# Geomorphology Assessment
## Calderwood Urban Development Project

Reference: 110026-03/Report 004 Rev 2
Prepared for Delfin Lend Lease
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Prepared by
for and on behalf of
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# Executive Summary

This Geomorphology Assessment has been prepared by Cardno to accompany a Concept Plan Application under Part 3A of the *Environmental Planning & Assessment Act, 1979* (EP&A Act) and a proposal for State Significant Site listing under Schedule 3 of *State Environmental Planning Policy Major Development 2005* (SEPP Major Development) in relation to the Calderwood Urban Development Project (CUDP).

The CUDP is a master planned community development by Delfin Lend Lease. The CUDP proposes a mix of residential, employment, retail, education, conservation and open space uses. The development proposes 4,800 dwellings and 50 hectares of retail, education, community and mixed use / employment land. The overall development will accommodate about 12,400 people and will deliver $3 billion in development expenditure and create 7,600 full time equivalent jobs by 2026.

The Part 3A process under the EP&A Act allows the CUDP to be planned, assessed and delivered in a holistic manner, with a uniform set of planning provisions and determination by a single consent authority. This Geomorphology Assessment has been prepared to fulfil the Environmental Assessment Requirements issued by the Director General for the Project.

The Geomorphology Assessment provides a description of the existing geomorphological features of the subject site and surrounds especially in relation to Marshall Mount Creek and Macquarie Rivulet. The likely impacts of the proposed Calderwood Urban Development on geomorphology of the existing watercourses and floodplains are then determined through an investigation of the effect of other urban development within the catchment.

An assessment was also undertaken to determine the condition and relative hydrological value of the smaller creeklines in the site. This included both a site inspection and detailed analysis of ALS data to ground truth existing stream data for the site (from the RCMS and LPMA) to provide an accurate assessment of the hydrology and stream structure within the site. This process resulted in a number of changes in the classifications of the streams on the site (with some streams being removed and others being upgraded or downgraded) based on both their hydrologic and ecological value. These classifications were then used to inform the allocation of riparian corridors widths and their inclusion into the Masterplan

To be able to quantify the impact of the development of Albion Park on Macquarie Rivulet, comparisons have been made between aerial photographs from before Albion Park was fully developed (LPMA, 1949) and aerial photography from well after Albion Park was developed (Hatch, 2001). Statements made about the geomorphological condition of Macquarie Rivulet, and impact of any development is also supported by published literature, where available and appropriate.

The case study presented in demonstrates that impacts of past urban development in the catchment have not led to significant changes in the geomorphology of Macquarie Rivulet.

If a development the size of Albion Park can be shown to have negligible effect on geomorphology, without the implementation of mitigation measures, a development of a similar size with mitigation measures would also be expected to have negligible impact. With the use of appropriately engineered stormwater control measures the development is not expected to have an adverse impact on the morphology of Macquarie Rivulet or Marshall Mount Creek.

# Table of Contents



## List of Tables

## List of Figures

# 1 Introduction

## 1.1 Background

This Geomorphology Assessment has been prepared by Cardno to accompany a Concept Plan Application under Part 3A of the *Environmental Planning & Assessment Act, 1979* (EP&A Act) and a proposal for State significant site listing under Schedule 3 of *State Environmental Planning Policy Major Development 2005* (SEPP Major Development) in relation to the CUDP.

The CUDP is a master planned community development by Delfin Lend Lease. The CUDP proposes a mix of residential, employment, retail, education, conservation and open space uses. The development proposes 4,800 dwellings and 50 hectares of retail, education, community and mixed use / employment land. The overall development will accommodate about 12,400 people and will deliver $3 billion in development expenditure and create 7,600 full time equivalent jobs by 2026.

The CUDP site is located within the Calderwood Valley in the Illawarra Region. It is approximately 700 hectares in area with approximately 600 hectares of land in the Shellharbour LGA and the balance located within the Wollongong LGA.

The Calderwood Valley is bounded to the north by Marshall Mount Creek (which forms the boundary between the Shellharbour and Wollongong LGAs), to the east by the Macquarie Rivulet, to the south by Johnson's Spur and to the west by the Illawarra Escarpment. Beyond Johnson's Spur to the south is the adjoining Macquarie Rivulet Valley within the suburb of North Macquarie. The CUDP land extends south from the Calderwood Valley to the Illawarra Highway (refer **Figure 1**).

The Calderwood Valley has long been recognised as a location for future urban development, firstly in the Illawarra Urban and Metropolitan Development Programmes and more recently in the Illawarra Regional Strategy (IRS).

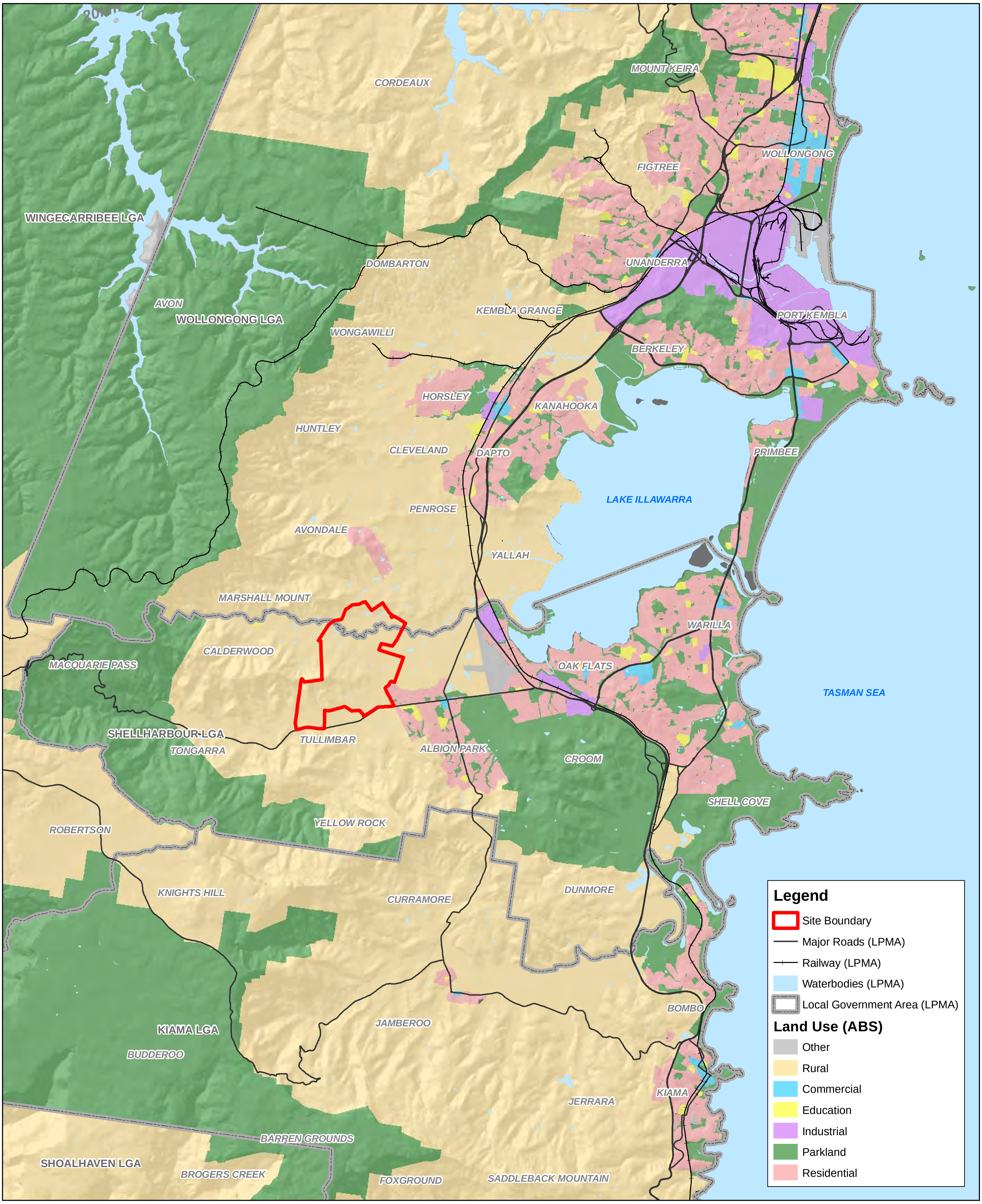
The IRS nominates Calderwood as an alternate release area if demand for additional housing supply arises because of growth beyond projections of the Strategy, or if regional lot supply is lower than expected.

