, with a sand bar. The flow ratings (are also only up to 4.26m on the gauge, or approximately $80m^3/s$. The flows at the Capertee River gauge at Glen Davis were particularly difficult to reproduce using the model. In each calibration event, this particular area received relatively low rainfall compared with the remainder of the Colo River catchment. There are also very few sub-daily rainfall gauges in this part of the catchment, making representation of the rainfall pattern across this catchment challenging. With a catchment area of $1030km^2$, there are only three or four sub-daily rainfall gauges at most (see example in **Figure 4-4**).

The Upper Colo River gauge is located approximately 30 kilometres upstream from the Colo and Hawkesbury River's junction. This gauge has a long record, with peak levels recorded back to 1909 and continuous records since the 1960s (although 1964 has limited recorded data).

The Upper Colo gauge is located in a reasonably confined valley. However, BoM (2018) notes that this gauge has complex floodplain dynamics, due to the presence of backwater areas/ billabongs which lie within the floodplain. This may increase the overall storage in the area. This would have the potential to influence the falling limb of the hydrograph in particular.

Testing of the rainfall losses at this location suggested that the flow estimates were very sensitive to rainfall loss adopted, although this is reflective of the low rainfalls.

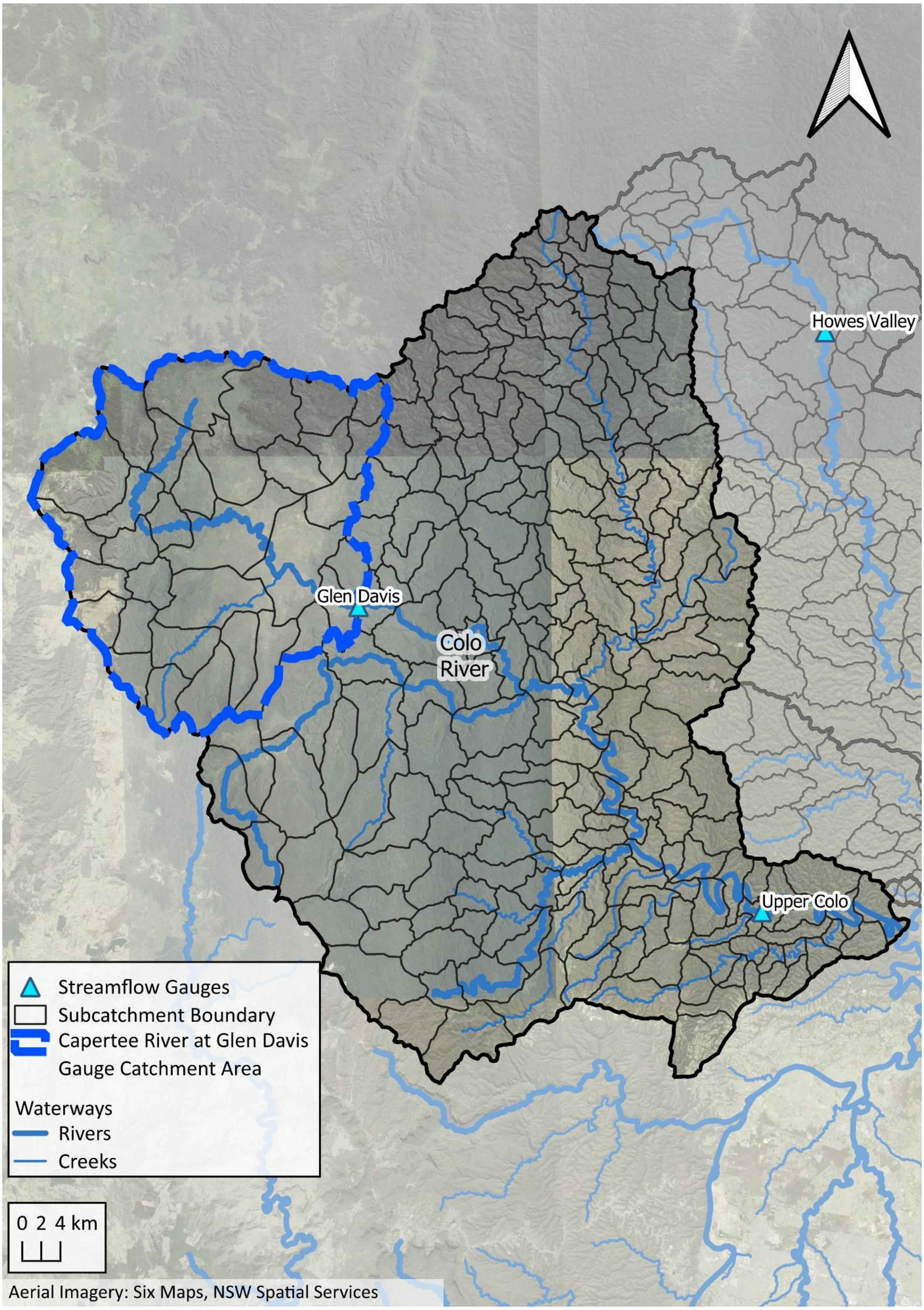

Figure 4-2 Colo River streamflow gauges and Glen Davis Gauge catchment area

4.2.1.2 *Rainfall Losses*

The refinement of rainfall losses was undertaken to update the hydrological model calibration for the Colo River catchment. Initial and continuing loss combinations for the historical events were originally based on calibration losses used in the Hawkesbury-Nepean River Flood Study (2024). An iterative process which involved the testing of various initial and continuing loss combinations was undertaken to improve the match to historical streamflow gauge data. The result of this process found that the losses used in the Hawkesbury-Nepean River Flood Study (2024) provided a reasonable representation of the catchment behaviour for three out of four historical events, with modifications required for the July 2022 event. For the July 2022 event, the Colo River continuing loss was changed from 0.35mm/hr to 0.8mm/hr to better match the recorded flows.

The adopted rainfall losses can be found in **Table 4-4**. These losses are substantially greater than the probability neutral burst losses from ARR Data Hub. For reference, the 5% AEP 72 hr probability neutral burst loss was 46.8 mm for the Colo River. The ARR Data Hub losses were checked and found to be too low to provide a suitable match for the hydrological calibration. The large difference in initial losses may be attributed to the long duration of the modelled rainfall events and antecedent moisture conditions associated with the calibration and validation events.

Table 4-4 Colo hydrological calibration model rainfall losses

Catchment	Representative Gauge	1978		2020		March 2022		July 2022	
		IL	CL	IL	CL	IL	CL	IL	CL
Capertee River	Glen Davis	140	4.8	110	2	45	5.5	55	0.6
Colo River	Upper Colo	110	2.1	170	3.1	90	0.9	80	0.8

IL = Initial Loss (mm), CL = Continuing Loss (mm/hr)

4.2.1.3 *Parameters*

The adopted hydrological calibration model inputs for the Colo River catchment are shown in **Table 4-5**.

Table 4-5 Colo River hydrological calibration model parameters

Parameter	Calibration Input
Rainfall Spatial Distribution	A total event rainfall isohyet map was prepared for each event based on the processed pluviograph and daily rainfall data from the Hawkesbury-Nepean River Flood Study (2024). The isohyets and rainfall gauges used for each historical event are shown in **Figure 4-3** to **Figure 4-6**.
Temporal Pattern	The temporal pattern applied to a subcatchment in the model was derived from the nearest pluviograph station. The stations used for each of the historical events are shown in in **Figure 4-3** to **Figure 4-6**.
Runoff Routing (WBNM 'C' Parameter)	A 'C' parameter of 1.55 was adopted for each calibration event, in line with the Hawkesbury-Nepean River Flood Study (2024).

Parameter	Calibration Input
Rainfall losses	Following an iterative process, variable rainfall losses were adopted across each calibration event. With the variance in catchment conditions between the Capertee River and Colo River, adopted rainfall losses differed between the Capertee River catchment and the remainder of the Colo River catchment. A summary of the rainfall losses adopted for each calibration event is shown in **Table 4-4**.

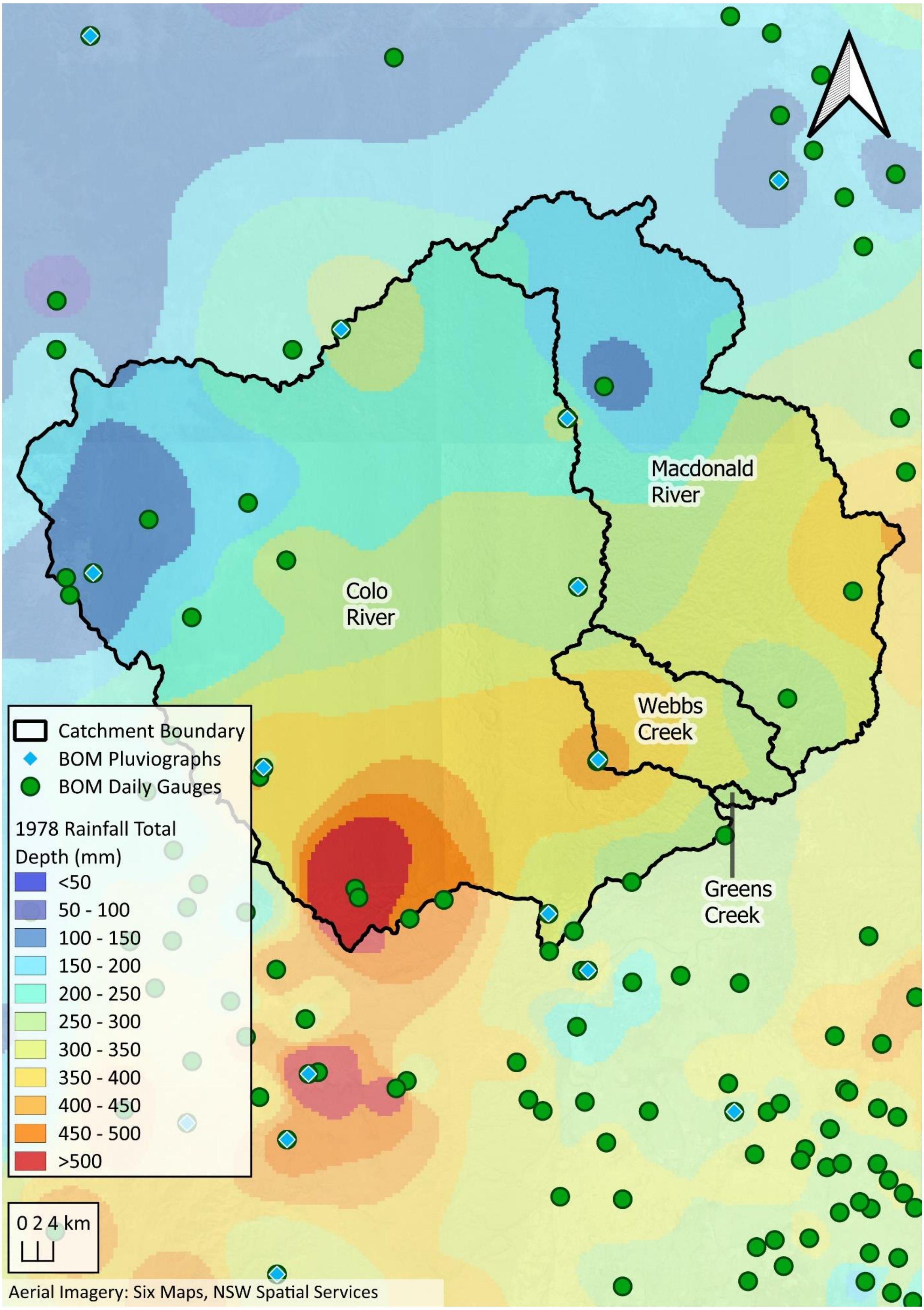

Figure 4-3 1978 event rainfall isohyet and available gauges

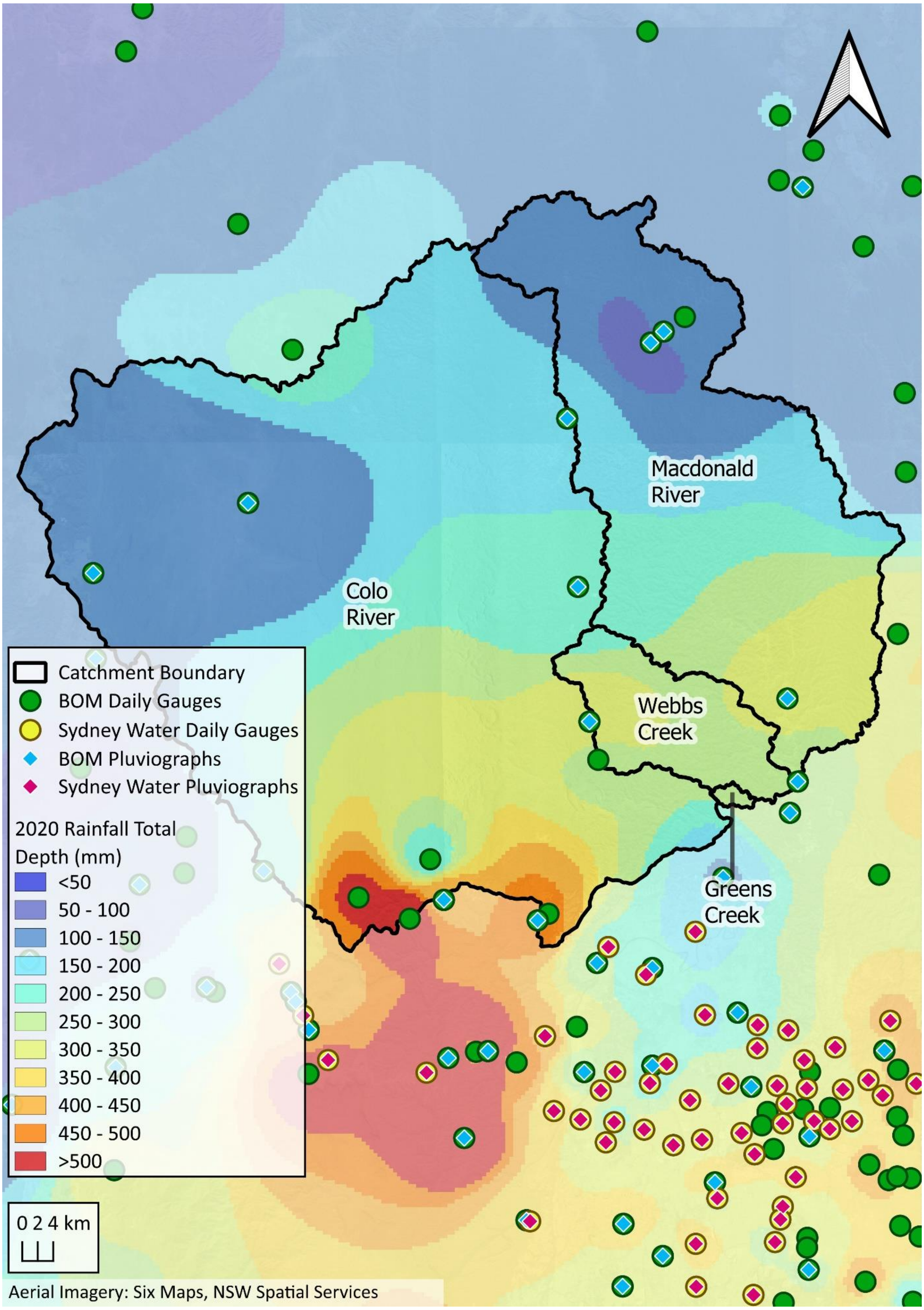

Figure 4-4 2020 event rainfall isohyet and available gauges

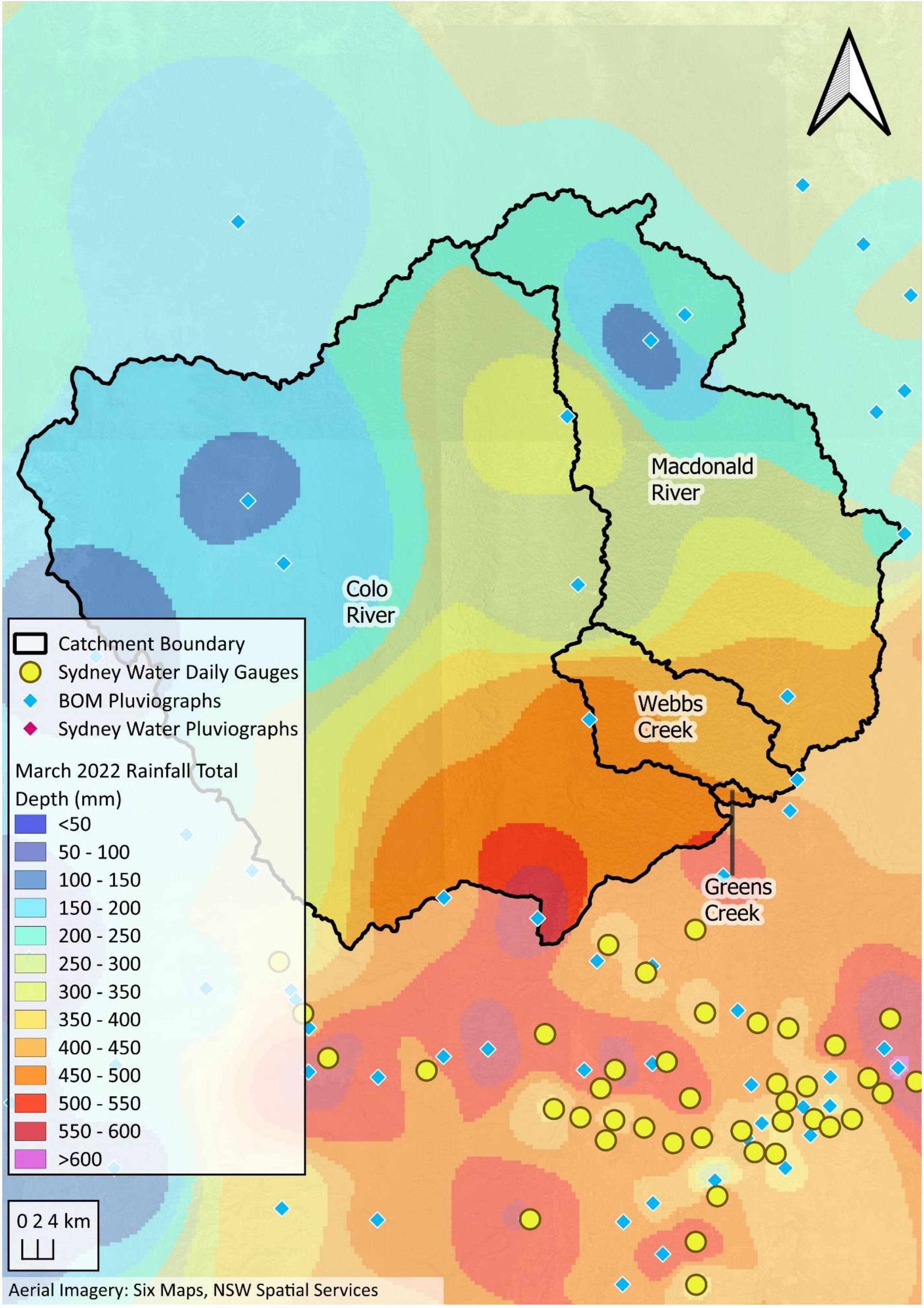

Figure 4-5 March 2022 event rainfall isohyet and available gauges

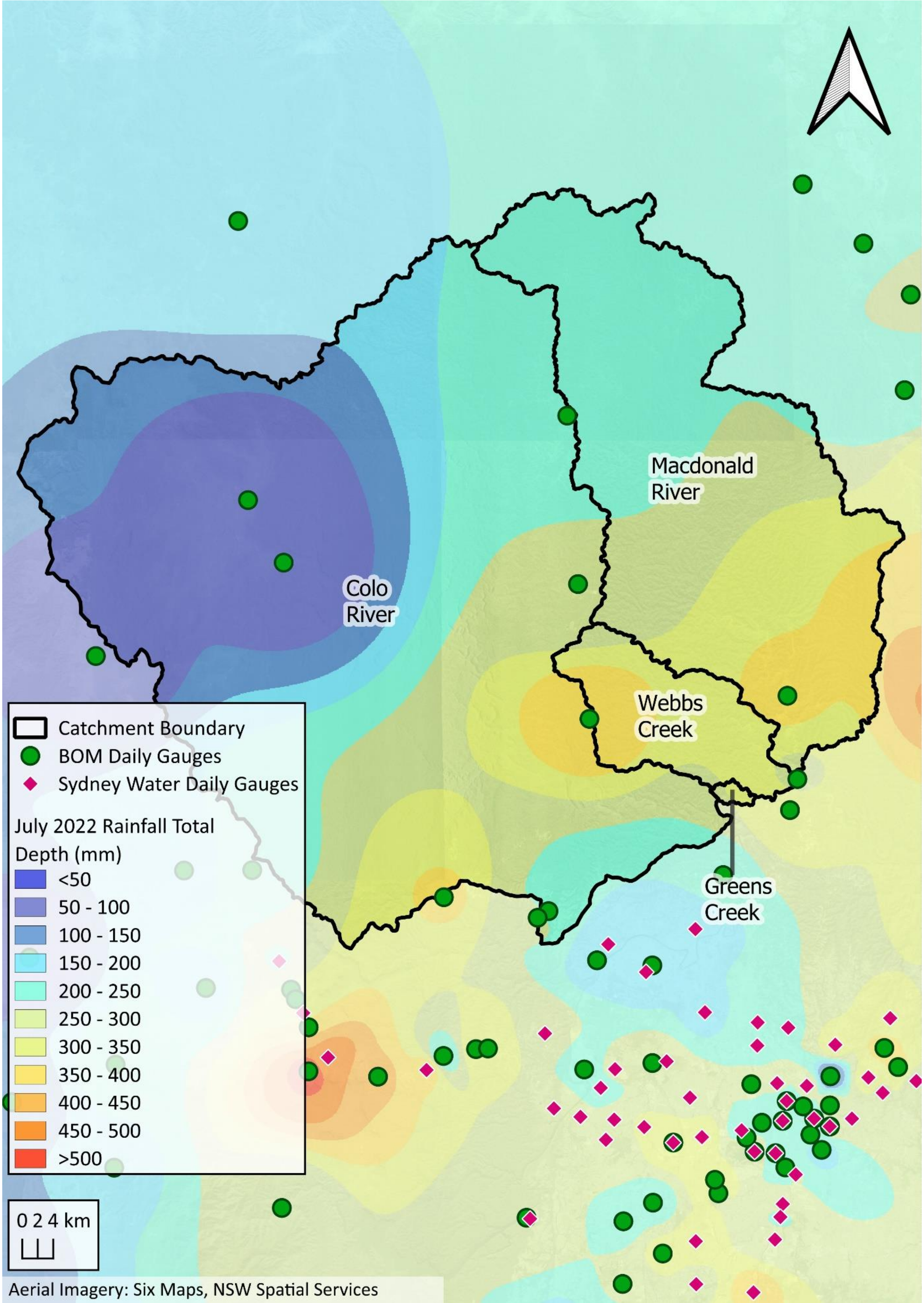

Figure 4-6 July 2022 event rainfall isohyet and available gauges

4.2.1.4 July 2022 Results

The July 2022 event occurred from 29th June till 7th July 2022, reaching a peak of roughly 2,100 m^3/s at the Colo River at Upper Colo gauge. The event was estimated to be a 1 in 10 to 1 in 20 AEP event for the Colo catchment.

The comparison of the WBNM flows and the Upper Colo gauge record is shown in **Figure 4-7** and the comparison for the Glen Davis gauge is presented in **Figure 4-8**.

The Upper Colo model hydrograph is a reasonable match for the peak flow and timing with the gauged results. The receding limb of the model hydrograph acted faster than the gauged hydrograph. As noted with the previous events, this can be a result of the hysteresis at the rating curve representation.

The modelled outputs for the Glen Davis gauge generally follow the shape of the gauged hydrograph well and captures the twin peaks of the flood event at the gauge. The peak flow is an overestimate by 9% compared to the gauged peak. The model has a faster rate of rise causing the modelled peak to occur 6 hours prior to the gauged peak. The offset in timing increases over the course of the model with the second peak being 9 hours early.

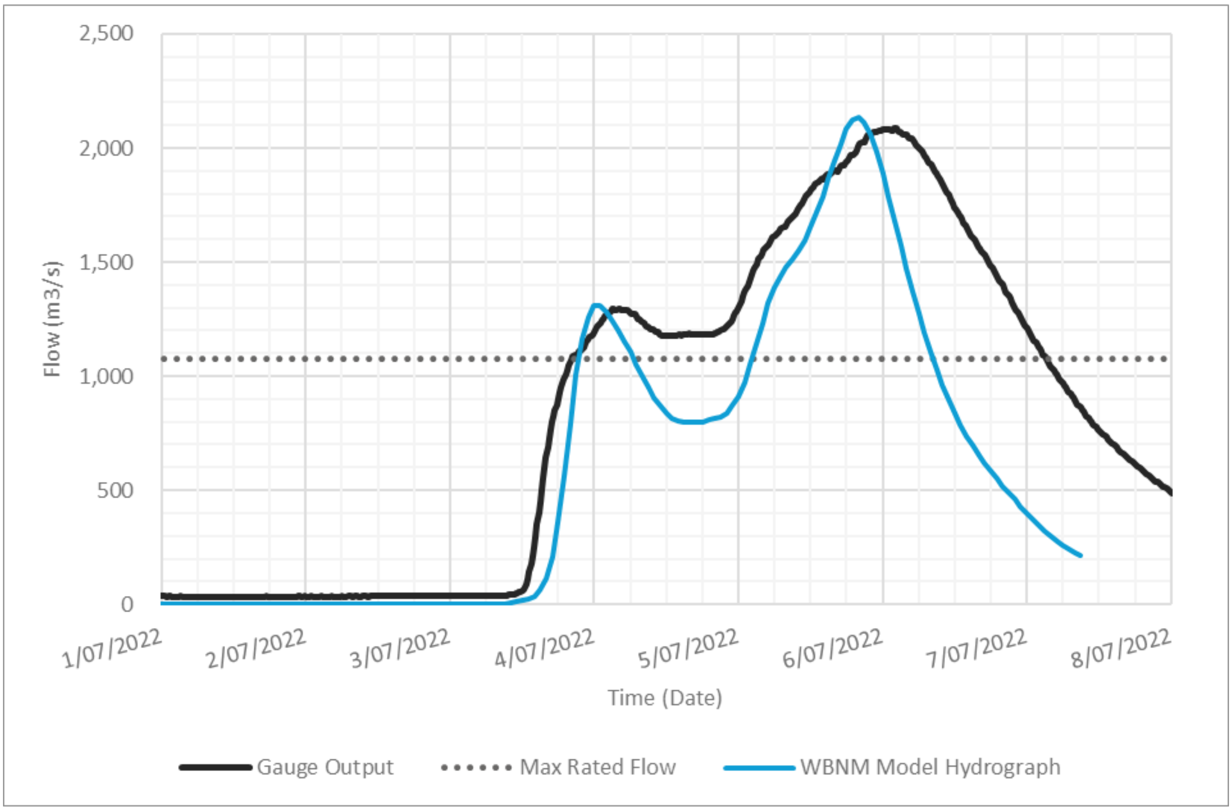

Figure 4-7 Upper Colo Gauge July-2022 calibration

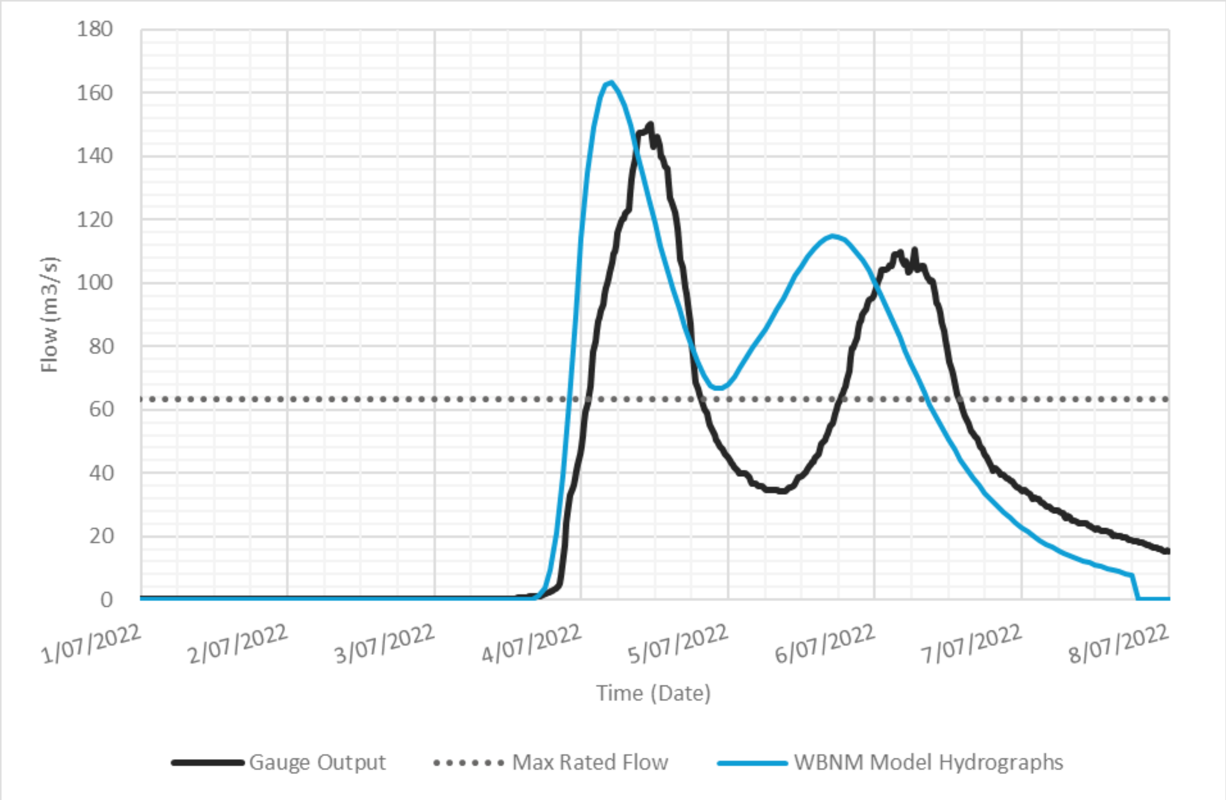

Figure 4-8 Glen Davis Gauge July-2022 calibration

4.2.1.5 March 2022 Results

The March 2022 event was approximately a 1 in 30 to 1 in 40 AEP flood event, reaching a peak of around 2,700m^3/s at the Colo River at Upper Colo gauge. The flood event occurred from 25th February to 15th March 2022.

The comparison of the WBNM flows and the Upper Colo gauge record is shown in **Figure 4-9** and the comparison for the Glen Davis gauge is presented in **Figure 4-10**.

The peak flow and timing from the modelled hydrograph for the Upper Colo gauge was a close match with the gauged record. The model reflected the rate of rise very well and highlighted the twin peak nature of the flood. The model underestimated the initial burst and overestimated the smaller first peak. The modelled result also shows a steeper receding limb compared with the gauged record.

The modelled hydrograph for the Glen Davis gauge was a much better match compared with the 1978 and 2020 calibrations, noting that the flows for Glen Davis were more significant in this event. The peak flows, twin peaks and rate of rise are all evident and reasonable in the modelled output.

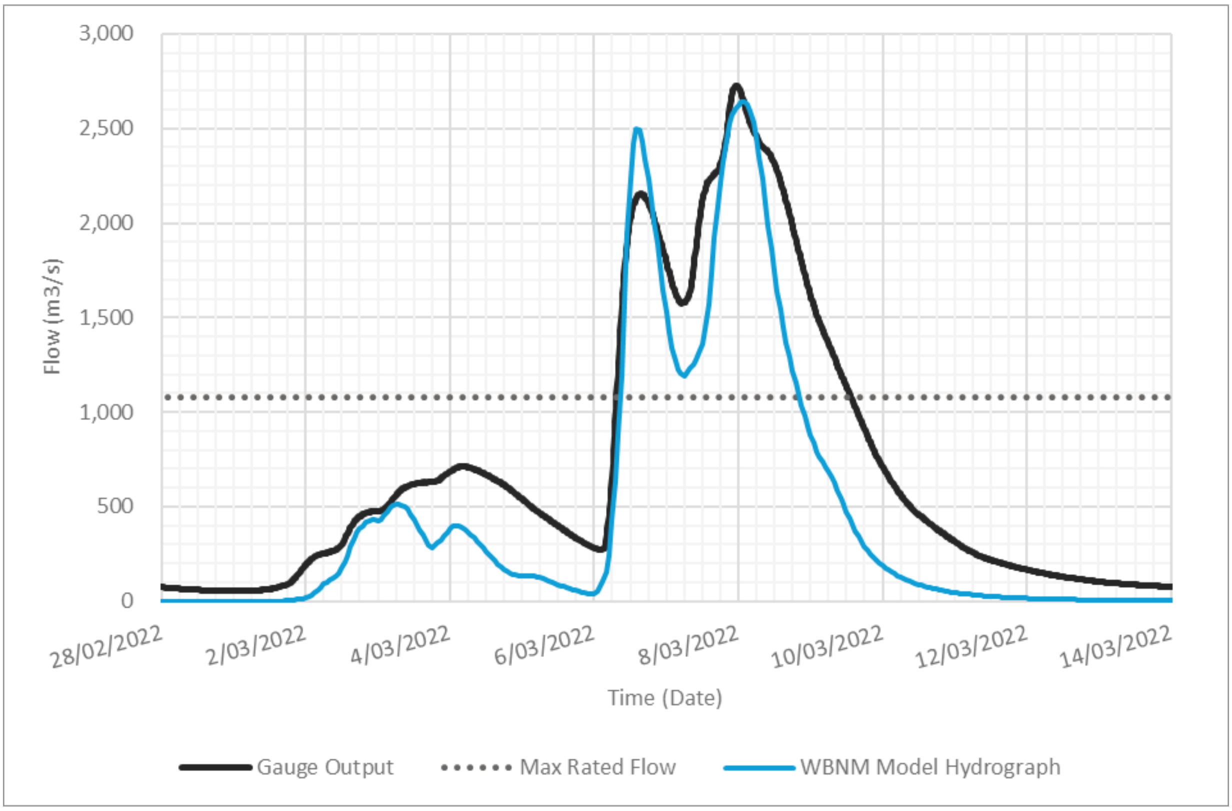

Figure 4-9 Upper Colo Gauge March-2022 calibration

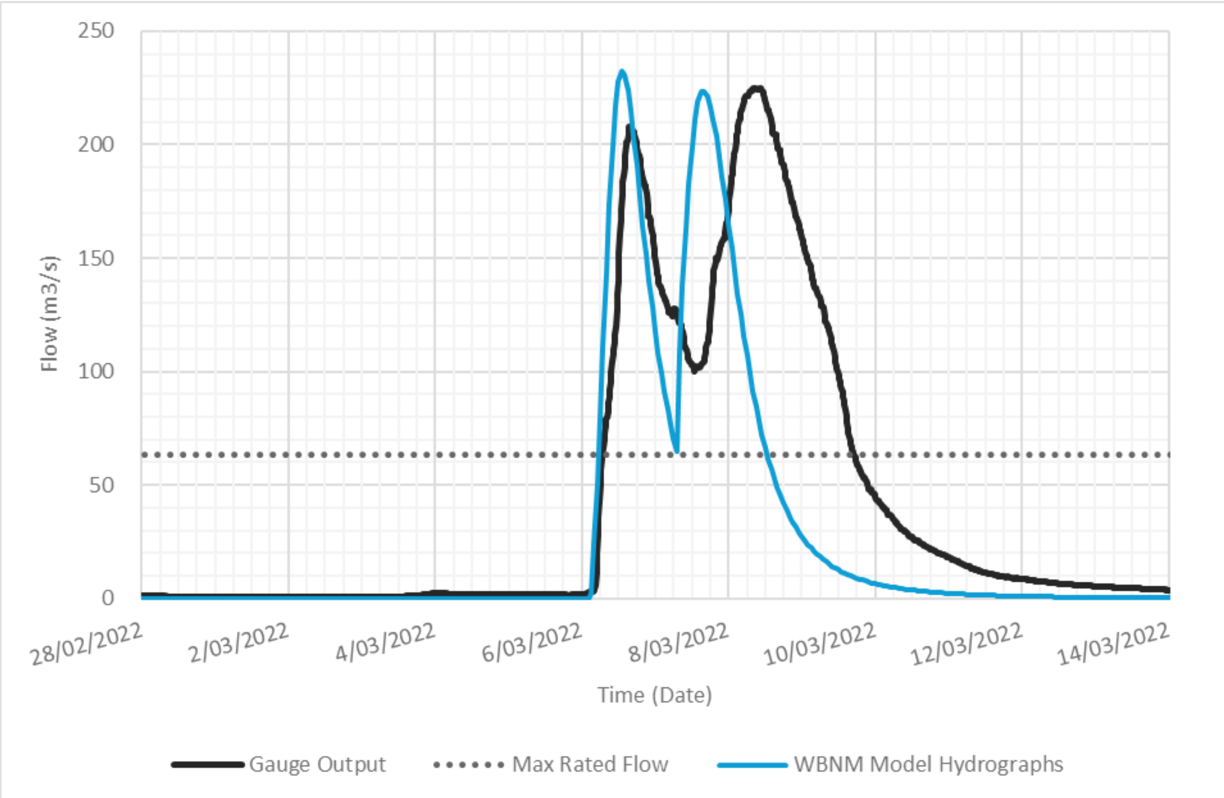

Figure 4-10 Glen Davis Gauge March-2022 calibration

4.2.1.6 2020 Results

The 2020 event commenced around the 5th of February and went through to around 12th February 2020, reaching a peak of approximately 2,400 m^3/s at the Colo River at Upper Colo gauge. The event was estimated to be between a 1 in 10 and 1 in 20 AEP event for the Colo catchment.

The comparison of the WBNM flows and the Upper Colo gauge record is shown in **Figure 4-11** and the comparison for the Glen Davis gauge is presented in **Figure 4-12**

The peak and timing of the 2020 Upper Colo gauge calibration event modelled flows are a close match to the gauged record. The shape of the hydrograph is also a reasonable fit, with the rate of rise being very similar, though delayed compared with the gauged record. The receding limb of the model hydrograph occurred at a faster rate than the gauged hydrograph. However, this can be due to the hysteresis in the rating. When these flows are run in the calibrated hydraulic model (where storage effects are better represented), the modelled receding limb more closely matches the gauge receding limb, as shown in **Appendix C**.

The modelled outputs at the Glen Davis gauge are similar to those in the 1978 event, with generally a poor match. As with the 1978 event, the poor coverage of rainfall data and the low flows make calibration to this gauge challenging. The peak flows based on the gauge represent less than 5% of the overall peak at the Upper Colo gauge. Further, the peak at the gauge occurs about 3 days after the Upper Colo gauge peak and would not have contributed to the peak flows at the Upper Colo.

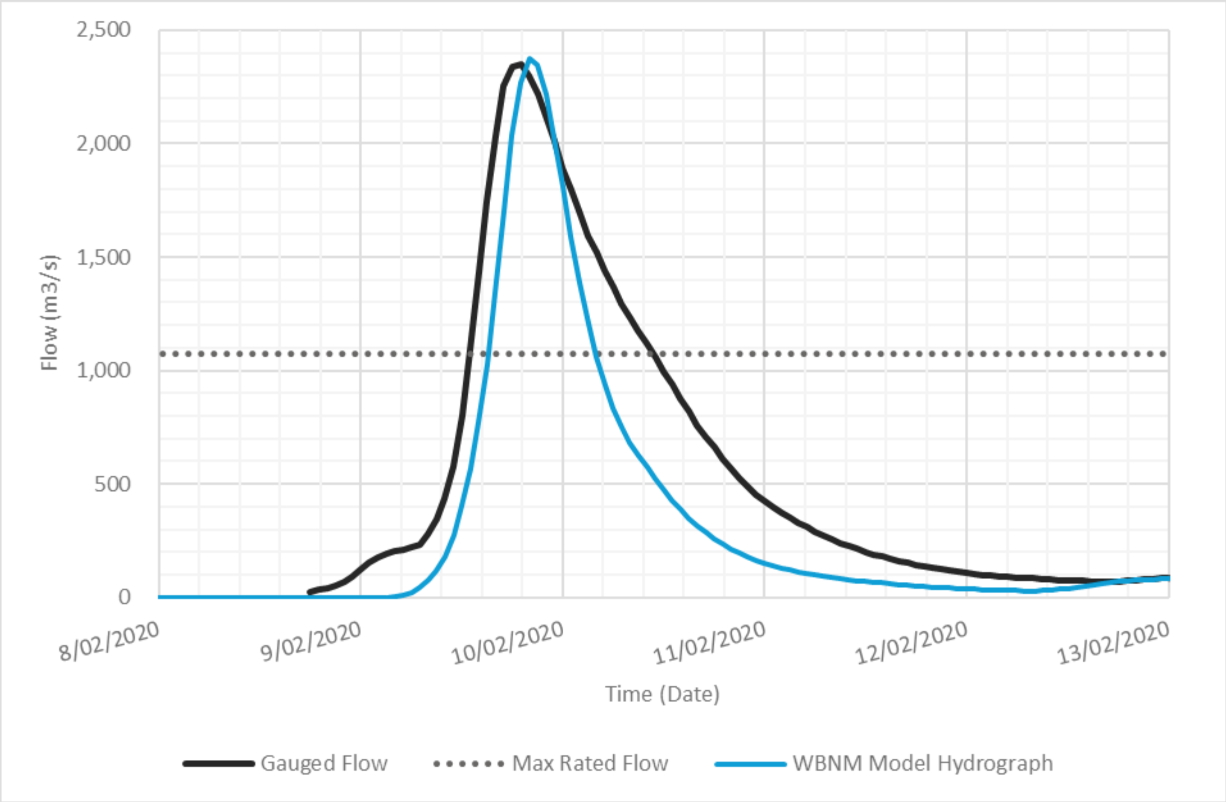

Figure 4-11 Upper Colo Gauge 2020 calibration

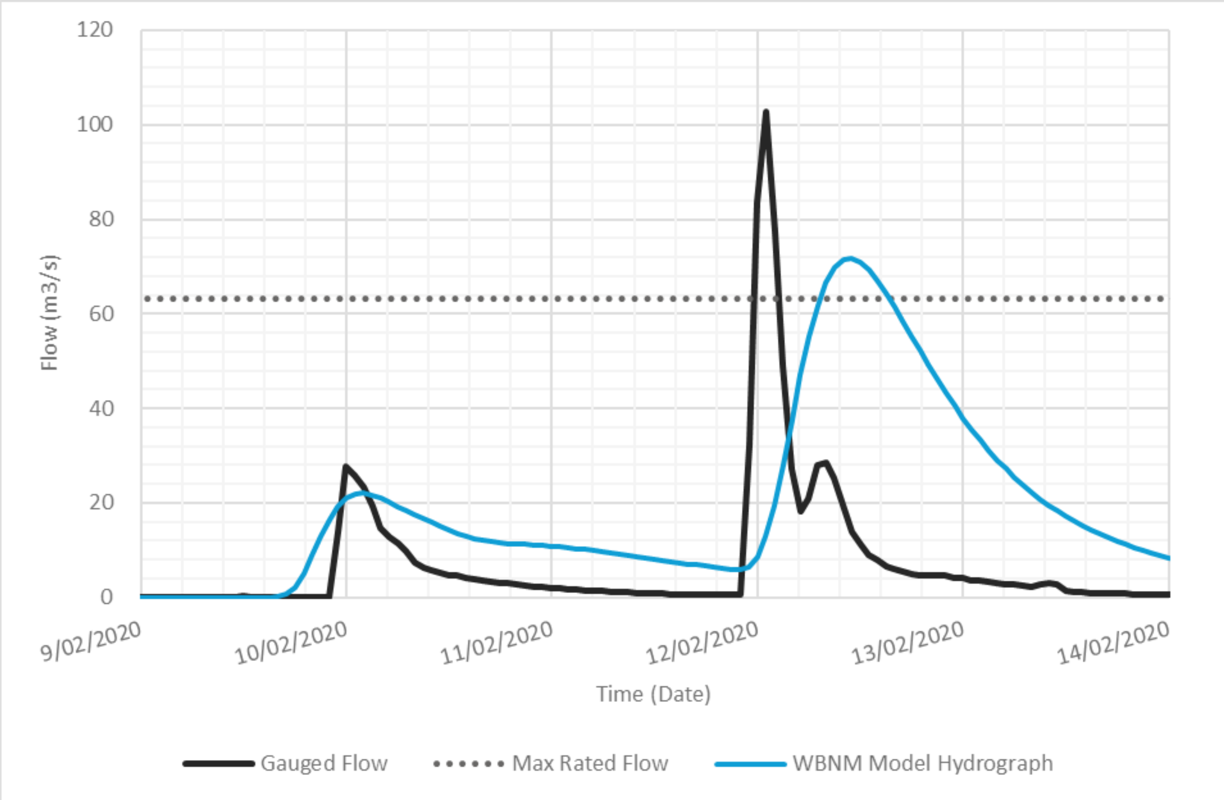

Figure 4-12 Glen Davis Gauge 2020 calibration

4.2.1.7 1978 Results

The 1978 event was the largest of the calibration events in the Colo River catchment. It reached a peak of approximately 3,800 m^3/s at the Colo River at Upper Colo gauge and was in the order of a 1 in 80 AEP flood event. The event occurred from 17th March through to 27th March 1978.

The WBNM model hydrograph and gauge hydrographs for the 1978 event at the Colo River at Upper Colo gauge are shown in **Figure 4-13**.

The model shows a good fit to the peak flow with the gauged record. The twin peaks were reflected in the results, albeit in a slightly different manner leading to a misalignment of the peak flows. The general shape of the hydrograph is a reasonable match, though the rate of rise is slower than the gauged data, whilst the rate of fall is faster than the gauged data.

The calibration to the Glen Davis gauge shown in **Figure 4-14** shows generally a poor alignment between model flows and gauge flows. This result suggests that the limited spatial and temporal rainfall data available for the Capertee River catchment was insufficient to capture the flood behaviour shown by the gauge for the 1978 flood event. It is worth noting that while the Capertee catchment represents nearly a quarter of the overall Colo River catchment, in this event the peak flows were less than 2% of the peak at the Upper Colo gauge, and therefore this part of the catchment contributed very little to the overall peak flows downstream.

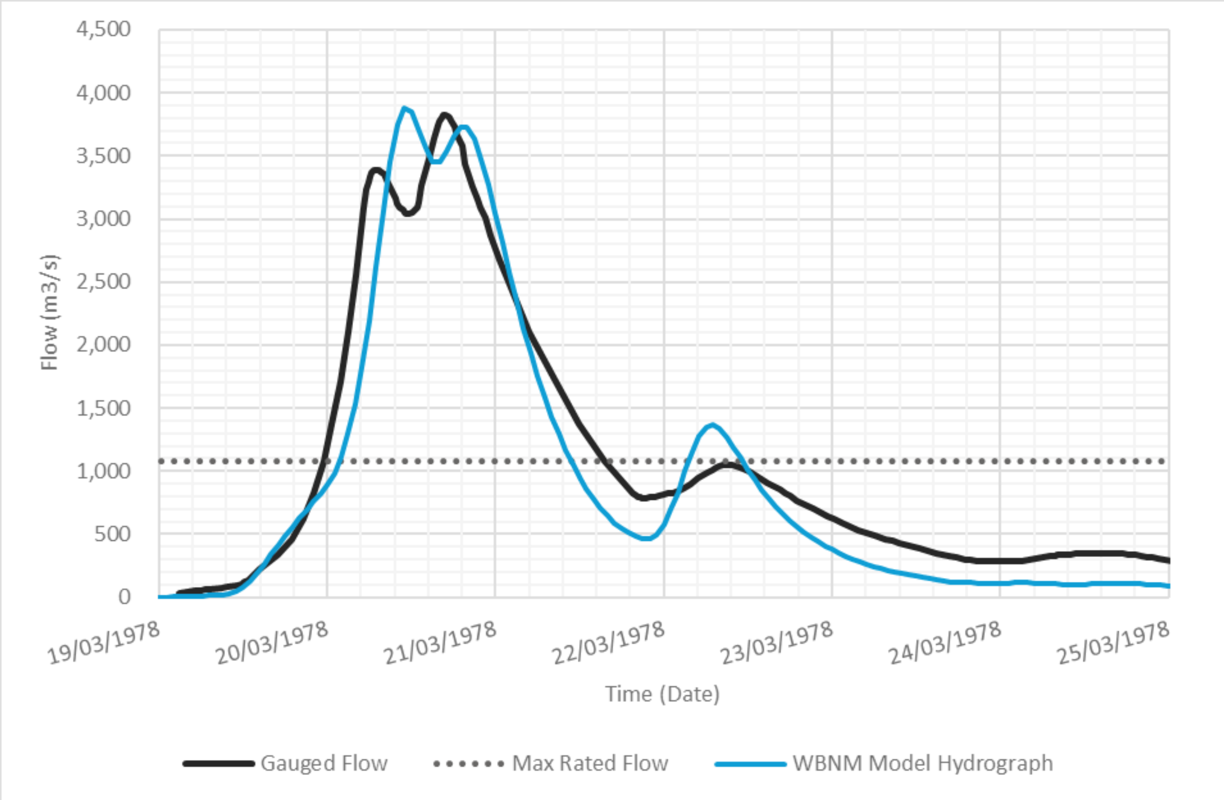

Figure 4-13 Upper Colo Gauge 1978 calibration

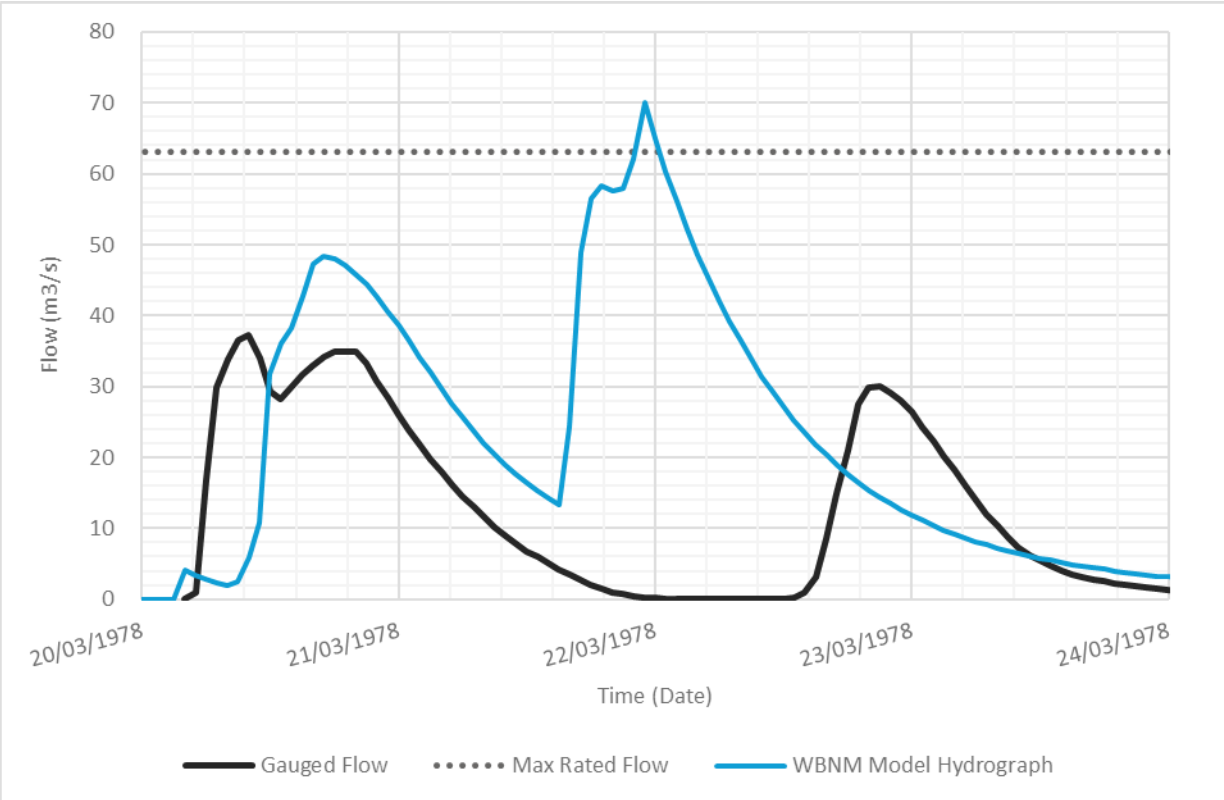

Figure 4-14 Glen Davis Gauge 1978 calibration

4.2.1.8 Calibration Outcome

The results of the above assessments indicated that the hydrological model is a reasonable representation of catchment hydrology. A summary of the peak flow differences is shown in **Table 4-6,** and a summary of the peak flow timing differences is shown in **Table 4-7.** As noted above, the key focus is on the Colo River at Upper Colo gauge, which is representative of the inflows to the study area. The Capertee River at Glen Davis gauge is further upstream in the catchment, and the rainfall in this area is generally lower and more difficult to represent due to the absence of gauges.

Table 4-6 Colo River catchment calibration peak flow difference summary

Catchment	Representative Gauge	1978 Peak flow difference	2020 Peak flow difference	March-2022 Peak flow difference	July-2022 Peak flow difference
Colo River	Upper Colo	-2%	1%	-3%	2%
Capertee River	Glen Davis	30%	-30%	-1%	9%

Table 4-7 Colo River catchment calibration peak flow timing difference summary

Catchment	Representative Gauge	1978 Peak flow timing difference (hr)	2020 Peak flow timing difference (hr)	March-2022 Peak flow timing difference (hr)	July-2022 Peak flow timing difference (hr)
Colo River	Upper Colo	2	1	3	-6
Capertee River	Glen Davis	7	10	-17	-6

A negative value refers to an early model and a positive value refers to a late model.

4.2.2 Macdonald River Calibration

4.2.2.1 Catchment Context

. The Macdonald River catchment areas and water level gauges are shown in **Figure 4-15**.

The total catchment area to the Macdonald River at St Albans gauge is 1740km^2. It is largely bushland with some rural areas primarily confined to the valley adjacent to the river. The catchment area to the Howes Valley gauge is approximately 20% of the area at St Albans, at around 300km^2

The gauge is located just downstream of the St Albans Bridge. This represents a reasonably confined part of the river, with high banks, as shown in **Figure 4-16**. While the riverbed is sandy in this location, which may affect lower flow estimates (due to geomorphic changes in the channel and the cross section), in higher flows the rating curve may be reasonable until flow overtops the bank on the St Albans village side. For the 1978 event, flow data for the St Albans gauge was reported in Webb McKeown & Associates (2004). This was digitised for the Hawkesbury-Nepean River Flood Study (2024) and included in the current study for the calibration.

A challenge in representation of the flows at St Albans gauge is the storage and conveyance characteristics upstream. For example, the large floodplain storage on Mogo Creek. These characteristics are represented in the TUFLOW hydraulic model, where routing and storage characteristics are better represented.

Similarly, immediately upstream of St Albans gauge (see **Figure 4-16**), the riverbank levels are lower and there is greater potential for the river to break its banks at lower levels and inundate the farmland on either side, as well as break out through St Albans township in larger events.

A further consideration is the potential backwater from the Hawkesbury River in larger flood events. In many of the historic events, the Hawkesbury River peaks after the Macdonald River, and can result in a much longer period with the gauge being elevated. This cannot be represented in the rating curve and is not included in the hydrology. Instead, these types of elevated characteristics are better represented in the hydraulic model.

However, as noted in **Section 5.3**, there are also some uncertainties in the gauge zero of the St Albans gauge. Therefore, there are some challenges with the hydraulic model calibration. Therefore, in undertaking the calibration, an iterative approach was undertaken by comparing results in both the hydraulic model (**Section 5.3**) and the hydrology model.

It is also noted that the Macdonald River is relatively sandy, and that the gauge is located in a relatively dynamic area. It is possible that after some of the larger historic events, that there may have been some change in the cross section either at, or upstream of, the gauge.

The catchment area to the Howes Valley gauge is approximately 20% of the area at St Albans, at around 300km^2.

The focus of the calibration was more on the St Albans gauge, given its proximity to the study area and hydraulic model boundary, rather than the Howes Valley gauge. However, a comparison of the hydrographs generally shows a reasonable representation of the Howes Valley gauged flows.

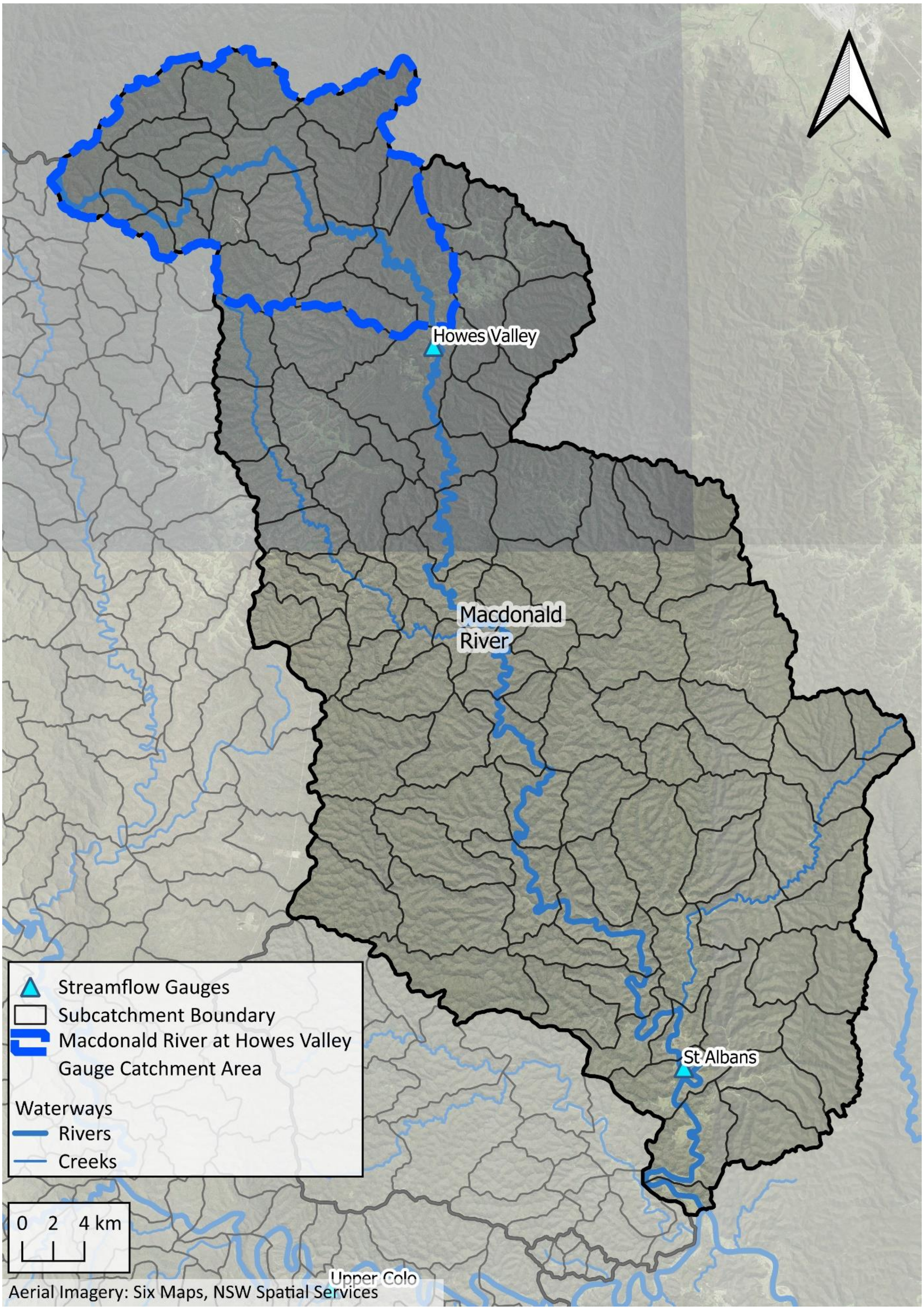

Figure 4-15 Macdonald River streamflow gauges and Howes Valley Gauge catchment area

Figure 4-16 Macdonald River near St Albans Gauge (top left – looking downstream at bridge, top right – looking upstream, approximately 300m upstream of bridge, bottom left – looking downstream of the bridge)

4.2.2.2 Rainfall Losses

The refinement of rainfall losses was undertaken to update the hydrological model calibration for the Macdonald River catchment. Initial and continuing loss combinations for the historical events were originally based on calibration losses used in the Hawkesbury-Nepean River Flood Study (2024). An iterative process which involved the testing of various initial and continuing loss combinations was undertaken to improve the match to historical streamflow gauge data. The result of this process found that the losses used in the Hawkesbury-Nepean River Flood Study (2024) provided a reasonable representation of the catchment behaviour for two out of four historical events (1978 and July 2022). Modifications were required for the 2020 and March 2022 event. For the 2020 event, the Macdonald River and Upper Macdonald River initial loss was changed to 205mm (from 185mm) and the continuing loss was changed to 1.9mm/hr (from 2.8mm/hr). For the March 2022 event, the Macdonald initial loss was changed to 110mm (from 80mm).

