Catchment Management Plan for Muscle Creek and Possum Gully

Client: Muswellbrook Shire Council

Reference: PA3263-RHD-MB-XX-RP-C-0001

Status: Final/02

Date: 2 July 2024

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Document title:	Catchment Management Plan for Muscle Creek and Possum Gully
Reference:	PA3263-RHD-MB-XX-RP-C-0001
Status:	02/Final
Date:	2 July 2024
Project name:	Catchment Management Plan for Muscle Creek and Possum Gully
Project number:	PA3263
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Date:	02/07/2024

Classification
Project related

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Acronyms

Term of Acronym	Description
AEP	Annual Exceedance Probability
ARI	Annual Recurrence Interval
ARTC	Australian Rail Track Corporation
BAM	Biodiversity Assessment Methodology
CMP	Catchment Management Plan
DBH	Diameters at breast height
DCP	Development control plan
FRMS&P	Floodplain Risk Management Study and Plan
HSWP	Hunter Strategic Weed Plan
LEP	Local environmental plan
LLS	Local Land Services
MSC	Muswellbrook Shire Council
NOW	NSW Office of Water
OEH	The NSW Office of Environment and Heritage
PCT	Plant Community Types
PMF	Probable Maximum Flood
REF	Review of Environmental Factors
RHDHV	Royal HaskoningDHV
VHR	Voluntary house raising
VMP	Vegetation Management Plan
VP	Voluntary purchase
WMS	Weed management strategy

Executive Summary

This Catchment Management Plan (CMP) was prepared by Royal HaskoningDHV (RHDHV) for Muswellbrook Shire Council (MSC) to address the management of Muscle Creek and Possum Gully.

The CMP provides a strategic overview of current practices and proposes a prioritised management plan to guide MSC in ensuring the ongoing health and stability of the creeks. The plan includes actions for short-term (2 years) and long-term (10 years) implementation as requested by MSC and is subject to funding sources being identified.

To develop a baseline understanding of the study catchment a combination of fieldwork and desktop work was undertaken. The fieldwork conducted in August 2023 gave on-the-ground insights into the catchment's geomorphology and vegetation management. The desktop study considered geomorphology, hydrology, drainage, flooding, ecology, and water quality within the catchment boundaries defined by previous flood and drainage studies.

Key insights learned from the fieldwork and desktop study could be summarised as follows:

- Historic land use changes, as observed through aerial imagery dating back to 1938, indicate shifts in vegetation and urbanisation.
- Geomorphologically, the region has experienced significant changes since European settlement, particularly related to riverbank clearing and sediment deposition in the Hunter River. Previous development and historic use of Muscle Creek for urban drainage has exacerbated existing instability of embankments, due to existing geomorphology, lack of vegetation cover near embankment toes and ongoing impacts from stormwater and flooding within the Creek. Climbing weeds are prevalent, stifling vegetation, while native bank vegetation is limited in parts. Steep, unstable banks near crucial infrastructure like homes and roads pose risks. Some areas lack riparian structure and remain underutilised.
- The catchment experiences fluctuations due to climatic events like El Niño and La Niña, impacting droughts and floods. The catchment is prone to flooding, with the potential to inundate crucial roads, posing challenges for emergency services.
- The study catchment includes a constricted stormwater network that consists of underground stormwater pipes, pits, GPTs, and substantial culverts at road crossings and open channels.
- The riverbanks across the catchment show signs of extensive erosion where vegetation was absent, where the ground cover layer or inefficient hydraulic structures and altered hydrological regimes were apparent. The vegetation within the catchment is currently subject to a range of management actions such as revegetation and regeneration activities outlined through evidence of extensive primary weed control, plantings, active regeneration and private and public landscaping.
- Data on water quality is limited. Historical water quality monitoring identified that at Muswellbrook there were elevated levels of water quality parameters such as faecal coliforms, nitrates and turbidity. Fieldwork confirmed that gross pollutants are prevalent throughout the waterways, with an increased load downstream of Muscle Creek and the daylighted sections of Possum Gully.
- Anticipated future changes include increased urbanisation, which is expected to elevate peak discharges and flooding risks. To address this impact, all development is to follow Council’s Development Control Plans (DCPs) (i.e., detention basins, protected spillways, GPTs). Climate change will further complicate flash floods and bank instability due to altered rainfall patterns and prolonged droughts. Elevated temperatures during droughts will exacerbate water shortages and environmental stress.

With this baseline understanding, key issues and opportunities for the study catchment were identified in relation to bank instability, vegetation, water quality and drainage and flood risk. The management plan solutions focus on addressing these concerns, and prioritising recommendations for the Council. To prioritise management solutions, they were assessed for effectiveness and feasibility.

A summary of high priority actions is as follows and shown visually in **Figure 1-1**. Note that these are high-priority actions, a comprehensive list of actions is shown in **Section 4**.

- BI1 – Creek bank stabilisation and/or relocation for two vulnerable areas in Muscle Creek (preceded by site-specific assessment).
- BI2 – Soft creek bank solutions such as planting along riverbanks.
- VM1 – Vegetation management at Reaches 5, 6 and 8
- VM2 – Vegetation management at Reach 2 and 5
- VM3 – Preparation of a detailed catchment-wide Vegetation Management Plan (or based on prioritised reaches)
- WQ1 – Regular maintenance and debris removal from gross pollutant traps/surcharge pits to prevent excess sediment from being discharged into the creek.
- FL1 – Emergency Management Planning (develop a Local Flood Plan)
- FL9 – Stormwater detention basin upstream of George Street
- FL10 – Channel improvements between Sowerby Street and Carl Street, and
- FL11 – Combination of FL9 and FL10.

In particular, creek bank stabilisation and/or relocation for two vulnerable areas in Muscle Creek of two vulnerable areas in Muscle Creek was identified as key management that should be undertaken by Council within the next two years. RHDHV have developed high-level methodologies for two sites for consideration in **Appendix A6**. It is proposed that detailed analysis (i.e., concept design, survey, soil testing, drone footage) is commissioned for bank instability options at specific high-risk locations.

These locations include the following:

- Rear of Remington Hotel and adjacent properties
- Muswellbrook and District Workers Club
- Riverside Caravan Park
- Where Muscle Creek is adjacent to the railway line in the golf course
- The end of Clifford Street
- Bend next to Olympic Park carpark

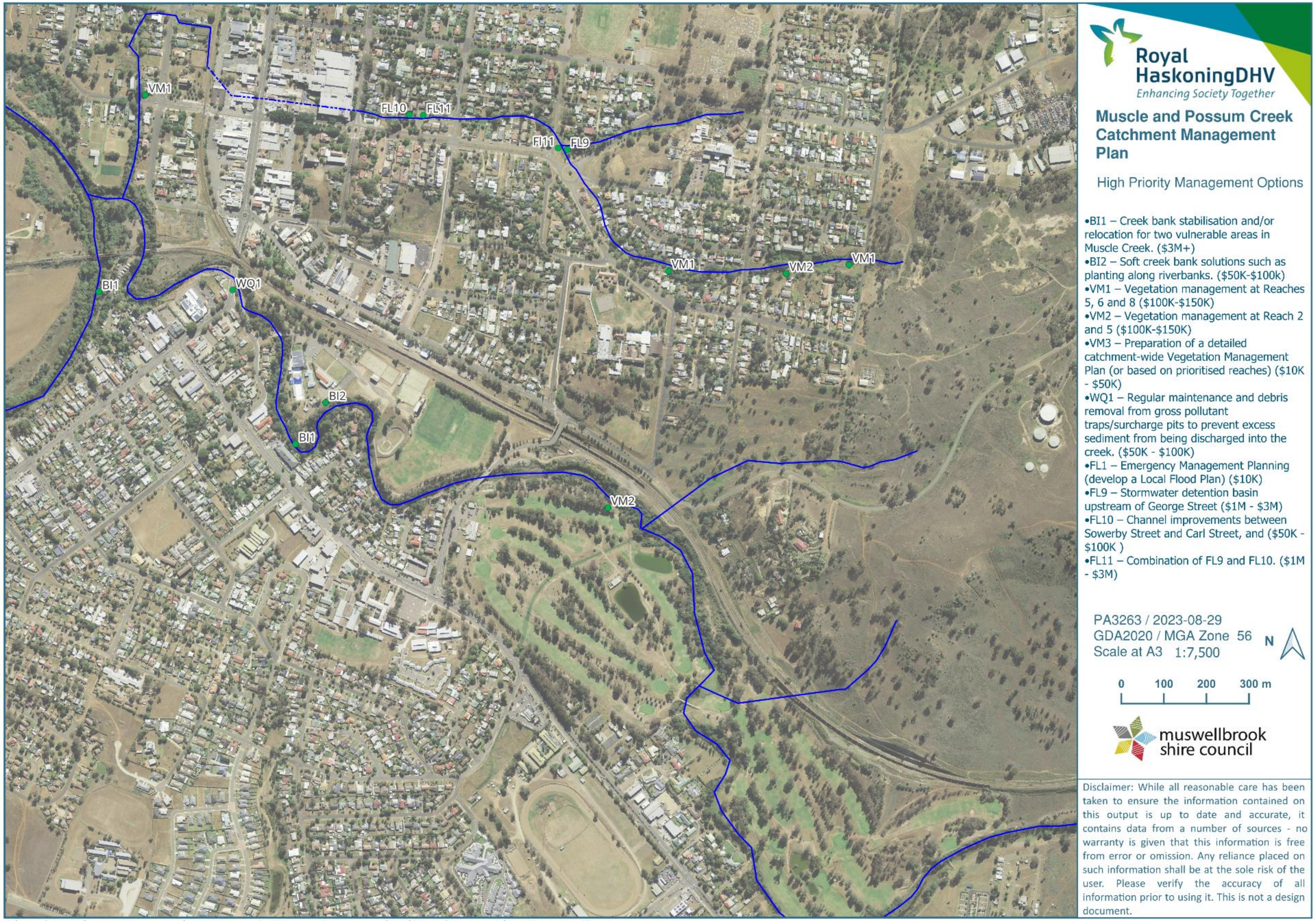

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Figure 1-1: High Priority Management Options

1 Introduction

1.1 Purpose

Muswellbrook Shire Council (MSC) engaged Royal HaskoningDHV (RHDHV) to develop a Catchment Management Plan (CMP) for Muscle Creek and Possum Gully.

The CMP's purpose is to describe the existing catchment environment and provide an overview and assessment of local land uses, future planned uses and develop options for managing the catchment. Specifically, the CMP focuses on improving the riparian management of the creeks and providing stormwater management practices and bank stabilisation measures to ensure the longevity of the waterways and consider the future impacts of climate change.

1.2 Objectives

The CMP aims to provide a strategic overview of existing catchment management practices and a clear prioritised direction going forward, along with a focused clear, pragmatic and prioritised plan of management to guide MSC management and ensure the ongoing health and stability of Muscle Creek and Possum Gully through improved strategic stormwater management practices, controlling stormwater inflows while managing and mitigating risks to adjoining properties from embankment deterioration or collapse.

The key objectives of this study are as follows:

- Establish an understanding of the baseline environment.
- Identify and define issues and opportunities, and
- Provide a prioritised list of management actions.

Management plan actions are presented for two periods: 2 years and 10 years as per MSC’s request.

1.3 Scope of the management plan

1.3.1 Technical scope

In preparation of this CMP, the technical areas considered include geomorphology, hydrology, drainage, flooding, ecology and water quality in the catchment. The technical work comprised a desk-based review of selected available information, supplemented by targeted fieldwork.

1.3.2 Geographical scope

The indicative perimeter of the catchment, for this CMP, is shown in **Figure 7-1**. Hereafter it is referred to as the ‘study catchment area’. The geographical extent of the CMP is broadly the downstream sections of Muscle Creek and Possum Gully (not the full watershed catchment) and for convenience is based on the extent which is defined by previous flood and drainage studies, namely modelling undertaken for the water shed catchment from the Muscle Creek Flood Study (Royal HaskoningDHV, 2017) and Possum Gully Catchment Stormwater Drainage Study (SMEC, 2015). Specifically, the Muscle Creek upstream extent is approximately 2 kilometres (km) east of the end of the golf course and the downstream extent is the confluence point with the Hunter River (approx. 9km^2). The Possum Gully study extents are confined to the urbanised region of north Muswellbrook (approx. 0.45km^2). The study area catchment therefore does not comprise the entire watershed catchment. The hatched area shown in **Figure 7-1** was not accessible and was not included in the visual inspection. Although it was not inspected, the impacts to watercourses from development and mitigation are as specified in Council’s Development Control Plans (DCPs).

1.4 Report structure

This report is divided into a main body and appendices with supporting information. **Appendix A1** contains standard format figures (i.e., catchment boundary, land use), and **Appendices A2 – A5** provide additional information, including geomorphology field sheets using during the field investigations.

Section 2 of the main body presents an overview of the catchment, covering hydrology, drainage, flooding, geomorphology, ecology, water quality, and anticipated future changes. **Section 3** outlines the catchment's identified issues and opportunities. **Section 4** outlines management plan solutions.

For both descriptions throughout and giving geographical context to the description of management options, the creek line has been split into reaches, as shown below in **Figure 1-1**. Readers are encouraged to familiarise themselves with the reaches as these are referenced throughout. See **Figure 7-11** in **Appendix A1** for reach scale maps of study creeks.

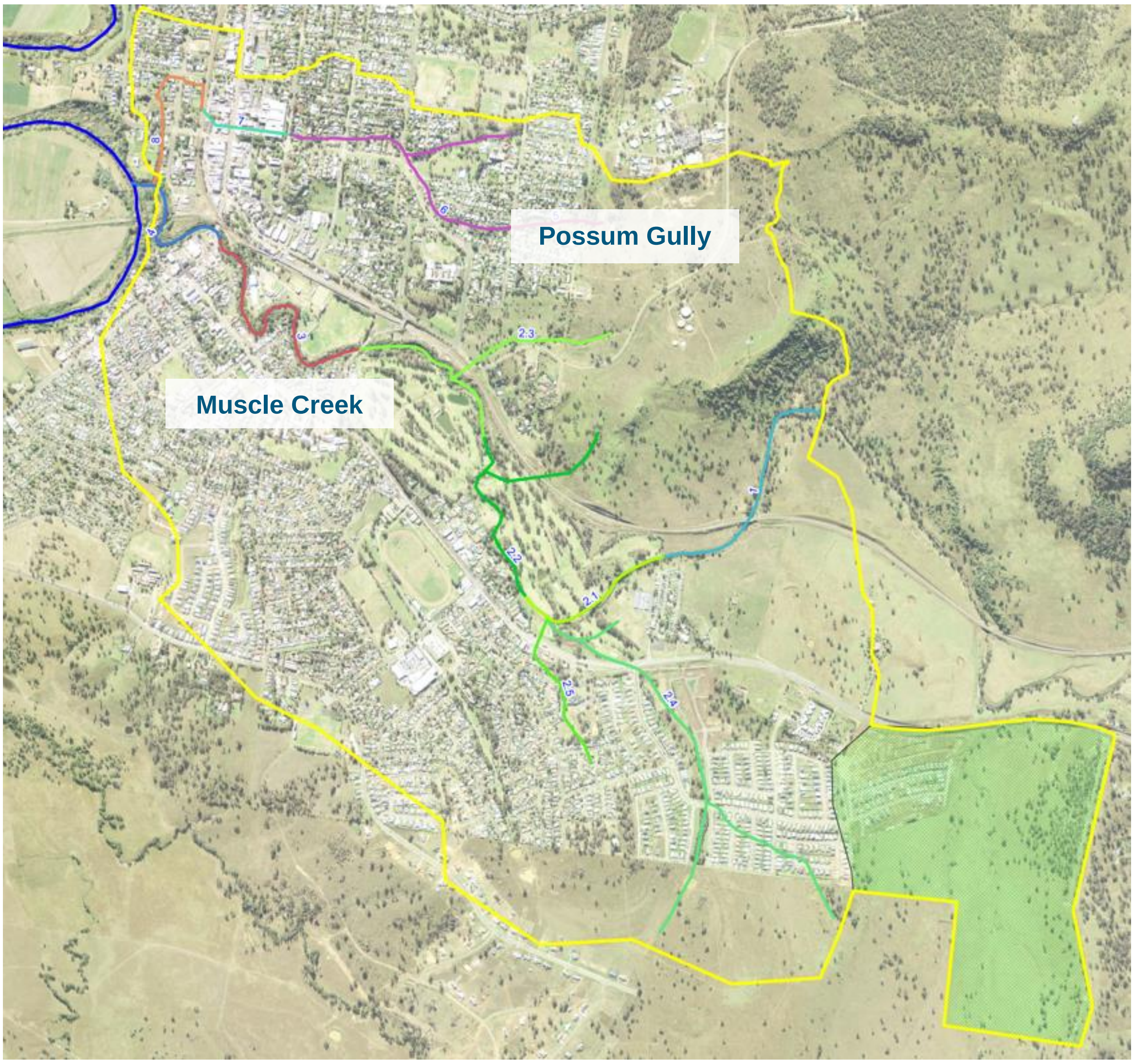

Figure 1-1: Study reaches covered by the CMP (hatched area inaccessible)

2 Existing Catchment Environment

2.1 Catchment overview

The CMP study area catchment, shown below in **Figure 1-2** (refer to **Figure 7-1** in **Appendix A1** for more detailed maps), is located in Muswellbrook central business district (CBD) and extends west (upstream). Muswellbrook is located in the Upper Hunter Valley, 110 km northwest of Newcastle and 230 km north-west of Sydney. The township is bordered by the Great Dividing Range to the west, Liverpool Range to the north and Mount Royal Range to the east.

Muscle Creek drains an area of some 92 square kilometres (km^2) upstream of Muswellbrook and flows centrally through the township of Muswellbrook before joining the Hunter River. There are four bridge crossings across the creek on Bell Street, Wilkinson Avenue, Wilder Street and Bridge Street.

Possum Gully drains a smaller catchment of 1.5 km^2 and is a tributary of Muscle Creek.

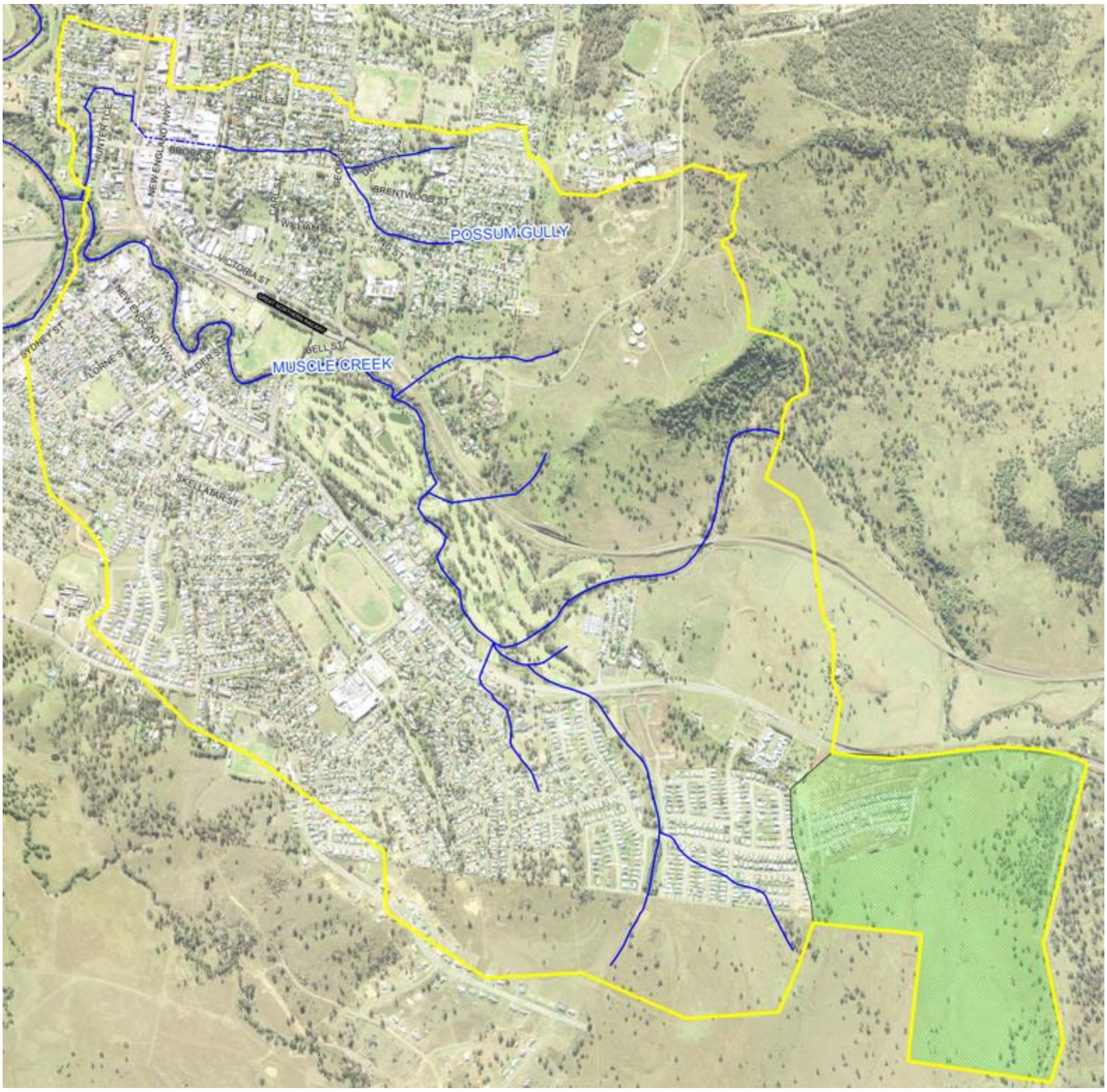

Figure 2-1: Study catchment area (hatched area inaccessible)

2.1.1 Current land use

The lower portion of the catchment is predominately rural but includes areas of mining (much open-cut), recreational (golf course) and agricultural land uses as well as some urban areas (including residential, private and public recreation).

Tributary ephemeral streams, such as the Eastbrook Links estate gully (around Bimbadeen Drive) flow into the golf course which acts as a buffer, protecting against potential flood events and contributing to improving water quality. Other than the golf course, there is a lack of buffers (i.e., vegetation, wetlands or open space) with adjoining land uses that could serve as a protective zone for flood mitigation, water quality and habitat.

Possum Gully flows through partly urbanised areas and in the lower portion of the creek, it flows through the Muswellbrook commercial area. Possum Gully drains to Muscle Creek west of Hunter Terrace. The lower reaches are urbanised, including the majority of the Muswellbrook commercial area. The catchment area includes several different land-use classifications, including environmental management (C3), private recreation (RE2) and public recreation (RE1), general residential (R1), infrastructure (SP2), local centre (E1) and light industrial (E4).

The existing (2023) land use for the catchment is shown in **Figure 7-2**.

2.1.2 Historic land use

An overview of historical land use and change over time has been determined from visual interpretation of available aerial imagery, including those from 1938, 1974, 1989, 1998 and 2014.

The 1938 aerial image (**Figure 7-3**), shows that the creek lines are generally in the same location as seen present-day. The catchment some 85 years ago was substantially less developed than the present-day catchment with limited urbanisation south of New England Highway, and the catchment overall. The riparian vegetation around Muscle Creek was substantially cleared compared to the present, presumably from past land use and farming practices.

By 1989, historical images show that urbanisation around the creek had expanded and riparian vegetation increased (**Figure 7-4**) from the earlier cleared condition. By 1998, urban development extended closer to the creek (**Figure 7-5**). In 2014, vegetation coverage and urbanisation broadly resembled the present-day condition (**Figure 7-6**).

The 1938 aerial imagery (**Figure 7-7**) shows that Possum Gully is less constrained by housing compared to the present and is less vegetated. The existing roads (and general location) existed; however, development was not present up to the gully. The CBD was less densely urbanised. By 1974, development extended closer to the gully, accompanied by increased vegetation (**Figure 7-8**). However, there is now more vegetation at the upstream end of Possum Gully compared to then. The increased upstream vegetation in Possum Gully is largely dominated by species of Eucalyptus, there are incursions of exotic species and weed species such as Balloon Vine (*Cardiospermum grandiflorum*) and Privet sp. The upper areas of Possum Gully offer a high potential for restoration and revegetation with adequate vegetation management. The existing native vegetation is of high benefit due to the potential for weed and exotic species suppression and recruitment of native vegetation through a seedbank and potentially acting as a detention basin. Areas such as this have the potential to be investigated for native seed collection for revegetation purposes.

2.1.3 Current Vegetation Management

The Muswellbrook Urban Riparian Landcare Master Plan (GHDWoodhead 2018) provides a broad overview of potential land-use opportunities for the Hunter River and Muscle Creek. Section 4 of the plan outlines native vegetation management constraints and opportunities as well as broad management aims to ensure appropriate vegetation management occurs across specific sites across Muswellbrook. Specific aims relating to previous and current vegetation management have been outlined for sites such as Karoola Wetlands, Karoola (Hunter River), Rutherford Park and in particular Muscle Creek.

The vegetation management proposed for Muscle Creek is broadly in alignment with the proposed vegetation management actions in **Section 4.3** of this CMP, notably the requirement for adequate sediment and erosion controls. Council correspondence has outlined that previous weed in areas with steep creek banks has result in bank instability. This indicates that current weed control practices may require adaptive management actions such as staged weed removal in conjunction with the implementation erosion and sediment control or retention of root mass from large woody weeds.

Proposed vegetation management practices should also consider replanting potential, subject to soil profile and characteristics, challenges to access for maintenance and watering particularly during dry periods. Council has indicated that they have had challenges in grant funded and widespread planting where tree species have not established before stripping of understorey vegetation and exotic weeds to ensure additional bank stability. This should be further investigated in the Vegetation Management Plan.

As outlined in the Muswellbrook Urban Riparian Landcare Master Plan site specific VMPs should be implemented for sites such as Muscle Creek, further to this a site specific VMP for Possum creek should also be implemented to detail future vegetation management.

2.2 Geomorphology

2.2.1 Wider Catchment Characteristics

As mentioned previously, Muscle Creek and Possum Gully are tributaries of the Upper Hunter River. The geology and geomorphology of the Hunter River Catchment broadly resemble (at least locally) that of Muscle Creek. The morphology and processes of the downstream sections of Muscle Creek are influenced by the adjacent Hunter River channel.

Following European settlement, the riparian vegetation that lined the banks of the Hunter River was cleared, destabilising the banks. As mentioned in **Section 2.1**, this was also the case in the Muscle Creek catchment. A significant amount of sand from the cleared land entered the river, burying its gravel pool and riffle structure and depositing large quantities of sand in the riverbed and floodplain (Erskine & Fityus, 1998).

Over time, sediment deposition occurred on the floodplain creating a deeper channel that extended downstream. The bed and banks of the Hunter River increased in elevation, eventually becoming higher than the adjacent backswamps. Occasionally, larger floods breached the natural river levees and redirected the main channel into lower areas of the floodplain, wherein the process of delta infilling, and floodplain development continued (Thomas & Druery, 1996).

At the confluence of Muscle Creek and the Hunter River, the Hunter River channel now comprises a gravel pool and riffle sequence with significant sand bedload. There is evidence of channel incision in the Hunter River, and bed elevations compared to train bridge abutments and piers would suggest that such incision is relatively recent (past 50 years) and ongoing.

Soil landscapes of the Muswellbrook area are displayed in the Soil Landscapes of the Singleton 1:250 000 Sheet Report. Soils in the area have been identified as the Hunter Soil landscape. This soil landscape covers the floodplains of the Hunter River and its tributaries. The main soils are all formed in alluvium and include Brown Clays, Black Earths, Red Podzolic Soils, Lateritic Podzolic Soils, Non-calcic Brown Soils and yellow Solodic Soils (GHD, 2012). The soil types in the region are shown in **Figure 7-9** and **Figure 7-10**.

In Muswellbrook, there is at least one terrace level present. Terraces are former floodplain surfaces that are now inundated less frequently than at a previous time, usually due to creek downcutting. The Charleston Bench is evident in Muswellbrook, where it is well developed to the south and east of the town as a result of river erosion when the river flowed at the same level as the bench. This bench has been much dissected since it was uplifted to its present position and has been largely removed (Sussmilch, 1940).

The geomorphology of Muscle Creek was assessed via fieldwork carried out by RHDHV personnel, which is described below and in relevant appendices. For convenience, an overview is provided below.

2.2.2 Geomorphological Assessment

In August 2023, a field-based geomorphological assessment was completed to support this CMP. For this CMP, both description and management have been split into reaches. Readers should familiarise themselves with the reaches in **Figure 7-11** in **Appendix A1**. Refer to the geomorphology fieldwork in **Appendix A2** for a detailed summary of the geomorphological findings at each reach. The direction in which the photos were taken (upstream or downstream) is indicated in figure captions.

The typical characteristics are broken down below in **Figure 2-2**. Generally, the channel of Muscle Creek and floodplain is not as modified physically as parts of the Lower Hunter (see (Thomas & Druery, 1996), however, the catchment modification has no doubt had an impact on the current morphology. Within the study area, Muscle Creek can be defined geomorphologically as follows:

- Upstream of the golf course, the creek retains many natural physical features. There is a sinuosity to the channel and connection to the floodplain. There are some pool and riffle sequences and some larger pools. Mainly though, the channel is small and comprises a defined low flow channel. Bank heights vary and appear to be influenced by the underlying geology, as well as contemporary processes. There is little channel modification, although there are several crossings. The bed and banks are a mixture of sand and clay, as is common throughout Muscle Creek. Reasonable riparian vegetation and lack of bed and bank modification lend to a relatively stable creek channel.

- Within the golf course, the creek channel is sinuous in places but appears to have been re-aligned / straightened adjacent to the rail line. The channel is not particularly incised and for the most part, has a connection with the floodplain.

- Within the township, the Muscle Creek channel is highly sinuous (compared to upstream). It becomes heavily incised, with high and steep banks, particularly downstream. Bank height and incision into the adjacent floodplain increase downstream to the confluence with the Hunter River. The channel increases and takes on a more defined trapezoidal shape. The incision has been somewhat arrested by several bed control structures.

- Downstream of the township and adjacent to the Hunter River, the channel is similar to upstream (through the township, i.e., large trapezoidal cross section), although here there is a distinct increase in incision, 2-3 meters in the base. This has formed very steep and high banks. Where properties have been developed adjacent the risk of continuing bank failure poses a risk (see below Section 2.2.3).

Possum Gully is heavily modified throughout, although retains some natural form (ephemeral ill-defined stream flowing over rock) upstream of the study area. Possum Gully is at risk of encroachment from nearby development, potentially causing altered hydrology and increased sedimentation, particularly in its upstream section passing through residential backyards. Within the study area, Possum Gully is culverted and built over, particularly in the lower portions. At the confluence with Muscle Creek, Possum Gully again is an open channel and is incised into the adjacent floodplain.

2.2.3 Creek Instability

Creek instability, including channels and banks, was observed along Muscle Creek in reaches 2, 3, and 4. In some locations the bank instability is does not pose ongoing risk to physical assets (such as in the golf course), and typically a product of vegetation clearing and natural channel migration. In other locations the creek and bank instability present a greater risk and potentially more problematic due mainly to the proximity to assets such as private property and infrastructure. These locations include the following:

- Rear of Remington Hotel and adjacent properties
- Muswellbrook and District Workers Club
- Riverside Caravan Park
- Where Muscle Creek is adjacent to the railway line in the golf course
- The end of Clifford Street
- Bend next to Olympic Park carpark

Locations of low risk bank instability and higher-risk bank instability are shown in **Figure 7-12** of **Appendix A1** and **Figure 7-35** of **Appendix A6** respectively. Locations where works have previously been undertaken to arrest instability, observed during fieldwork, have been noted in **Figure 7-13** and **Figure 7-14**.

Current management of creek instability includes vegetation planting (primarily on bank and riparian zone), gabion protection and rock protection of creek banks and in-channel bed control structures, such as rock weirs.

Access to the creek for management, in a number of areas, is constrained by existing development and steep embankment batters.