In 2008, the former Growth Centres Commission reviewed the proposed West Dapto Release Area (WDRA) draft planning documents. The GCC concluded that forecast housing land supply in the IRS cannot be delivered as expected due to implementation difficulties with the WDRA, and the significantly lower than anticipated supply of housing land to market in the Illawarra Region is now been recognised as a reality.

The GCC Review of the WDRA also recognised that there is merit in the early release of Calderwood in terms of creating a higher dwelling production rate and meeting State government policy to release as much land to the market as quickly as possible. Given the demonstrated shortfall in land supply in the Illawarra Region and the WDRA implementation difficulties highlighted in the GCC Report, the release of Calderwood for urban development now conforms to its strategic role under the IRS as a source of supply triggered by on-going delays in regional lot supply. The CUDP can deliver about 12% of the IRS' new dwelling target.

Changes in outlook arising from global, national and regional factors influencing investment and delivery certainty, housing supply and affordability and employment and economic development also add to the case for immediate commencement of the Calderwood Project.

In April 2008 the Minister for Planning issued terms of reference for the preparation of a Justification Report to address the implications of initiating the rezoning of Calderwood for urban development including associated staging, timing and infrastructure considerations.




Delfin Lend Lease

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Scale 1:100,000 (at A3)

Metres

0 1000 2000 3000 4000 5000

# Location Plan

FIGURE 1

CALDERWOOD URBAN DEVELOPMENT PROJECT

Cardno

Map Produced by Cardno Wollongong
Date: 15 February 2010
Coordinate System: Zone 56 MGA/GDA 94
GIS MAP REF: 110026-01_18022_LocationPlan.mxd 06

In February 2009 the Minister for Planning considered a Preliminary Assessment Report for the CUDP that provided justification for the planning, assessment and delivery of the project to occur under Part 3A of the *EP&A Act*, having regard to the demonstrated contribution that the project will have to achieving State and regional planning objectives.

Subsequently, on the 16 April 2009, pursuant to Clause 6 of SEPP Major Development, the Minister for Planning formed the opinion that the CUDP constitutes a Major Project to be assessed and determined under Part 3A of the EP&A Act, and also authorised the submission of a Concept Plan for the site. In doing so, the Minister also formed the opinion that a State significant site (SSS) study be undertaken to determine whether to list the site as a State Significant site in Schedule 3 of SEPP Major Development.

The Part 3A process under the EP&A Act allows for the CUDP to be planned, assessed and delivered in a holistic manner, with a uniform set of planning provisions and determination by a single consent authority. Given the scale of the proposal, the Concept Plan and SSS listing provide the opportunity to identify and resolve key issues such as land use and urban form, development staging, infrastructure delivery and environmental management in an integrated and timely manner.

## 1.2 Director Generals Requirements

This Geomorphology Assessment has been prepared to fulfil the Environmental Assessment Requirements issued by the Director General for the inclusion of the Calderwood site as a State Significant Site under SEPP Major Development, and for a Concept Plan approval for the development. Specifically, this Geomorphology Assessment addresses the Director General Requirements relating to the assessment of potential Geomorphological Impacts of the proposal, viz;

***Assess geomorphic impacts on the watercourses and floodplain area affected by the proposal.***

This Report has been prepared in conjunction with the Floodplain Risk Management Study and Water Cycle Management Study. **Table 1.1** shows the relationship between theses reports and demonstrates compliance with tall of the flooding and stormwater management DGRs.

**Table 1.1 – Director General Requirements**

| Director General Requirement | Section of this Report where Compliance is Confirmed |
|---|---|
| Assessment of any flood risk for the site should be conducted in accordance with the NSW Government's Flood Prone Land Policy as set out in the Floodplain Development Manual 2005 | Rienco Consulting has been commissioned to prepare a flood risk assessment. This is provided in a separate report. |
| Flood Study Report for existing conditions is to be prepared to include hydrologic and hydraulic models, calibration against existing local flood records, downstream and upstream conditions, and floodplain characteristics. | Refer to Macquarie Rivulet Flood Study (Rienco, 2009). This study wholly meets the objectives of the DGRs and the principles of the Floodplain Development Manual. |
| Flood Risk Management Assessment Report for the development including estimation of Flood Planning Levels and Flood Planning Area, extent of flood prone and mapping, flood behaviour, flood risks up to the PMF, evacuation, and impacts of climate change. | Such an assessment has been undertaken and provided in the Floodplain Risk Management Study (Cardno, 2010) and is issued under separate cover. |
| Consider Shellharbour Council's Floodplain Risk Management DCP and justify any departure. | An assessment of Shellharbour Council's Floodplain Risk Management DCP provided in the Floodplain Risk Management Study (Cardno, 2010) and is issued under separate cover. . |

| Director General Requirement | Section of this Report where Compliance is Confirmed |
|---|---|
| Consideration of upstream and downstream flows and impacts of development yet to be built. | As all development is required to have no impacts on peak flows upstream or downstream, it has been assumed that any future development would have no impacts on the Calderwood project. This is further described in detail in the Macquarie Rivulet Flood Study (Rienco, 2009) under separate cover. |
| Assess geomorphic impacts on the watercourses and floodplain area affected by the proposal. | This Assessment is contained within this report. |
| Details on any water management structures/dams both existing and proposed including size and storage capacity. | Such an assessment has been undertaken and provided in the Water Cycle Management Study (Cardno, 2010) and is issued under separate cover. |
| The EA should address drainage and stormwater management issues, including on site detention of stormwater; water sensitive urban design (WSUD) and drainage infrastructure. | Such an assessment has been undertaken and provided in the Water Cycle Management Study (Cardno, 2010) and is issued under separate cover. |

## 1.3 Concurrent Studies

The Geomorphology Assessment should be read in conjunction with all other reports prepared to support the concept application for the development, specifically including:

- Flood Study (Rienco)
- Floodplain Risk Management Study (Cardno)
- Water Cycle Management Study (Cardno)
- State Significant Site Listing and Concept Plan Application (JBA Urban Planning)
- Project Application Stage 1 (Cardno)
- Riparian Consistency Report (Eco Logical Australia)
- Flora and Fauna Assessment (Eco Logical Australia)
- Bushfire Assessment (Eco Logical Australia)
- European Heritage Study (Eco Logical Australia/ Paul Davies)
- Aboriginal Heritage Study (Eco Logical Australia/Austral Archaeology)
- Land Capability, Contamination and Geotechnical Studies (Douglas Partners)
- Landscape and Visual Study (Environmental Partnership NSW)
- Community Facilities and Open Space Study (Elton Consulting)

## 1.4 Purpose of this Report

The purpose of this Geomorphology Assessment is to

- Provide a description of the existing geomorphological features of the subject site and surrounds especially in relation to Marshall Mount Creek and Macquarie Rivulet.
- Provide a description and mapping of wall watercourses in the subject site and the proposed riparian corridors.
- Determine the likely impacts of the proposed Calderwood Urban Development on geomorphology of the existing watercourses and floodplains.

## 1.5 Structure of this Report

This report has been structured as follows:

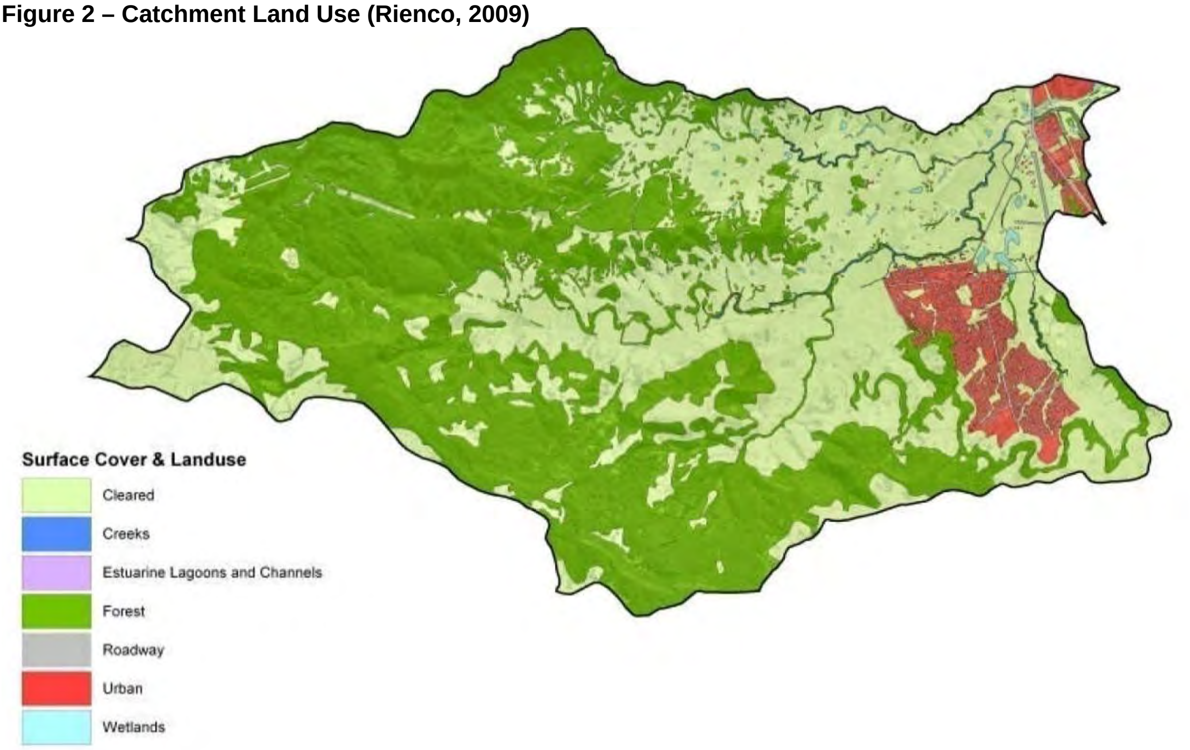
- **Chapter 1** describes the purpose of this study identifies the DGR's that relate to this study and identifies the relationships with other studies.
- **Chapter 2** describes the existing environment including a detailed assessment of the structure and condition of the two major watercourses and associated floodplain in and around the subject site.
- **Chapter 3** provides details of the existing watercourses and riparian corridors based on ground truthed ALS data and Strahler Stream Classification.
- **Chapter 4** outlines the proposed development and provides details on how and where it will interact with existing geomorphological features and the potential impacts.
- **Chapter 5** provides a case study examining how the development of the suburb of Albion Park may have affected geomorphological processes in the Macquarie Rivulet Catchment. This can be used to determine the possible impacts of the Calderwood Urban Development on the same catchment.
- **Chapter 6** provides recommendations and conclusions.

# 2 Existing Environment

The Calderwood Urban Development Area (subject site) drains into of the two main watercourses in the area, the Macquarie Rivulet and Marshall Mount Creek. Although they act as separate sub-catchments in the vicinity of the subject site (with Marshall Mount Creek to the north and Macquarie Rivulet to the south), the two creeks combine downstream and continue to Lake Illawarra as Macquarie Rivulet. For the purpose of this report, Macquarie Rivulet and Marshall Mount Creek catchments will be treated as separate catchments.

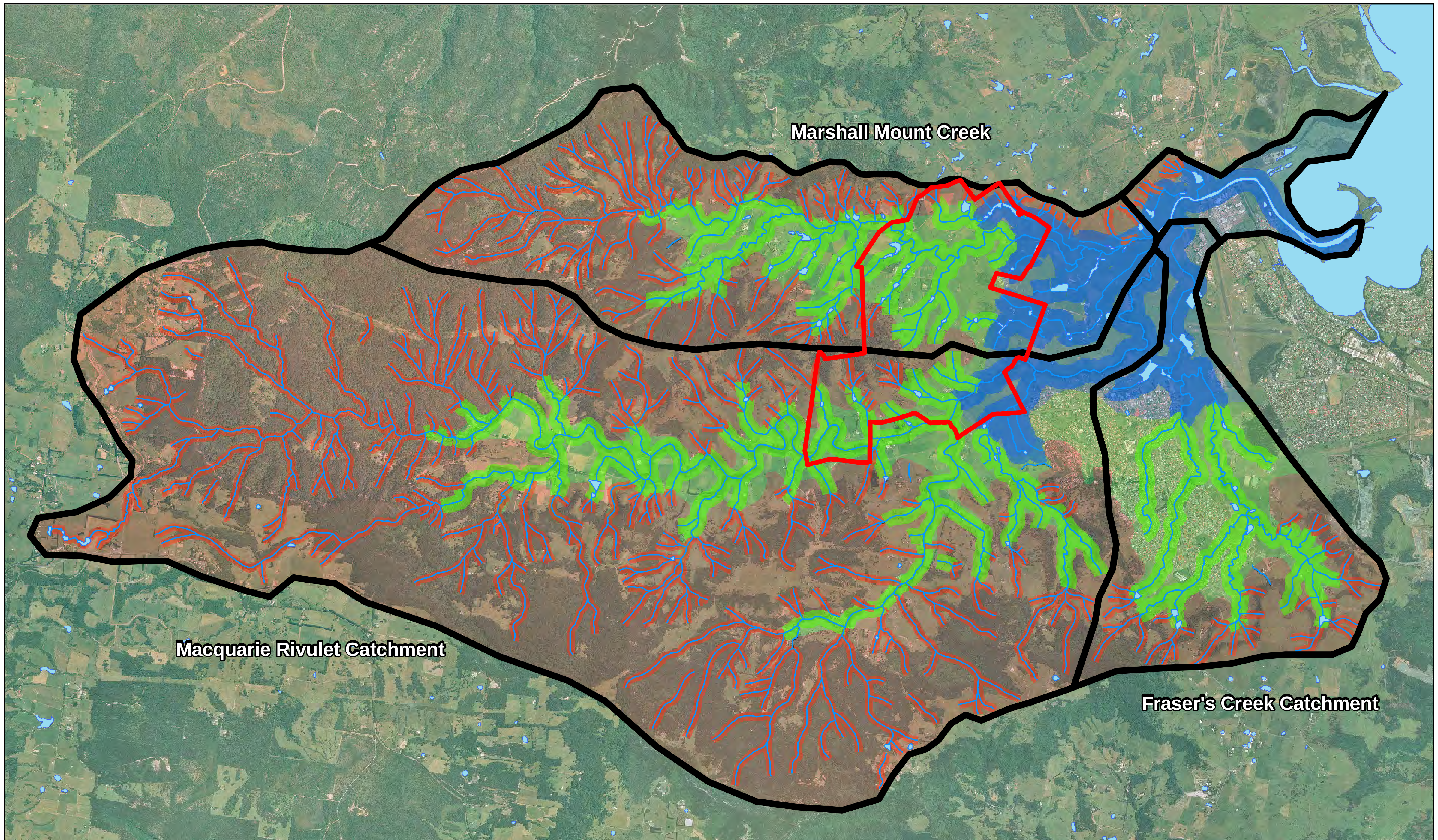
Since European settlement the coastal plain around the subject site has been subject to extensive clearing, for forestry and farming, and is now being subject to increasing levels of urban development with West Dapto and Calderwood areas being identified as future urban centres. These changing land uses have led to geomorphic changes within the creeks in the area, most of which are now in a highly modified state. **Figure 2** (Rienco, 2009) shows the different hydrologic land uses within the Macquarie Rivulet and Marshall Mount Creek catchments.

**Figure 2 – Catchment Land Use (Rienco, 2009)**



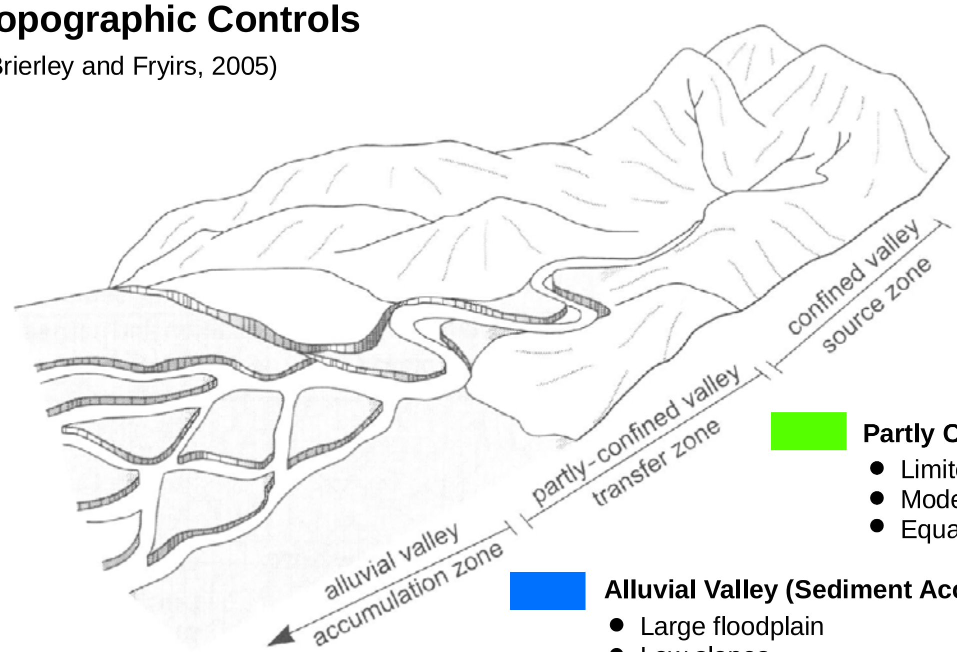

Like most catchments in the Illawarra, the Macquarie Rivulet and Marshall Mount Creek catchments are characterised by their steep upper slopes, originating on the Illawarra Escarpment followed by a transition to a confined valley form. On the coastal floodplain the channels then straighten and take a wide meandering form. In the lower Illawarra creeks often cross a considerable distance of rural land before reaching the coastal urban development and then entering estuarine water bodies before discharging into the sea. The structure of Macquarie Rivulet and Marshall Mount Creek in relation to their topography is shown in **Figure 2**.