The adopted rainfall losses can be found in **Table 4-4**. These losses are much higher than the probability neutral burst losses from ARR Data Hub, particularly for the Macdonald River catchment which encompasses most of the total catchment (see **Figure 4-15**). For reference, the 5% AEP 72 hr probability neutral burst loss was 52.2mm for the Macdonald River. The ARR Data Hub losses were checked and found to be too low to provide a suitable match for the hydrological calibration at the St Albans gauge. The large difference in initial losses may be attributed to the long duration of the modelled rainfall events and associated antecedent moisture conditions associated with the calibration and validation events.

Table 4-8 Macdonald River hydrological calibration model rainfall losses

Catchment	Representative Gauge	1978		2020		March 2022		July 2022	
		IL	CL	IL	CL	IL	CL	IL	CL
Macdonald River – upper	Howes Valley	65	4	205	1.9	20	0	55	0
Macdonald River	St Albans	180	0.6	205	1.9	110	1	155	1.4

IL = Initial Loss (mm), CL = Continuing Loss (mm/hr)

4.2.2.3 Parameters

The adopted hydrological model inputs for the Macdonald River catchment are shown in **Table 4-9**.

Table 4-9 Macdonald River hydrological calibration model parameters

Parameter	Calibration Input
Rainfall Spatial Distribution	A total rainfall isohyet map was prepared for each event based on processed pluviograph and daily rainfall data from the Hawkesbury-Nepean River Flood Study (2024). These isohyets are the same isohyets adopted for the Colo River catchment. The isohyets and rainfall gauges used for each historical event are shown in **Figure 4-3** to **Figure 4-6**.
Temporal Pattern	The temporal pattern applied to the subcatchments in the model was adopted from the nearest pluviograph station. The stations used for each of the historical events are shown in **Figure 4-3** to **Figure 4-6**.
Runoff Routing (WBNM 'C' Parameter)	A 'C' parameter of 1.9 was adopted for each event, in line with the Hawkesbury-Nepean River Flood Study (2024).
Rainfall losses	Following an iterative process, variable rainfall losses were adopted across each calibration event. With the variance in catchment conditions between the Upper Macdonald River and Lower Macdonald River, adopted rainfall losses differed between the catchments. A summary of the rainfall losses adopted for each event is shown in **Table 4-8**

4.2.2.4 July 2022 Results

The July 2022 event was the largest of the calibrated events in the Macdonald River catchment. It reached a peak of approximately 1,100 m^3/s at the Macdonald River at St Albans gauge and was in the order of a 1 in 20 AEP event. The event occurred from 29th June till 7th July 2022.

The comparison of the WBNM flows and the St Albans gauge record is shown in **Figure 4-17** and the comparison for the Howes Valley gauge is presented in **Figure 4-18**.

The St Albans model hydrograph is a reasonable match for the peak flow timing with the gauged results from the July 2022 event. The peak flow itself was 28% higher than the gauged hydrograph and occurred in a rapid manner compared with the gauged record. However, this same effect is not observed in the TUFLOW hydraulic model, which may be better at representing the other routing characteristics upstream (Section 5.3).

The receding limb of the model hydrograph acted faster than the gauged hydrograph. However, in this event the Hawkesbury River at Wisemans Ferry was quite elevated and may have influenced the recession limb of the hydrograph. This is demonstrated in the better comparison between the TUFLOW model and the gauge in Section 5.3.

The modelled outputs for the Howes Valley gauge follow the shape of the gauged hydrograph well. In contrast to the St Albans gauge, the peak flow was an underestimate by 34% although it is noted that the flows are well above the maximum gauging, so there is a degree of uncertainty in the gauged flows at this level. The rate of rise and receding limb were closely matched.

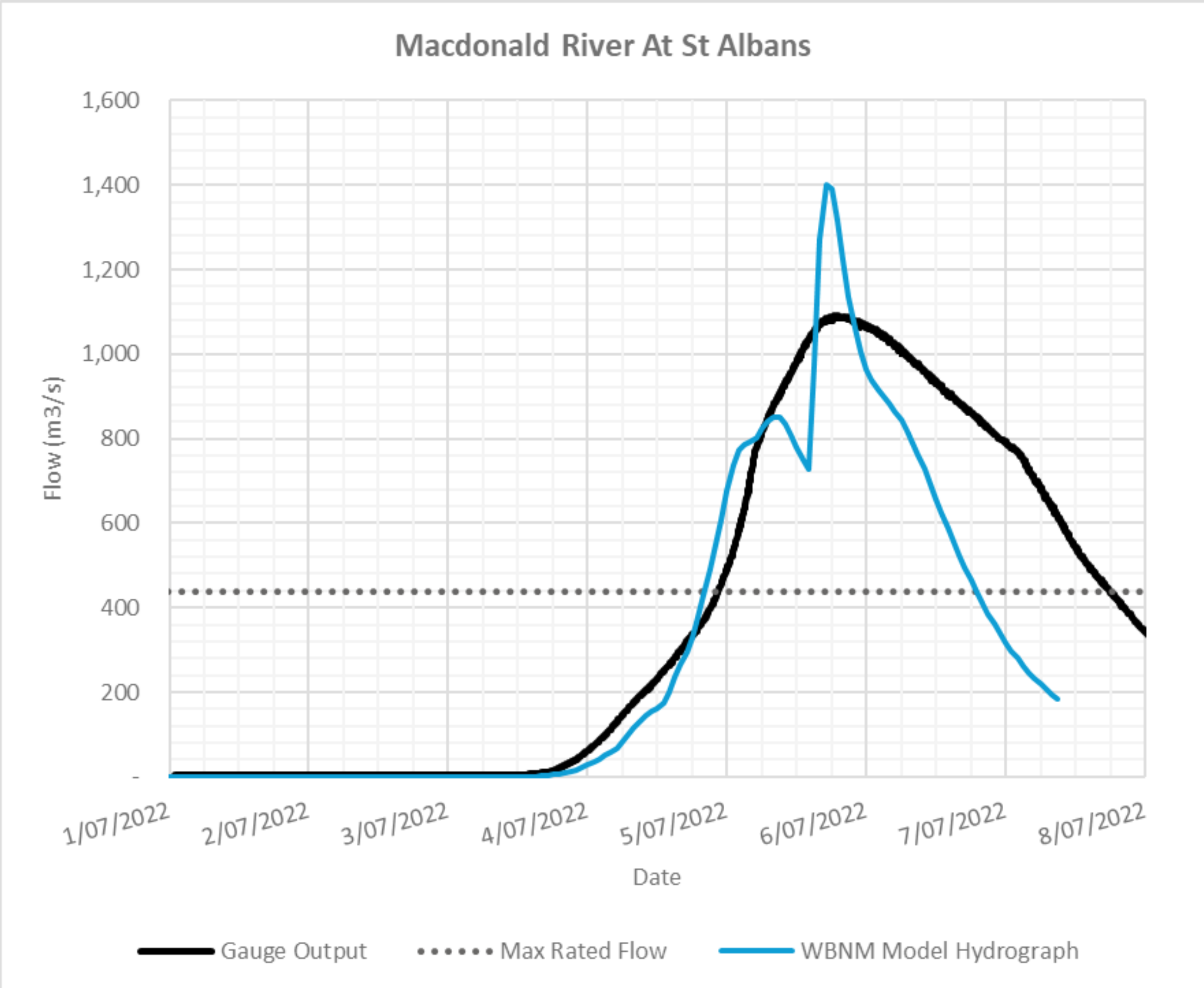

Figure 4-17 St Albans Gauge July-2022 calibration

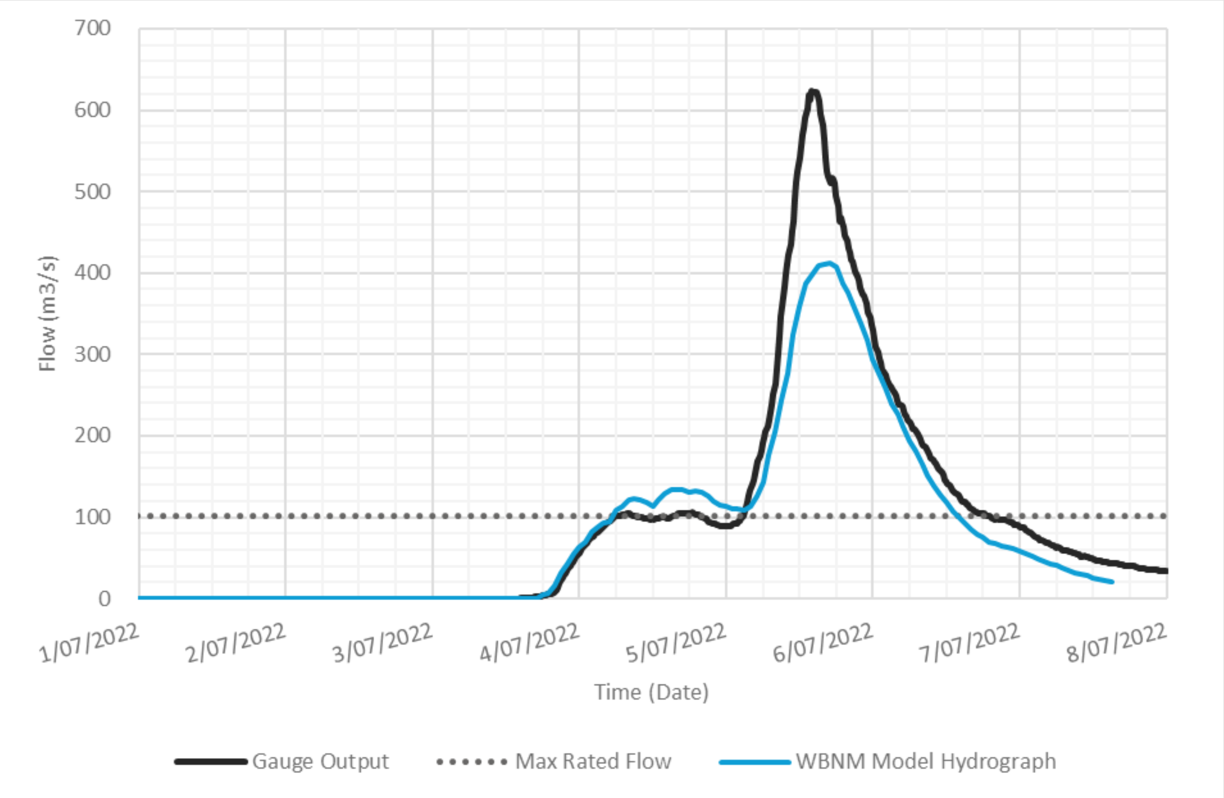

Figure 4-18 Howes Valley Gauge July-2022 calibration

4.2.2.5 March 2022 Results

The March 2022 event was approximately a 1 in 10 to 1 in 20 AEP flood event, reaching a peak of 900m^3/s at the Macdonald River at St Albans gauge. The flood event occurred from 25th February to 15th March 2022.

The comparison of the WBNM flows and the St Albans gauge record is shown in **Figure 4-19** and the comparison for the Howes Valley gauge is presented in **Figure 4-20**.

The peak flow and peak flow timing from the modelled hydrograph for the St Albans gauge was a reasonable match with the gauged record. The peak flow was lower by 9% and the timing was early by 4 hours. The model reflected the rate of rise very well. The sustained nature of the flooding was captured by the model, though a greater reduction in flows was witnessed over the course of the model run compared with the gauge data. The receding limb occurred early compared with the gauged record, but the rate of fall portrayed is similar.

While the model suggests that the volume of the event is underpredicted, the TUFLOW model results (Section 5.3), show that the modelled volume is a better fit (and potentially over-estimates).

The numerous peak flows and timings of the Howes Valley gauge record were suitably fitted by the modelled hydrograph. The 'spiky' nature of the gauged hydrograph was matched with modelled flows. The main differences arise from the increased flows early in the model run and decreased flows towards the end of the flood.

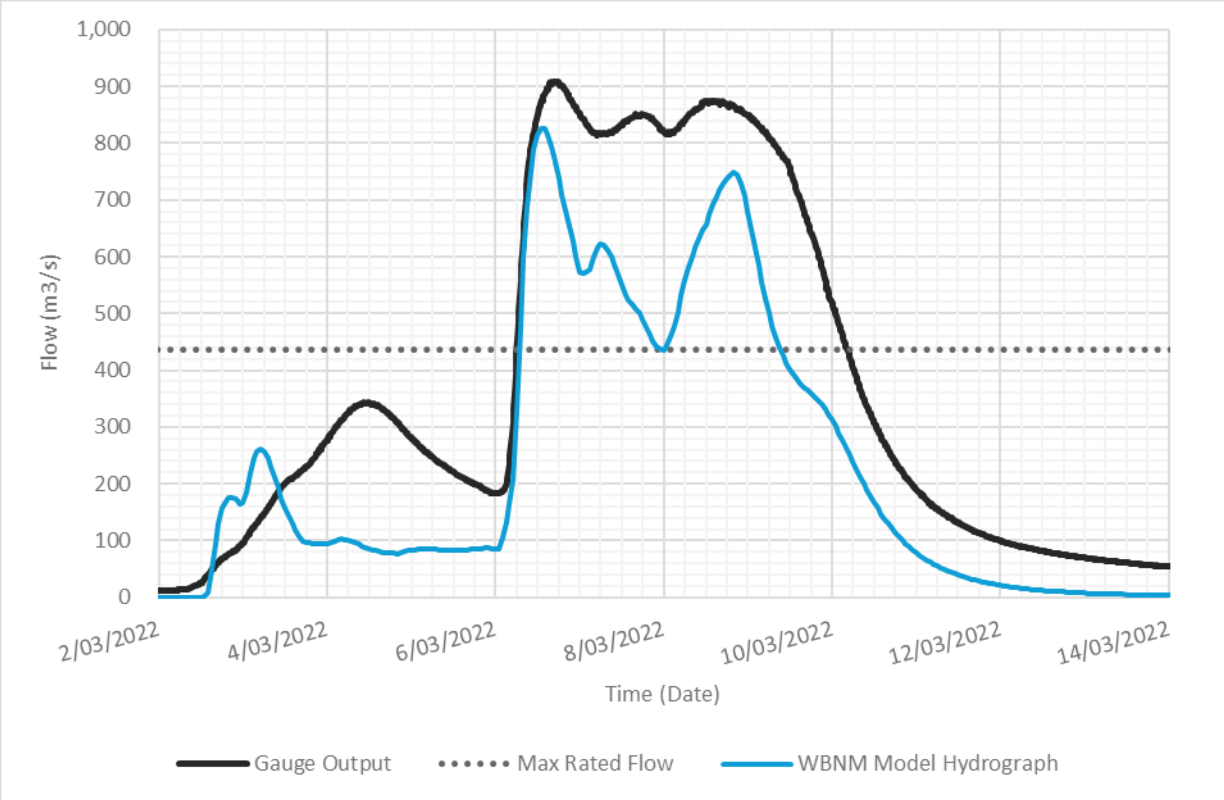

Figure 4-19 St Albans Gauge March-2022 calibration

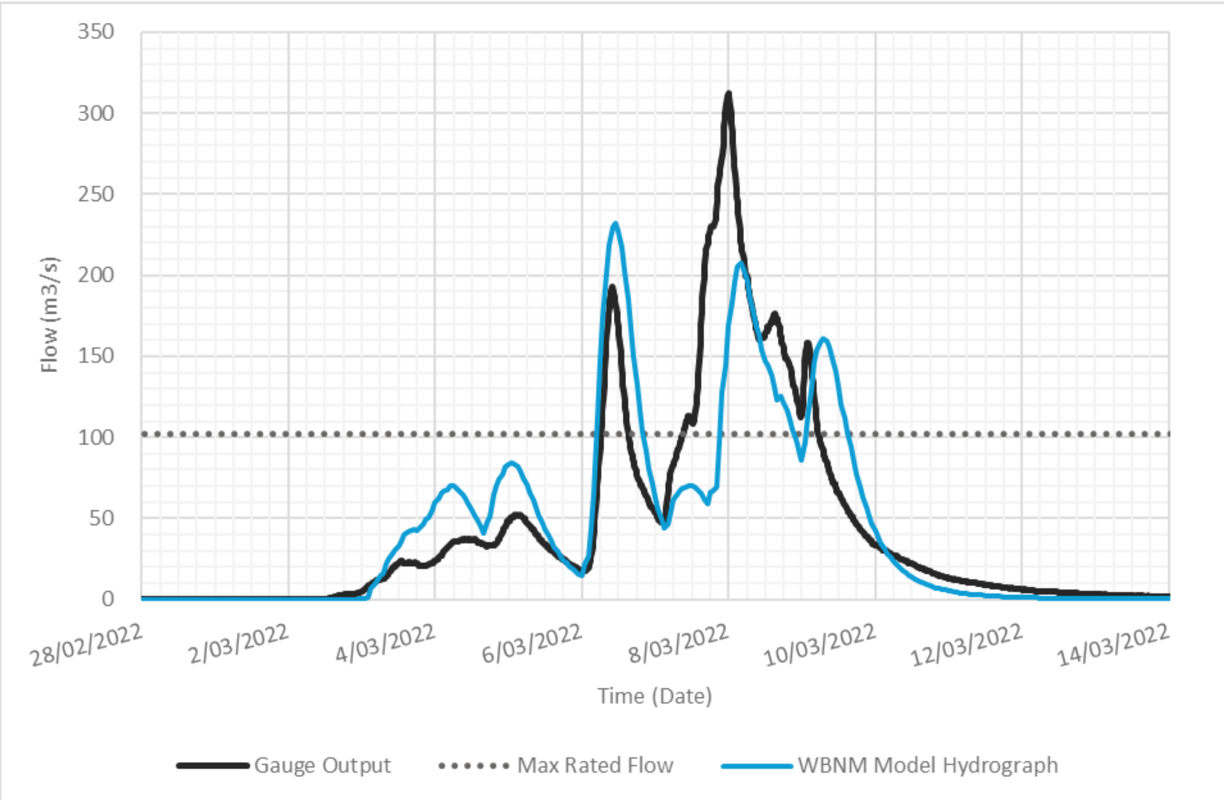

Figure 4-20 Howes Valley Gauge March-2022 calibration

4.2.2.6 2020 Results

The 2020 event commenced around the 5th of February and went through to 12th February 2020, reaching a peak of approximately 400 m^3/s at the Macdonald River at St Albans gauge. The event was estimated to be less than a 1 in 5 AEP event for the Macdonald River catchment.

The comparison of the WBNM flows and the St Albans gauge record is shown in **Figure 4-21**.

The general shape of the hydrograph reasonably matches the shape of the gauged record, with the rate of rise being similar, though the timing of the peak was early compared to the gauged record. While there is an underestimation of the volume for this event, this is not observed in the TUFLOW model calibration (Section 5.3).

The Howes Valley gauge did not provide suitable data for the 2020 calibration and the results of the calibration at the gauge were not considered.

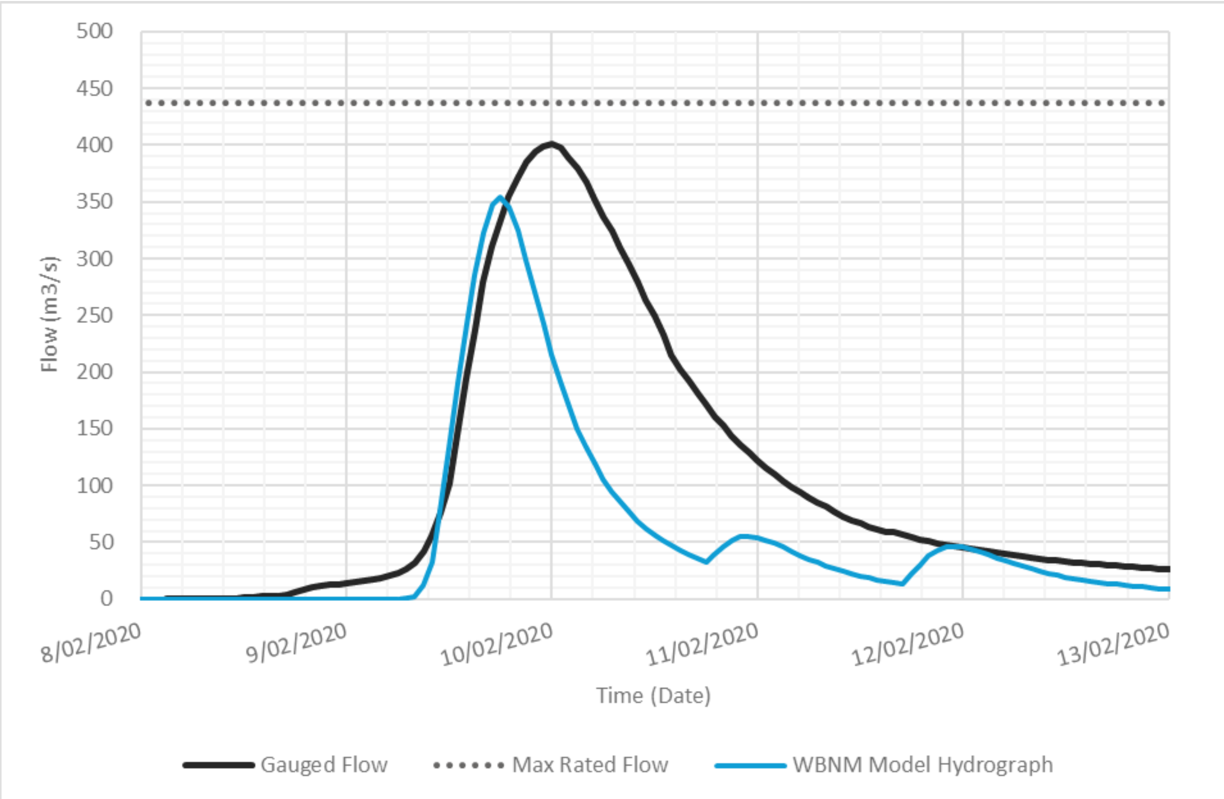

Figure 4-21 St Albans Gauge 2020 calibration

4.2.2.7 1978 Results

The 1978 event occurred from 17th March through to 27th March 1978, reaching a peak of roughly 930 m^3/s at the Macdonald River at St Albans gauge. The event was estimated to be between a 5% and 10% AEP event for the Macdonald catchment.

The comparison of the WBNM flows and the St Albans gauge record is shown in **Figure 4-22** and the comparison for the Howes Valley gauge is presented in **Figure 4-23**.

The peak flow and peak flow timing of the model matched very well with the St Albans gauge for the 1978 event. The rate of rise was similar to the gauged hydrograph, and the receding limb followed the shape of the hydrograph well, though responded faster compared with the gauged record.

The Howes Valley gauge also had a close fit for the peak flow and peak flow timing with the gauged record. The rate of rise was a close fit with the record, while the rate of fall was a good representation of the gauge.

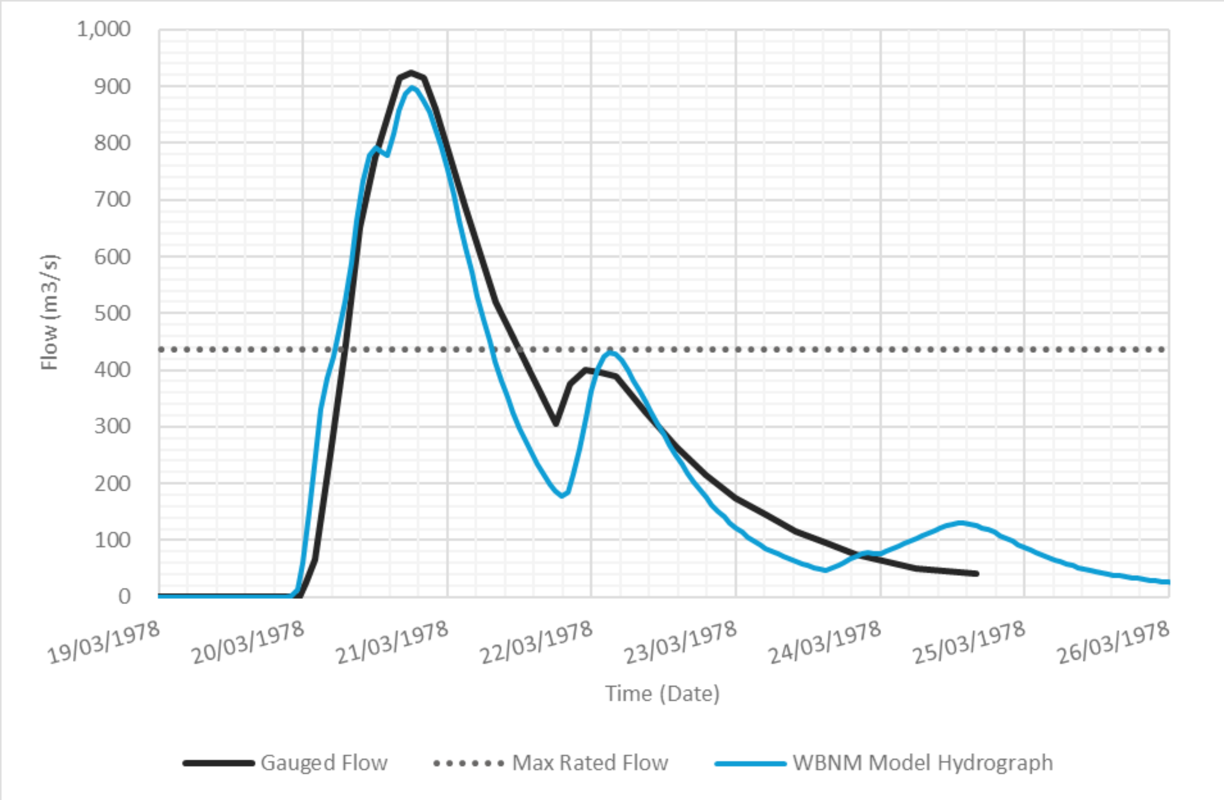

Figure 4-22 St Albans Gauge 1978 calibration

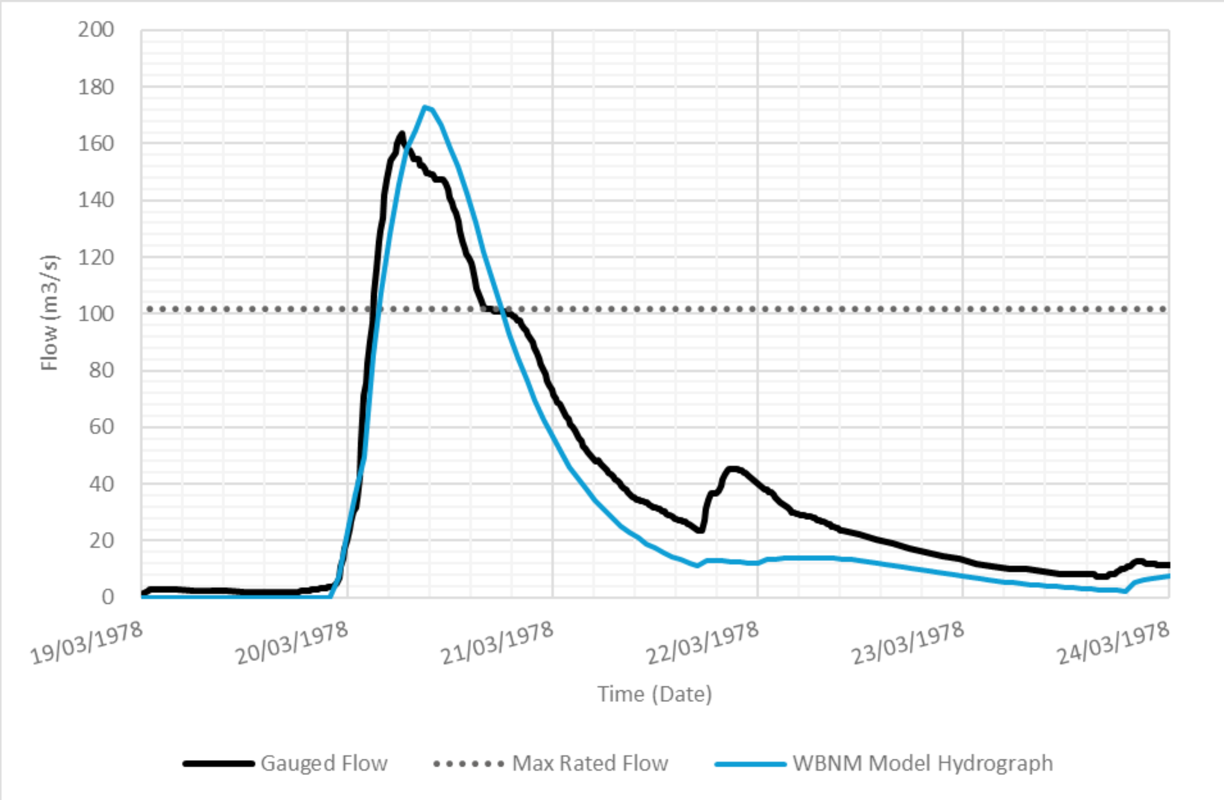

Figure 4-23 Howes Valley Gauge 1978 calibration

4.2.2.8 Calibration Outcome

The results of the above assessments indicated that the hydrological model is a reasonable representation of catchment hydrology. A summary of the peak flow differences is shown in **Table 4-10,** and a summary of the peak flow timing differences is shown in **Table 4-11.**

Table 4-10 Macdonald River catchment calibration peak flow difference summary

Catchment	Representative Gauge	1978 Peak flow difference	2020 Peak flow difference	March-2022 Peak flow difference	July-2022 Peak flow difference
Macdonald River	St Albans	-3%	-12%	-9%	28%
Macdonald River – upper	Howes Valley	6%	N/A	-34%	-34%

Table 4-11 Macdonald River catchment calibration peak flow timing difference summary

Catchment	Representative Gauge	1978	2020	March-2022	July-2022
		Peak flow timing difference (hr)	Peak flow timing difference (hr)	Peak flow timing difference (hr)	Peak flow timing difference (hr)
Macdonald River	St Albans	0	-6	-4	-2
Macdonald River – upper	Howes Valley	3	N/A	4	3

A negative value refers to an early model and a positive value refers to a late model.

4.3 Flood Frequency Analysis

4.3.1 Colo River at Upper Colo FFA

A Flood Frequency Analysis (FFA) was completed for the Colo catchment using TUFLOW FLIKE. The annual maximum water level from the Upper Colo gauge was extracted and converted to a flow value using the AWACS (1997) rating curve. The use of the AWACS (1997) curve was based on the Colo River gauge review from **Section 3.3.3**. Annual maximum flows were estimated from a period spanning 134 years from 1889 to 2022.

The annual maximum flow time series used as the inputs for the Colo FFA are shown in **Figure 4-24** including threshold values.

For years where the water level or flow values were not known or highly uncertain, a threshold value was prescribed. The reasoning behind each threshold is as follows:

- >3830 m^3/s – Evidence from Rhelm CSS (2024) suggests the 1889 flood event exceeded the largest gauged flood event (1978) which had a gauge height water level of 19.2 m and a flow of 3830 m^3/s. The catchment was ungauged at the time of the event. Given the anecdotal nature of the estimate, this was included as a lower limit threshold value.
- >2000 m^3/s – The 1904 flood event was a large flood event with a flow exceedance estimate of roughly 2000m^3/s based on Rhelm CSS (2024). The catchment was ungauged at the time of the event. As the value is an estimate, a lower limit threshold was prescribed for the 1904 flood event.
- (<)2000 – For years between 1890 and 1908 (inclusive), the Upper Colo was ungauged resulting in large uncertainties regarding flow estimates for this period. The lack of historical records for these years suggests that another large flood event akin to the 1904 flood event did not occur during this time. Hence, an upper limit threshold of 2000 m^3/s was adopted for this duration.
- (<)500 – For the years 1934 to 1941, 1947 and 1960, gauge data was not available at the Upper Colo gauge. Given the lack of historical or anecdotal records during this time, it has been assumed that a large flood event did not occur during these years. As there is an increased likelihood in the fact a large flood event did not occur, an upper limit threshold of 500 m^3/s was adopted for this period.
- (<)103 – In addition to the other thresholds, FLIKE allows for the application of the Grubbs Beck test to the time series to identify Potentially Influential Low Flows. The application of the test identified 10 years with these low flows. Following guidance from Australian Rainfall and

Runoff (Ball et al, 2019), these flows were excluded from the series and represented with this threshold.

- (<)20 – For the years 1965, 1993, 1994 and 2006, a water level value was provided by the gauge but was too low for the applicability of the AWACS rating curve. For these years, a nominal upper limit threshold of 20m^3/s was prescribed.

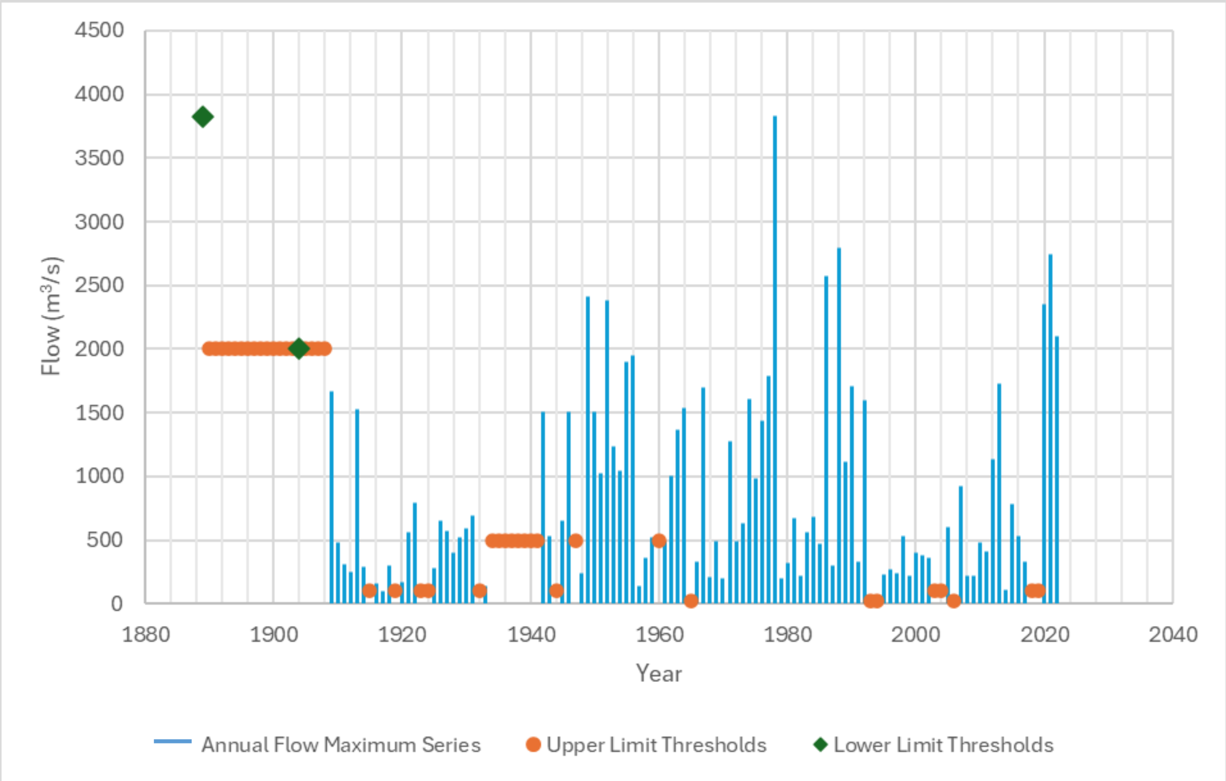

Figure 4-24 Colo River at Upper Colo Gauge annual maximum flow time series

With a Log-Pearson III probability model fit, the resultant flood frequency is shown in **Figure 4-25**. The curve expresses a close match to all the plotted points in the dataset, with all rarer record flows falling within the confidence limits. Caution should be applied with the application of the curve for events rarer than the 1 in 100 AEP.

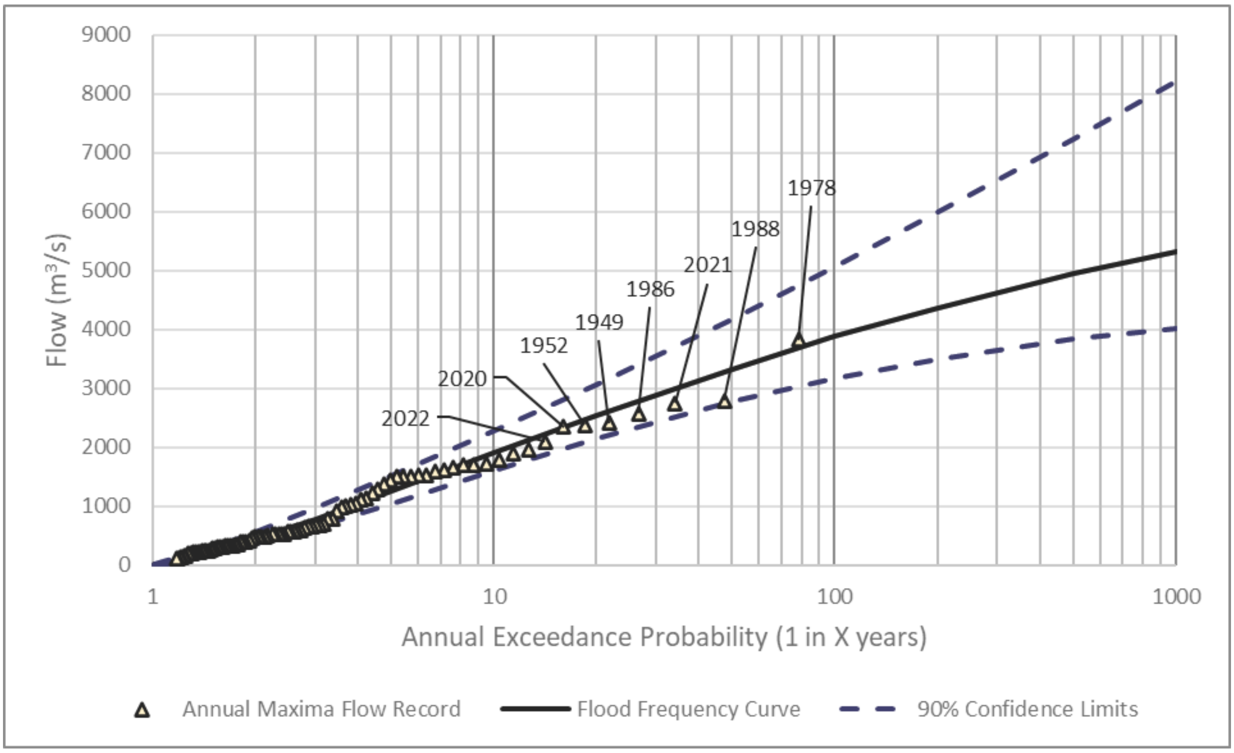

Figure 4-25 Colo River at Upper Colo flood frequency analysis

4.3.2 Macdonald River at St Albans FFA

As per the Colo catchment, the Flood Frequency Analysis (FFA) for the Macdonald River catchment used TUFLOW FLIKE. Flows were estimated for 156 years from 1867 to 2022 based on the reviewed rating curve adopted for this study (**See Section 3.3.3**).

For older events, the accuracy was treated with greater certainty than the Colo River catchment as historical records refer to specific locations near the gauge. Hence, the lower limit threshold approach for high flows used in the Colo FFA was not necessary for the Macdonald FFA.

The annual maximum flow time series and threshold values used as the inputs for the Macdonald River FFA are shown in **Figure 4-26**.

Figure 4-26 Macdonald River at St Albans Gauge annual maximum flow time series

Using a Log-Pearson III probability model fit, the flood frequency for the Macdonald River at St Albans is shown in **Figure 4-27**. The flood frequency curve is reasonable, and the plotted flow record is within the confidence limits for the events that were included in the FLIKE analysis. Given the nature of the thresholds applied, the match is an underestimate for the low flow records up to the 1 in 5-year AEP and the curve should be viewed with caution at this range. The application of the curve for events rarer than the 1 in 200 AEP should be treated with care.

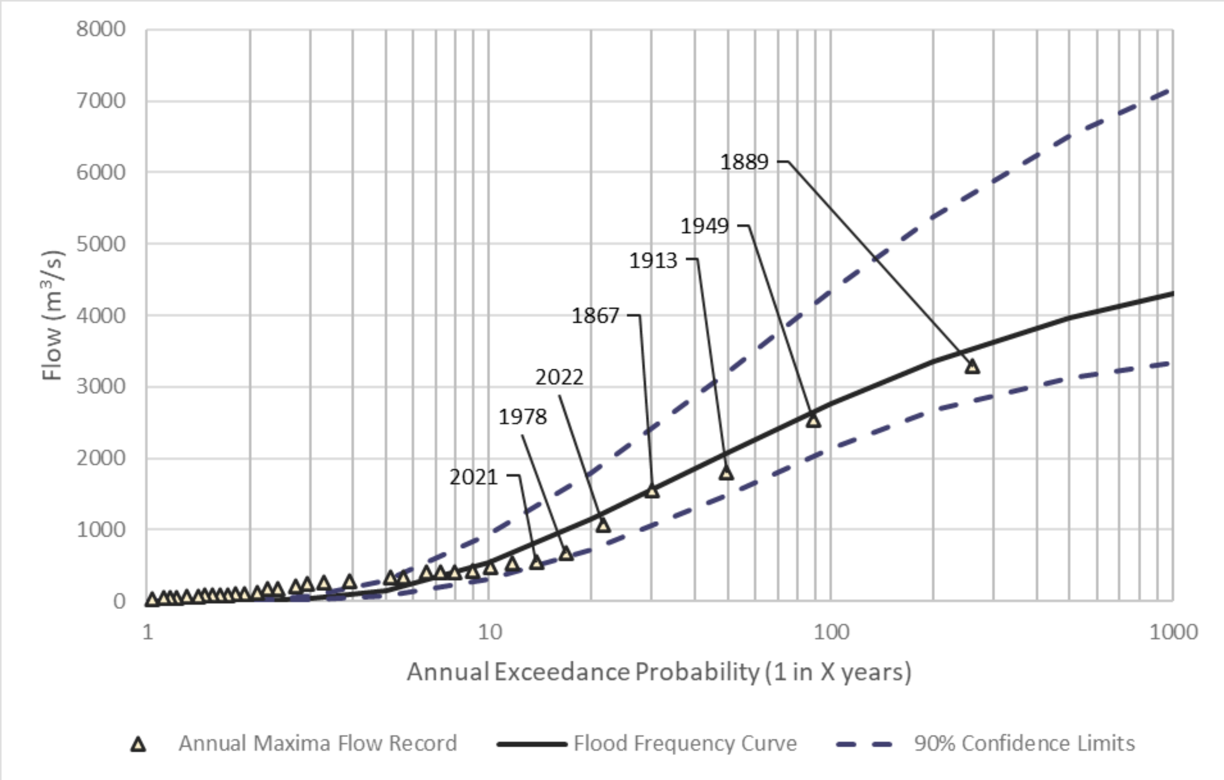

Figure 4-27 Macdonald River at St Albans flood frequency analysis

4.4 Hydrologic Design Modelling

Design hydrology for each of the four catchments was assessed using the Australian Rainfall and Runoff (Ball et al, 2019) guidelines and BOM IFD data.

To account for the spatial variation in rainfall across the catchments, 20 IFD Zones were selected across the four catchments. The IFD Zones with an example BoM IFD raster are shown in **Figure 4-28**. The zones were chosen based on the spatial variance exhibited by the BoM IFDs and were created to be evenly distributed across the four catchments. The rainfall information for each IFD Zone was applied to each subcatchment using the inverse distance weighting function of WBNM.

To ensure catchment-specific outcomes were met, the hydrology model was modified based on the information available for each catchment. In the case of the Colo and Macdonald River catchments, the completed flood frequency analyses (see **Section 4.3**) was used to inform the application of losses across design events. For the Greens and Webbs Creek catchments, the probability neutral burst losses from ARR (Ball et al, 2019) were used for the initial losses. For more information, refer to the catchment-specific sections below.

Whilst being catchment-specific, the four design hydrological models share common features as summarised in **Table 4-12**. The different features and outcomes of the design hydrological models are shown in the individual sections below.

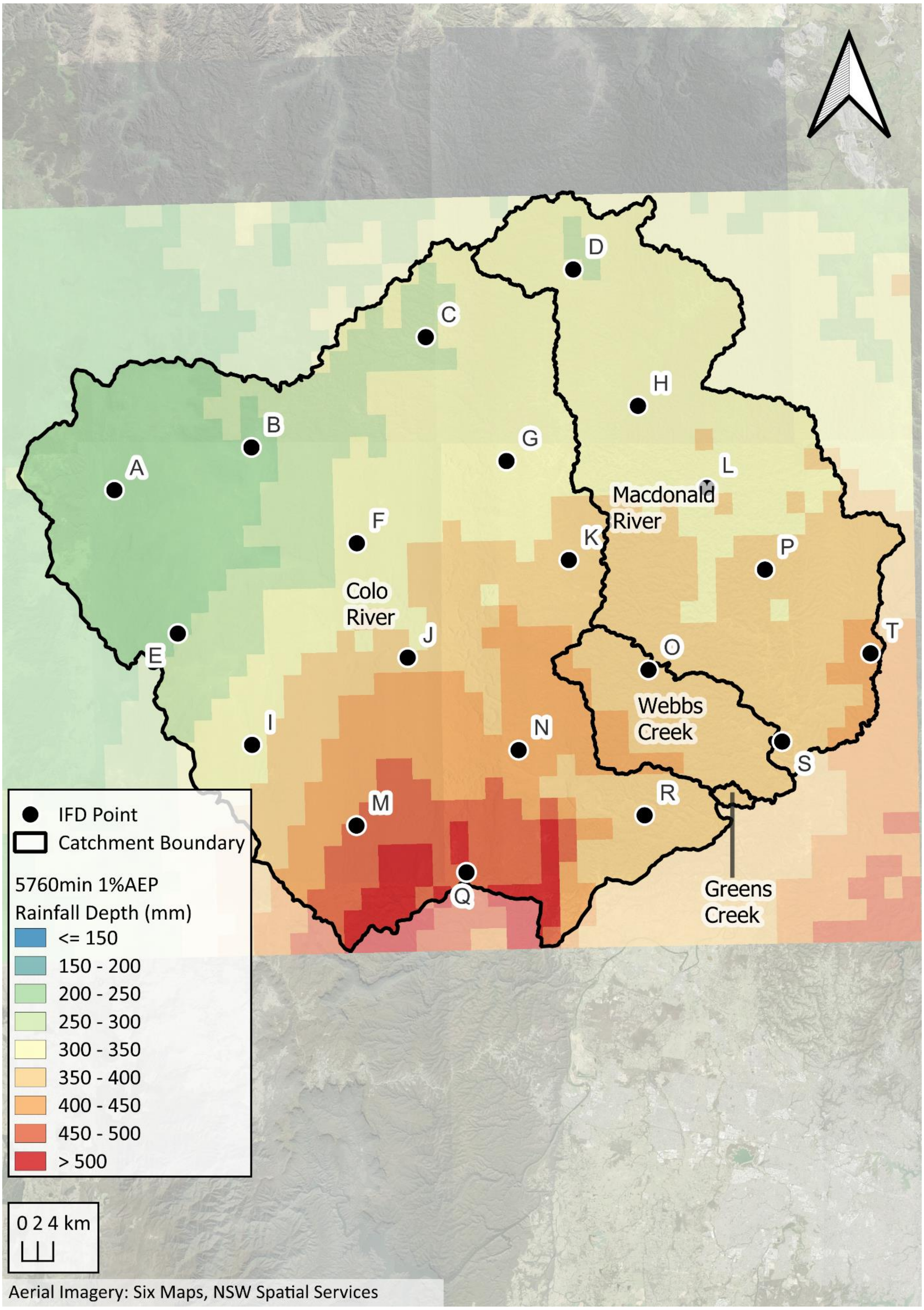

Figure 4-28 Design hydrology IFD zones with example BoM IFD event

Table 4-12 Design hydrological model input data

Parameter	Data Source
Subcatchment delineation	The subcatchments used for each model follow the same setup as shown in **Figure 4-1**. Note that the applicability of the model to a subcatchment is based on the underlying creek or river catchment. For example, the Macdonald hydrological model outputs should not be used to determine flow behaviour in a Colo River subcatchment.
Percentage impervious	The percentage impervious considerations for the design hydrology models are the same as described in **Table 4-2**.
Runoff Routing (WBNM 'C' Parameter)	A 'C' parameter of 1.55 was adopted for the Colo River catchment, and 1.9 was adopted for the Macdonald River and Webbs Creek catchments. For Greens Creek, a 'C' parameter of 1.9 was adopted. This follows the values used in the Hawkesbury-Nepean River Flood Study (2024) and the historical calibration process.
Rainfall Intensity-Frequency-Duration Information	Rainfall Intensity- Frequency- Duration (IFD) information is required in design hydrology to dictate the rainfall intensity to apply for a given AEP and storm duration. The information was sourced from BoM (2016). The IFDs were processed using the 20 points shown in **Figure 4-28**, and the WBNM inverse distance weighting function.

4.4.1 Colo River Design Modelling

The design hydrology modelling inputs that are specific to the Colo River are shown in **Table 4-13**.

Table 4-13 Colo River design hydrological model input data

Parameter	Design Model Input
Temporal Pattern	A series of ten areal temporal patterns with a reference area of 5000km^2 were assessed for the design event hydrology in the Colo River catchment. The ten temporal patterns assessed per event and duration were sourced from the ARR Data Hub (2016). The critical temporal pattern was the pattern which caused a peak flow closest to the mean peak flow (with a bias factor of 2 for patterns greater than the mean) for the Upper Colo gauge subcatchment.
Rainfall losses	Rainfall losses were formulated through an iterative process to match critical peak flows with the Colo River FFA reported in **Section 4.3.1**. Preliminary loss testing was originally undertaken in accordance using the loss hierarchy dictated by NSW Specific Data guidance from OEH (2019. The preliminary testing started with average calibration losses using a 110mm initial loss, and a 3mm/hr continuing loss. The average continuing loss (or near the average) was not used in any calibration event. A value of 3mm/hr was tested in place of the average. The design losses from the Hawkesbury-Nepean River Flood Study (2024) and the ARR Data Hub loss values (Probability Neutral Burst Loss with a 0.4 multiplication factor for the continuing loss) were also considered. The result of this preliminary testing is shown in **Figure 4-29**. From the preliminary results, the losses were found to be inadequate for a suitable match to the FFA. The losses from the Hawkesbury-Nepean River Flood Study were the closest match to the FFA and were used as a starting point for the iterative testing of various loss combinations. This process led to losses which differed by event and are shown in **Table 4-14**. It is noted that the trend of the continuing losses is increasing with AEP and is similar to the performance of proportional losses.

Parameter	Design Model Input
Areal reduction factors	Areal reduction factors were implemented using ARR2019. The factors were based on the following characteristics: • Region – SE Coast • Catchment Area – 4632km^2 • Duration – Differed based on the model run. • AEP – Differed based on the model run.
Probable Maximum Precipitation	The Generalised Southeast Australia Method (GSAM) was used to determine the Probable Maximum Precipitation (PMP) for the Colo River catchment. The GSAM parameters used to calculate the rainfall intensities were: • Moisture Adjustment Factor (Annual) – 0.91 • Moisture Adjustment Factor (Autumn) – 0.84 • Catchment-Average Topographical Adjustment Factor – 1.56 • Unfactored Rainfall Intensity – Uses rainfall intensities for catchments that are 4500km^2 or greater. The calculated rainfall intensities were used in conjunction with GSAM preburst and storm burst temporal pattern information for durations greater than and equal to 24 hours. The PMP model also differed in the following ways: • The spatial variance of rainfall was implemented by subcatchment-specific Topographical Adjustment Factors (TAF) which were added as a proportion of the catchment-average. For the variation of TAF across the catchment, see **Figure 4-30**. • The rainfall losses were: Initial Loss = 0 mm and Continuing Loss = 1mm/hr. This follows guidance from Australian Rainfall and Runoff (Ball et al, 2019). Based on this assessment, the critical duration of the PMP was determined to be 24 hours for the Colo River catchment.

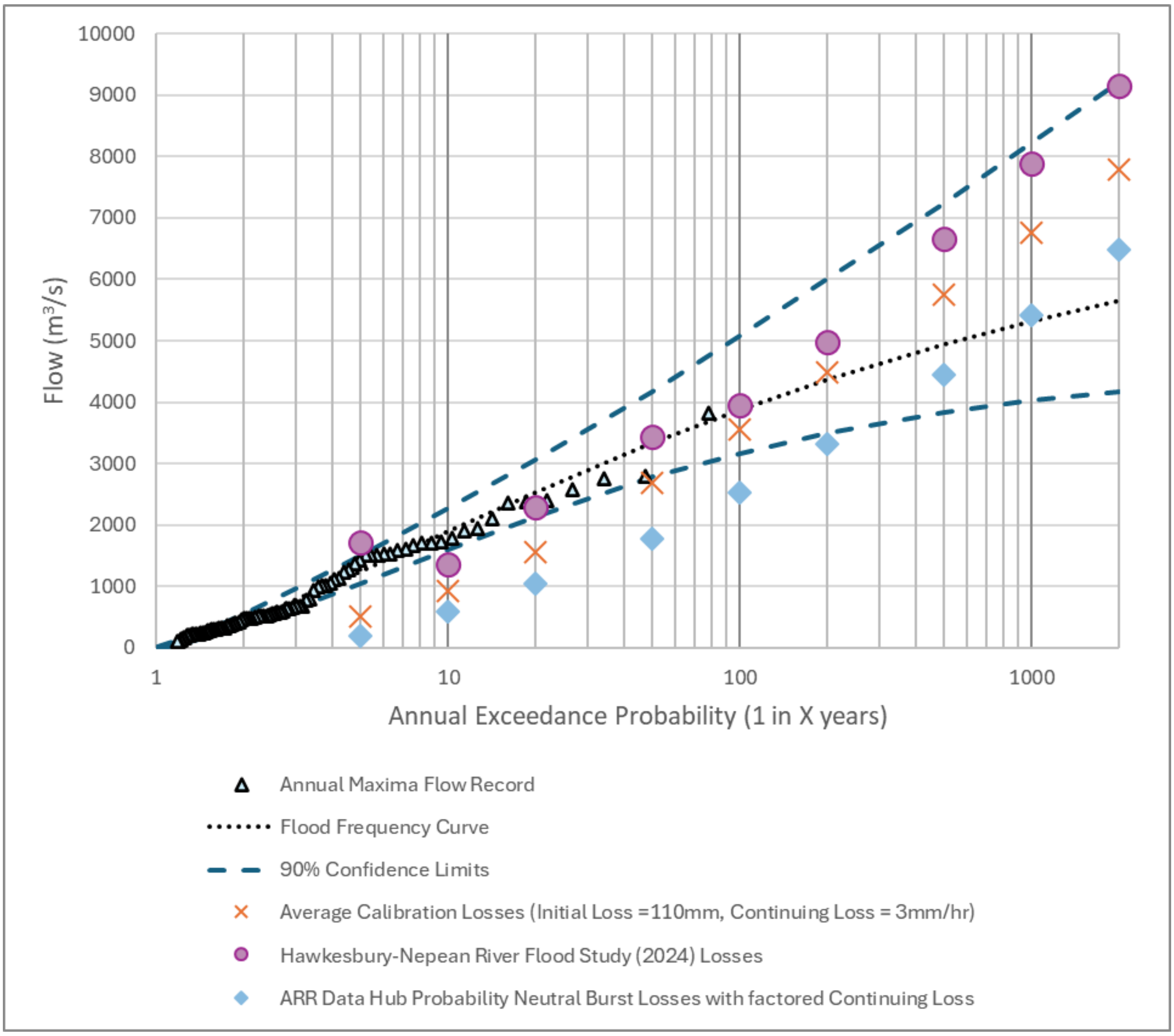

Figure 4-29 Upper Colo preliminary design model flow testing comparison with the FFA

Table 4-14 Colo River design rainfall losses

AEP	Initial Loss (mm)	Continuing Loss (mm/hr)
20% AEP	50	2.5
10% AEP	50	2.5
5% AEP	50	2.7
2% AEP	50	3
1% AEP	50	3
1 in 200	50	3
1 in 500	50	3
1 in 1000	50	3
1 in 2000	50	3
PMP	0	1

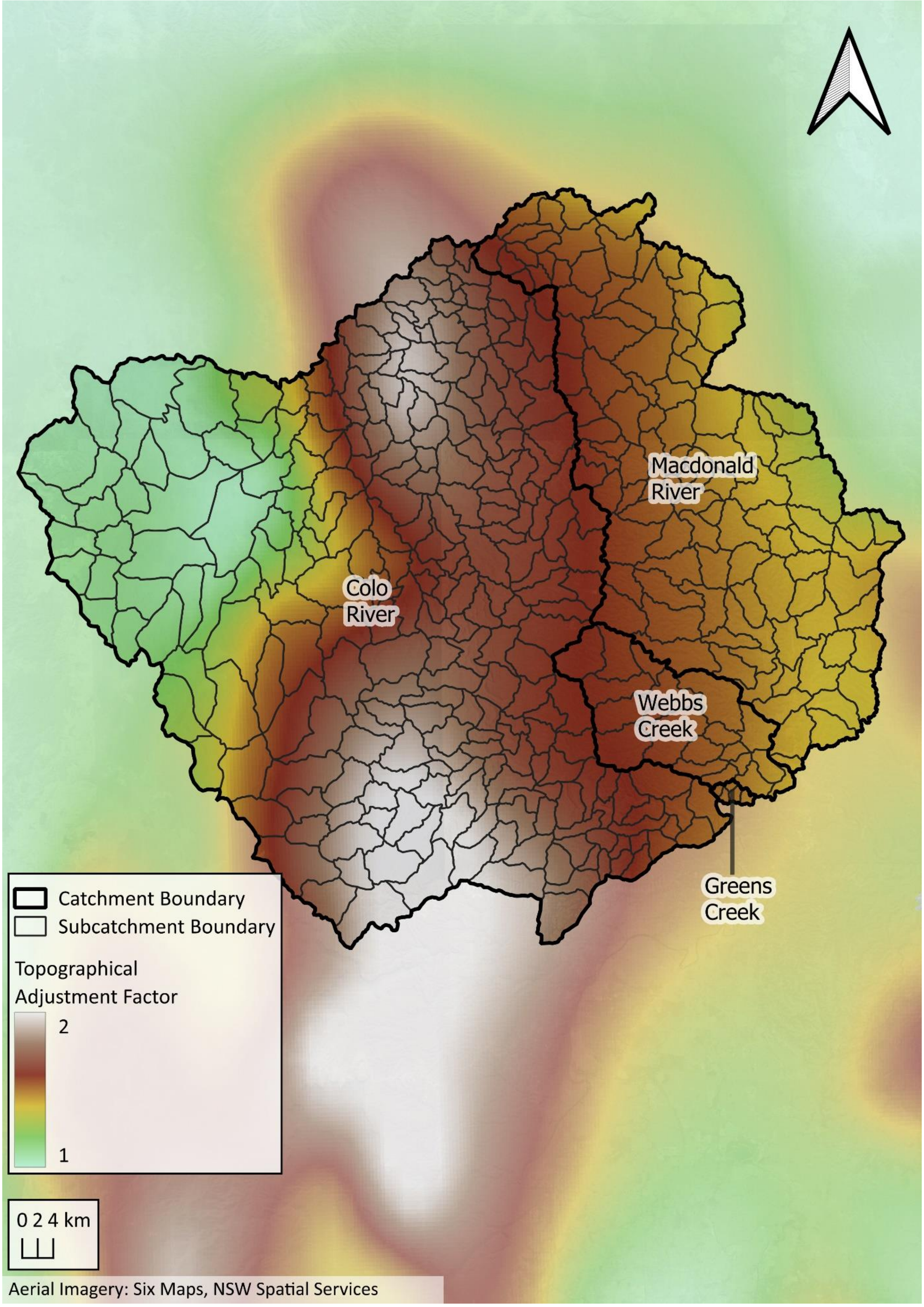

Figure 4-30 Topographical Adjustment Factor and GSAM rainfall spatial variance

Table 4-15 Colo River peak flow summary

AEP	Critical Duration at Upper Colo Gauge (hr)	Peak Flow at Upper Colo Gauge (m³/s)	Critical Duration at Outlet (hr)	Peak Flow at Outlet (m³/s)
20% AEP	96	1075	96	1120
10% AEP	96	1948	96	2073
5% AEP	96	2604	96	2770
2% AEP	96	3413	96	3641
1% AEP	96	3941	96	4157
1 in 200	96	4822	48	5292
1 in 500	48	6305	48	6753
1 in 1000	48	7846	48	8299
1 in 2000	48	9105	48	9641
PMP (GSAM)	24	43527	24	46167

A comparison of the design flows and the FFA at the upper Colo Gauge is provided in **Figure 4-31.** For the events ranging from a 1 in 5 AEP to a 1 in 200 AEP, the design events closely match the flood frequency curve. For the rarer events (1 in 500 to 1 in 2000 AEP), the design events are greater than the flood frequency curve, but within the confidence limits. It should be noted that there is a significant degree of uncertainty for design events greater than the 1 in 100 AEP at the Upper Colo gauge FFA.