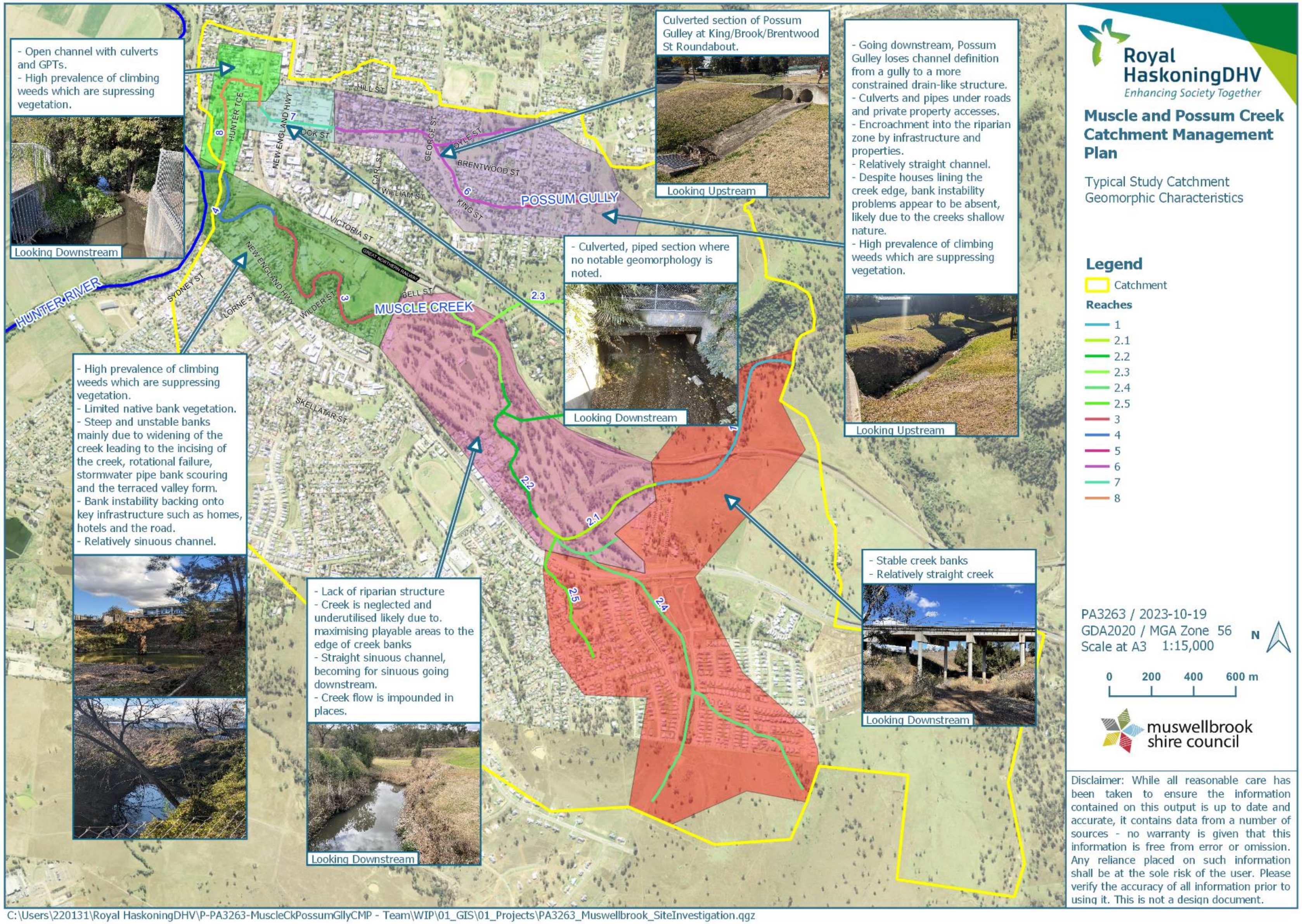

Figure 2-2: Typical study catchment geomorphic characteristics (reach assessment areas are shaded)

2.3 Hydrology, Drainage and Flood Risk

2.3.1 Catchment hydrology

The climate of the Hunter region is subtropical to temperate, with annual rainfall across the region averaging about 870 mm. Rainfall varies from the coast inland, ranging from more than 1,100 mm per year on the coast and the Barrington Tops, down to less than 600 mm per year in parts of the upper Hunter (**Figure 2-3**). Rainfall is greatest in summer and autumn, with a higher proportion of winter rainfall on the coast than inland. It is mild to warm in summer throughout much of the region, however, winters are cool in more elevated parts of the region further inland.

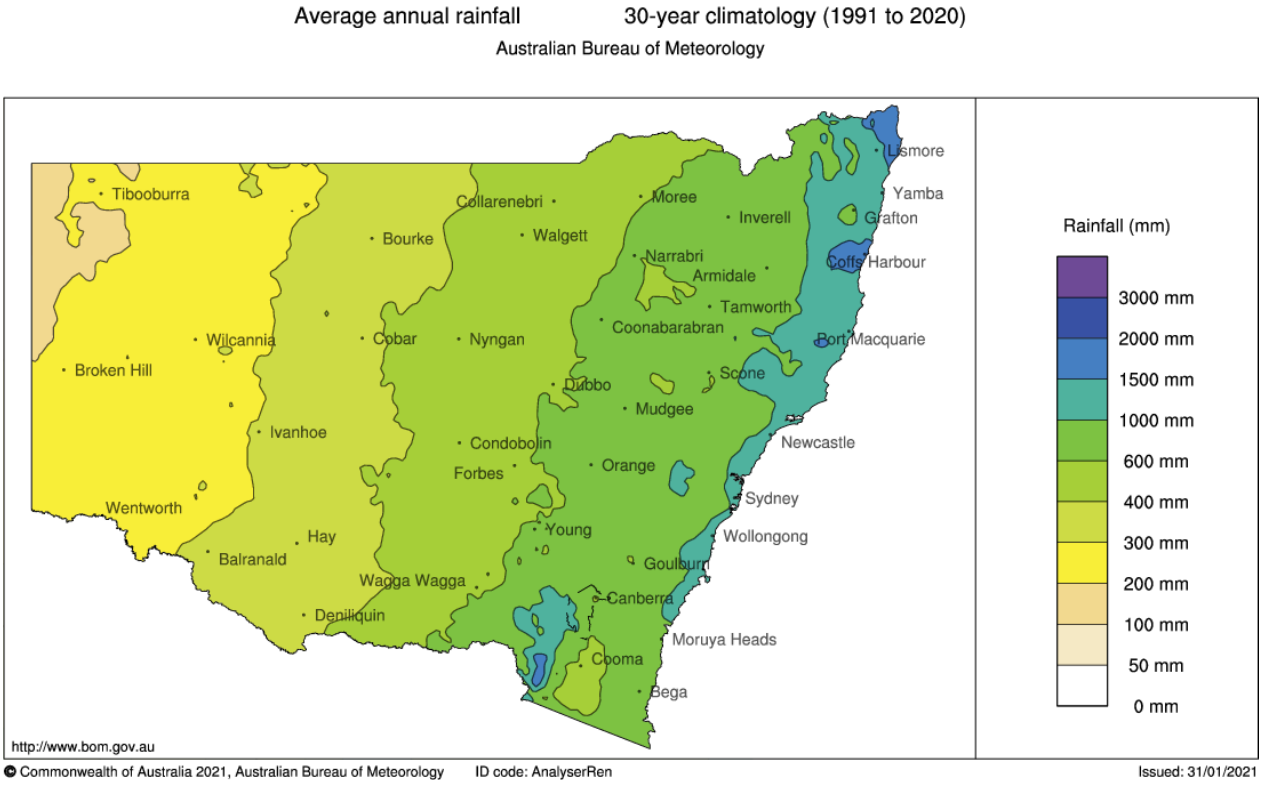

Figure 2-3: Average annual rainfall in NSW (BOM, 2021)

The study area is located in a mild temperate climatic zone and experiences a summer dominated rainfall pattern, however, heavy isolated falls may occur during winter (**Figure 2-4**). The average annual rainfall near Muswellbrook[1] is around 650 mm.

[1] *No official weather station is available in the Muswellbrook LGA but stations at Scone are typically representative.*

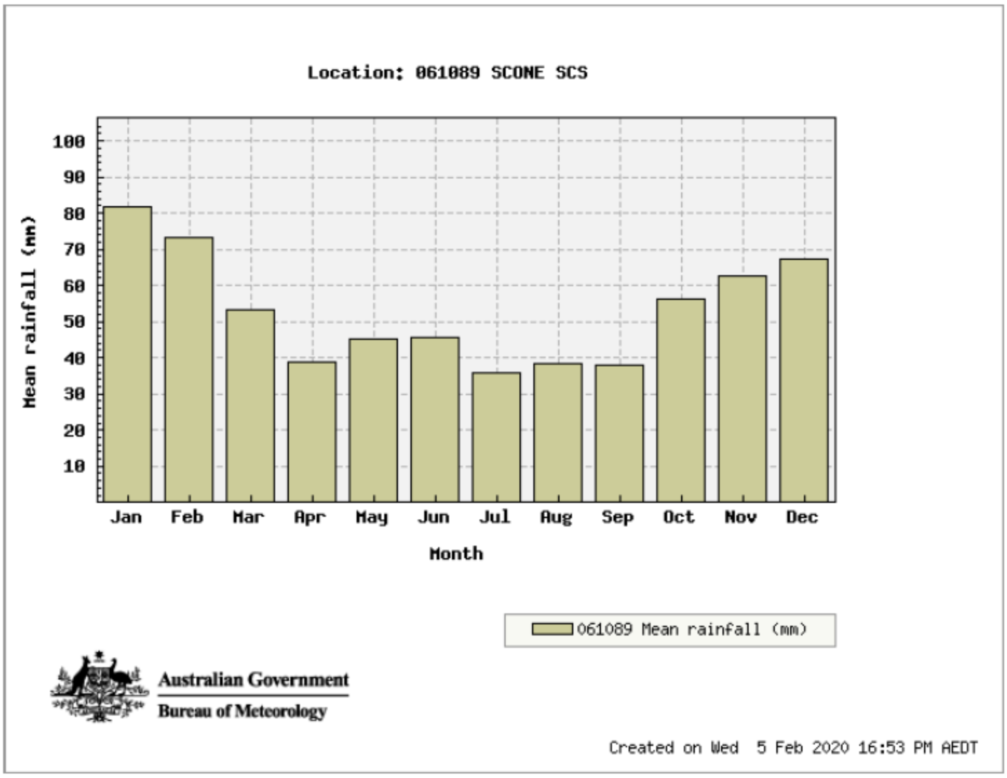

Figure 2-4: Long-term mean monthly rainfall at Scone (Station 061089)

The Muswellbrook region experiences significant fluctuations in weather patterns, influenced by phenomena such as El Niño and La Niña. These climatic events exacerbate periods of drought and flooding. During El Niño events, the region often experiences reduced rainfall, higher temperatures, and increased evaporation rates. This has led to extended periods of drought and water shortages, placing stress on local ecosystems and agricultural activities. Conversely, during La Niña events, the Muswellbrook region may see increased rainfall and cooler temperatures, which can help alleviate drought conditions but also pose risks of flooding and increased soil erosion and bank instability.

The hydrological impact of water upstream of the catchment influences the dynamics of erosion downstream. Increased water flow from upstream sources, especially in catchment areas with elevated impervious surfaces (i.e., in the Eastbrook Links estate), intensifies the potential for downstream erosion. As water travels downstream, it gains momentum and can erode banks, contributing to soil degradation and sediment transport. The alteration of natural flow patterns, whether due to urbanisation or land-use changes, can exacerbate erosion processes. To address this impact, all development is to follow Council's Development Control Plans (DCPs) (i.e., detention basins, protected spillways, GPTs). There is a renewed focus that mitigation measures including stormwater quality and quantity controls are strictly controlled. Refer to **Section 2.7.1**.

2.3.2 Stormwater network

The stormwater drainage network in the study area is generally characterised by Muscle Creek and Possum Gully draining from the surrounding hills into the flat alluvial plains adjacent to the Hunter River. Several drainage lines traverse the study area and drain into the Hunter River, Muscle Creek and Possum Gully.

The study catchment includes a constricted stormwater network that consists of underground stormwater pipes, pits, gross pollutant traps (GPTs), substantial culverts at road crossings, stormwater detention basins and open channels. Stormwater detention basins within the catchment reduce stormwater quantity and pollutants to Muscle Creek. The stormwater network is shown in **Figure 7-15**. Many stormwater outlets to Muscle Creek discharge at levels above the low flow channel and most do not have adequate (or in some cases any) scour protection, therefore causing bank scour as shown in **Figure 2-5**.

SMEC (2017) identifies that there are 12 basins within Muswellbrook. A qualitative risk assessment of the basins (SMEC, 2017) flagged two detention basins in Muswellbrook as posing a high risk as they are at close proximity to residential communities. These basins are located near the Muswellbrook Shire Council office and along Bimbadeen Drive. The inspection revealed issues like erosion/scouring, debris blockage, and a lack of proper signage to warn of potential flooding. MSC is undertaking ongoing asset management and inspections to identify and mitigate risks with detention basins.

Figure 2-5: Stormwater outlets that do not have adequate scour protection, therefore causing bank scour. Examples given are located in reach 3 (left) and reach 4 (right).

2.3.3 Historic flooding

Annual Exceedance Probability (AEP) - AEP (measured as a percentage) is a term used to describe flood size. It is a means of describing how likely a flood is to occur in a given year. For example, a 1% AEP flood is a flood that has a 1% chance of occurring, or being exceeded, in any one year. It is also referred to as the ‘100 year flood’ or 1 in 100 year flood’.

Annual Recurrence Interval (ARI) - ARI (measured in years) is a term used to describe flood size. It is the long-term average number of years between floods of a certain magnitude. For example, a 100 year ARI flood is a flood that occurs or is exceeded on average once every 100 years.

While the 1% AEP Flood and the 100 year ARI Flood are statistically equivalent, experts are moving away from using ARI terminology. The term "100 year flood" can be misleading, as it suggests that a 100 year flood occurs once every 100 years, which is not necessarily true.

The study catchment is prone to flooding and has been subject to historical flooding.

The largest flood to have been formally recorded within the catchment occurred in February 1955 (recorded peak discharge 5013 m^3/s). The event had an estimated Average Recurrence Interval (ARI) of 500 years. Large areas within Muswellbrook were inundated during the event.

The 1955 flood occurred because of heavy rainfall across the catchment over several days and resulted in what is often regarded as one of the worst natural disasters in recent Australian history. The event had an estimated Average Recurrence Interval (ARI) of 100 years at Muswellbrook (Muswellbrook Flood Study, WRC 1986).

A large flood event occurred in Muscle Creek in June 2007. A review of available rainfall data by Umwelt estimated the event to be similar to a 50 year ARI (or 2% AEP) event (Umwelt, 2009).

Figure 2-6 shows the raised water levels that occurred at Muscle Creek in November 2021 where Bridge Street and Muscle Creek cross.

Council recounts that more recent flooding has occurred at the end of 2022 and early 2023 in Muswellbrook. Council reports that debris markers at Tarinpa (formerly Hunter Beach), located off Aberdeen St, indicate flood heights reaching approximately 5 meters during the late 2022 flooding events.

Additional photos provided by MSC showing flooding during the February and November 2022 flood events are shown in **Figure 2-7** to **Figure 2-12**.

Figure 2-6: Bridge Street Muscle Creek Flooding in November 2021 (ARTC, 2021)

Figure 2-7: Muscle Creek after rain – 14th February 2022 (Council Staff Record)

Figure 2-8: Muscle Creek after rain – 14th February 2022 (Council Staff Record)

Figure 2-9: Muscle Creek after rain (behind Remington Hotel) – 14th February 2022 (Council Staff Record)

Figure 2-10: Muscle Creek after rain – 14th February 2022 (Council Staff Record)

Figure 2-11: Muscle Creek after rain – 14th February 2022 (Council Staff Record)

Figure 2-12: Muscle Creek after rain – 11th November 2022 (Council Staff Record)

2.3.4 Estimated flood risk

Muscle Creek

In 2019 Royal HaskoningDHV undertook a Flood Risk Management Study and Plan which provide the most recent assessment of flood risk. Flooding in the 5% AEP (20yr ARI) event can inundate the only two roads connecting the northern and southern parts of Muswellbrook creating a potential issue for emergency services (**Figure 7-29** in **Appendix A3**) (Royal HaskoningDHV, 2019).

As shown in the 1% AEP and PMF peak flood depth maps (**Figure 7-30** and **Figure 7-31**), during flood events, inundation is estimated to occur within the Muswellbrook Golf Course, which is located upstream of Bell Street. Flood waters from the golf course area are known to overtop Bell Street and flow through residential areas located between Bell Street and Wilder Street before re-entering the channel. Surface levels suggest that some flood waters will also flow down the New England Highway. If a Muscle Creek flood event occurs in conjunction with a Hunter River flood event, widespread flooding is expected to occur in the area downstream of Bell Street (Royal HaskoningDHV, 2017). This would be primarily associated with backwater flooding from the Hunter River.

With increased urbanisation, the additional impervious surfaces have led to faster runoff response, greater volume of runoff and a reduction in groundwater recharge.

Possum Gully

The Possum Gully Catchment Stormwater Drainage Study (SMEC, 2015) established that houses within the upstream section of Possum Gully between Queen Street and Brecht Street are mostly unaffected by flooding. There are several properties approximately 3-5) between King Street and Sowerby Street where flood waters reach the habitable floor level in the 100-year ARI design storm event. The section of Possum Gully downstream of the railway line is significantly influenced by tailwater levels within Muscle Creek.
The hydraulic modelling for the Drainage Study identified the following key stormwater drainage issues:

1. Backup of flow behind several culverts within Possum Gully leading to overtopping of the gully/channel at various locations including road crossings (Carl Street and Brentwood Street);
2. Obstruction within the gully/channel (i.e., driveway/track accesses, dense vegetation, sediment build-up & fallen trees) reducing the hydraulic conveyance;
3. Future urbanisation of the contributing catchment leads to an expected increase in peak discharge (to be managed by Council's DCP for stormwater quality and quantity for new development, refer to **Section 2.7.1**.); and
4. Constrictions in the available waterway area within downstream sections of the watercourse, including both the underground pipe/culvert network and overland flow paths. An example is the constriction caused by the reduced culvert size under Muswellbrook Marketplace.

These flooding issues at Possum Gully are shown in **Figure 7-32** in **Appendix A3**.

RHDHV has been engaged by MSC to undertake an investigation and preliminary design of a trunk drainage diversion line in Possum Gully catchment. The works propose to upgrade the trunk drainage system between Bridge Street (the New England Highway) and the Hunter River. The trunk diversion line works align with this CMP's objectives of providing clear prioritised direction to improve stormwater management practices, controlling stormwater inflows and managing embankment deterioration.

Two options were investigation:

- Option A (updated trunk drainage): Drainage infrastructure sized to convey the existing run-off contained within the pipe downstream of the brick arch culvert on Bridge Street directly to the

Hunter River, incorporating a high flow bypass east of Hunter Terrace (i.e., to divert flows away from Possum Gully downstream from Brook Street).

- Option B (without updated trunk drainage): The infrastructure would be sized assuming that a detention basin has been constructed in the catchment upstream. The arrangement documented as Option 1 in SMEC (2015) has been adopted for modelling Option B.

Both options have demonstrated improvement in flood levels and flow velocities along Muscle Creek. The feasibility of the options is currently being finalised.

2.3.5 Flood mitigation infrastructure

Glenbawn Dam, located in the upper watershed catchment of the Hunter River some 20 km northeast of Muswellbrook, has significantly reduced the flood risk characteristics along the Hunter River downstream (Royal HaskoningDHV, 2019). Despite the presence of the dam, further significant flood events occurred in Muswellbrook in February 1971, January 1976, August 1998, November 2000 and June 2007. The inundation that occurred during the June 2007 flood event was primarily the result of flooding from Muscle Creek. The 1971 event is estimated to be a 50-100 year ARI magnitude while the other Hunter River events were of the order of 20-50 year ARI (Royal HaskoningDHV, 2019). The June 2007 rainfall on Muscle Creek was estimated to be an approximate 50-year ARI event (Royal HaskoningDHV, 2019).

Muswellbrook is now protected by a 1.16 km levee that was constructed in 1992 and provides significant flood relief for events up to the 500-year ARI. It should be noted that while the levee protects Muswellbrook from upstream flooding, tailwater flooding in events greater than the 10-year ARI still results in floodwaters backing up from the end of Scott / Brook Street (GHD, 2019). MSC are collaboratively working alongside Public Works NSW to improve and repair existing levees as part of investigations and planning commenced in 2023.

We are aware that MSC is currently developing a flood warning system for the catchment to increase flood warning time and time available for the safe evacuation of high-risk areas.

2.4 Vegetation Assessment

A vegetation assessment was conducted in August 2023 to establish biometric attributes of the existing vegetation across eight reaches within the catchment. These biometric attributes were collected in close alignment with the Biodiversity Assessment Methodology (BAM) and consisted of the following attributes:

- Ground truthing of native Plant Community Types (PCTs) and Vegetation
- Percentage cover and abundance of native and exotic species (including both priority and high-threat weeds)
- Counts of trees and categorised into size classes based on their diameters at breast height (DBH)
- Total length of logs greater or equal to 10cm and longer than 50cm, and,
- Observations of clearing, soil erosion, urban encroachment and stormwater runoff.

The results of the baseline vegetation assessments will assist in informing areas of prioritisation and determining vegetative management actions associated with each of the reaches within the catchment.

Within the priority rating broad details were provided of vegetation management and costs for feasibility, but specific details would need to be detailed in a vegetation management plan (VMP). The Muscle Creek Weed Management Strategy weed management plan was reviewed (**Section 2.4.3**) and it requires updating to align with the current legislation, regional weed priorities and strategies and contemporary weed control methods.

2.4.1 Ecology and Vegetation

The Ecological values present within the catchment broadly consist of riverine forests and riparian ecosystems that provide a range of ecosystem services such as regulating water and air quality, riverbank stabilisation, nutrient cycling and supporting biodiversity. The riverbanks across the catchment showed signs of extensive erosion where vegetation was absent, in particular where the ground cover layer or inefficient hydraulic structures and altered hydrological regimes were apparent.

The existing vegetation consisted of PCTs such as:

- PCT 4089 - *Namoi-Upper Hunter River Red Gum Forest*.
- PCT 3397 - *Northwest Flats Yellow Box Woodland* and
- PCT 3431 - *Central Hunter Ironbark Grassy Woodland*

The PCTs range in condition from good to poor based on the absence of one or more stratum layers, high incursions of weed and exotic species or degradation of soil. Where PCTs were not identified, vegetation consisted of a mix of native and exotic species in varying degrees of cover and abundance. The vegetation within the catchment is currently subject to a range of management actions such as revegetation and regeneration activities outlined through evidence of extensive primary weed control, plantings, active regeneration and private and public landscaping. Refer to **Figure 7-33** in **Appendix A4** for a revegetation map showing previously completed and continued revegetation works in the study catchment area.

Whilst no threatened flora species were identified during the most recent surveys and assessment, the catchment likely supports a vast range of threatened fauna species periodically throughout the year and with proper management provides a habitat for threatened flora species to become established. Adjacent to the Remington Hotel, there is a flying fox colony. Habitat features on-site consisted broadly of the riparian zone and associated microhabitat such as woody debris, bush rock, canopy and shrub layer vegetation providing foraging, sheltering/roosting and breeding habitat and aquatic habitat such as snags, soaks, creeks and riffles. As a result, MSC has indicated that woody debris within areas like Muscle Creek are generally not to be disturbed without consultation with DPIE-Water or suitable Review of Environmental Factors (REF) related to the risk of a tree falling into the creek, which otherwise would be natural fish habitat.

2.4.2 Priority Weeds and Exotic Species

The Hunter Strategic Weed Plan (HSWP) (HLLS 2017) aims to provide a cooperative and coordinated approach to weed management. The HSWP categorises weed species into the following categories based on their position on the invasive species curve and management objectives within the state and region:

- Prevention - *To prevent the weed species from arriving and establishing in the region*.
- Eradication - *To permanently remove the species and its propagules from the region* OR *to destroy infestations to reduce the extent of the weed in the region with the aim of local eradication*.
- Containment - *To prevent the ongoing spread of the species in all or part of the region* and
- Asset protection - *To prevent the spread of weeds to key sites/assets of high economic*, *environmental and social value, or to reduce their impact on these sites if spread has already occurred*.

Priority weed and exotic species identified during the baseline site assessment including those listed under the HSWP are outlined in **Table 2-1**. Other weeds and exotic species not outlined in the HSWP but identified on-site are outlined in **Table 2-2**.

Table 2-1: Priority weeds and species of concern

Common Name	Scientific Name	HSWP Weed Management Category	Characteristics of weeds in this category	Control Methods
African lovegrass	*Eragrostis curvula*	Weed of community concern for Agricultural outcomes.	Species that are of concern to the Hunter community or are a high priority for several current programs, though not feasible to contain or eradicate.	Crown out by hand in proximity to waterways and revegetation/regeneration sites. Spray with Glyphosate Biactive 360 g/L for larger infestations.
Balloon vine	*Cardiospermum grandiflorum*	Weed of community concern for environmental outcomes.	Species that are of concern to the Hunter community or are a high priority for a number of current programs, though not feasible to contain or eradicate.	Skirt and dig out root mass. Cut and paint with Glyphosate Biactive 360 g/L for large root masses.
Camphor laurel	*Cinnamomum camphora*	Weed of community concern for Agricultural and environmental outcomes.	Species that are of concern to the Hunter community or are a high priority for a number of current programs, though not feasible to contain or eradicate.	Cut and paint with Glyphosate Biactive 360 g/L. For larger individuals mechanical removal is preferred or stem injection if mechanical removal is not economically viable.

Common Name	Scientific Name	HSWP Weed Management Category	Characteristics of weeds in this category	Control Methods
Cockspur coral tree	*Erythrina crista-galli*	Weed of community concern for environmental outcomes.	Species that are of concern to the Hunter community or are a high priority for a number of current programs, though not feasible to contain or eradicate.	Cut and paint with Glyphosate Biactive 360 g/L. For larger individuals' mechanical removal is preferred or stem injection if mechanical removal is not economically viable.
Fireweed	*Senecio madagascariensis*	Asset protection – State Weed of community concern for Agricultural outcomes.	These weed species are widespread and unlikely to be eradicated or contained within the wider regional context. Effort is focused on reducing weed threats to protect priority high value assets such as waterways and ecological restoration and revegetation works.	Crown out by hand in proximity to waterways and revegetation/regeneration sites. Spray with Glyphosate Biactive 360 g/L for larger infestations.
Green cestrum	*Cestrum parqui*	Asset protection - Regional	These weed species are widespread and unlikely to be eradicated or contained within the wider regional context. Effort is focused on reducing weed threats to protect priority high value assets such as waterways and ecological restoration and revegetation works.	Cut and paint with Glyphosate Biactive 360 g/L.
Giant reed	*Arundo donax*	Weed of community concern for Agricultural and environmental outcomes.	Species that are of concern to the Hunter community or are a high priority for a number of current programs, though not feasible to contain or eradicate.	Brush cut first then spray with Glyphosate Biactive 360 g/L.

Common Name	Scientific Name	HSWP Weed Management Category	Characteristics of weeds in this category	Control Methods
Willows	*Salix sp*. (excludes *S.babylonica*, *S.X calodendron* & *S*. *x reichardtii*)	Asset protection - State	These weed species are widespread and unlikely to be eradicated or contained within the wider regional context. Effort is focused on reducing weed threats to protect priority high value assets such as waterways and ecological restoration and revegetation works.	Individuals <50cm in height should be hand pulled, individuals >50cm should be stem injected using Glyphosphate Biactive 360g/L, left for a period of 12 months, then mechanically removed through chain sawing or for larger individuals removed by a machine. All vegetative materials will be disposed of at licenced waste facility.

Table 2-2: Other weed and exotic species of concern

Common Name	Scientific Name	Control Methods
Broad-leaf Privet	*Ligustrum lucidum*	Cut and paint using Glyphosate Biactive 360 g/L or pull by hand. Mechanical removal i.e., chainsaw, forestry mulch larger infestations.
Castor oil plant	*Ricinus communis*	Forestry mulch larger infestations. Cut and paint individuals using Glyphosate Biactive 360 g/L or hand pull and removal propagules.
Madeira vine	*Anredera cordifolia*	Removal of tubers by hand where possible. Skirt and dig out root mass. Spot spray plants lower to the ground with Glyphosate Biactive 360 g/L.
Narrow-leaf Privet	*Ligustrum sinense*	Cut and paint using Glyphosate Biactive 360 g/L or pull by hand. Mechanical removal i.e., chainsaw, forestry mulch larger infestations.
Phoenix Palm	*Phoenix canariensis*	Stem injected with Glyphosate Biactive 360 g/L or chainsaw and cut and painted with Glyphosate Biactive 360 g/L

2.4.3 Muscle Creek Weed Management Strategy Review

A weed management strategy (WMS) was previously developed for Muscle Creek by Local Land Services (LLS) in 2016. The weed survey divided the left and right banks (facing downstream) into 66 sites of various sizes and assessed these sites using a standard template to record:

- Native Vegetation Abundance in Overstorey, Mid-Storey and Ground layer;
- Weed Abundance; and,
- Key weed types and names.

Abundance was measured as:

- Low: < 33% cover
- Moderate: 33% - 67% cover
- High: >67% cover

Individual sites were prioritised using several factors including:

- New weed species present
- Cost-benefit – the effort required and the likelihood of success
- Protecting areas worked on previously
- Not working on patches of dense woody weeds
- Starting higher in the catchment and working downstream, and
- Ensuring erosion control is achieved.

The plan stresses that a low priority for weed control does not necessarily equate with a low priority for revegetation and stresses the importance of revegetation works accompanying weed control efforts.

The recommendations of the WMS are sound and many recommendations have been implemented over the past seven years. It is appropriate to update the plan to reflect works completed to date and recent changes in legislation and strategic policy. Notably the Noxious Weeds Act is being replaced with the Biosecurity Act and the release of the Hunter Regional Strategic Weed Management Plan 2017 - 2022 (2017).

Weed control and revegetation works have been particularly successful in Reach 3 (from Bell Street to Sydney Street) and partially successful within Reach 2 (Golf Course) with more work required in this reach, particularly on the right (northern) bank. The assessment completed as part of preparing this CMP has not used the same 66 sites as in the original plan but has aligned management zones with geomorphic reaches, simplifying the number of locations needing to be prioritised. Consistent with the WMS, we recommend that maintenance and improvement of existing rehabilitation areas and areas of existing vegetation should be prioritised before moving into highly degraded areas such as the lower reaches of Muscle Creek noted as Reaches 4 and 8 in this CMP.

Regeneration methods should follow those prescribed within the WMS while incorporating any learnings or observations made by staff over the past seven years. Revegetation should use species consistent with PCTs observed within the corridor and therefore plant species list will go beyond those listed in the WMS. Rehabilitation works should ideally be captured within a Vegetation Management Plan (VMP) which details weed control, rehabilitation methods, planting plans and cost estimates in a single cohesive document. Detailed rehabilitation strategies for the eight reaches adopted within this current catchment management plan should be prepared as part of the VMP.

2.5 Water Quality

Both the Hunter River and Muscle Creek are located within areas dominated by agricultural land with associated mining activities. These activities can reduce the quality of the water through sedimentation, decreased oxygen, pathogens and contaminants within water and sediment. The Hunter River is experiencing increasing pressure from agricultural activities, mining and urban development.

The golf course operated by Muswellbrook Golf Club forms a substantial portion of the study catchment and can adversely affect water quality through the heavy use of fertilisers and water. Fertiliser contains excess nutrients like nitrogen and phosphorus and can leach into water bodies, causing pollution and eutrophication. Additionally, the substantial irrigation required for maintaining the greens can strain local water resources and lead to the runoff of chemicals into nearby water sources. The MGC should strive to mitigate these impacts by considering irrigation efficiencies to minimise water waste, implement best practices for fertiliser and pesticide use and plant trees and shrubs to fill runoff and prevent erosion.

The urbanisation of the catchment alters the natural flow and dynamics of water within a watershed. The increased impervious surfaces like roads and buildings prevent rainwater from infiltrating into the ground, causing rapid runoff. This accelerated runoff, often carrying pollutants such as oil, heavy metals, and chemicals, can overwhelm local drainage systems, leading to increased flooding and water quality degradation downstream. Additionally, the alteration of land surfaces and vegetation can disrupt the natural balance of a catchment, affecting groundwater recharge, biodiversity, and overall ecosystem health.

Data on water quality is limited. Water quality monitoring was conducted in Muscle Creek and was finalised in 2016. pH, Turbidity, EC, hardness and turbidity were done in the field with portable meters and tested in Council's lab and ALS. The monitoring program ceased as it was originally State Government funded via the Catchment Management Authority and when this stopped, funding was shifted elsewhere. The testing program was discontinued as Council did not have suitable equipment or resources to conduct these tests.

The water quality modelling program values at Muswellbrook Bridge are averaged yearly from 1998 to 2009 and shown graphically in **Appendix A5**. The environmental trigger values for the environmental parameters are shown in **Table 2-3**. Monitoring results indicate that faecal coliforms, nitrates and turbidity were well above the environmental trigger values. In 2003, there was a large increase in mean phosphorus concentration to 5.2 mg/L, in comparison to the trigger value of 0.05 mg/L, which is unknown.

Table 2-3: Environmental trigger values used for river sampling program

Parameter	Parameter in data	Low Value	High Value	Primary Contact	Secondary Contact	Stock Water
Salinity (EC uS/cm)	Electrical Cond uS	125	2200.00			3500
Faecal coliforms/100mL	F. Coliforms/100ml			150	1000	
Total N (mg/L)	Nitrates mg/L		0.50			
pH	pH	6.5	8.50			
Total P (mg/L)	Phosphorous mg/L		0.05			
Thermotolerant coliforms/100mL	T. Coliforms/100ml					100
Turbidity (NTU)	Turbidity	6	50.00			

Fieldwork confirmed that there is a significant presence of gross pollutants throughout the waterways, with an increase in travelling downstream of Muscle Creek and the daylighted sections of Possum Gully.

GHD (2019) notes that water quality within the Hunter River and Muscle Creek is of moderate to good quality depending on flow rates. However, the Review of Environmental Factors for the Muscle Creek Bank Erosion Management (2012) indicates that there is a section of poor water quality around Bridge Steet. Two surcharge pits with trash racks discharge into the creek from the northern bank, on either side of Bridge Street. Poor visibility and discolouration of water within the creek indicated high levels of turbidity and sedimentation (GHD, 2012).

Current management includes gross pollutant traps (GPTs) throughout the catchment, shown in **Figure 7-15**. Council has advised that regular maintenance of GPTs has been undertaken.

2.6 Anticipated Future Changes

2.6.1 Land Use

The anticipated future land use, informed from an Urban Release Area DPE GIS layer provided by Council is shown in **Figure 7-16**. It indicates that there are five urban release areas (approximately 300 hectares) proposed in the future. They are located at the upstream end of Reach 2.4 (Eastbrook Links Estate, around Bimbadeen Drive) and upstream of Reach 1.