More details on the entire Macquarie Rivulet Catchment (including Marshall Mount Creek) can be found in the Floodplain Risk Management Studies supporting both the concept and project applications for the CUDP (Cardno 2009a, Cardno 2009b).




## Topographic Controls

(Brierley and Fryirs, 2005)




**Confined Valley (Sediment Source Zone)**

- No floodplain (confined channel)
- Steep slopes
- High potential for erosion of sediment

**Partly Confined Valley (Sediment Transfer Zone)**

- Limited floodplain
- Moderate slopes
- Equal potential for erosion and deposition of sediment

**Alluvial Valley (Sediment Accumulation Zone)**

- Large floodplain
- Low slopes
- High potential for deposition of sediment

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# Macquarie Rivulet Topology and River Character

CALDERWOOD
URBAN DEVELOPMENT PROJECT

**Legend**

- Site Boundary
- Catchment Boundaries
- Waterbodies (LPMA)
- Watercourses (LPMA)

**Topographic Controls**

- Confined Valley - Source Zone
- Partly Confined Valley - Transfer Zone
- Alluvial Valley - Accumulation Zone

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**FIGURE 3**

**Scale 1:60,000 (at A3)**

Metres
0 500 1,000 2,000 3,000 4,000

Cardno

Map Produced by Cardno Wollongong
Date: 24 February 2010
Coordinate System: Zone 56 MGA/GDA 94
GIS MAP REF: 110026-01_38011_MacquarieRivuletTopology.mxd 03

Aerial Imagery supplied by LPI

Around the Calderwood Urban Development Site, Macquarie Rivulet and Marshall Mount Creek are defined as partially confined valleys and alluvial valleys. As described by Brierley and Fryirs (2005) partially confined valleys, as found on the upper portions of the site, exhibit a limited floodplain and equal amounts of erosion and deposition are expected to occur. Towards the bottom of the site the morphology of the creeks changes to an alluvial valley system. This system exhibits straighter channels, larger floodplains and higher rates of sediment deposition on the floodplain (refer **Figure 3**). Nanson and Young (1981) also describe a reduction in channel size in the downstream reaches or Macquarie Rivulet. This is contrary to the usual widening and deepening of channels tat usually occurs downstream and has been attributed to the extensive floodplains in the lower catchment. Bankfull discharges often occur in extreme events with flows being carried over the floodplain and hence there is no requirement for a larger channel to carry peak flows. .

There are at least two terrace levels in the floodplain extending some 2km west of the existing township of Albion Park (Douglas Partners, 2010). The lower of these terraces is associated with the current active channel and floodplain (and is also referred to as a ledge). The upper terrace is located approximately 5m above the current ledge levels and is comprised of materials from a previous deposition. This terrace is not subject to inundation under normal flow regimes and is only engaged during peak flows (i.e. subject to inundation in the 1% AEP) (Rienco, 2009). These terraces are a well known feature of Macquarie Rivulet with Neller (1979) describing three sequences of alluvial sediment, an upper terrace, lower terrace and the present floodplain.

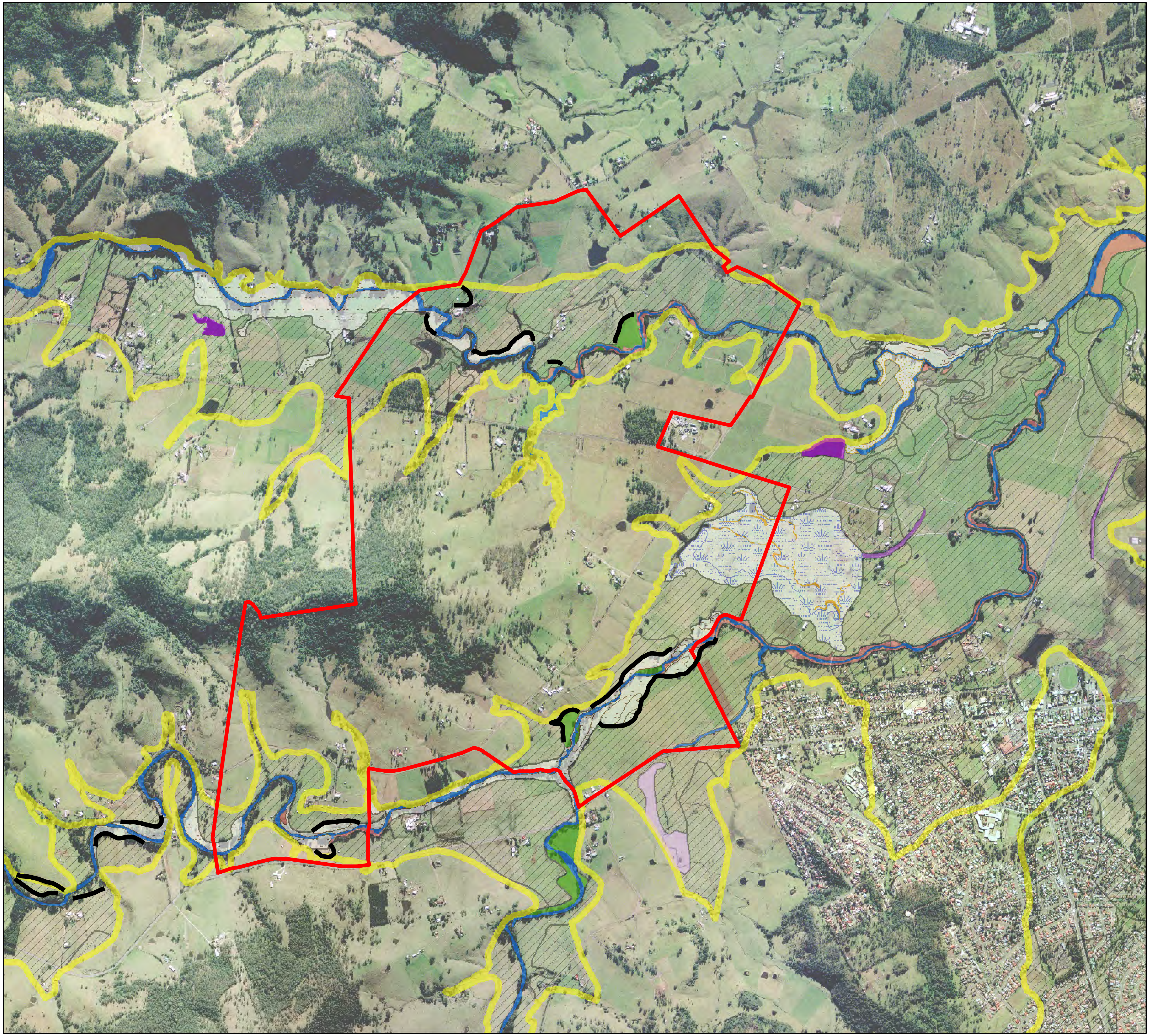
Both Macquarie Rivulet and Marshall Mount Creek have beds comprised of course bedload sediments (sand and gravels) indicating an alluvial composition. Indeed, Douglas Partners (2010) mapped the immediate area around both creeks as Quaternary Alluvium, however, they stated that the boundary between the alluvium and the colluvial/residual soils is often poorly defined in the area due to the deposition of colluvium at the base of steeper hillsides. The stream beds are characterised by sequences of pools and riffles in the confined valley meanders of the sediment transport zone, with sandy bars becoming the more prevalent feature as the channels straighten and widen into the alluvial channels and sediment deposition zone. There is anecdotal evidence from farmers in the area that sand deposition has occurred on the floodplain during several historic, rare flood events.