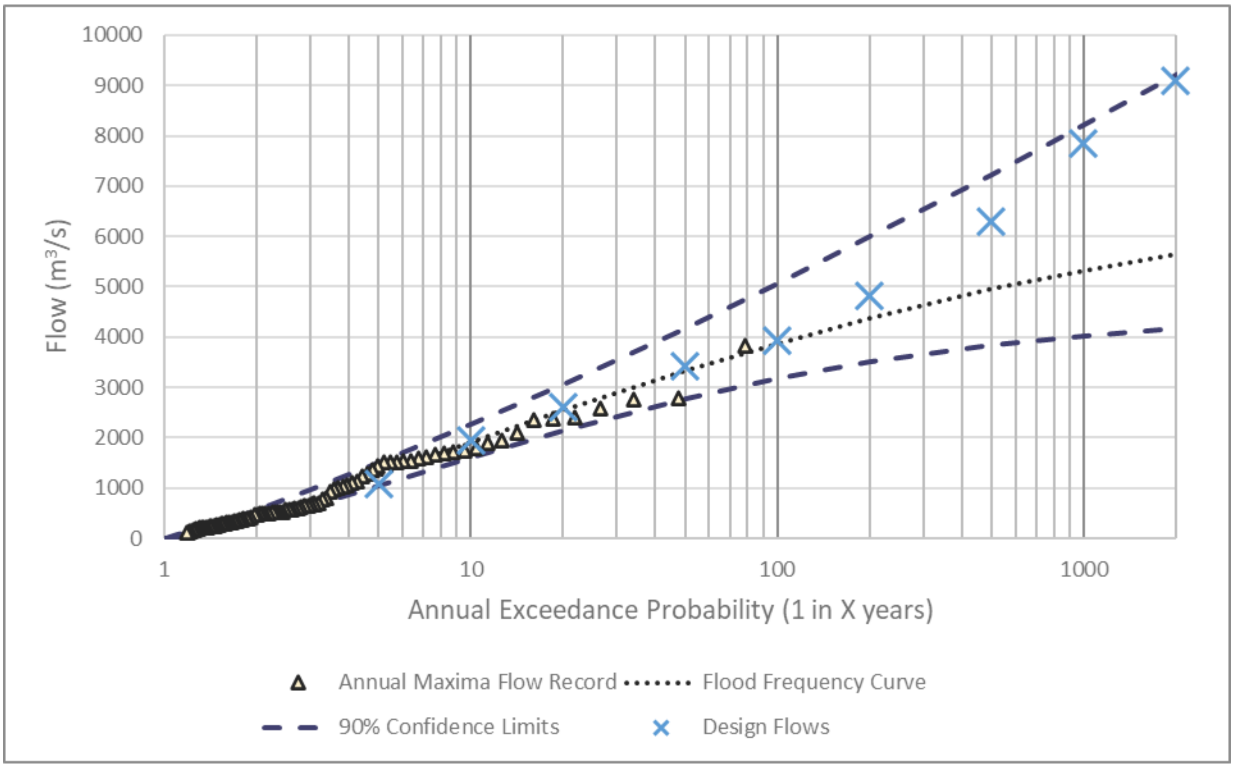

Figure 4-31 Upper Colo design model flow comparison with the FFA

4.4.2 Macdonald River Design Modelling

The design hydrology modelling inputs that are specific to the Macdonald River are shown in **Table 4-16**.

Table 4-16 Macdonald River design hydrological model input data

Parameter	Design Model Input
Temporal Pattern	Areal temporal patterns with a reference area of 2500km^2 were used for the Macdonald River catchment. Ten temporal patterns were assessed per event and duration. These were sourced from ARR Data Hub (2016). The critical temporal pattern was chosen as the pattern which caused a peak flow closest to the mean peak flow (with a bias factor of 2 for patterns greater than the mean) for the St Albans gauge subcatchment.
Rainfall losses	To match the Macdonald River FFA reported in **Section 4.3.2** with critical peak flows, an iterative process was used to determine rainfall losses. While the use of the Hawkesbury-Nepean River Flood Study (2024) losses as a starting point was envisioned akin to the Colo River testing (see **Table 4-13)**, the trend of increasing continuing losses for increased rainfall intensity was not reflected when fitting the FFA. In fact, the opposite was shown to be true after testing a single initial and continuing loss combination reflective of calibration testing (100mm initial loss with a 1.5mm/hr continuing loss). Further testing showed that both initial and continuing loss would require adapting to ensure that reasonable loss values can provide a suitable match with the FFA. Consistent with the Colo River testing, iteration was used to determine design rainfall losses. Using the calibration continuing losses (0.6-1.9mm/hr) and the Probability Neutral Burst losses (20-50mm) as a starting range, the match to the FFA was refined. A higher continuing loss than the initial range was required for frequent events. Some of the tested combinations are shown in **Figure 4-32**. The final losses differed by event and are shown in **Table 4-17**.
Areal reduction factors	Areal reduction factors were implemented based on the catchment characteristics. The factors were: • Region – SE Coast • Catchment Area – 1915km^2 • Duration – Differed based on the model run. • AEP – Differed based on the model run.

Parameter	Design Model Input
Probable Maximum Precipitation	The Generalised Southeast Australia Method (GSAM) was used to determine the Probable Maximum Precipitation (PMP) for the Macdonald River catchment. The GSAM parameters used to calculate the rainfall intensities were: • Moisture Adjustment Factor (Annual) – 0.92 • Moisture Adjustment Factor (Autumn) – 0.85 • Catchment-Average Topographical Adjustment Factor – 1.48 • Unfactored Rainfall Intensity – Linearly interpolated between rainfall intensities for catchments that are 1500km^2 and 2000km^2. The calculated rainfall intensities were used in conjunction with GSAM preburst and storm burst temporal pattern information for durations greater than and equal to 24 hours. The PMP model also differed in the following ways: • The spatial variance of rainfall was implemented by subcatchment-specific Topographical Adjustment Factors (TAF) which were added as a proportion of the catchment-average. The variation of the TAF across the catchment is shown in **Figure 4-30**. • The rainfall losses were: Initial Loss = 0 mm and Continuing Loss = 1mm/hr. This follows guidance from Australian Rainfall and Runoff (Ba;; et al, 2019). Based on this assessment, the critical duration of the PMP was determined to be 24 hours for the Macdonald River catchment.

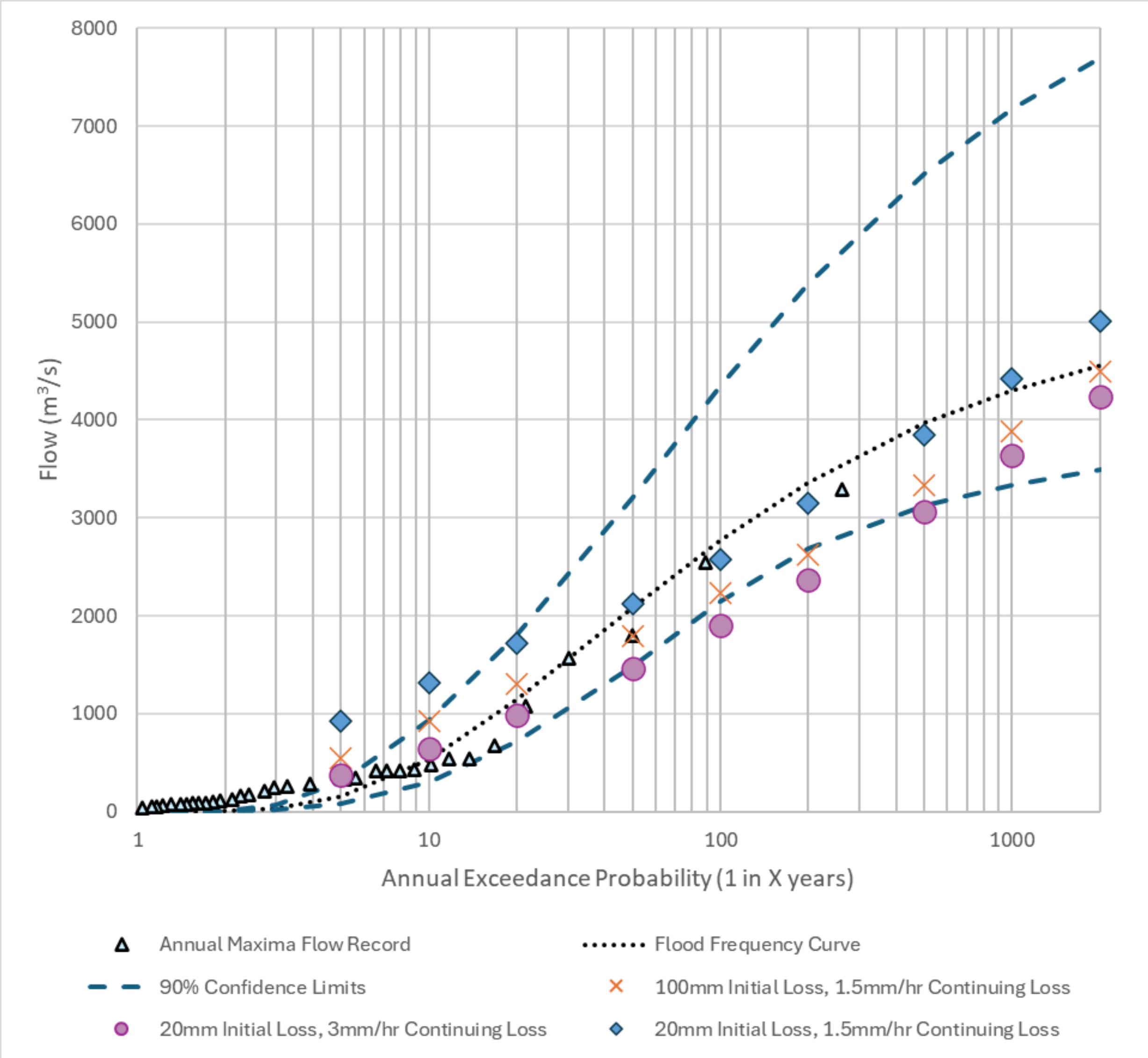

Figure 4-32 St Albans preliminary design model flow testing comparison with the FFA

Table 4-17 Macdonald River design rainfall losses

AEP	Initial Loss (mm)	Continuing Loss (mm/hr)
20% AEP	50	3
10% AEP	50	3
5% AEP	50	2.5
2% AEP	20	1.5
1% AEP	20	1.5
1 in 200	20	1.5
1 in 500	20	1.5
1 in 1000	20	1.5
1 in 2000	20	1.5
PMP	0	1

Table 4-18 Macdonald River peak flow summary

AEP	Critical Duration at St Albans Gauge (hr)	Peak Flow at St Albans Gauge (m^3/s)	Critical Duration at Outlet (hr)	Peak Flow at Outlet (m^3/s)
20% AEP	96	336	96	366
10% AEP	96	474	96	512
5% AEP	96	1044	96	1106
2% AEP	48	2105	48	2279
1% AEP	24	2555	48	2770
1 in 200	48	3134	48	3409
1 in 500	36	3828	48	4199
1 in 1000	36	4397	36	4812
1 in 2000	36	4992	36	5469
PMP (GSAM)	24	18280	24	19661

A comparison of the design flows and the FFA at the At Albans Gauge is provided in **Figure 4-33.** The design events generally match closely to the flood frequency curve. The 1 in 5 AEP design flows are slightly overestimated when compared to the frequency curve, however the estimate is within the confidence limits.

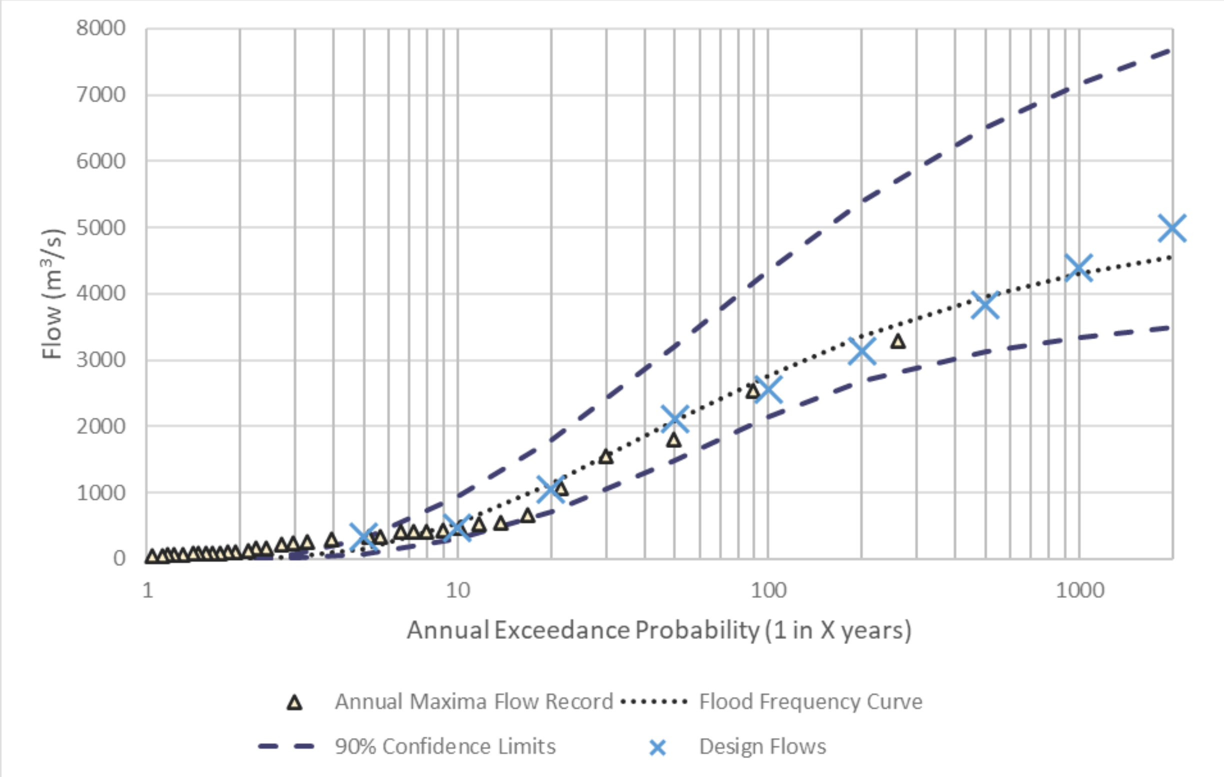

Figure 4-33 St Albans design model flow comparison with the FFA

4.4.3 Greens Creek Design Modelling

The design hydrology modelling inputs that are specific to the Greens Creek are shown in **Table 4-19**.

Table 4-19 Greens Creek design hydrological model input data

Parameter	Design Model Input
Temporal Pattern	The Greens Creek catchment size of 11 km^2 resulted in a series of point temporal patterns being used. A suite of ten temporal patterns were assessed per event and duration. These were sourced from ARR Data Hub. The critical temporal pattern was the one which caused a peak flow closest to the mean peak flow (with a bias factor of 2 for patterns greater than the mean) for the downstream end of the Greens Creek catchment.
Rainfall losses	The initial losses for the Greens Creek catchment used probability neutral burst losses from the ARR Data Hub. For the continuing loss, values were adopted in line with the Macdonald River catchment. See **Table 4-20** for these values.
Areal reduction factors	Areal reduction factors were implemented based on the current factors: • Region – SE Coast • Catchment Area – 11km^2 • Duration – Differed based on the model run. • AEP – Differed based on the model run

Parameter	Design Model Input
Probable Maximum Precipitation	The Generalised Short-Duration Method (GSDM) was used to determine the Probable Maximum Precipitation (PMP) for the Greens Creek catchment. The GSDM parameters used to calculate the rainfall intensities were: • Elevation Adjustment Factor – 1.0 • Moisture Adjustment Factor – 0.70 • Catchment Roughness – 100% Rough, 0% Smooth • Unfactored Rainfall Intensity – Determined using Depth-Duration-Area curves in the GSDM guidance or a table of values if a PMP ellipse was fully encompassed by the Greens Creek catchment. Rainfall intensities were calculated for each GSDM ellipse that affects the Greens Creek catchment. The placement of the GSDM ellipses over the Greens Creek catchment is shown in **Figure 4-34**. The calculated rainfall intensities were used in conjunction with GSDM storm burst temporal pattern information for a range of durations from 15 minutes to 6 hours. The PMP model also differed in the following ways: • The spatial variance of rainfall was implemented by ascribing subcatchments to a relevant GSDM ellipse using the location of the subcatchment centroid. • The rainfall losses were: Initial Loss = 0 mm and Continuing Loss = 1mm/hr. This follows guidance from Australian Rainfall and Runoff (2019). Based on this assessment, the critical duration of the PMP was determined to be 3 hours for the Greens Creek catchment.

Table 4-20 Greens Creek design rainfall losses

AEP	Initial Loss (mm)	Continuing Loss (mm/hr)
20% AEP	Probability Neutral Burst Loss	3
10% AEP	Probability Neutral Burst Loss	3
5% AEP	Probability Neutral Burst Loss	2.5
2% AEP	Probability Neutral Burst Loss	1.5
1% AEP	Probability Neutral Burst Loss	1.5
1 in 200	Probability Neutral Burst Loss	1.5
1 in 500	Probability Neutral Burst Loss	1.5
1 in 1000	Probability Neutral Burst Loss	1.5
1 in 2000	Probability Neutral Burst Loss	1.5
PMP	0	1

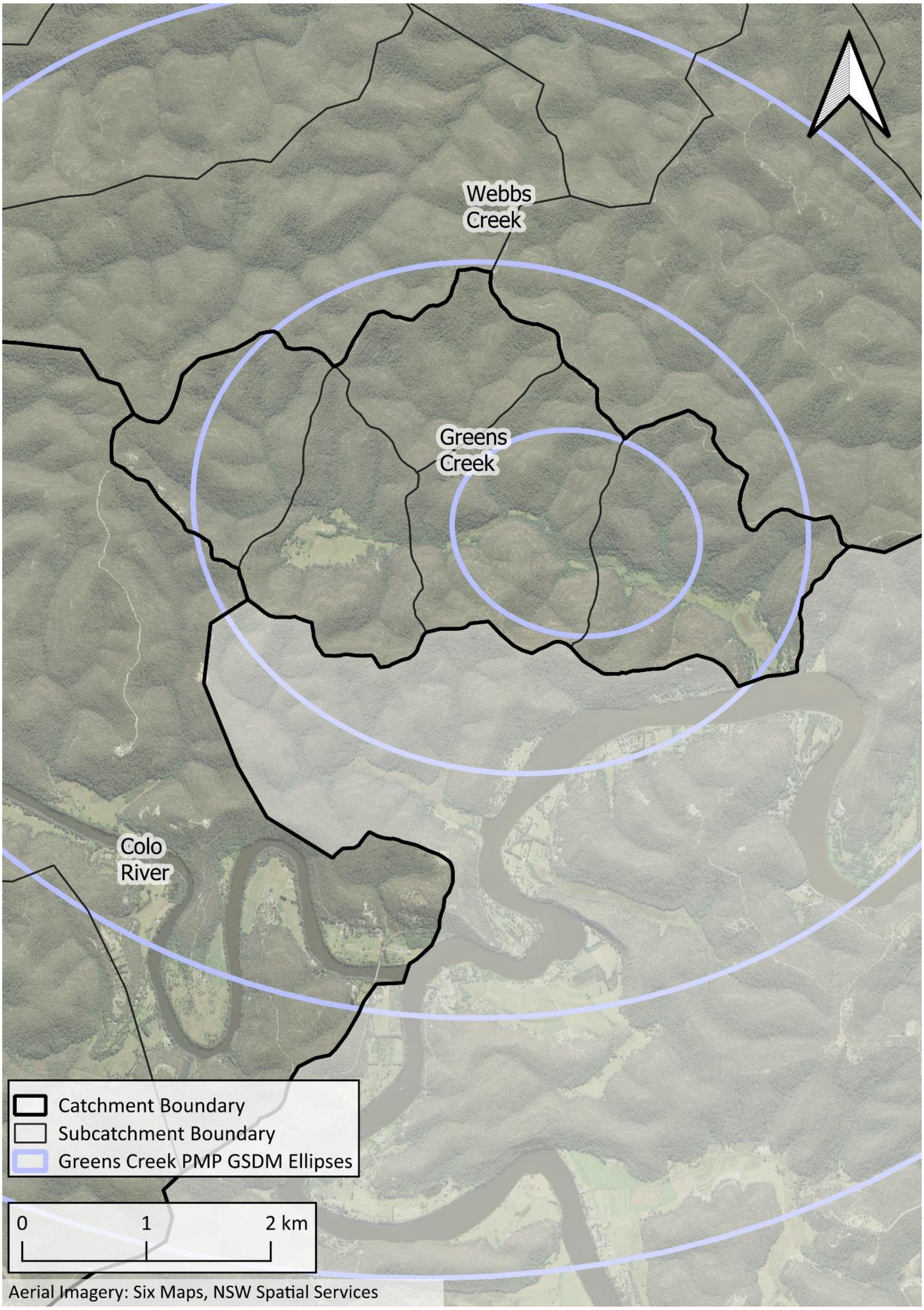

Figure 4-34 Greens Creek PMF GSDM ellipses

Table 4-21 Greens Creek peak flow summary

AEP	Critical Duration (hr)	Peak Flow at Outlet (m^3/s)
20% AEP	9	13
10% AEP	9	20
5% AEP	6	27
2% AEP	12	41
1% AEP	12	49
1 in 200	12	54
1 in 500	12	63
1 in 1000	12	69
1 in 2000	12	76
PMP (GSDM)	3	556

4.4.4 Webbs Creek Design Modelling (exc. PMP)

The design hydrology modelling inputs that are specific to the Webbs Creek are shown in **Table 4-22**.

Table 4-22 Webbs Creek design hydrological model input data

Parameter	Design Model Input
Temporal Pattern	Areal temporal patterns with a reference area of 500km^2 were used for the Webbs Creek catchment. Ten temporal patterns were assessed per event and duration. These were sourced from ARR Data Hub. From the ten temporal patterns, the critical pattern based on which pattern caused a peak flow closest to the mean peak flow (with a bias factor of 2 for patterns greater than the mean) for the downstream end of the Webbs Creek catchment.
Rainfall losses	The initial losses for the Webbs Creek catchment used probability neutral burst losses from the ARR Data Hub. For the continuing loss, values were adopted in line with the Macdonald River catchment. See **Table 4-23** for these values.
Areal reduction factors	Areal reduction factors were implemented based on the following characteristics: • Region – SE Coast • Catchment Area – 360km^2 • Duration – Differed based on the model run. • AEP – Differed based on the model run.
Probable Maximum Precipitation	The Webbs Creek catchment was different to the other catchments as the GSAM and GSDM approaches were both assessed given the intermediate catchment size. Further details regarding the Webbs Creek PMP estimate are provided below.

Table 4-23 Webbs Creek design rainfall losses

AEP	Initial Loss (mm)	Continuing Loss (mm/hr)
20% AEP	Probability Neutral Burst Loss	3
10% AEP	Probability Neutral Burst Loss	3
5% AEP	Probability Neutral Burst Loss	2.5
2% AEP	Probability Neutral Burst Loss	1.5
1% AEP	Probability Neutral Burst Loss	1.5

AEP	Initial Loss (mm)	Continuing Loss (mm/hr)
1 in 200	Probability Neutral Burst Loss	1.5
1 in 500	Probability Neutral Burst Loss	1.5
1 in 1000	Probability Neutral Burst Loss	1.5
1 in 2000	Probability Neutral Burst Loss	1.5
PMP	0	1

Table 4-24 Webbs Creek peak flow summary

AEP	Critical Duration (hr)	Peak Flow at Outlet (m^3/s)
20% AEP	24	147
10% AEP	24	254
5% AEP	24	403
2% AEP	24	660
1% AEP	24	809
1 in 200	24	908
1 in 500	24	1085
1 in 1000	24	1224
1 in 2000	24	1368
PMP (GSAM and GSDM)	12	7399

Webbs Creek PMP Design Modelling

The Webbs Creek PMP Model involved both the GSAM and GSDM approaches for PMP estimation. The process used is detailed below.

<u>**GSAM**</u>

GSAM was used for durations greater than or equal to 24 hours, while GSDM was used for durations less than or equal to 6 hours.

The GSAM parameters used to calculate rainfall intensities were:

- Moisture Adjustment Factor (Annual) – 0.91
- Moisture Adjustment Factor (Autumn) – 0.85
- Catchment-Average Topographical Adjustment Factor – 1.55
- Unfactored Rainfall Intensity – Uses rainfall intensities for catchments that are 350km^2.

The calculated rainfall intensities were used in conjunction with GSAM preburst and storm burst temporal pattern information for durations from 24 hours to 96 hours.

The GSAM PMP estimate also considered:

- The spatial variance of rainfall through subcatchment-specific Topographical Adjustment Factors (TAF) which were added as a proportion of the catchment-average. The variation of the TAF across the catchment is shown in **Figure 4-30**.

- The rainfall losses were: Initial Loss = 0 mm and Continuing Loss = 1mm/hr. This follows guidance from Australian Rainfall and Runoff (Ball et al, 2019).

GSDM

The GSDM parameters used to calculate the rainfall intensities were:

- Elevation Adjustment Factor – 1.0
- Moisture Adjustment Factor – 0.70
- Catchment Roughness – 100% Rough, 0% Smooth
- Unfactored Rainfall Intensity – Determined using Depth-Duration-Area curves in the GSDM guidance or a table of values if a PMP ellipse was fully encompassed by the Webbs Creek catchment.

Rainfall intensities were calculated for each GSDM ellipse that affects the Webbs Creek catchment. The placement of the GSDM ellipses over the Webbs Creek catchment is shown in **Figure 4-35**.

The calculated rainfall intensities were used in conjunction with GSDM storm burst temporal pattern information for a range of durations from 15 minutes to 6 hours.

The rainfall losses were: Initial Loss = 0 mm and Continuing Loss = 1mm/hr. This follows guidance from Australian Rainfall and Runoff (Ball et al, 2019).

12-hour duration

It is important to note that 12-hour duration storms are not explicitly covered by either GSAM or GSDM approaches, though guidance is provided.

For Webbs Creek, the 12-hour rainfall intensity was interpolated between the 24-hour GSAM and 6 hour GSDM intensities as per the guidance from BoM (2006). The spatial variation of the 12-hour event followed the GSAM approach with the factoring of the TAF for each subcatchment.

Result

With the approach outlined above, the 12-hour PMP storm was found to be the critical duration.

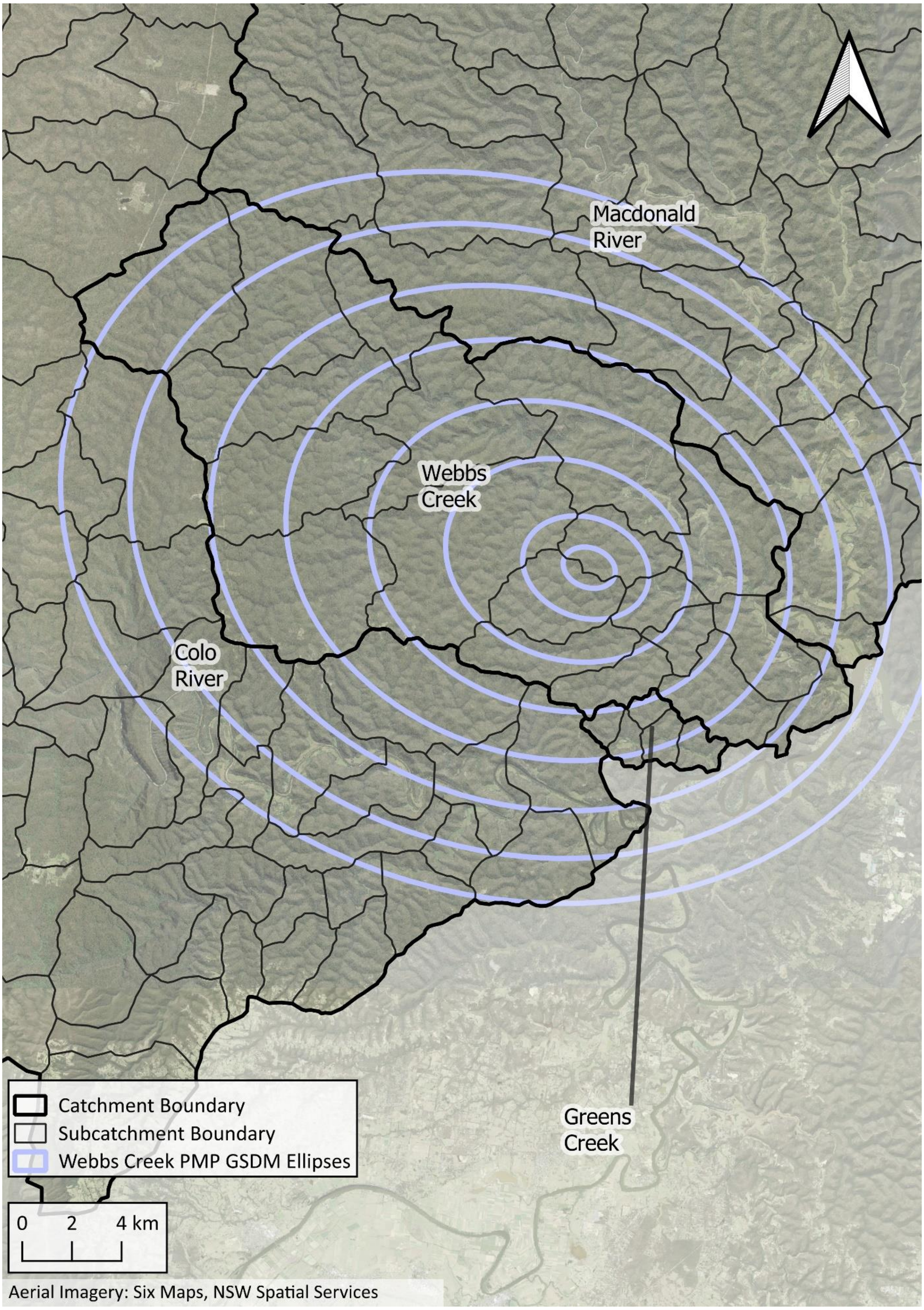

Figure 4-35 Webbs Creek PMF GSDM ellipses

4.5 Other Considerations

A review of the historic flood events used for the calibration, together with those reported in Rhelm CSS (2024), shows that rainfall is generally more intense on the eastern half of the Colo catchment, compared with the western half and in particular, the Capertee catchment. As noted in the calibration discussion (**Section 4.2.1**), often the flows in the Capertee catchment represented less than 5% of the flows at the Upper Colo gauge.

The areal reduction factors are intended to account for some of this effect, whereby in larger catchments it is unlikely to get the same intensity rainfall across the entirely of the catchment. However, in this case, there is likely a bias toward the eastern part of the catchment for events that cause larger flows at Upper Colo.

An indicative correlation analysis was undertaken for recorded events for Capertee River at Glen Davis versus the Colo River at Upper Colo, as shown in **Figure 4-36**. While the flood frequency is indicative for Glen Davis, it shows that there is relatively low correlation between large events in the Colo River versus large events in Glen Davis. This supports the historic calibration observations, showing low flow contributions in some events from Glen Davis.

On this basis, the traditional areal reduction factors may not be as capable of representing an appropriate design rainfall. A more complex Monte Carlo analysis (beyond the scope of this study) that considered various spatial patterns of rainfall may provide additional nuance.

For this study, the increasing continuing losses that have been adopted may be a result of this uneven distribution of rainfall.

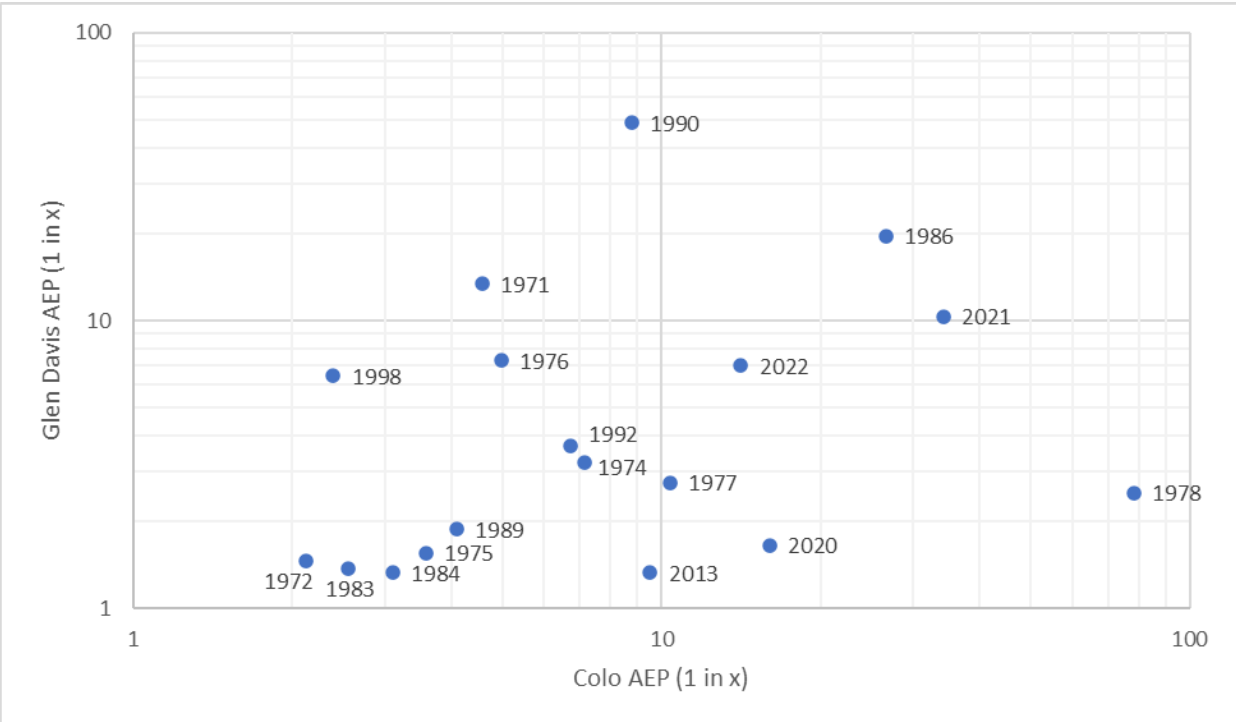

Figure 4-36 Indicative Correlation between Glen Davis and Upper Colo Gauge

5 Hydraulic Model

This section details the 2D hydraulic model build, calibration and design event modelling,

5.1 Model Setup

5.1.1 Model Extent

Each of the four watercourses (Colo River, Greens Creek, Webbs Creek and Macdonald River) were represented by an individual TUFLOW model. The extent of each model in relation to each other is shown in **Figure 5-1.** A more detailed view of each TUFLOW model layout is also provided in:

- Colo River: **Figure 5-2**
- Greens Creek: **Figure 5-3**
- Webbs Creek: **Figure 5-4**
- Macdonald River: **Figure 5-5**

As the focus of the study involves the more populated areas of each catchment, the TUFLOW model extents are focussed on the downstream end of each catchment. The exception is Greens Creek, where the TUFLOW model extent covers almost the entire catchment.

As shown in **Figure 5-2** to **Figure 5-5**, the downstream boundary of each model is placed at the Hawkesbury River junction. Although emphasis is placed on investigating mainstream flood behaviour for the main waterways within each catchment, inclusion of the model boundary at this location allows the impact of coincidental Hawkesbury River flooding to be considered.

Preliminary simulations were completed to confirm that the extent of each model was sufficient to cater for backwater storage along the various tributary catchment draining into each main watercourse.

5.1.2 Grid size and Topography

The TUFLOW software uses a grid to define the spatial variation in topography and hydraulic properties (e.g., ground elevations and hydraulic roughness) across the model area. As a result, the choice of grid size can have a significant impact on the performance of the model. In general, a smaller grid size will provide a more detailed and reliable representation of flood behaviour relative to a larger grid size. However, a smaller grid size will take longer to perform all the necessary hydraulic calculations. Therefore, it is typically necessary to select a grid size that makes an appropriate compromise between the level of detail provided by the model and the associated computational time required. A grid size of 10 metres was ultimately adopted for each model area and was considered to provide a reasonable compromise between detail and simulation time.

In addition, a TUFLOW feature called sub-grid sampling (SGS) was employed as part of the model setup. When SGS is employed, TUFLOW will calculate water level versus storage volume relationships based on a more detailed underlying terrain representation rather than relying on a single elevation at the centre of the grid cell. Similarly, TUFLOW will calculate water level versus discharge relationships across each cell side based on the more detailed terrain rather than relying on the elevation at the midpoint of each cell to control when water moves from one cell to the next. This feature allows storage and conveyance to be represented in more detail than would have otherwise been allowed. The 1 metre DEM derived from the LiDAR described in **Section 3.2.1** was used for this purpose.

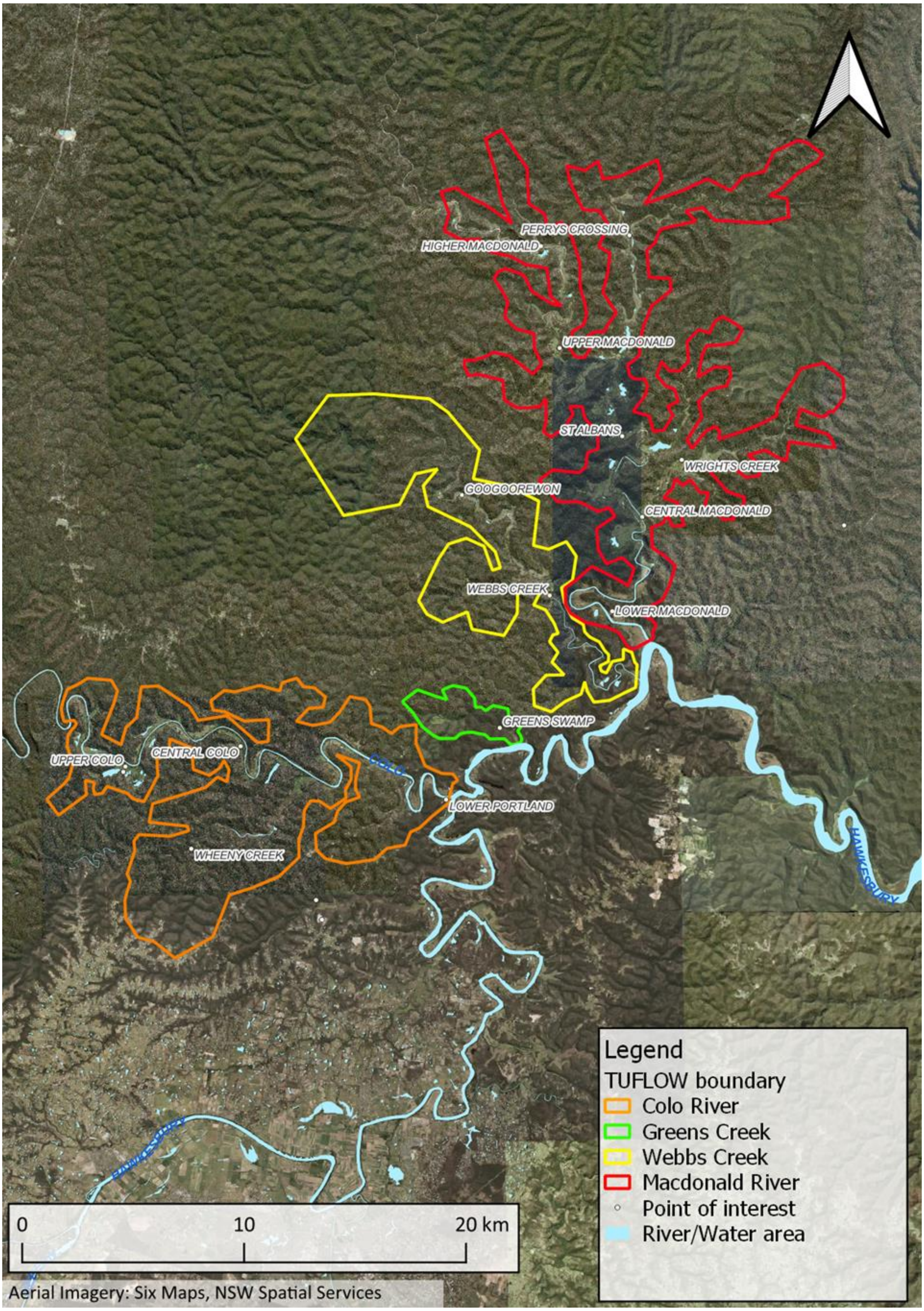

Figure 5-1 TUFLOW model extent overview

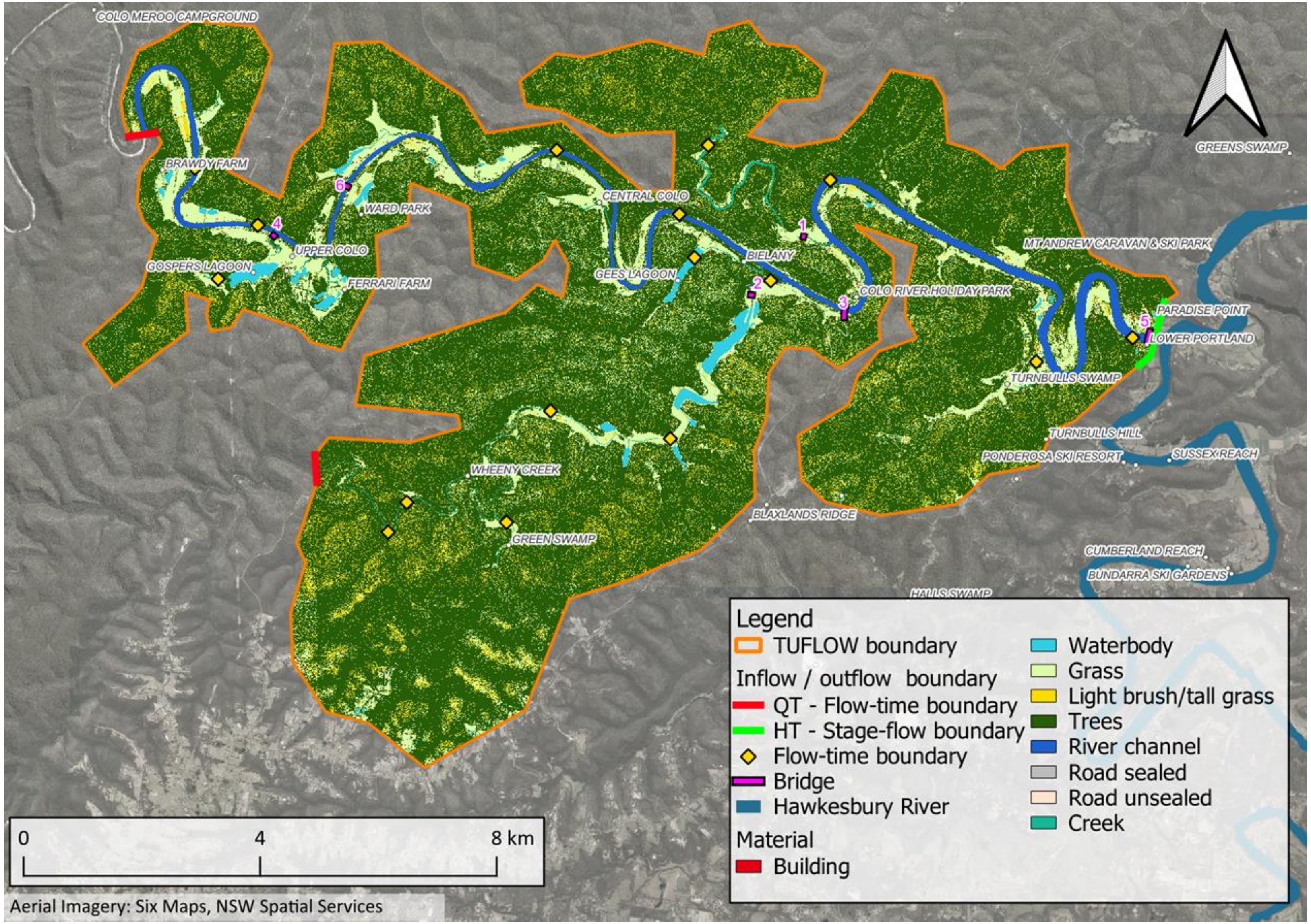

Figure 5-2 Colo River TUFLOW model layout

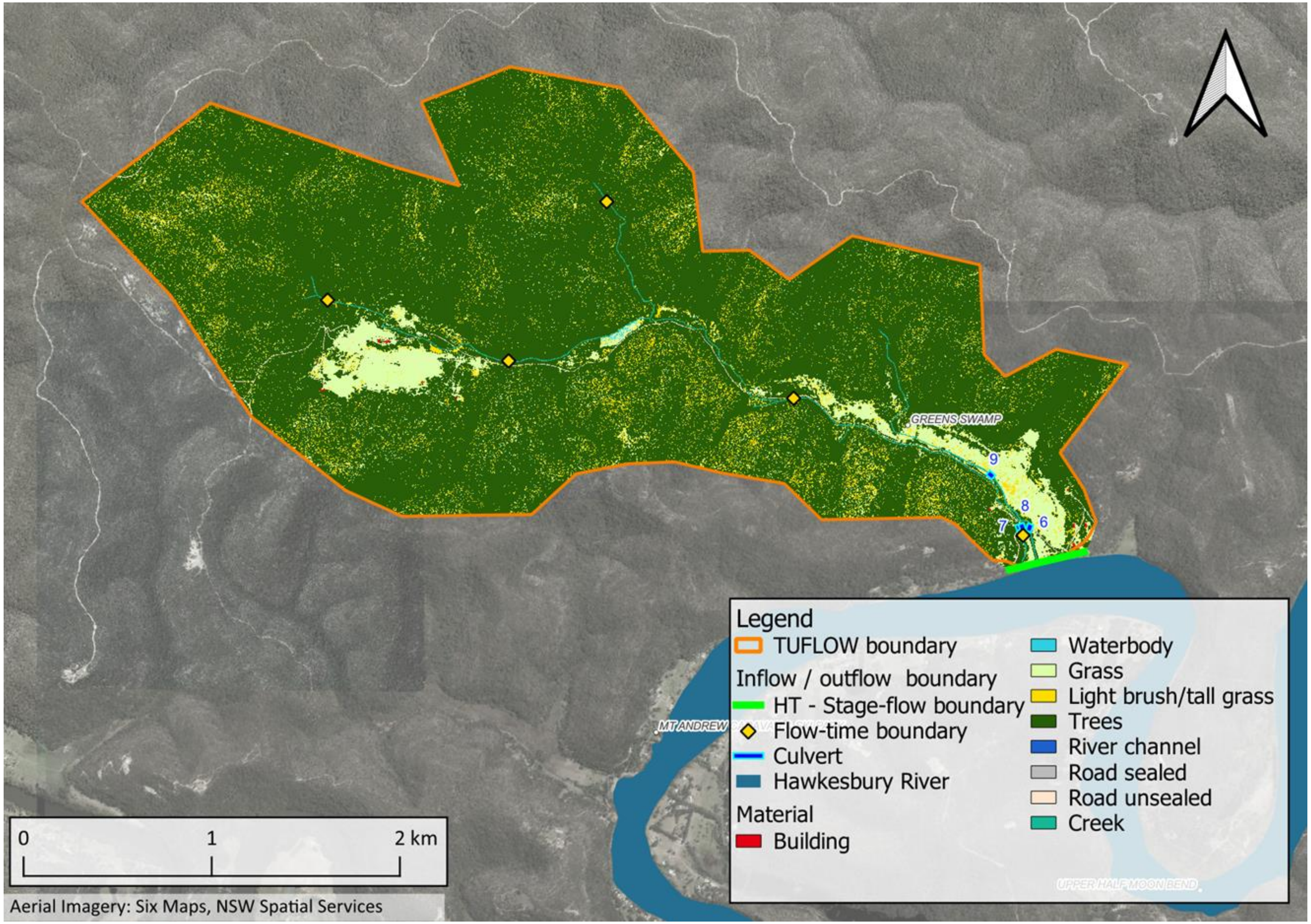

Figure 5-3 Greens Creek TUFLOW model layout

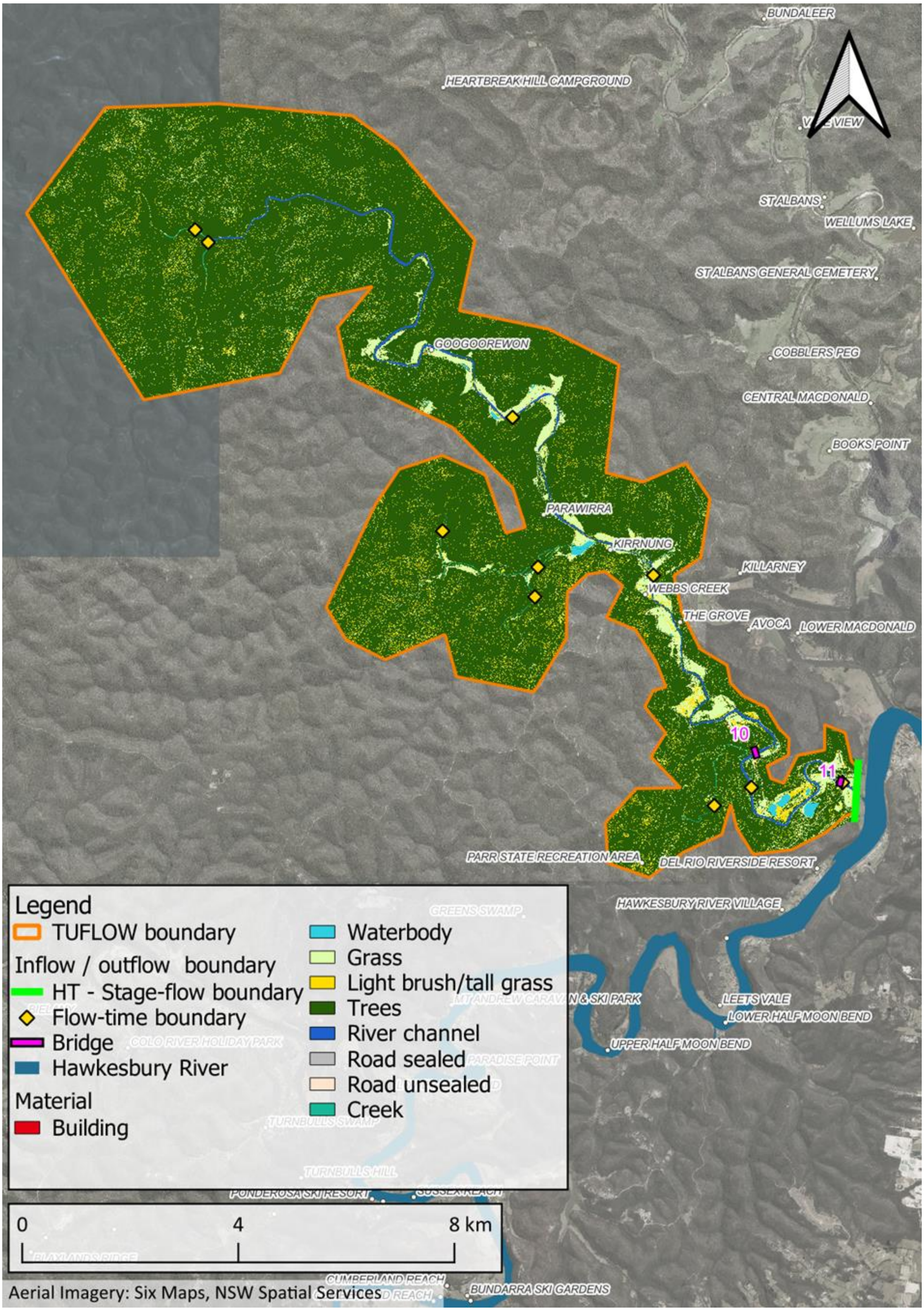

Figure 5-4 Webbs Creek TUFLOW model layout

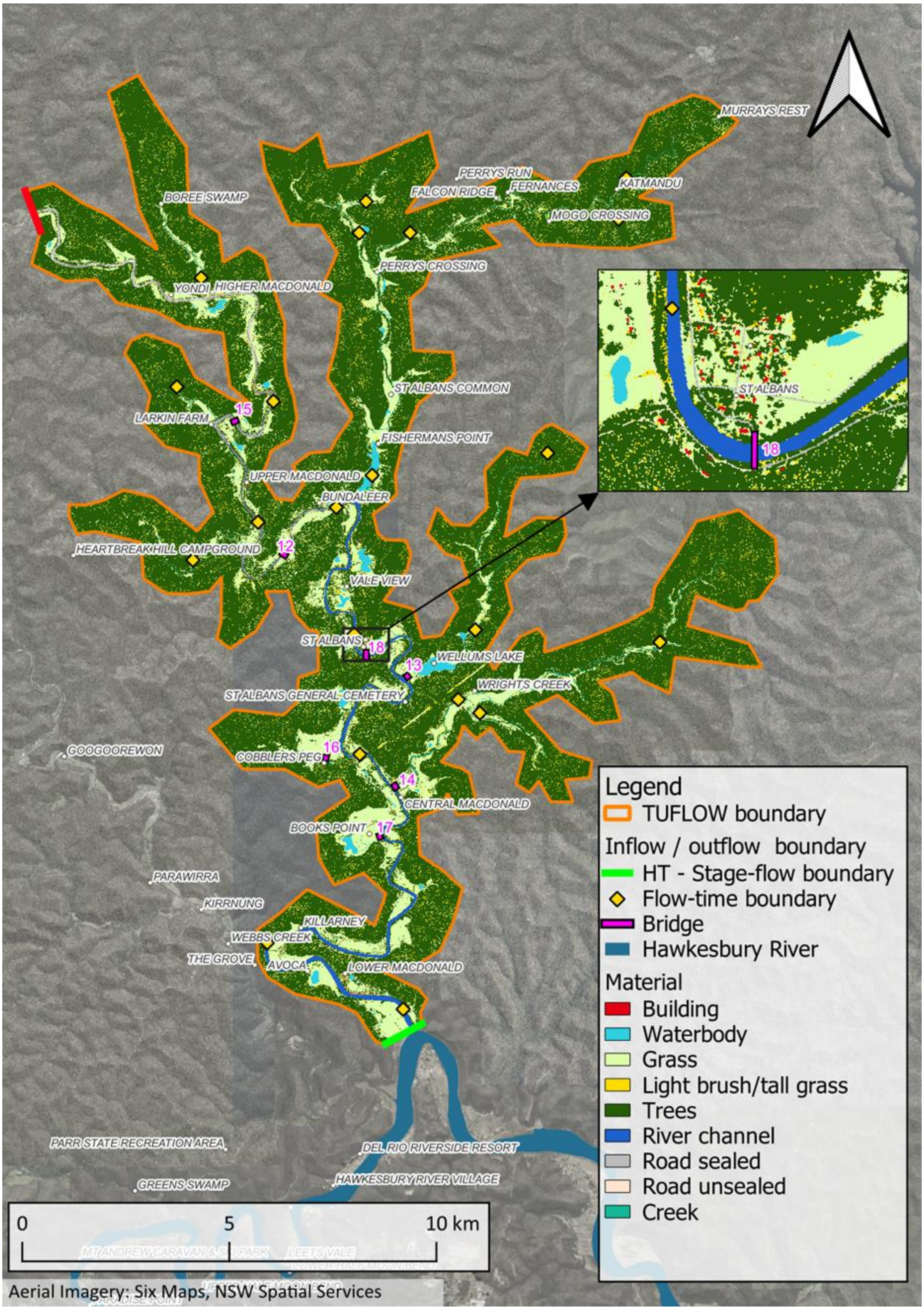

Figure 5-5 Macdonald River TUFLOW model layout

The topography below the water surface is generally not well captured by the LiDAR. Therefore, the LiDAR was supplemented with bathymetric survey information to ensure the conveyance of each watercourse was reliable represented.