The Possum Gully Catchment Stormwater Drainage Study (2015) modelling results indicate that peak discharges will increase significantly with the anticipated further urbanisation of the Possum Gully Catchment. The results suggest that generally a 50-60% increase in peak discharges is expected for the range of design storm events because of future urbanisation of the contributing catchment.

The anticipated increased urbanisation over time across the Muswellbrook catchment will lead to increased areas of impervious surfaces, increased runoff and reduced groundwater recharge, leading to greater flooding.

Council’s DCP for stormwater management aims to manage and control the impacts from urbanisation (i.e., through the use of regional detention basins and rainwater tanks). Refer to **Section 2.7.1**.

2.6.2 Climate Change

2.6.2.1 Flash floods and bank instability

Climate Change will exacerbate existing challenges related to flooding and bank stability in catchment areas. Altered rainfall patterns, characterised by an anticipated heightened intensity of rainfall events along with prolonged drought periods, will significantly impact hydrological processes and the response/adjustment of creeks and rivers to those new conditions. The increased intensity of rainfall can lead to rapid surface runoff, overwhelming drainage systems and natural watercourses, consequently elevating the risk of flash floods.

Simultaneously, extended drought periods can induce soil desiccation and compromise the root structure of vegetation that typically reinforces banks, rendering them susceptible to erosion. Subsequent heavy rainfall under such conditions can exacerbate bank erosion (particularly steep sections of the embankment), jeopardising their stability and potentially causing substantial damage to infrastructure and surrounding landscapes.

2.6.2.2 Elevated temperatures and water shortages

Elevated temperatures during droughts will increase evaporation rates, depleting moisture from soil, water bodies, and vegetation. This diminishes water availability in the catchment, impacting ecosystems and communities, and leading to water scarcity. This scarcity affects the natural environment, as well as agriculture and industries reliant on these water sources. The rise in temperatures during droughts stresses ecosystems by disrupting their water supply, causing biodiversity loss, harming flora and fauna, and leading to habitat degradation. Additionally, reduced water flow and higher temperatures can intensify water pollution, endangering aquatic life and human health.

2.7 Review of Relevant Council Plans and Policies

Muswellbrook Shire Council's Development Control Plans (DCPs), Muswellbrook Local Environment Plan (LEP) 2009, and relevant policies have been reviewed for this plan in the context of this CMP.

2.7.1 Current management practices

Key aspects related to current management practices in Muswellbrook are summarised below.

DCP Section 5 – Subdivision:

The current management practices in improving stormwater management and planning in Muswellbrook include the following:

- Ensuring that the quality of runoff water from the subject land is the same or better than pre-development conditions. This is determined through water quality testing.
- Ensuring that the volume of stormwater discharge from proposed lots is consistent with the pre-development stormwater patterns and flow regime.
    - Council addresses this by requiring additional water treatment / detention basins in new subdivisions.
- Design levels must be constructed to ensure that the allotments drain towards the street and/or an existing or proposed stormwater drainage system. Inter-allotment drainage may be installed to prevent ponding or increased runoff onto adjoining properties.
- All lots created for residential purposes are required to have adequate provision of services and should not result in a detrimental impact on the environment.
- These practices aim to ensure that stormwater management is effectively planned and implemented to minimise the impact on the environment.

DCP Section 6 – Residential Development:

This refers to single dwellings, dual occupancies, and residential flat buildings. Current stormwater management practices/requirements include:

- Discharge for collected stormwater runoff is required to be via the street drainage system, inter-allotment drainage, or to a public space (subject to approval).
- Drainage systems are required to be gravity-fed systems with pumping of stormwater not permitted.
- Development sites are required to provide an overland flow path for the major storm event (1% AEP).

Council has advised that in residential developments, additional detention basins with consideration of water quality measures have been designed and accepted to reduce to pre-development discharge. On constrained or smaller sites, consideration of 50% rainwater and 50% detention in oversized tanks have been adopted within existing strategies under a B88 instrument.

DCP Section 13 – Floodplain Management:

The extent of flood related information required to be submitted with a development application depends on the following factors:

- Type of development
- Scale of the development
- Extent to which the site is affected by flooding.
- The amount of flood related information already held by Council regarding flood behaviour at the site and within its catchment.

Depending on the nature of the development, the following items may be required to be submitted to Council as part of current stormwater management practices:

- Survey Plans
- Flood Hazard Assessment (FHA)
- Flood Impact & Risk Assessment (FIRA)
- Flood Management Compliance Report
- Flood Evacuation Plan

DCP Section 20 – Erosion and Sediment Control:
Based on the information provided in DCP Section 20, there are several management practices in place to improve stormwater management and planning in Muswellbrook. These practices include:

- Erosion and Sediment Control Plans (ESCP): Depending on the size and nature of the development, ESCP may be required. These plans outline measures to minimise erosion and sedimentation during construction activities. Specific to stormwater management, ESCP's are required to make comment on the existing and proposed drainage patterns including:
    - Catchment boundaries
    - Existing watercourses or drainage patterns flowing through or adjacent to the site.
    - Location and extent of impervious surfaces
    - Location and capacity of the proposed temporary and permanent site drainage or stormwater system. Any stormwater discharge points are required to ensure no increased erosion or embankment failure (example – Muswellbrook Animal Shelter).
- Landscape Plans: For larger areas of disturbance, a Landscape Plan is required along with the Erosion and Sediment Control Plan. This plan includes details of vegetation preservation and restoration to minimise the impact of development on the environment.
- Staged Development Strategy: Subdivisions that are proposed as staged developments must provide a staged Erosion and Sediment Control Strategy. This strategy outlines the erosion and sediment control measures to be implemented at each stage of the development.
- Maintenance Program: A regular maintenance program for erosion and sediment controls must be submitted with any plan or strategy. This ensures that the controls are regularly inspected and maintained to effectively manage stormwater runoff.
- Protection of Existing Vegetation: Existing vegetation must not be cleared in areas that are not directly impacted by the development. This helps to preserve the natural environment and prevent erosion.

These management practices aim to minimise soil erosion, sedimentation, and pollution of water bodies caused by construction activities. The implementation of these measures aims to improve stormwater management and protect the local environment.

DCP Section 22 – Land Use Buffers:
Land use buffers play an important role in reducing the risk of land use conflict and impacts between incompatible land uses through the separation of land uses. They define a minimum buffer distance between incompatible land uses and key natural resource assets.

Current use of buffers for improving stormwater management include:

- Biological and vegetation buffers
- Landscape and ecological buffers

The use of vegetated buffers is effective in reducing peak flows downstream and providing natural filtration of stormwater, thus reducing the concentrations of pollutants.

Buffer zones and management options vary according to the significance of a site, its locality, the topography of the land, and its relationships to a range of other geographic and culturally relevant factors.

Table 22.2 in DCP Section 22 outlines the minimum buffer distance for key environmental assets.

DCP Section 25 – Stormwater Management:
The current management practices in improving stormwater management and planning in Muswellbrook include the following:

- Compliance with standards: All stormwater drainage systems must comply with AS3500.3.
- BASIX compliance: Development applications must comply with BASIX (Building Sustainability Index) requirements where applicable, which aim to improve water efficiency in buildings and reduce water consumption.
- Collection of roof water: Gutters and downpipes are required to be installed to collect roof water.
- Collection of yard water: Pits are required to be installed to collect water from low points in yards, preventing collection of nuisance water.
- Connection to discharge controls: Downpipes and pits are to be connected to the site's discharge controls, ensuring that stormwater is properly managed and directed.
- Site discharge indicator: The development must have a site discharge indicator of at least 0.3 for residential development and at least 0.5 for non-residential development, as determined by Water Smart Practice Note No. 11. Preliminary stormwater design details demonstrating compliance with this requirement must be submitted with the development application.
- Pollutant management: Stormwater systems must be designed to capture and remove all litter larger than 5mm. Pollution reduction devices such as GPTs are a requirement for some developments to remove oil, sediment and other pollutants before stormwater discharges into the receiving system beyond the site.
    - Council has advised that GPTs, oil and sediment treatment (secondary) including pit baskets in private car parks and commercial developments are required. Where new car parks are proposed as part of development, concrete detention tanks including filter units and/or additional pre-treatment have been proposed and accepted.
- Soil and Erosion Control Plans: Soil and erosion plans must be submitted in accordance with the provisions of DCP Section 20, ensuring that soil erosion is minimised during construction and development.
- Comprehensive Water Cycle Strategy Plans: These plans investigate hydrological issues attributed to developments and consider goals for water quality, water efficiency, vegetation conservation, flood risk management, and erosion control. They also propose measures to manage site constraints and hazards.

Additional management practices include:

- Ensuring all impervious areas are designed so that overflows do not adversely affect neighbouring properties by way of intensification, concentration, or inappropriate disposal across property boundaries.
- Ensuring post-development runoff reflects pre-development conditions.

- Providing industrial developments with an onsite stormwater retention tank based on the roof area of the building.
- All public stormwater management assets are to be installed outside the riparian zone of creek lines.

These practices are in line with the goal of water smart development, which seeks to minimise the impact of urban development on the natural water cycle and protect the environment.

Muswellbrook Local Environment Plan (LEP) 2009:
Current stormwater management practices within the LEP include:

- For Zone SP2 (Infrastructure) Land – required to integrate stormwater treatment devices for flow and water quality management.
- For urban release areas – a DCP is required to be granted development consent on land in an urban release area. With respect to stormwater management, the DCP must provide for stormwater and water quality management controls.
- For industrial building developments – all roof and surface water must be drained to the street and discharge to the consent authority's nearest stormwater system in accordance with a suitably qualified engineer's design. The drainage system must be designed for a 10-year return period, with excess flows designed to flow overland to the street. Stormwater must be disposed of by way of:
    - A registered stormwater easement, or
    - An inter-allotment stormwater pit within the property boundary, or
    - A pipe that connects to the kerb and gutter, or
    - An existing approved stormwater drain on site.

Muswellbrook Shire Council Public Domain Manual:
Stormwater management practices/requirements include:

- Implementation of rain gardens in proposed streetscapes and open spaces to collect and treat runoff prior to discharge; or to collect, store and reuse for irrigation purposes.
- All new pavements are required to be free draining and evenly graded between level points.
- For plain concrete footpaths where a satisfactory single pavement crossfall cannot be achieved, a V-shaped footpath may be utilised. The V-drain should be located on the alignment of the previous kerb line. Subsurface drainage within the footpath is required where surface runoff will be excessive.
- For decorative concrete footpaths, 300 x 300mm stainless steel drainage inlet grates (or similar) flush with the pavement and with a suitable subsurface stormwater pipe connected to the existing stormwater system are required.
- Pavement subsoil drainage is required to intercept groundwater and prevent water build up under pavements and footpaths. Subsoil drainage is required to be connected to the stormwater drainage system.

Muswellbrook Shire Council Rivers and Drainage Channels Policy R25/1:

- Stormwater must be managed to minimise nutrient and sediment run-off entering constructed drainage lines or rivers.
- Where development is unavoidable within the Vegetated Riparian Zone (VRZ), it must be demonstrated that potential impacts on water quality aquatic habitat, and riparian vegetation will be negligible and can be effectively managed. A Plan of Management must also be submitted in accordance with State Government guidelines.
- Wherever possible, rivers and urban drainage systems are to be publicly accessible.
- Wherever possible, easements for access and drainage must be created to the benefit of Council.
- Property owners are required to accept natural flows from adjoining properties and control and dispose of flows properly.

- Applications and requests for improvements or rehabilitation within drainage easements are assessed based on whether the work is of net benefit to the community and the environment. If Council is to contribute to the works, the property owner **must** contribute at least half of the cost of the works. If the work is required to facilitate the development of the land, then the works, if approved, are at full cost to the owner.
- Owners wishing to undertake works in rivers and/or riparian corridors are responsible for arranging and carrying out the work at their own cost, subject to obtaining necessary approvals.
- In most cases, all maintenance, improvements and rehabilitation work to drains in inter-allotment drainage easements within private property are the responsibility of property owners and users of the easement.

Council has advised that there needs to be an action to amend the rivers and drainage policy to make the requirements for maintenance of vegetation along Possum Gully clearer. It is private land and is the responsibility of landowners.

2.7.2 Strategies for new developments

RHDHV has undertaken a review of current management practices for controlling flows from upstream developments to improve creek health.

Existing measures include:

- **Detention basins:** Maintain pre-development flow patterns through detention basin requirements. Smaller sites may use combination rainwater harvesting and detention tanks.
- **Rain gardens:** Promote infiltration and filtration in streetscapes and open spaces.
- **Drainage easements:** Assess improvement requests based on community and environmental benefit. Cost-sharing- between landowner and Council applies depending on net benefit to the community.
- **Stormwater treatment:** Require GPTs, oil/sediment treatment, and filtration for car parks.
- **Development Control Plans (DCPs):** Mandate stormwater management controls for new developments.
- **Riparian zone revegetation:** Encourage natural bank stabilisation.

Our recommendations for new developments are as follows.

1. **Impervious surface reduction using permeable pavements and increase of green space[2]:**

   Benefits:
   - Reduces nuisance flooding by lowering peak stormwater discharges from paved areas.
   - Improves the health of aquatic environments from a reduction in stormwater inflows and improvement in stormwater quality.
   - Increases the health of soils through greater soil moisture and groundwater recharge. Healthier soils support healthier and more drought-resilient street trees and green areas. This allows trees to grow and sustain a larger canopy area and to live longer.
   - Reduces the need for large-scale stormwater management infrastructure.
   - Provides for a cooler urban environment in summer due to the circulation of precipitation, air and water as well as increased shading.

   Challenges:

[2] *It should be noted that Council has existing planning controls that outlines metrics associated with impervious ratios. However, we suggest that if there are additional opportunities to increase green space, this is beneficial.*

- Permeable pavements require maintenance to clean out rubbish and vegetation.
- Gravel pavements often need to be resealed and the seal has a shorter lifespan than the permeable pavements. This increases maintenance cost and effort.
- Porous asphalt pavements will require maintenance to address potholes forming as a result of settlement or weakening of the base layers.
- Most successful permeable pavements require sub-surface drainage and connection into the stormwater network. This can cause pressure on the stormwater drainage network as more flow will enter. Without sub-surface drainage, water will infiltrate into base-course materials in roads and cause challenges.
- Council generally does not support permeable pavement options due to maintenance requirements and feel they are unreliable.

Permeable pavements are surfaces that allow water to drain through them to reduce overland flooding, improve water quality, and recharge groundwater supplies (depending on the type of pavement). Pavement design is required to ensure the designed permeable pavement meets the design life and adequate sub-soil drainage is designed for example.

There are many different types of permeable pavements (proprietary and non-proprietary), including:

- Open graded asphalt pavements: This kind of pavement is a paved surface and subbase comprised of aggregates and asphalt binder, designed, placed and compacted in a manner resulting in a highly permeable asphalt concrete surface with voids. This is designed to be water permeable and could be utilised for parking lots. They can perform a water storage and infiltration function. For very weak soils or those that have low infiltration rates, underdrains may be necessary.

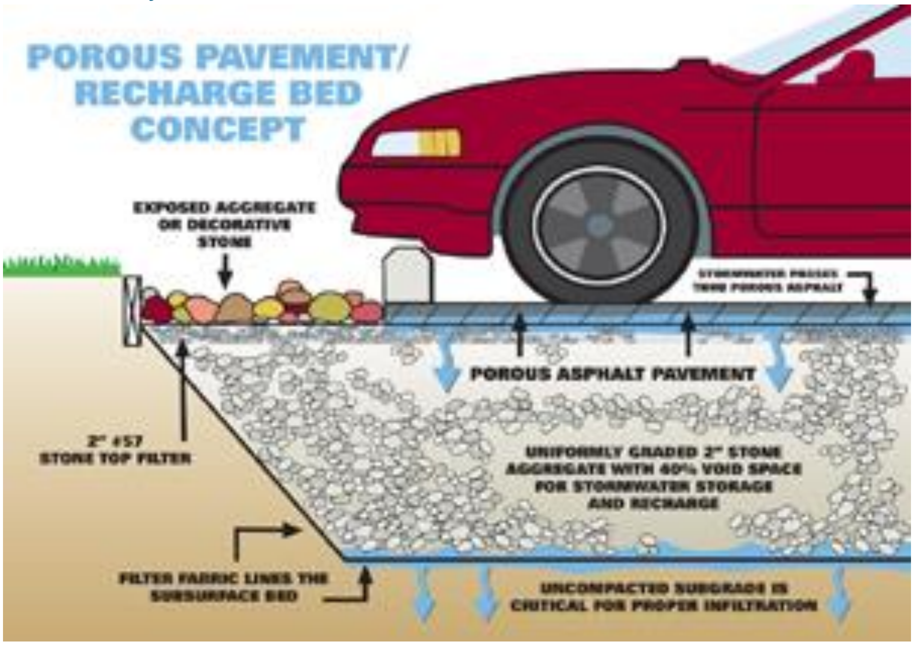

Figure 2-13: Open graded asphalt pavements use for parking lots (Virginia Asphalt Association, 2016)

- Permeable interlocking concrete pavements (PICPs): These are grids of concrete pavers with spaces in between that are filled with gravel or another material that allows water to drain through. Examples are shown in **Figure 2-14** and **Figure 2-15**.

Figure 2-14: Permeable pavers (Island Block & Paving, n.d.)

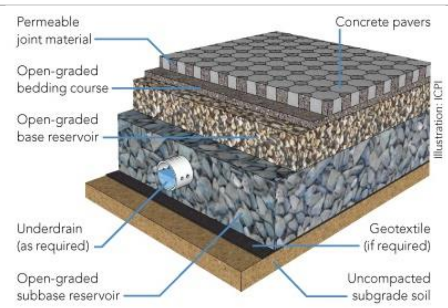

Figure 2-15: Permeable pavement design (Farley, n.d.)

- Grass pavers: These are hollow precast concrete units that are filled with soil and planted with grass. The pavers protect grassroots from damage and can meet the demands of vehicles. They are useful for overflow car parks and residential parking for example. Examples are shown in **Figure 2-16** and **Figure 2-17**.

Figure 2-16: Grass pavers install (All Stake Supply, n.d.)

Figure 2-17: Grass pavers established (All Stake Supply, n.d.)

- Gravel pavements: These are simply gravel surfaces that are compacted to create a stable surface. An example is shown in **Figure 2-18**.

Figure 2-18: Gravel pavement residential installation (MatsGrids, 2015)

Increase of green space can be achieved by planting trees, shrubs, and other vegetation in areas that are currently covered by pavement. Green space can help to absorb rainwater, reduce flooding, improve air quality, and provide habitat for wildlife. Strategies to increase green space are as follows:

- Bioswales: These are landscaped depressions that are designed to collect and filter stormwater runoff. Dirty and polluted water from rooftops, roads and parking lots enters the bioswale. Water is slowed down by various plants and rocks, pollutants settle out, clean water infiltrates the soil. Water enters the perforated pipe and is slowly absorbed into the ground. Excess stormwater exits the bioswale and flows through the pipe into the recipient, cleaner than when it entered and, in the amount, significantly reduced. Examples are shown in **Figure 2-19** and **Figure 2-20**.

Figure 2-19: Bioswale concept diagram (Brankovic, n.d.)

Figure 2-20: Bioswale in carpark (Michigan State University, 2015)

- Green roofs: These are roofs that are covered with vegetation. Green roofs can help to insulate buildings, reduce energy costs, and provide habitat for wildlife. Examples are shown in **Figure 2-21** and **Figure 2-22**.

Figure 2-21: Green roof components (Khawaja, 2018)

Figure 2-22: Green roof (Medium, 2023)

- Pocket parks: These are small, public parks that can be created in vacant lots or other underutilised spaces. An example is shown in **Figure 2-23**.

Figure 2-23: Pocket park (The Property Tribune, 2023)

2. **Implement bioretention basins for runoff capture and filtration.**

Bioretention basins are landscaped depressions or shallow basins used to slow and treat on-site stormwater runoff. Stormwater is directed to the basin and then percolates through the system where it is treated by a number of physical, chemical and biological processes. An example is shown in **Figure 2-24**.

Bioretention areas are similar to rain gardens, but are more highly engineered to include an underdrain, overflow inlet, gravel bed, and engineered soils to promote infiltration.

<u>Benefits:</u>

- Water Quality Improvement: Bioretention basins act as natural filters. As stormwater runoff passes through the basin, it gets filtered by the soil and vegetation. This process removes pollutants like sediment, excess nutrients, and even some heavy metals, preventing them from reaching waterways.
- Flood Control: These basins can help manage stormwater by capturing and slowly releasing rainwater. This reduces the peak flow of stormwater runoff, which can overwhelm storm drains and contribute to flooding.
- Groundwater Recharge: The filtered water that permeates through the bioretention basin can replenish groundwater supplies. This is crucial during droughts and helps maintain healthy water tables.
- Habitat Creation: The plants used in bioretention basins create a mini-habitat for pollinators, birds, and other small creatures. This can increase biodiversity in urban areas.
- Aesthetics: Well-designed bioretention basins can be attractive additions to a landscape. They can incorporate native plants, flowers, and even small trees, creating green spaces in urban environments.

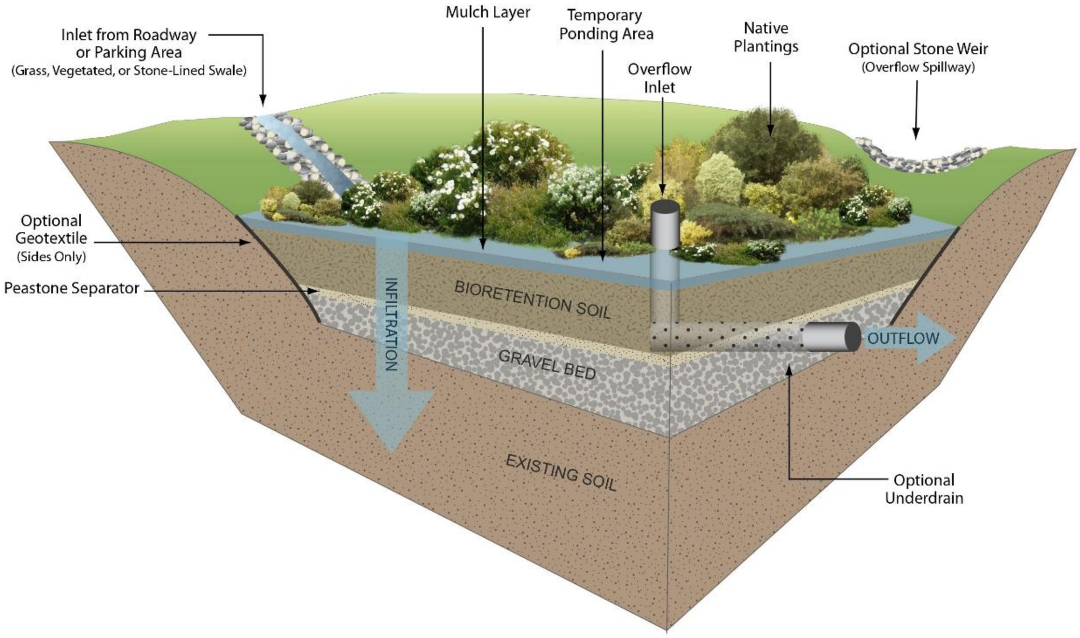

Figure 2-24: Schematic of a typical bioretention area (Massachusetts Department of Environmental Protection, 2016)

3 Issues and Opportunities

Based on a review of available data and fieldwork, issues and opportunities have been identified.

Subcategories have been used to group observed catchment issues and opportunities, as listed below:

- Bank instability
- Vegetation management
- Water quality, and,
- Drainage and flood risk.

The issues and opportunities are detailed in the sections below.

3.1 Bank Instability

Although the study catchment generally has stable banks (see **Section 2.1.3**), there are specific areas with bank instability issues. At some locations (such as the golf course), the bank instability is benign (unlikely to cause extensive damage to infrastructure/loss of life; having minimal consequences). Whereas in others the bank instability is more problematic due to the proximity to homes and infrastructure (rear of the Remington Hotel, Muswellbrook and District Workers Club and Riverside Caravan Park for example).

The issues and opportunities related to bank instability in the catchment are summarised in **Table 3-1** and **Table 3-2** respectively.

Table 3-1: Issues - Bank Instability

ID	Issue
IS_BI1	Steep and unstable banks are present in reaches 2, 3, and 4.
IS_BI2	Climate change will exacerbate existing challenges related to bank stability around the catchment.
IS_BI3	Stormwater swale next to the Wayfarer Motel is experiencing headcut erosion just upstream of the confluence with Muscle Creek.
IS_BI4	Notably in reach 3 and 4, two stormwater outlets to Muscle Creek discharge at levels above the low flow channel and most do not have adequate scour protection, therefore causing bank scour.
ID_BI5	Incision of the lower reaches of Muscle Creek.
ID_BI6	Acute signs of bank failure, examples of this are near Remington Hotel.

Table 3-2: Opportunities - Bank Instability

ID	Opportunity
OP_BI1	Alter the cross-sectional profile of Muscle Creek within the site through excavation and provision of near vertical retaining walls.
OP_BI2	Rock bed control to prevent bed cutting and deepening of the stream.
OP_BI3	Removal of weeds and planting of native vegetation to reduce bank instability issues associated with soil erosion.
OP_BI5	Rock drop structure at locations of head cut erosion.
OP_BI6	Naturalising concrete channel in sections of Possum Gully (piped sections).
OP_BI7	Scour protection works for stormwater outlets discharging at Muscle Creek.
OP_BI8	Swale stabilisation works in the golf course to reduce erosion and deposition of sediment in the creek from runoff.
OP_BI9	Creek restoration
OP_BI10	Soft solutions such as planting.
OP_BI11	Soften existing stabilisation.

3.2 Vegetation Management

The riverbanks across the catchment showed signs of extensive erosion where vegetation was absent, in particular where the ground cover layer or inefficient hydraulic structures and altered hydrological regimes were apparent. Priority weeds and exotic species identified during the baseline site assessment include African lovegrass, Balloon vine, Camphor laurel, Cockspur coral tree, Fireweed, Green cestrum, Giant reed and Willows.

The issues and opportunities related to vegetation management in the are summarised in **Table 3-3** and **Table 3-4** respectively.

Table 3-3: Issues - Vegetation Management

ID	Issue
IS_VM1	There is a high weed prevalence including woody weeds and climbing weeds which are suppressing native vegetation, observed in reaches 5, 6 and 8.
IS_VM2	There is a moderate to high cover of weed species observed in some areas of reaches 1, 2 and 5 of the catchment. As these reaches are considered to be the upper reaches of the catchment, the presence of a moderate to high cover of woody weeds is potentially resulting in altered hydrological regimes, increased dispersal of propagules throughout the lower reaches of the catchment and suppression of native vegetation.
IS_VM3	Reach 3 does not currently exhibit notable issues. Potential issues may arise from decreased maintenance activities of the revegetation and regeneration efforts before the vegetation becomes established and can withstand weed and exotic species incursions.
IS_VM4	Reach 4 exhibits a high cover of vines, woody weeds and exotic species. Reach 4 has been deemed a lower priority due to its position within the catchment and accessing issues resulting in inefficient vegetation management.
IS_VM5	Reach 7 currently exhibits a highly urbanised channel that is largely free of vegetation and unlikely to be subject to any vegetation management such as revegetation and regeneration. Weed and exotic species established in hydraulic and drainage structures are unlikely to significantly impact any vegetation management activities conducted in reach 8.
IS_VM6	The site walk conducted in August 2023 captured high-level vegetation management options. Due to time and budget constraints, a comprehensive VMP could not be prepared.

Table 3-4: Opportunities - Vegetation Management

ID	Opportunity
OP_VM1	Increased native vegetation on the embankments.
OP_VM2	Increased native vegetation stratums, notably native canopy cover and increased native seed dispersal.
OP_VM3	Improved soil stability from reinforcement of riverbank soils by tree roots.
OP_VM4	Increased suppression of weed incursions.
OP_VM5	Decreased dispersal of weed propagules within the catchment.
OP_VM6	Increased native seed dispersal throughout the lower reaches of Muscle Creek.
OP_VM7	Preparation of a vegetation management plan.
OP_VM8	Improvement of accessibility to maintain weeds.

3.3 Water Quality (WQ)

Data on water quality is limited. The golf course forms a substantial portion of the study catchment and can adversely affect water quality through the heavy use of fertilisers and water. The urbanisation of the catchment alters the natural flow and dynamics of water within the catchment, leading to increased flooding and water quality degradation downstream.

Historical water quality monitoring identified that at Muswellbrook there were elevated levels of water quality parameters such as faecal coliforms, nitrates and turbidity. Fieldwork confirmed that there is significant presence of gross pollutants throughout the waterways, with an increase in travelling downstream of Muscle Creek and the daylighted sections of Possum Gully.

The issues and opportunities related to WQ in the catchment have been tabulated in **Table 3-5** and **Table 3-6** respectively.

Table 3-5: Issues – Water Quality

ID	Issue
IS_WQ1	Poor water quality (high turbidity and sedimentation) where two surcharge pits with trash racks discharge into the creek from the northern bank, either side of Bridge Street.
IS_WQ2	There is a lack of natural buffers with adjoining land uses that could serve as a protective zone (i.e., vegetation, wetlands or open space) for water quality.
IS_WQ3	Lack of water quality reporting across the catchment to understand areas that should have targeted management.
IS_WQ4	People entering waterways near the Possum Gully culvert crossings during peak flooding events.

Table 3-6: Opportunities - WQ

ID	Opportunity
OP_WQ1	Increased native vegetation to embankments to improve water quality.
OP_WQ2	Addressing bank instability issues would reduce the entry of erosion and deposition of sediment in the creek from runoff, improving WQ outcomes.
OP_WQ3	Trapping sediment, nutrients and other contaminants through gross pollutant traps.
OP_WQ4	Stormwater detention basin upstream of George Street (Possum Gully Stormwater Drainage Study Options Assessment, 2015) may provide some level of water quality treatment particularly if a designated bio-retention area is incorporated within the basin
OP_WQ5	Off-line ‘Dry’ Detention Basin (Adjacent to Brentwood St & Doyle St, Lot 25) to attenuate peak flows for Possum Gully and water quality benefits.
OP_WQ6	Development of baseline water quality reporting and associated sampling (one-off or ongoing monitoring network).
OP_WQ7	Warning signage.
OP_WQ8	Water use/re-use.
OP_WQ9	Water harvesting.
OP_WQ10	Water stewardship.
OP_WQ11	Use of green roofs, permeable pavement, and rain gardens in urban areas to manage stormwater and reduce runoff.
OP_WQ12	Regular maintenance and debris removal from gross pollutant traps/surcharge pits to prevent excess sediment from being discharged into the creek.

3.4 Drainage and Flood Risk

As summarised in **Section 2.3**, a significant portion of the study area catchment is prone to flood risk.

With the increase in urbanisation over time, the increased areas of impervious surfaces have led to more runoff and changes in groundwater recharge due to land use changes. Climate change will accentuate existing challenges related to flooding and bank stability in catchment areas. The increased intensity of rainfall can lead to rapid surface runoff, overwhelming drainage systems and natural watercourses, consequently elevating the risk of flash floods.

The issues and opportunities related to flooding in the catchment have been tabulated in **Table 3-7** and **Table 3-8** respectively. The majority of these issues and solutions have been taken from the Muscle Creek Flood Study (Royal HaskoningDHV, 2017), Possum Gully Catchment Stormwater Drainage Study (SMEC, 2015) and Muswellbrook Floodplain Risk Management Study and Plan (Royal HaskoningDHV, 2019).

Table 3-7: Issues - Flooding

ID	Issue
IS_FL1	In the 5% AEP flood event, inundation of the only two roads connecting the northern and southern parts of Muswellbrook creates a potential issue for emergency services.
IS_FL2	Flooding in Muswellbrook Golf Course in the 1% AEP event.
IS_FL3	The section of Muscle Creek and Possum Gully downstream of the railway line (end of Scott / Brook Street) is significantly influenced by tailwater levels from the Hunter River in events greater than the 10-year ARI.
IS_FL4	The anticipated increased urbanisation over time across the Muswellbrook catchment will lead to greater flooding.
IS_FL5	Climate change will accentuate existing challenges related to flooding in catchment areas.
IS_FL6	There is a lack of buffers with adjoining land uses that could serve as a protective zone (i.e., vegetation, wetlands or open space) for flood mitigation.
IS_FL7	There is potential for property damage and risks to life associated with Bell Street overflows in 5% AEP and greater magnitude events.
IS_FL8	Limited effective flood warning time can lead to social losses from floods.
IS_FL9	In Possum Gully, several culverts present a constriction to flood flows within the main channel, resulting in stormwater backing up on the upstream side of a number of culvert crossings and/or overtopping of the road at the location of the culvert crossings.
IS_FL10	Nuisance flooding at locations within Possum Gully, such as the low-lying houses adjacent to the Possum Gully channel along Sowerby Street.
IS_FL11	Obstruction within Possum Gully (i.e., driveway/track accesses, dense vegetation, sediment build-up & fallen trees) reducing the hydraulic conveyance.
IS_FL12	There is encroachment into the riparian zone by infrastructure and properties, predominantly in Possum Gully reaches 5 and 6.
IS_FL13	A lack of riparian structure is observed particularly for Muscle Creek with sections that are neglected and underutilised (reach 2.2, 2.3 and 2.4).
IS_FL14	Modified and culverted (in places) creek lines along Possum Gully (i.e., Sowerby Street, Carl Street, Brentwood Street)

Table 3-8: Opportunities - Flooding

ID	Opportunity
Muscle Creek	
OP_FL1	Establishing a flood warning system in the Muscle Creek Catchment to increase flood warning time and time available for the safe evacuation of high-risk areas. This would substantially reduce the risk to life in an extreme Muscle Creek flood event.
OP_FL2	Removal of exotic weeds that have been established on the Muscle Creek channel banks and re-vegetate with lower density native species. This would result in a modest increase in channel flow conveyance, reducing Bell Street overflows.
OP_FL3	Raising floor levels in homes around Muscle Creek to reduce above-floor flood inundation.
OP_FL4	Property acquisition and demolition of severe flood-affected residential properties which pose a significant risk to life during flood events around Muscle Creek. The removal of these properties may restore the hydraulic capacity of the floodplain if the properties are located in a “floodway”.
OP_FL5	Enhancing Muscle Creek bank adjacent to the golf course (Muscle Creek FRMS&P, 2019) to elevate two low points could ensure floodwaters are maintained in the channel reducing the number of properties that are flooded. This would use 3 small levees/bunds on Muscle Creek to prevent overland flows from cutting Bell Street (a vital emergency access route).
OP_FL6	Construction of a large levee/bund adjacent to Muswellbrook Golf Club and a small levee/bund on the north bank of Muscle Creek to prevent overland flows from cutting Bell Street (a vital emergency access route) (Muscle Creek FRMS&P, 2019).
OP_FL7	Emergency Management Planning involves the collaboration of emergency services including the SES and other rescue services to develop a Local Flood Plan.
OP_FL8	Update the Local Environmental Plan (LEP) to ensure future development considers locations with high flood risk.