This observation of deposition of sediment on the floodplains is consistent with the engagement of the floodplains in peak flows described in Nanson and Young (1981) and the terracing observed in the catchment, which Neller (1979) considered to be deposition from large, rare storm events, rather than the effect of climate change. In fact this vertical accretion of floodplains a by depositions episodic stripping and sedimentation (rather than the constant climate change induced change as occurs in laterally developed floodplains) is common in coastal watercourses in South East NSW (Nanson. 1986).

Floodplains in the Macquarie Rivulet and Marshall Mount, especially around the subject site, would be classified as Medium Energy non-cohesive (Nanson and Croke, 1992). Such floodplains are considered to be in dynamic equilibrium with the flow regime of the river. These floodplains are not as affected by large events as “high energy” floodplains; however flooding does cause deposition and dispersion of energy over the floodplain. Nanson and Croke (1992) also provide nine sub categories of catchment type. Along the length of Macquarie Rivulet and Marshall Mount Creek there are good examples of three of these; valley confinement (in the upper reaches), overbank vertical accretion (around the subject site) and organic accumulation (at the Macquarie Rivulet Delta).

According to Douglas Partners (2010) there are localised and discontinuous areas of erosion along both Macquarie Rivulet and Marshall Mount Creek, usually around farm dams or road crossing outlets. Isolated outcrops of rocks from the Berry Formation and Budgong Sandstone are also found along the watercourses. Further details of the existing condition and geomorphic features of each of the sub catchments that run through the subject site are shown in **Figure 4** and described below.

The following sections provide a more detailed account of the individual features of each of Macquarie Rivulet and Marshall Mount Creek. These descriptions are based on observations from a literature review, the interpretation of ALS data (AAM Hatch, 2001) and aerial photography (Hatch 2001, Aerial Acquisitions 2009) as well as information obtained from a site inspection undertaken on 21 January 2010.



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# Geomorphological Units

CALDERWOOD
URBAN DEVELOPMENT PROJECT

## Legend

Site Boundary

**Natural Features**

- Terrace
- Back Basin
- Bank
- Bench
- Channel
- Floodplain
- Ledge
- Paleochannel
- Bar
- Valley Margin

**Man Made Features**

- Anthropogenic Channel
- Anthropogenic Dam
- Anthropogenic Wetlands

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**FIGURE 4**

**Scale 1:20,000 (at A3)**

Metres
0 500 1,000

Cardno

Map Produced by Cardno Wollongong
Date: 24 February 2010
Coordinate System: Zone 56 MGA/GDA 94
GIS MAP REF: 110026-01_38016_Geomorphology.mxd 03

Aerial Imagery supplied by AAM Hatch (2001)

## 2.1 Macquarie Rivulet

### 2.1.1 Overview

Macquarie Rivulet is one of the major watercourses in the southern Illawarra. It drains a large catchment of approximately 10,500 ha over a range of different land uses with its headwaters located above the Illawarra Escarpment.

In its upper reaches, located on the escarpment around Macquarie Pass, Macquarie Rivulet is comprised of a deep bedrock and boulder stream which drains a relatively steep, heavily forested area. As it progresses into the escarpment foothills, upstream of the subject site the steep valley walls make way to a small floodplain, which along with the rest of the coastal plain, has been cleared for rural use. Riparian vegetation, including trees and a weedy understorey is often present along the banks, but rarely overbank.

The channel is confined by valley margins the bottom of the escarpment, upstream of the subject site, whereafter it becomes confined by large terraces, formed by erosion of the floodplain during past peak flows. Some of these terraces still form part of the active floodplain (as ledges) whilst others are classified as alluvial terraces (abandoned floodplains). The active channel occupies only a small part of floodplain.

Towards its lower reaches, as it crosses the coastal plain, the floodplain widens and the channel becomes less confined. The large floodplain and relatively flat grades mean that this area tends to be flood prone. At this point, Macquarie Rivulet beings to pass though existing residential development of Albion Park, which is located on the southern side of Macquarie Rivulet and drains into it at several different points. In this area the floodplain on the northern side of the channel remains mostly as cleared rural land. Macquarie Rivulet eventually drains into Haywards Bay in Lake Illawarra, where it is currently depositing a birdsfoot delta (Sloss *et al*, 2004)

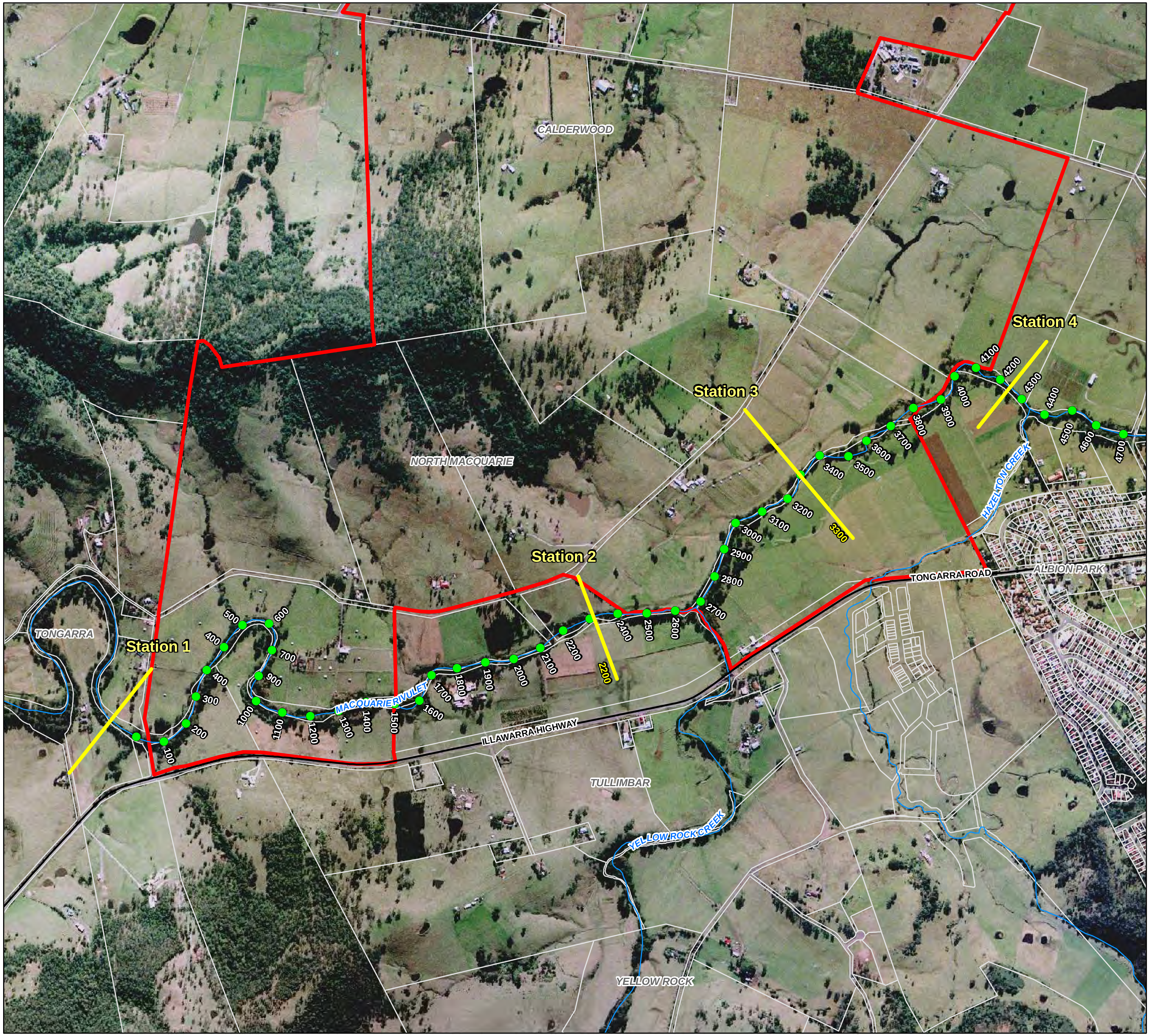
All of the features of Macquarie Rivulet discussed in the following sections, including cross section locations and chainages are shown in **Figure 5**.

### 2.1.2 Within the Subject Site

Within the subject site, Macquarie Rivulet exhibits a distinctive meander pattern, as described by Neller (1976). The meanders in Macquarie Rivulet are characteristic of an Osage stream and are larger than would be expected under the current flow regimes. Neller (1976) undertook an investigation into the formation of these meanders in relation to the geomorphic features of Macquarie Rivulet and determined that they were likely to be the morphological effect of flood events. The presence of terraces along the channel provides evidence of high flow events in Macquarie Rivulet, and the wide meanders are likely an adaptation to these large flow events.