5.1.3 Roughness Coefficients

The TUFLOW software uses land use information to define the hydraulic roughness assigned to each grid cell in the model. For this study, land use information derived from LiDAR was used to identify different land uses across the TUFLOW model area. This technique of land use classification was based on research titled 'Using LiDAR Survey for Land Use Classification' (Ryan, 2013). The classification algorithm divided the model areas into the following land use classifications:

- Buildings
- Water
- Trees
- Light brush/tall grass
- Grass
- Roads

Additional data sources were used to supplement remote sensing land use classifications such as the NSW Digital Cadastral Database Clip and Ship (NSW Spatial services, 2023) and building footprints produced by Bing Maps (Microsoft, 2023). The land use map for each catchment is shown in **Figure 5-2** through **Figure 5-5**.

The roughness coefficient values were initially populated from values documented in 'Australian Rainfall & Runoff' (Ball et al, 2019) and were then refined as part of the model calibration process. Further details of the TUFLOW model calibration are provided in **Section 5.3.4**. The final roughness coefficients are listed in **Table 5-1** and

Table 5-2 for each land use.

Depth varying roughness coefficients were applied to some vegetation types. This follows on from work completed as part of the 'Hawkesbury-Nepean River Flood Study – Flood Study Report' (Rhelm CSS, 2024), which confirmed that locations with significant flood height ranges can expect to see variation in hydraulic roughness with respect to water depths as water, for example, encounters tree canopy and then subsequently overtops the tree.

5.1.4 Culverts and Bridges

Culverts and bridges can have a significant influence on flood behaviour. Therefore, bridges and culverts within the TUFLOW model area were represented as 1D (1d_nwk) and 2D (2d_lfcsh) hydraulic structures. Attributes of each bridge and culvert were based on available survey data, design drawings and photos and are presented in **Table 5-3**. The location of culverts and bridges that were included within each TUFLOW model is shown in **Figure 5-2** through **Figure 5-5**.

5.2 TUFLOW Model Calibration

Computer flood models are approximations of a very complex process and are generally developed using parameters that are subject to natural variability. Accordingly, the model should be calibrated using rainfall, flow, and flood mark information from historic floods to ensure the adopted model parameters are producing reliable estimates of flood behaviour. Hydraulic model calibration is typically completed by adjusting hydraulic model parameters to match historical flood level data. The

outcomes of the hydraulic model calibrations are presented in the following sections. Table 5-1 TUFLOW roughness coefficients

Material Description	Colo River	Macdonald River	Green Creek	Webbs Creek
Grass	0.048 for all models			
Light brush / tall grass	0.055 for all models			
Roads (sealed)	0.016 for all models			
Roads (unsealed)	0.020 for all models			
Water body	0.030 for all models			
River channel	0.028	0.032	0.040	0.032
Creeks with moderate vegetation	0.040 for all models			

Table 5-2: Depth varying roughness coefficients

Material Description	Depth 1 (m)	Roughness 1	Depth 2 (m)	Roughness 2	Depth 3 (m)	Roughness 3
Buildings	0.15-3.5	1	3.51	0.016	-	-
Trees (Colo River)	0-2.5	0.060	3-12	0.085	30	0.03
Trees (Macdonald River)	0-2.5	0.090	3-12	0.130	30	0.03
Trees (Webbs Creek and Greens Creek)	0-2.5	0.075	3-12	0.100	30	0.03

Table 5-3 Culverts and Bridges included in TUFLOW models

No.	Structure	Culvert diameter / span widths (m)	Number of culverts / bridge spans	Road	River/Creek	Lat	Lon	Data Source(s)
Colo River								
1	Bridge	8.3	1	Near McDougall Drive	Whatleys Creek	-33.42	150.821	BCE Spatial Survey Site 12
2	Bridge	19.9	1	Upper Colo Road	Wheeny Creek	-33.429	150.811	BCE Spatial Survey Site 14
3	Bridge	22; 5x28; 22	7	Putty Road	Colo River	-33.432	150.828	Department of Public Works Drawings (1966)
4	Bridge	15	1	Upper Colo Road	Gospers Creek	-33.419	150.724	BCE Spatial Survey Site 17/ LiDAR/Estimated dimensions
5	Bridge	22	8	Greens Road	Colo River	-33.437	150.883	Road and Traffic Authority of NSW Schedule of Drawings (1994)
6	Bridge	12.2; 3x12; 12.2	5	Colo Heights Road	Colo River	-33.411	150.738	Bridge Design Pty Ltd (included only in design simulations)
Greens Creek								
6	Culvert	1.2	1	Greens Road	Greens Creek	-33.414	150.916	BCE Spatial Survey Site 11 - east
7	Culvert	0.6	1	Green Swamp Trail	Road Drainage	-33.414	150.916	BCE Spatial Survey Site 11 - west
8	Culvert	1.2	2	Greens Road	Greens Creek	-33.414	150.916	BCE Spatial Survey Site 11 - west
9	Culvert	0.9	1	-	Greens Creek	-33.412	150.914	LiDAR/Estimated dimensions
Webbs Creek								
10	Bridge	100	1	Barry Road	Webbs Creek	-33.383	150.956	LiDAR/Photos/Estimated dimensions
11	Bridge	14.3; 32.3; 14.3	3	Chaseling Road	Webbs Creek	-33.388	150.973	Department of Main Roads NSW Drawings (1970)
Macdonald River								
12	Bridge	10.4	6	Upper Macdonald Road	Macdonald River	-33.271	150.951	BCE Spatial Survey Site 4
13	Bridge	6.2	3	Settlers Road	Wellums Creek	-33.298	150.983	BCE Spatial Survey Site 8
14	Bridge	10.7	3	Settlers Road	Wrights Creek	-33.322	150.979	BCE Spatial Survey Site 10S
15	Bridge	14.9	3	Upper Macdonald Road	Macdonald River	-33.242	150.939	BCE Spatial Survey Site 1
16	Bridge	15.0	1	St Albans Road	Flemings Creek	-33.316	150.961	LiDAR/Google Streetview/Estimated dimensions
17	Bridge	18.0	1	St Albans Road	Bakers Gully	-33.333	150.975	LiDAR/Google Streetview/Estimated dimensions
18	Bridge	9.1; 2x10.7; 2x36; 9.1	6	Wollombi	Macdonald River	-33.293	150.972	Department of Public Works Drawings (1901)

5.3 TUFLOW Model Calibration

Computer flood models are approximations of a very complex process and are generally developed using parameters that are subject to natural variability. Accordingly, the model should be calibrated using rainfall, flow, and flood mark information from historic floods to ensure the adopted model parameters are producing reliable estimates of flood behaviour.

Hydrological model calibration is typically completed by routing recorded rainfall from historic floods through the hydrologic model and comparing simulated flows against recorded flows at stream gauge locations. Hydraulic model calibration is typically completed by adjusting hydraulic model parameters to match historical flood level data.

5.3.1 Stream gauge data

Stream gauge data are valuable as it describes the time variation in water level throughout the flood in addition to the flood peak. **Table 3-3** summarises the gauges that were active along the Colo and Macdonald Rivers during potential calibration historical floods. There are no stream gauges along Greens Creek or Webbs Creek.

5.3.2 Historical flood marks

In addition to gauged water levels, peak flood levels for historical floods have been recorded at multiple locations along the Colo and Macdonald Rivers from a range of sources (e.g., debris/high water marks and flood photographs). **Table 5-4** provides a summary of the number of flood marks per catchment for a select number of flood events. It indicates that a significant number of flood marks are available for the Colo River and Macdonald River for the March and July 2022 floods.

Table 5-4 Historical flood marks per catchment

River	Number of historical flood marks per flood event			
	Mar 1978	Feb 2020	Mar 2022	Jul 2022
Colo River	4		10	11
Greens Creek	-	-	-	-
Webbs Creek	-	-	-	-
Macdonald River	-	-	37	19

5.3.3 Selected flood events

The March 2022 and July 2022 events were selected as the primary calibration events based on the greater amount of data available for those two events. This includes stream gauge data as well as surveyed flood marks away from gauge locations. The February 2020 and March 1978 floods were selected as additional validation events.

5.3.4 Calibration process

As outlined above, the March 2022 and July 2022 floods provide the greatest abundance of stream gauge information and historical flood marks for both the Colo and Macdonald Rivers. In general, the quantity and quality of recorded data diminishes moving back in time. More recent floods also require fewer assumptions to be made to update the model to reflect topographic and development conditions at the time of the flood. Therefore, there is greater certainty about the hydraulic model representation for more recent floods.

In recognition of this, the calibration proceeded and is documented in reverse chronological order. That is, calibration commenced with the July 2022 flood simulation. Once a satisfactory agreement was achieved, the calibration moved to the March 2022 to confirm the adopted model parameters were providing a reliable description of both floods. Hydraulic roughness parameters were iteratively adjusted until a reasonable correlation was achieved for both events.

The end goal was to adopt a consistent set of model parameters for each watercourse that provided a reasonable reproduction of historical flood information for each flood simulation. However, a perfect correlation between simulated and recorded flood information cannot be expected due to hydrologic limitations (e.g., not all events provided a sufficient density of rain gauges to reliably describe the spatial and temporal variation in historical rainfall), other unknowns (e.g., the degree of blockage of major hydraulic structures during each flood), as well as factors that cannot be represented in the hydraulic model (e.g., wave action, local eddies around bridge piers, small scale topographic features). The quality of some of the documented historical flood levels was also subject to some uncertainty, particularly due to poor GPS signal strength during the survey.

5.3.5 Boundary Conditions

5.3.5.1 Upstream Boundaries

Calibrated flow hydrographs produced by the WBNM model were used to define upstream (i.e., inflow) boundary conditions to the TUFLOW models. The location where flow hydrographs were applied to each TUFLOW model is shown in **Figure 5-2** through **Figure 5-5**.

5.3.5.2 Downstream boundaries

The downstream boundaries of the Colo River and Macdonald River hydraulic models were set as HT (water level-time) boundaries at their respective junctions with the Hawkesbury River. For the Colo River model, the downstream water level time series was based on the Lower Portland (212407) gauge. For the Macdonald River model, the downstream water level time series was interpolated between the water level time series of the Webbs Creek (212408) and Wisemans Ferry Wharf (212460) gauges.

5.3.6 July 2022 Results

5.3.6.1 Colo River

Peak floodwater depths were extracted from the results of the July 2022 flood simulation and are included on **Map RG-00-001-1** for the Colo River. Also included on **Map RG-00-001-1** are peak flood level comparisons.

A longitudinal surface water profile along the Colo River for the July 2022 event is also provided in **Appendix C**. A stage hydrograph comparison for the Upper Colo gauge site is presented in **Appendix C.** This provides peak simulated water levels along the centre of the river along with surveyed peak flood marks and the recorded flood level peak at the Upper Colo gauge.

A comparison between the peak flood levels generated by the TUFLOW model and the surveyed flood marks along the Colo River for the July 2022 flood are presented in **Appendix C**.

The flood mark comparison in **Appendix C** shows that the TUFLOW model produces peak flood levels that are most commonly higher than surveyed flood marks, with the average absolute difference being 0.35 m. However, 2 of the 11 surveyed flood marks have been identified as potentially erroneous values based on their elevation compared to nearby flood marks. Poor reception impacted several survey measurements as noted in **Appendix C**. With two potentially problematic flood marks removed, the average absolute difference between simulated and surveyed flood marks reduced to 0.1 m.

The stage hydrograph comparison between observed and simulated water levels at the Upper Colo Gauge (212290) (**Appendix C**) shows the simulated water levels provide a reasonable correlation of the time variation in water levels at the Upper Colo gauge. However, the peak simulated flood level is approximately 1.8 metres higher than the recorded gauge peak. The Upper Colo gauge is located along a moving sand bar with the current gauge zero reported at 1.468 mAHD with a the 'cease to flow' at 0.62 m. A recent cross-sectional survey completed at the gauge conducted as part of this study showed a bed level of 3.5-4.3 mAHD, which is roughly 1.5 m higher than the combined gauge zero and cease to flow level. A separate survey of the Upper Colo bridge in 2020, located downstream from the gauge, showed the bed level at 3.1 mAHD. Thus, concerns were raised about the accuracy of the gauge zero for Upper Colo gauge and the issue is currently being investigated by WaterNSW. The survey collected as part of this study would suggest the gauge zero level be increased by at least 1.5 m to 2.968 mAHD, which would bring the simulated and recorded flood levels into much better alignment.

5.3.6.2 Macdonald River

Calibration of the TUFLOW computer model was attempted based upon 37 surveyed flood marks and the water level record at the St Albans gauge (212218).

Peak floodwater depths were extracted from the results of the July 2022 flood simulation and are included on **Map RG-001-2**

A longitudinal surface water profile along the Macdonald River for the July 2022 event is provided in **Appendix C**. A comparison between the peak flood levels generated by the TUFLOW model and the surveyed flood marks for the July 2022 flood is also provided in **Appendix C**.

The flood mark comparison in **Appendix C** shows that the TUFLOW model produces peak flood levels that are most commonly lower than surveyed flood marks, with the average absolute difference being 0.44 m.

The stage hydrograph comparison between observed and simulated water levels at the St Albans Gauge (212228) (**Appendix C**) indicates a peak simulated flood level of 13.02 mAHD that is roughly 0.33 m higher than the recorded gauge value of 12.69 mAHD. However, surveyed flood marks in St Albans suggest that peak July 2022 flood levels were between 13.0 to 13.4 mAHD. Thus, these results suggest that the gauge zero for the St Albans of 2.76mAHD gauge could also be too low.

5.3.7 March 2022 Flood Results

5.3.7.1 Colo River

Calibration of the TUFLOW computer model was then undertaken based upon 10 surveyed flood marks and water level record at the Upper Colo gauge (212290) for the March 2022 flood. A comparison between the peak flood levels generated by the TUFLOW model and the surveyed flood marks for the March 2022 flood are presented in **Map RG-00-002-1.** A longitudinal surface water profile and a stage hydrograph comparison for the Upper Colo gauge site is also included in **Appendix C**.

The flood mark comparison table shows that the TUFLOW model produces peak flood levels that are most commonly lower than surveyed flood marks, with the average absolute difference being 0.23 m.

The stage hydrograph comparison between observed and simulated water levels at the Upper Colo Gauge (212290) for the March 2022 event indicates a peak simulated flood level of 19.58 mAHD that s higher than the recorded flood peak of 18.12 mAHD. However, as noted in the previous section, it is likely that the gauge zero for the Upper Colo gauge should be increased by 1.5 metres which would bring the recorded flood peak into good alignment with the simulated flood peak.

5.3.7.2 Macdonald River

Calibration of the TUFLOW computer model to the March 2022 flood was undertaken based upon 19 surveyed flood marks along the Macdonald River and water levels recorded at the St Albans gauge (212218). Peak floodwater depths were extracted from the results of the March 2022 flood simulation and are included on **Map RG-002-2**. A comparison between the peak flood levels generated by the TUFLOW model and the surveyed flood marks for the March 2022 flood is also provided in **Appendix C** along with a longitudinal profile along the Macdonald River as well as stage hydrograph comparison at the St Albans gauge.

The flood mark comparison in **Appendix C** and the longitudinal profile shows that the TUFLOW model produces peak flood levels that are most commonly higher than surveyed flood marks, with the average absolute difference being 0.59 m. However, the quality of most flood marks was classified as low, and improved agreement between surveyed and simulated peak flood levels are found for survey sites with higher quality.

The stage hydrograph comparison at the St Albans Gauge (212228) indicates a peak simulated flood level of 11.85 mAHD which is roughly 0.79 m higher than the recorded gauge value of 11.06 mAHD. However, surveyed flood marks near the St Albans gauge suggest that March 2022 flood levels were between 11.3 to 11.6 mAHD in the area. Similar to the July 2022 event, these results suggest that the gauge zero for the St Albans gauge could to low.

5.3.8 February 2020 Flood Results

5.3.8.1 Colo River

Validation of the TUFLOW computer model for the Colo River was restricted to the recorded water levels at the Upper Colo gauge (212290). Modelled flood depths and levels from the February 2020 event are shown in **Map RG-00-003-1.** The stage hydrograph comparison plot is provided in **Appendix C** for the Upper Colo Gauge shows a simulated peak flood level of 17.87 mAHD that is roughly 0.65 m above the observed flood level peak of 17.21 mAHD. This difference of 0.65 m between simulated and observed peak flood levels for the Upper Colo gauge, is less than the ~1.5 m difference found for the March 2022 and July 2022 events. This lower difference in simulated vs observed peak flood levels could potentially be attributed to several factors, including the fact that the model was calibrated for higher flow rates, as well as the uncertainty associated with the hydrological inputs and potential bed movement at the gauge location. Nevertheless, without additional evidence such as flood marks, the performance of the model was deemed acceptable.

5.3.8.2 Macdonald River

Map RG-00-003-2 shows the simulated flood depths and levels for the February 2020 event in the Macdonald River. The stage hydrograph comparison for the St Albans gauge (refer to **Appendix C**) shows a simulated water level roughly 1.0 m above the observed flood level peak of 7.96 mAHD. This difference is largely consistent with the results of the March and July 2022 floods simulations, although could be further skewed by erosion of the riverbed between the 2020 and 2022 floods.

5.3.9 March 1978 Flood Results

5.3.9.1 Colo River

The March 1978 validation for the Colo River was based upon water level records extracted from Figure 4 in the *March 1978 Flood Report* for the Upper Colo and Moran's Rock locations. It should be noted that the "Upper Colo" location presented in Figure 1 of the *March 1978 Flood Report* is situated approximately 1.5 km downstream of the current Upper Colo gauge location.

Map RG-00-004-1 shows the simulated flood depths and levels for the March 1978 event in the Colo River. The stage hydrograph comparison plot in **Appendix C** for the Upper Colo location shows a simulated peak water level of 20.7 mAHD which agrees closely to the observed flood level peak of 20.66 mAHD. However, the stage hydrograph comparison for the Moran's Rock location (near Putty Road Bridge) shows a simulated water level that is around 1.0 m below the observed flood level peak of 15.74 mAHD. It was noted that the Moran's Rock location is situated on the outer bend of the Colo River where a localised a build-up of water and superelevation of the water surface may have resulted in localised water level increases at that location that may not be fully reflected in the simulated hydrograph.

Appendix C shows the simulated surface water profile Colo River for the March 1978 event. Four peak flood levels are shown on the profile, which were extracted from Table 1 in the March 1978 Flood Report. This includes the peak flood level of 20.66 mAHD observed at the Upper Colo Gauge, 17.86 mAHD at Central Colo, 15.74 mAHD at Moran's Rock and 10.42 mAHD at Jones Road. Simulated peak flood levels match well at Upper Colo and Jones Road, while recorded flood peaks at Central Colo and Moran's Rock are roughly 1.0 m above simulated levels. This underestimation of peak flood levels is only reflected in the middle reaches of the Colo River (i.e., upstream and downstream levels correlate well). Although these differences are higher than desirable, it is acknowledged that the peak recorded flood levels presented in the March 1978 Flood Report have several associated uncertainties, including their exact locations and accuracy of measurements.

5.3.9.2 Macdonald River

Validation of the TUFLOW computer model was also attempted based upon a stage hydrograph documented in Figure 4 in the *March 1978 Flood Report*.

Map RG-00-004-1 shows the modelled depths and water levels for the March 1978 event.

The stage hydrograph comparison plot for the St Albans Gauge location (**Appendix C**) shows a simulated water level of 12.20 mAHD that is 0.95 m above the extracted peak flood level of 11.25 mAHD. This difference in peak flood levels could potentially be attributed to several factors, including the uncertainty associated with the extracted water level time series from Figure 4 in the *March 1978 Flood Report* and the uncertainty related to the downstream boundary condition for this event (the water levels at St Albans are impacted by the prevailing water levels in the Hawkesbury River). However, the largest area of uncertainty concerns the rainfall distribution across the upstream catchment due to the limited availability of rain gauge data.

5.4 Design Flood Parameters

The following section describes the parameters that were applied to each TUFLOW model for the design flood simulations.

5.4.1 Boundary Conditions

5.4.1.1 Inflow boundaries

As discussed in the previous chapter, a WBNM hydrologic model was used to simulate the transformation of rainfall into runoff and generate discharge hydrographs throughout the catchment for each design storm. The discharge hydrographs generated by the WBNM model were used to define inflow boundary conditions for each TUFLOW model. The adopted temporal patterns and storm durations that were selected for application to the TUFLOW models for each AEP are summarised in **Table 5-5** and **Table 5-6**.

Table 5-5 Adopted storm durations and temporal patterns for the Colo River and Macdonald River

AEP	Design Storm Durations and Temporal Pattern ID					
	Macdonald River				Colo River	
	24 hr	36 hr	48 hr	96 hr	48 hr	96 hr
20%	-	-	-	586	-	593
10%	-	-	-	585	-	594
5%	-	-	-	587	-	594
2%	-	-	407 405	-	-	594
1%	228	-	407	-	-	591
1 in 200	-	-	407	-	416	591
1 in 500	-	316	408	-	416	-
1 in 1000	-	316	-	-	418	-
1 in 2000	-	316	-	-	418	-

Table 5-6 Adopted storm durations and temporal patterns for Greens Creek and Webbs Creek

AEP	Design Storm Durations and Temporal Pattern ID			
	Greens Creek			Webbs Creek
	6 hr	9 hr	12 hr	24 hr
20%	-	4770	-	210
10%	-	4763	-	208
5%	4729	-	-	208
2%	-	-	4747	202
1%	-	-	4787	207

AEP	Design Storm Durations and Temporal Pattern ID			
	Greens Creek			Webbs Creek
	6 hr	9 hr	12 hr	24 hr
1 in 200	-	-	4787	208
1 in 500	-	-	4787	208
1 in 1000	-	-	4787	208
1 in 2000	-	-	4787	208

5.4.1.2 Downstream boundary

All four of the study area catchments drain into the Hawkesbury River. Accordingly, the prevailing water level within the Hawkesbury River can have a significant impact on flood behaviour across the downstream reaches of each watercourse. Therefore, it is important to define a reliable Hawkesbury River boundary condition as part of the design flood simulations. At the same time, it was also considered important to note that the goal of the current study is to define flood behaviour for the each of the four study area catchments, and not re-define flood behaviour for the Hawkesbury River, which was completed as part of the Hawkesbury-Nepean River Flood Study (Rhelm CSS, 2024).

Firstly, it is unlikely that floods of equivalent frequency will occur simultaneously in each study area catchment and the Hawkesbury River, due to the different characteristics of each catchment, particularly during large events.

The correlation between Hawkesbury River flooding, and flooding in the Colo River and Macdonald River is complex, as it depends not only on the peak levels and flows, but also on the timing of the Colo River and the Macdonald River. Rhelm CSS (2024) demonstrated that the timing of the flows can be influential on the overall levels in the Lower Hawkesbury River. While in many events the Colo River and Macdonald River peaks occur more than a day before the Hawkesbury River, there are events, such as the July 2022 event, where the peaks were more closely aligned.

Recognising the uncertainty around the timing of the peaks, a review was undertaken on the peaks in both the Colo and Macdonald River, compared with the Hawkesbury River at Windsor (where there is a long historic record). This comparison is shown in Figure 5-6 and Figure 5-7.

Generally, there is not a strong correlation between large events on the Hawkesbury River compared with Colo River and Macdonald River floods. Furthermore, for the smaller catchments of Greens Creek and Webbs Creek, an even weaker correlation is expected between catchment driven events and large events on the Hawkesbury River.

Following an approach adopted by other tributary flood studies within the Hawkesbury-Nepean Rivers catchment, an envelope approach was adopted. This involves simulating a combination of high local tributary flows with a lower Hawkesbury River flow, and a high Hawkesbury River flow with a lower local tributary flow. The resulting flood combinations are then 'enveloped' together to produce the final design results for each flood frequency.

For local catchment floods in Colo River and Macdonald River, it was assumed that floods of equivalent severity occurred only in frequent floods (i.e., up to and including the 10% AEP). For larger catchment floods, it was assumed that a 5% AEP Hawkesbury River level would be more suitable. The only exception is the PMF, where a 1% AEP Hawkesbury River level was adopted as a downstream boundary (i.e., a PMF within the local catchment is likely to also generate higher flood levels within adjoining catchments including the broader Hawkesbury River catchment).

For local catchment floods in Greens Creek and Webbs Creek, a High High Water Solstices Spring (HHWSS) tidal level was adopted as the Hawkesbury River level across all events. The only exception is the PMF, where a 20% AEP Hawkesbury River level was adopted as a downstream boundary.

The combinations of local catchment flood frequency and Hawkesbury River flood frequency that were combined to form each design flood event is presented in **Table 5-7** for the Colo River and Macdonald River, **Table 5-8** for Greens Creek and Webbs Creek.

Table 5-9 presents the actual Hawkesbury River design water level at each downstream model boundary.

This correlation between the adopted local catchment and Hawkesbury River floods is also plotted on **Figure 5-6** and **Figure 5-7**.

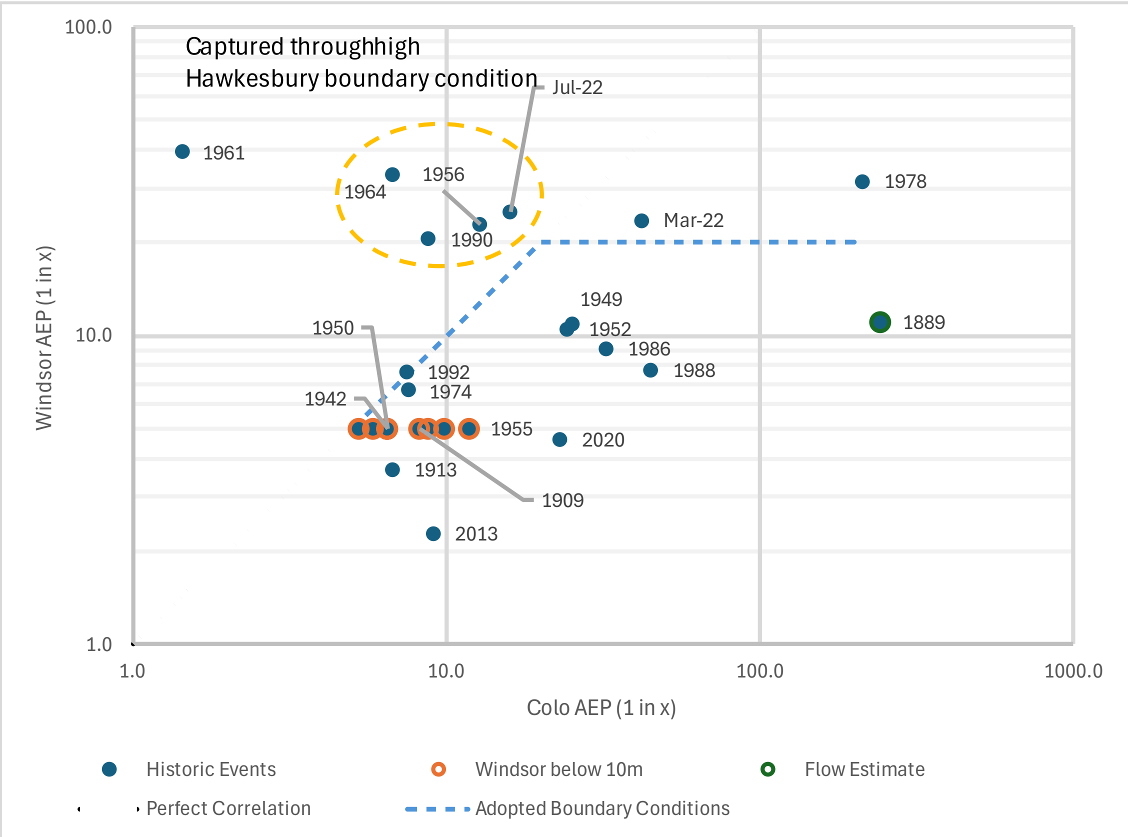

Figure 5-6. Peak Level Correlation between Windsor and Colo River

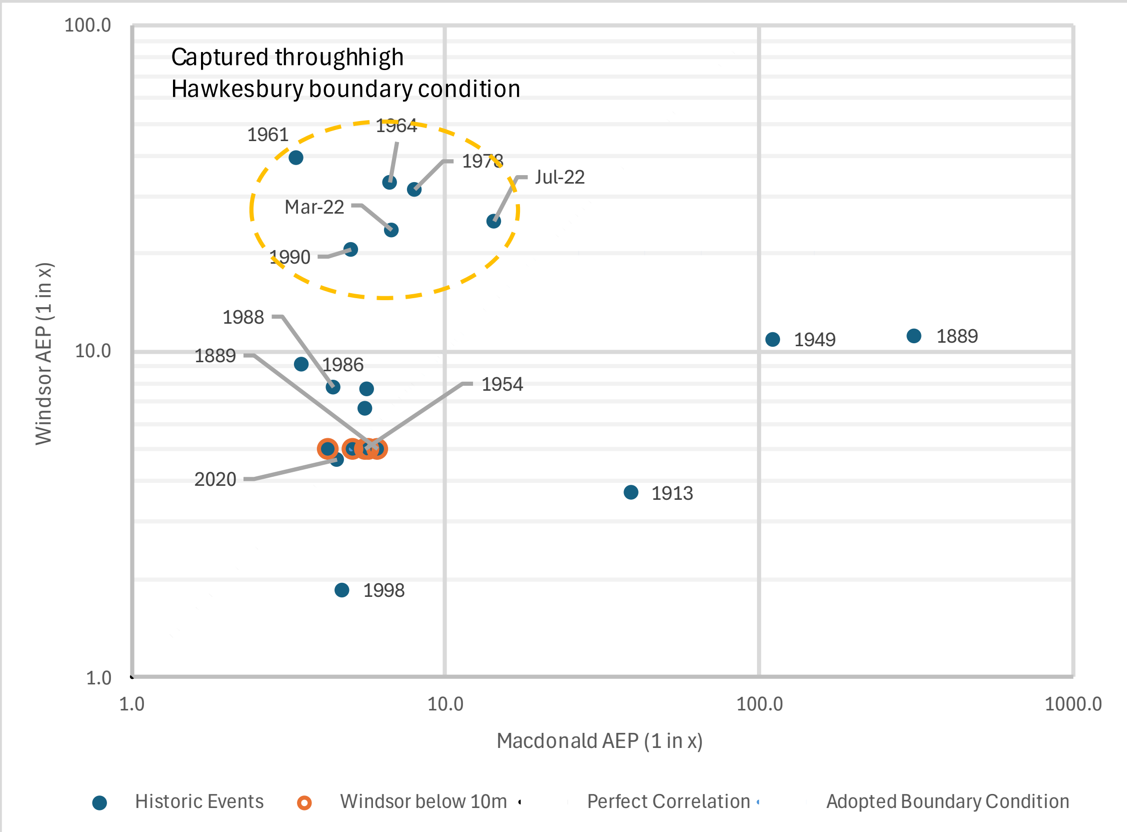

Figure 5-7. Peak Level Correlation between Windsor and Macdonald River

Table 5-7 Adopted downstream boundary conditions for local catchment driven events (AEP)

Design flood event (AEP)	Design flood in local catchment (AEP)	Design flood level at Hawkesbury River junction (AEP)
20%	20%	20%
10%	10%	10%
5%	5%	5%
2%	2%	5%
1% (level)	1%	5%
1% (velocity		ISLW
1in 200	1in 200	5%
1in 500	1in 500	5%
1in 1000	1in 1000	5%
1 in 2000	1 in 2000	5%
PMF	PMF	1%

Table 5-8 Adopted downstream boundary conditions for local catchment driven events in Greens Creek and Webbs Creek

Design flood event (AEP)	Design flood in local catchment (AEP)	Design flood level at Hawkesbury River junction (AEP)
20%	20%	HHWSS
10%	10%	HHWSS
5%	5%	HHWSS
2%	2%	HHWSS
1% (level)	1%	HHWSS
1% (velocity)		ISLW
1in 200	1in 200	HHWSS
1in 500	1in 500	HHWSS
1in 1000	1in 1000	HHWSS
1 in 2000	1 in 2000	HHWSS
PMF	PMF	20%

Table 5-9 Adopted Hawkesbury River design water levels

AEP	Hawkesbury River Flood Level (mAHD)			
	Lower Portland Colo Junction	Greens Creek Junction	Webbs Creek Junction	Macdonald Junction
ISLW^	-0.66	-0.69	-0.78	-0.78
HHWSS^	1.23	1.24	1.25	1.24
20%*	4.0	3.4	2.3	2.2
10%*	5.8	5.0	3.2	3.2
5%*	7.6	6.5	4.4	4.3
2%*	9.8	8.4	5.6	5.5
1%*	11.0	9.5	6.6	6.5
1in 200*	12.8	11.1	8.0	8.0
1in 500*	15.0	13.2	10.2	10.2
1in 1000*	17.0	15.0	11.5	11.5
1 in 2000*	18.7	16.6	12.9	12.9
PMF*	26.6	23.6	19.2	19.3

^Extracted from Figure 5-12 in Manly Hydraulic Laboratory (2023).

Extracted from Hawkesbury-Nepean River Flood Study (Rhelm CSS, 2024)

As shown **Table 5-7** and **Table 5-8**, each catchment driven event was combined with a single Hawkesbury River level to represent each design flood. The only exception is the 1% AEP event, where an additional combination of catchment runoff and Hawkesbury River water level was simulated to encompass an expanded range of flood characteristics (notably peak velocity) given the importance of this design flood for planning purposes.

As discussed earlier, although this study is focussed on defining "mainstream" flood behaviour for the four catchments, it was considered important to capture the potential impact of Hawkesbury River flooding. In this regard, separate simulations were completed by enveloping a small local catchment with large design floods along the Hawkesbury River. The differing design frequencies along the Hawkesbury River versus each local catchment, again, reflects the different catchment characteristics that are unlikely to produce flood of equivalent frequencies at the same time. As shown in **Table 5-10**, the 10% AEP local catchment flood was adopted to reflect local catchment flood behaviour with each Hawkesbury River design flood. All Hawkesbury River driven events were defined using a static Hawkesbury River design water level (refer to

Table 5-9). Depth, level, velocity and hazard mapping for the Hawkesbury Driven Events are provided in the **Map Compendium – Hawkesbury Driven Events**.

Table 5-10 Adopted downstream boundary conditions for Hawkesbury River driven events

Design flood event in local catchment	Design flood level in Hawkesbury River at junction
10%	2%
10%	1%
10%	1in 200
10%	1in 500
10%	1in 1000
10%	1 in 2000
10%	PMF

5.4.2 Hydraulic Structure Blockage

Blockage factors for each mainstream bridge and culvert were estimated based upon recommendations in Chapter 6 of Book 6 of 'Australian Rainfall & Runoff' (Ball et al, 2019). This involved calculating 'base' blockage factors for each structure which were subsequently adjusted up or down depending on the severity of the design event (i.e., higher blockage factors during larger/rarer floods and lower blockage factors during smaller/more frequent floods). The blockage scenarios that were adopted for each design simulation are presented in **Appendix F** and are summarised below:

- Low blockage scenario: 20% AEP, 10% AEP
- Medium blockage scenario: 5% AEP, 2% AEP, 1% AEP and 1 in 200 AEP
- High blockage scenario: 1 in 500 AEP, 1 in 1000 AEP, 1 in 2000 AEP and PMF

6 Flood Model Results

As discussed, a range of design storm durations and temporal patterns were simulated for each design event as well as local catchment plus Hawkesbury River driven floods. Therefore, the results from each simulation for each design flood frequency were combined to form a "design flood envelope" for each design flood. It is this "design flood envelope" comprising the most critical depths, velocities and levels from a risk management perspective that forms the basis for the results documented in the following sections.

6.1 Peak Depths, Levels and Velocities

Peak results were extracted from the final design flood envelopes and were used to prepare a range of flood maps for the 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 1 in 200 AEP, 1in 500 AEP, 1 in 1000 AEP and 1 in 2000 AEP floods as well as the PMF. This information is provided in:

- Flood Depths and Levels: **Map RG-00-101 to Map RG-00-110**
- Flow Velocity: **Map RF-00-201 to Map RG-00-210**

Peak design floodwater surface profiles were also extracted for the catchment and are presented in **Appendix D**.

Design stage hydrographs were also extracted at the Upper Colo and St Albans gauge locations and are provided in **Appendix D**. In reviewing the stage hydrographs, the potential gauge datum issues documented in **Section 5.3.6.1** should be taken into consideration. Design stage hydrographs are also presented for Green Creeks (upstream of Greens Road crossing) and Webbs Creek (upstream of Chaseling Road Bridge) in **Appendix D**.

6.2 Gauge Height Relationships

Table 6-1 to **Table 6-3** provide flood gauge and gauge height relationships for the stream flow gauges at St Albans, Upper Colo and Putty Road. **Figure 3-2** shows the location of the gauges. These tables can be used by emergency services and the community to compare gauge height (m) to level (mAHD). The equivalent design flood AEP is also provided**.**

Table 6-1 St Albans (61426)

Classification	Depth at Gauge (m)	Gauge Level (mAHD)	AEP
Not classified	6.1	8.9	20%
	6.9	9.9	10%
	9.3	12.0	5%
	12.1	14.9	2%
	12.9	15.7	1%
	13.9	16.7	0.5%
	27.9	30.7	PMF

Table 6-2 Upper Colo (563033)

Classification	Depth at Gauge (m)	Gauge Level (mAHD)	AEP
Minor	5.1	9.6	
Moderate	8.6	13.1	
	9.3	13.8	20%
	13.7	18.2	10%
Major	14.3	18.8	
	14.8	19.3	5%
	16.3	20.8	2%
	17.1	21.6	1%
	18.6	23.1	0.5%
	44.8	49.3	PMF

Table 6-3 Putty Road (Forecast Gauge

Classification	Depth at Gauge (m)	Gauge Level (mAHD)	AEP
Not classified	6.5	7.0	20%
	9.6	10.1	10%
	11.7	12.2	5%
	13.3	13.8	2%
	14.0	14.5	1%
	15.8	16.3	0.5%
	39.3	39.8	PMF

6.3 Comparison with Previous Macdonald River Study

Flood levels generated as part of the current study at key locations in the catchment have been compared against flood level results provided in the 2004 Lower Macdonald River flood study (WMAWater 2004).

Figure 6-1 shows the locations along the Macdonald River where flood levels have been compared. **Table 6-4** compares the design flood levels from the 2004 Lower Macdonald River flood study (WMAWater 2004) with the results of this study.

The comparison in **Table 6-4** shows that during more frequent events (20% AEP, 10% AEP and 5% AEP), the levels from the 2004 study are generally higher than the levels generated in this study. For the rarer events (2% AEP and larger), the design flood levels from this study are generally higher than the 2004 study. In the 1% AEP event at St Albans, the peak water level in this flood study is 1.26 m higher than the 2004 study.

The main reasons the flood levels in the 2004 study differ to the current study include:

- The downstream boundary conditions for the current study have been based on a coincident event analysis and updated Hawkesbury River water levels from the Hawkesbury Nepean River Flood Study (Rhelm, CSS 2024). This has resulted in adoption of lower tailwater levels for the Hawkesbury River and is the main reason for the lower design flood levels in the current study along the Lower Macdonald across all events.
- The hydraulic model used in the 2004 study was 1D while this study is based on a 2D hydraulic model. The 1D model from the 2004 study was based on cross sections that were spaced 1.5 km to 3 km apart. The widely spaced 1D cross sections would not represent local features in the floodplain between cross-section locations and may not account for bend losses. Analysis completed by Rhelm and CSS (2024) showed hydraulic losses around bends can be significant during larger floods in semi confined valley's, resulting in higher flood levels during such events.
- The 2004 study used only two "cross-section averaged" roughness coefficients across the model area, with the highest roughness coefficient being 0.041. The current study included a more detailed representation of hydraulic roughness including dense trees and vegetation across parts of the floodplain, which comprise a much higher roughness (i.e., more than double the highest roughness value adopted in the 2004 study). The impact of the higher roughness is more pronounced during larger floods where a greater proportion of flow travels outside of the river channel. This is one of the main reasons behind the higher flood levels in the current study during larger floods.
- The 2004 study did not model a PMF event but used a flow 3 times the 1% AEP flow to represent an extreme event. Based on this study, the PMF flow at St Albans is approximately 8 times larger than the 1% AEP event. Therefore, with the exception of the area near the confluence with the Hawkesbury River (Point 4 in **Figure 6-1**) the PMF levels in from this study are significantly higher than the extreme event levels from the 2004 study.

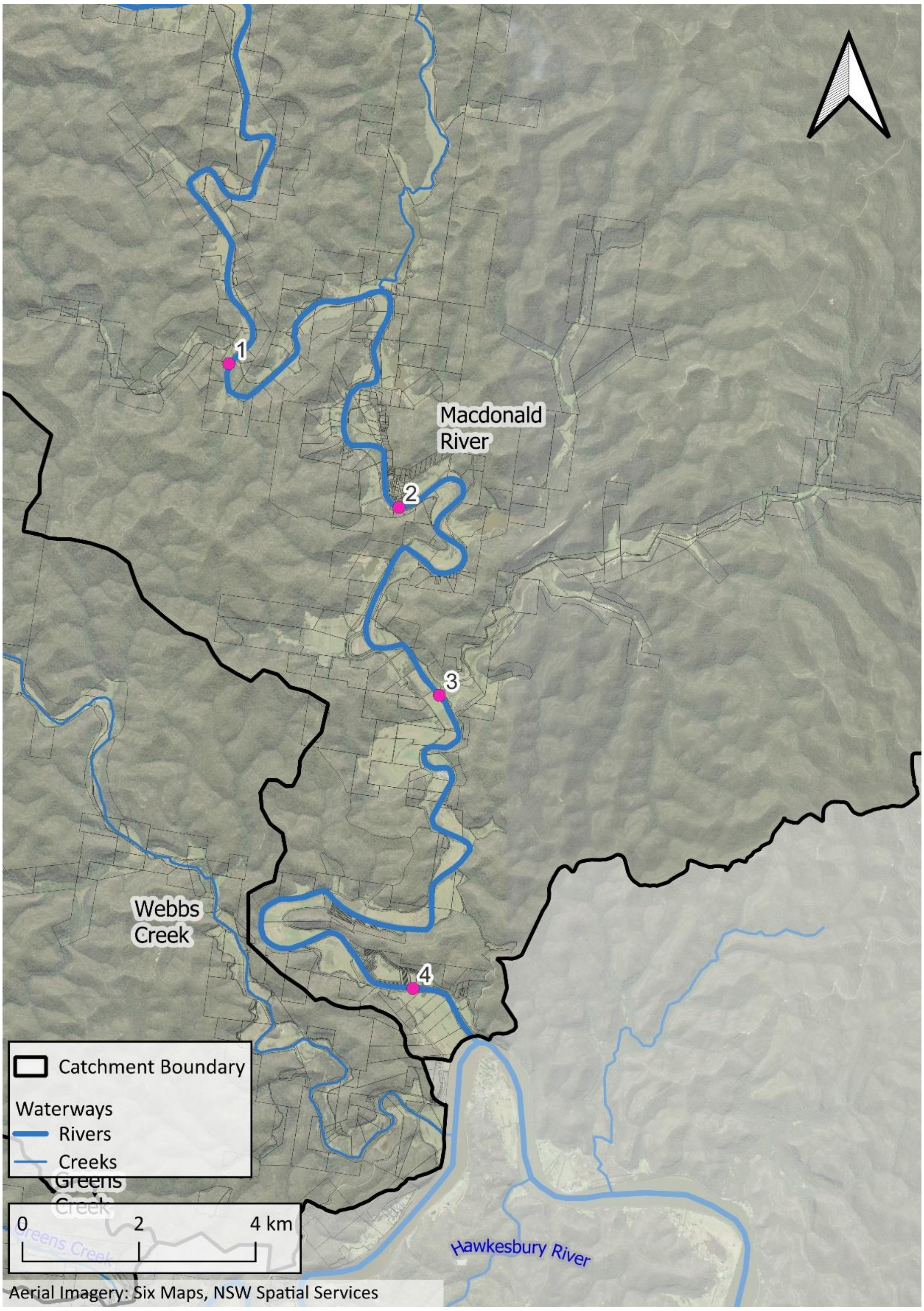

Figure 6-1 Flood level comparison locations

Table 6-4 Comparison of design flood levels in the Macdonald River from this study and the 2004 flood study

Event	Study	Location 1 Downstream of Gorricks Creek	Location 2 St Albans, upstream of St Albans Bridge	Location 3 Upstream of Wrights Creek	Location 4 Lower Macdonald
20% AEP	This Study	12.69	9.03	5.43	2.36
	2004 Study	12.50	10.10	7.00	3.20
	Difference	**0.19**	**-1.07**	**-1.57**	**-0.84**
10% AEP	This Study	13.73	9.92	6.24	3.27
	2004 Study	13.80	11.60	7.10	3.90
	Difference (m)	**-0.07**	**-1.68**	**-0.86**	**-0.63**
5% AEP	This Study	16.74	12.31	7.92	4.38
	2004 Study	15.0	13.0	8.9	4.4
	Difference (m)	**1.74**	**-0.69**	**-0.98**	**-0.02**
2% AEP	This Study	19.34	15.05	10.75	4.90
	2004 Study	16.20	13.70	10.10	5.60
	Difference (m)	**3.14**	**1.35**	**0.65**	**-0.7**
1% AEP	This Study	20.20	15.86	11.55	5.16
	2004 Study	17.20	14.60	11.00	6.70
	Difference (m)	**3.0**	**1.26**	**0.55**	**-1.54**
1 in 200 year	This Study	21.24	16.85	12.54	5.51
	2004 Study	18.10	15.50	11.90	8.00
	Difference (m)	**3.14**	**1.35**	**0.64**	**-2.49**
1 in 500 year	This Study	22.46	18.11	13.83	6.00
	2004 Study	19.30	16.70	12.90	9.60
	Difference (m)	**3.16**	**1.41**	**0.93**	**-3.6**
PMF (this study) / Extreme event (2004 study)	This Study	35.78	30.85	25.57	10.93
	2004 Study	22.50	19.60	16.30	16.30
	Difference (m)	**13.28**	**11.25**	**9.27**	**-5.37**

6.4 Flood Hazard

Flood hazard defines the potential impact that flooding will have on vehicles, people and property across different sections of the floodplain. More specifically, it describes the potential for floodwaters to cause damage to property, mobilise vehicles and result in loss of life/injury. For this study, the variation in flood hazard across the study was defined using flood hazard vulnerability curves presented in the NSW Government's 'Flood Risk Management Guideline FB03 – Flood Hazard' (2023b). The hazard curves are reproduced in **Figure 6-2**.

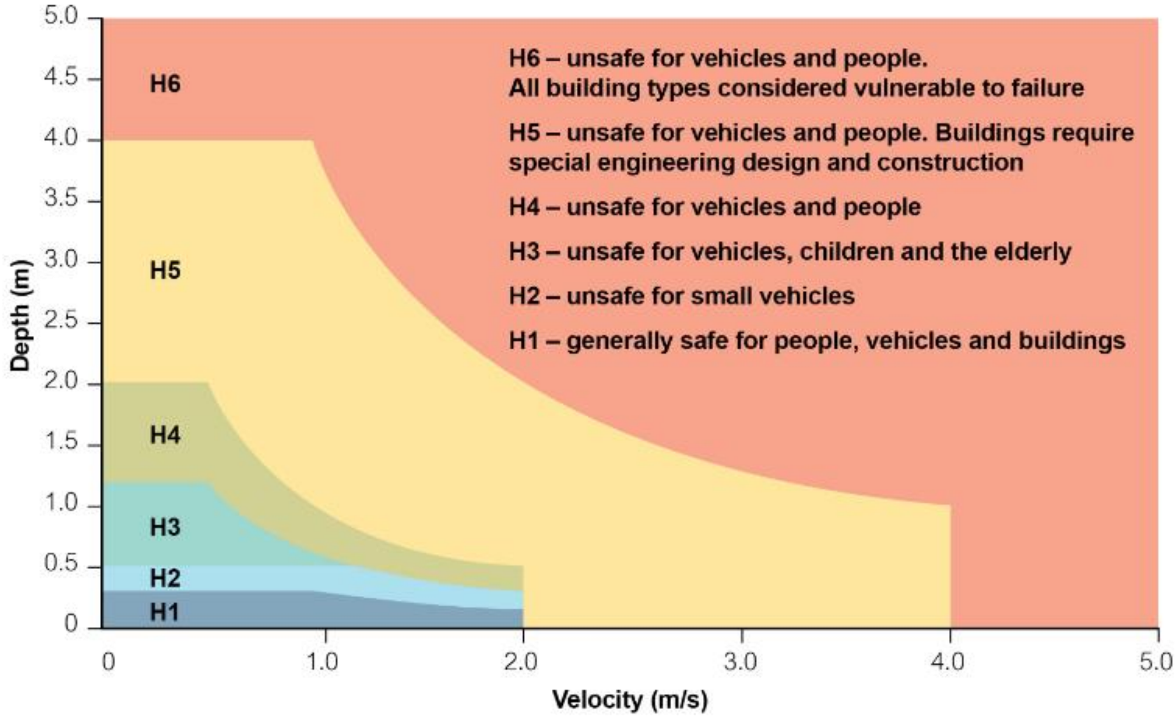

Figure 6-2 Flood hazard vulnerability curves (NSW Government, 2023b)

As shown in **Figure 6-2**, the hazard curves assess the potential vulnerability of people, cars and structures based upon the depth and velocity of floodwaters at a particular location. Therefore, peak depth, velocity and velocity-depth product outputs generated by the TUFLOW model were used to map the variation in flood hazard across the catchment based on the hazard criteria shown in **Figure 6-2** for each design flood. The resulting hazard category maps are shown in **Map RG-00-301 to Map RG-00-310** for the for the full range of flood events.

6.5 Flood function

The 'Flood Risk Management Manual' (NSW Government, 2023a) subdivides flood prone areas according to the three flood function categories presented in the first column of **Table 6-5**. The flood categories provide an indication of the potential for development across different sections of the floodplain to impact on existing flood behaviour and highlights areas that should be retained for the conveyance or storage of floodwaters.

Guidance for establishing flood function categories is provided in the '*Flood Risk Management Guideline FB02 - Flood Function*' (NSW Government, 2023c). However, explicit quantitative criteria for defining each category are not provided. This is because the extent of floodway, flood storage and flood fringe areas are typically specific to a particular catchment. Therefore, it was necessary to review the modelling results and use this information as a basis for developing criteria to describe each flood function category.

Table 6-5 Qualitative and quantitative criteria for flood function categories

Flood Function	Flood Risk Management Manual Definition	Adopted Criteria*
Floodway	Are generally areas which convey a significant portion of water during floods and are particularly sensitive to changes that impact flow conveyance. They often align with naturally defined channels.	Area within flowpaths that conveys 80% of the peak flow (conveyance technique).
Flood Storage	Are areas outside of floodways, are generally areas that store a significant proportion of the volume of water and where flood behaviour is sensitive to changes that impact on the storage of water during a flood.	• Not floodway and • Depth ≥ 0.2 m (Greens Creek and Webbs Creek) • Depth ≥ 0.5 m (Colo River and Macdonald River)
Flood Fringe	Are areas within the extent of flooding for the event but which are outside floodways and flood storage areas. Flood fringe areas are not sensitive to changes in either flow conveyance or storage.	Remaining areas of the floodplain not defined as floodway or flood storage

For this study, the following approach was employed to develop the flood function categories:

- Floodways
  - The conveyance technique was applied to the mainstream watercourse of each catchment. This approach identifies floodways as the area that conveys 80% of the peak flow. The VxD outputs generated by the hydraulic were used as a proxy to estimate the conveyance at regular intervals along each watercourse and, in turn, estimate the area of the watercourse containing 80% of the peak flow.
  - The suitability of the above floodway estimates was then cross-checked at selected locations by partly obstructing sections of floodway and confirming if a significant impact on flood behaviour/ or a significant redistribution of flow occurred. The outcome of this verification is presented in **Appendix E**.
- Flood Fringe
  - Floodways were removed.
  - A water depth threshold was then used to identify potential flood fringe areas.
  - The suitability of the flood fringe was tested by blocking out all flood fringe areas and re-running the design flood and confirming if this produced an unacceptable flood impact. Removing flood fringe areas should not have a significant impact on flood behaviour). For this study an “unacceptable impact” was quantified as a flood level increase of 0.1 m.

   - The depth threshold was adjusted iteratively until the flood level impacts were contained below 0.1 m. The outcome of this verification is presented in **Appendix E**
- Flood Storage
   - Remaining areas after floodway and flood fringe areas were removed.

The velocity and depth results produced by the TUFLOW model for each design flood were combined with the criteria detailed in **Table 6-5** to produce flood function category maps. The resulting maps are shown in the following maps:

- **Map RG-00-401 -** 1% AEP Flood Function
- **Map RG-00-402** - 1 in 200 AEP (0.5% chance per year)
- **Map RG-00-403** - 1 in 500 AEP (0.2% chance per year)
- **Map RG-00-404** - PMF

6.6 Discussion on Flood Behaviour

The flood mapping shows that inundation extents are generally contained close to each of the main waterways, even during events as large as the PMF. A comparison of the inundation extents also shows that the extent of inundation does not vary dramatically between events, which is a product of the incised nature of most of the catchment areas. However, the confined topography does produce a significant flood height range. This produces some significant increases in water depth as the severity of flooding increases. For example, at St Albans, the peak 20% AEP water depth within the Macdonald River channel is predicted to reach about 6.5 metres. During the 1% AEP flood, this is predicted to exceed 13.5 metres and during the 1 in 2000 AEP flood, the peak depth is predicted to exceed 17 metres. Therefore, although a significant area of additional floodplain is not necessarily activated as flood severity increases, the flood depth increases significantly in all catchments.

This increase in flood risk with increasing flood severity is also reflected in the flow velocity mapping. Along the Colo River, peak velocities along the river during the 20% AEP flood are typically contained well below 2 m/s. During the 1% AEP flood, peak velocities are commonly more than 2 m/s with localised areas (primarily river bends) exposed to velocities of more than 3 m/s.

As a result of the high-water depths and velocities, the flood hazard along each watercourse and floodplain is also predicted to be high. This includes:

- Colo River: H6 hazard is predicted across most low-lying areas during floods as frequent as the 5% AEP event. This includes the significant backwater area of Wheeny Creek
- Green Creek: H5 hazard is predicted across most of the inundated area during a 10% AEP flood. This is predicted to increase to H6 hazard during the 2% AEP flood.
- Webbs Creek: H5 hazard becomes prominent across the floodplain during the 5% AEP flood. This escalates quickly with much of the floodplain becoming exposed to H6 hazard during the 2% AEP flood:
- Macdonald River: H5 and H6 hazard areas are typically contained to formal watercourses during events up to and including the 5% AEP flood. Similar to Webbs Creek, the hazard escalates quickly in the 2% AEP flood, with much of the floodplain adjoining the Macdonald River exposed to H5 and H6 hazard. This includes parts of St Albans.

The water surface profiles confirm that backwater inundation from the Hawkesbury River is the dominant flooding mechanism for Green Creek.

The water level profiles also show that the PMF is significantly higher than each of the other design events along all four watercourses. This includes the PMF typically being 10 metres higher than the 1% AEP flood level. Although the chance of a PMF occurring is very rare, the significant increase in flood depths and velocities associated with this event must be considered as part of the flood risk management process.

6.7 Model Sensitivity

Computer flood models require the adoption of parameters that are not necessarily known with a high degree of certainty or are subject to variability. Each of these parameters can impact on the results generated by the model.

As outlined in Section 5.2 and Section 6.2, computer models are typically calibrated using recorded rainfall, stream flow and/or flood mark information. Calibration is achieved by adjusting the parameters that are not known with a high degree of certainty until the computer model is able to reproduce the recorded flood information. Calibration is completed to ensure the adopted model parameters are generating realistic estimates of flood behaviour.

As flood information for calibration is typically limited, it is important to understand how any uncertainties and variability in model input parameters may impact on the results produced by the model. Therefore, a model sensitivity analysis was undertaken to establish the sensitivity of the results generated by the computer model to changes in hydrologic and hydraulic model input parameter values. The outcomes of the sensitivity analysis are presented below.

6.7.1 Hydraulic Model Inputs

6.7.1.1 Roughness Coefficients

Roughness coefficients are used to describe the resistance to flow afforded by different land uses and surfaces across the catchment. However, they can be subject to variability (e.g., vegetation density in the summer would typically be higher than the winter leading to higher roughness values). Therefore, additional analyses were completed to quantify the impact that any uncertainties associated with roughness values may have on design flood behaviour.

The TUFLOW model was updated to reflect a 20% increase and a 20% decrease in the adopted design roughness values and additional 20% AEP and 1% AEP simulations were (no changes to hydrology were completed as part of this assessment). Downstream boundary (tailwater) conditions also remained unchanged.

Peak flood levels were extracted from the results of the modelling and were used to prepare flood level difference mapping, which are presented in **Maps RG-00-505 to Map RG-00-508.** General ranges of flood level differences were extracted for each catchment and are presented in **Table 6-7** and **Table 6-8** for the 20% AEP and 1% AEP events respectively.

Changes in the 20% AEP and 1% AEP flood levels associated with increases and decreases in roughness values are predicted to vary per catchment and also vary along the length of each watercourse. Due to design tailwater levels remaining unchanged, peak flood levels in the lowest reaches of each catchment undergo relatively minor increases/decreases in peak flood levels.

Greens Creek experiences minor increases/decreases (<0.1 m) in peak flood levels for both the 20% AEP and 1% AEP events, due to the greater influence of the Hawkesbury River tailwater level on the smaller catchment. Greater increases/decreases in peak flood level are experienced along the upper reaches of

Colo River, Webbs Creek and Macdonald River. For the 20% AEP event, peak flood level differences generally vary between 0.2-0.5 m for Colo River and Macdonald River, and 0.1-0.2 m for Webbs Creek. For the 1% AEP event, differences in peak flood level increase to 0.4-0.8 m for the Colo River and Macdonald River, and 0.1-0.3 m for Webb Creek.