OP_FL9	A community flood education program would allow an increased understanding of flood risk in Muswellbrook.
OP_FL10	Levee to prevent backwater flooding (Muscle Creek FRMS&P, 2019) outflanking the existing Muswellbrook Levee. A large, flapped outlet is required to drain Possum Gully Creek.
OP_FL11	Construction of an 840m long earth levee parallel to Sydney Street (Muscle Creek FRMS&P, 2019).
OP_FL12	Preventing intensification of development to mitigate further flood risk to flood-affected residential properties (i.e., knock down/rebuild).
Possum Gully	
OP_FL12	Stormwater detention basin upstream of George Street (Possum Gully Stormwater Drainage Study Options Assessment, 2015) to attenuate peak flows.
OP_FL13	Culvert upgrades under key roadways (major roundabout upstream of George Street, Carl Street, culverts immediately downstream of the Carl Street crossing and Sowerby Street) (Possum Gully Stormwater Drainage Study Options Assessment, 2015).
OP_FL14	Channel Improvements Between Sowerby Street and Queen Street (Possum Gully Stormwater Drainage Study Options Assessment, 2015) including trimming/removing excessive vegetation along sections of the main channel in parallel with (where feasible) removing accumulated sediment/silt within this channel section to reduce flood levels within the channel.
OP_FL15	Queen Street Basin Augmentation (Possum Gully Stormwater Drainage Study Options Assessment, 2015) by raising the height of the existing basin spillway to decrease peak discharge.
OP_FL16	Channel Improvements Between Sowerby Street and Carl Street (Possum Gully Stormwater Drainage Study Options Assessment, 2015) to increase the hydraulic capacity of the channel. This would include clearing/trimming of dense vegetation along the identified channel; and for the section of channel between the inlet to the Sowerby Street culverts up to the first property access crossing, additionally provide concrete/shotcrete lining.
OP_FL17	Combination of Mitigation OP_FL12 and OP_FL16 (Possum Gully Stormwater Drainage Study Options Assessment, 2015) including a new stormwater detention basin upstream of George Street and channel improvements within a section of channel between Sowerby Street and Carl Street.
OP_FL18	Off-line ‘Dry’ Detention Basin (Adjacent to Brentwood St & Doyle St, Lot 25) to attenuate peak flows and water quality benefits.
OP_FL19	Bunding adjacent to properties most affected by nuisance flooding along Possum Gully.
OP_FL20	Upgrading of culverts under Muswellbrook Marketplace & culverts under the Shopping Arcade to the railway line to prevent backup of flood flows upstream of constricted reaches.
OP_FL21	Increase buffers with adjoining land uses that could serve as a protective zone (i.e., vegetation, wetlands or open space) for flood mitigation.

4 Plan of Management

4.1 Overview

The following sections summarise the recommended and prioritised management actions proposed to be undertaken. Locations and geographical context are visually presented in **Figure 7-45** of **Appendix A7**.

To prioritise management solutions, each management option / action was assessed for effectiveness and feasibility. Effectiveness gauges the impact on catchment issues as well as importance, while feasibility considers implementation practicality including cost. The combined score, where higher values indicate higher priority, ensures that the most effective and feasible strategies take precedence in catchment management planning. A visual representation of the tool is shown in **Figure 4-1**. Subcategories were used to group observed catchment management options, as shown in **Figure 4-2**.

Prioritisation Rating System		Effectiveness		
		Low effectiveness	Moderate effectiveness	High effectiveness
Feasibility	Low feasibility	Not Effective	Low	Low - Medium
	Moderate feasibility	Low	Low - Medium	Medium - High
	High feasibility	Low - Medium	Medium - High	High

Figure 4-1: Prioritisation rating system

Indicative cost estimates have been provided in ranges. These ranges have been developed based on past project experience and encapsulates both design and capital costs. The estimates do not include maintenance costs, approvals and associated studies. The assumption has been made that design costs constitute 10% of the capital costs. Any additional assumptions made are explicitly documented as footnotes in the tables below.

The costing ranges are as follows:

- $0 - $10K
- $10K - $50K
- $50K - $100K
- $100K - $150K
- $150K - $500K
- $500K - $1M
- $1M - $3M
- $3M +

Legend	
	Bank Instability
	Vegetation Management
	Water Quality
	Flooding

Figure 4-2: Legend for the categorisation of management options

4.2 Bank Instability

Bank instability management actions across the catchment will consist of the following reach-specific activities outlined in **Table 4-1**. Refer to **Appendix A6**, which aims to distil the methodology and considerations that need to be made for two high-risk bank instability locations along Muscle Creek.

Table 4-1: Bank Instability Management Plan Solutions

ID	Solution / Action	Location	Prioritisation rating	High-level cost ranges (excl GST)	Timeline for Implementation	Barriers for implementation	Issues addressed	Category
BI1	Creek bank stabilisation and/or relocation (refer to **Appendix A6** for the methodology for two vulnerable areas in Muscle Creek).	Reaches 2, 3 and 4 (refer to **Figure 7-35** for high-risk bank instability locations).	High	$3M+[3]	2 years	• Constrained site • Access • Likely cost • Proximity of buildings	IS_BI1 IS_BI2 IS_BI6	
BI2	Scour protection works for stormwater outlets discharging at Muscle Creek (refer to **Figure 2-5**). This may include rock armouring or concrete apron and would require concept design.	Stormwater outlets discharging along Muscle Creek embankments (Reach 3 and 4)	High	$50-$100K[4]	2 years	• Constrained site • Access	IS_BI4	
BI3	Soft solutions such as planting along riverbanks.	Benign bank instability locations such as along the Golf Course (Reach 2 and 3), refer to **Figure 7-12**.	High	$100K-$150K[5]	2 years	• Maintenance	IS_BI1	
BI4	Swale stabilisation works in the golf course to reduce erosion and deposition of sediment in the creek from runoff.	Stormwater swale next to the Wayfarer Motel (Reach 2.5)	Medium – High	$150K-$500K[6]	2 years	• Maintenance requirements	IS_BI3	

[3] Based on 200m of rock bags in the short term (including supply, delivery, filling, and placement of 500-1000 4t rock bags) and rock revetment in the long term
[4] Based on rock armour protection to three (3) stormwater outlets ($50m^3$ assumed area of armouring at each outlet) discharging into Muscle Creek, assuming supply and place of geotextile separation layer & D50 520mm revetment rock. Does not include costs of design.
[5] Based on 100m of plantations, with assumed riverbank widths of 10m, and dense planting at approximately 0.5m to 1.0m centres, excluding maintenance
[6] Based on 50m of a combination of rock armouring and soft solutions (planting)

Project related

ID	Solution / Action	Location	Prioritisation rating	High-level cost ranges (excl GST)	Timeline for Implementation	Barriers for implementation	Issues addressed	Category
	This may include soft solutions, rock armouring etc.							
BI5	Soften existing stabilisation.	Hard structures in reach 2, 3 and 4 (refer to **Figure 7-14**)	Medium - High	$500K-$1M[7]	10 years	• Reluctance to modify hard structures that have been effective. • Additional cost.		
BI6	Creek restoration to address incision of riverbank.	Hunter River and the lower reaches of Muscle Creek (Reach 3 and 4)	Low - Medium	$100K-150K	10 years	• Constrained site • Access	IS_BI5	
BI7	Moving infrastructure back to avoid the bank erosion slip circle.	Riverside Caravan Park (Reach 4)	Low	$10K-$50K[8]	2 years	• Limited space. • Opposition to works from residents. • Inability to relocate buildings.	IS_BI1	

[7] *Based on at least 500m of channel/creek renewal works within Muscle Creek*
[8] *Based on two (2) day crane hire for relocation of infrastructure*

4.3 Vegetation Management

The reaches within the catchment were consolidated into vegetation management zones and corresponded accordingly with the issues and opportunities outlined in **Section 2**. Reach 7 has not been included as it has been determined that this reach will not result in any benefit from vegetation management. Refer to **Figure 7-34** in **Appendix A4** for a visual representation of prioritisation areas.

Vegetation management includes:

- Erosion and sediment control as required utilising coir logs and brush matting with native species on exposed areas.
- Primary and secondary weed control. [9]
- Revegetation and regeneration of native flora species.
- Establishment of revegetation and regeneration through maintenance weed control and replacement plantings of any individuals lost.

Vegetation management actions across the catchment will consist of the following reach-specific activities outlined in **Table 4-2**.

Table 4-2: Vegetation Management Plan Solutions

ID	Solution / Action	Location	Prioritisation rating	High-level cost ranges (excl GST)	Timeline	Barriers for implementation	Issues addressed	Category
VM1	• Implement erosion and sediment controls such as coir logs and brush matt exposed areas. • Conduct primary weed control works i.e., remove vines/climbing weeds through skirting and cut and painting within the first three years. • Conduct secondary weed control works with a focus on vines/climbing weeds. • Establish/maintain existing native canopy and shrub layer in the first three years. • Conduct Infill planting in areas where extensive primary and secondary weed control has occurred. Infill planting is	Reaches 5, 6 and 8	High	$100K - $150K	10 years	• High level of costs • Extensive control of large wood weeds and vines and potential high costs for machinery • Access issues for weed control and maintenance	IS_VM1	

[9] *In areas that are safe to access by staff and/or contractors as many embankments are unsafe or inaccessible. Alternative toe protection / embankment protection with or without vegetation may be required on steep embankments.*

ID	Solution / Action	Location	Prioritisation rating	High-level cost ranges (excl GST)	Timeline	Barriers for implementation	Issues addressed	Category
	established and 100% free of weeds and exotic species in three years. • Maintain and establish plantings through weekly watering for the first month. Double weekly watering efforts in extended hot and dry conditions. • Conduct assisted natural regeneration around existing patches of native vegetation through weed and exotic species control. • Conduct maintenance weed control until existing patches of native vegetation and vegetation become self-sustaining. • Monitoring revegetation, regeneration and weed control works through annual monitoring for 10 years. <u>Adaptive management</u> • Review control methods/herbicide use if weed species are not controlled within the first two years. • Replace any plants lost at a 1:1 ratio representative of the species lost. • Continued maintenance of any infill plantings. Increase maintenance schedules if signs of failure in revegetation efforts such as dieback on individuals.							
VM2	• Implement erosion and sediment controls such as coir logs and brush matt exposed areas. • Conduct primary weed control works. Mechanical removal of large woody weeds and exotic species where possible i.e., chain sawed, root ball retain for erosion control and following up herbicide control as required. Removal of 100% of large woody weeds and exotic species by year five.	Reaches 2 and 5	High	$100K - $150K	10 years	• High level of costs • Extensive control of large wood weeds and vines and potential high costs for machinery • Longer term establishment of any revegetation and regeneration activities • Access issues for weed control and maintenance	IS_VM2	

ID	Solution / Action	Location	Prioritisation rating	High-level cost ranges (excl GST)	Timeline	Barriers for implementation	Issues addressed	Category
	• Conduct primary weed control works i.e., remove vines/climbing weeds through skirting and cut and paint by year five. • Logs of large woody weeds free of weed propagules are to be retained as erosion control and provide fauna habitat. • Stem injection of large wood weeds as a secondary control method. Dead woody weeds must not be left standing due to risk to human health. • Conduct secondary weed control works with a focus on regenerating woody weeds and vines/climbing weeds in year 1-2. • Establish/maintain existing native canopy and shrub layer by year 2-10. • Conduct Infill planting in areas where extensive primary and secondary weed control has occurred by year 2-5. Infill planting is established and 100% free of weeds and exotic species by year 5-10. • Maintain and establish plantings through weekly watering for the first month. Double weekly watering efforts in extended hot and dry conditions. • Conduct assisted natural regeneration around existing patches of native vegetation. • Conduct maintenance weed control until existing patches of native vegetation and revegetation becomes self-sustaining. • Monitoring revegetation, regeneration and weed control works through annual monitoring for 10yrs. Adaptive management • Review control methods/herbicide use if weed species are not controlled within the first two years.							

ID	Solution / Action	Location	Prioritisation rating	High-level cost ranges (excl GST)	Timeline	Barriers for implementation	Issues addressed	Category
	• Replace any plants lost at a 1:1 ratio representative of the species lost. • Continued maintenance of any infill plantings. Increase maintenance schedules if signs of failure in revegetation efforts such as dieback on individuals.							
VM3	Preparation of a detailed Vegetation Management Plan. Sub-activities include: • Accurately ground truth PCTs and their extents across the reaches, establish monitoring points and determine a vegetation integrity score across each of the reaches in alignment with the Biodiversity Assessment Methodology (BAM). • Determine effectiveness of large-scale mechanical weed control. • Outline an appropriate species planting list for the associated PCTs. • Formulate reach specific vegetation works in the VMP. • Look to conducting vegetation management works in reach 4 once upper reaches are self-sustaining.	Study catchment-wide (or based on prioritised reaches)	High	$10K - $50K	2 years	• Substantial amount of time and cost to cover a finer look at an extensive site. • Weather conditions – flooding may wash away vegetation management. • Access issues.	IS_VM6	
VM4	• Conduct primary and secondary weed control targeting vines and woody weeds. • Establish a canopy layer in areas free of native vegetation in reach 1. • Continued establishment of native revegetation and regeneration. Conduct revegetation works in reach 1. • Conduct replacement plantings of any native plants lost. • Conduct infill planting in areas where extensive weed control works has occurred. • Ensure existing plantings remain free of weeds and exotic species until established and self-sustaining.	Reach 1 & 3	Medium - High	$10K - $50K	Present - 2 years	• Improper weed control maintenance regimes • Incursion of woody weeds and vines • Failure to establish any revegetation, infill or replacement plantings	IS_VM3	

ID	Solution / Action	Location	Prioritisation rating	High-level cost ranges (excl GST)	Timeline	Barriers for implementation	Issues addressed	Category
	• Replace any plants lost at a 1:1 ratio representative of the species lost. • Monitoring revegetation, regeneration and weed control works through annual monitoring for 2yrs. <u>Adaptive management</u> • Review control methods/herbicide use if weed species are not controlled within the first two years. • Increase maintenance schedules if signs of failure in revegetation efforts such as dieback on individuals.							
VM5	• Establish a canopy layer in areas free of native vegetation in reach 1. • Continued establishment of native revegetation and regeneration. Conduct revegetation works in reach 1. • Conduct replacement plantings of any native plants lost. • Implement erosion and sediment controls such as coir logs and brush matt exposed areas. • Conduct primary weed control works. Mechanical removal of large woody weeds and exotic species where possible i.e., chain sawed, root ball retain for erosion control and following up herbicide control as required. Removal of 100% of large woody weeds and exotic species by year five. • Conduct primary weed control works i.e., remove vines/climbing weeds through skirting and cut and painting by year 5. • Logs of large woody weeds free of weed propagules to be retained as erosion control and provide fauna habitat. • Conduct secondary weed control works with a focus on regenerating woody weeds and vines/climbing weeds in year 1-2.	Reach 4	Low - Medium	$50K - $100K	Present – 10 years	• High level of costs • Extensive control of large wood weeds and vines and potential high costs for machinery • Longer term establishment of any revegetation and regeneration activities • Access issues for weed control and maintenance	IS_VM4	

ID	Solution / Action	Location	Prioritisation rating	High-level cost ranges (excl GST)	Timeline	Barriers for implementation	Issues addressed	Category
	• Conduct Infill planting in areas where extensive primary and secondary weed control has occurred by year 5. Adaptive management • Review control methods/herbicide use if weed species are not controlled within the first two years. • Replace any plants lost at a 1:1 ratio representative of the species lost. • Continued maintenance of any infill plantings. Increase maintenance schedules if signs of failure in revegetation efforts such as dieback on individuals.							

4.4 Water Quality

Without ongoing water quality monitoring in Muscle Creek and Possum Gully catchments and no recent sampling data, it is difficult to ascertain problem areas that need to be targeted. However, conducting such an assessment has low feasibility due to access limitations and equipment/resources limitations, and the outcomes of such a study may prove to be minimally effective. A better approach involves maintaining current pollutant traps and implementing management plan solutions for bank stability, vegetation control, and flood management. These measures aim to decrease sediment runoff and deposition in the creek and incorporate bioretention basins, leading to holistic water quality improvement across the catchment.

Water quality management actions across the catchment will consist of the following reach-specific activities outlined in **Table 4-3**.

Table 4-3: Water Quality Management Plan Solutions

ID	Solution / Action	Location	Prioritisation rating	High-level cost ranges (excl GST)	Timeline	Barriers for implementation	Issues addressed	Category
WQ1	Continued regular maintenance and debris removal from gross pollutant traps/surcharge pits to prevent excess sediment from being discharged into the creek.	Either side of Bridge Street	High	$50K - $100K[10]	2 years (yearly)	• Resource constraints. • Access challenges. • Long term commitment which can be challenging if funding or support fluctuates over time.	IS_WQ1	
WQ2	**Stormwater re-use** Capture and store rainwater from rooftops and paved areas for later use (i.e., private rainwater tanks) for non-potable purposes such as irrigation and toilet flushing.	Private properties	Medium – High	150K-500K[11]	2 years	• Limited space on properties may make it challenging to install sufficiently large rainwater tanks to meet non-potable water needs. • Maintenance requirements. • The lack of incentives or rebates for private rainwater harvesting system installations can deter community.	IS_FL1 IS_FL2 IS_FL9 IS_FL10	
WQ3	**Green infrastructure** Use of green roofs, permeable pavement, and rain gardens in urban areas to manage stormwater and reduce runoff.	Council-owned land	Medium – High	$150-500K[12]	2 years	• Maintenance requirements. • Green infrastructure may be more costly than their traditional counterparts. • Resistance to adopting new construction and design practices.	IS_FL1 IS_FL2 IS_FL9 IS_FL10	
WQ4	**Community awareness campaigns** Placement of warning signage for the culvert crossings in Possum Gully where people may enter the waterway during peak events. Launch educational campaigns to inform residents about the importance of responsible waste disposal, the risks of illegal dumping, and the role of pollutants in algae outbreaks. Use various communication channels, including	Catchment-wide	Low - Medium	$10K - $50K	2 years	• Limited resources to execute programs. • Resistance to change. • In areas with relatively good water quality (or lack of awareness of issues), community members may not perceive a pressing need for education and may be less motivated to participate.	IS_WQ4	

[10] Assuming maintenance of seven (7) GPTs, at least twice a year, including disposal costs.
[11] Based on installation of at least one-hundred, 3000-litre slimline rainwater tanks on private properties, excluding all maintenance costs
[12] Based on assumed construction of at least $500m^2$ of permeable pavement & $200m^2$ of proposed green roof construction, excluding all maintenance requirements

Project related

ID	Solution / Action	Location	Prioritisation rating	High-level cost ranges (excl GST)	Timeline	Barriers for implementation	Issues addressed	Category
	Council's website, social media and flyers. Signage can be installed in areas prone to algae outbreaks.							
WQ5	**Water quality assessment** Conduct a 2-day water quality sampling program (post-rainfall event and low flow event), collecting samples from 5 locations within the catchment to provide a current snapshot of water quality. This should include water quality reporting, identifying problem areas and recommendations (localised solutions such as pollutant traps or bioretention basins).	Catchment-wide	Low	$10K-$50K[13]	10 years	• Lack of equipment and resources. • Access issues due to high and steep embankments in areas.	IS_WQ3	
WQ6	**Water stewardship** Engaging a consultant to undertake a holistic approach to protect and enhance water quality and availability while balancing the needs of various stakeholders, including communities, businesses, and the environment.	Catchment-wide	Low	$50K-$100K	10 years	• Having multiple government agencies, municipalities, and stakeholders may lead to fragmented governance and decision-making processes, making it challenging to coordinate efforts. • Different stakeholders within a catchment may have conflicting interests and priorities, making it difficult to reach a consensus on management strategies. • Data gaps. • The absence of strong leadership for water stewardship initiatives can slow down progress and hinder the mobilisation of resources and support.	IS_FL1 IS_FL2 IS_FL9 IS_FL10	

[13] *Based on a 2-day sampling schedule (post-rainfall event & during low flow event for completeness), at 5 locations within the catchment, and allowing for subsequent reporting*

4.5 Drainage and Flood Risk

Drainage and flood risk management actions across the catchment will consist of the following reach-specific activities outlined in **Table 4-4** and **Table 4-5**. The tables are the shortlisted set of potential flood mitigation measures from the Muscle Creek FRMS&P (2019) and the Possum Gully Stormwater Drainage Options Assessment (2015).

Table 4-4: Flooding Management Plan Solutions – Muscle Creek

ID	Solution / Action	Location	Prioritisation rating	High-level cost ranges (excl GST)	Timeline	Barriers for implementation	Issues addressed	Category
FL1	**Emergency Management Planning (develop a Local Flood Plan)** This involves the collaboration of emergency services including the SES and other rescue services to develop a Local Flood Plan to: • Increase efficiency • Reduce risk to residents and emergency services.	Muswellbrook Catchment	High	$10K[14]	2 years	• This solution should be implemented alongside other solutions and is not a standalone solution.	IS_FL4 IS_FL5	
FL2.1	**Enhance the creek banks adjacent to golf course[15]** Elevation of two low points could ensure floodwaters are maintained in the channel reducing the number of properties that are flooded. This	Muscle Creek bank adjacent to Bell Street, the Golf Course and the railway (Reach 2.3, 3)	Medium - High	$500K - $1M	2 years	• Environmental impacts due to groundworks and excavation. • Ongoing maintenance is required. • Minimal disruption due to the levee being on public land. • Land ownership and access for construction	IS_FL7 IS_FL2 IS_FL1 IS_FL4 IS_FL5	

[14] *Based on approximate Council / SES staff time*

[15] *The Muswellbrook FRMS&P 2019 suggests that either FL2.1 or FL2.2 should be adopted. Both options can significantly reduce flood risk in Muswellbrook. FL2.2 provides greater reduction in flood damages and provides flood storage. Therefore, due to its ability to provide a greater degree of protection in more extreme events and despite the additional cost it is the favourable option in terms of reducing flood risk.*

ID	Solution / Action	Location	Prioritisation rating	High-level cost ranges (excl GST)	Timeline	Barriers for implementation	Issues addressed	Category
	would use 3 small levees/bunds on Muscle Creek to prevent overland flows from cutting Bell Street (a vital emergency access route). A flapped culvert would be required to ensure adequate drainage of the golf course.					and maintenance would need to be considered.		
FL2.2	**Golf course flood bund**[15] Construction of a large levee/bund adjacent to Muswellbrook Golf Club and a small levee/bund on the north bank of Muscle Creek to prevent overland flows from cutting Bell Street (a vital emergency access route).	Muscle Creek bank adjacent to the Golf Course and the railway (Reach 2.3. 3)		$1M - $3M		• Environmental impacts due to groundwork and excavation. • as the larger levee is on the Golf Course there is the potential for objections from Golf Course owners and users. • Ongoing maintenance is required. • Land ownership and access for construction and maintenance would need to be considered.		
FL3	**Flood warning system for Muscle Creek**[16] Establishing a flood warning system in the Muscle Creek Catchment to: • Increase flood warning time.	Muscle Creek catchment	Medium - High	$50K to $100K ($5,000/year)	2 years	• This solution should be implemented alongside other solutions and is not a standalone solution.	IS_FL8 IS_FL4 IS_FL5	

[16] *If FL2.1 or FL2.2 are not likely to be implemented within a 2 to 5 year timeframe, then a flood warning system is recommended to reduce risk to life from rapidly rising floodwaters that sweep through residential areas of Muswellbrook to the south of Muscle Creek and can isolate the southern side of town as frequently as the 5% AEP flood event.*

Project related

ID	Solution / Action	Location	Prioritisation rating	High-level cost ranges (excl GST)	Timeline	Barriers for implementation	Issues addressed	Category
	• Increase the time available for the safe evacuation of high-risk areas.							
FL4	**Update the LEP** Update the Local Environmental Plan (LEP) to ensure future development considers locations with high flood risk.	Muswellbrook Catchment	Medium - High	$0K-10K[17]	2 years	• If appropriate land zonings are not adopted, risk to life and increases in flood damages could result.	IS_FL8 IS_FL4 IS_FL5	
FL5	**Community Flood Education** A community flood education program would allow an increased understanding of flood risk in Muswellbrook to: • Increase flood preparedness • Reduce damages during a flood event	Muswellbrook Catchment	Medium - High	$0K-10K[18]	2 years	• Community members are likely to ignore flood information if too much is given. Communication needs to be direct and concise. • This solution should be implemented alongside other solutions and is not a standalone solution.	IS_FL8 IS_FL4 IS_FL5	
FL6	**Voluntary purchase (VP) and/or voluntary house-raising (VHR)** Voluntary purchase and/or voluntary house raising for severe flood-affected residential properties that pose a significant	Flood prone homes that aren't protected by other options (i.e., FL2.1 or FL2.2 below)	Low - Medium	$1M - $3M[19]	2 years	• Further analysis is required to identify which of the VHR/VP properties are in a high risk and should be prioritised.	IS_FL1 IS_FL2 IS_FL3 IS_FL7 IS_FL12 IS_FL4 IS_FL5	

[17] Based on approximate Council staff time
[18] Based on approximate Council / SES staff time
[19] Based on the VHR of 12 properties and VP of 6 properties

Project related

ID	Solution / Action	Location	Prioritisation rating	High-level cost ranges (excl GST)	Timeline	Barriers for implementation	Issues addressed	Category
	risk to life during flood events to: • Reduce above floor flood inundation for those currently experiencing above floor flooding in the 5% AEP flood event. • Reduce risk to life during flood events. • Restoring hydraulic capacity of properties are in a "floodway".							
FL7	**Muswellbrook Backwater Levee** Levee to prevent backwater flooding outflanking the existing Muswellbrook Levee. A large, flapped outlet is required to drain Possum Gully.	Outflanking existing Muswellbrook Levee (Reach 4)	Low - Medium	$1M – $3M	10 years	• Due to the high cost and low benefit/cost ratio of these options, they would require long term planning and it may be difficult to obtain funding from OEH until higher priority flood risks in NSW have been dealt with. • Environmental impacts due to groundwork and excavation. • Ongoing maintenance is required. • Minimal disruption as the levee is at the rear of the properties.	IS_FL3 IS_FL4 IS_FL5	
FL8	**Sydney Street Levee** Construction of an 840m long earth levee parallel to Sydney	Parallel to Sydney Street and Maitland Street (Reach 3, 4)	Low - Medium	$3M +	10 years	• Due to the high cost and low benefit/cost ratio of these options, they would require long term planning and it may be	IS_FL3 IS_FL4 IS_FL5	

ID	Solution / Action	Location	Prioritisation rating	High-level cost ranges (excl GST)	Timeline	Barriers for implementation	Issues addressed	Category
	Street, a 550m long brickwork levee parallel to Maitland Street and four temporary barriers at each road crossing.					difficult to obtain funding from OEH until higher priority flood risks in NSW have been dealt with. • Negotiation is required with residents due to levees being between properties making ownership, monitoring and maintenance difficult. • Environmental impacts due to groundworks and excavation. • Ongoing maintenance is required. • Deployment of temporary flood barrier required. • Adversely affects flood levels for some properties outside the protected area.		

Table 4-5: Flooding Management Plan Solutions – Possum Gully

ID	Solution	Location	Prioritisation rating	High-level costs (excl GST)	Timeline	Barriers for implementation	Issues addressed	Category
FL9	**Stormwater detention basin upstream of George Street** This option involves a 2,300m^2 stormwater detention basin, 13 m basin spillway and a new	Upstream of George Street culverts (Reach 6)	High	\$1M - \$3M[20]	2 years	• The footprint area for the basin is limited, particularly due to the existing pump station[21], which likely requires relocation. • Construction of the detention basin impacts the existing access track from Doyle Street used to service the pump station.	IS_FL9 IS_FL10 IS_FL4 IS_FL5	

[20] *Excluding ongoing costs and property acquisition*
[21] *The Possum Gully Stormwater Drainage Study Options Assessment (2015) states that discussions held between Council and SMEC on 14th August 2014 indicate there may be potential to raise the pump station and incorporate the pump station into the basin embankment.*

ID	Solution	Location	Prioritisation rating	High-level costs (excl GST)	Timeline	Barriers for implementation	Issues addressed	Category
	low flow outlet to attenuate peak flows and provide a level of water quality treatment, particularly if a designated bio-retention area is designed as part of the basin.					• May require approval from the NSW Office of Water (NOW) as the works undertaken may be classified as a 'controlled activity' under the NOW guidelines. • The construction of a basin may not be aesthetically pleasing to local residents. • Wet weather risks include flooding due to the function of the basin. • Environmental and aesthetic impacts due to the clearing/removal of vegetation (including mature trees). • A geotechnical investigation will be required as part of the foundation and embankment design but also to confirm groundwater levels and the potential for issues related to salinity.		
FL10	**Ongoing channel improvements/ maintenance between Sowerby Street and Carl Street** This involves: • Clearing/trimming of dense vegetation from Sowerby Street to Carl Street, and, • Additionally providing concrete/shotcrete lining for the section of the channel between the inlet to the Sowerby Street culverts up to the first property access crossing. Noting these works have already been undertaken. This would:	Between Sowerby Street and Carl Street (Reach 6)	High	$50K - $100K	2 years	• Properties benefitting are mostly confined to the area of Muswellbrook between Carl Street and Sowerby Street. • Increase in peak flow (due to reduced attenuation within the channel), leading to locally higher channel velocities and increased risk of erosion and scour within sections of the channel. Clearing of any sections of the channel will need to be carefully managed with appropriate erosion and scour protection measures (e.g. rock protection, revegetation of channel with appropriate species etc.) • Likely access issues require notification for residents in advance of proposed channel improvement works. • May require approval from the NSW Office of Water (NOW) as the works undertaken may be classified as a 'controlled activity' under the NOW guidelines. • Environmental and aesthetic impacts due to clearing/removal of vegetation within the channel between Sowerby Street and Carl Street.	IS_FL9 IS_FL4 IS_FL5	

Project related

ID	Solution	Location	Prioritisation rating	High-level costs (excl GST)	Timeline	Barriers for implementation	Issues addressed	Category
	• Increase the hydraulic capacity of the channel to reduce flood levels within the channel. • Address community complaints surrounding the overground channel.					• As the area of the gully is private land, current Council policy requires the landowner to be responsible for vegetation maintenance. • Potential reduction in water quality treatment that may have previously been provided by vegetation within the channel. • Potential loss of habitat for fauna.		
FL11	**Combination of FL9 and FL10** This option involves a new stormwater detention basin upstream of George Street and channel improvements between Sowerby Street and Carl Street.	Upstream of George Street culverts Between Sowerby Street and Carl Street (Reach 6)	High	$1M - $3M[22]	2 years	• As above for FL9 and FL10.	IS_FL9 IS_FL10 IS_FL4 IS_FL5	
FL12	**Upgrading of culverts** To: • Address issues relating to constriction caused by culverts. • Prevent backup of flood flows upstream of constricted reaches.	Culverts under Muswellbrook Marketplace & culverts under the Shopping Arcade to the railway line. (Reach 7)	Medium - High	N/A	2 years	• Not modelled and should be modelled to examine. • Could potentially be cost-prohibitive. • Potential for construction issues due to the restricted location of the culvert(s).	IS_FL9 IS_FL4 IS_FL5	
FL13	**Off-line 'Dry' Detention Basin[23]** This option has potentially greater capacity and area for basin footprint than FL9.	Adjacent to Brentwood St & Doyle St, Lot 25 (Reach 6)	Low – Medium	N/A	2 years	• Not modelled and should be modelled to examine. • Land zoned as 'SP2- Infrastructure' and designated 'Health Service Facility', therefore may not be able to construct a basin on this lot.	IS_FL9 IS_FL10 IS_FL4 IS_FL5	

[22] *Excluding ongoing costs and property acquisition*
[23] *FL9 and/or FL12 should be considered.*

ID	Solution	Location	Prioritisation rating	High-level costs (excl GST)	Timeline	Barriers for implementation	Issues addressed	Category
	It would attenuate peak flows and provide water quality benefits.							
FL14	**Bunding** Bunding adjacent to properties most affected by nuisance flooding along Possum Gully.	Most affected properties along Possum Gully	Low	N/A	2 years	• Not modelled and should be modelled to examine. • Bunding/filling in 'floodway' and/or 'flood storage areas' may potentially result in local increases in flood levels. • Lack of footprint area/easement to construct a bund.	IS_FL10 IS_FL4 IS_FL5	

5 Recommendations

To address deficiencies in information, this CMP will be best supported by further investigations. These would include:

- Detailed analysis (i.e., concept design, survey, soil testing, drone footage) is required for bank instability options at specific high-risk locations identified in **Figure 7-35** of **Appendix A6**.
- Detailed analysis for scour protection at outlet structures **(Figure 2-5)** based on the Department of Planning and Environment guidelines for outlet structures on waterfront land.
- Updated modelling can be undertaken for extreme flood events such as 0.05% or 0.02% AEP for high risk proposals when setting flood planning levels to support land use planning.
- Vegetation management plan that builds off the priority areas identified in this CMP, detailing species planting list. This should include reviewing recent REFs that will have ground-truthed Plant Community Types, fauna species observations, flora lists and weed lists.
- Soil testing may be required in areas proposed for revegetation that are suspected to be contaminated. This may result in soil remediation activities such as phytoremediation using successional and primary colonising species. We believe the most cost effective and useful-to-council way of doing this would be to link this to a Vegetation Management Plan. Our ecologist believes a full scale soil sampling isn't cost-effective for Council if the intent is to understand potential issues with areas proposed for revegetation being contaminated. Ideally the ecologist would need to undertake another site walk reviewing the most appropriate soil sampling sites (based off the proposed revegetation sites) and produce a vegetation management plan as an output.
- Auditing of existing stormwater quality improvement devices (GPTs) in the catchment.
- Drone footage can provide an effective method to map vegetation such as native vegetation cover and weed/exotic species cover, outline signs of erosion and determine the success of revegetation and regeneration activities. The footage will provide a "continuous view" of the reaches within the catchment enable for a large scale means of monitoring vegetation over time and the success of the CMP.