Macquarie Rivulet has a deep and wide channel, which is the result of erosion caused by clearance of land for rural activities. Aerial photography from 1949 (LPMA, 1949) shows that the area had been cleared of most vegetation, particularly around the channel which exhibited very little vegetation on its banks.

Large terraces are also evident in the 1949 photography. Comparison of this photography with recent (Hatch 2001, Aerial Acquisitions 2009) photography shows that the channel has exhibited limited lateral movement over the past 60 years. Further comparison between historical and recent photography shows that a significant amount of vegetation has become established along the channel and its banks, however this revegetation is comprised mainly of weeds and exotics. This revegetation may have assisted in limiting this lateral movement by providing erosion protection on the creek banks.

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# Macquarie Rivulet Chainages and Cross Section Locations

CALDERWOOD
URBAN DEVELOPMENT PROJECT

**Legend**

- Site Boundary
- Chainages (Cardno)
- Major Roads (LPMA)
- Major Watercourses (LPMA)
- Cross Section Locations (Cardno)
- Cadastre (LPMA)

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**FIGURE 5**

**Scale 1:12,500 (at A3)**

Metres
0 125 250 500 750

Cardno

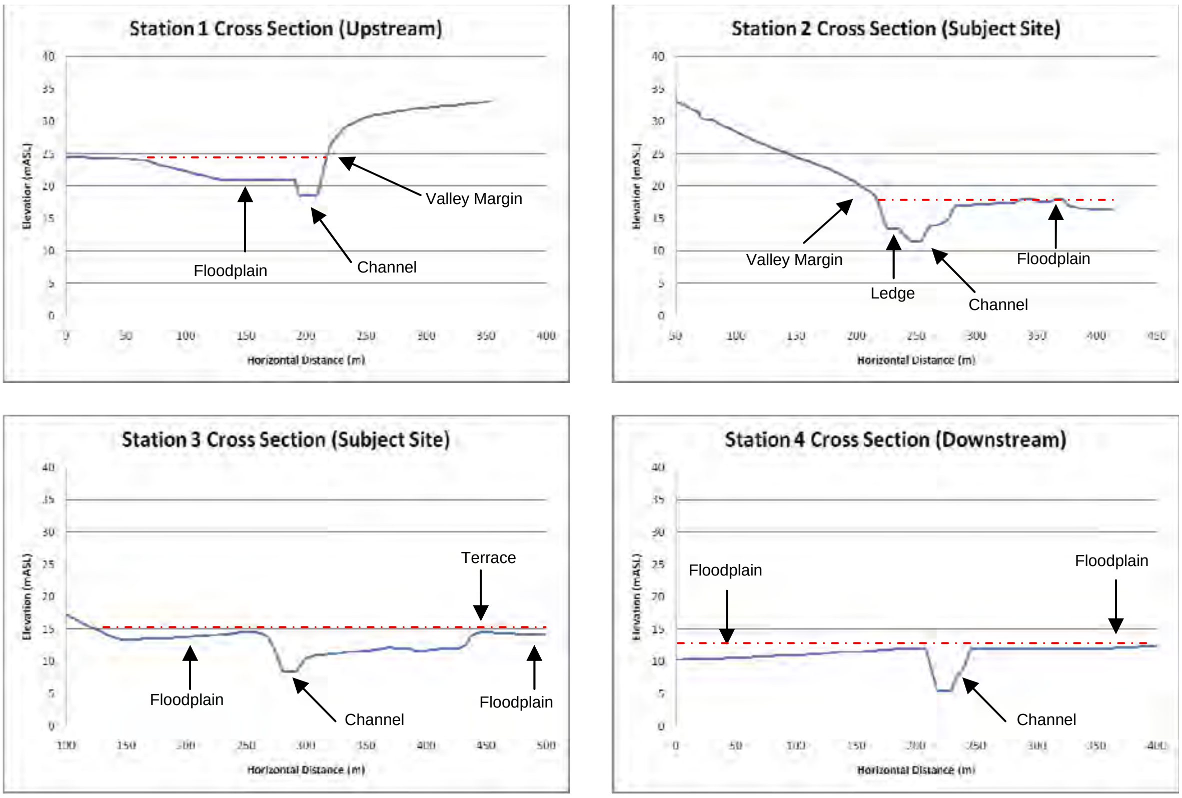
Map Produced by Cardno Wollongong
Date: 24 February 2010
Coordinate System: Zone 56 MGA/GDA 94
GIS MAP REF: 110026-01_38051_Macquarie_Rivulet_Xsecs.mxd 02

Aerial imagery supplied by AAM Hatch (2001)

As Macquarie Rivulet traverses the subject site several examples of pools and riffles (consisting mainly of cobbles) exist. Small lateral bars are also present, which are mainly vegetated with mature trees and woody weeds (such as Lantana). Macquarie Rivulet also exhibits examples of terracing, an feature of floodplain deposition form historic high flow events.

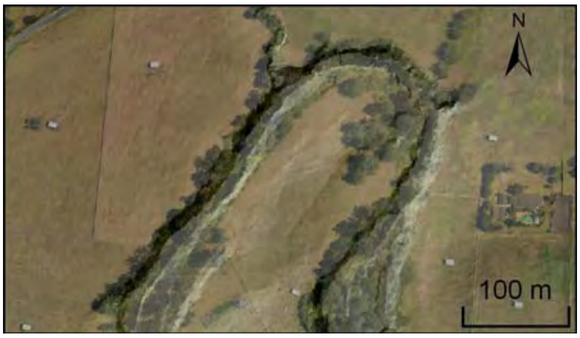
The following cross sections (**Figure 6**) show the form of the Macquarie Rivulet channel in and around the subject site (refer **Figure 5** for locations). They show the progression of Macquarie Rivulet from a partially confined valley, above the subject site, to an alluvial valley, with larger floodplain, below the site. **Table 2.1** provides a summary of the key features Macquarie Rivulet in and around the subject site (refer **Figure 5** for chainages).

**Figure 6 – Macquarie Rivulet Cross Sections**

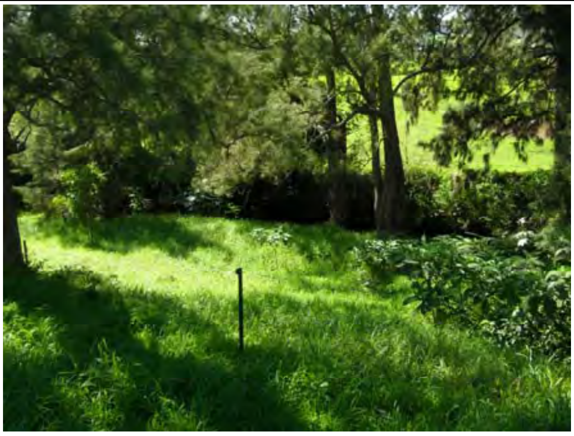
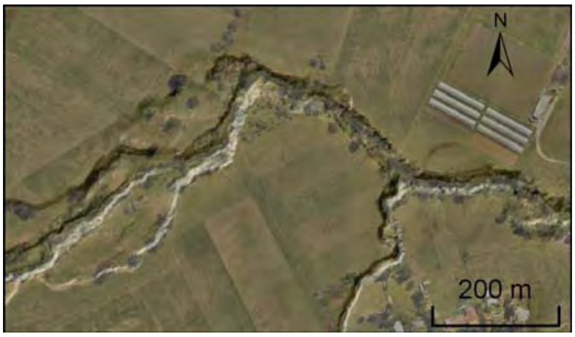



( -·-·-·-·- = 1% AEP [approx])