The more significant increases in peak flood levels in Colo River, Macdonald River and Webbs Creeks indicates the model's sensitivity to changes in Manning's 'n' values. During the hydraulic model calibration (Section 5.3), it was found that the model is particularly sensitive to changes in assigned roughness to the majority land use category, ''Trees''. A 20% percentage increase/decrease across all roughness coefficients can disproportionately impact higher roughness categories, such as ''Trees'', in terms of absolute increases. Thus, it is likely that the increases/decreases in peak flood levels observed during the roughness coefficient sensitivity testing is predominantly caused by higher/lower roughness coefficients assigned to the "Trees" land use category.

6.7.1.2 Blockage

As discussed in Section 5.4.2, blockage factors were applied to all hydraulic structures as part of the design flood simulations. However, as it is not known which structures will be subject to what percentage of blockage during any flood, additional TUFLOW simulations were completed to determine the impact that alternate blockage scenarios would have on flood behaviour.

For culverts, the 'baseline' 20% AEP and 1% AEP simulations utilised the "AEP >5%" and "AEP 5% - 0.5%" design blockage level of 25% as documented in **Appendix F**. The sensitivity simulations were completed by updating the 20% AEP and 1% AEP flood simulations to use 0% blockage for a "low blockage scenario" and the less frequent (AEP < 0.5%) design blockage of 50% for a "high blockage scenario".

For bridges, modelled 2D layered flow constriction (2d_lfcsh) layers were updated to reflect a 0% blockage for L1 (below obvert) and L3 (handrail) for "low blockage scenario", while for the "high blockage scenario", L1 blockage was increased by an additional 10% over the baseline value and L3 blockage was set to 100%.

Peak flood levels were extracted from the results of the modelling and were used to prepare flood level difference mapping, which is presented in **Maps RG-00-501 to Map RG-00-504.**

The results indicate that changes in blockage levels produce localised changes of less than ±0.10 m in the immediate vicinity of some hydraulic structures for both the 20% AEP and 1% AEP events. More extensive changes in peak flood levels are experienced in Greens Creek, upstream and downstream of the Greens Road crossing, but these flood level differences are also less than 0.10 m.

6.7.2 Climate Change

Climate change refers to a significant and lasting change in temperature and weather patterns arising from both natural and human induced processes. In 2021, the Intergovernmental Panel for Climate Change (IPCC) released the Working Group I contribution to its sixth assessment report (AR6) (IPCC, 2021). The key findings are:

- It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred.
- Continued global warming is projected to further intensify the global water cycle, including its variability, global monsoon precipitation and the severity of wet and dry events.

- It is very likely to virtually certain[1] that regional mean relative sea level rise will continue throughout the 21st century. Due to relative sea level rise, extreme sea level events that occurred once per century in the recent past are projected to occur at least annually at more than half of all tide gauge locations by 2100 (high confidence). Relative sea level rise contributes to increases in the frequency and severity of coastal flooding in low-lying areas and to coastal erosion along most sandy coasts.

It is therefore important to provide an assessment of the potential impact that climate change may have on the flood risk across the study area. In this regard, additional simulations were completed to understand the potential impact that rainfall increases may have on current 20% and 1% AEP design flood estimates.

Climate change was incorporated using updated guidance from Book 1 Chapter 6 of ARR2019 v4.2 (2024). Climate change impacts were assessed across the study area based on 2050 and 2100 planning horizons. SSP3 was adopted for the assessment to simulate a high warming scenario. The assessment includes an update to hydrology underpinned by a rainfall intensity increase, with resultant outputs used as the inflows for the hydraulic models.

Based on the climate change guidance from ARR2019 v4.2, hydrology model parameters were updated using the values shown in **Table 6-6**. The SSP scenario is associated with a temperature increase. Combined with a rate of change (α) linked to the storm duration, a percent increase for the design storm rainfall intensity was calculated. Loss adjustments provided by ARR2019 v4.2 were also adopted. The updated climate change hydrology was applied to the critical storms determined by the design hydrology assessment (see **Section 4.4**). **Table 6-6** shows that under SSP3, peak for in 1% event is predicted to increase by around 20%-25% in by 2050 and around 40%-50% by 2100. Some of the potential flood planning implications of these significant increases are discussed in the flood risk management study.

[1] Very Likely refers to a probability of 90 – 100% , while Virtually Certain refers to a 99 – 100% probability (IPCC, 2010)

Table 6-6 Summary of sensitivity testing outcomes for the 20% AEP event

Updated Hydrology Model Parameter	Colo River	Greens Creek	Webbs Creek	Macdonald River
SSP3 – 2050 Parameters				
Temperature Increase	1.8°C	1.8°C	1.8°C	1.8°C
Rate of Change (α)	8	9 – 9.5 (dependent on duration)	8	8
Rainfall Intensity Increase	15%	17% – 18%	15%	15%
Initial Loss Increase	4%	4%	4%	4%
Continuing Loss Increase	7%	7%	7%	7%
20% AEP Peak Flow Increase	29%	32%	31%	45%
1% AEP Peak Flow Increase	25%	20%	21%	21%
SSP3 – 2100 Parameters				
Temperature Increase	3.3°C	3.3°C	3.3°C	3.3°C
Rate of Change (α)	8	9 – 9.5 (depends on duration)	8	8
Rainfall Intensity Increase	29%	33% – 35%	29%	29%
Initial Loss Increase	7%	7%	7%	7%
Continuing Loss Increase	14%	14%	14%	14%
20% AEP Peak Flow Increase	59%	66%	63%	91%
1% AEP Peak Flow Increase	48%	39%	41%	41%

The updated hydrology was then applied to the TUFLOW hydraulic models and re-simulate the current 20% and 1% AEP design flood under potential future climate change conditions. Peak flood levels were extracted from the results of the climate change modelling and were used to prepare flood level difference mapping. The 1% AEP sensitivity under SSP3 is presented in **Maps RG-00-601** for 2050 **and RG-00-602 for** 2100. General ranges of flood level differences were extracted for each catchment and are presented in **Table 6-7** and **Table 6-8.** The flood level difference mapping shows that rainfall increases have the potential to significantly increase existing design flood levels across most catchments. More specifically, peak flood levels along the Colo River and Macdonald River are predicted to increase by at least 0.5 metres at most locations. Localised increases of more than 2 metres are predicted along part sections of the Colo River.

Although the flood level increases due to rainfall increases along Greens Creek are not predicted to be as significant, it should be recognised that backwater flooding from the Hawkesbury River is the dominant flooding mechanism across this catchment. Although the impacts of climate change on Hawkesbury River flood levels were not considered as part of the current study, the 'Hawkesbury-Nepean River Flood Study' (Rhelm CSS, 2024) determined that peak 1% AEP flood levels along the Lower Hawkesbury River could increase by more than 2 metres under climate change conditions. Therefore, climate change also has the potential to significantly impact on current design flood levels for the Greens Creek catchment.

Table 6-7 Summary of sensitivity testing outcomes for the 20% AEP event

Sensitivity Simulation	Parameter Change	Typical peak flood level differences for 20% AEP (m)			
		Colo River	Greens Creek	Webbs Creek	Macdonald River
Hydraulic Model Inputs					
Roughness coefficients	±20%	0.2-0.5	<0.1	0.1-0.2	0.2-0.4
Blockage	Culverts - Low Blockage: 0% Culverts - High blockage: 50% Bridges - Low Blockage: L1 0%, L3 0% Bridges - High blockage: L1+10%, L3 100%	<0.1	<0.1	<0.1	<0.1
Climate Change					
SPP3-2050	1.8°C temperature increase	0.6-1.2	0.1-0.2	0.2-0.4	0.5-1.1
SPP3-2100	3.3°C temperature increase	1.1-2.5	0.3-0.4	0.5-0.8	0.9-2.2

Table 6-8 Summary of sensitivity testing outcomes for the 1% AEP event

Sensitivity Simulation	Parameter Change	Typical peak flood level differences for 1% AEP (m)			
		Colo River	Greens Creek	Webbs Creek	Macdonald River
Hydraulic Model Inputs					
Roughness coefficients	±20%	0.5-0.8	<0.1	0.1-0.3	0.4-0.7
Blockage	Culverts - Low Blockage: 0% Culverts - High blockage: 50% Bridges - Low Blockage: L1 0%, L3 0% Bridges - High blockage: L1+10%, L3 100%	<0.1	<0.1	<0.1	<0.1
Climate Change					
SPP3-2050	1.8°C temperature increase	1.2-1.5	0.1-0.2	0.4-0.6	0.4-0.9
SPP3-2100	3.3°C temperature increase	2.0-2.8	0.2-0.4	0.7-0.9	1.0-1.8

7 Conclusions and Recommendations

The Combined Macdonald River, Colo River, Webbs Creek & Greens Creek Flood Study has been prepared for Hawkesbury City Council City Council to define the existing flood behaviour in the study area. The flood study will form the basis for the flood risk management study and plan.

The flood study, which is a comprehensive technical investigation of flood behaviour that provides the main technical foundation for the development of a robust flood risk management plan. It aims to provide a better understanding of the full range of flood behaviour. It involves consideration of the local flood history, available collected flood data, and the development of hydrologic and hydraulic models that are calibrated and verified, against historic flood events.

Flood behaviour has been assessed using a WBNM hydrological model and TUFLOW hydraulic model. The WBNM hydrologic model was developed as part of the Hawkesbury Nepean River Flood Study (Rhelm CSS, 2024). Minor modifications were made to the WBNM model as part this study. TUFLOW hydraulic models were established for each catchment in the study area.

The models were calibrated using the July 2022, March 2022 events and validated using the February 2020 and March 1978 event.

The hydrological and hydraulic models were analysed for the Probable Maximum Flood (PMF), 1 in 2000 AEP, 1 in 1000 AEP, 1 in 500 AEP, 1 in 200 AEP , 1% AEP, 2% AEP, 10% AEP and 20% AEP events. The design events are based on ARR2019 methods. For the Macdonald and Colo Rivers, the design events have been calibrated using flood frequency analysis.

The flood study will form the basis for the flood management study and plan.

8 References

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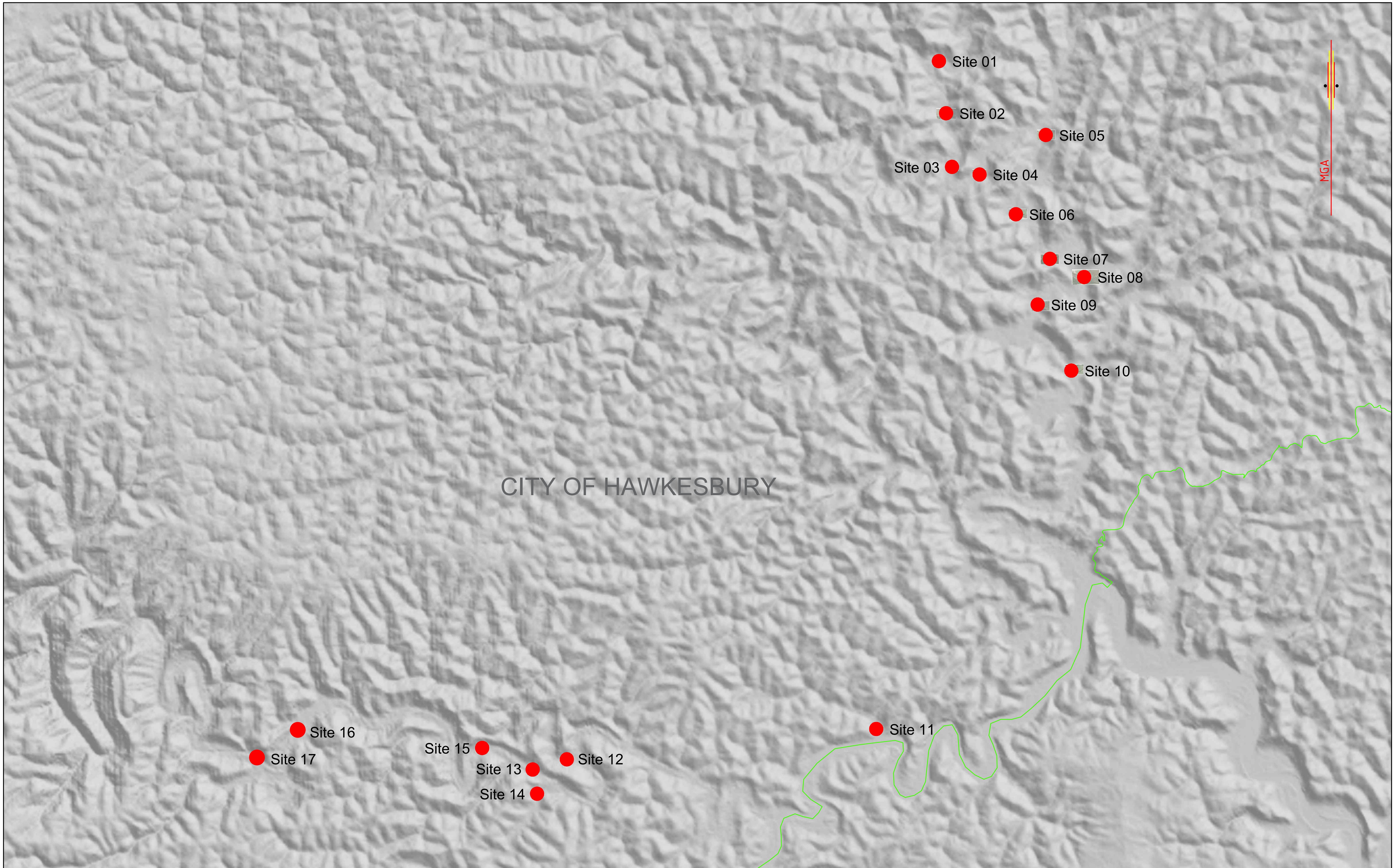
Appendix A

Survey



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VERTICAL : AHD 71
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RIVER CROSS SECTION

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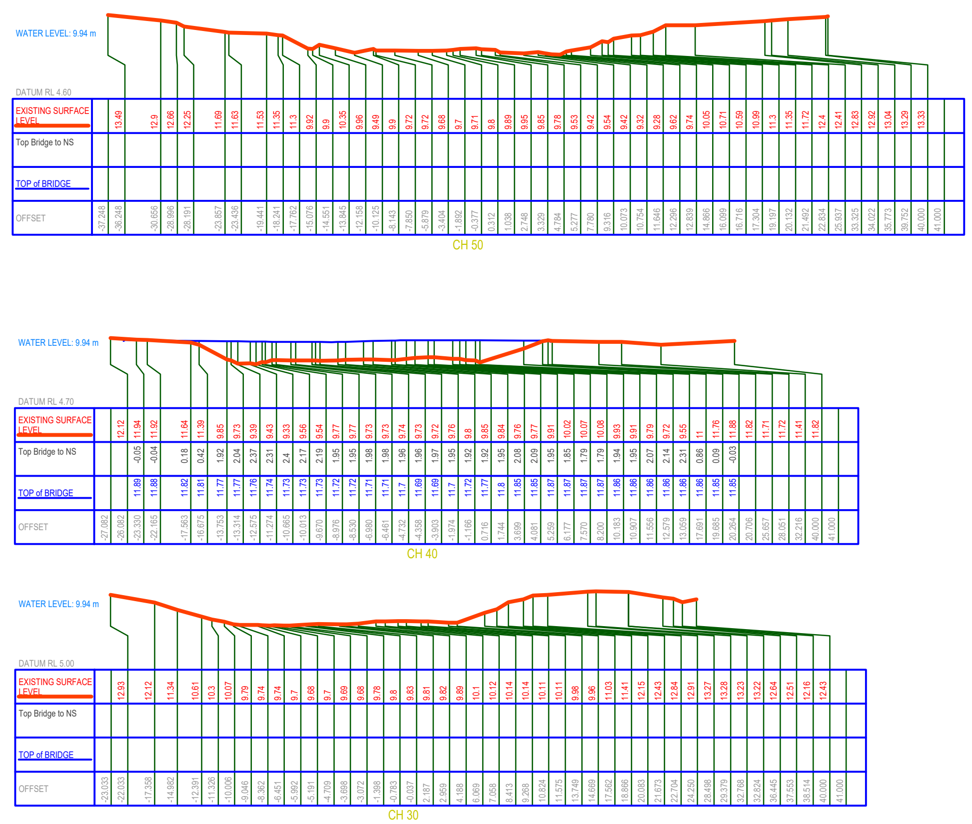

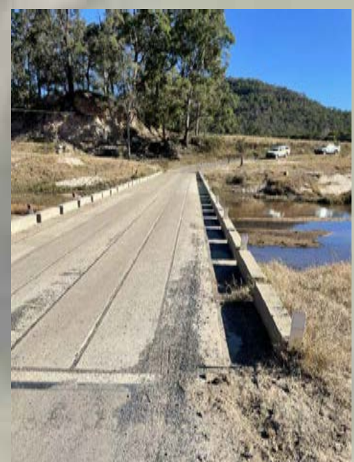

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- CONCRETE WALL
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- BACK OF KERB

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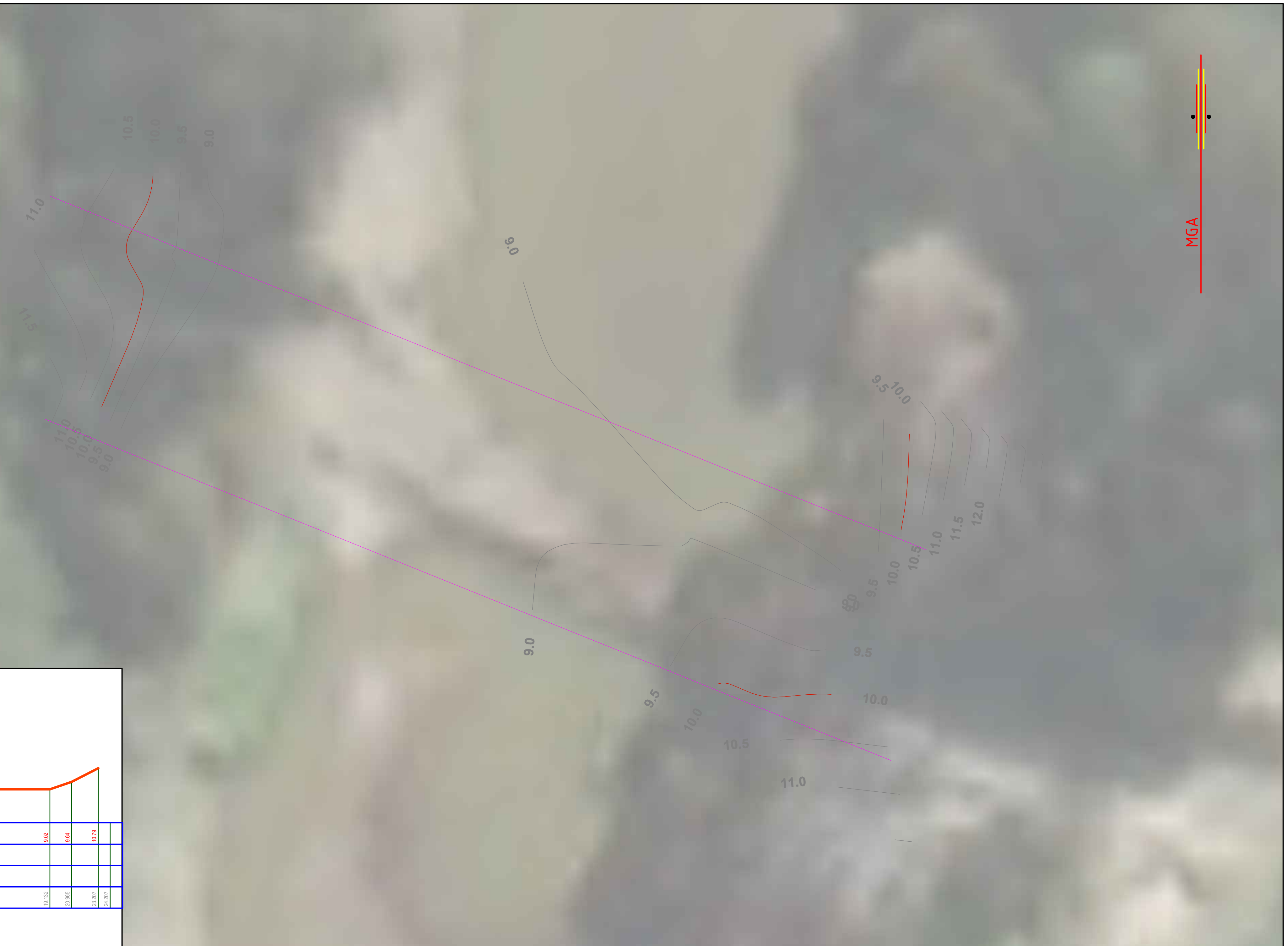

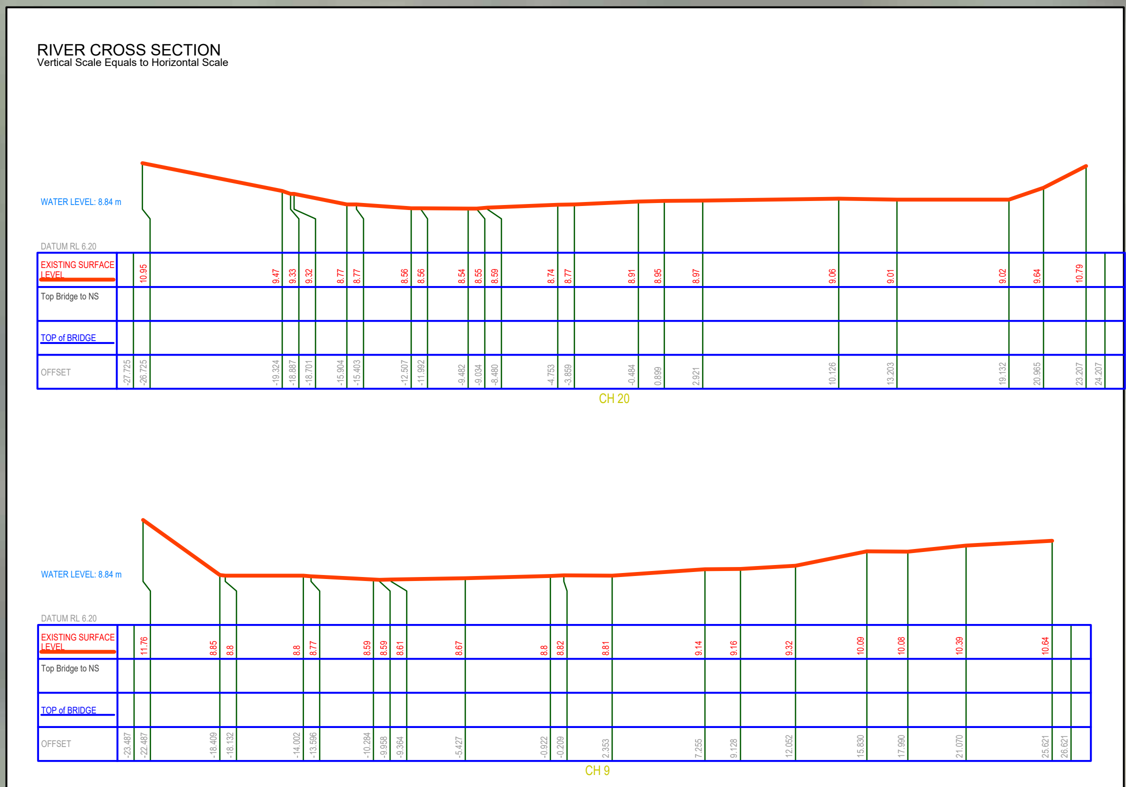

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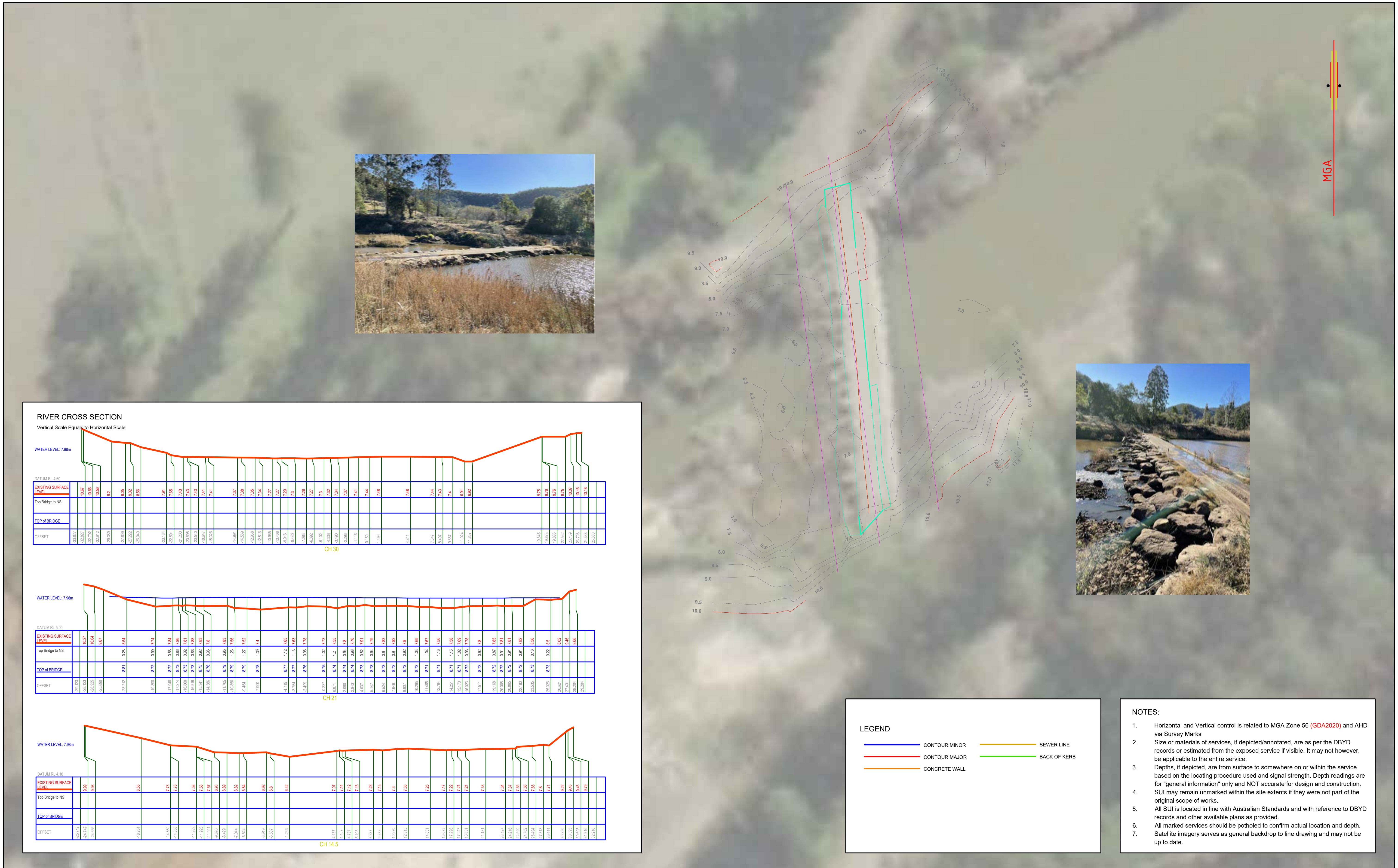

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- BACK OF KERB

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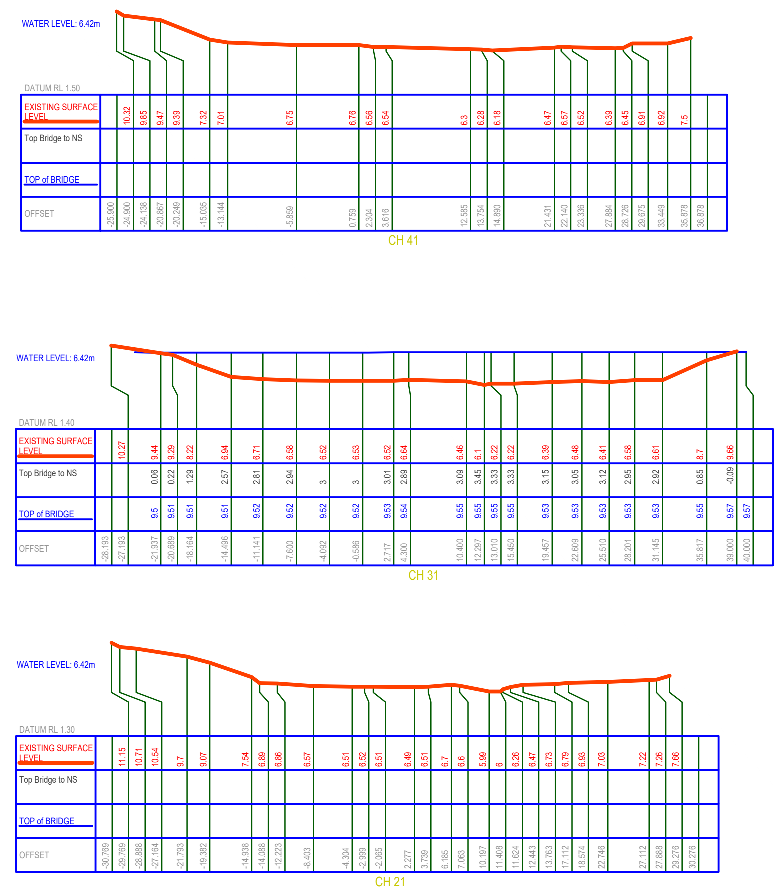

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CONTOUR MAJOR	BACK OF KERB
CONCRETE WALL	

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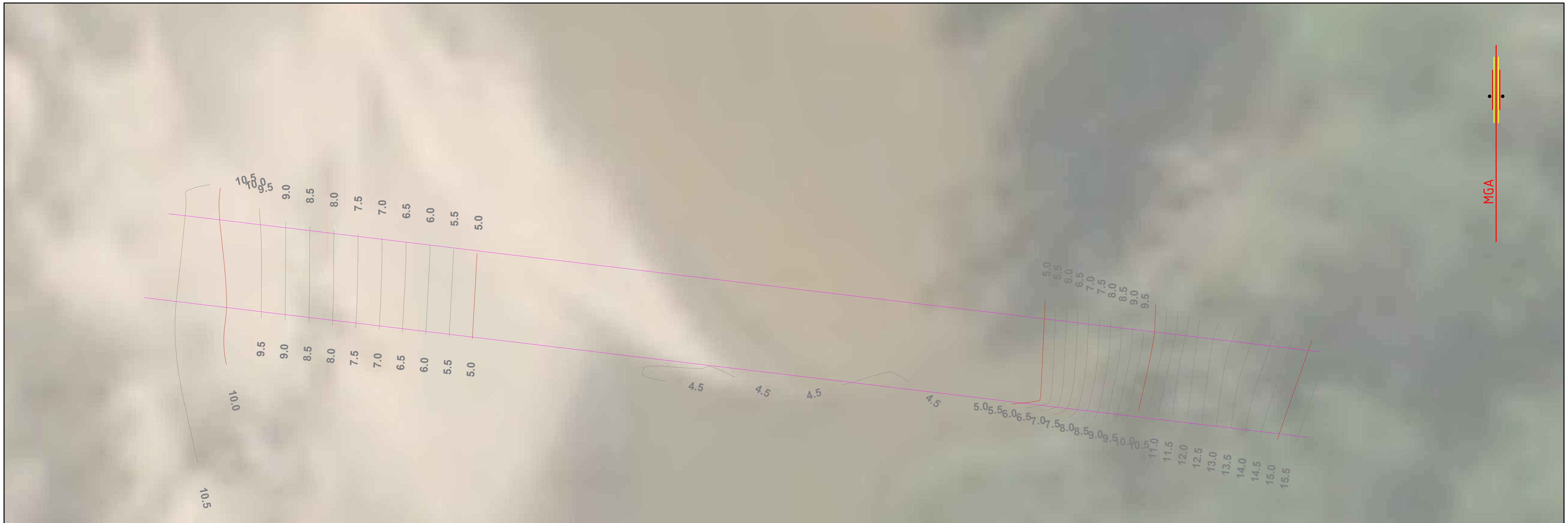

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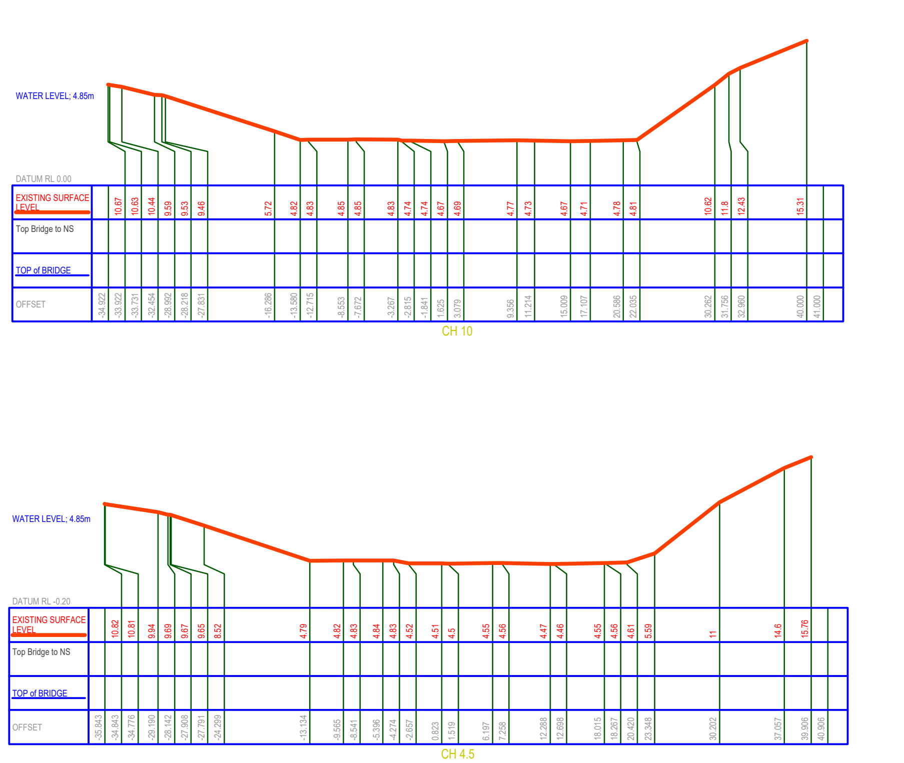

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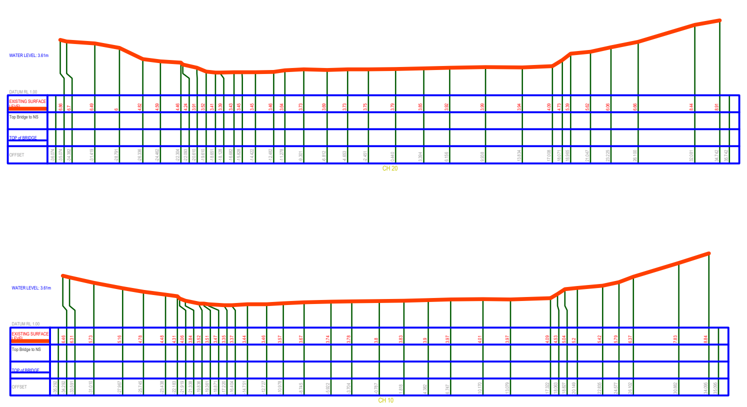

LEGEND

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SCALE: 1:100,000

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COORDINATE DATUM
HORIZONTAL : MGA 2020 ZONE 56
VERTICAL : AHD 71
Contour Interval : 0.5 meter

NORTH POINT

B C E SPATIAL
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JOB No. N1235

PLAN No. N1235-00

Sheet 1 of 1

SCALE: Scale 1 : 100K @ A3

REVISION: A

LEGEND

- CONTOUR MINOR
- CONTOUR MAJOR
- CONCRETE WALL
- SEWER LINE
- BACK OF KERB

NOTES:

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REV	DATE	DESCRIPTION	DRAWN	SURVEYOR	APPROVED
A	10/08/2023	Initial Issue	DN	MD	LM

CLIENT: Hawkesbury City Council

SCALE: 1:100,000

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COORDINATE DATUM
HORIZONTAL : MGA 2020 ZONE 56
VERTICAL : AHD 71
Contour Interval : 0.5 meter

NORTH POINT

B C E SPATIAL
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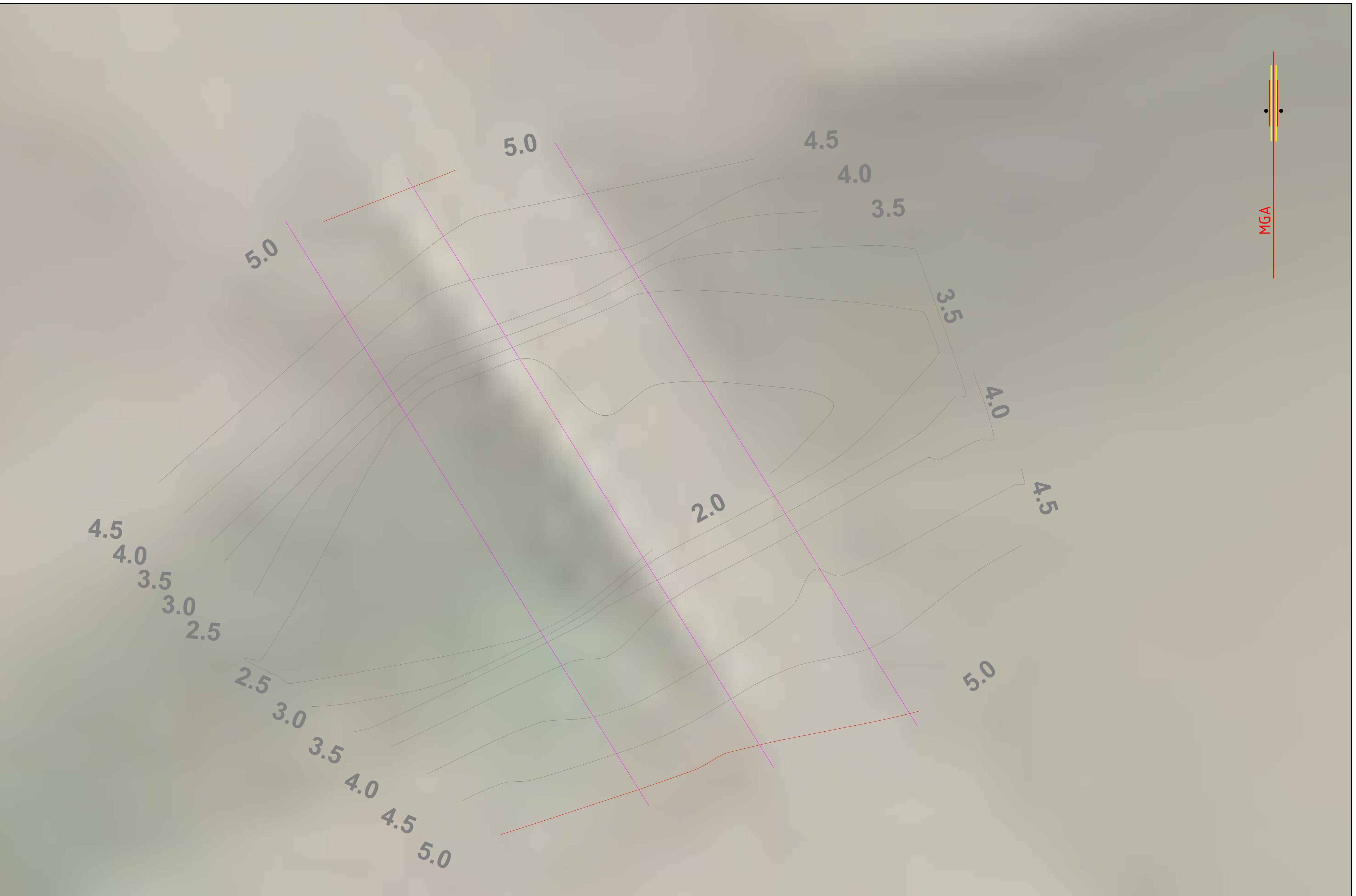
JOB No. N1235

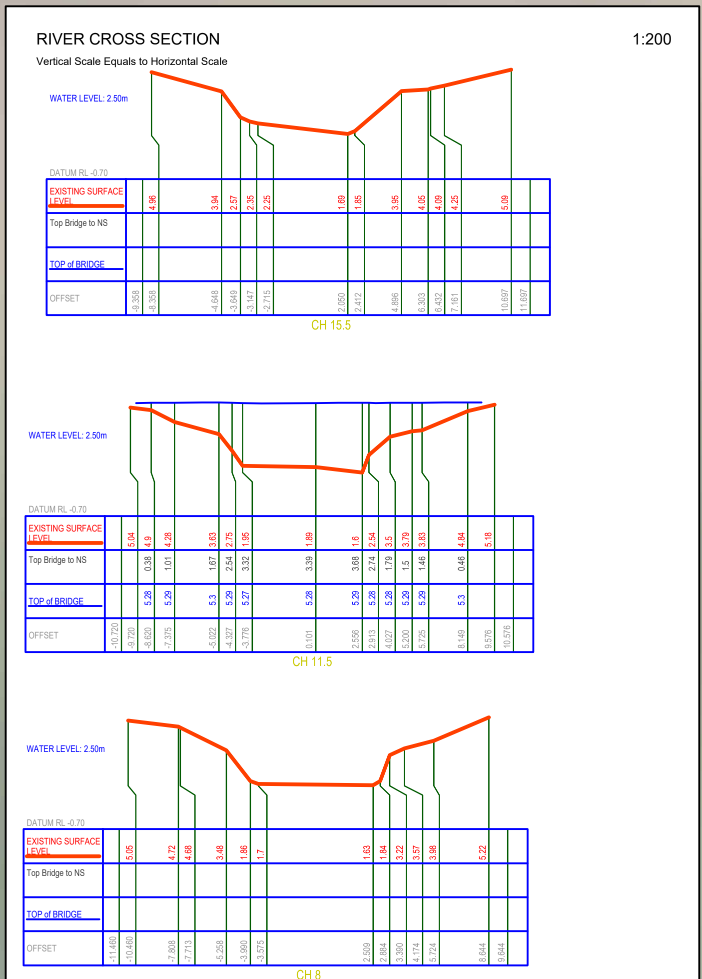
PLAN No. N1235-07

Sheet 1 of 1

SCALE: Scale 1 : 100K @ A3

REVISION: A





LEGEND

- CONTOUR MINOR
- CONTOUR MAJOR
- CONCRETE WALL
- SEWER LINE
- BACK OF KERB

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REV	DATE	DESCRIPTION	DRAWN	SURVEYOR	APPROVED
A	10/08/2023	Initial Issue	DN	MD	LM

CLIENT: Hawkesbury City Council

SCALE: 1:125

COORDINATE DATUM
HORIZONTAL : MGA 2020 ZONE 56
VERTICAL : AHD 71
Contour Interval : 0.5 meter

NORTH POINT

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JOB No. N1235
PLAN No. N1235-08
Sheet 1 of 1
SCALE: Scale 1 : 125 @ A3
REVISION: A

LEGEND

- CONTOUR MINOR
- CONTOUR MAJOR
- CONCRETE WALL
- SEWER LINE
- BACK OF KERB

NOTES:

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REV	DATE	DESCRIPTION	DRAWN	SURVEYOR	APPROVED
A	10/08/2023	Initial Issue	DN	MD	LM

CLIENT: Hawkesbury City Council

SCALE: 1:500

COORDINATE DATUM
HORIZONTAL : MGA 2020 ZONE 56
VERTICAL : AHD 71
Contour Interval : 0.5 meter

NORTH POINT

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JOB No. N1235

PLAN No. N1235-09

Sheet 1 of 1

SCALE: Scale 1 : 500 @ A3

REVISION: A

LEGEND

- CONTOUR MINOR
- CONTOUR MAJOR
- CONCRETE WALL
- SEWER LINE
- BACK OF KERB

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A	10/08/2023	Initial Issue	DN	MD	LM

CLIENT: Hawkesbury City Council

SCALE: 1:500

COORDINATE DATUM
HORIZONTAL : MGA 2020 ZONE 56
VERTICAL : AHD 71
Contour Interval : 0.5 meter

NORTH POINT

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JOB No. N1235

PLAN No. N1235-10R

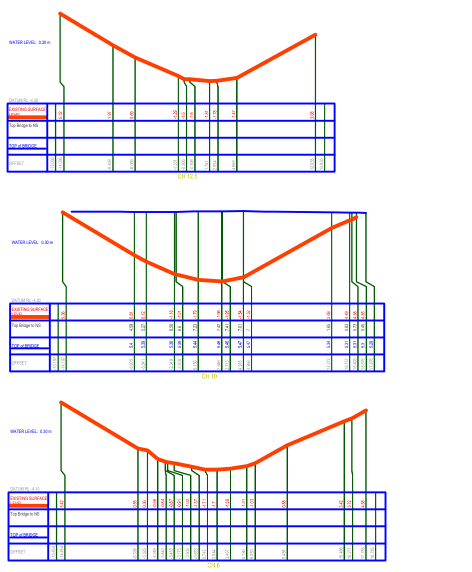
Sheet 1 of 1

SCALE: Scale 1 : 500 @ A3

REVISION: A

RIVER CROSS SECTION

Vertical Scale Equals to Horizontal Scale



LEGEND

- CONTOUR MINOR
- CONTOUR MAJOR
- CONCRETE WALL
- SEWER LINE
- BACK OF KERB

NOTES:

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REV	DATE	DESCRIPTION	DRAWN	SURVEYOR	APPROVED
A	10/08/2023	Initial Issue	DN	MD	LM

CLIENT: Hawkesbury City Council

SCALE: 1:250

COORDINATE DATUM
HORIZONTAL : MGA 2020 ZONE 56
VERTICAL : AHD 71
Contour Interval : 0.5 meter

NORTH POINT

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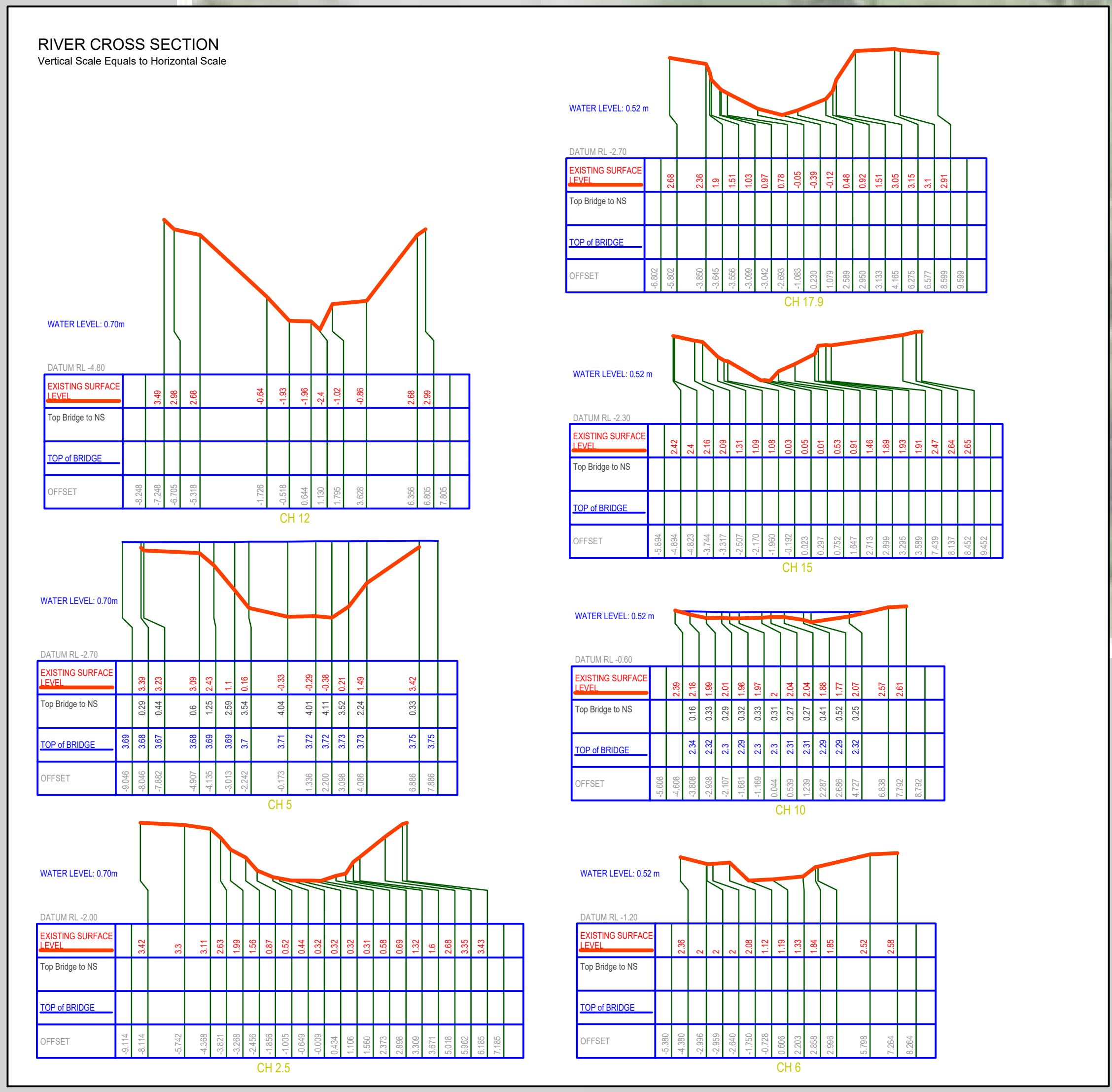
JOB No. N1235

PLAN No. N1235-10S

Sheet 1 of 1

SCALE: Scale 1 : 250 @ A3

REVISION: A



LEGEND

- CONTOUR MINOR
- CONTOUR MAJOR
- CONCRETE WALL
- SEWER LINE
- BACK OF KERB

NOTES:

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A	10/08/2023	Initial Issue	DN	MD	LM

CLIENT: Hawkesbury City Council

SCALE: 1:250

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COORDINATE DATUM
HORIZONTAL : MGA 2020 ZONE 56
VERTICAL : AHD 71
Contour Interval : 0.5 meter

NORTH POINT

B C E SPATIAL
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JOB No. N1235

PLAN No. N1235-11

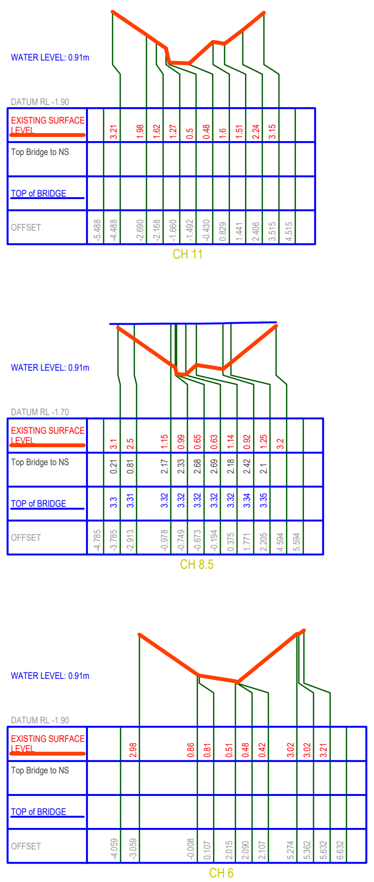
Sheet 1 of 1

SCALE: Scale 1 : 250 @ A3

REVISION: A

RIVER CROSS SECTION

Vertical Scale Equals to Horizontal Scale



LEGEND

- CONTOUR MINOR
- CONTOUR MAJOR
- CONCRETE WALL
- SEWER LINE
- BACK OF KERB

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A	10/08/2023	Initial Issue	DN	MD	LM

CLIENT: Hawkesbury City Council

SCALE: 1:125

COORDINATE DATUM
HORIZONTAL : MGA 2020 ZONE 56
VERTICAL : AHD 71
Contour Interval : 0.5 meter

NORTH POINT

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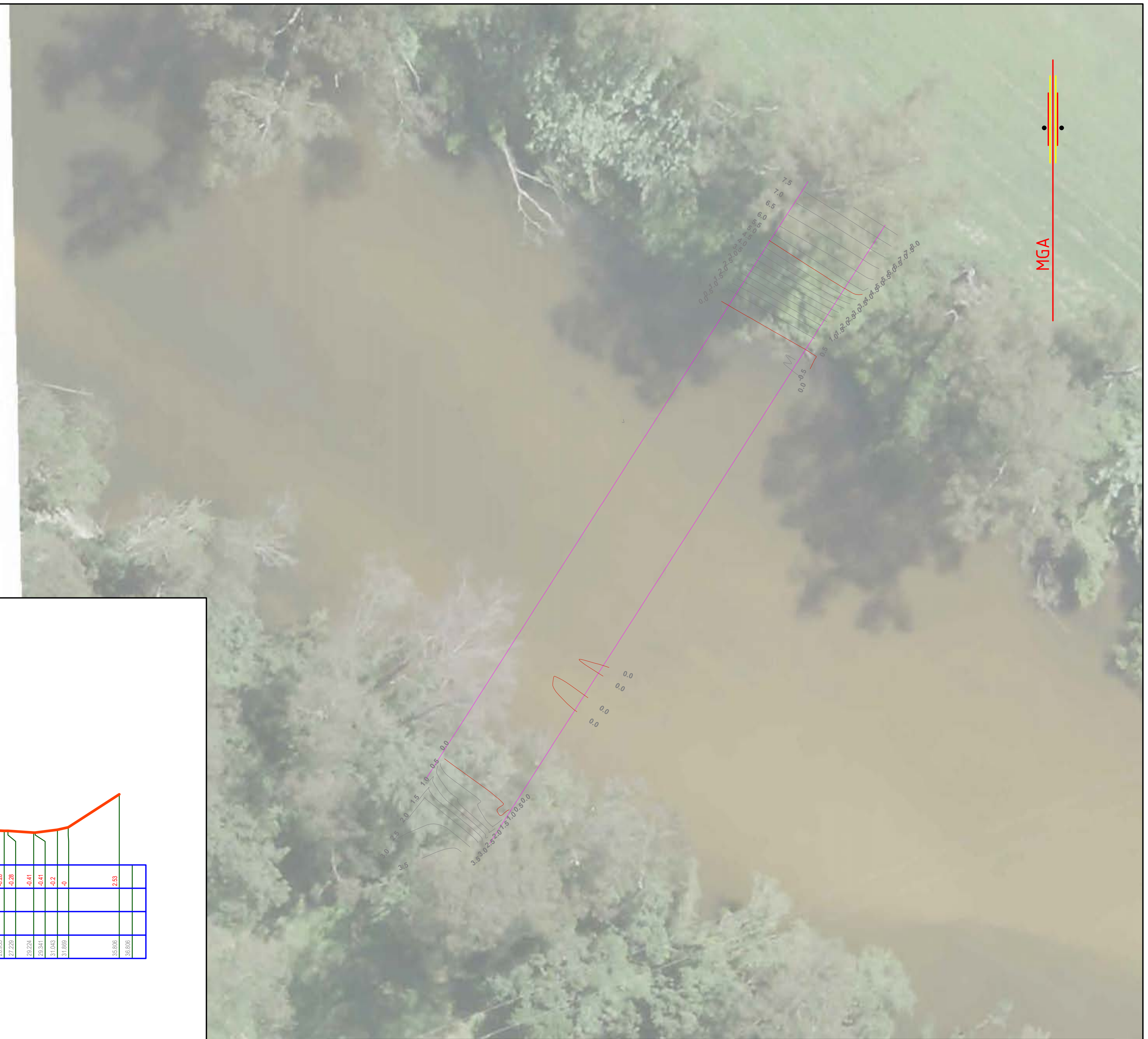
JOB No. N1235

PLAN No. N1235-12

Sheet 1 of 1

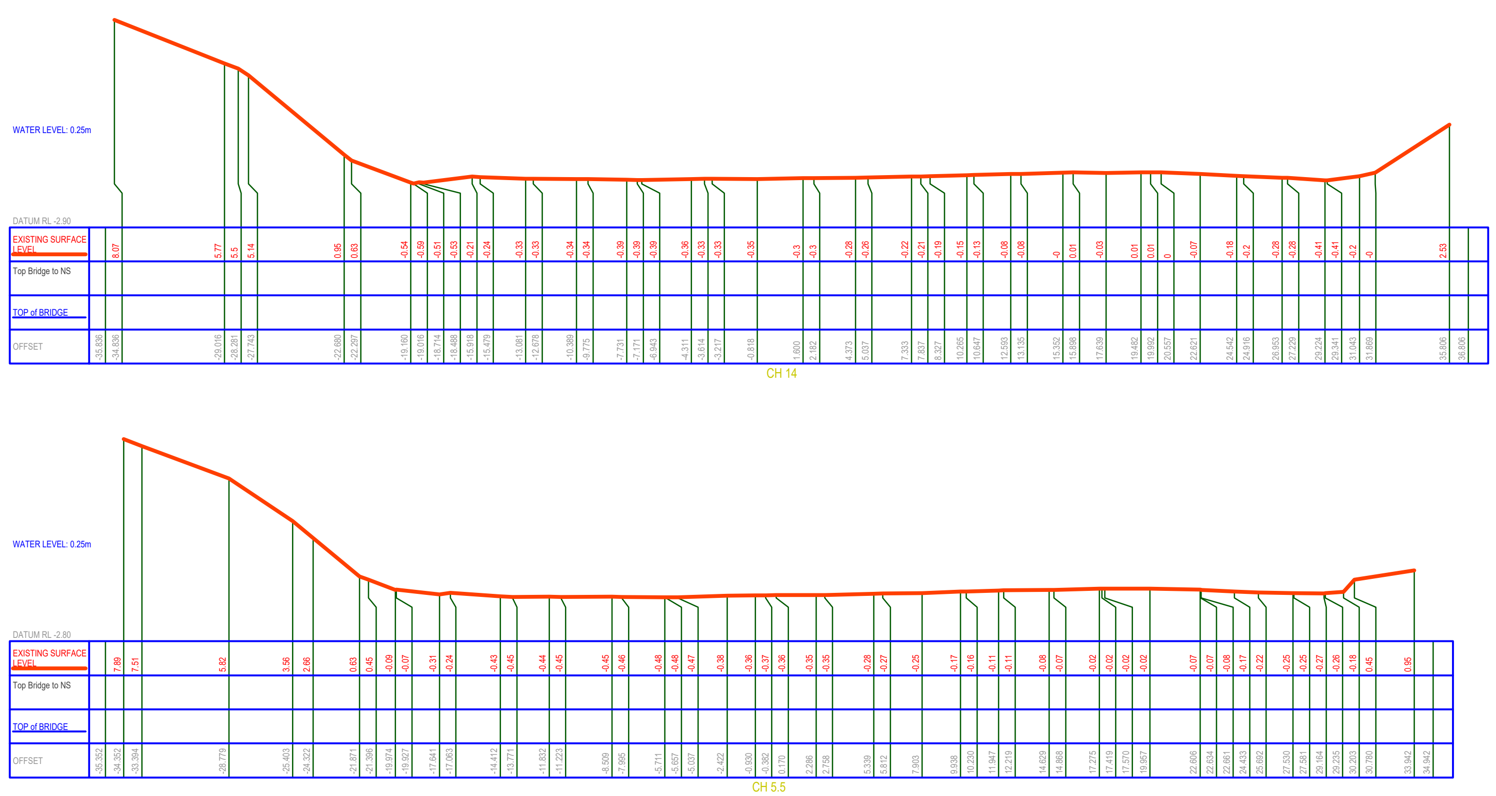
SCALE: Scale 1 : 125 @ A3

REVISION: A



RIVER CROSS SECTION

Vertical Scale Equals to Horizontal Scale



LEGEND

- CONTOUR MINOR
- CONTOUR MAJOR
- CONCRETE WALL
- SEWER LINE
- BACK OF KERB

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A	10/08/2023	Initial Issue	DN	MD	LM