6 Conclusion

This CMP was prepared following the development of a baseline understanding of the study catchment, which was used to determine and consolidate the issues and opportunities. Prioritised management actions have been proposed to address the identified issues and opportunities and are brought together into a plan of management.

To develop a baseline understanding of the study catchment a combination of fieldwork and desktop work was undertaken. The fieldwork conducted in August 2023 gave on-the-ground insights into the catchment's geomorphology and vegetation management, while the desktop study provided an overview of its flood risk, drainage, water quality and anticipated changes.

Key insights learned from the fieldwork and desktop study are as follows:

- Historic land use changes, as observed through aerial imagery dating back to 1938, indicate shifts in vegetation and urbanisation.
- Geomorphologically, the region has experienced significant changes since European settlement, particularly related to riverbank clearing and sediment deposition in the Hunter River. Climbing weeds are prevalent, stifling vegetation, while native bank vegetation is limited in parts. Steep,

unstable banks near crucial infrastructure like homes and roads pose risks. Some areas lack riparian structure and remain underutilised.
- The catchment experiences fluctuations due to climatic events like El Niño and La Niña, impacting droughts and floods. The catchment is prone to flooding, with the potential to inundate crucial roads, posing challenges for emergency services.
- The study catchment includes a constricted stormwater network that consists of underground stormwater pipes, pits, GPTs, and substantial culverts at road crossings and open channels.
- The riverbanks across the catchment show signs of extensive erosion where vegetation was absent, where the ground cover layer or inefficient hydraulic structures and altered hydrological regimes were apparent. The vegetation within the catchment is currently subject to a range of management actions such as revegetation and regeneration activities outlined through evidence of extensive primary weed control, plantings, active regeneration and private and public landscaping.
- Data on water quality is limited. Historical water quality monitoring identified that at Muswellbrook there were elevated levels of water quality parameters such as faecal coliforms, nitrates and turbidity. Fieldwork confirmed that gross pollutants are prevalent throughout the waterways, with an increased load downstream of Muscle Creek and the daylighted sections of Possum Gully.
- Anticipated future changes include increased urbanisation, which is expected to elevate peak discharges and flooding risks. To address this impact, all development is to follow Council's Development Control Plans (DCPs) (i.e., detention basins, protected spillways, GPTs). Climate change will further complicate flash floods and bank instability due to altered rainfall patterns and prolonged droughts. Elevated temperatures during droughts will exacerbate water shortages and environmental stress.

With this baseline understanding, key issues and opportunities for the study catchment were identified in relation to bank instability, vegetation, water quality and drainage and flood risk. The management plan solutions discussed in **Section 4** focus on addressing these concerns, and prioritising recommendations for the Council. To prioritise management solutions, they were assessed for effectiveness and feasibility.

High priority management actions include:

- BI1 – Creek bank stabilisation and/or relocation for two vulnerable areas in Muscle Creek (preceded by site-specific assessment).
- BI2 – Soft creek bank solutions such as planting along riverbanks.
- VM1 – Vegetation management at Reaches 5, 6 and 8
- VM2 – Vegetation management at Reach 2 and 5
- VM3 – Preparation of a detailed catchment-wide Vegetation Management Plan (or based on prioritised reaches)
- WQ1 – Regular maintenance and debris removal from gross pollutant traps/surcharge pits to prevent excess sediment from being discharged into the creek.
- FL1 – Emergency Management Planning (develop a Local Flood Plan)
- FL9 – Stormwater detention basin upstream of George Street
- FL10 – Channel improvements between Sowerby Street and Carl Street, and
- FL11 – Combination of FL9 and FL10.

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Appendices

A1 Figures

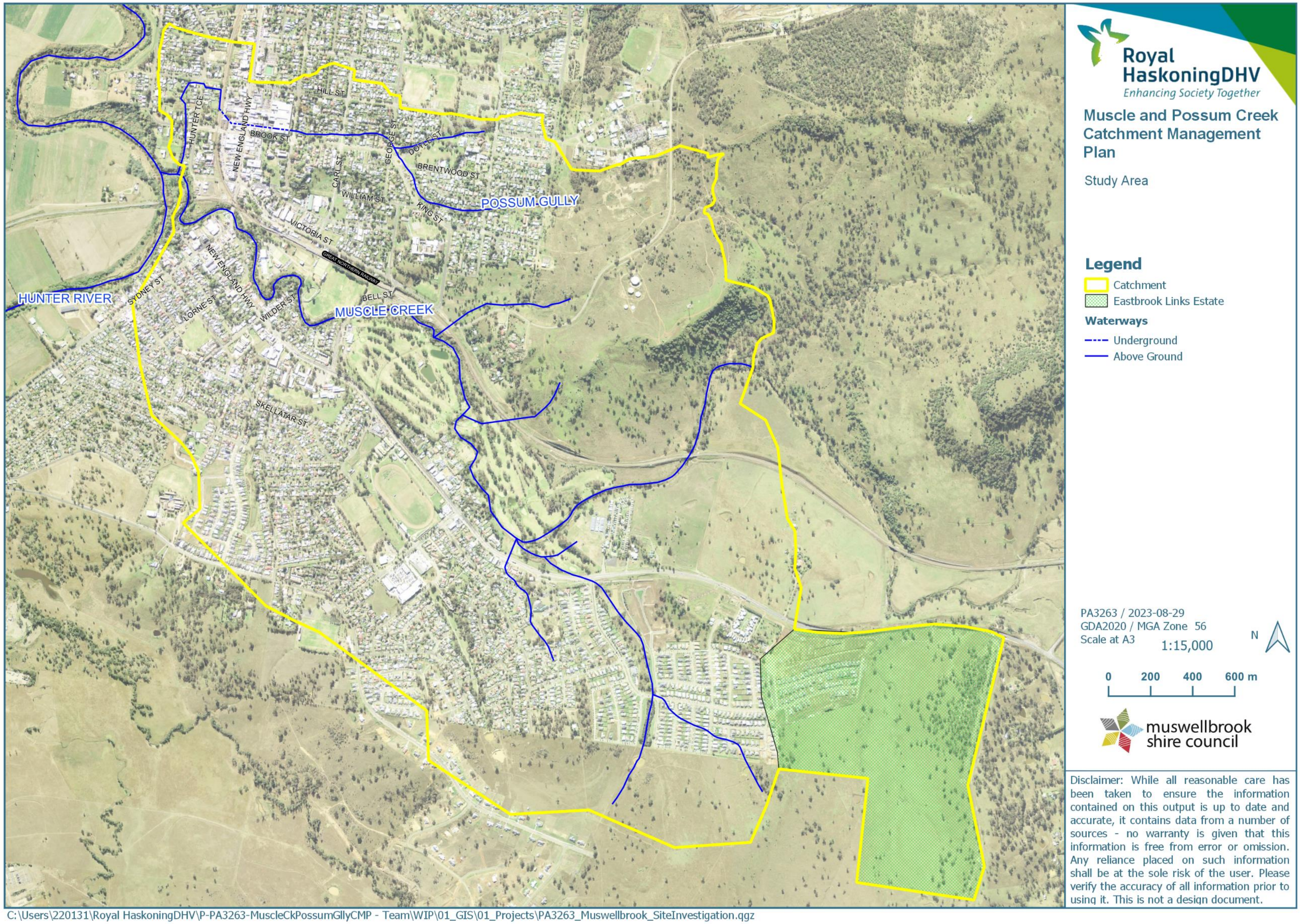

Figure 7-1: Study Area Catchment (hatched area inaccessible).

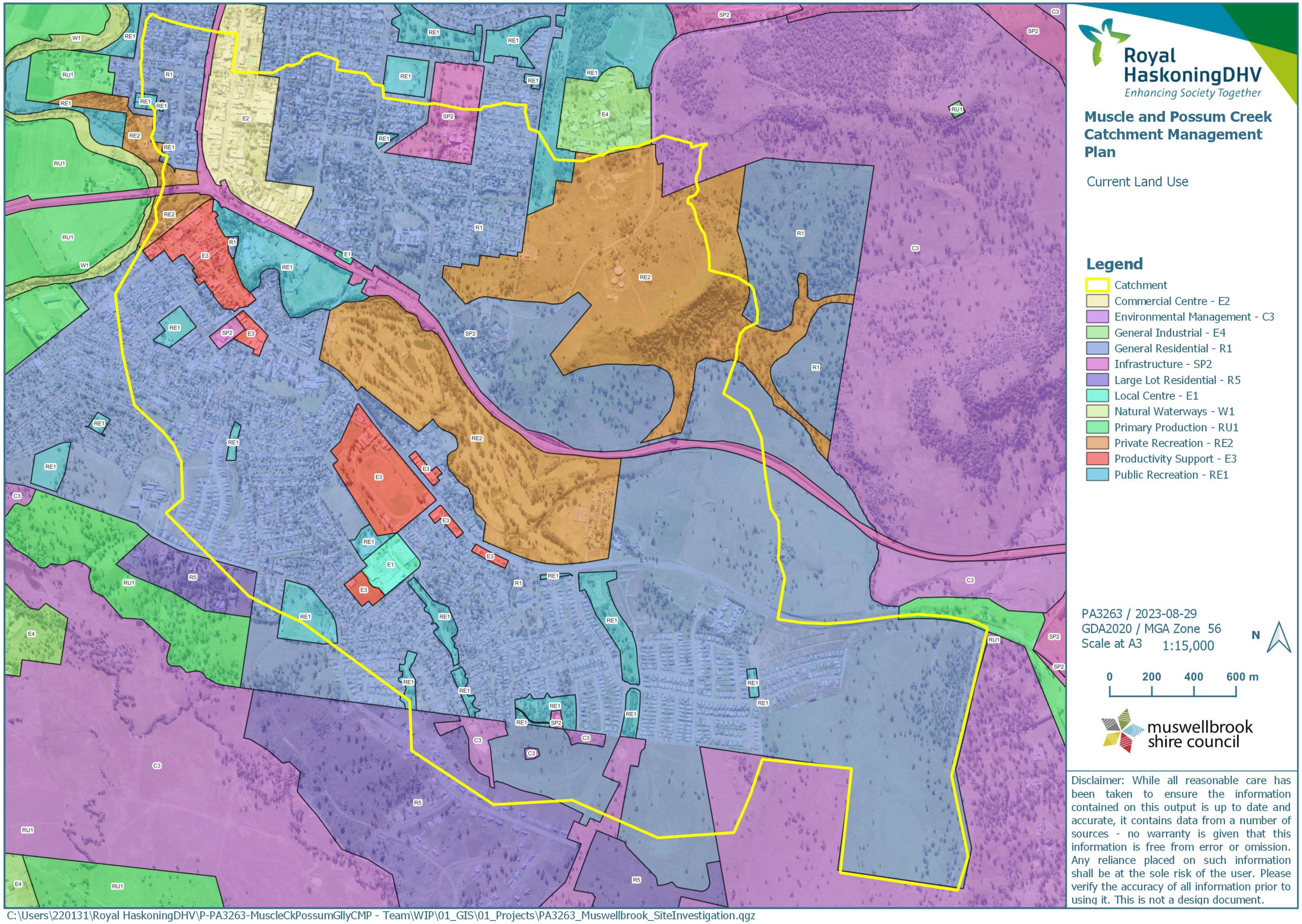

Figure 7-2: Current Land Use

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Figure 7-3: Muscle Creek aerial images 1938 vs 2023

Figure 7-4: Muscle Creek aerial images 1989 vs 2023

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Figure 7-5: Muscle Creek aerial images 1998 vs 2023

Figure 7-6: Muscle Creek aerial images 2014 vs 2023

Figure 7-7: Possum Gully aerial images 1938 vs 2023

Figure 7-8: Possum Gully aerial images 1974 vs 2023

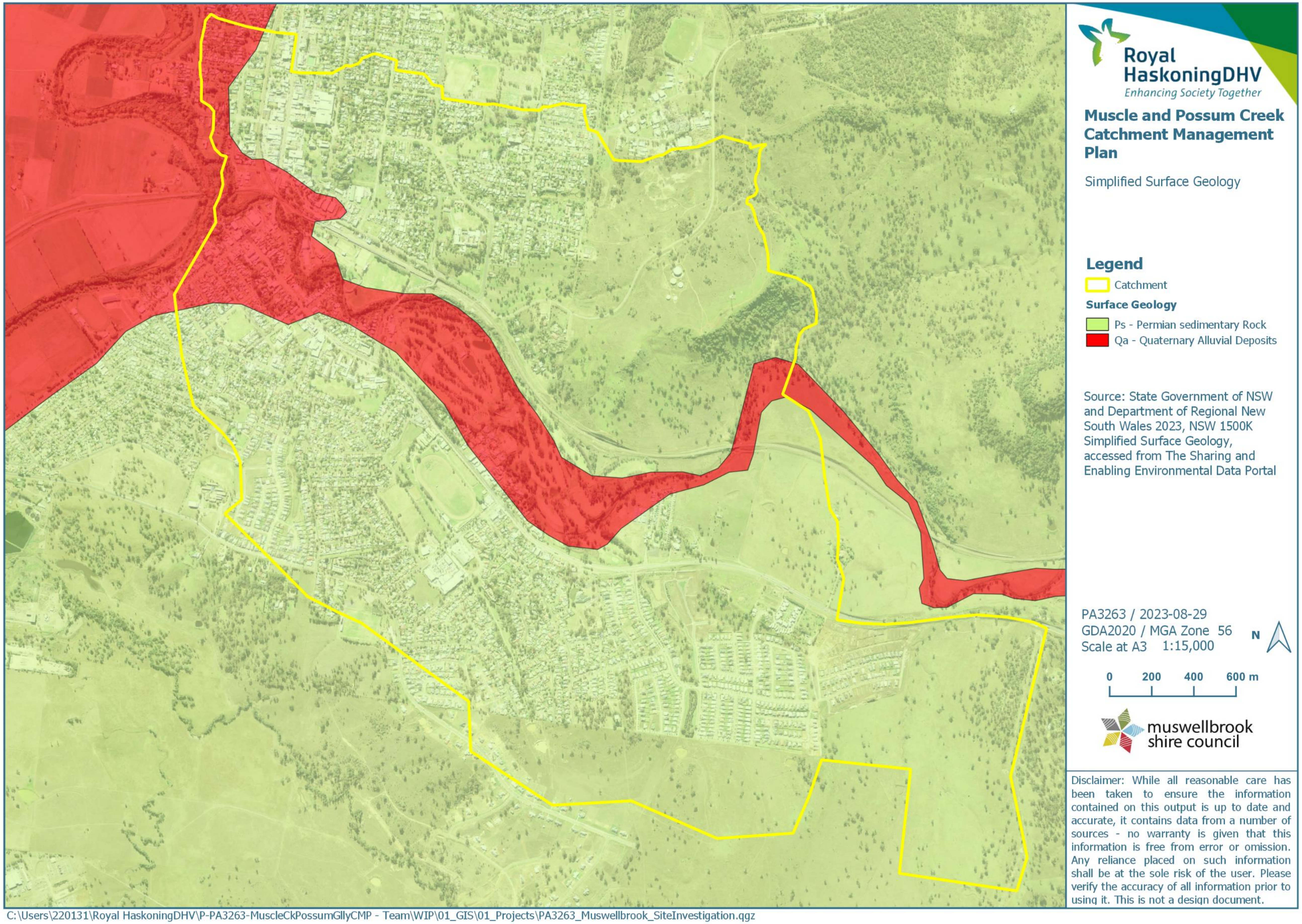

Figure 7-9: Surface Geology

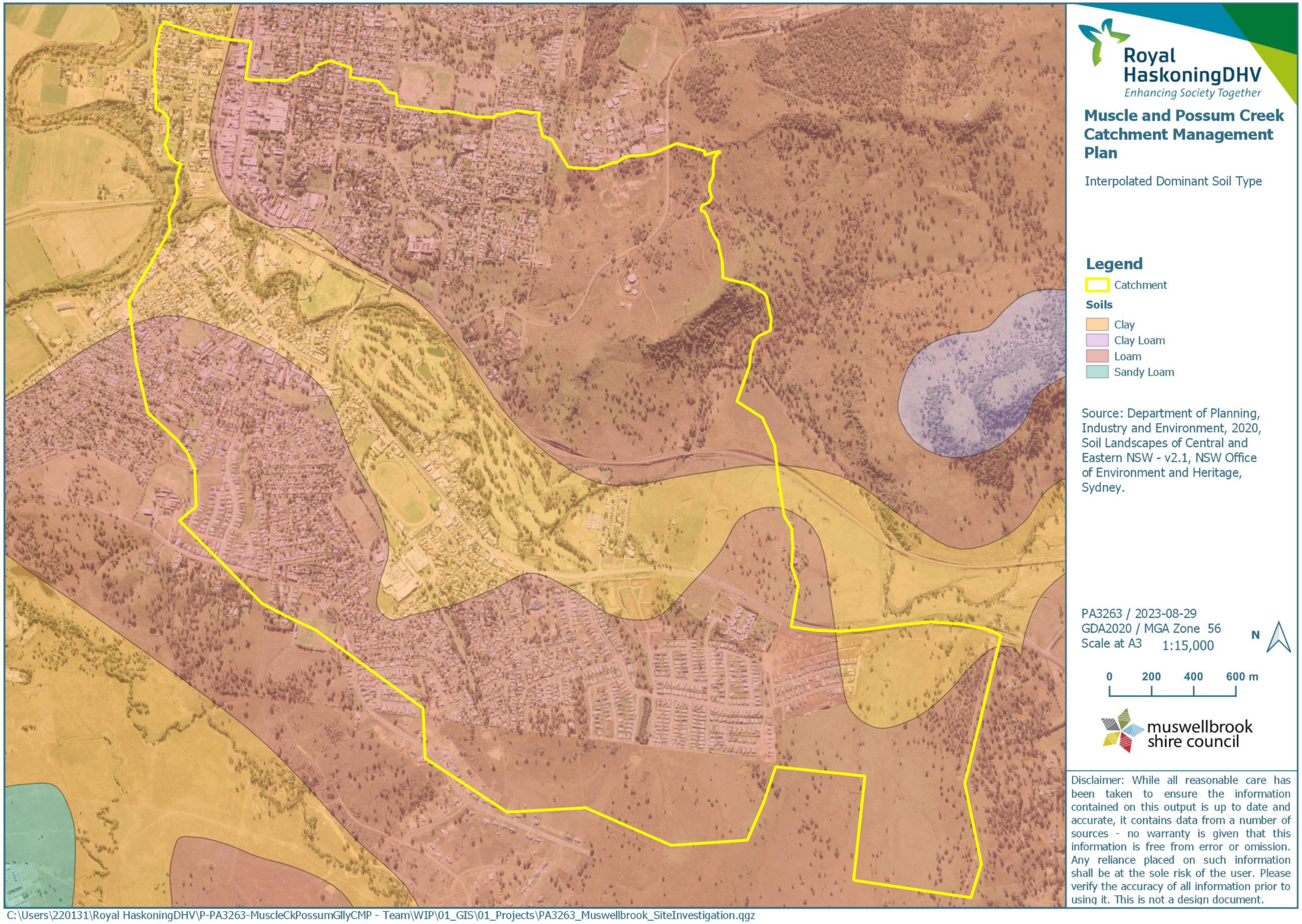

Figure 7-10: Interpolated Dominant Soil Type

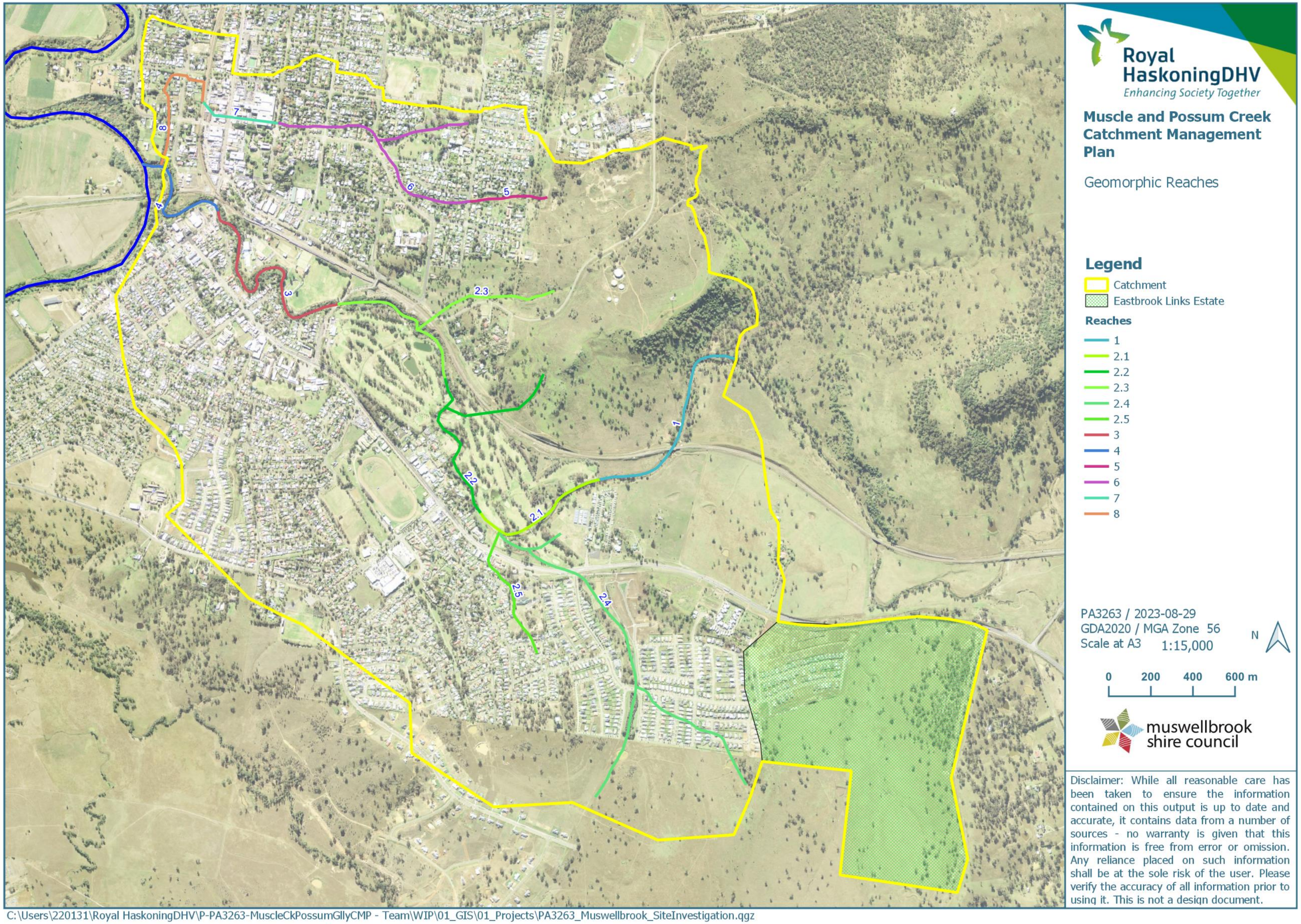

Figure 7-11: Geomorphic Reaches (hatched area inaccessible)

Figure 7-12: Benign bank instability locations

Figure 7-13: Current bank stabilisation works (soft)

Figure 7-14: Current bank stabilisation works (hard)

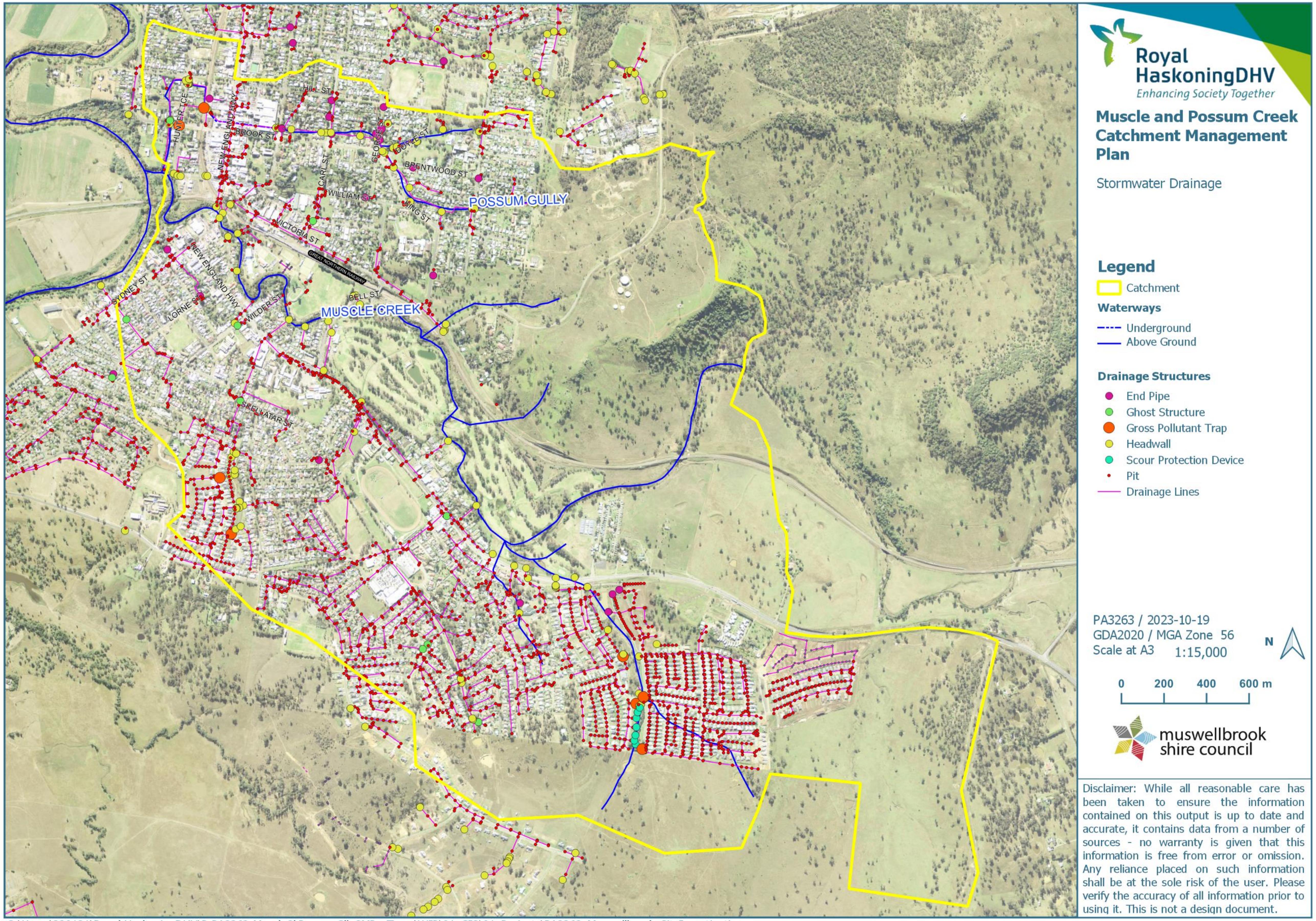

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Figure 7-15: Stormwater Drainage

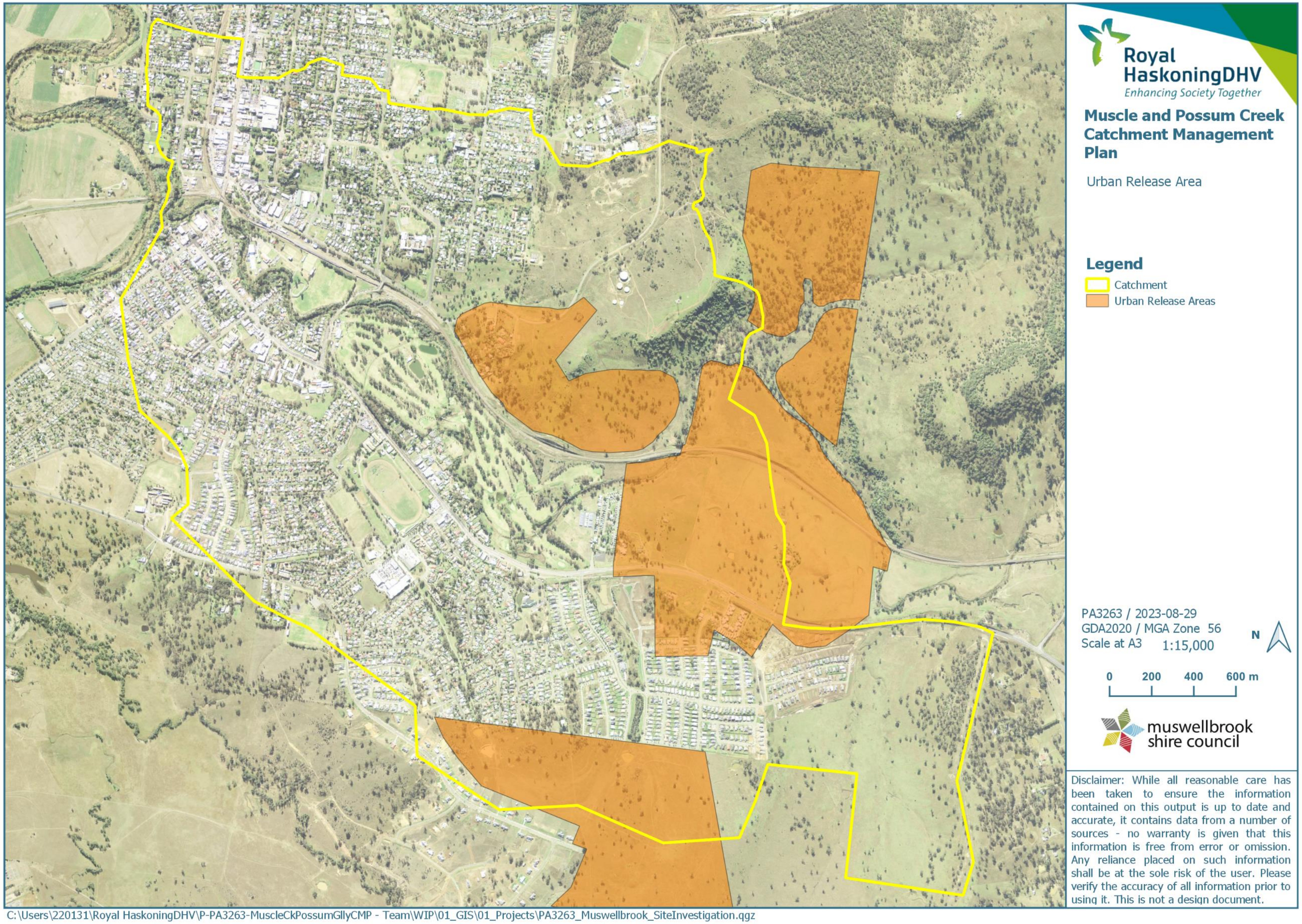
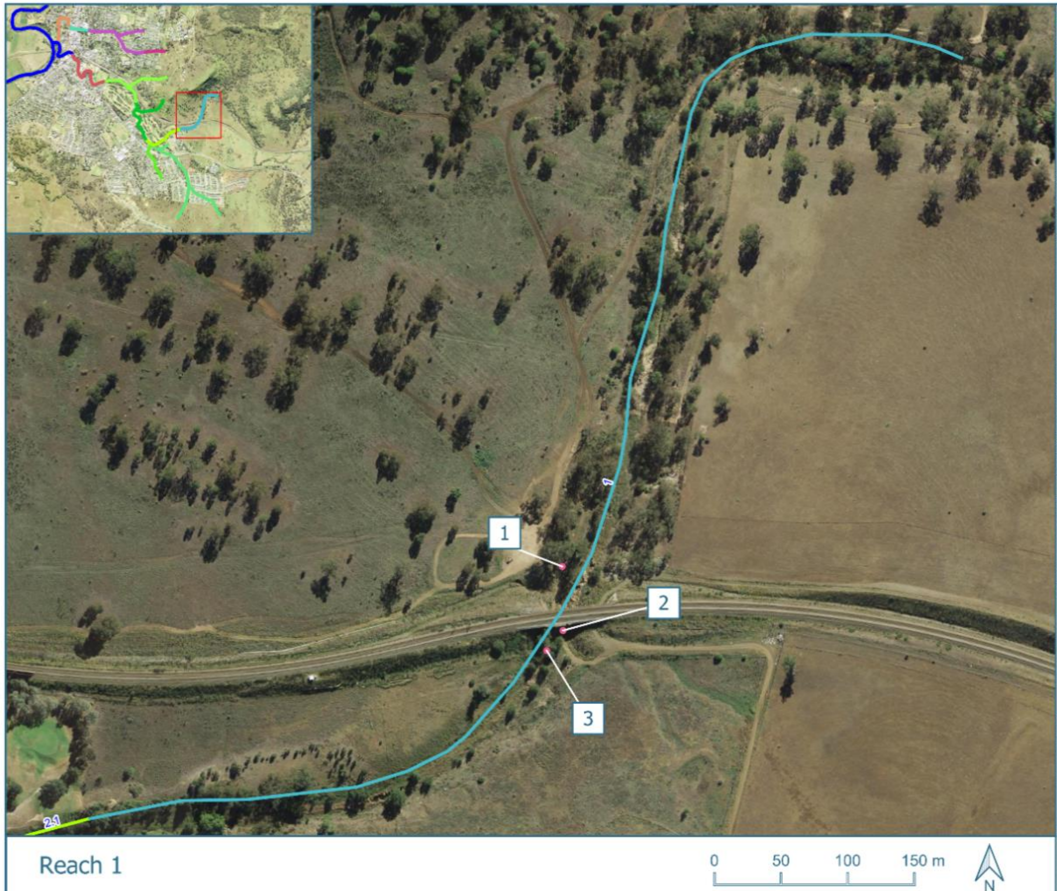


Figure 7-16: Urban Release Area

A2 Geomorphology Field Sheets



Reach 1

Reach 1 features stable creek banks devoid of homes or valuable assets at risk of erosion. Its upstream and downstream limits are the Muscle Creek Flood Study's upstream boundary and one end of the Golf Course, respectively. The land on both sides of the creek hosts shrubs and a railway line. The creek follows a relatively straight path. In the middle of this stretch, beneath the bridge, there's marginal deadwater due to sediment accumulation caused by elements like large debris and grassy vegetation in the channel. The bridge's height and slender piers limit impoundment. The riparian buffer strip, less than one river width wide, is fragmented. The bank profile is stable and graded, with semi-continuous and intricate tree lining. This area falls within Aboriginal land.