**Table 2.1 – Existing Features of Macquarie Rivulet**

| Chainage (m) | Key Channel Features | Generic Photograph/Image of Area (not indicative of whole area) |
|---|---|---|
| 0 – 50<br>Upstream of Bridge | • Wide shallow channel<br>• Scour on southern bank<br>• Sandy northern bank<br>• Course bed sediment (50-200mm)<br>• Significant shallow on oxbow meander<br>• Numerous pools | <br>Photograph looking upstream (west) |
| 50 - 200<br>Down-stream of Bridge | • Channel becomes deeper and narrower than upstream<br>• Boulders (>300mm) present in bed<br>• Southern bank confined by bedrock | <br>Photograph looking downstream (east) |
| 450 – 800 | • Large meander<br>• Undercut on northern bank<br>• Extensive vegetation on banks, little overbank vegetation<br>• Channel located in partially confined valley. | <br>Aerial photograph with hill-shade |
| 1000 - 1800 | • Channel begins to straighten downstream<br>• Channel bound by valley margin to south<br>• Terraces over both banks | <br>Aerial photograph with hill-shade |

| Chainage (m) | Key Channel Features | Generic Photograph/Image of Area (not indicative of whole area) |
|---|---|---|
| 1800 - 2300 | • Channel becomes very straight<br>• Channel bound by Valley margin on northern bank<br>• The confluence of the Macquarie Rivulet and floodplain and the Yellow Rock Creek floodplain occurs in this area (downstream of image) | <br>Aerial photograph with hill-shade |
| 2700 | • Yellow Rock Creek confluence with Macquarie Rivulet located in this area<br>• Large riffle present in the channel (Particle size ~50 – 100mm)<br>• Extensive vegetation on banks, particularly weed species such as Lantana<br>• Undercutting occurring on southern bank | <br>Example of riffle |
| 2700 - 3000 | • Vegetation generally confined to banks (no overbank vegetation)<br>• Woody debris present in channel in some areas<br>• Undercutting of banks occurring<br>• Section contains a sequence of pools and riffles (particle size ~50 - 100mm)<br>• Small channel for regular flow,<br>• Larger channel confined by terraces for larger events (not visible in photo)<br>• Banks consist of sand/clay mixture<br>• Large bar on southern boundary of creek | <br>Photograph looking downstream (east) |

| Chainage (m) | Key Channel Features | Generic Photograph/Image of Area (not indicative of whole area) |
|---|---|---|
| 3000 - 3250 | • Main channel becomes deeper<br>• Terraces becoming higher<br>• Top of bank between terraces becomes wider<br>• Grass present on ledges | <br>Photograph looking south |
| 4050 | • Terraces on opposite banks converge (closer than upstream)<br>• Eastern terrace moves closer to the channel<br>• Confluence with Hazelton Creek in this area | <br><br>Aerial photograph with hill-shade |
| 4750 | • Bridge at Calderwood Road<br>• Small main channel inside larger channel confined by very large terraces (>3m height) located<br>• Extensive vegetation lining banks, particularly mature trees | <br>Photograph taken on bridge looking upstream (west) |

## 2.2 Marshall Mount Creek

### 2.2.1 Overview

Marshall Mount Creek also has its headwaters in the Illawarra Escarpment but drains an area of approximately 1,900 ha. Like Macquarie Rivulet, its higher reaches are characterised by a steep bedrock confined channel draining a heavily vegetated area. It then takes on a meandering sediment transport and sediment deposition structure as it crosses the coastal plain. Although it drains a much smaller catchment and carries less flow volume the morphology of Marshall Mount Creek is quite similar to that of Macquarie Rivulet. The confluence of Marshall Mount Creek and Macquarie Rivulet is approximately 2kms downstream of the subject site.

Nanson and Young (1981) describe the 10km basin as relatively narrow and having a total relief of approximately 620m. The upper 25% of the channel is described as step, confined and strewn with boulders. The lower 75% of comprised of an alluvial channel and floodplain. The cross sectional channel area and width increase in the downstream direction in the upper basin, but decline markedly near the basin exit. This description is consistent with the observations made during the current study.

Marshall Mount Creek is an intermittent stream which exhibits pooling during low flow regimes. It was dry on the day of the inspection with only a few pools of stagnant water and local residents have stated that the creek is dry most of the time. The channel is mostly devoid of vegetation, with the bank vegetation being comprised mainly of grasses, pasture species and weeds. There is also a sparse cover of trees in the riparian zone before the vegetation gives way to cleared pasture and grasslands. Vegetative cover tends to decrease towards the downstream end of the creek.

All of the features of Macquarie Rivulet discussed in the following sections, including cross section locations and chainages are shown in **Figure 7**.

### 2.2.2 Within the Subject Site

Where it flows through the site Marshall Mount Creek has very different characteristics to Macquarie Rivulet. Where Macquarie Rivulet has taken on the form of an Osage stream, Marshall Mount Creek exhibits the characteristic meander patters of a large stream flowing through a semi confined valley, with steep undercut banks on outside of meander bends and a series of pools and riffles.

Just before it enters the site, Marshall Mount becomes shallow and unedified with a large flat floodplain. However, this is not characteristic of the channel upstream, which generally takes the form of a partially confined valley. As Marshall Mount Creek traverses the site the alluvial channel becomes wider and straighter and the floodplain becomes gradually larger, until by the bottom of the site, the floodplain is unconfined by valley margins. Downstream of the site, the meander patterns lose definition and transition into a more straight alignment of interlinked pools, suggesting these reaches function as a net sediment deposition area.

In the upper reaches of the site, Marshall Mount Creek exhibits examples of pools and riffles, as well as lateral vegetated bars as seen in Macquarie Rivulet. The banks of Marshall Mount Creek are very steep, and undercutting is evident on many outside bends of meanders. Trees on the steep banks have their roots exposed, suggesting that there has been lateral movement of the channel and/or bank collapse. A low flow channel is evident in the upper reaches of the site, which hugs the outside of meander bends. There is little or no overbank vegetation at the upper reaches, with the exception of grass and pasture land from the top of bank. Vegetation density on the banks is generally low in the channel and on the banks in this area.

Towards the lower end of the site, Marshall Mount Creek becomes relatively straight, and due to the lack of perennial flow, does not contain an immediately visible low flow channel, as evident in Macquarie Rivulet. The channel is wide and deep in these reaches and contains very little vegetation on the banks, with the exception of grass and other pasture species.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# Marshall Mount Creek Chainages and Cross Section Locations

CALDERWOOD
URBAN DEVELOPMENT PROJECT

## Legend

- Site Boundary
- Chainages (Cardno)
- Major Watercourses (LPMA)
- Cross Section Locations (Cardno)
- Cadastre (LPMA)