CLIENT: Hawkesbury City Council

SCALE: 1:500

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COORDINATE DATUM
HORIZONTAL : MGA 2020 ZONE 56
VERTICAL : AHD 71
Contour Interval : 0.5 meter

NORTH POINT

B C E SPATIAL
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JOB No. N1235

PLAN No. N1235-13

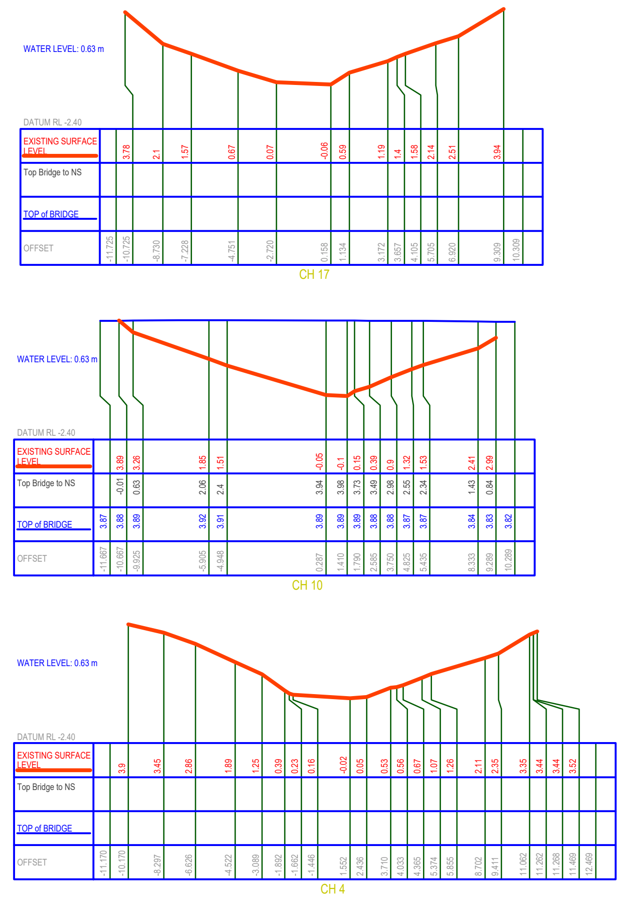
Sheet 1 of 1

SCALE: Scale 1 : 500 @ A3

REVISION: A

RIVER CROSS SECTION

Vertical Scale Equals to Horizontal Scale



LEGEND

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- BACK OF KERB

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REV	DATE	DESCRIPTION	DRAWN	SURVEYOR	APPROVED
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CLIENT: Hawkesbury City Council

SCALE: 1:250

COORDINATE DATUM
HORIZONTAL : MGA 2020 ZONE 56
VERTICAL : AHD 71
Contour Interval : 0.5 meter

NORTH POINT

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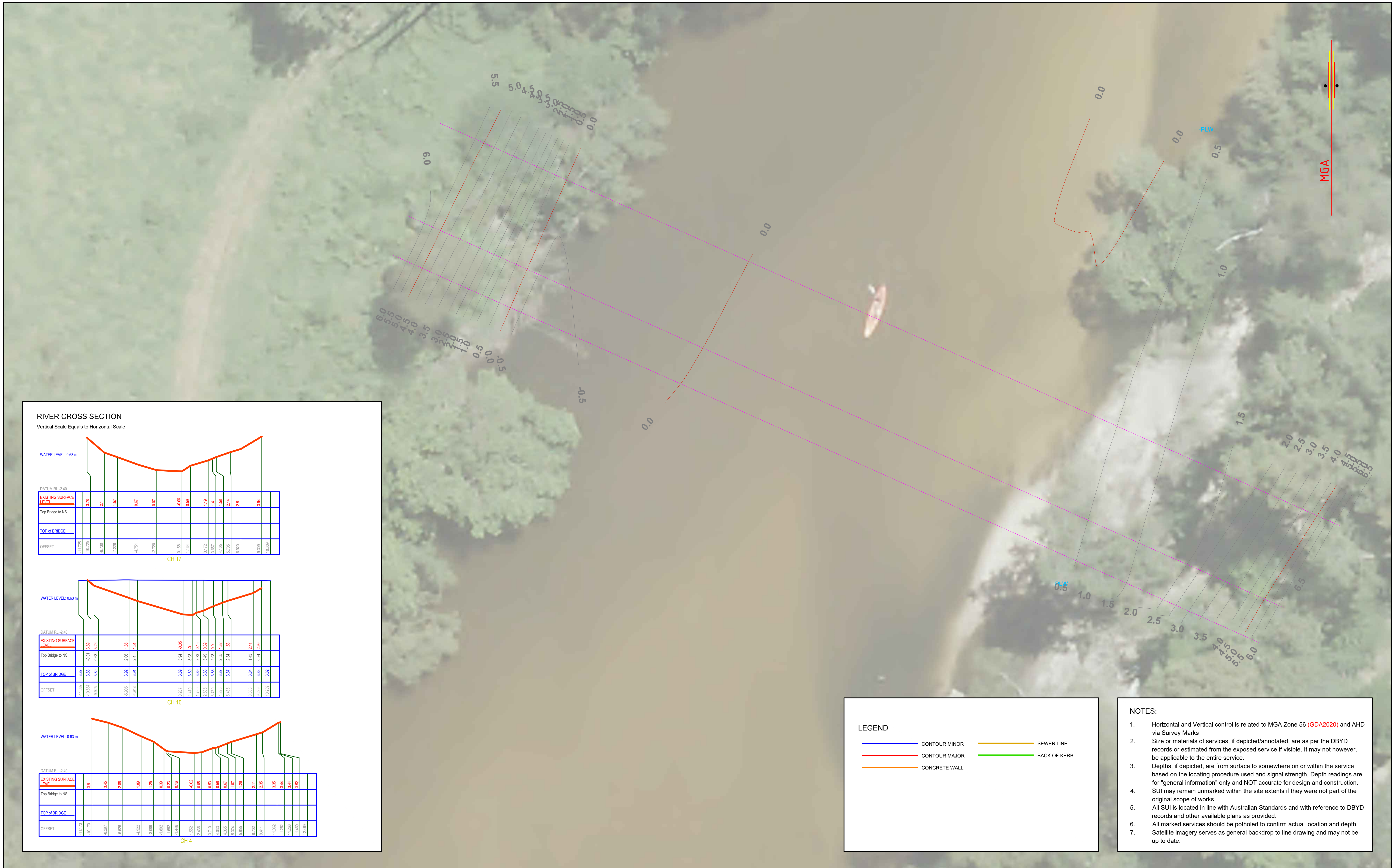
JOB No. N1235

PLAN No. N1235-14

Sheet 1 of 1

SCALE: Scale 1 : 250 @ A3

REVISION: A



LEGEND

- CONTOUR MINOR
- CONTOUR MAJOR
- CONCRETE WALL
- SEWER LINE
- BACK OF KERB

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CLIENT: Hawkesbury City Council

SCALE: 1:250

COORDINATE DATUM
HORIZONTAL : MGA 2020 ZONE 56
VERTICAL : AHD 71
Contour Interval : 0.5 meter

NORTH POINT

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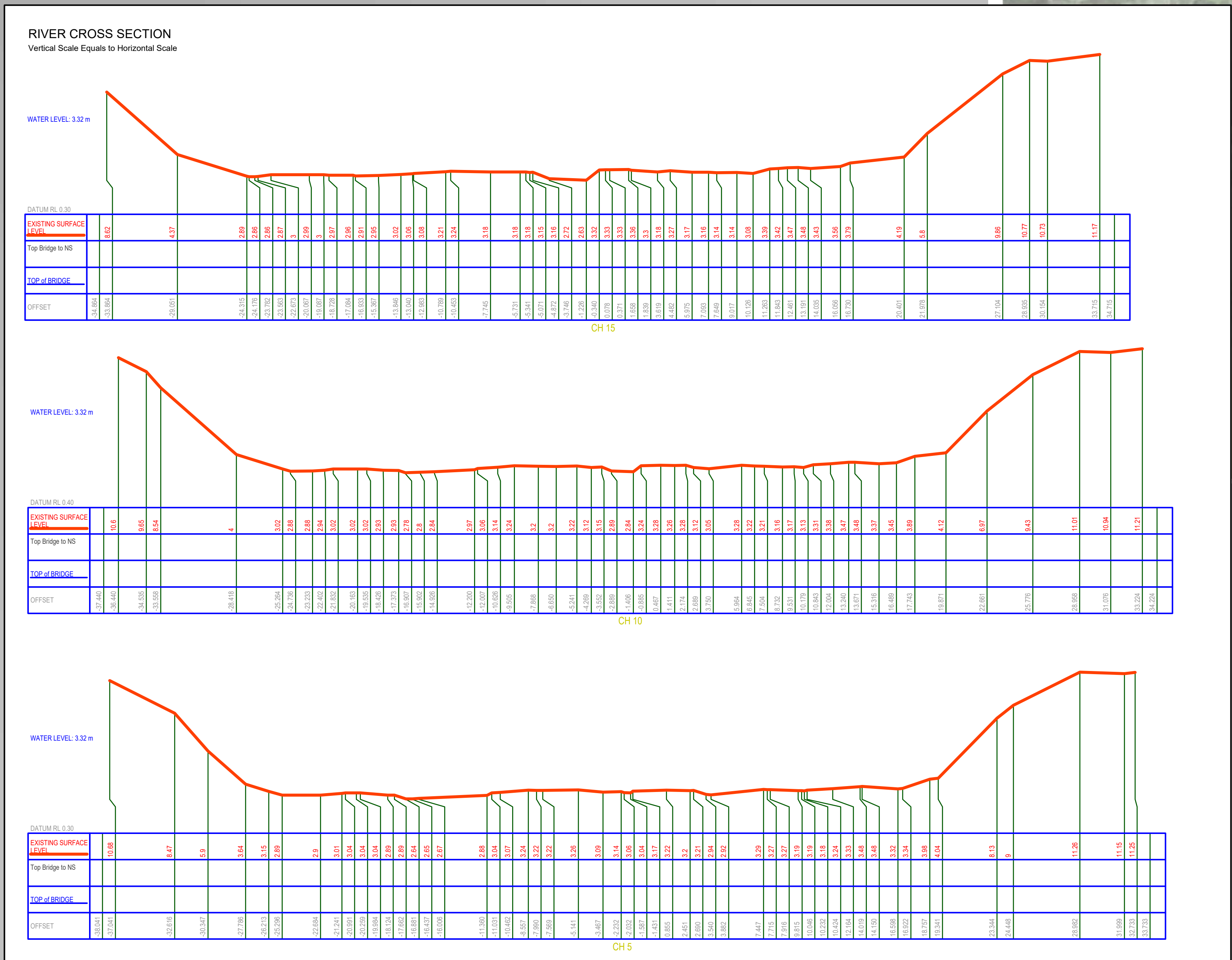
JOB No. N1235

PLAN No. N1235-14

Sheet 1 of 1

SCALE: Scale 1 : 250 @ A3

REVISION: A



LEGEND

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- CONCRETE WALL
- SEWER LINE
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6. All marked services should be potholed to confirm actual location and depth.
7. Satellite imagery serves as general backdrop to line drawing and may not be up to date.

REV	DATE	DESCRIPTION	DRAWN	SURVEYOR	APPROVED
A	10/08/2023	Initial Issue	DN	MD	LM

CLIENT: Hawkesbury City Council

SCALE: 1:500

DISCLAIMER
This plan has been prepared for the client only and should not be used in whole or part for any other purposes unless authorised by BCE Surveying Pty Ltd.

COORDINATE DATUM
HORIZONTAL : MGA 2020 ZONE 56
VERTICAL : AHD 71
Contour Interval : 0.5 meter

NORTH POINT

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LICENSED & ENGINEERING SURVEYING CONSULTANTS

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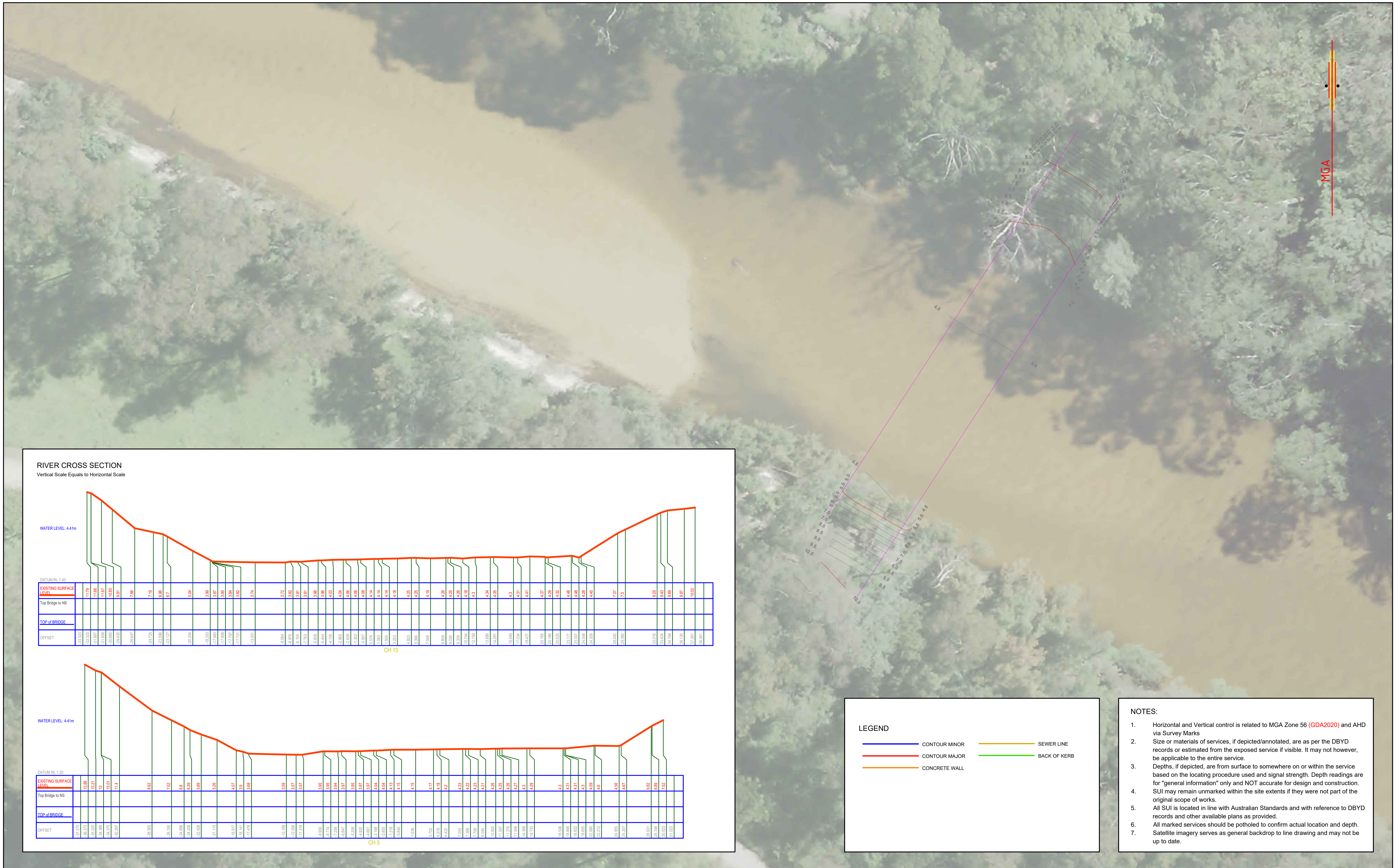
JOB No. N1235
PLAN No. N1235-16
Sheet 1 of 1
SCALE: Scale 1 : 500 @ A3
REVISION: A



LEGEND

- CONTOUR MINOR
- CONTOUR MAJOR
- CONCRETE WALL
- SEWER LINE
- BACK OF KERB

NOTES:

1. Horizontal and Vertical control is related to MGA Zone 56 (GDA2020) and AHD via Survey Marks
2. Size or materials of services, if depicted/annotated, are as per the DBYD records or estimated from the exposed service if visible. It may not however, be applicable to the entire service.
3. Depths, if depicted, are from surface to somewhere on or within the service based on the locating procedure used and signal strength. Depth readings are for "general information" only and NOT accurate for design and construction.
4. SUI may remain unmarked within the site extents if they were not part of the original scope of works.
5. All SUI is located in line with Australian Standards and with reference to DBYD records and other available plans as provided.
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A	10/08/2023	Initial Issue	DN	MD	LM

CLIENT: Hawkesbury City Council

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COORDINATE DATUM
HORIZONTAL : MGA 2020 ZONE 56
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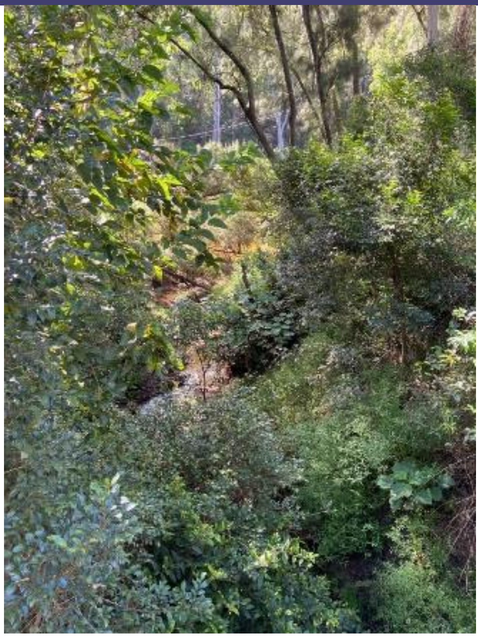
JOB No. N1235
PLAN No. N1235-17
Sheet 1 of 1
SCALE: Scale 1 : 500 @ A3
REVISION: A

Appendix B

Site Inspection Photographs

Colo River 17/02/2022



Looking towards Upper Colo River Guage from Upper Colo Road

Looking across to Upper Colo Reserve from Upper Colo Road

Culvert beneath Upper Colo Road connecting tributary to Upper Colo River

Looking North from Upper Colo Road

Colo River 17/02/2022	
 Looking down at damaged Upper Colo Bridge from Colo Heights Road	 Upper Colo Bridge. Damaged by flooding in 2021
 Tributary leading north to Upper Colo River from Upper Colo Road	 Looking north from Bielany Campground across mid-Colo River

Colo River 17/02/2022	
 Putty Road Bridge, looking upstream	 Looking west across Lower Colo River from Lower Colo Road
 Looking north towards Whatleys Creek, a tributary of lower Colo River	 Looking north across lower Colo River floodplain

Colo River 17/02/2022	
 Looking east at the Colo River from Lower Colo River Road across from Hebron Farm	 Looking west at Greens Road Bridge from the confluence of Colo and Hawkesbury Rivers

Macdonald River 18/02/2022	
 Looking upstream from Upper MacDonald Road Bridge towards Macdonald Inflow	 Looking upstream from bridge at intersection of Upper MacDonald Road and Kander Road
 Looking downstream from bridge at intersection of Upper MacDonald Road and Kander Road	 Looking south from Wollombi Road at Mago Creek

Macdonald River 18/02/2022	
 Looking upstream of MacDonald River, across from Bulga Street	 Sandbank along mid-McDonald River next to St Albans RFS
 St Albans Bridge	 St Albans Road Bridge across Flemmings Creek

Macdonald River 18/02/2022	
 Culvert next to St Albans Road Bridge across Flemmings Creek	

Webbs Creek 17/02/2022	
 Looking towards Webbs Creek from Webbs Creek Road, near Dinki Dell Campsite	 Looking upstream from bridge at Chaseling Road North, just upstream of confluence of Webbs Creek and Hawkesbury River

<table>
<tr><th colspan="2">Greens Creek 17/02/2022</th></tr>
<tr><td>
Greens Creek looking north from Greens Road</td><td>
Greens Road Bridge across Greens Creek, next to Green Swamp Trail</td></tr>
<tr><td>
Floodplain at confluence of Greens Creek and Haweksbury River from Greens Road</td><td></td></tr>
</table>

Appendix C

Hydraulic Model Calibration

Catchment Simulation Solutions

Rhelm

Appendix C – Hydraulic Model Calibration and Validation

Please note: gauge zero values of 1.468 mAHD and 2.76 mAHD were adopted for Upper Colo gauge (212290) and the St Albans gauge (212228) respectively.

1 July 2022

1.1 Stage hydrograph comparison

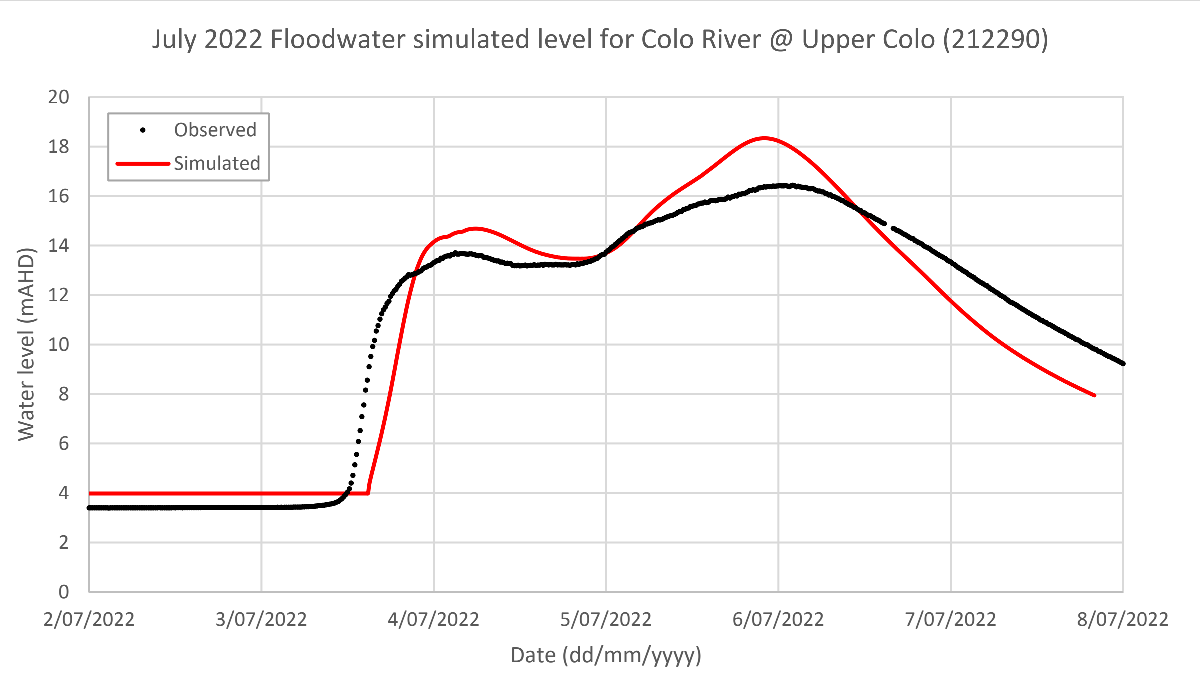


Figure C1 July 2022 Observed vs Simulated water level for Upper Colo gauge (212290)

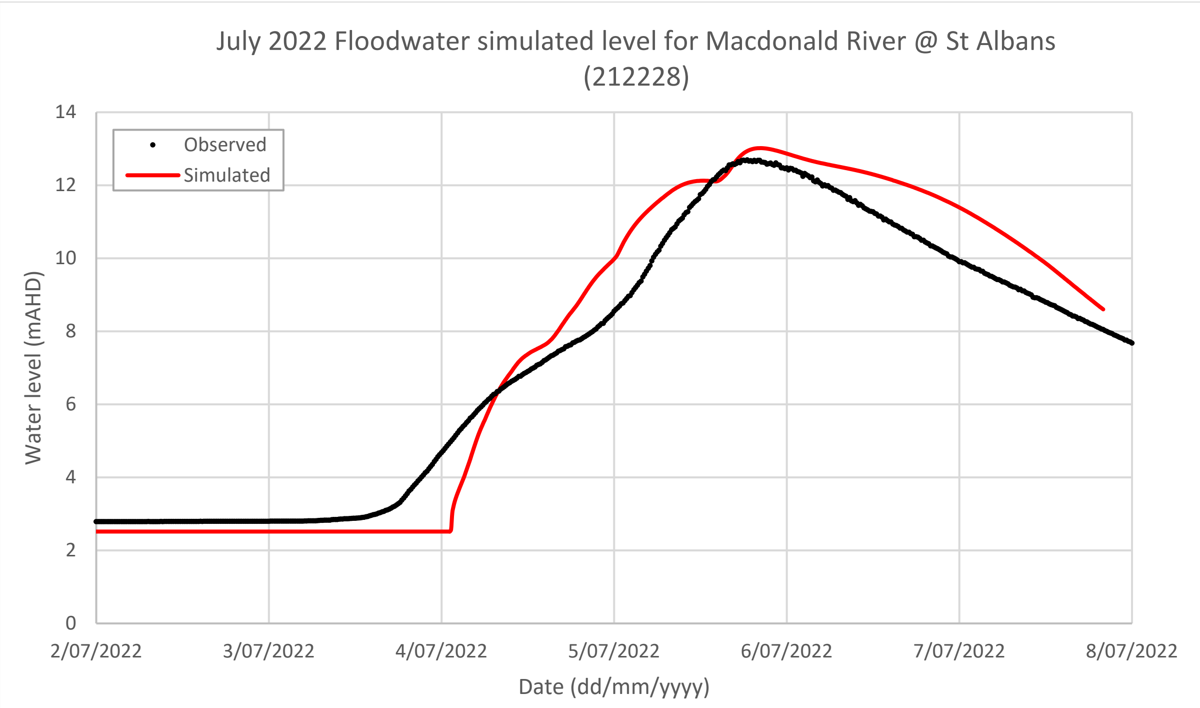


Figure C2 July 2022 Observed vs Simulated water level for St Albans gauge (212228)

Appendix C – Hydraulic Model Calibration and Validation

1.2 Surface water profile

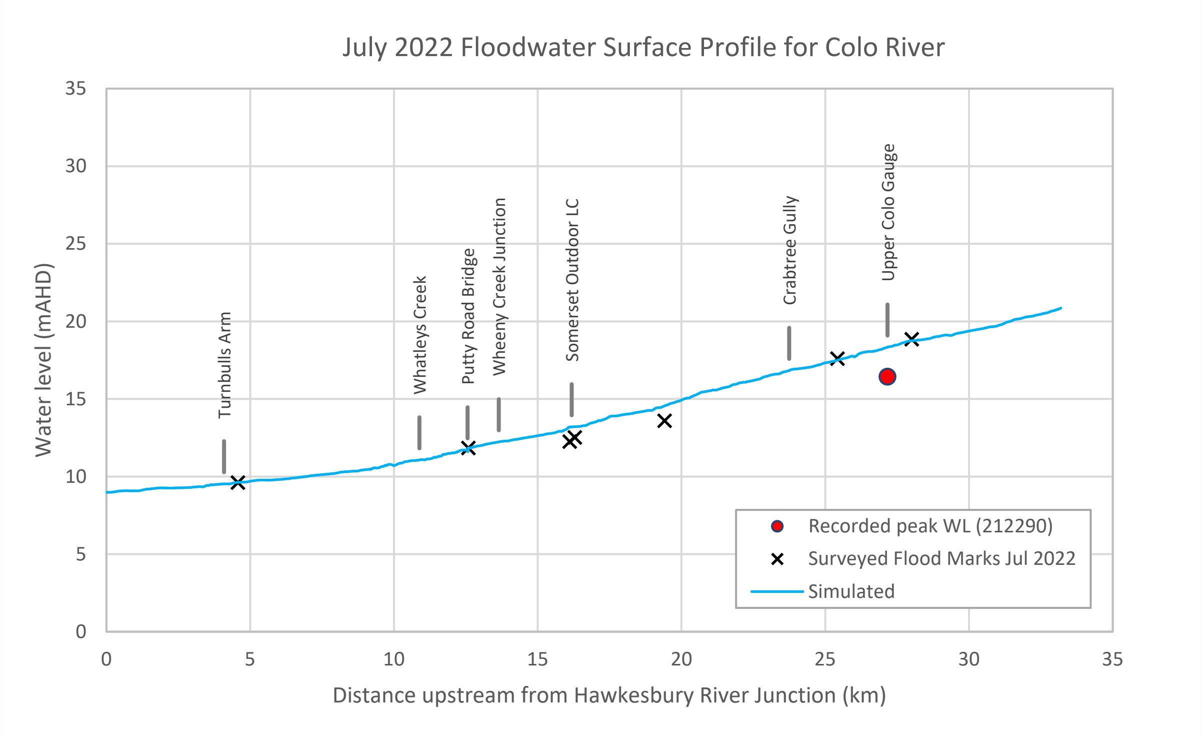


Figure C3 Simulated July 2022 floodwater surface profile for Colo River

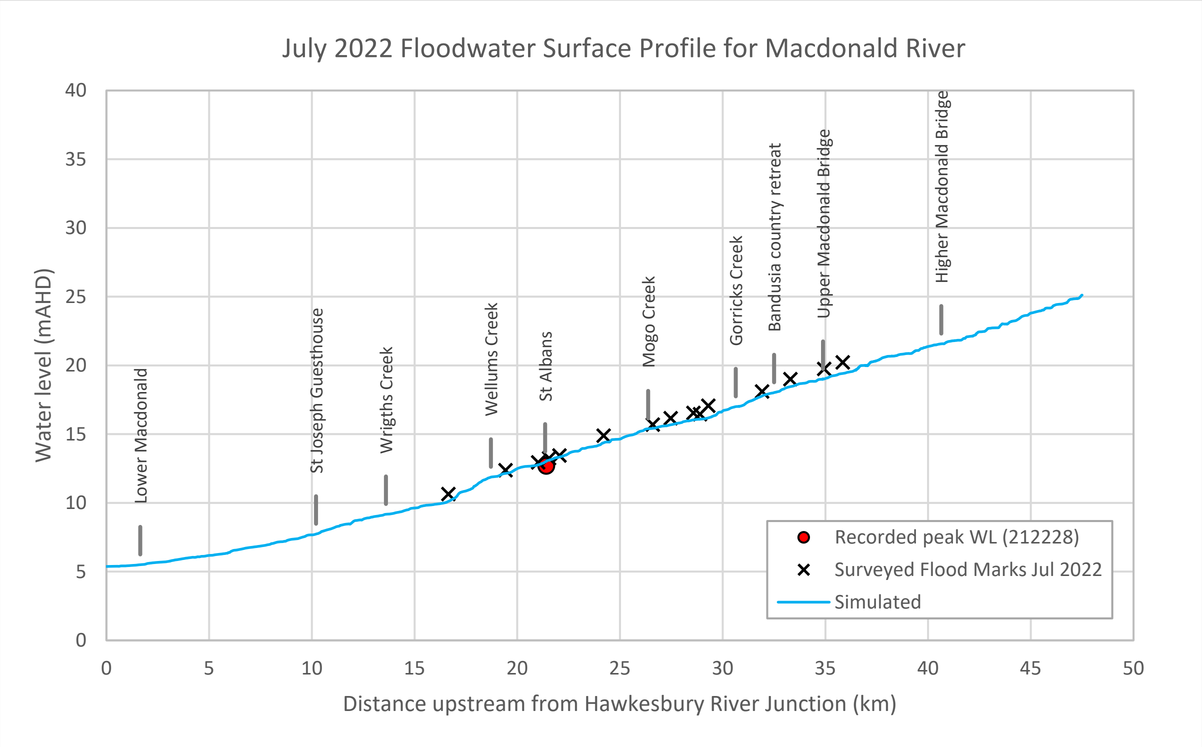


Figure C4 Simulated July 2022 floodwater surface profile for Macdonald River

Appendix C – Hydraulic Model Calibration and Validation

1.3 Flood mark comparison

Table C1 Simulated and surveyed flood levels the July 2022 flood in Colo River

Site	Quality of Evidence	Survey (mAHD)	Simulated (mAHD)	Difference (m)	Comments
Site 800	High	19.77	19.10	-0.67	
Site 802	Med	18.85	18.76	-0.08	
Site 802	Med	17.00	18.06	1.07	Survey 0.6m lower than DS flood mark. Survey mark likely problematic.
Site 803	Low	17.60	17.39	-0.21	
Site 804	Low	13.60	14.26	0.65	
Site 805	Med	12.25	13.04	0.78	
Site 806	Med	12.53	13.15	0.63	
Site 806	Med	10.42	12.24	1.82	Survey 1.4m lower than DS flood mark at Putty Road bridge. Survey mark likely problematic.
Site 808	Med	11.81	11.72	-0.08	
Site 809	Med	11.84	11.73	-0.11	
Site 808	Med	9.61	9.64	0.03	
			Average	0.35	

Table C2 Simulated and surveyed flood levels the July 2022 flood in Macdonald River

Site	Quality of Evidence	Survey (mAHD)	Simulated (mAHD)	Difference (m)	Comments
Site 900	Med	19.74	19.02	-0.72	
Site 900	Med	19.26	19.02	-0.23	
Site 901	Med	20.23	19.38	-0.84	
Site 904	Med	19.47	18.94	-0.53	
Site 904	Med	20.37	18.93	-1.44	
Site 904	Med	19.44	18.94	-0.51	
Site 905	High	19.00	18.48	-0.52	
Site 905	Med	19.00	18.45	-0.55	
Site 906	High	18.10	17.71	-0.39	
Site 906	High	18.06	17.70	-0.36	
Site 907	High	15.69	15.32	-0.37	
Site 908	Med	14.55	14.38	-0.16	
Site 908	High	14.88	14.38	-0.50	
Site 909	High	16.16	15.63	-0.52	
Site 909	Med	15.88	15.64	-0.24	
Site 910	Low	17.07	16.18	-0.89	
Site 911	Low	16.45	16.09	-0.36	
Site 912	Med	16.73	16.01	-0.71	
Site 912	Med	16.54	16.01	-0.53	

Appendix C – Hydraulic Model Calibration and Validation

Site	Quality of Evidence	Survey (mAHD)	Simulated (mAHD)	Difference (m)	Comments
Site 913	Med	13.44	13.33	-0.11	
Site 913	Med	13.45	13.33	-0.12	
Site 914	Low	14.47	13.76	-0.71	
Site 915	High	13.21	13.08	-0.13	
Site 915	High	13.25	13.08	-0.17	
Site 915	High	13.25	13.05	-0.19	
Site 915	High	13.32	13.12	-0.20	
Site 915	High	13.09	12.98	-0.10	
Site 916	Med	12.95	12.72	-0.23	
Site 916	Med	12.94	12.72	-0.22	
Site 917	Low	12.31	12.17	-0.14	
Site 917	High	12.37	12.16	-0.21	
Site 917	High	12.30	12.16	-0.13	
Site 918	High	11.03	10.01	-1.02	
Site 918	Med	10.64	10.04	-0.60	
Site 918	Med	10.63	10.00	-0.63	
			Average	-0.44	

2 March 2022

2.1 Stage hydrograph comparison

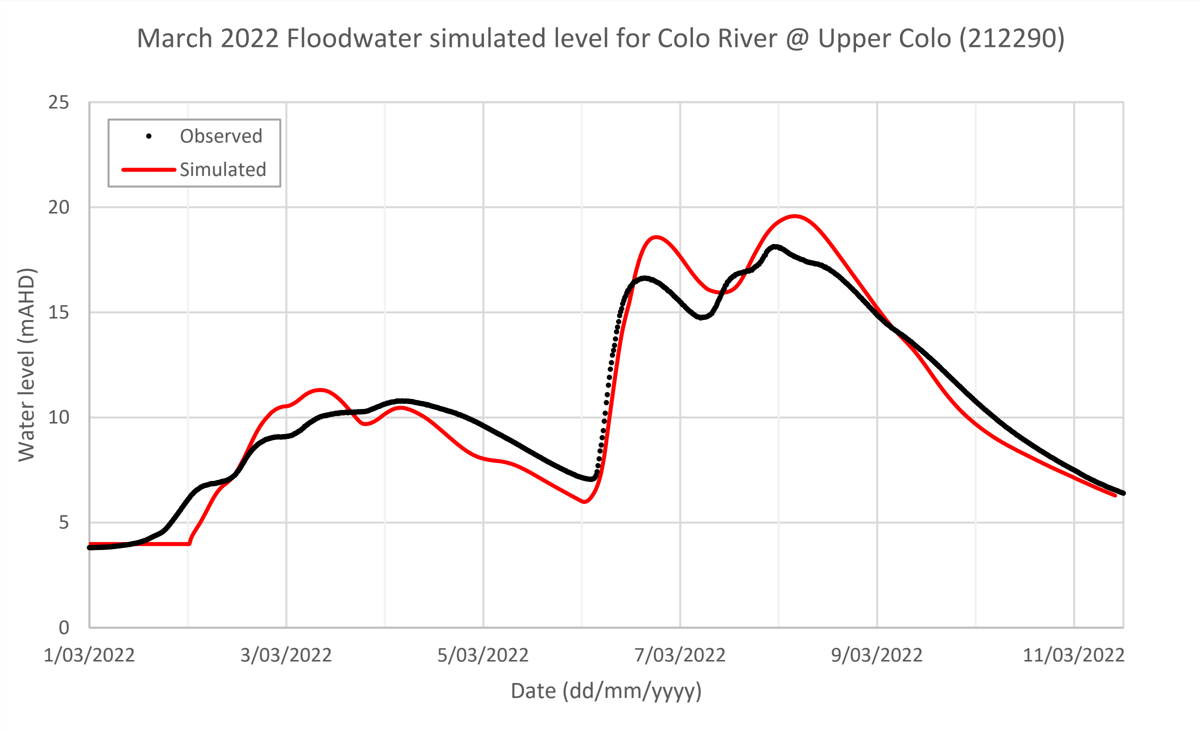


Figure C5 March 2022 Observed vs Simulated water level for Upper Colo gauge (212290)

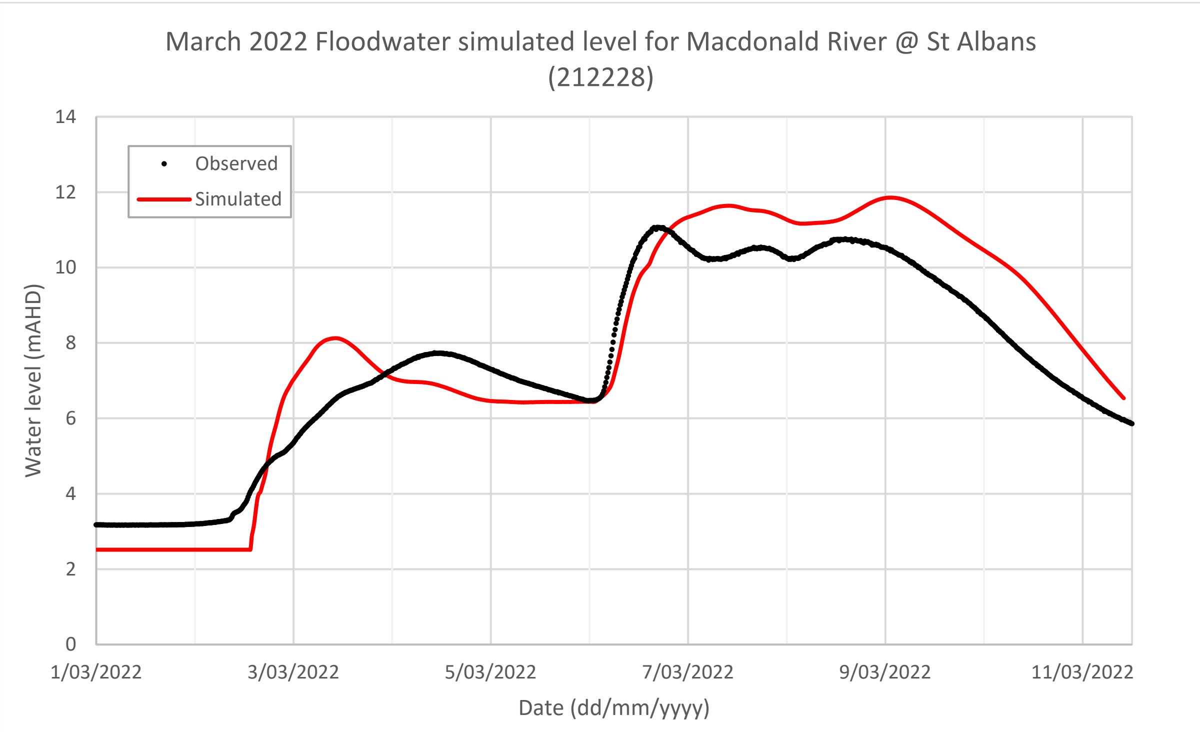


Figure C6 March 2022 Observed vs Simulated water level for St Albans gauge (212228)

Appendix C – Hydraulic Model Calibration and Validation

2.2 Surface water profile

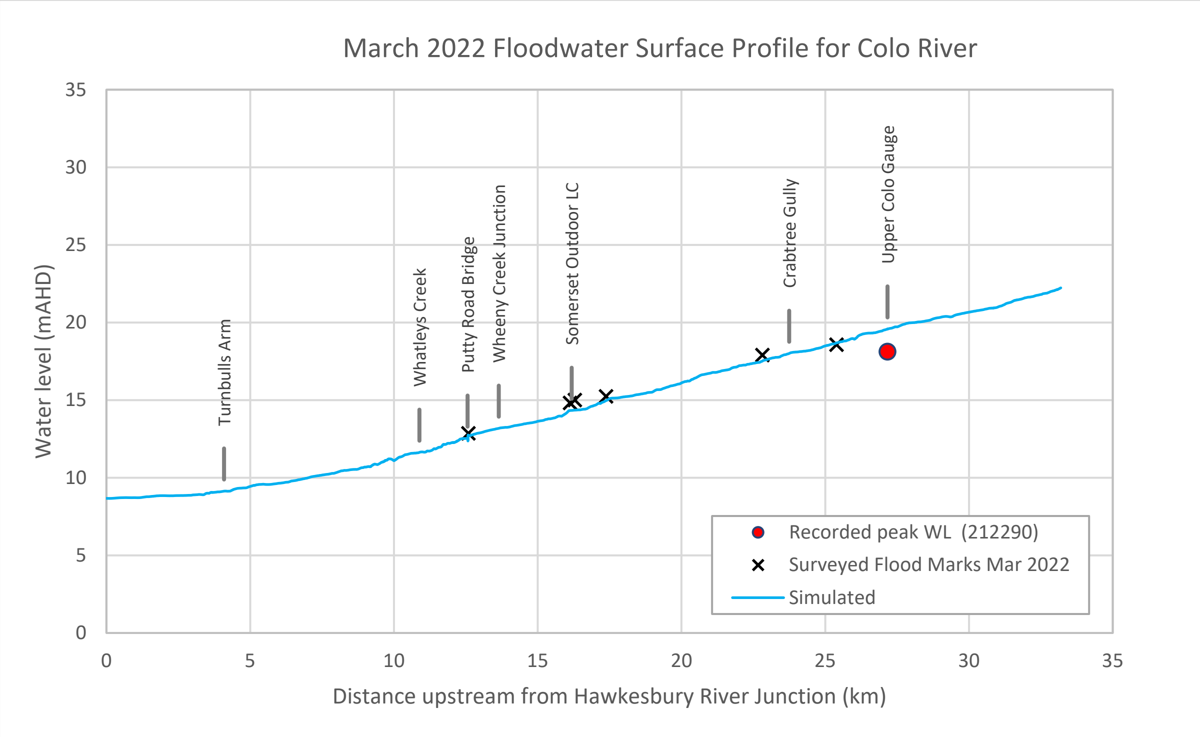


Figure C7 Simulated March 2022 floodwater surface profile for Colo River

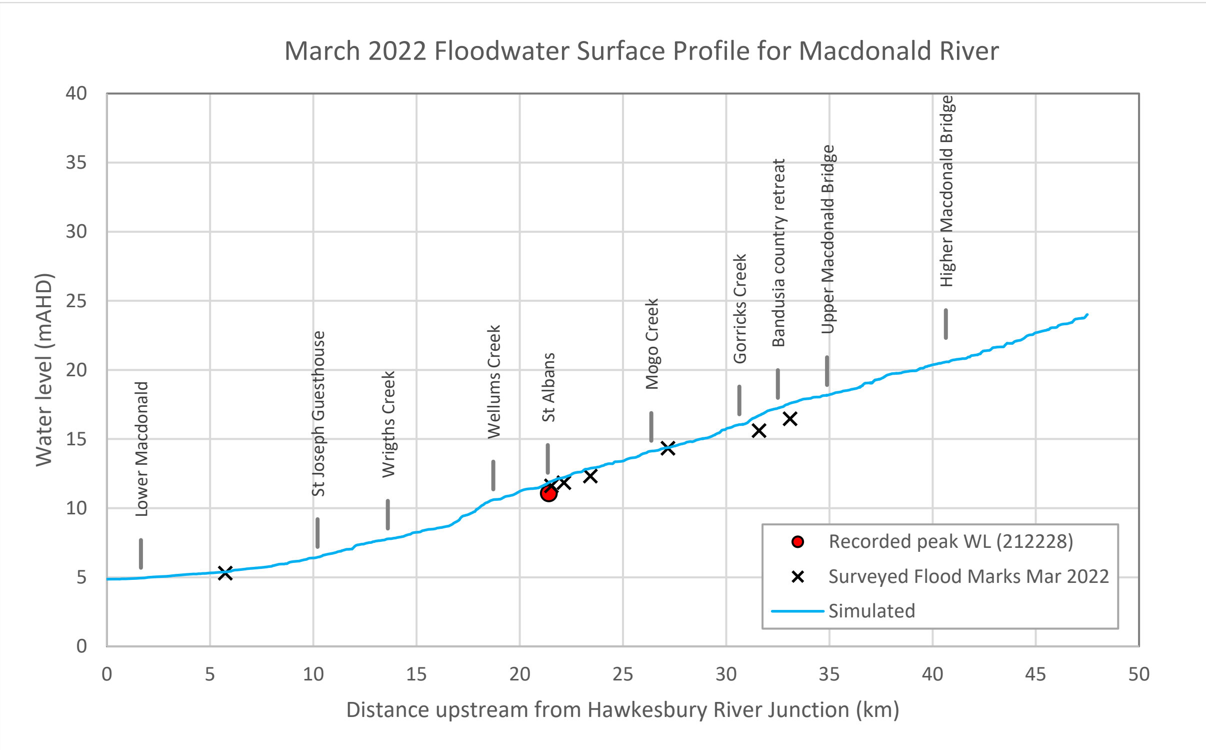


Figure C8 Simulated March 2022 floodwater surface profile for Macdonald River

2.3 Flood mark comparison

Table C3 Simulated and surveyed flood levels the March 2022 flood in Colo River

Site	Quality of Evidence	Survey (mAHD)	Simulated (mAHD)	Difference (m)	Comments
Site 400	High	20.97	20.40	-0.56	
Site 401	High	19.99	19.33	-0.66	
Site 403	Low	18.58	18.58	0.00	
Site 404	Low	17.90	17.44	-0.46	
Site 405	Low	15.25	15.16	-0.09	
Site 406	Low	14.82	14.16	-0.66	
Site 407	Low	15.01	14.27	-0.74	
Site 408	Med	12.44	13.20	0.77	Surveyed flood mark 0.4m lower than DS flood mark near Putty Road bridge. Likely problematic survey mark.
Site 410	High	8.93	9.32	0.39	Poor reception during survey
Site 411	High	12.87	12.61	-0.25	
			Average	-0.23	

Table C4 Simulated and surveyed flood levels the March 2022 flood in Macdonald River

Site	Quality of Evidence	Survey (mAHD)	Simulated (mAHD)	Difference (m)	Comments
Site 100-CORS	High	5.22	4.87	-0.36	
Site 101	Low	5.13	5.38	0.25	
Site 101	Low	5.30	5.38	0.08	
Site 101	Low	5.32	5.41	0.09	
Site 106	Low	11.86	12.60	0.74	
Site 106	High	12.27	12.60	0.33	
Site 107	Low	11.32	12.19	0.86	
Site 108	Low	11.59	11.92	0.33	
Site 109	High	11.34	11.94	0.61	
Site 110	High	11.61	11.93	0.32	
Site 111	Low	11.31	12.11	0.80	
Site 112	Med	11.85	12.22	0.37	
Site 114	Low	12.31	12.92	0.61	
Site 113	Low	11.75	12.92	1.17	
Site 115	High	14.33	14.36	0.03	
Site 116	Med	16.46	17.60	1.14	
Site 117	Med	16.41	17.58	1.17	
Site 118	Low	15.61	16.74	1.14	
Site 119	Med	15.21	16.69	1.49	
			Average	0.59	

Appendix C – Hydraulic Model Calibration and Validation

3 February 2020

3.1 Stage hydrograph comparison

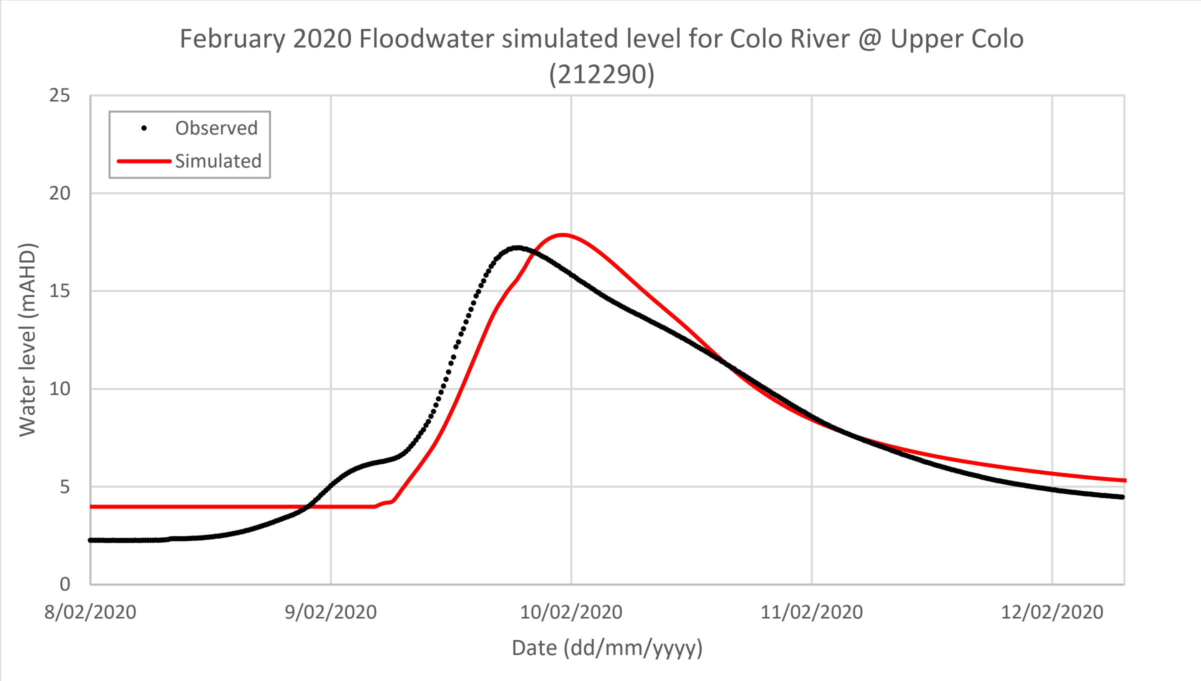


Figure C9 February 2020 Observed vs Simulated water level for Upper Colo gauge (212290)

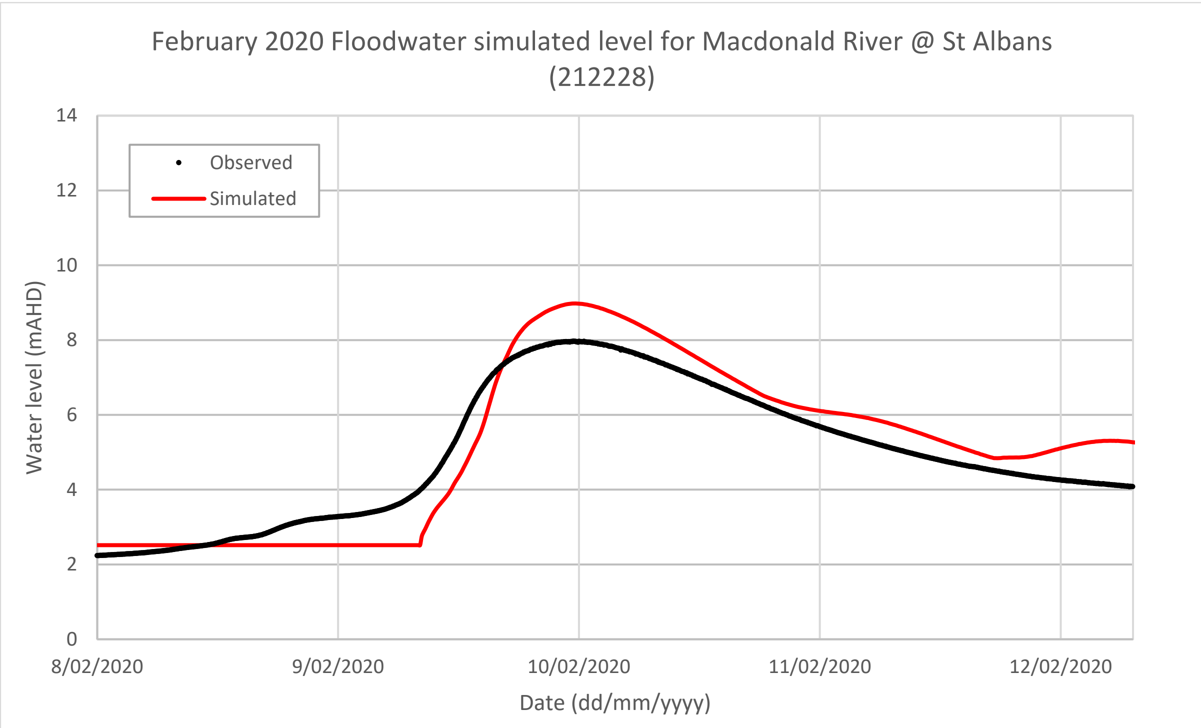


Figure C10 February 2020 Observed vs Simulated water level for St Albans gauge (212228)

3.2 Surface water profile

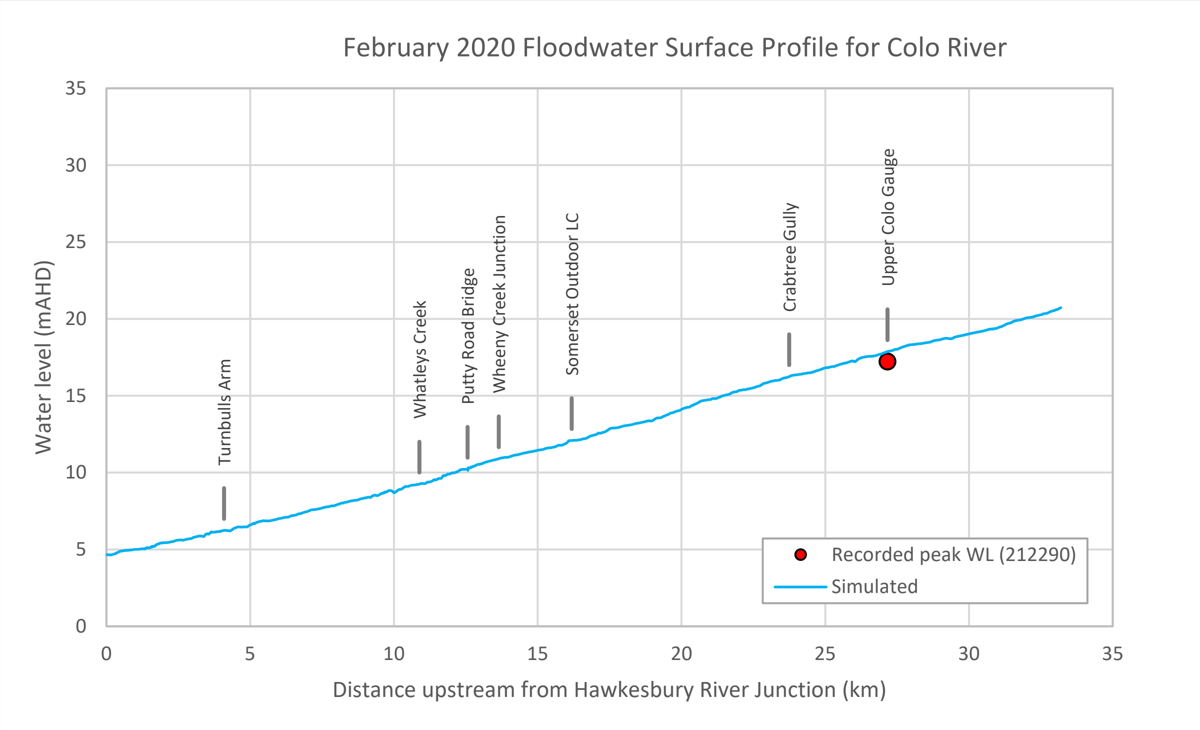


Figure C11 Simulated February 2020 floodwater surface profile for Colo River

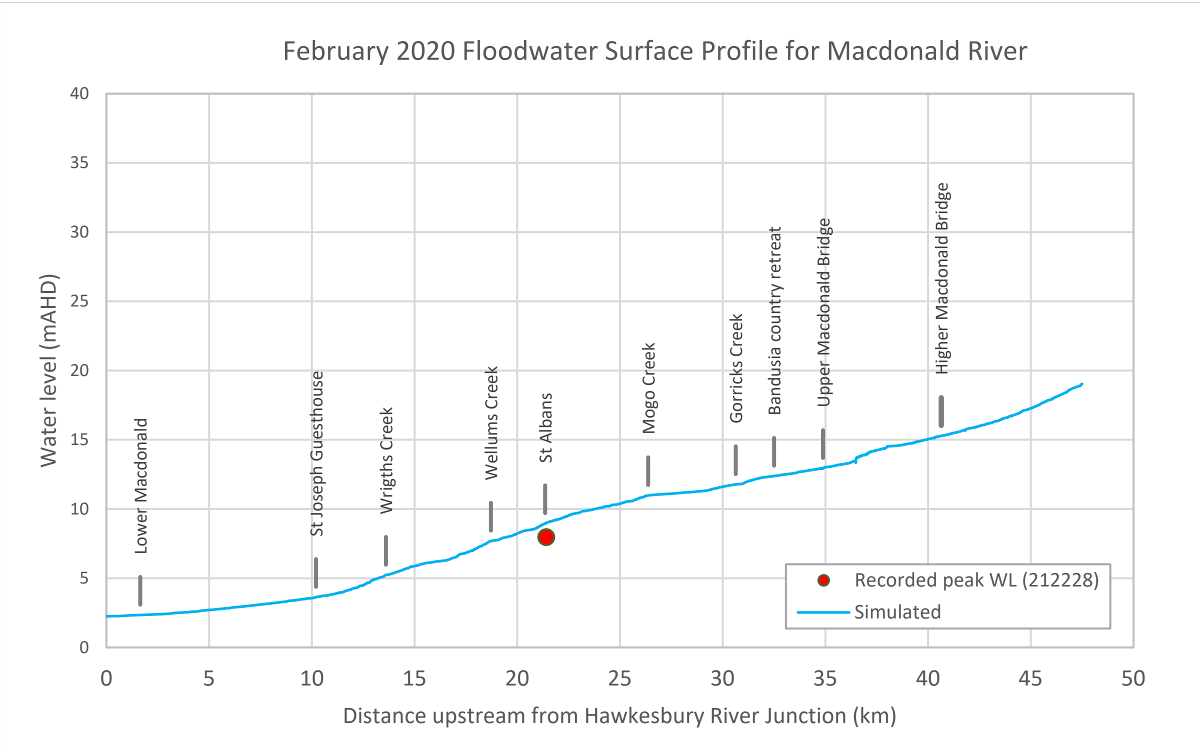
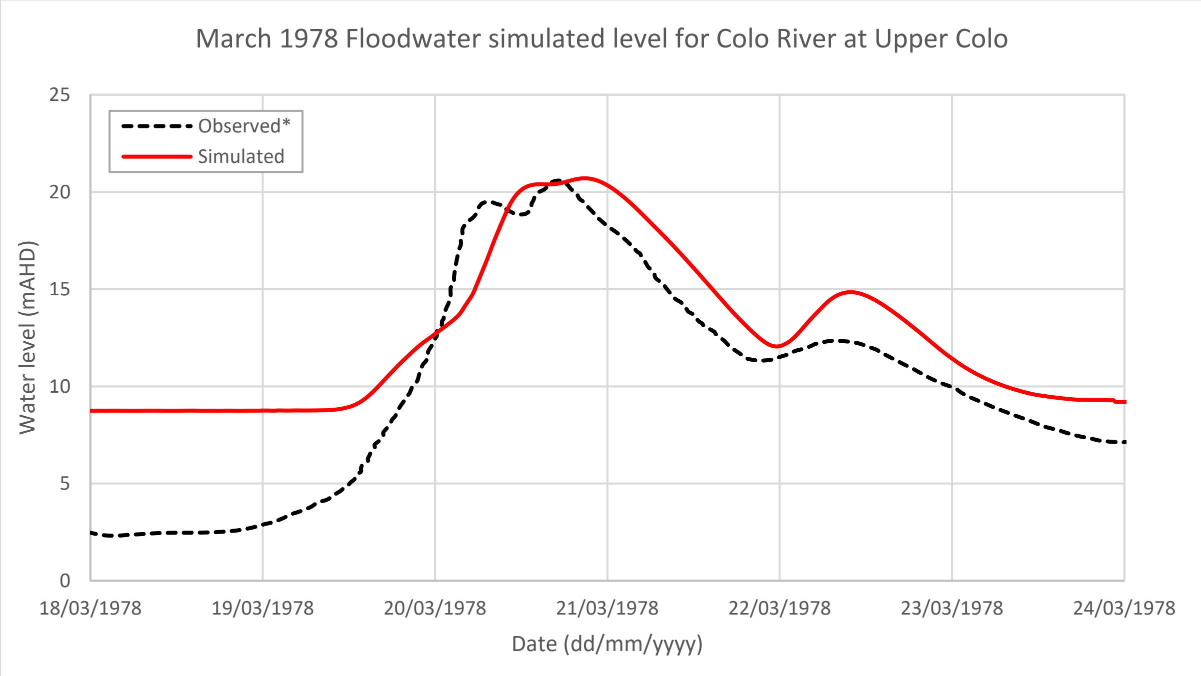