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Figure 7-17: Reach 1 fieldwork sheet

Reach 2.1

Reach 2.1 is characterised by a causeway that's impounding the creek's flow. Sediment plugs, not from man-made structures, exist. The bank slope is graded and lacks protection measures. Tree lining is sparse and scattered, while bank face vegetation is complex. The riparian strip is minimal, possibly for expanded golf course space, impacting creek health. The channel's planform is mostly straight, with variable dimensions. Bank height ranges from 4 to 8 meters. The valley shape resembles a shallow vee. Recreational land use is present on both the left-hand bank (LHB) and right-hand bank (RHB), with residential use on the RHB and shrubs on the LHB. In one area, infrastructure in the creek acts as a makeshift weir. The elevated bridges are unlikely to obstruct water flow. The upstream boundary is the end of the golf course.

0 30 60 90 m N


1 (Looking Downstream)


2 (Looking Downstream)


3 (Looking Downstream)


4

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Figure 7-18: Reach 2.1 fieldwork sheet

Reach 2.2

Reach 2.2's upstream boundary marks a shift in valley and channel form. It features a more sinuous planform compared to Reach 2.1. This reach has impeding causeways. Recreational land use is dominant, with a railway on the right-hand bank (RHB). The channel has a trapezoidal cross-section, and its width and depth vary with the planform. The bank slope is graded, lacking protective measures. Bank face vegetation is basic and bare along the reach. The riparian strip is minimal, likely due to golf course expansion, affecting creek health.

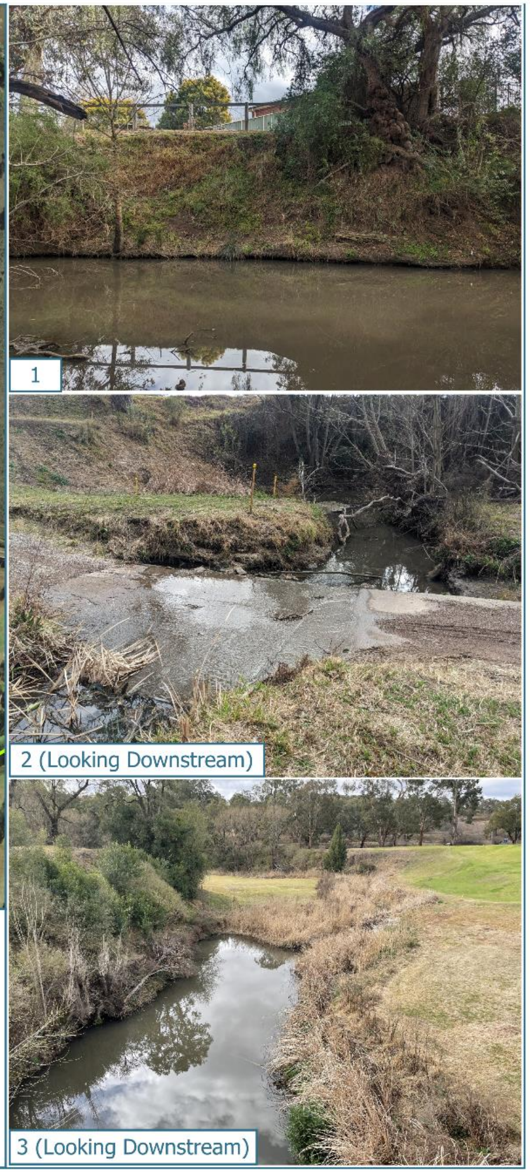

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Figure 7-19: Reach 2.2 fieldwork sheet

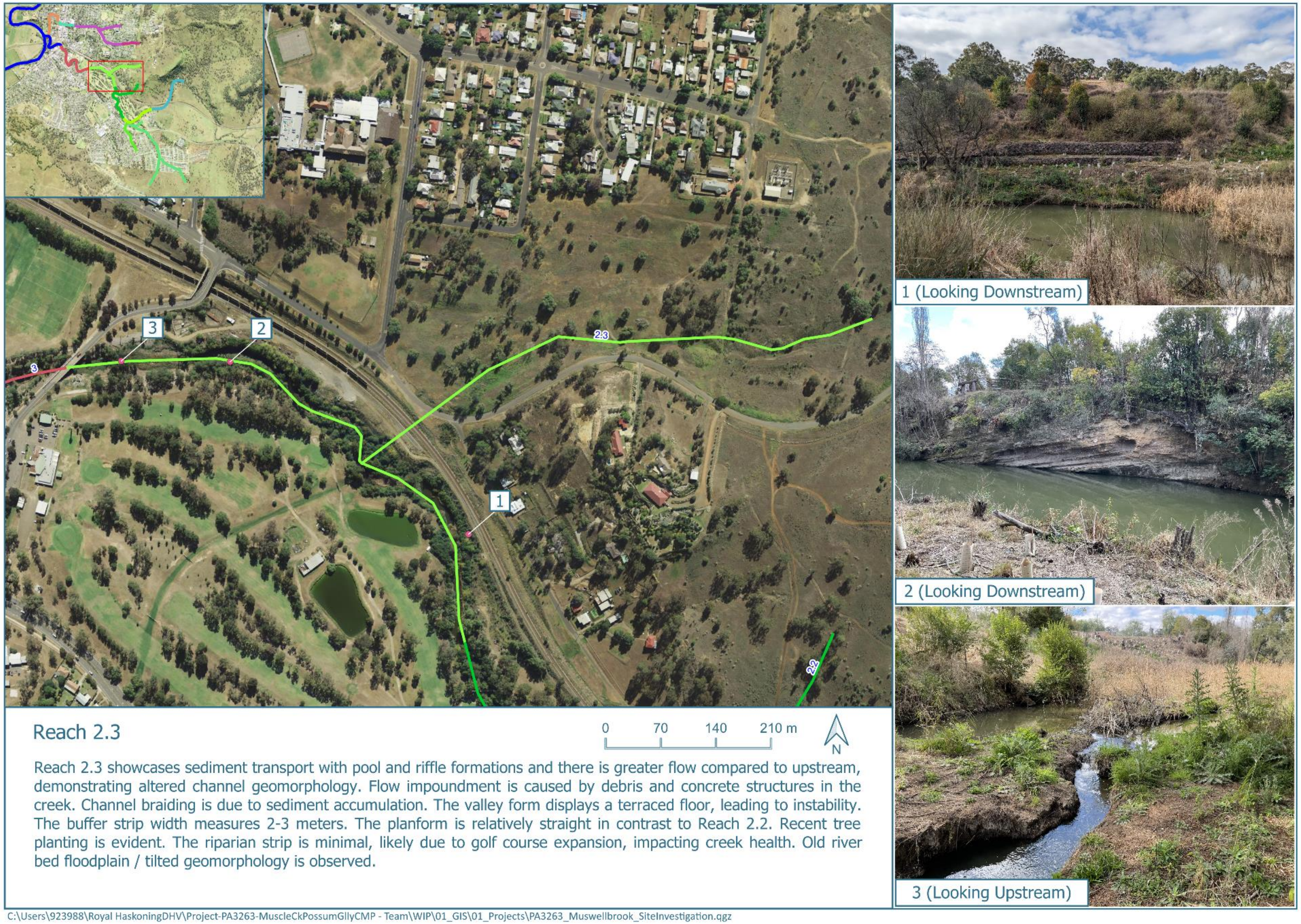

Figure 7-20: Reach 2.3 fieldwork sheet

Figure 7-21: Reach 2.4 fieldwork sheet

Reach 2.5

Reach 2.5, a southern Muscle Creek tributary, begins near Hakea Drive's residential area and ends at the Golf Course downstream. The downstream golf course section seems grassed, with vegetation being scarce elsewhere. A pond near Richard Gill School seems to serve as a sediment sink. Limited vegetation/buffer area presents an opportunity, as does potential biofiltration. A rock gabion armory design is being developed on the left-hand bank (LHB) of this reach on the golf course.

0 50 100 150 m

N

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Figure 7-22: Reach 2.5 fieldwork sheet

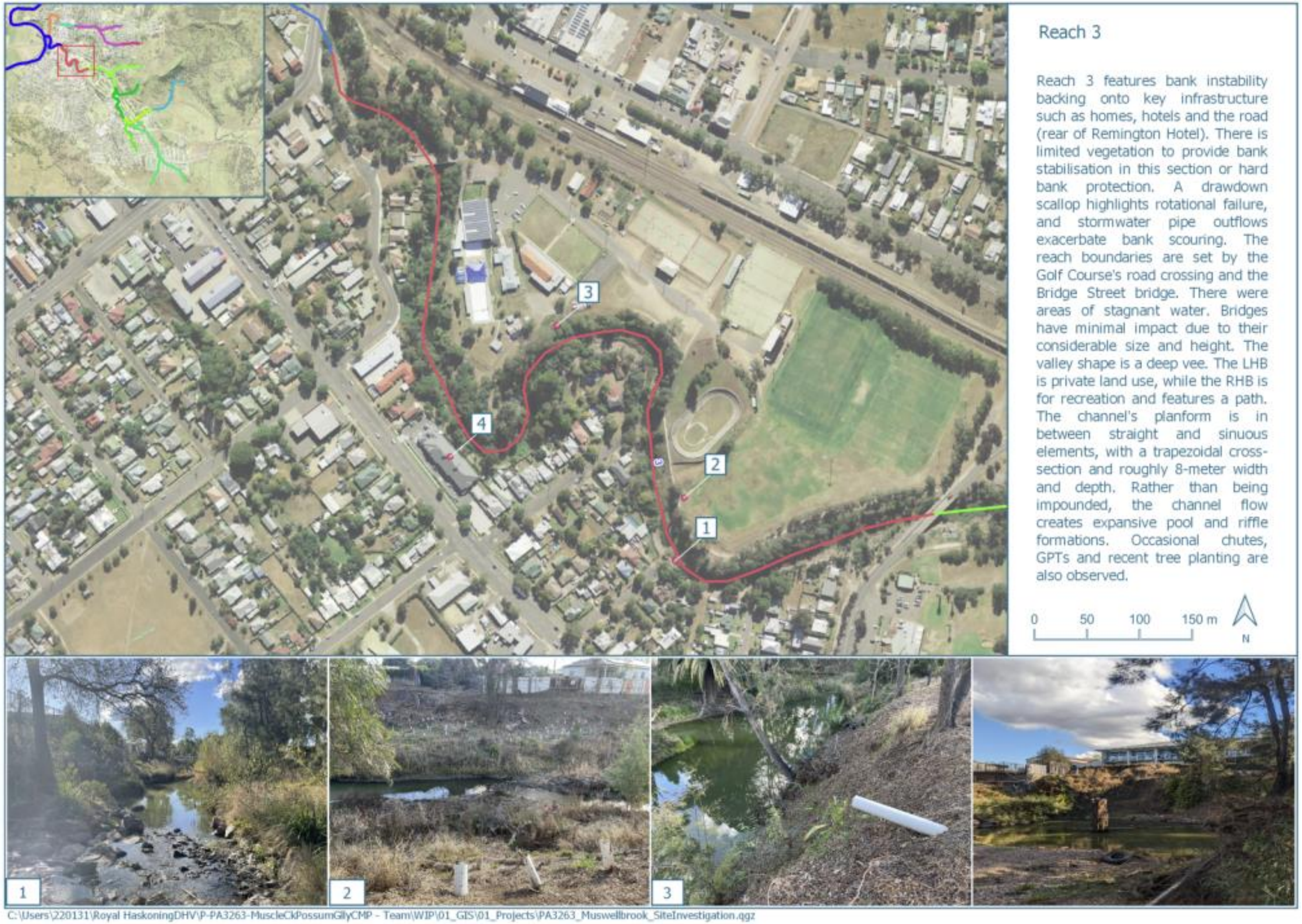

Figure 7-23: Reach 3 fieldwork sheet

Reach 4

Reach 4 features cliff/vertical bank profile creating significant bank instability. The channel geometry is sinous and trapezoidal with relatively uniform dimensions along planform.The footings and piers in the Hunter River are visible, demonstrating that that the river has incisised, deepening of the river over time which in turn led to widening. However it should be noted that the eastern piers are not incised. It appears that as the main Hunter River channel has deepened and enlarged, Muscle Creek has overwidened/deepened as well. Bank face vegetation was densely covered in weeds. Significant subvertical incising is observed behind the Muswellbrook & District Workers Club and Riverside Caravan Park, though it appears relatively stable, albeit prone to collapse under saturation.

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Figure 7-24: Reach 4 fieldwork sheet

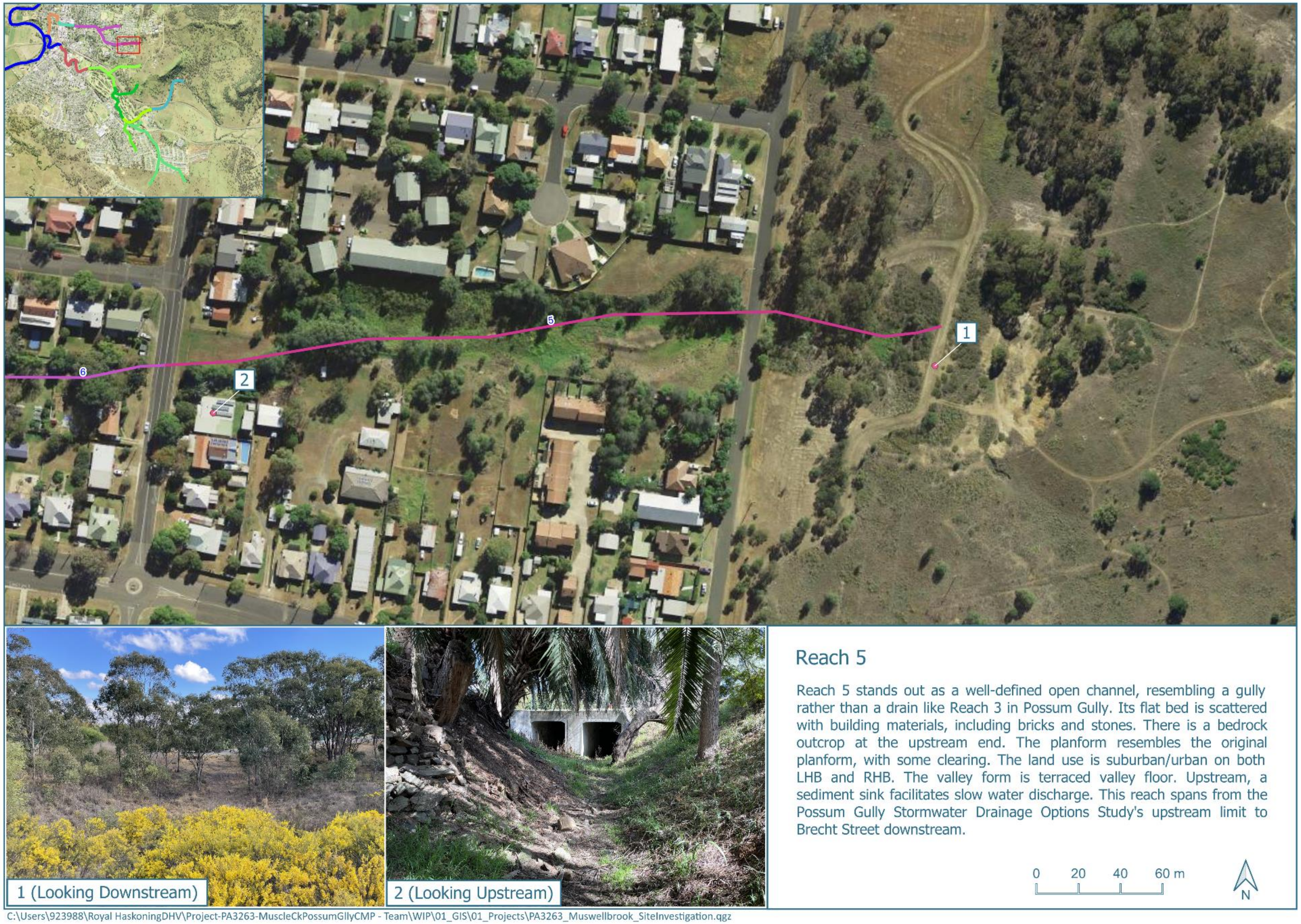


Figure 7-25: Reach 5 fieldwork sheet

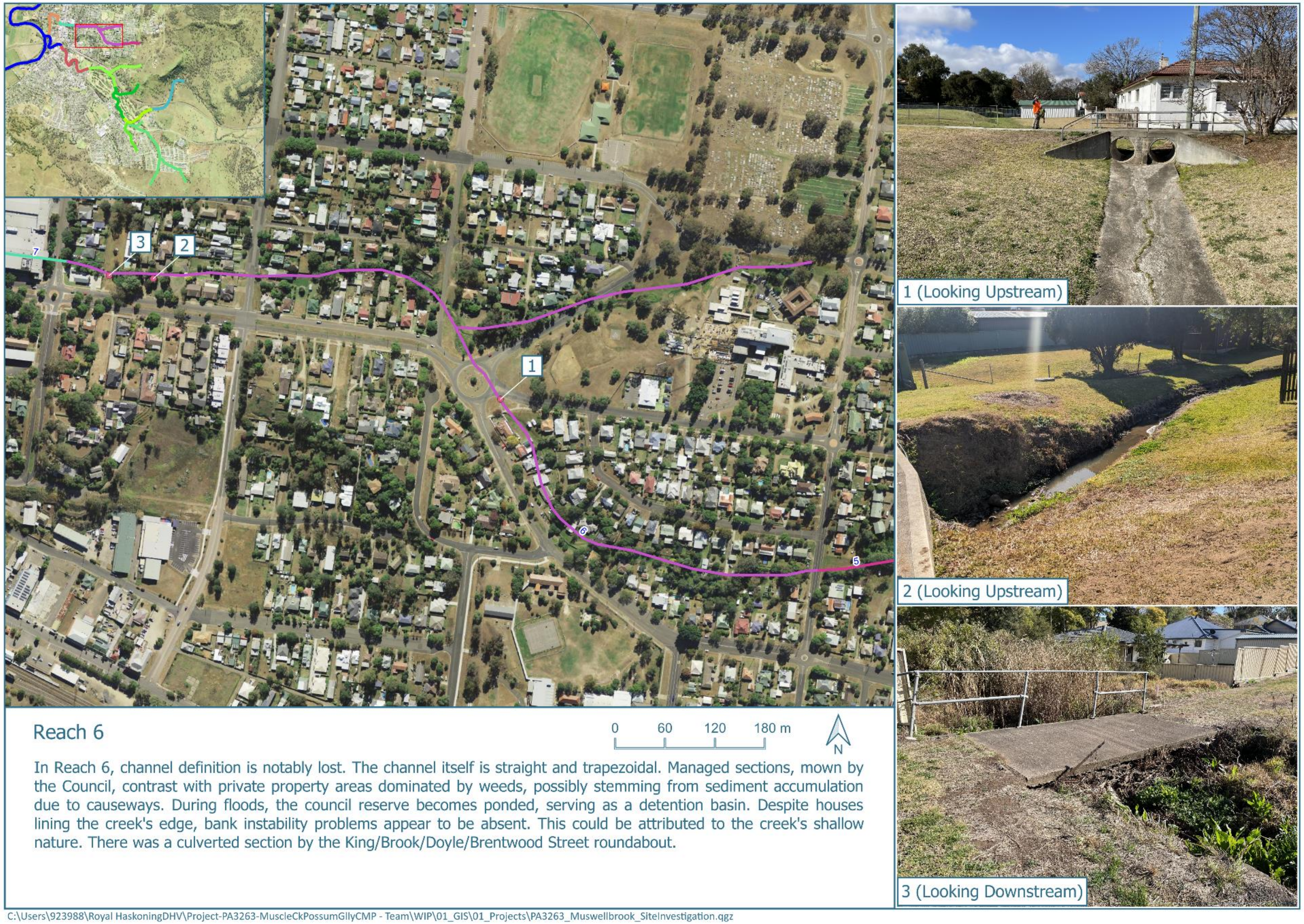


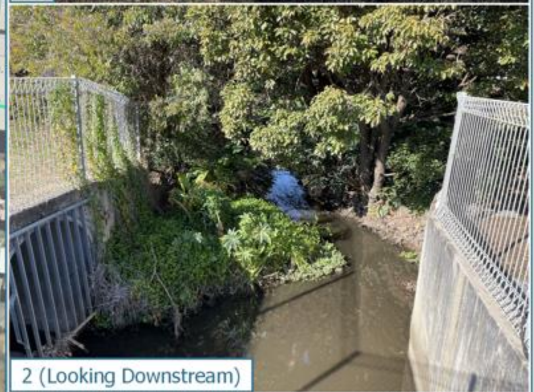
Figure 7-26: Reach 6 fieldwork sheet

Reach 7

Reach 7 is a culverted, piped section of Possum Gully, where no notable geomorphology is noted. The upstream reach boundary was chosen as this is where the piped section is daylighted.

Figure 7-27: Reach 7 fieldwork sheet


1


2 (Looking Downstream)


3 (Looking Downstream)

Reach 8

0 50 100 150 m

N

Reach 8 is a section of open channel with culverts and GPTs. An empheral stream was observed at the Hunter River confluence. Signficant density of weeds was observed on the bank face. Impoundment was observed. The bank profile is graded. Landform-wise, it is relatively straight, and the valley shape is a shallow vee upstream near Brook Street. Downstream the landform is deeper.

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Figure 7-28: Reach 8 fieldwork sheet

A3 Flood Maps

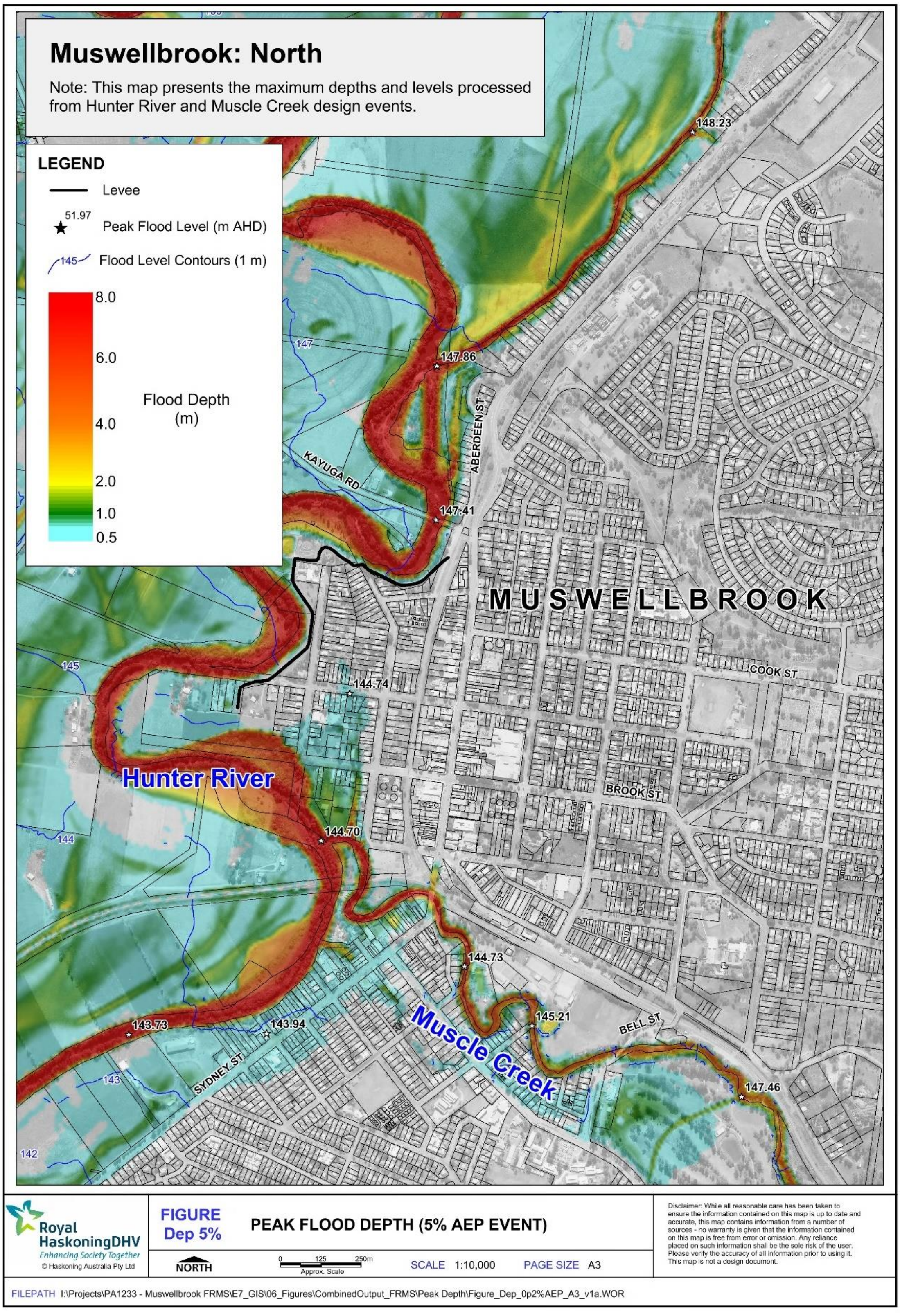

Figure 7-29: Peak Flood Depth 5% AEP Event (Muswellbrook FSMS&P, 2019)

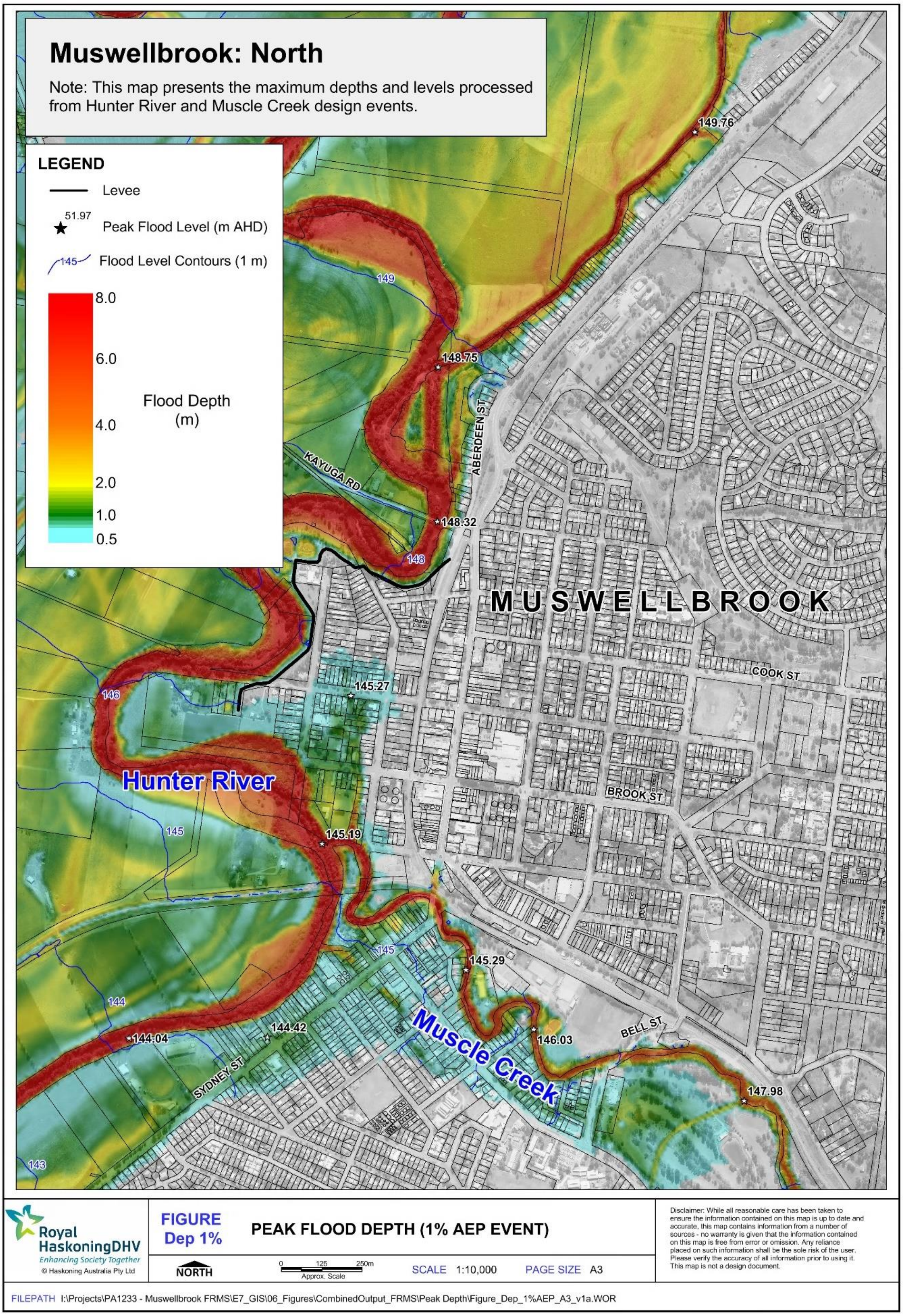

Figure 7-30: Peak Flood Depth 1% AEP Event (Muswellbrook FSMS&P, 2019)