Figure C12 Simulated February 2020 floodwater surface profile for Macdonald River

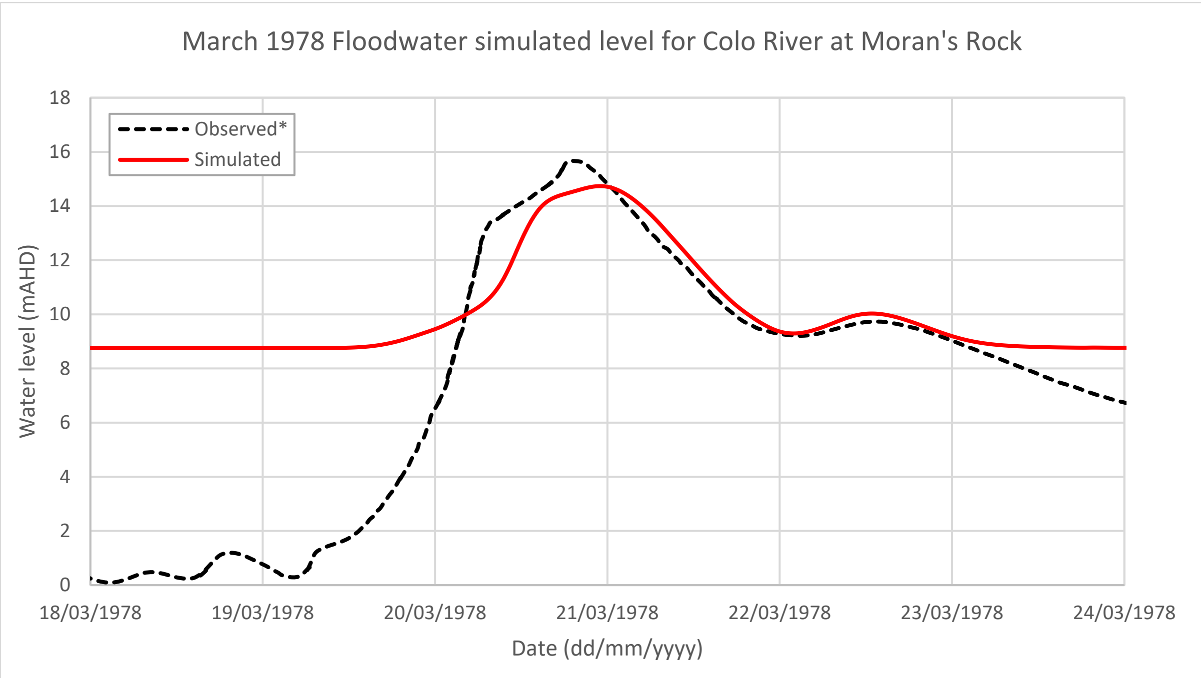
4 March 1978

4.1 Stage hydrograph comparison



**Observed water level time series extracted from PWD (1979) Figure 4. Please note 'Upper Colo' location in PWD (1979) Figure 1 is not equivalent to current Upper Colo gauge (212290) location.*

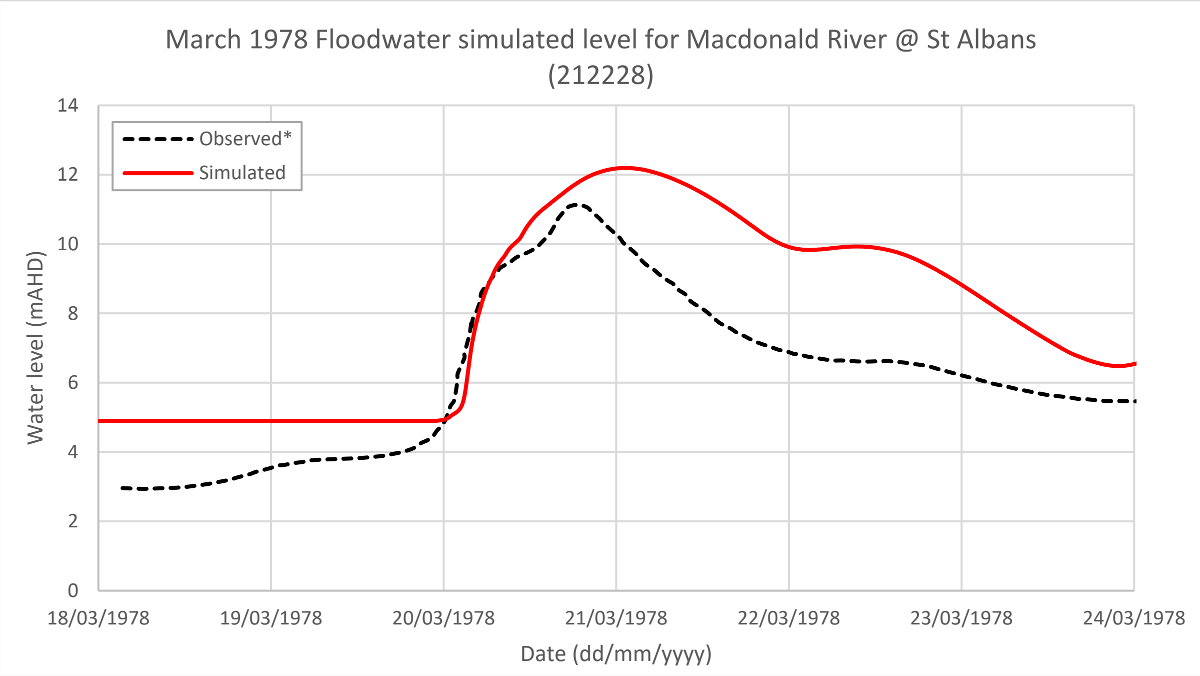
Figure C13 March 1978 Observed vs Simulated water level for Colo River at Upper Colo



**Observed water level time series extracted from PWD (1979) Figure 4.*

Figure C14 March 1978 Observed vs Simulated water level for the Colo River at Moran's Rock

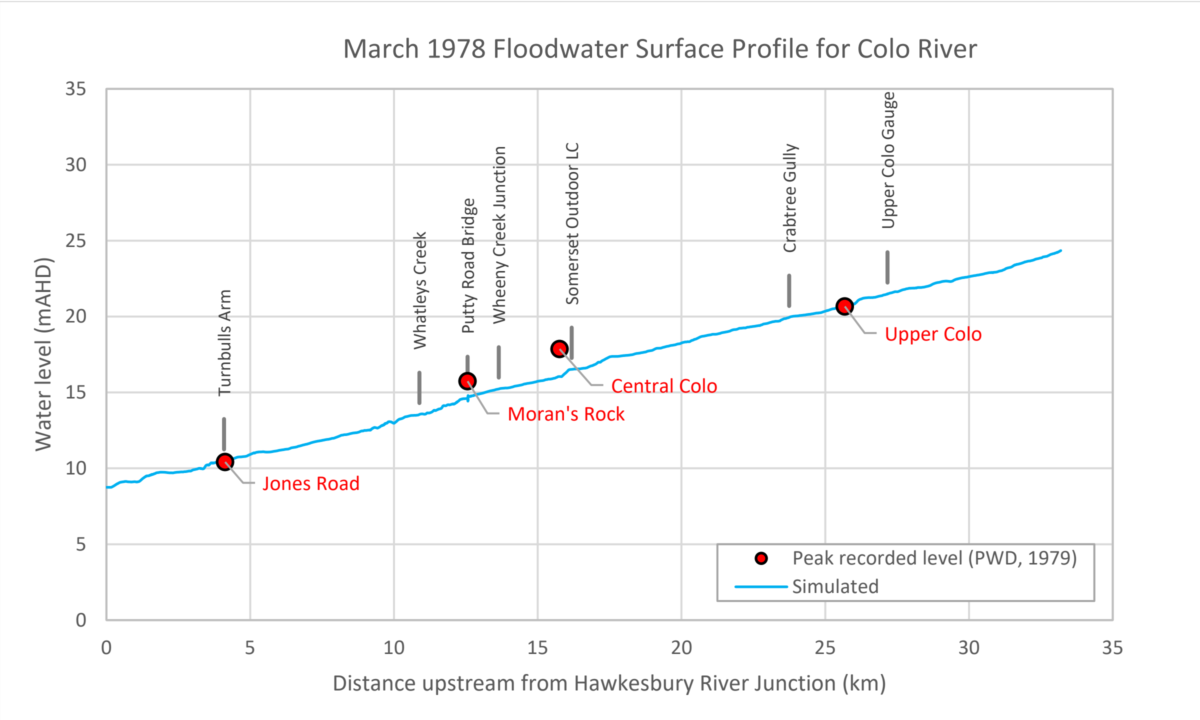
Appendix C – Hydraulic Model Calibration and Validation



**Observed water level time series extracted from PWD (1979) Figure 4*

Figure C15 March 1978 Observed vs Simulated water level for Macdonald River at St Albans gauge (212228)

4.2 Surface water profile



**Peak water levels extracted from PWD (1979) Table 1. Please note 'Upper Colo' location in PWD (1979) Figure 1 is not equivalent to current Upper Colo gauge (212290) location.*

Figure C16 Simulated March 1978 floodwater surface profile for Colo River

Appendix C – Hydraulic Model Calibration and Validation

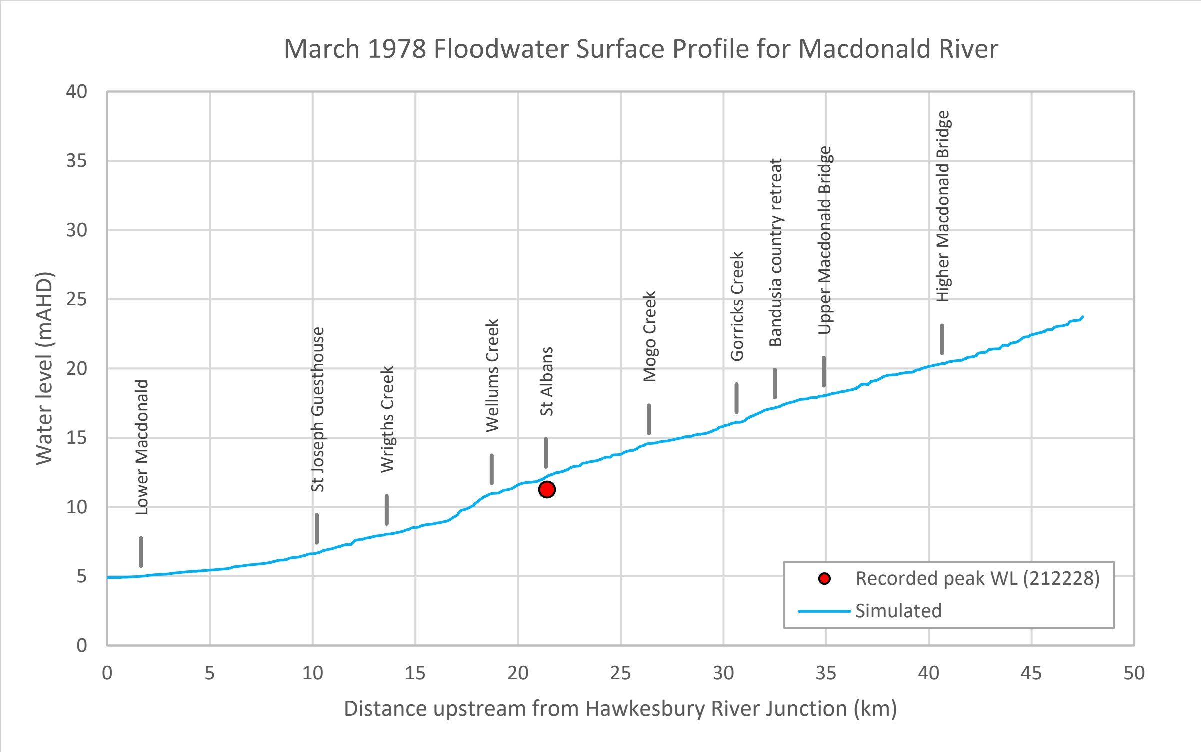


Figure C17 Simulated March 1978 floodwater surface profile for Macdonald River

Appendix D

Design Stage Hydrographs and Profiles

1 Catchment driven events

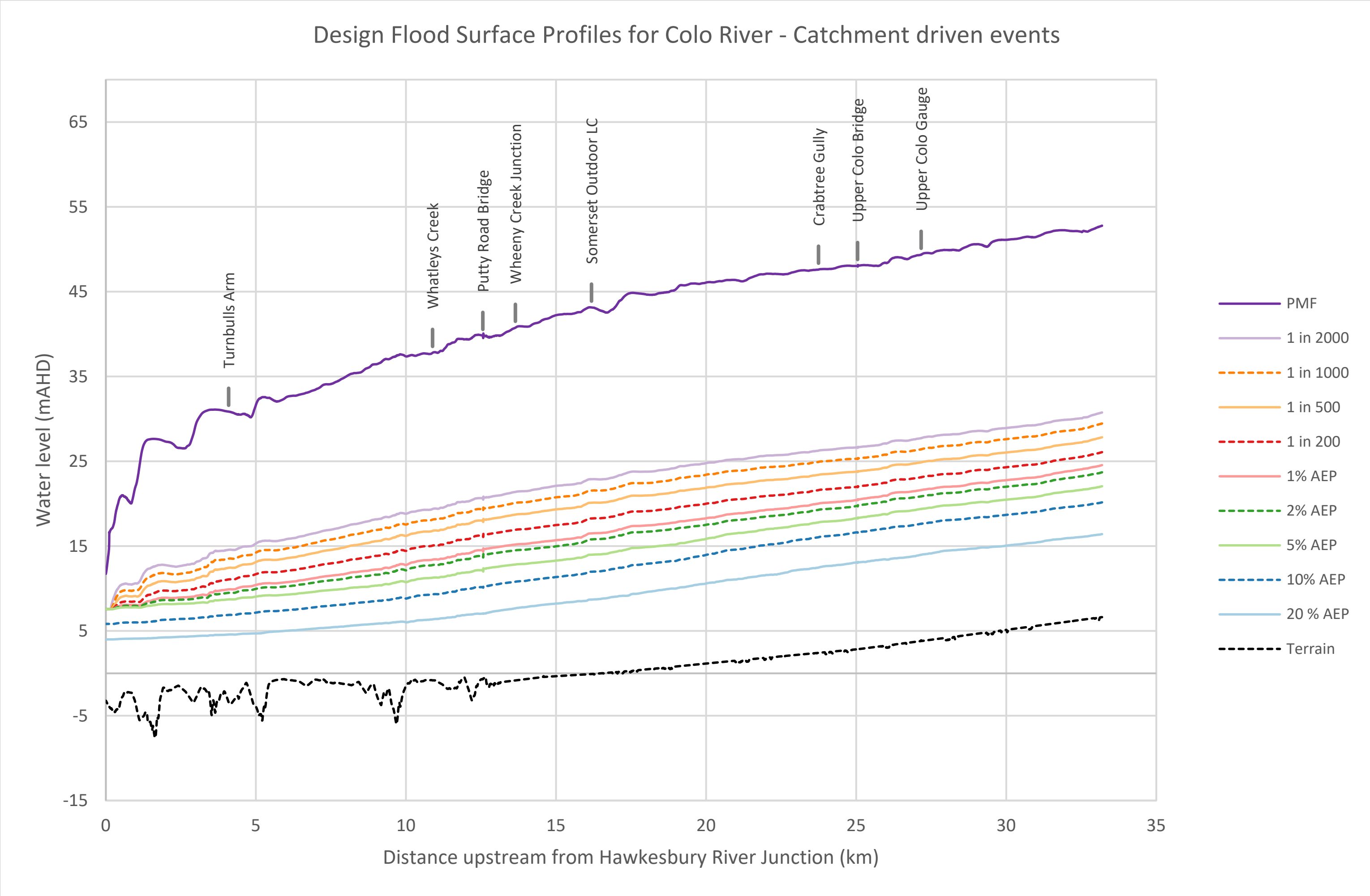


Figure D1 Design event peak flood level profiles for catchment driven events in Colo River

Appendix D – Design stage hydrographs and flood level profiles

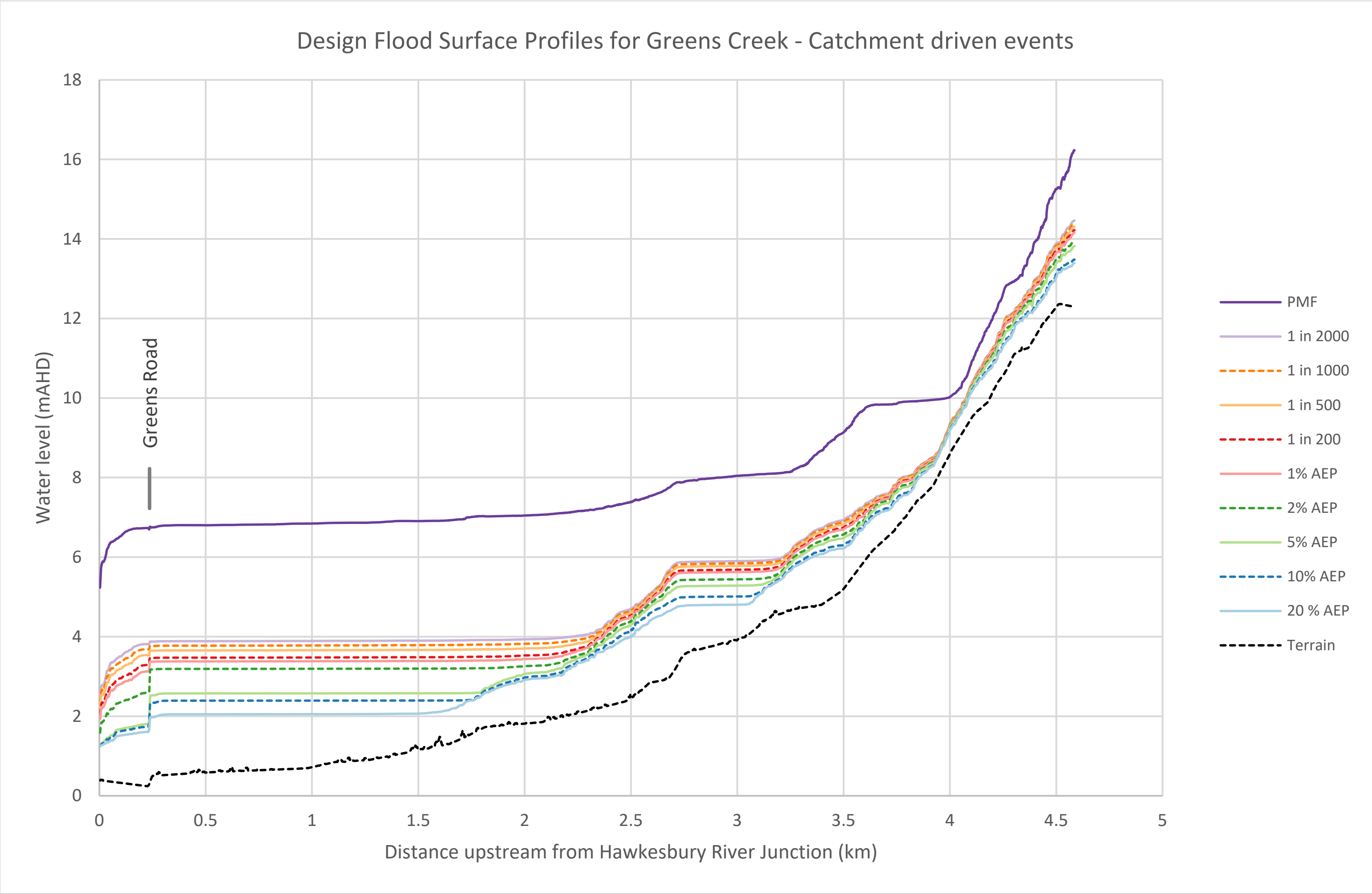


Figure D2 Design event peak flood level profiles for catchment driven events in Greens Creek

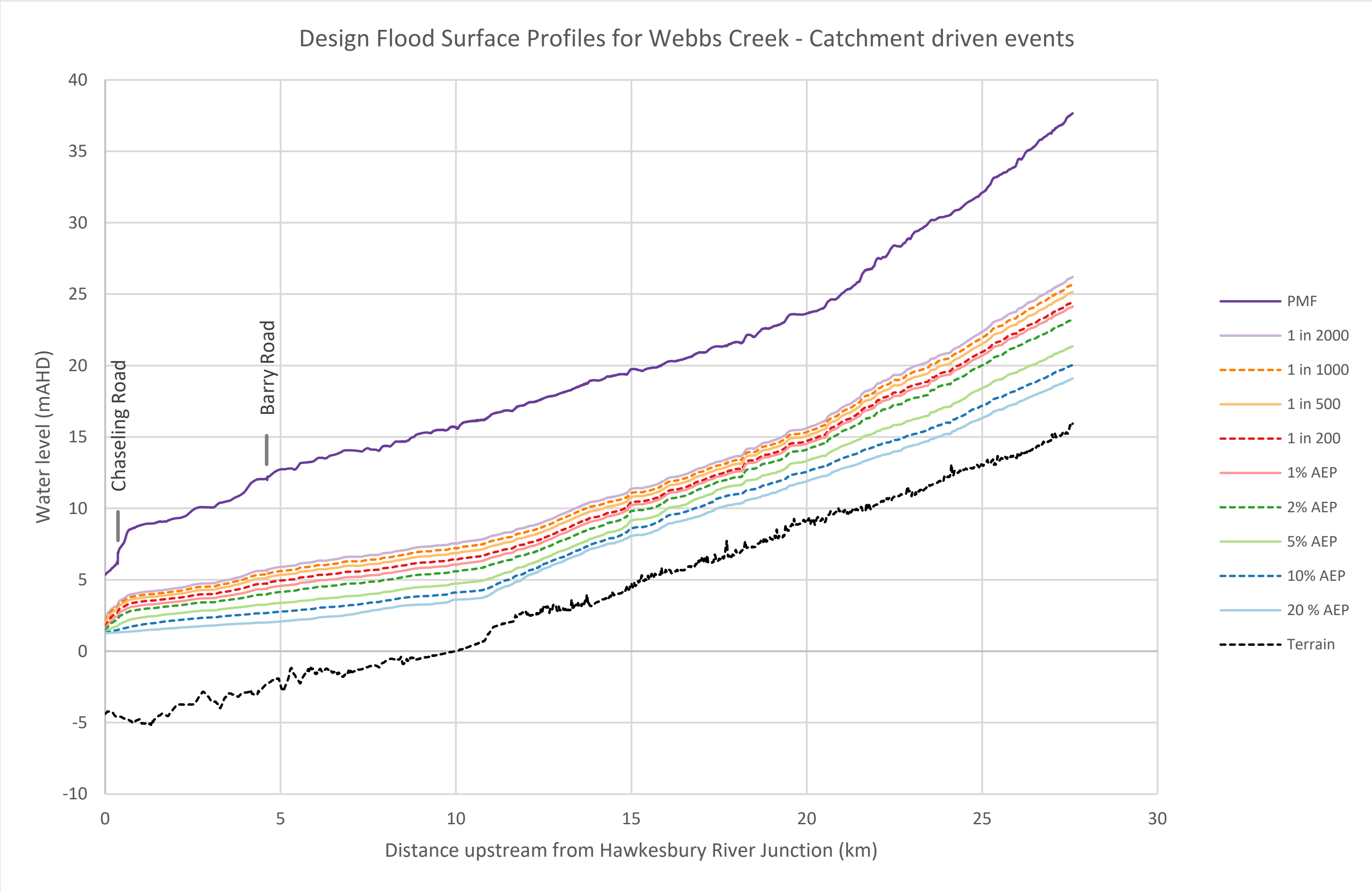


Figure D3 Design event peak flood level profiles for catchment driven events in Webbs Creek

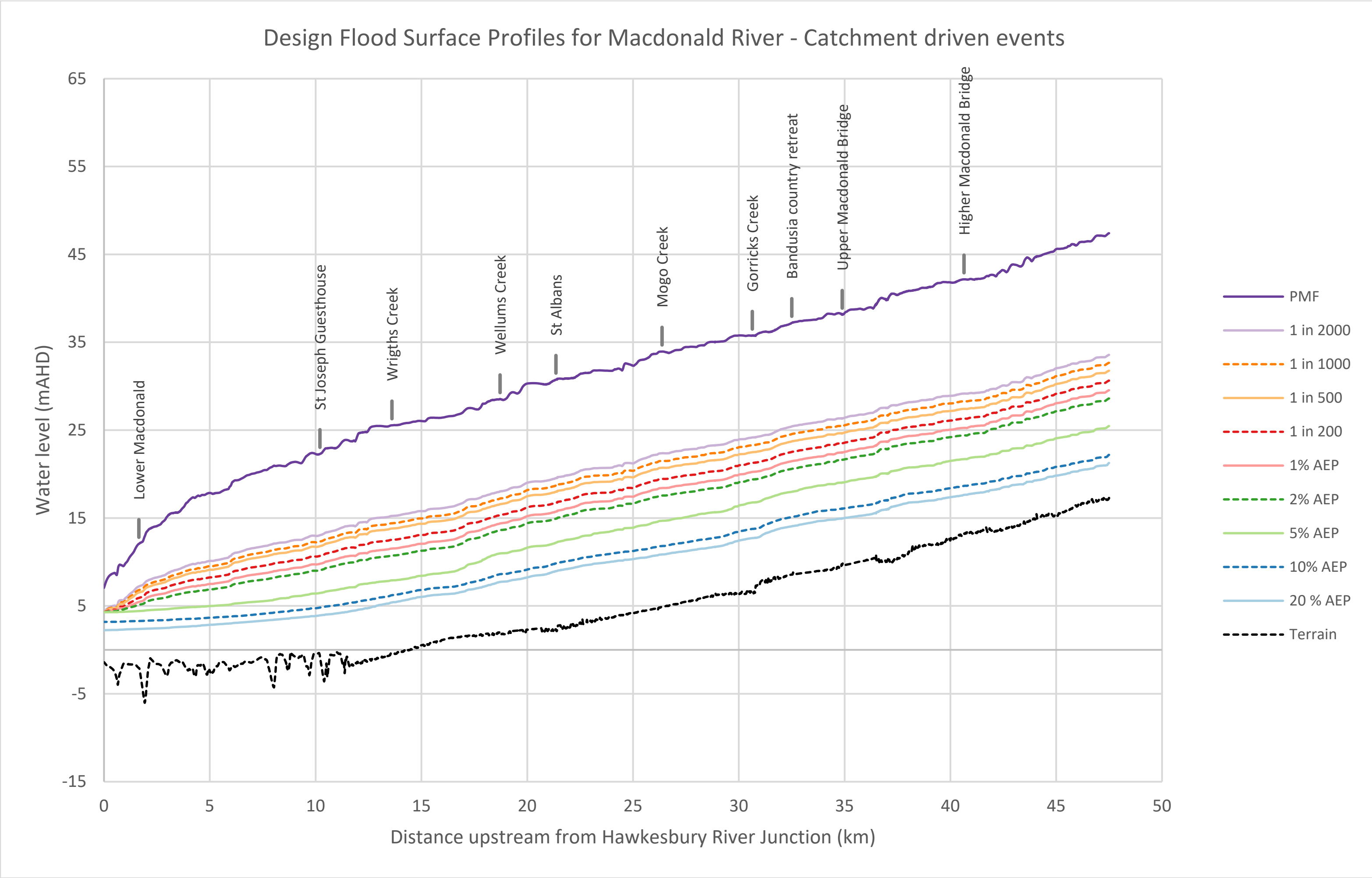


Figure D4 Design event peak flood level profiles for catchment driven events in Macdonald River

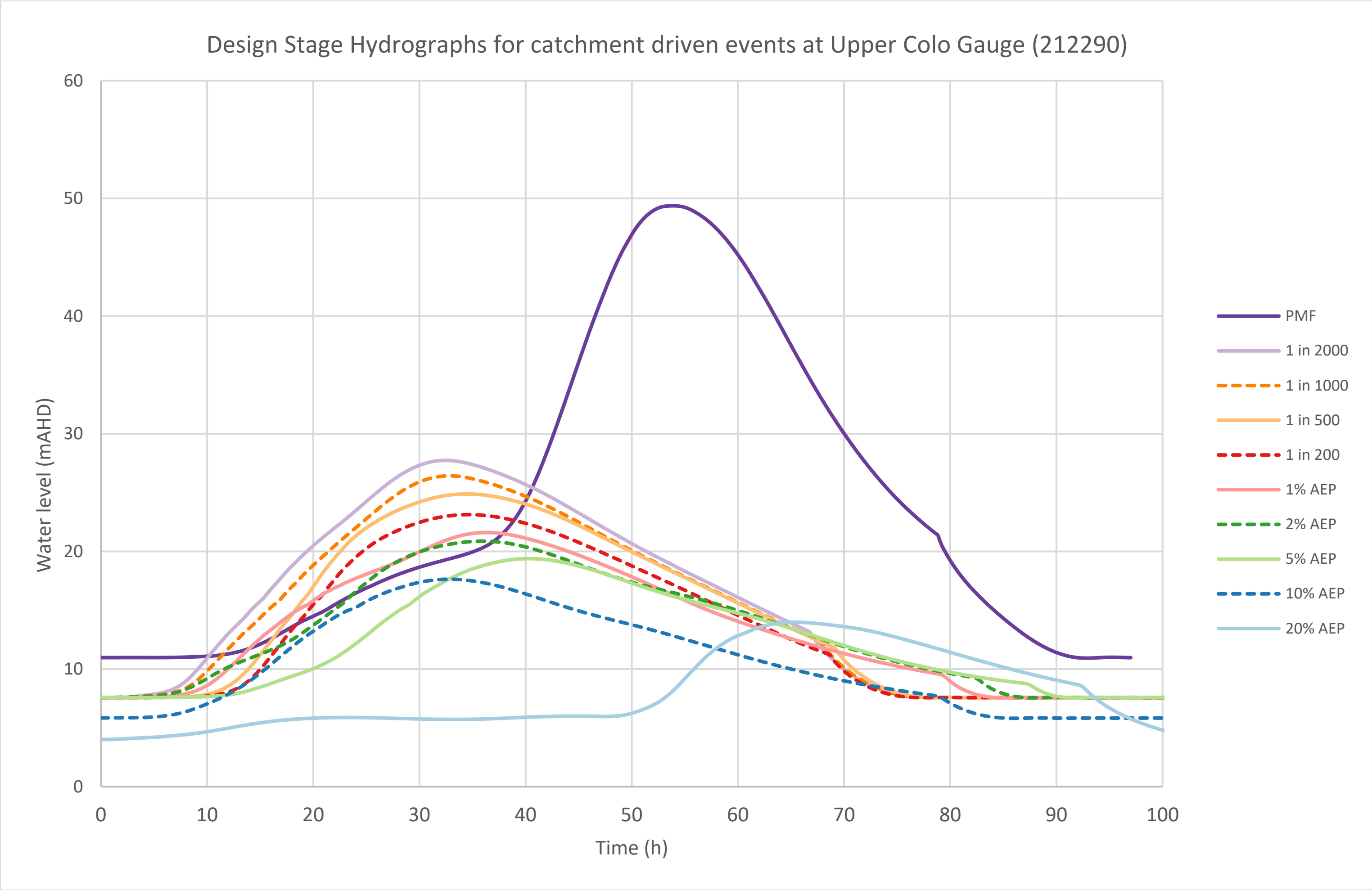


Figure D5 Design stage hydrographs for catchment driven events at Upper Colo gauge (212290)

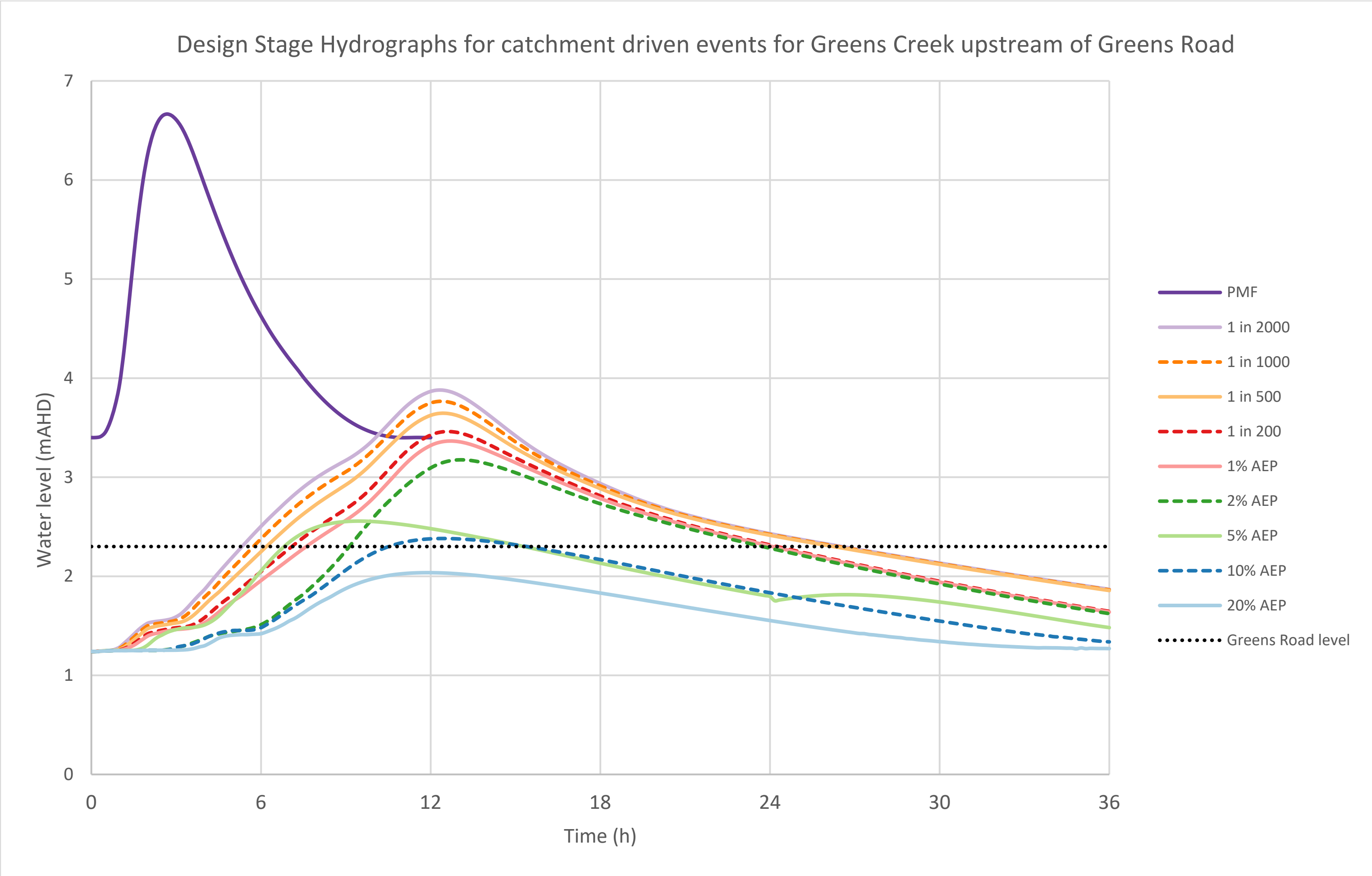


Figure D6 Design stage hydrographs for catchment driven events at Greens Creek upstream of Greens Road

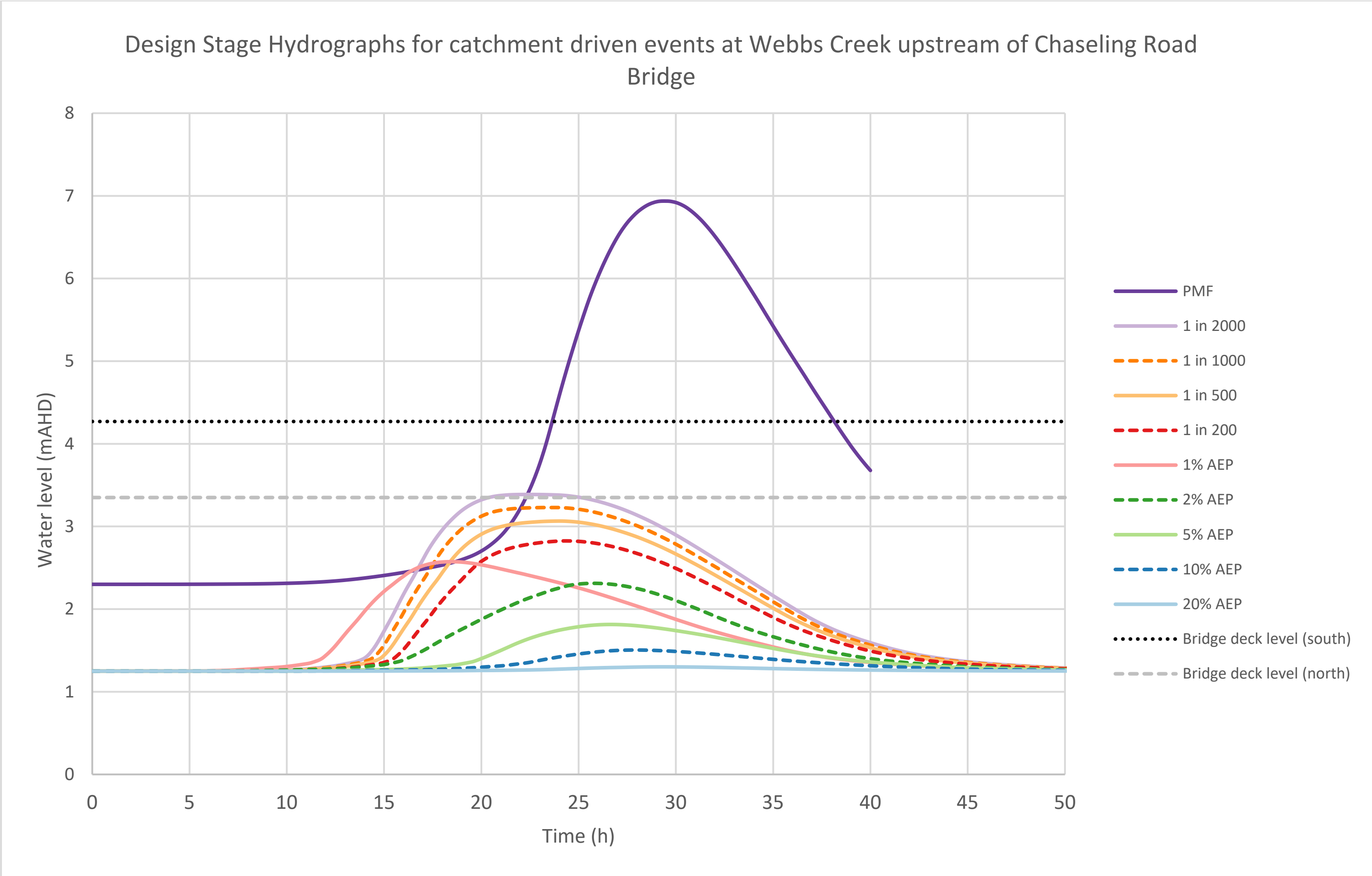


Figure D7 Design stage hydrographs for catchment driven events at Webbs Creek upstream of Chaseling Road Bridge

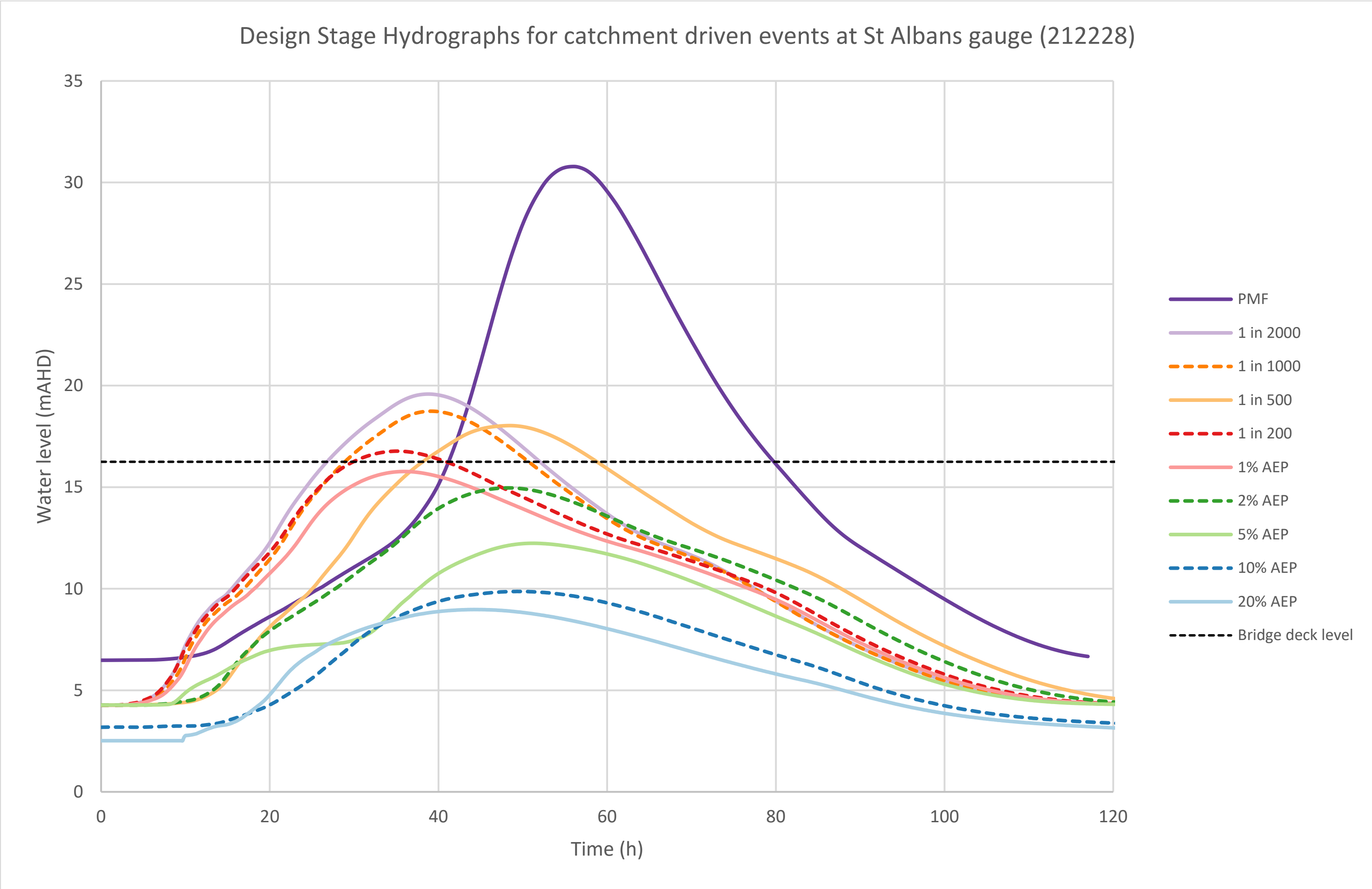


Figure D8 Design stage hydrographs for catchment driven events at St Albans gauge (212228)

2 Hawkesbury River driven events

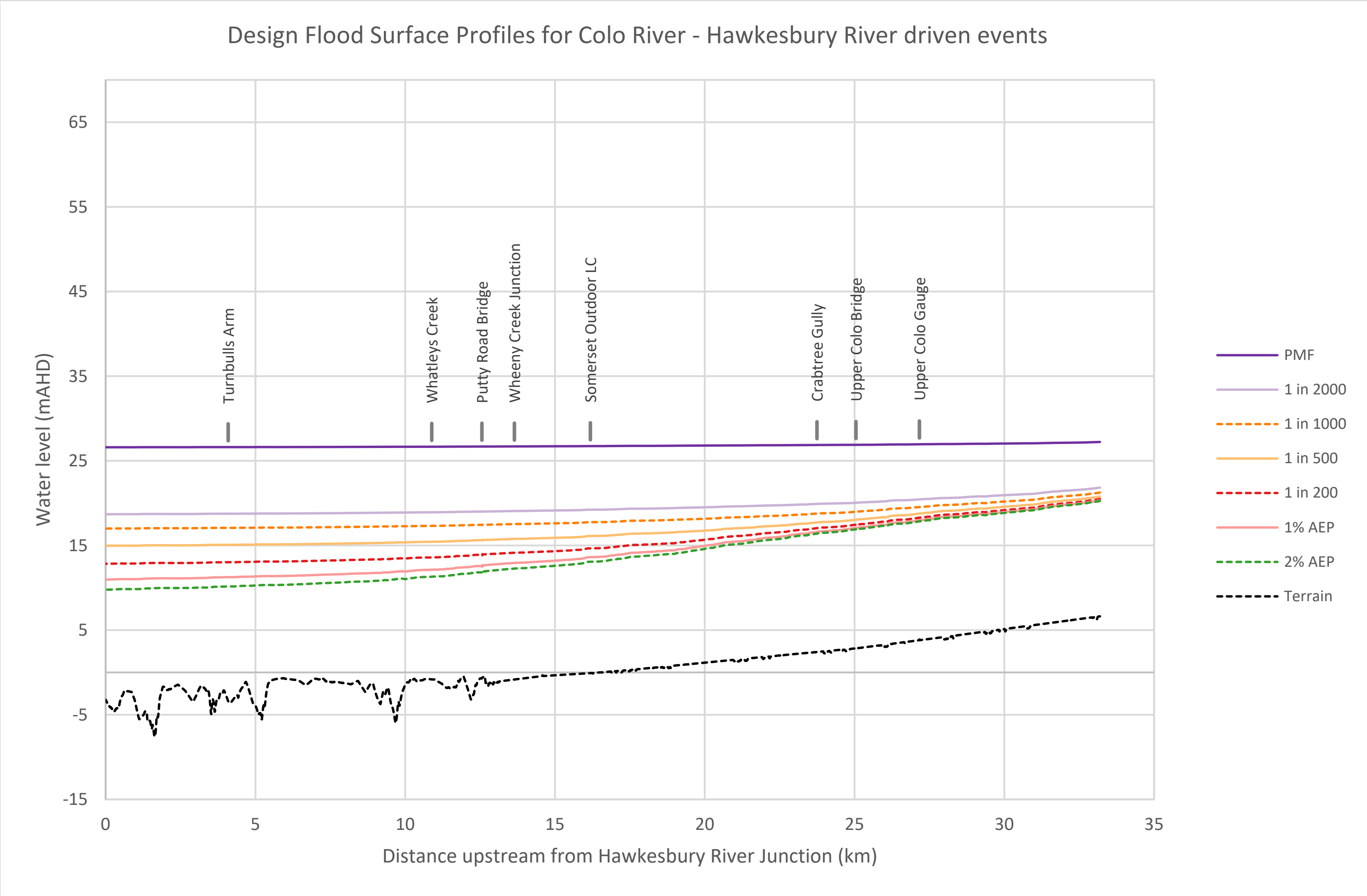


Figure D9 Design event peak flood level profiles for Hawkesbury River driven events in Colo River

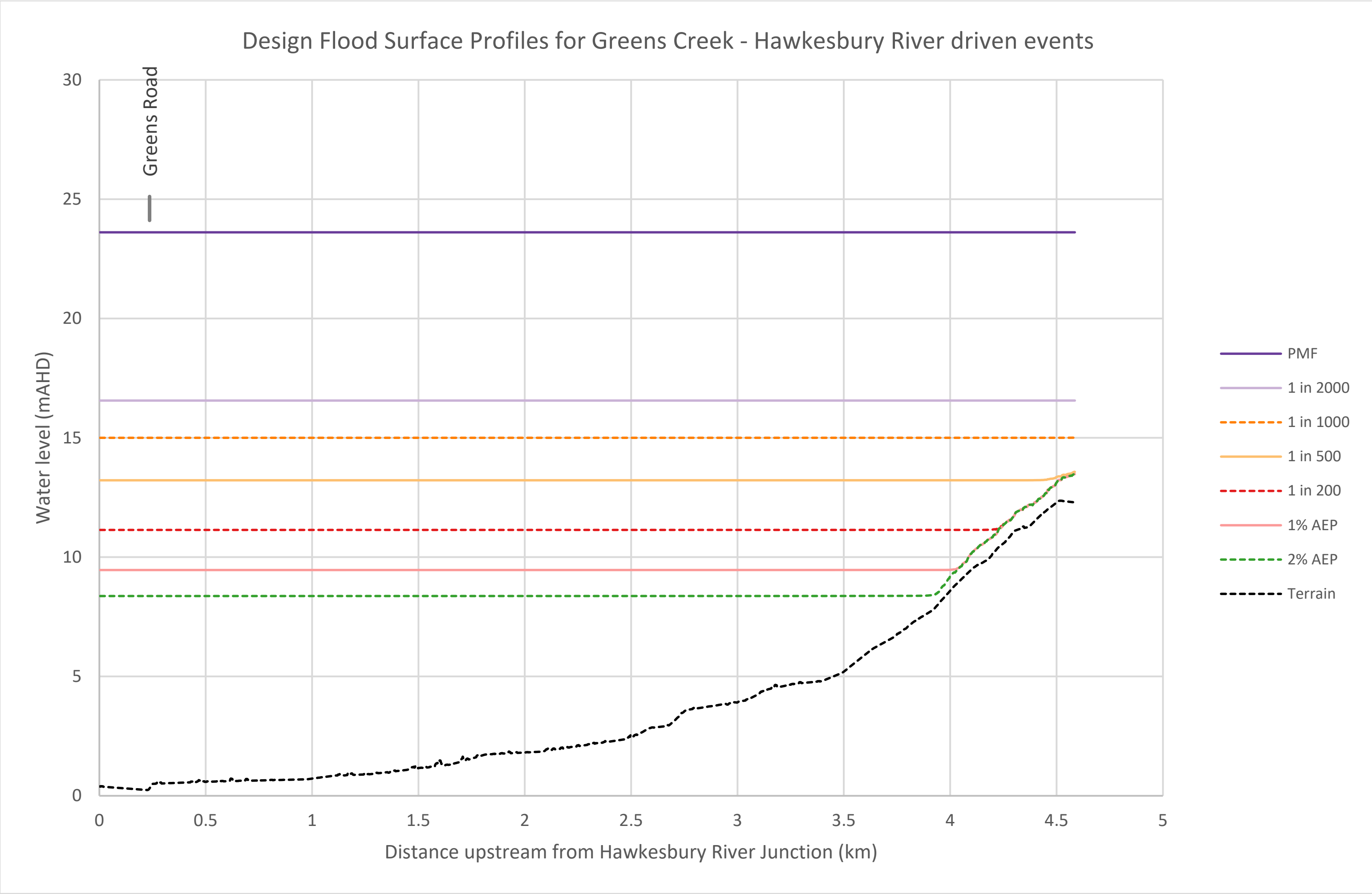


Figure D10 Design event peak flood level profiles for Hawkesbury River driven events in Greens Creek

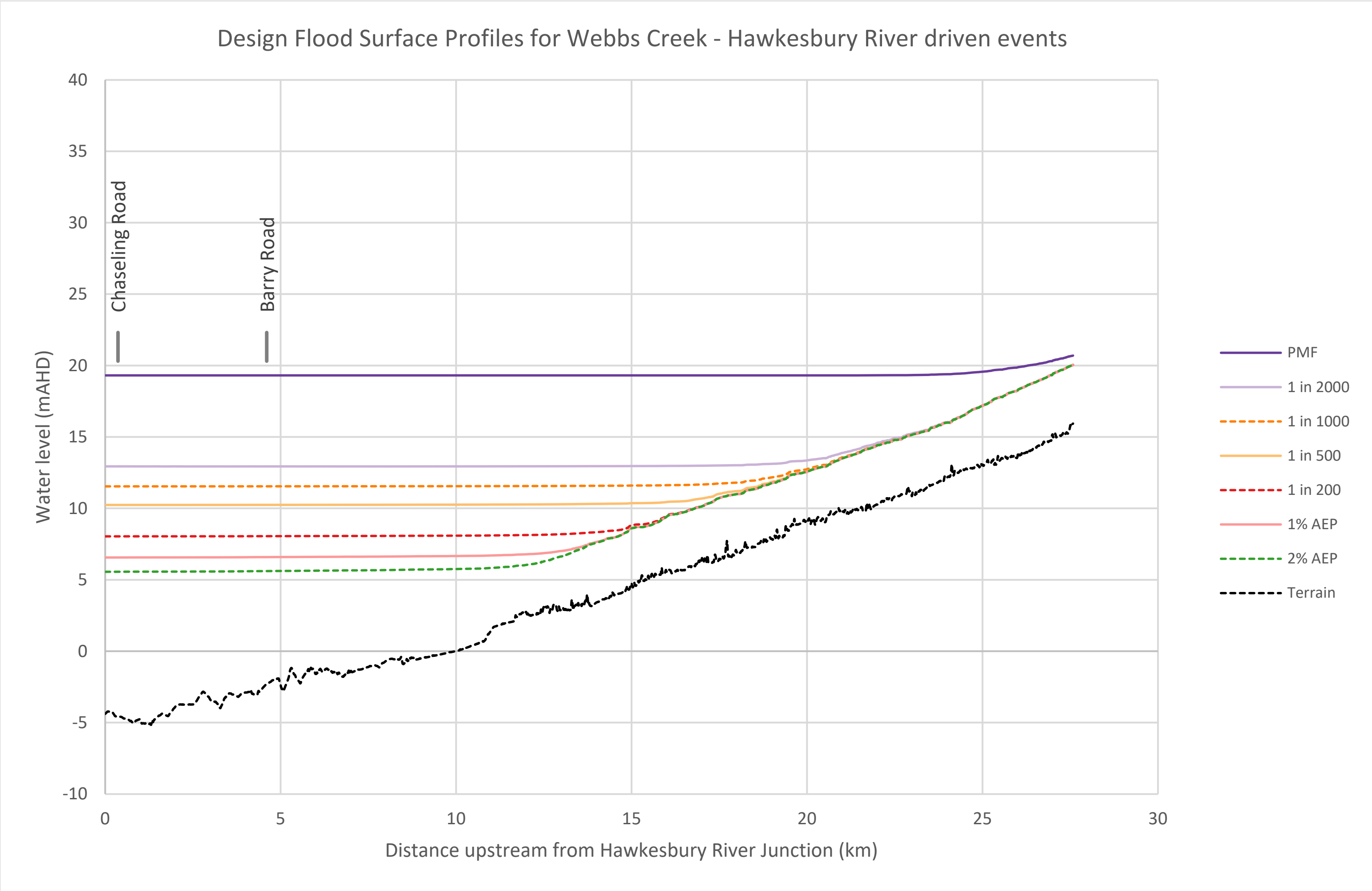


Figure D11 Design event peak flood level profiles for Hawkesbury River driven events in Webbs Creek

Appendix D – Design stage hydrographs and flood level profiles

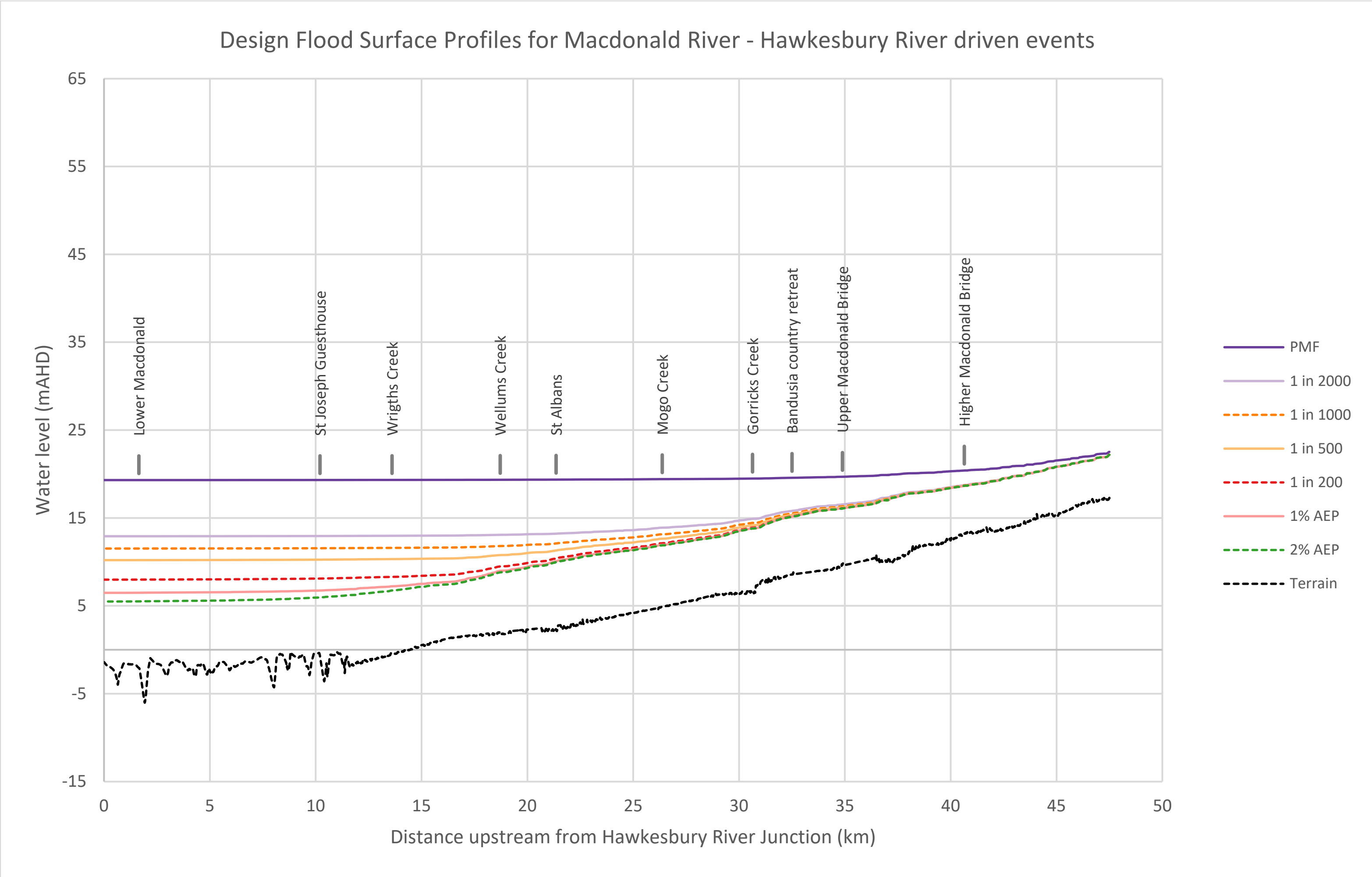


Figure D12 Design event peak flood level profiles for Hawkesbury River driven events in Macdonald River

Appendix E

Flood Function Verification

Appendix E – Flood Function Verification

1 Overview

Flood function (hydraulic) categories are an important output from the Flood Study process as they assist in defining the potential for development across different sections of the floodplain to impact on existing flood behaviour and highlights areas that should be retained for the conveyance and storage of floodwaters. Further details on how the hydraulic categories were defined are provided in Section 7.3 of the Flood Study Report.