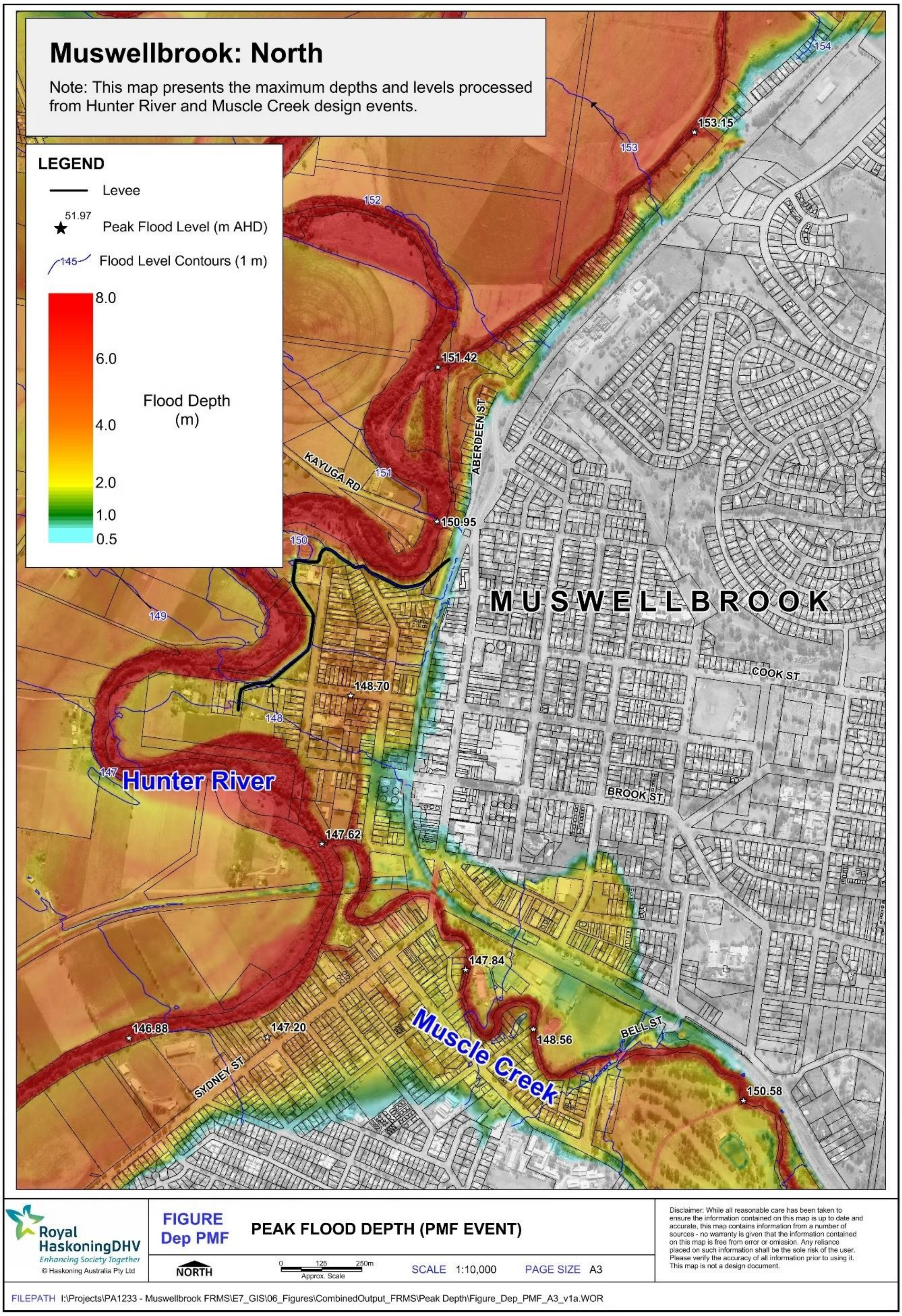

Figure 7-31: Peak Flood Depth PMF Event (Muswellbrook FSMS&P, 2019)

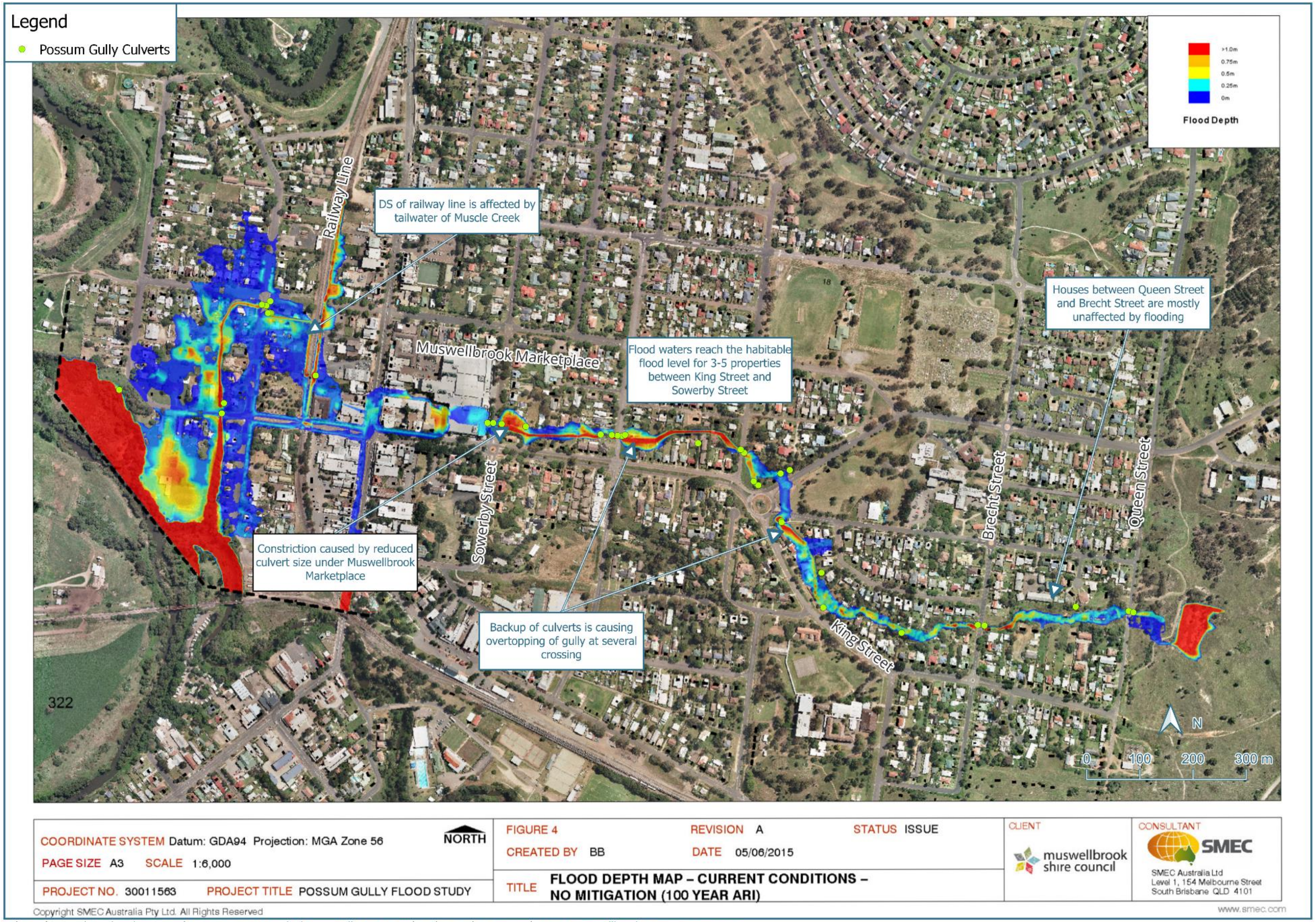

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Figure 7-32: Mark-up of Possum Gully 1% AEP Flood Depth Map

A4 Ecologic Assessment

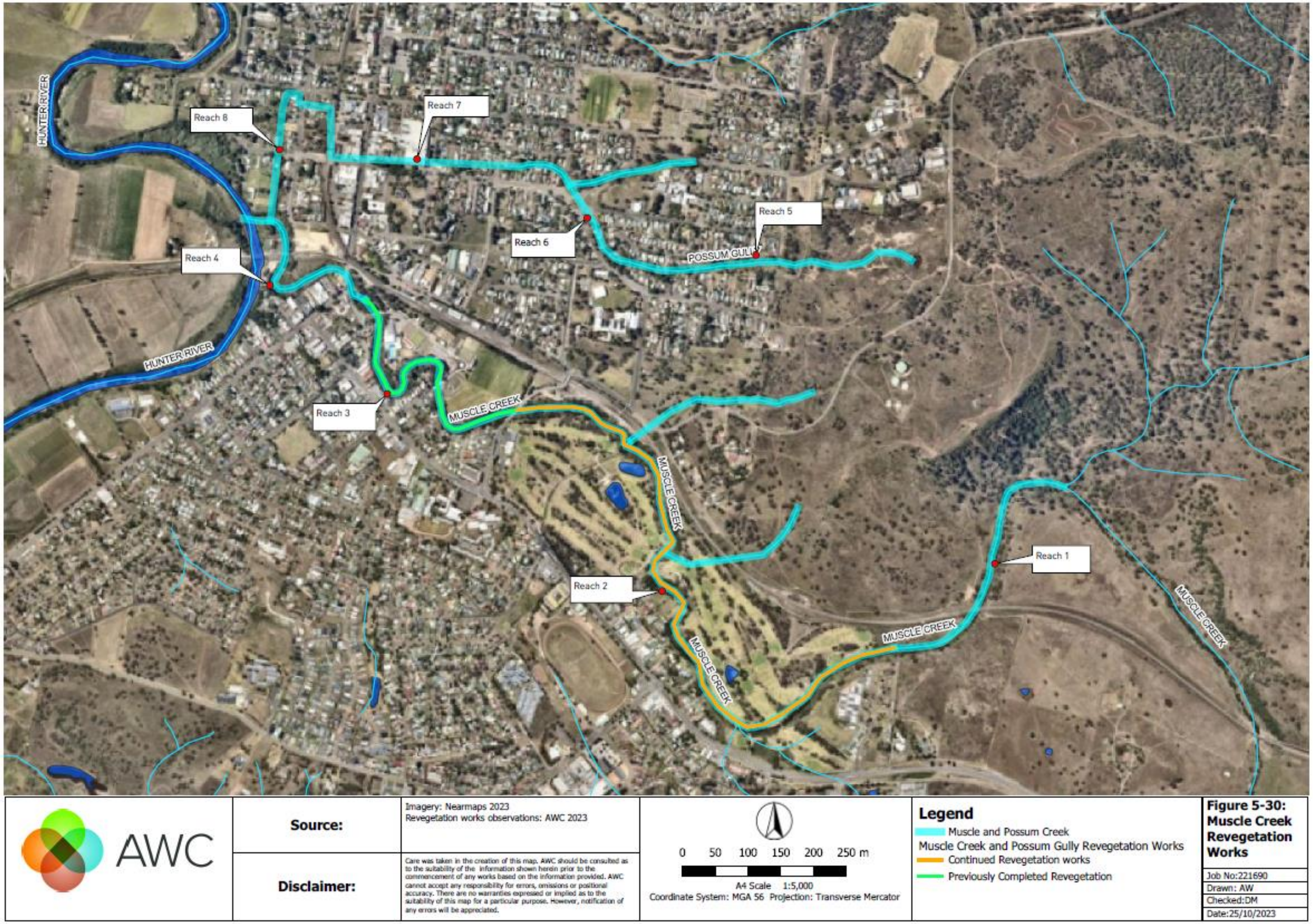


Figure 7-33: Revegetation Works

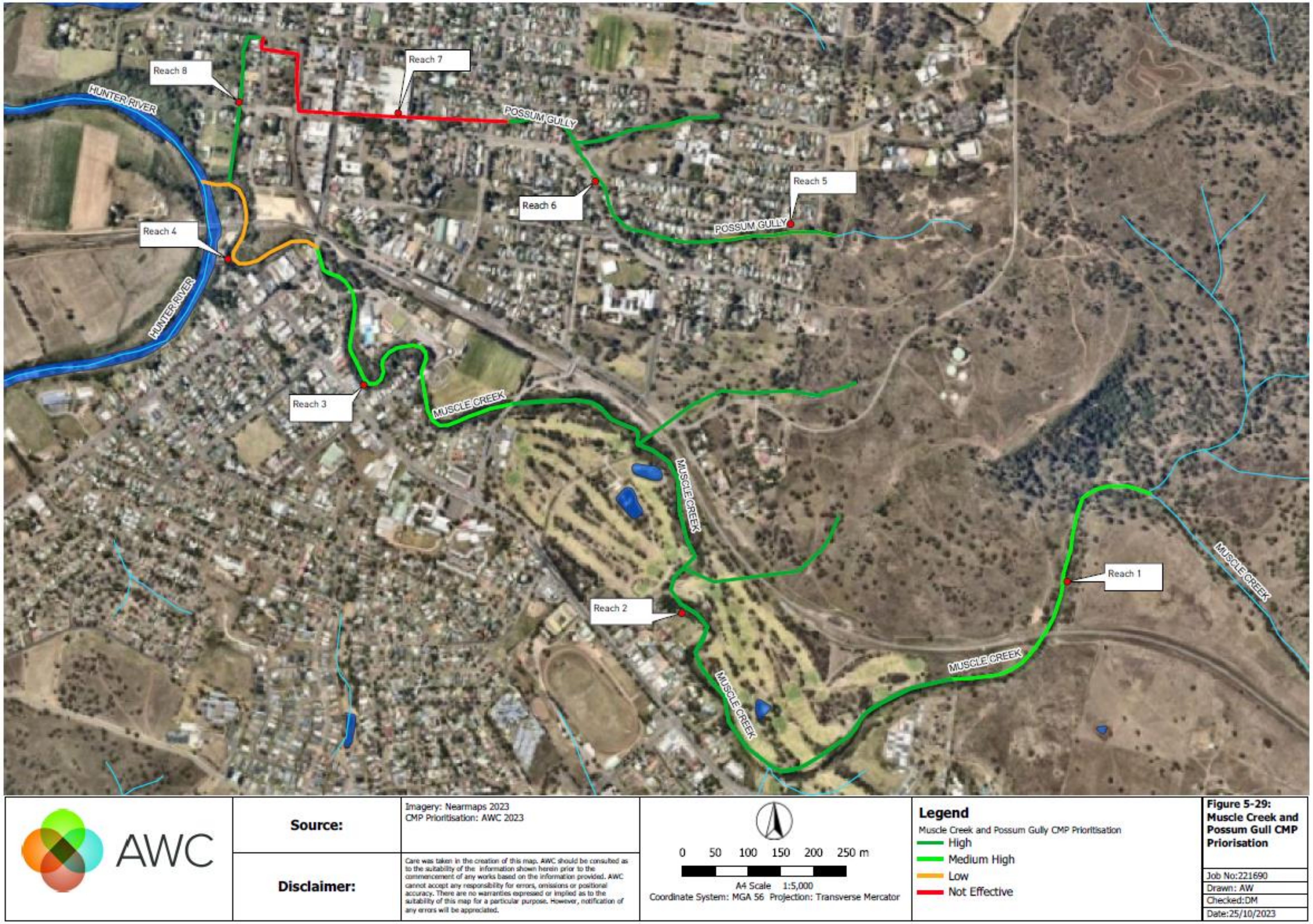
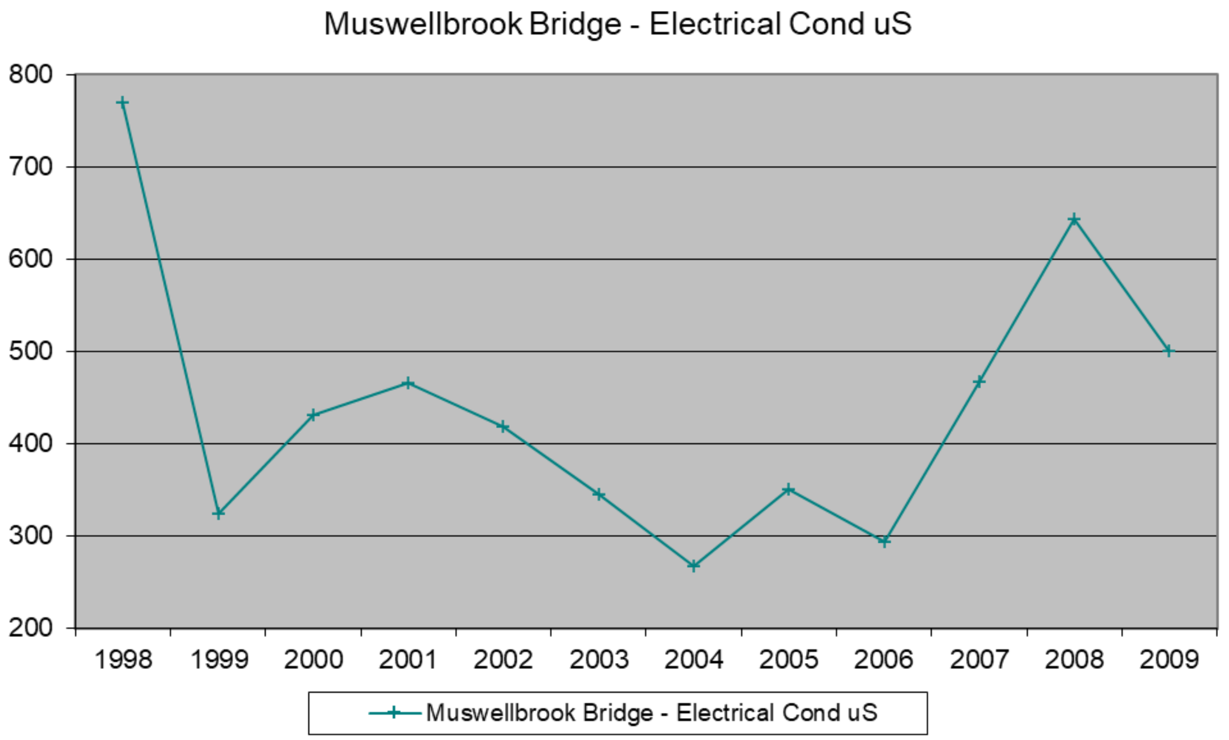
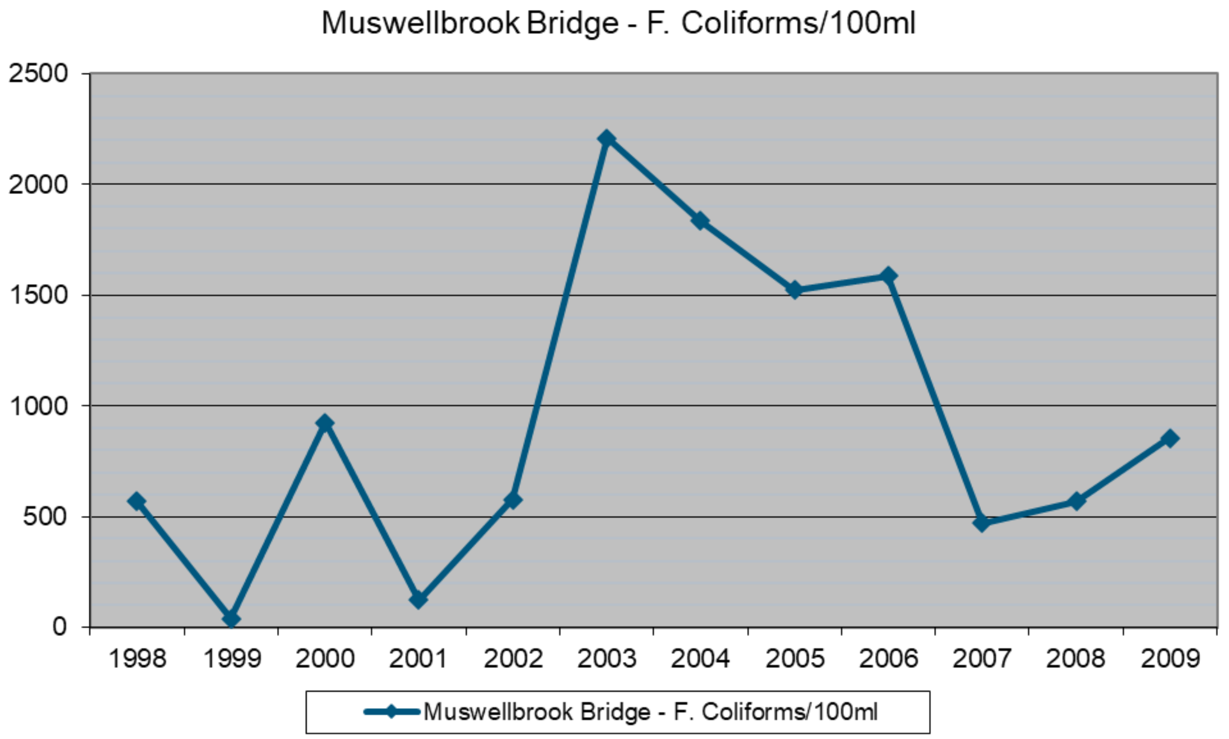
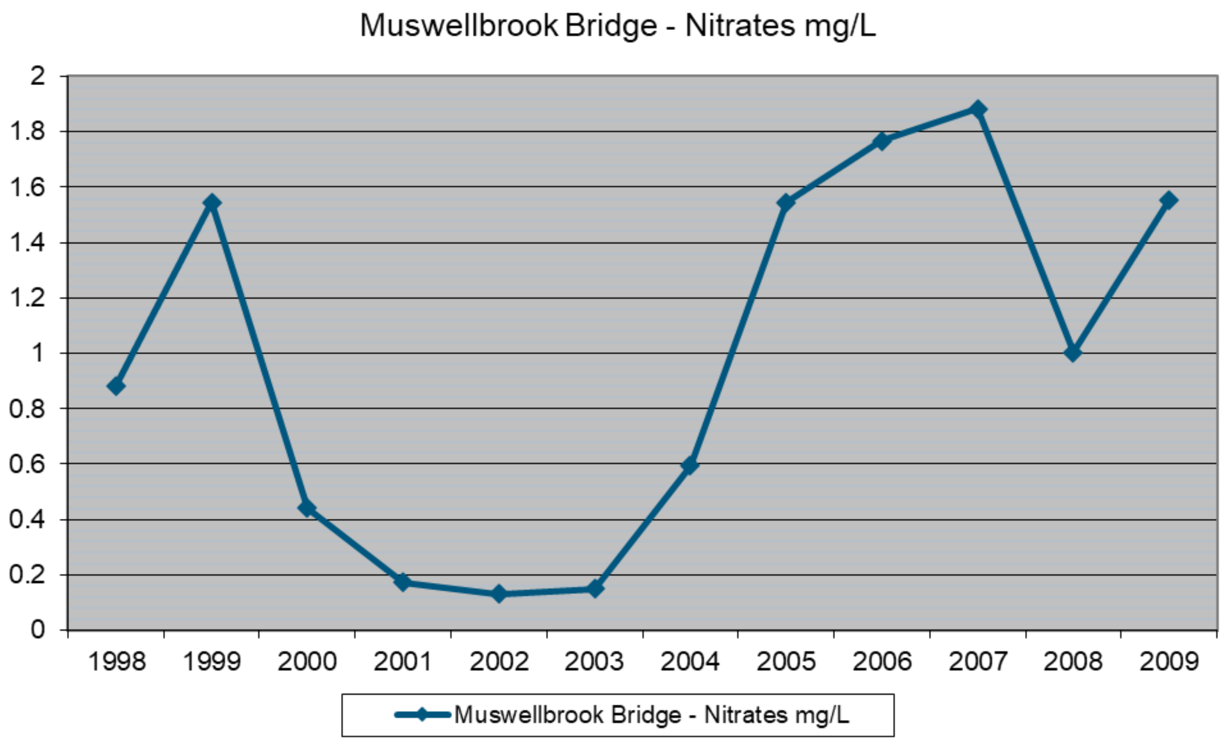


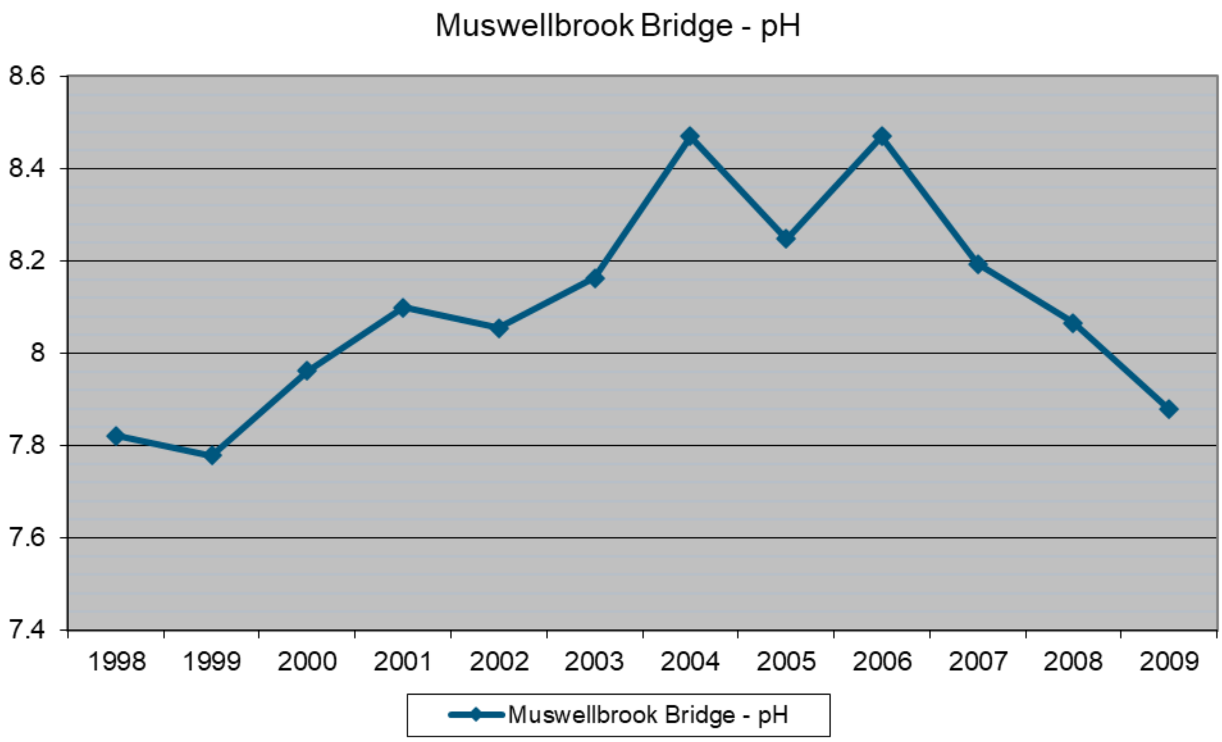
Figure 7-34: Vegetation areas prioritisation map

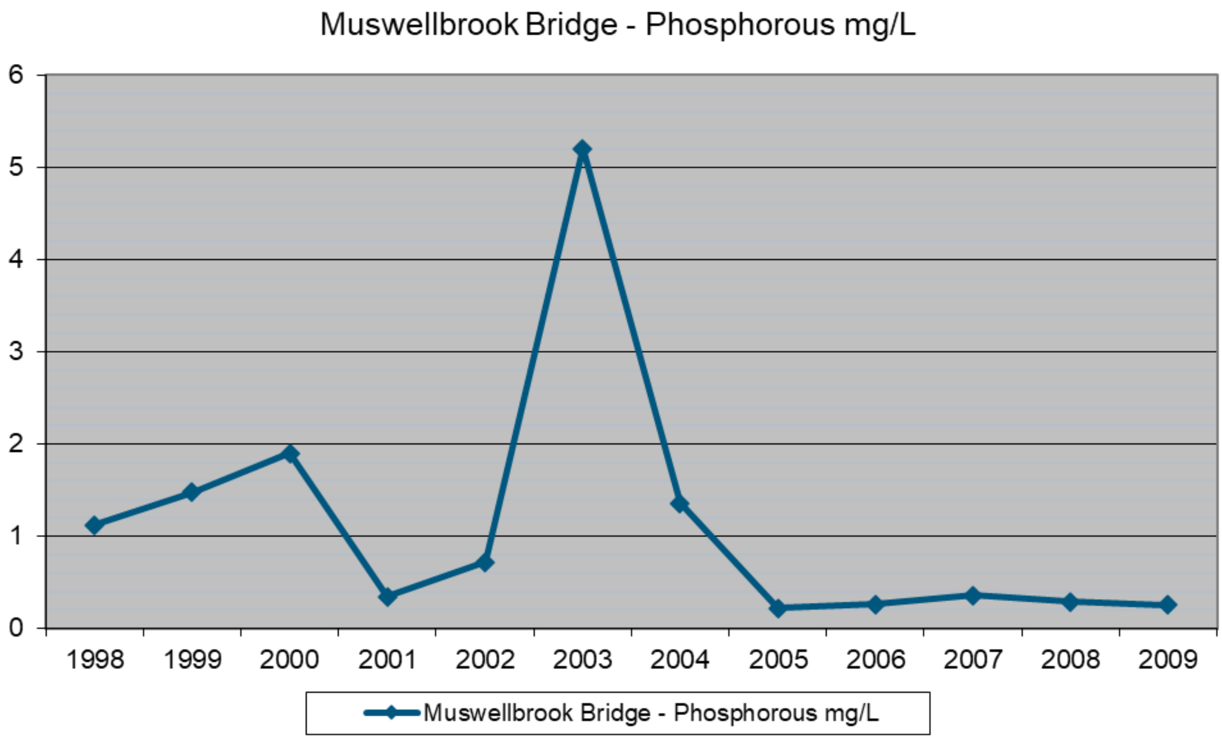
A5 Water Quality Charts

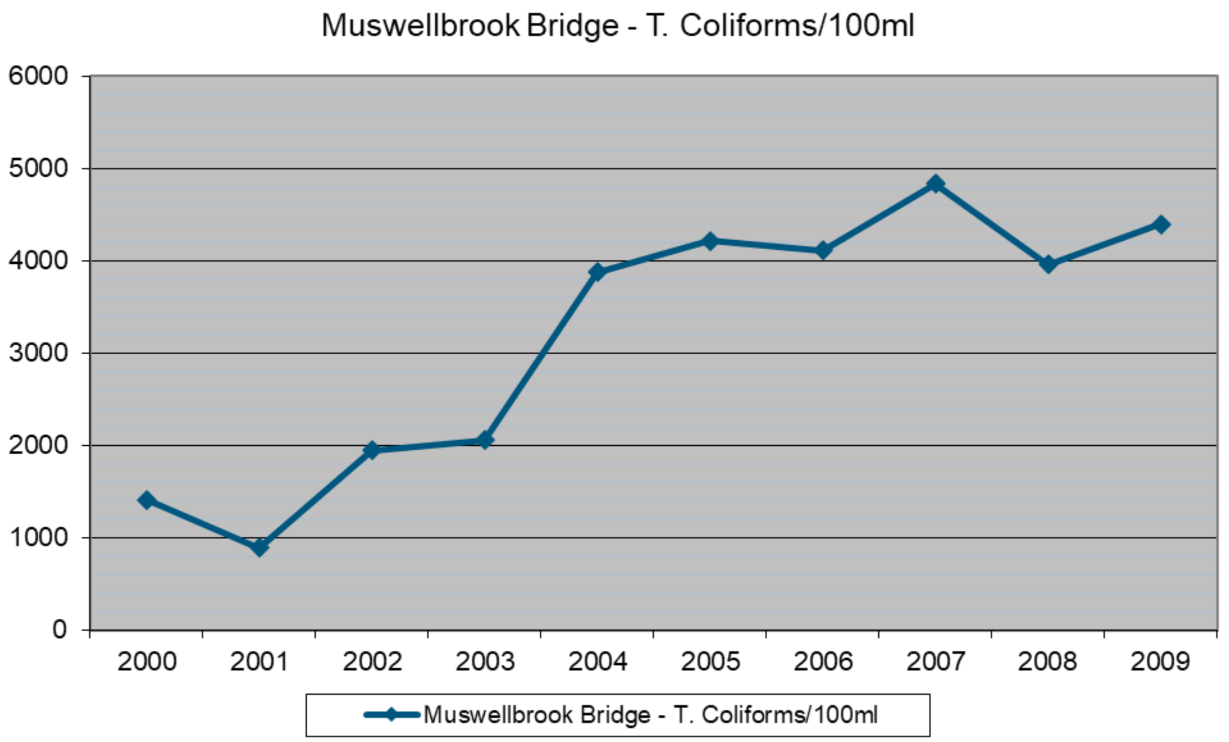


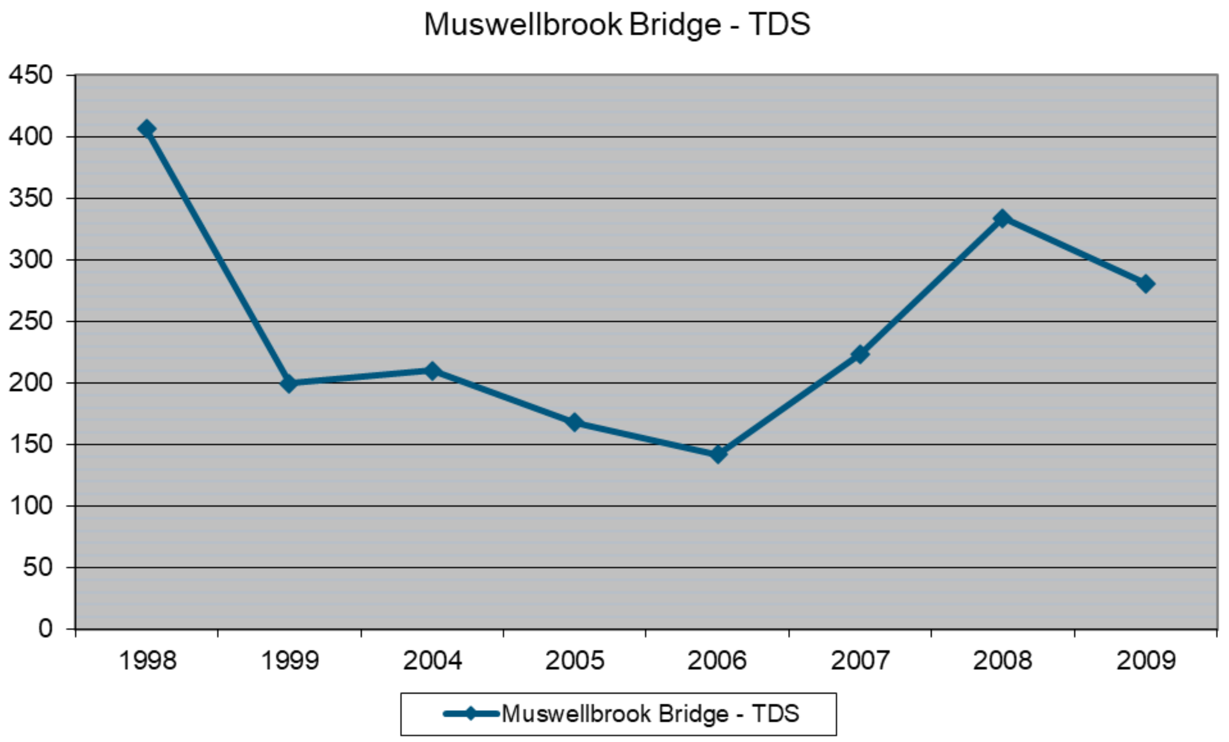


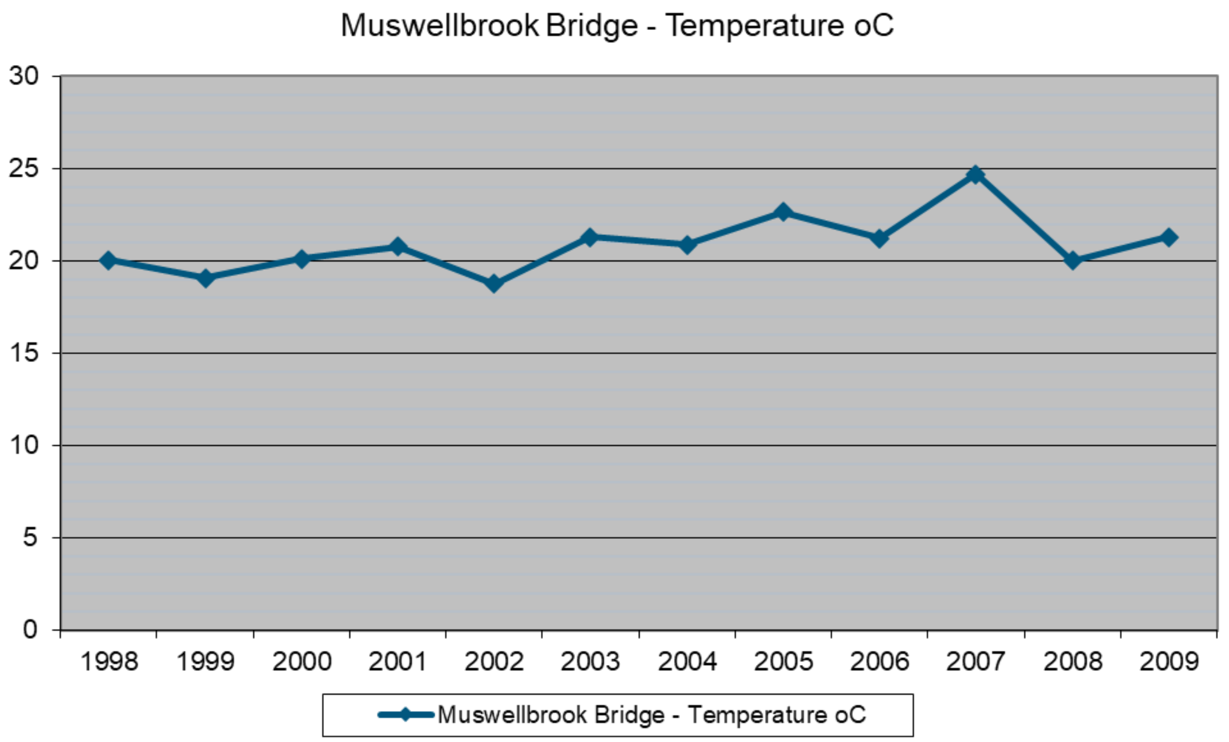

Muswellbrook Bridge - Nitrates mg/L
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Muswellbrook Bridge - Nitrates mg/L

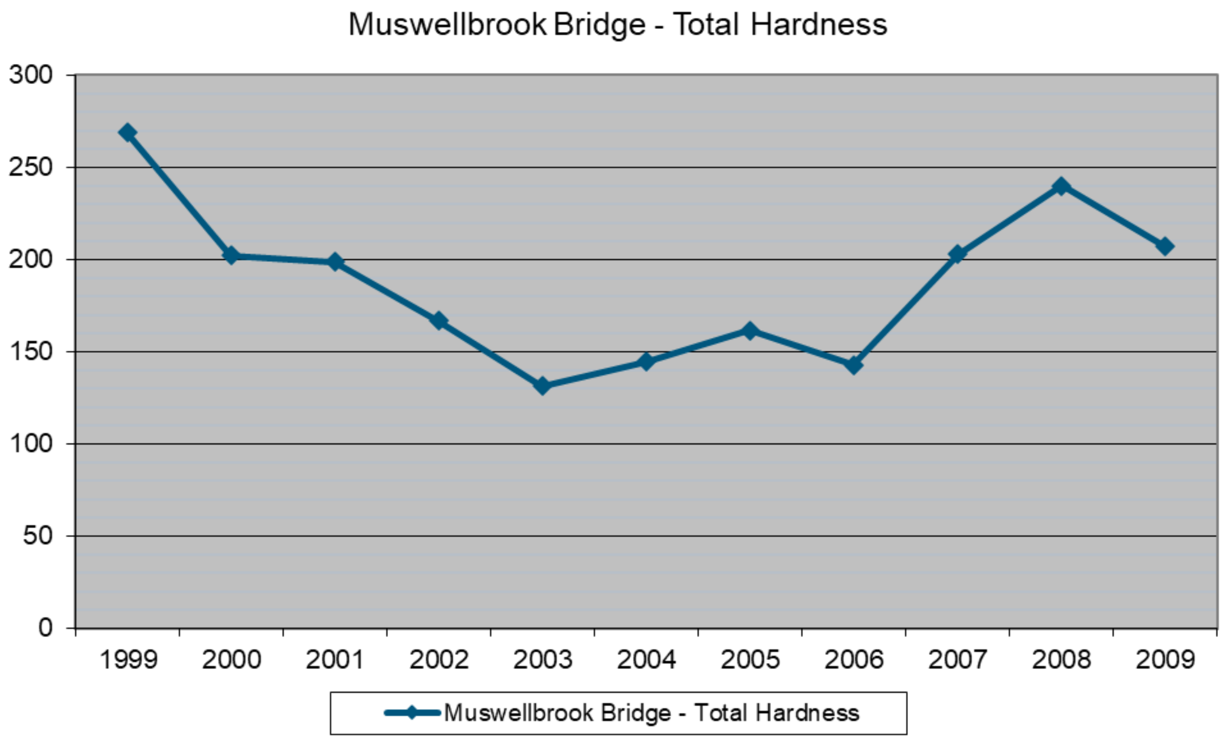

Muswellbrook Bridge - pH
8.6
8.4
8.2
8
7.8
7.6
7.4
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Muswellbrook Bridge - pH

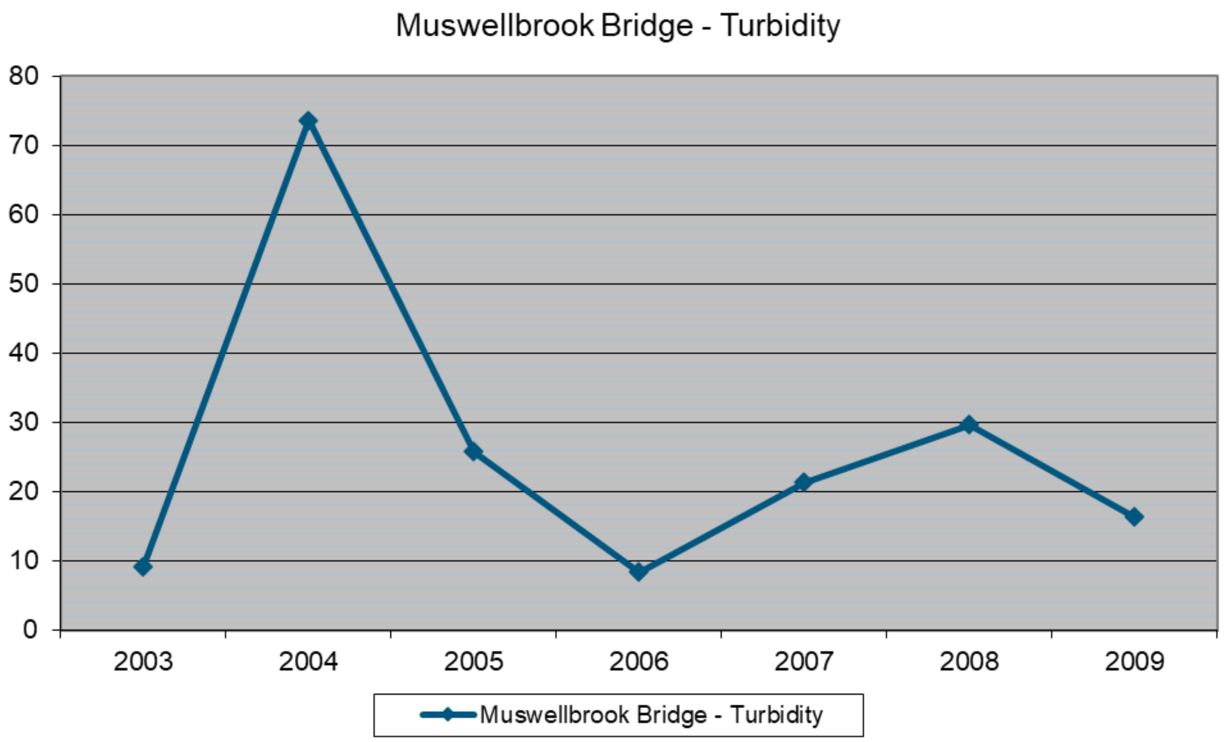

Muswellbrook Bridge - Phosphorous mg/L
6
5
4
3
2
1
0
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Muswellbrook Bridge - Phosphorous mg/L


Muswellbrook Bridge - T. Coliforms/100ml
6000
5000
4000
3000
2000
1000
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Muswellbrook Bridge - T. Coliforms/100ml


Muswellbrook Bridge - TDS
450
400
350
300
250
200
150
100
50
0
1998
1999
2004
2005
2006
2007
2008
2009
Muswellbrook Bridge - TDS


Muswellbrook Bridge - Temperature oC
30
25
20
15
10
5
0
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Muswellbrook Bridge - Temperature oC


Muswellbrook Bridge - Total Hardness
300
250
200
150
100
50
0
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Muswellbrook Bridge - Total Hardness


Muswellbrook Bridge - Turbidity
80
70
60
50
40
30
20
10
0
2003
2004
2005
2006
2007
2008
2009
Muswellbrook Bridge - Turbidity

A6 Creek Bank Stability Methodology Discussion

This Appendix discusses potential methodology and considerations for selected (two) high-risk bank instability locations along Muscle Creek. Other high risk bank instability locations are shown in **Figure 7-35**.

Two locations have been chosen to discuss potential approaches and methodology. The two selected sites for discussion are referred to as: (1) Remington Hotel; and (2) Muswellbrook and District Workers Club site. Both are in the lower reaches of Muscle Creek within the township of Muswellbrook.

It is considered that a combination of short and long-term measures could be required at these sites to address bank instability risks. This two-stage approach is considered likely as: (1) the risk level is current and relatively high; and (2) the long term solution is complex and will likely need specific design, assessment, approvals and time.

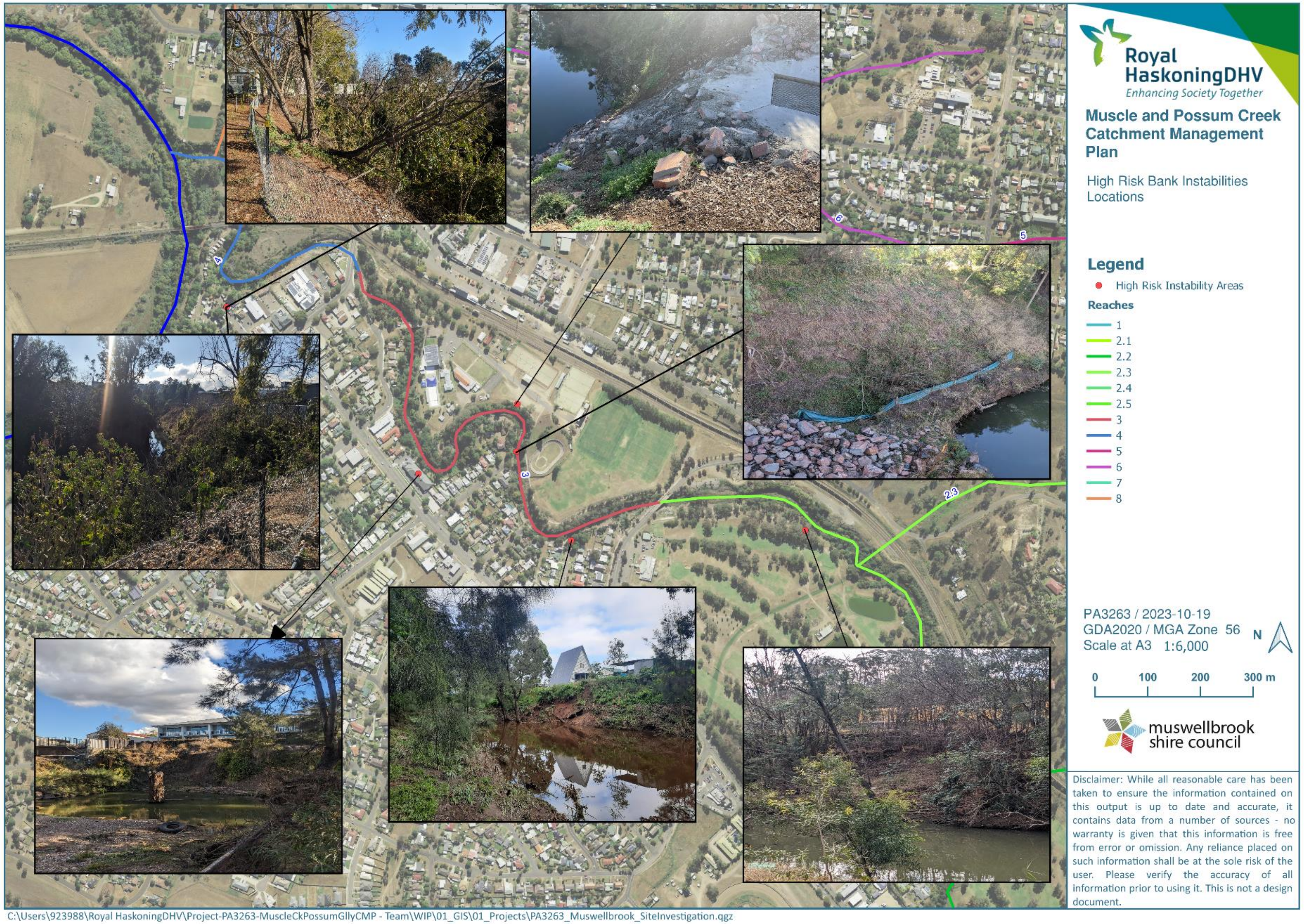


Figure 7-35: High Risk Bank Instability

A6.1 Remington Hotel Site

The creek bank at the site of the Remington Hotel is showing evidence of instability (refer **Figure 7-37**). In addition to the Remington Hotel, adjacent properties such as 6 Wilder Street are also impacted by this instability. The sub-vertical scarp that has formed within the 6m high creek bank, as well as the proximity of adjacent buildings would suggest a moderate to high risk (particularly to adjacent properties).

The site is on the outside of a relatively acute meander bend (refer **Figure 7-41**). The creek bank is understood to comprise highly erodible alluvial soils. The erosion is likely due to both angular momentum of creek flows causing scour, as well as geotechnical failure of the bank, exacerbated during flood draw-down conditions. Both mechanisms can work concurrently and expected to be most prevalent following rainfall and high river levels. Such processes are potentially exacerbated by previous vegetation clearing, as well as incision (deepening) of the channel. While relatively natural processes (typical riverine processes), they are causing risk due to the location of properties at the top of the creek bank.

The existing situation at the site warrants the consideration of erosion protection, noting that relocating the building is unlikely to be feasible. The site is highly constrained from a construction access point of view. The bank impacted by erosion (left hand bank looking downstream) provides no access to the creek due to the proximity of properties, unless craning material over. With a reasonable amount of temporary work, including access tracks, access could be gained from the right hand bank (looking downstream), from the car park. However, this is currently an informal footpath and has significant ecological sensitivities.

Importantly, there is an existing Flying Fox colony at the site, which provides a significant environmental constraint to construction, as any works in the area will require consideration when determining construction methodologies.

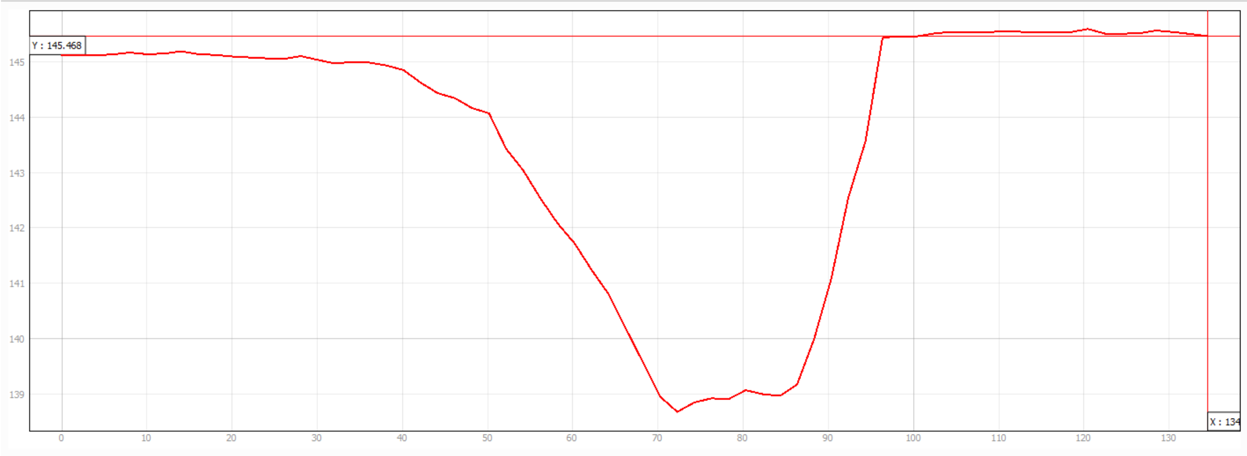


Figure 7-36: Cross-section of Muscle Creek at the rear of the Remington Hotel. LiDAR data captured on November 2017, looking downstream (source: ELVIS).

Figure 7-37: Creek bank erosion at Motor Inn site, looking downstream from right hand bank.

Figure 7-38: Aerial photo showing location of Remington Hotel (source: NSW Six Map). Photo orientated north.

Short Term Solutions

Given the current state of bank instability at the site, short term (emergency-type) solutions could be considered. Short-term (temporary) solutions could involve emergency measures such as placement of material. It would be expected that short term measures would focus on the toe of the bank (at least half way up the bank, 2-3m), with lighter approaches up the bank, to cover the bare soil.

Such short term solutions could include rock bags, however other short term options should also be considered, including sand filled geobags and loose rock rip-rap placement.

Rock bags can be used to provide creek and riverbank protection and are a relatively new and ever-increasingly used approach to short and medium term coastal and riverbank protection, particularly where access constraints exist. The example provided in **Figure 7-39** shows rock bags being used to provide short term / emergency works riverbank stabilisation at Morpeth, on the Hunter River. A primary advantage in the use of rock backs (in temporary applications) is that bags can be craned in from a distance, for example over properties (refer **Figure 7-40**). The bags themselves can be made of 100% recycled polyester (PET) material, which is a similar material to geotextile fabric. Rock bags have also been used extensively by RHDHV for emergency protection works in the coastal zone. It should be noted that rock bags are not considered an appropriate long term solution, without a specific design.

Pros:

- Rock bags will provide stability and protection against further erosion.
- Relatively quick installation.
- Rock bags can be stacked, albeit it on an appropriate angle.
- Rock bags can be craned over from distance away.
- There is no need for equipment in channel which assists the limited access at both sites.
- Environmentally friendly as natural vegetation can grow within the rock bags.
- Relatively durable, but subject to damage due to flood debris, so long term solution still needed.
- Cost-effective.

Cons:

- While rock bags are suitable for erosion control, if placed in a relatively uncontrolled fashion, i.e., as part of emergency works without adequate foundations etc., then they may have limited load bearing capacity.
- Rock bags within a creek / river environment are susceptible to debris damage and / or snagging from woody debris (and other).
- Maintenance requirements.

Figure 7-39: Rock bags used to provide short term riverbank stabilisation at Morpeth on the Hunter River.

Figure 7-40: Rock bags being craned over properties during placement, Wamberal, NSW.

Long Term Solutions

Relocating the building out of the zone of erosion is unlikely to be feasible and bank stabilisation works will be the most likely solution. Therefore, long-term solutions at the Remington Hotel could include keeping the buildings and placing a hard structure (i.e., rock revetment) in front of the buildings.

Given the physical space available within the relatively wide channel, should accessibility constraints be overcome, then there appears to be space to construct erosion protection within the front of the current slip, i.e., building out into the creek channel. Therefore, construction of a rock revetment with associated fill, geotextile, foundation and filter layers, along with any required benching should be achievable. RHRHV are of the opinion that bed control structures should also be considered, given evidence of significant bed lowering in this reach.

The long term solution may make use of any material previously placed as part of a temporary solution (see above).

Pros:

- Effective protection of assets (roads, buildings) in the zone of erosion.
- Does not require the use of piling equipment (such as that required for sheet piles or other vertical structural options).
- Potential to bench and / or integrate softer solutions.

Cons:

- Limited access to bring plant into the creek to install hard structure or rock protection.
- High cost.
- Once constructed, rock revetments are difficult to modify, which can be a disadvantage when site conditions change.
- While they require less maintenance than some other structures, over time, rocks may shift, dislodge, or need repositioning or repair.

Regardless of the solution, the available space should allow for alterations to the creek bank batter slope (toward the creek), therefore the consideration of softer solutions and / or softer elements within a hard solution. The use of vegetation should be maximised. Large trees at the top of the slope should however be avoided. Such approaches are more conducive to creek restoration than hard structures alone.

Given the space available within the current creek cross section, building out into the creek in front of the bank should be feasible. However, to assist with maintaining an adequate creek cross section, channel shaping and battering of the slope on the right hand (opposite) bank could be considered. However, whilst this may provide some relief regarding hydraulic pressures, it would not address the primary mechanisms of the current issue, as the mechanism is not likely contraction scour (increase in creek flow velocity locally due to a narrowing of the creek channel), but rather, as outlined above, the result of angular scour at the bend, and draw-down induced geotechnical instability (working together).

Further, any works directly to the creek bank and cross section could include bed control structures and / or features to reduce velocities. These would need to be investigated as part of a design.

To inform the design of the long term works, typical further assessments would include geotechnical and hydraulic analysis.

A6.2 Muswellbrook and District Workers Club Site

Between the road crossing and rail crossing on Muscle Creek, the creek is heavily incised into the floodplain. Such incision is in part driven by the historical incision of the Hunter River (see section on Geomorphology). The creek channel in this location has formed steep (1v:1h) 10m high creek banks (refer **Figure 7-42**). In the base of the creek there is (from visual inspection only) a 1-2m low flow channel / further incision, indicating further head-cutting is active.

The site is on a relatively straight run of creek, then an outside of a relatively acute meander bend. The creek bank is understood to comprise erodible alluvial soils, although at the base of the creek banks this appears to be more consolidated, forming vertical scarps. The potential instability arises from the abovementioned incision of the creek channel, plus the potential for geotechnical failure of the bank given the high and steep banks. Both mechanisms can work concurrently and expected to be most prevalent following high river levels and subsequent draw down of river levels. Such processes are potentially exacerbated by previous vegetation clearing, as well as incision (deepening) of the channel in response to the Hunter River's historical incision.

There are properties located at the top of bank on the left hand bank (looking downstream) (refer **Figure 7-41**), including at the caravan park and Workers Club. Due to the steep banks, there is a significant risk to properties that are located (in the main) immediately at the top of bank.

The existing situation at the site warrants assessment by a geotechnical engineer and consideration of creek bank stabilisation / erosion protection, assuming that it is not feasible to relocate properties. Any caravans that are relocatable, should be removed (set back) immediately from the slip zone as a matter of priority.

The site is highly constrained from a construction access point of view. The bank impacted by erosion (left hand bank looking downstream) provides no access to the creek due to the proximity of properties and height of the creek bank, unless craning material over.

The physical form of the creek, i.e. steep and deep creek channel, particularly the bank height, presents a significant risk to stability and constraint to management options. Access, regardless of property location, is a significant constraint. Also, working on and from such high and steep banks would form health and safety considerations, as well as potentially increasing instability risk during construction (loading).

A geotechnical assessment (initially visual most likely) is recommended.

Figure 7-41: Aerial showing rear of Muswellbrook and District Workers Club (source: NSW Six Map)

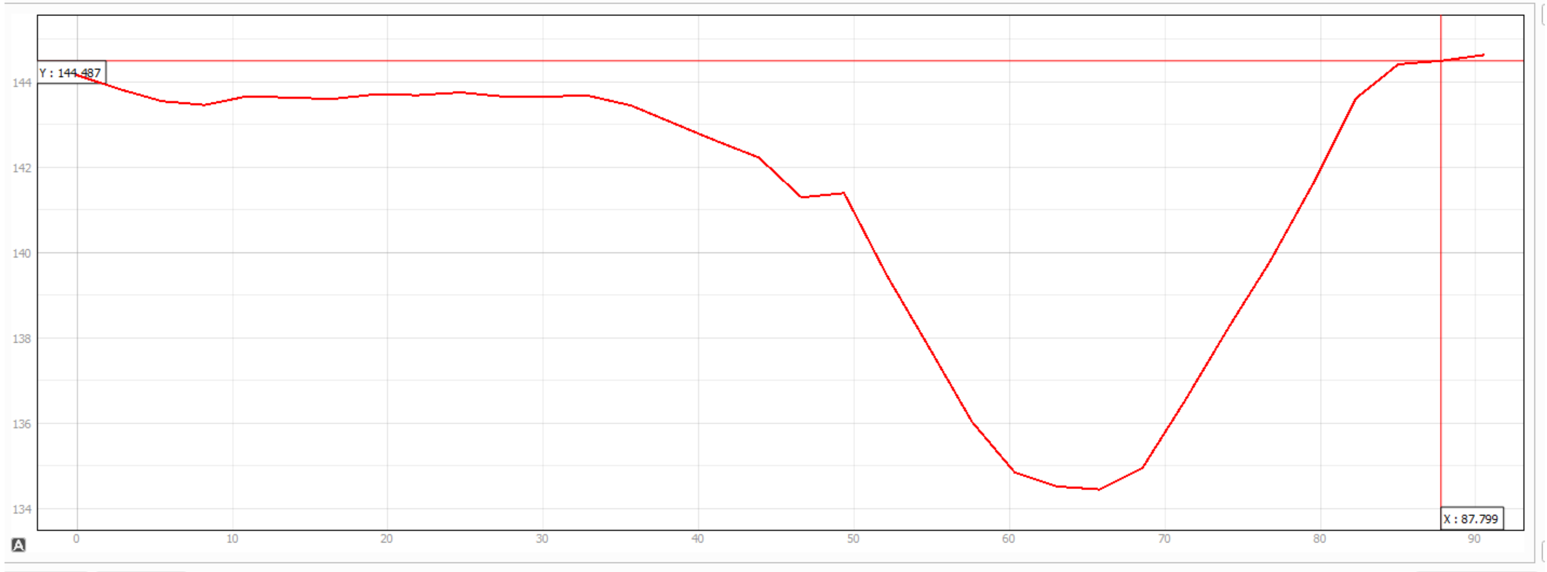


Figure 7-42: Cross-section of Muscle Creek at the rear of the Muswellbrook and District Workers Club. LiDAR data captured on November 2017, looking downstream (source: ELVIS).

Figure 7-43: Creek bank looking upstream, fronting the Workers Club shown by white arrow. Creek flow direction is toward the foreground.

Figure 7-44: Caravans located immediately at the top of steep, high unstable creek bank.

Short Term Solutions

As there are properties at the top of bank, it is considered a short term priority solution to move caravans from the top of the bank. Similar to the Motor Inn site, a short term measure could include the use of rock bags, which can be craned in. The short term solution here may also include bed control structures to arrest further incision and allow the re-grading of the creek long section in this reach.

The short term solution would likely only be able to focus on the creek bank toe. The effectiveness of this would need to be assessed by a Geotechnical Engineer.

Long Term Solutions

Long-term solutions at Muswellbrook and District Workers Club and other adjacent properties could include setting back the caravans from the top of bank.

Placing hard structures or rock protection would be difficult to construct at this location due to the steep banks and access issues. If there were sufficient space to relocate the car park to allow a slackened batter, then this would likely be the most cost-effective solution. No feasible location exists to relocate the car park to.

Given the space available within the current creek cross section, building out into the creek in front of the bank would need to be tightly controlled. To assist with maintaining an adequate creek cross section, channel shaping and battering of the slope on the right hand (opposite) bank could be considered. This land, whilst owned by someone, does not comprise physical assets, and is likely flood affected. This may allow construction to take place.

For the bed and bank protection measures, these would need to be continuous from near the confluence with the Hunter River to upstream of the Workers Club. Further, any works directly to the creek bank and cross section could include bed control structures to control the incision and / or features to reduce localised velocities. These would need to be investigated as part of any bank / creek restoration design, however should consider the whole reach. Bed control structures could be implemented to raise the bed in this reach by say 1-2m.

To inform the design of the long term works, typical further assessments would include geotechnical and hydraulic analysis as a minimum. It would also be recommended that a civil works construction contractor is engaged to provide constructability advice to inform the design.

Given the access constraints, there would likely be significant temporary works needed to form access paths and / or pads for craning in materials. Once established, it is likely that a solution comprising rock would be best suited to this environment. This could include the use (re-use) of any material placed as part of the temporary solution. Piling or other structural options would be costly and difficult to construct in this environment, however may be required.

A7 Map of proposed management Plan Solutions/Actions

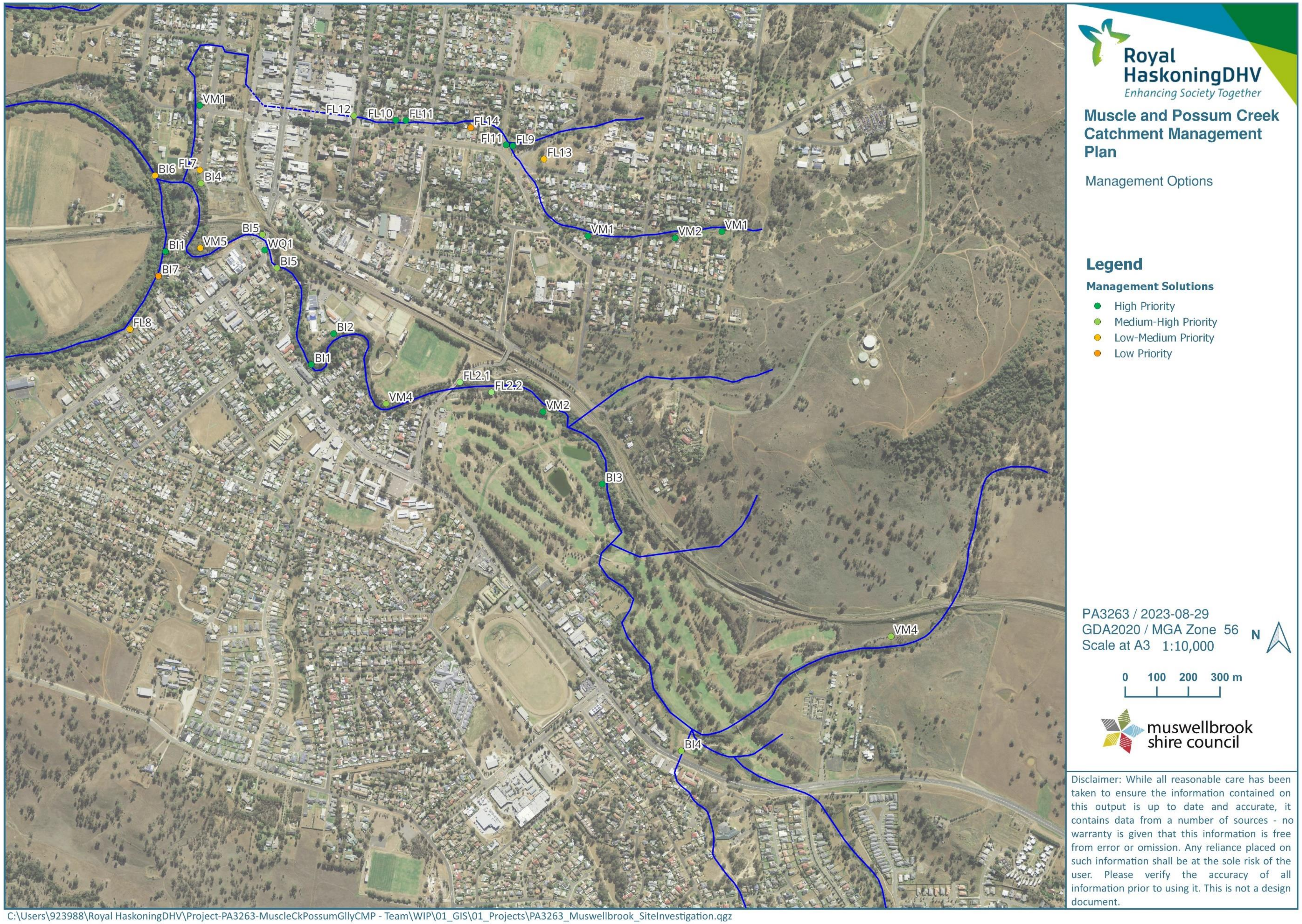


Figure 7-45: Catchment management option