The following sections describe how the flood function categories developed as part of the flood study were verified.

2 Floodway

A floodway is an area that if only partially blocked would produce a significant impact on upstream water levels and/or would divert water from existing flowpaths resulting in the development of new flowpaths (NSW Government, 2023c). Accordingly, the suitability of the delineated floodways was verified by partially blocking the floodways and quantifying the impact that this blockage had on peak 1% AEP flood levels. This approach is consistent with verification techniques outlined in the '*Flood Risk Management Guideline FB02 – Flood Function*' (NSW Government, 2023c).

The TUFLOW hydraulic model was updated to include partial blockage of the delineated floodways at several locations across the model areas and was re-run for the 1% AEP event. The peak 1% AEP flood levels from the partly obstructed floodway models runs were compared against 'existing' 1% AEP flood levels to create flood level difference maps (i.e., maps showing the location and magnitude of changes in flood level). The difference maps are shown in **Figure E1** to **Figure E5**.

Figure E1 and **Figure E2** show that the obstructions increase peak 1% AEP flood levels in the Colo River by up to 0.5 metres upstream of each blockage locations. This is considered to be a 'significant impact' on upstream water levels. Increases in flood extent are limited due to the steep terrain. **Figure E3** shows that lower increases of up to 0.15 metres in peak 1% AEP flood levels are experienced upstream of blockage locations in Greens Creek. **Figure E4** and **Figure E5** show that obstructions increase peak 1% AEP flood levels in Webbs Creek and Macdonald River by approximately 0.3-0.5 meters.

Overall, the partial blockage of the delineated floodways is predicted to produce significant impacts on upstream water levels. Therefore, it is considered that the delineated floodway extents for each catchment conform to the '*Flood Risk Management Guideline FB02 – Flood Function*' definitions and are suitable for application across the study area.

Appendix E – Flood Function Verification

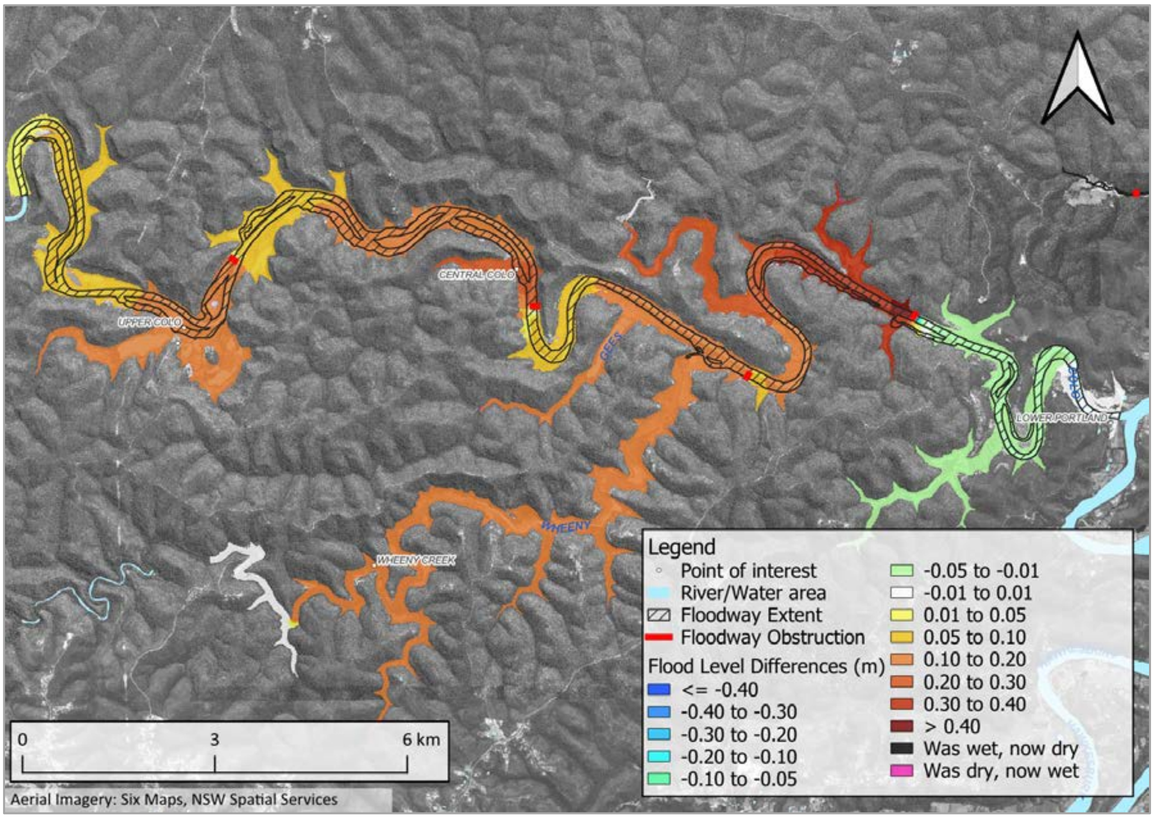


Figure E1 1% AEP Flood Level Differences associated with obstructions of the floodway in Colo River

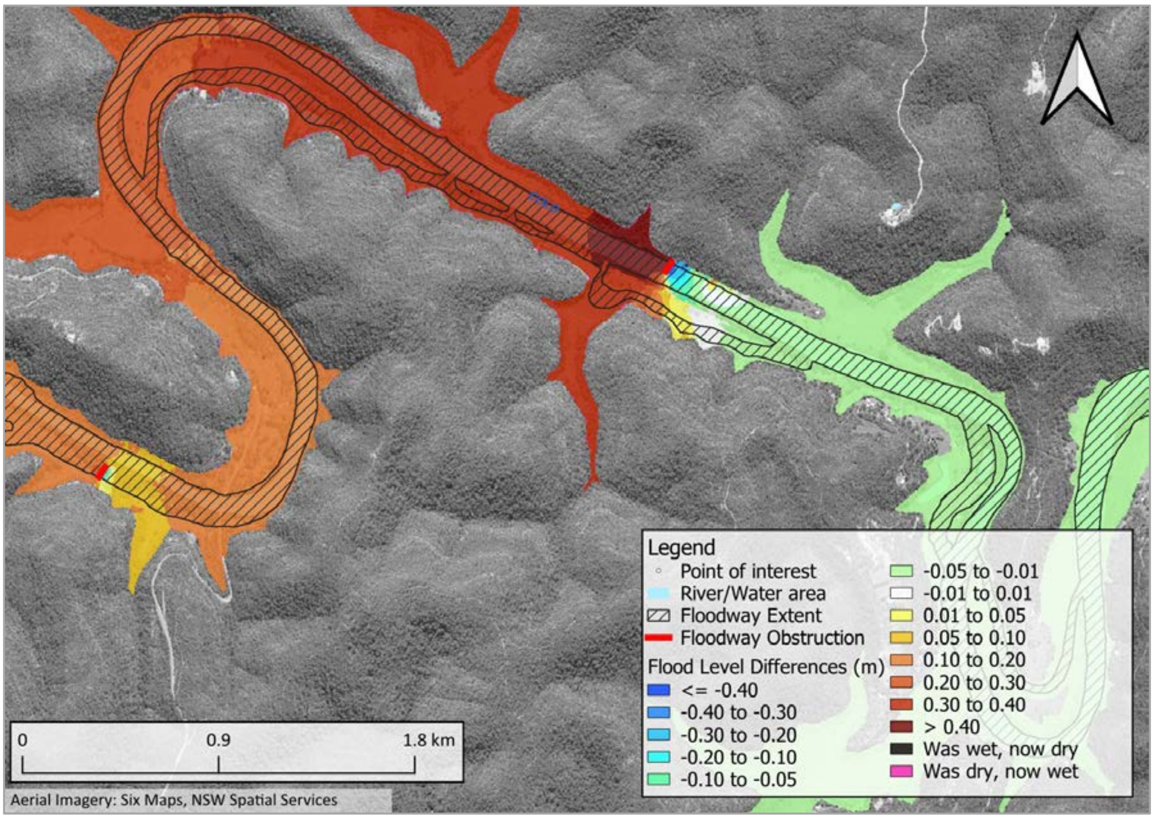


Figure E2 1% AEP Flood Level Differences associated with obstructions of the floodway in Colo River (lower reach)

Appendix E – Flood Function Verification

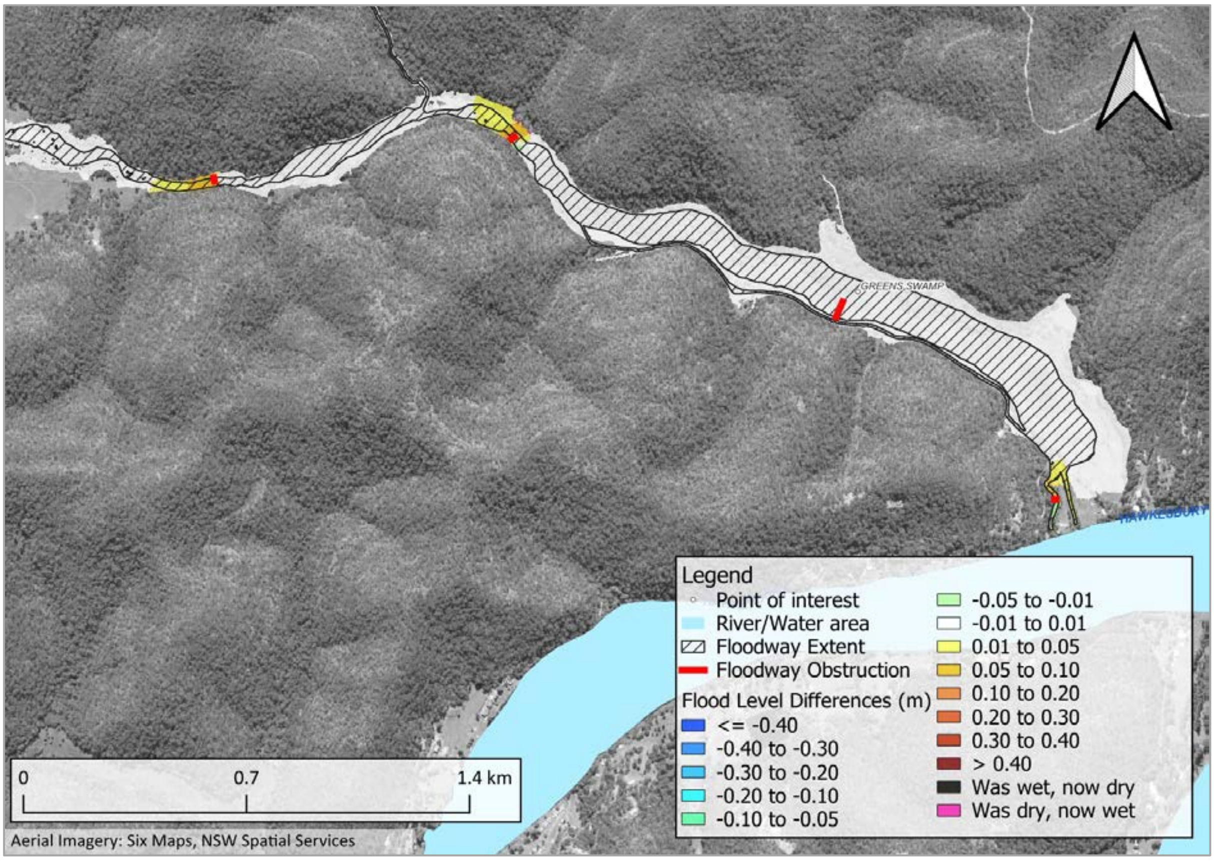


Figure E3 1% AEP Flood Level Differences associated with obstructions of the floodway in Greens Creek

Appendix E – Flood Function Verification

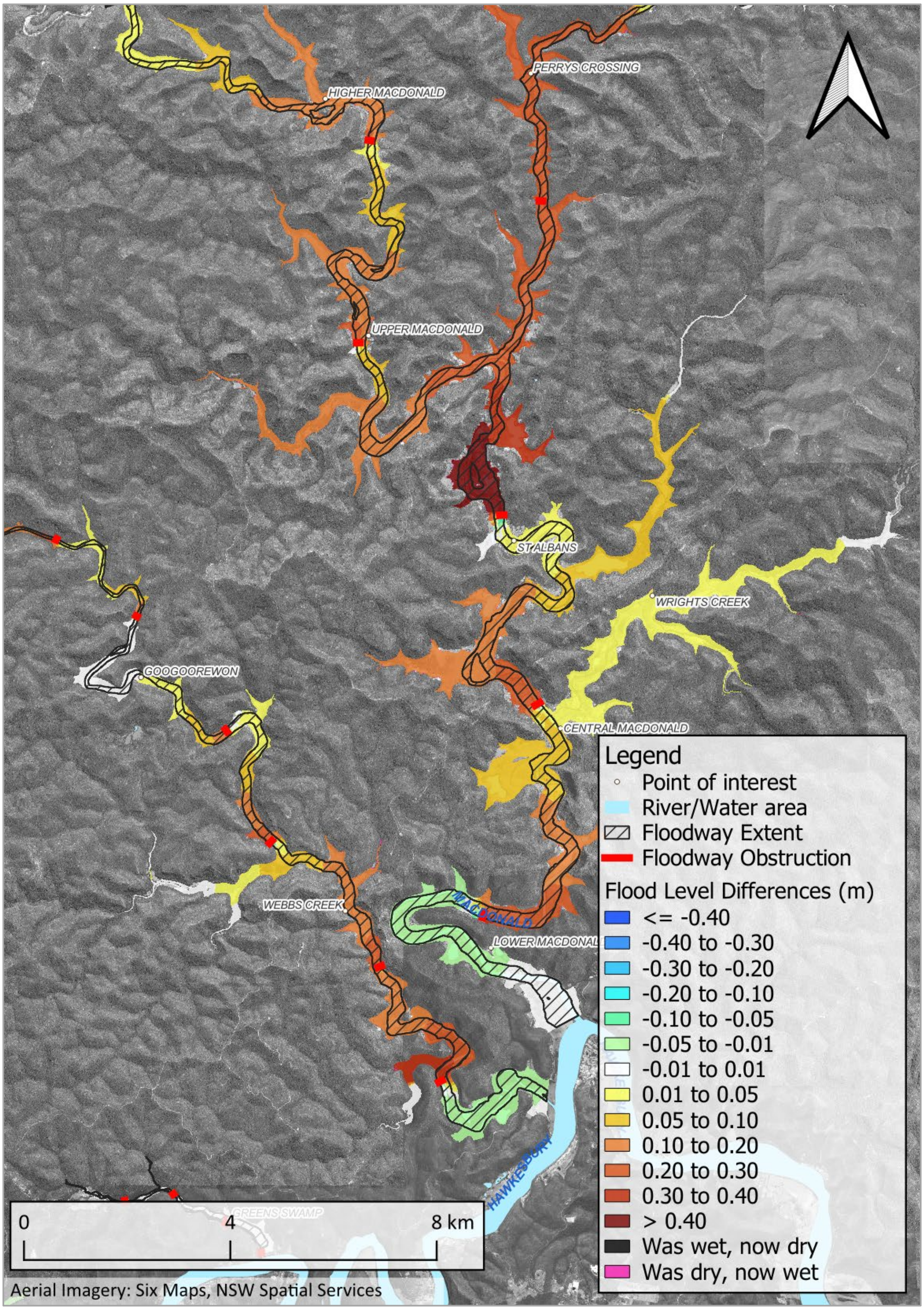


Figure E4 1% AEP Flood Level Differences associated with obstructions of floodway in Webbs Creek and Macdonald River

Appendix E – Flood Function Verification

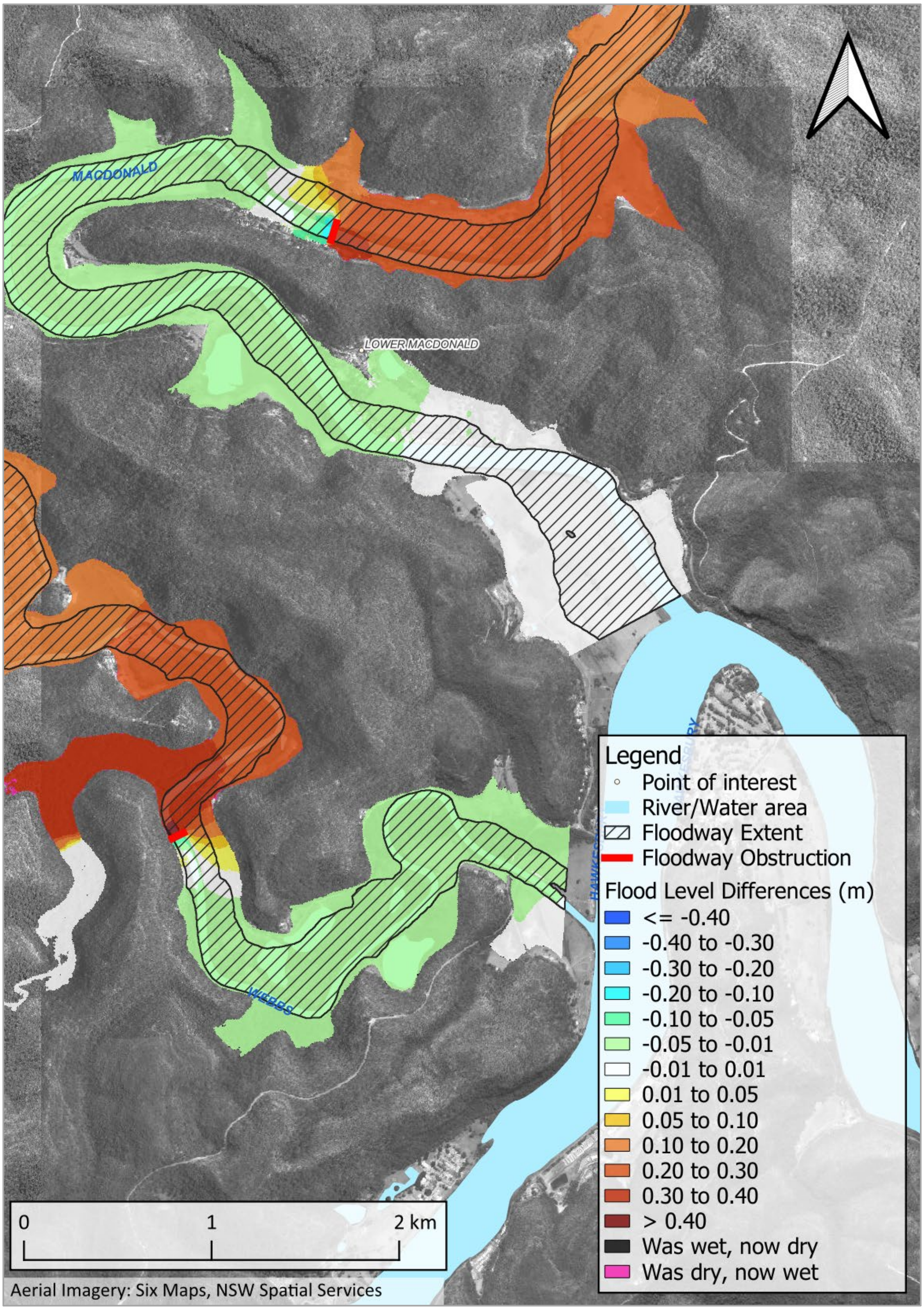


Figure E5 AEP Flood Level Differences associated with obstructions of floodway in Webbs Creek and Macdonald River (lower reaches)

Appendix E – Flood Function Verification

3 Flood Fringe

Flood fringe areas are areas that, if filled/removed, would result in insignificant impacts to flood levels and extents. To confirm the suitability of the flood fringe areas, flood fringe areas were 'blocked out' from the modelled domain. The updated model was used to re-simulate the 1% AEP flood with the flood fringe areas removed. Peak 1% AEP flood levels were compared against 'existing' 1% AEP flood levels and the resulting difference mapping is shown in **Figure E6** and **Figure E10**.

The difference maps show that removal of all flood fringe areas would generate increases and decreases in peak 1% AEP flood levels. However, the differences are generally less than 0.05 metres, with isolated areas of slightly higher increases and decreases (although all flood level impacts are les than 0.1 metres). Considering this assessment considered blockage of all fringe areas, flood level differences of this magnitude are considered to be insignificant. Accordingly, it is considered that the extent of the delineated flood fringes is appropriate and suitable for application across the study area.

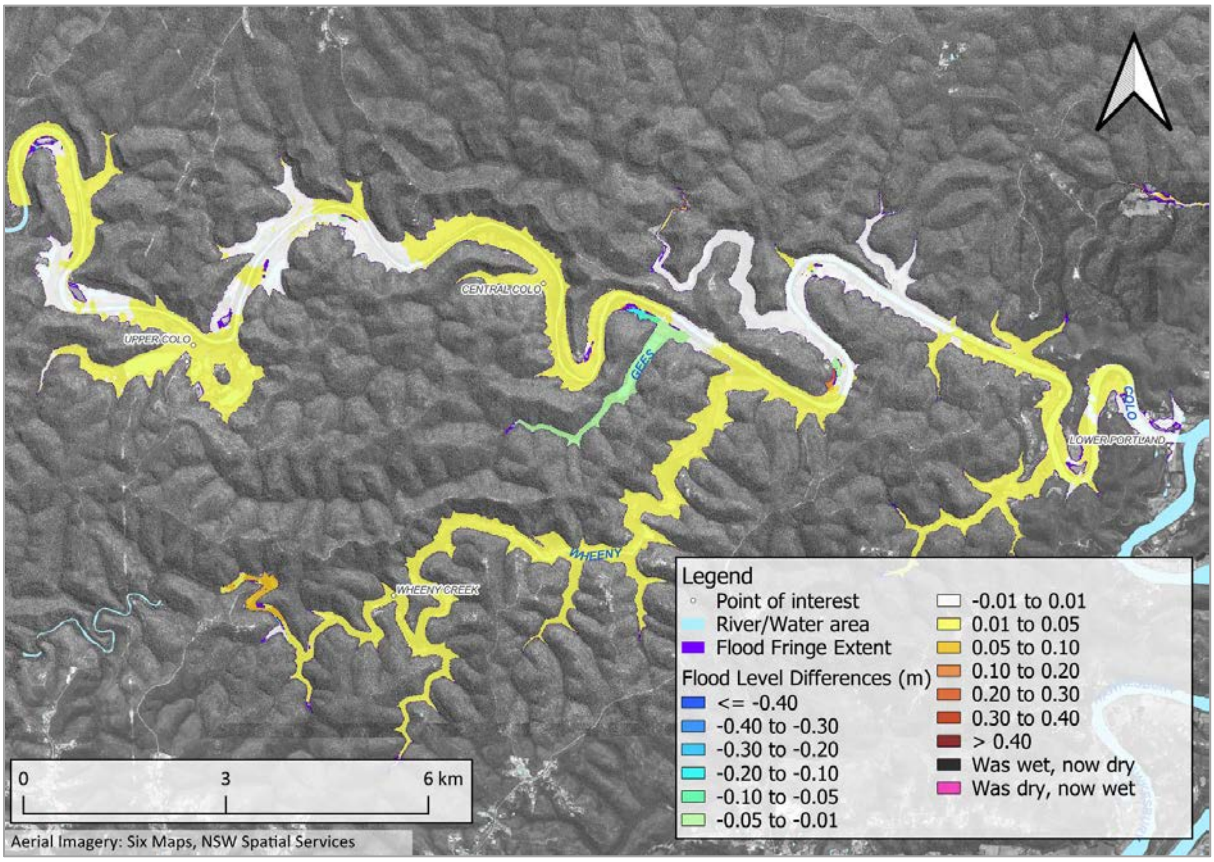


Figure E6 1% AEP flood level differences associated with filling across Flood Fringe Areas of Colo River

Appendix E – Flood Function Verification

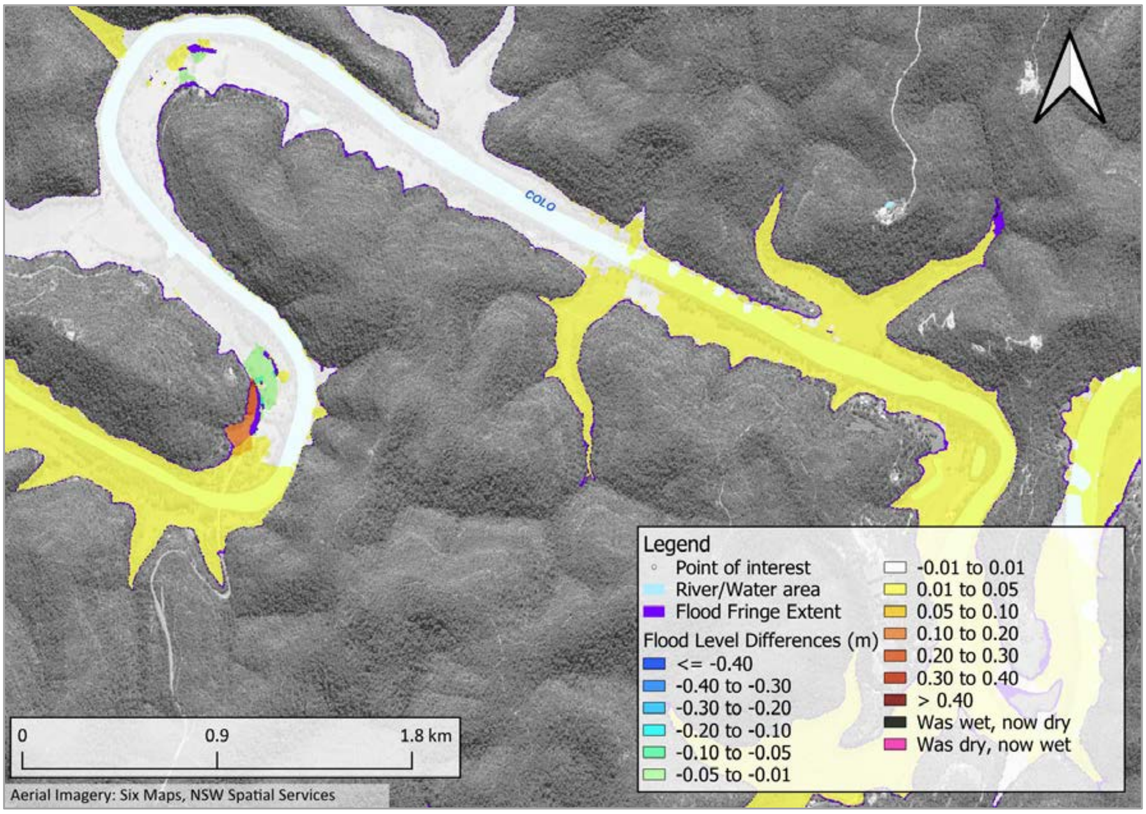


Figure E7 1% AEP flood level differences associated with filling across Flood Fringe Areas in Colo River (lower reach)

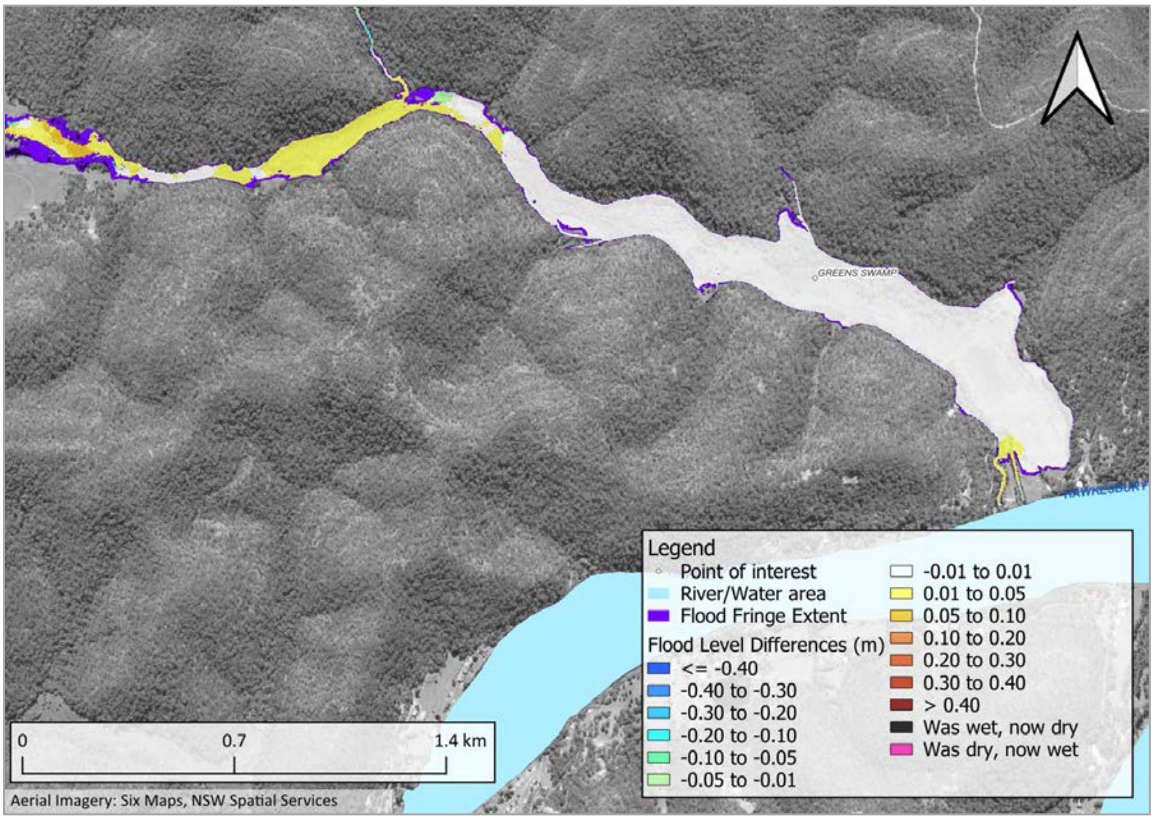


Figure E8 1% AEP flood level differences associated with filling across Flood Fringe Areas in Greens Creek

Appendix E – Flood Function Verification

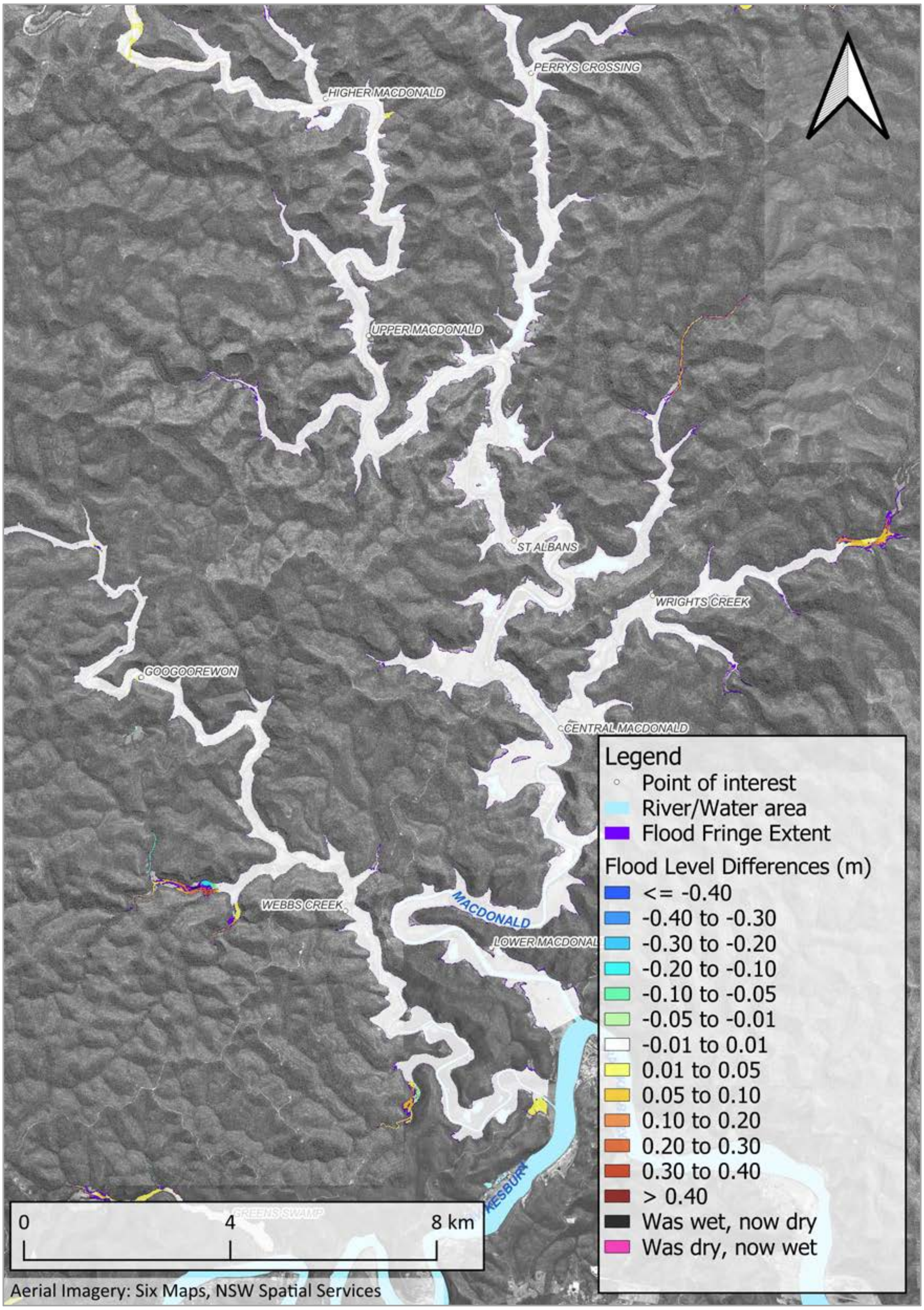


Figure E9 1% AEP flood level differences associated with filling across Flood Fringe Areas in Webbs Creek and Macdonald River

Appendix E – Flood Function Verification

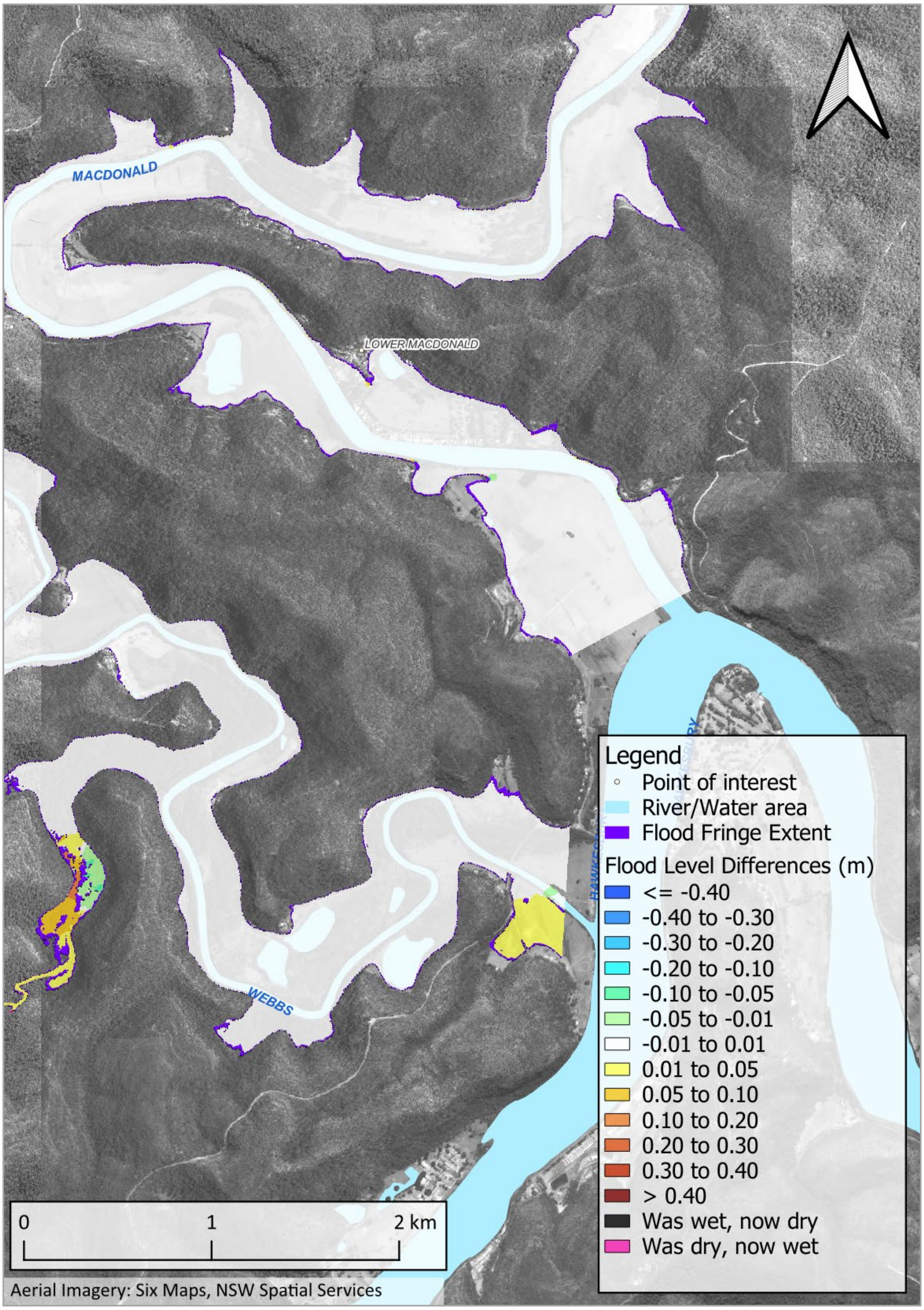


Figure E10 1% AEP flood level differences associated with filling across Flood Fringe Areas in Webbs Creek and Macdonald River (lower reach)

Appendix F

Bridge Loss Calculations and Blockage

Name: Upper Colo Bridge (Previous)
Road: Colo Heights Road
Watercourse: Colo

Reference: 'Hydraulics of Bridge Waterways: HDS 1' (Bradley, March 1978) + 'Technical Guideline: Hydrologic & Hydraulic Modelling' (TMR, 2019)

Hawkesbury City Council Design Plans

The total backwater (i.e., energy loss) coefficient is calculated as:
$K^* = K_b + K_p + K_e + K_s$

K_b (base coefficient)

Kb = 0 as contraction losses are fully represented in 2D   M = 1

K_b = **0.00**

K_p (Pier Coefficient)

Pier Number	Pier Top Elevation (mAHD)	Pier Bottom Elevation (mAHD)	Pier Height (m)	Pier Width (perpendicular to direction of flow) (m)	Pier Length (parallel to direction of flow) (m)
1	5.60	-1.00	6.60	0.6	0.6
2	5.60	-1.00	6.60	0.6	0.6
3	5.60	-1.00	6.60	0.6	0.6
4	5.60	-1.00	6.60	0.6	0.6

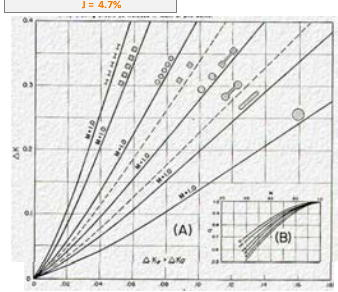
Area calculations based on river stage = 5.60 mAHD

Ratio of gross waterway area to pier area

$J = A_p / A_{n3}$ A_p = 16 m^2

J = 0.046830653 A_{n2} = 338 m^2

J = 4.7%



Pier Type: Dual Circular Pier

$\sigma = 1.00$
$\Delta K = 0.11$

$K_p = \sigma\Delta K$

K_p = **0.11**

K_e (Eccentricity Coefficient)

Ecentricity represented in 2D.

K_e = **0.00**

K_s (Skew Coefficient)

Bridge skew represented in 2D

K_s = **0.00**

(K*) Total Backwater Coefficient for Bridge Substructure

$K^* = K_b + K_p + K_e + K_s$

K* = **0.11**   Blockage = **4.7%**

Bridge Deck and Guardrails

Bridge deck: Lc = 1.6 & 100% blockage (AustRoads Waterway Design, Fig 5.18, 1994)
Guardrail: Lc = 0.0 & 50% blockage (TMR, 2019)

Name:	Upper Colo Bridge
Road:	Colo Heights Road
Watercourse:	Colo

Reference: 'Hydraulics of Bridge Waterways: HDS 1' (Bradley, March 1978) + 'Technical Guideline: Hydrologic & Hydraulic Modelling' (TMR, 2019)

Bridge Design Pty Ltd 2021

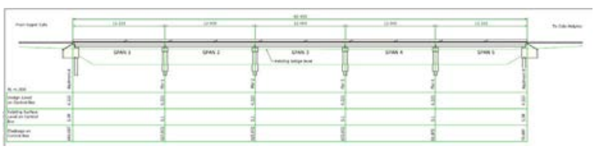
The total backwater (i.e., energy loss) coefficient is calculated as:
$K^* = K_b + K_p + K_e + K_s$

K_b (base coefficient)

Kb = 0 as contraction losses are fully represented in 2D   M = 1

K_b = **0.00**

K_p (Pier Coefficient)



Pier Number	Pier Top Elevation (mAHD)	Pier Bottom Elevation (mAHD)	Pier Height (m)	Pier Width (perpendicular to direction of flow) (m)	Pier Length (parallel to direction of flow) (m)
1	4.95	2.90	2.05	0.6	0.6
2	4.95	2.90	2.05	0.6	0.6
3	4.95	2.90	2.05	0.6	0.6
4	4.95	2.90	2.05	0.6	0.6

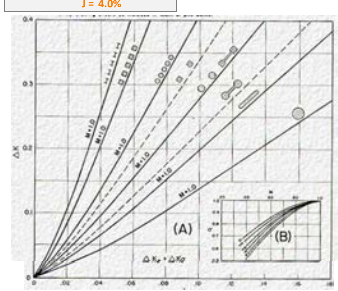
Area calculations based on river stage = 4.95 mAHD

Ratio of gross waterway area to pier area

$J = A_p / A_{n3}$ A_p = 5 m^2

J = 0.039735099 A_{n2} = 124 m^2

J = 4.0%



Pier Type: Dual Circular Pier

σ = 1.00
ΔK = 0.09

$K_p = \sigma\Delta K$
K_p = **0.09**

K_e (Eccentricity Coefficient)

Ecentricity represented in 2D.

K_e = **0.00**

K_s (Skew Coefficient)

Bridge skew represented in 2D

K_s = **0.00**

(K*) Total Backwater Coefficient for Bridge Substructure

$K^* = K_b + K_p + K_e + K_s$
K* = 0.09   **Blockage = 4.0%**

Bridge Deck and Guardrails

Bridge deck: Lc = 1.6 & 100% blockage (AustRoads Waterway Design, Fig 5.18, 1994)
Guardrail: Lc = 0.0 & 50% blockage (TMR, 2019)

Name:	Putty Road Bridge
Road:	Putty Road
Watercourse:	Colo

Reference: 'Hydraulics of Bridge Waterways: HDS 1' (Bradley, March 1978) + 'Technical Guideline: Hydrologic & Hydraulic Modelling' (TMR, 2019)

Roads and Traffic Autority NSW 1993

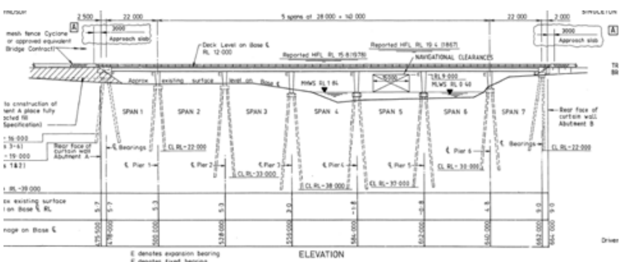
The total backwater (i.e., energy loss) coefficient is calculated as:
$K^* = K_b + K_p + K_e + K_s$

K_b (base coefficient)

Kb = 0 as contraction losses are fully represented in 2D M = 1

K_b = **0.00**

K_p (Pier Coefficient)



Pier Number	Pier Top Elevation (mAHD)	Pier Bottom Elevation (mAHD)	Pier Height (m)	Pier Width (perpendicular to direction of flow) (m)	Pier Length (parallel to direction of flow) (m)
1	9.00	5.30	3.70	1.6	6.8
2	9.00	5.30	3.70	1.6	6.8
3	9.00	3.00	6.00	1.6	6.8
4	9.00	-1.80	10.80	1.6	6.8
5	9.00	-0.80	9.80	1.6	6.8
6	9.00	4.80	4.20	1.6	6.8

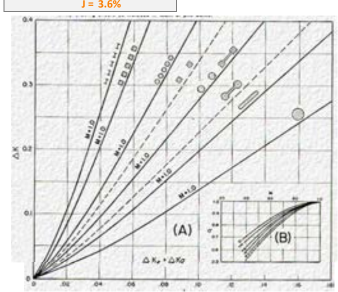
Area calculations based on river stage = 9.00 mAHD

Ratio of gross waterway area to pier area

$J = A_p / A_{n3}$ A_p = 61 m^2

J = 0.036027115 A_{n2} = 1697 m^2

J = 3.6%



Pier Type: Single Rectangular Pier

σ = 1.00
ΔK = 0.06

$K_p = \sigma \Delta K$
K_p = **0.06**

K_e (Eccentricity Coefficient)

Ecentricity represented in 2D.

K_e = **0.00**

K_s (Skew Coefficient)

Bridge skew represented in 2D

K_s = **0.00**

(K*) Total Backwater Coefficient for Bridge Substructure

$K^* = K_b + K_p + K_e + K_s$
K^* = **0.06** Blockage = 3.6%

Bridge Deck and Guardrails

Bridge deck: Lc = 1.6 & 100% blockage (AustRoads Waterway Design, Fig 5.18, 1994)
Guardrail: Lc = 0.0 & 50% blockage (TMR, 2019)

Name: Lower Portland Bridge
Road: Greens Road
Watercourse: Colo

Reference: 'Hydraulics of Bridge Waterways: HDS 1' (Bradley, March 1978) + 'Technical Guideline: Hydrologic & Hydraulic Modelling' (TMR, 2019)

Department of Public Works NSW 1966

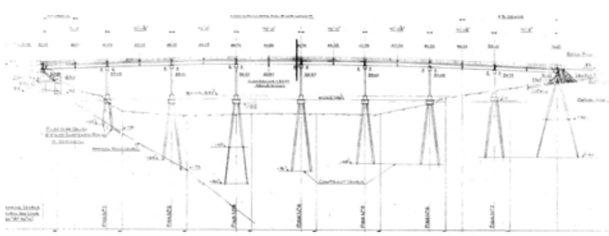
The total backwater (i.e., energy loss) coefficient is calculated as:
$K^* = K_b + K_p + K_e + K_s$

K_b (base coefficient)

Kb = 0 as contraction losses are fully represented in 2D   M = 1

K_b = **0.00**

K_p (Pier Coefficient)

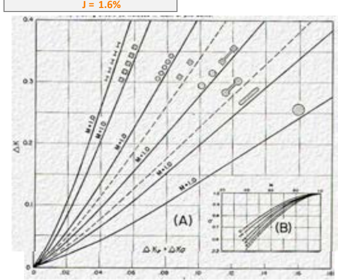


Pier Number	Pier Top Elevation (mAHD)	Pier Bottom Elevation (mAHD)	Pier Height (m)	Pier Width (perpendicular to direction of flow) (m)	Pier Length (parallel to direction of flow) (m)
1	10.57	-0.66	11.23	0.4572	0.4572
2	11.40	-4.96	16.36	0.4572	0.4572
3	11.99	-4.48	16.47	0.4572	0.4572
4	12.32	-3.67	15.99	0.4572	0.4572
5	12.28	-2.63	14.91	0.4572	0.4572
6	11.99	-0.66	12.65	0.4572	0.4572
7	11.40	3.35	8.05	0.4572	0.4572

Area calculations based on river stage = 10.00 mAHD

Ratio of gross waterway area to pier area

$J = A_p / A_{n3}$ A_p = 38 m^2
J = 0.015996093 A_{n2} = 2392 m^2
J = 1.6%



Pier Type: Linked Circular Pier

σ = 1.00
ΔK = 0.02

$K_p = \sigma \Delta K$
K_p = **0.024**

K_e (Eccentricity Coefficient)

Ecentricity represented in 2D.

K_e = **0.00**

K_s (Skew Coefficient)

Bridge skew represented in 2D

K_s = **0.00**

(K*) Total Backwater Coefficient for Bridge Substructure

$K^* = K_b + K_p + K_e + K_s$
K* = **0.024**   **Blockage = 1.6%**

Bridge Deck and Guardrails

Bridge deck: Lc = 1.6 & 100% blockage (AustRoads Waterway Design, Fig 5.18, 1994)
Guardrail: Lc = 0.0 & 50% blockage (TMR, 2019)

Name:	Webbs Creek Bridge
Road:	Chaseling Road
Watercourse:	Webbs Creek

Reference: 'Hydraulics of Bridge Waterways: HDS 1' (Bradley, March 1978) + 'Technical Guideline: Hydrologic & Hydraulic Modelling' (TMR, 2019)

Department of Main Roads, NSW 1970

The total backwater (i.e., energy loss) coefficient is calculated as:
$K^* = K_b + K_p + K_e + K_s$

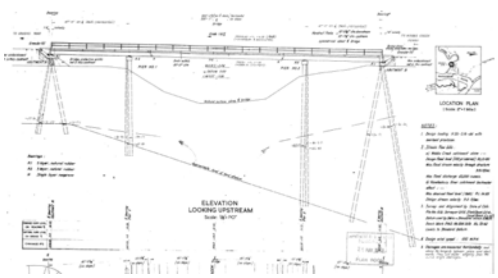
K_b (base coefficient)

Kb = 0 as contraction losses are fully represented in 2D

M = 1

K_b = **0.00**

K_p (Pier Coefficient)



Pier Number	Pier Top Elevation (mAHD)	Pier Bottom Elevation (mAHD)	Pier Height (m)	Pier Width (perpendicular to direction of flow) (m)	Pier Length (parallel to direction of flow) (m)
1	3.04	0.30	2.74	0.635	0.635
2	2.56	0.30	2.26	0.635	0.635

Area calculations based on river stage = 2.56 mAHD

Ratio of gross waterway area to pier area

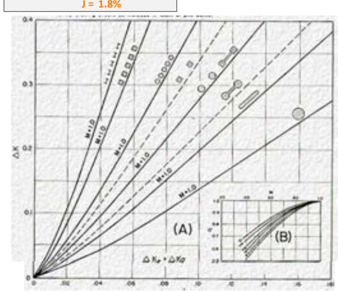
$J = A_p / A_{n3}$

A_p = 3 m^2

A_{n2} = 156 m^2

J = 0.018345531

J = 1.8%



Pier Type: Multi- Circular Pier

σ = 1.00

ΔK = 0.06

$K_p = \sigma\Delta K$

K_p = **0.06**

K_e (Eccentricity Coefficient)

Ecentricity represented in 2D.

K_e = **0.00**

K_s (Skew Coefficient)

Bridge skew represented in 2D

K_s = **0.00**

(K*) Total Backwater Coefficient for Bridge Substructure

$K^* = K_b + K_p + K_e + K_s$

K^* = **0.06**

Blockage = **1.8%**

Bridge Deck and Guardrails

Bridge deck: Lc = 1.6 & 100% blockage (AustRoads Waterway Design, Fig 5.18, 1994)
Guardrail: Lc = 0.0 & 50% blockage (TMR, 2019)

Name:	St Albans Bridge
Road:	Wollombi Road
Watercourse:	Macdonald

Reference: 'Hydraulics of Bridge Waterways: HDS 1' (Bradley, March 1978) + 'Technical Guideline: Hydrologic & Hydraulic Modelling' (TMR, 2019)

Department of Public Works

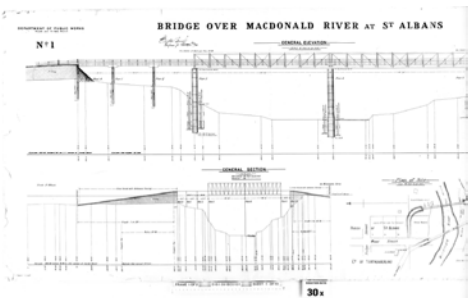
The total backwater (i.e., energy loss) coefficient is calculated as:
$K^* = K_b + K_p + K_e + K_s$

K_b (base coefficient)

Kb = 0 as contraction losses are fully represented in 2D — M = 1

K_b = **0.00**

K_p (Pier Coefficient)



Pier Number	Pier Top Elevation (mAHD)	Pier Bottom Elevation (mAHD)	Pier Height (m)	Pier Width (perpendicular to direction of flow) (m)	Pier Length (parallel to direction of flow) (m)
1	14.89	10.98	3.91	0.4826	0.4826
2	14.89	10.30	4.60	0.4826	0.4826
3	14.89	5.08	9.81	1.39065	1.39065
4	14.89	0.75	14.14	1.8288	1.8288
5	14.89	7.28	7.61	0.3048	0.3048

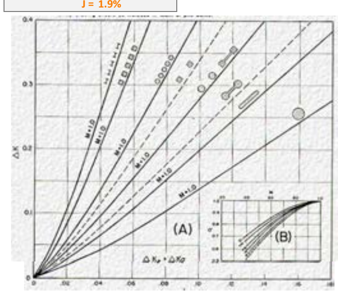
Area calculations based on river stage = 8.00 mAHD

Ratio of gross waterway area to pier area

$J = A_p / A_{n3}$ — A_p = 15 m^2 — A_{n2} = 808 m^2

J = 0.018531196

J = 1.9%



Pier Type: Linked Circular Pier

σ = 1.00
ΔK = 0.03

$K_p = \sigma\Delta K$

K_p = **0.028**

K_e (Eccentricity Coefficient)

Ecentricity represented in 2D.

K_e = **0.00**

K_s (Skew Coefficient)

Bridge skew represented in 2D

K_s = **0.00**

(K*) Total Backwater Coefficient for Bridge Substructure

$K^* = K_b + K_p + K_e + K_s$

K^* = **0.028** — Blockage = **1.9%**

Bridge Deck and Guardrails

Bridge deck: Lc = 1.6 & 100% blockage (AustRoads Waterway Design, Fig 5.18, 1994)
Guardrail: Lc = 0.0 & 50% blockage (TMR, 2019)

STRUCTURE BLOCKAGE ASSESSMENT

Structure Details			Structure Dimensions			Debris Potential								Adjustment for AEP			Design Blockage Level		
ID	**Structure Type**	**Culvert Type: C - Circular, R-Rectangular**	**Inlet clear width (W)**	**Inlet clear height (D)**	**Cells / Spans**	**Upstream Land Use**	**Max. L10 (m)**	**Control Dimension**	**Debris Availability (L, M, H)**	**Debris Mobility (L, M, H)**	**Debris Transportability (L, M, H)**	**Debris Potential**	**Debris Potential at Structure**	**AEP >5%**	**AEP 5%-0.5%**	**AEP < 0.5%**	**AEP >5%**	**AEP 5%-0.5%**	**AEP < 0.5%**
6	Culvert	C	1.2		1	Trees - high density	3.00	W<L	M	L	M	**MLM**	Low	Low	Low	Medium	25%	25%	50%
7	Culvert	C	0.6		1	Trees - high density	3.00	W<L	M	L	M	**MLM**	Low	Low	Low	Medium	25%	25%	50%
8	Culvert	C	1.2		2	Trees - high density	3.00	W<L	M	L	M	**MLM**	Low	Low	Low	Medium	25%	25%	50%
9	Culvert	C	0.9		1	Trees - high density	3.00	W<L	M	L	M	**MLM**	Low	Low	Low	Medium	25%	25%	50%

engineering | environmental | economics | engagement

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