FIGURE 7

**Scale 1:10,000 (at A3)**

Metres
0 50 100 200 300 400 500

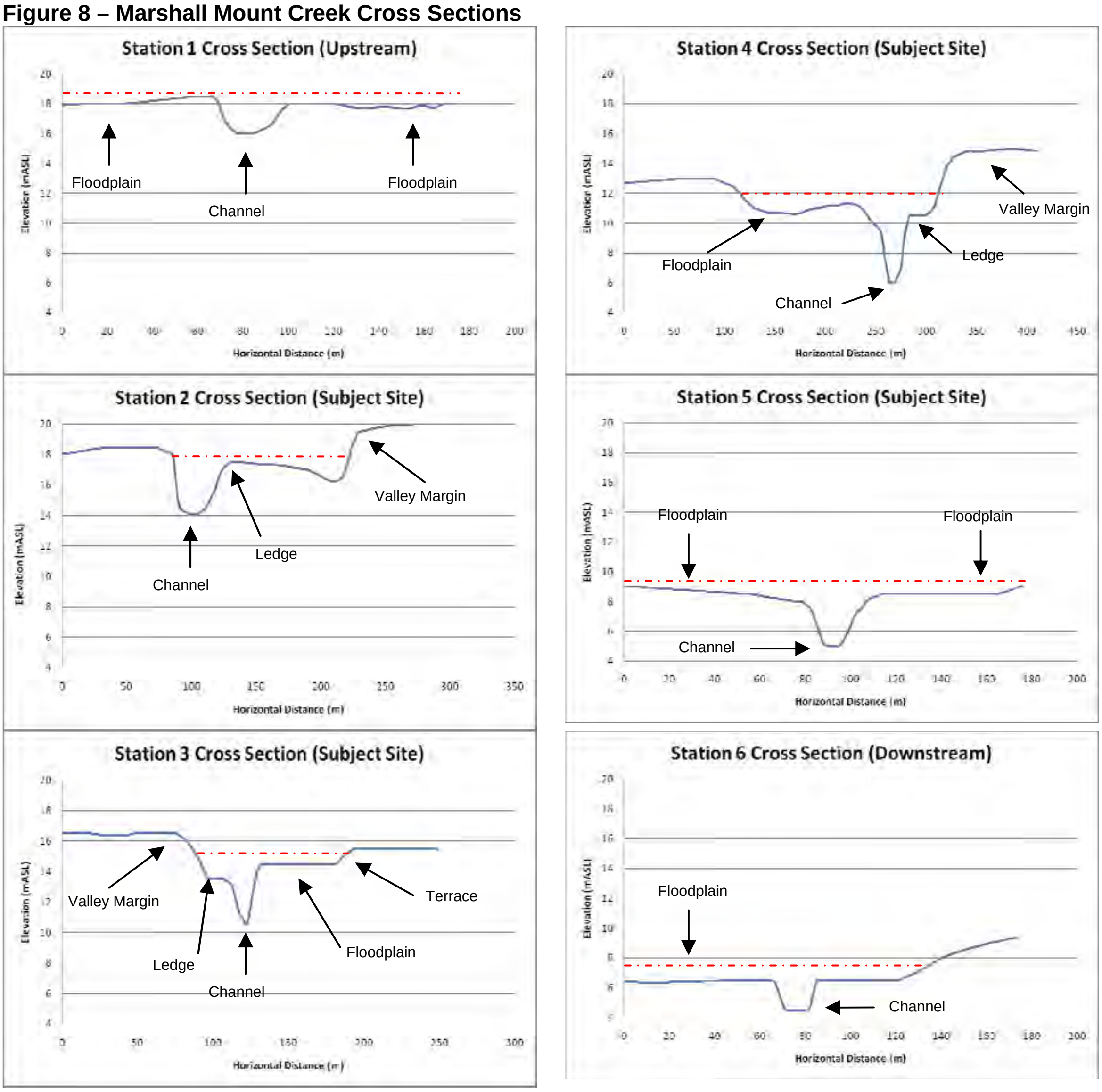
Cardno

Map Produced by Cardno Wollongong
Date: 24 February 2010
Coordinate System: Zone 56 MGA/GDA 94
GIS MAP REF: 110026-01_38052_Marshall_Mount_Xsecs.mxd 02

Aerial imagery supplied by AAM Hatch (2001)

The following cross sections (**Figure 8**) show the form of the Marshall Mount Creek channel in and around the subject site (refer **Figure 7** for locations). They show the progression of Marshall Mount Creek a partially confined valley, above the subject site, to an alluvial valley, with larger floodplain, below the site. **Table 2.2** provides a summary of the key features Macquarie Rivulet in and around the subject site (refer **Figure 7** for chainages).

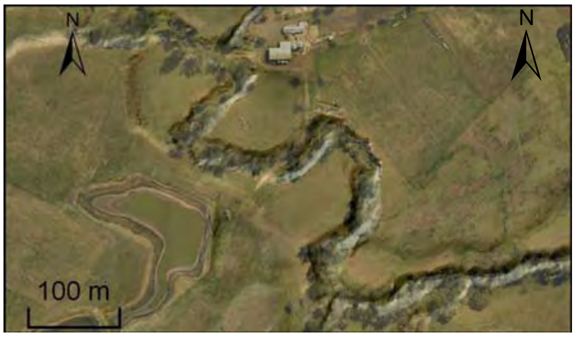
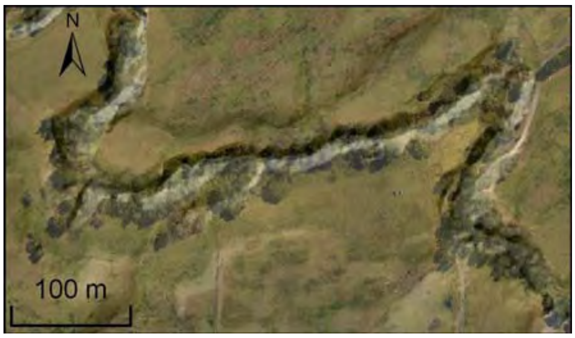
**Figure 8 – Marshall Mount Creek Cross Sections**




(-·-·-·-·- = 1% AEP [approx])

**Table 2.2 – Existing Features of Marshall Mount Creek**

| Chainage (m) | Key Channel Features | Generic Photograph/Image of Area (not indicative of whole area) |
|---|---|---|
| 0 – 50<br>Upstream of bridge | • Trees present in channel<br>• Terraces located on southern bank of channel (not visible in photo)<br>• Northern bank confined by valley margin | <br>Upstream of bridge, channel is on right |
| 50 - 200<br>Downstream of bridge | • No well defined channel<br>• Banks poorly defined<br>• Channel and banks lined with grass<br>• Scattered trees throughout this area (~1 every 30 metres) | <br>Downstream of bridge, channel is on left |
| 200 | • Bar in middle of channel vegetated with grass<br>• Extremely steep northern bank<br>• Undercutting occurring on northern bank<br>• Roots of tree on northern bank are exposed | <br>Photograph looking upstream (west) |

| Chainage (m) | Key Channel Features | Generic Photograph/Image of Area (not indicative of whole area) |
|---|---|---|
| 250 - 350 | • Channel becomes better defined than upstream<br>• Series of pools and riffles<br>• Riffles grain size > 100mm<br>• Channel and banks lined with grass<br>• Density of trees increasing ~1 every 15m | <br>Photograph looking south. Pool on right, riffle on left |
| 350 - 450 | • Southern bank extremely steep<br>• Channel becomes wider than upstream<br>• Series of pools and riffles present in this area<br>• Grass on embankment with sparse trees (~1 every 15m)<br>• Tree roots exposed where undercutting is occurring | <br>Photograph of southern bank |
| 150 - 450 | • Channel takes a more meandering form than the confined valley<br>• Banks on outside of meanders remain steep (channel partially confined)<br>• Terrace present over southern bank | <br>Aerial photograph with hill-shade |
| 900 - 1150 | • Channel straightens through this section.<br>• A terrace is located over the northern bank<br>• Banks become steeper than the upstream banks | <br>Aerial photograph with hill-shade |

| Chainage (m) | Key Channel Features | Generic Photograph/Image of Area (not indicative of whole area) |
|---|---|---|
| 1200 - 3050 | • Channel resumes meandering nature after passing through straight section upstream.<br>• Channel also becomes wider than upstream.<br>• Meander wavelengths and amplitude become larger downstream in this section | <br><br>Aerial photograph with hill-shade |
| 3100 - 3250 | • Channel straightens out<br>• Whilst straightening the channel becomes wide and deep<br>• Channel now comprised of fine sediments as compared to larger cobbles upstream,<br>• In channel of fine sediments apparent as creek becomes an accumulation zone.<br>• Pooling and drying occurs in alluvial low flow channel<br>• Very few (3-4) trees located along the banks in this area<br>• Grass lines banks, but no vegetation in channel<br>• Evidence of cattle access to creek channel | <br>Photograph looking upstream (west) along channel |
| 3300 | • Vehicular crossing at this location over existing riffle<br>• Evidence of bank and bed erosion possibly due to crossing or cattle access.<br>• Channel continues to be wide, poorly defined and subject to sediment deposition as describes above.<br>• Floodplain becomes wider. | <br>Photograph looking downstream (east) at vehicular crossing |

| Chainage (m) | Key Channel Features | Generic Photograph/Image of Area (not indicative of whole area) |
|---|---|---|
| 3350 - 3400 | • Grass lines channel and banks<br>• No defined low flow channel, just wide deep channel | <br>Photograph looking upstream (west) at grassed channel |
| 3450 - 3550 | • Steep but low banks lined with grass<br>• Further downstream, trees line both banks,<br>• Little overbank vegetation present in some areas<br>• Channel becomes even wider downstream, and pooling is present. | <br>Photograph looking downstream (east) |

# 3 Riparian Corridors

A site-specific riparian strategy has been prepared for the Calderwood project in line with the Delfin Lend Lease riparian strategy. This is described in the Riparian Corridor Consistency Report (Eco Logical 2010). The resultant corridor widths and revegetation strategy have been determined as part of a triple bottom line assessment and detailed site inspections undertaken by the design team. The proposed riparian corridor widths have been optimised to meet a range of objectives ranging from hydraulic impacts, ecological outcomes and future ownership and maintenance issues.

As part of the preparation of the Riparian Strategy, the hydraulic value of the watercourses within and around the site was assessed. This process was undertaken as a part of the Geomorphology Assessment and is described in this section. The assessment of the relevant legislation, policies and guidelines, along with agency consultation is described in the Riparian Corridor Consistency Report (Eco Logical, 2010).

The first step in the process was to undertake a site inspection of all creek lines over the entire catchment, not just Macquarie Rivulet and Marshall Mount Creek. This process was then used to verify existing LPMA data regarding watercourses for the site. The locations of creeks and corridors as determined by LPMA are shown in **Figure 9**.

As a result of the site inspections and ALS data interpretation undertaken by Cardno and Delfin Lend Lease, a revised set of creeks was determined. Several creeks were removed from the mapping (for a range of reasons) as they were found to be, in effect, paper streams, with no hydrological capacity or no evidence of their existence on site. Justifications for the removal of streams included;

- Watercourse had a catchment of less than 20ha
- Mapped creek was present only in the form of an historic channel not relevant to current drainage pattern
- Creek was found to have little hydrological function
- For other reasons as specified in Table 1 of the Riparian Corridor Consistency Report (Eco Logical, 2010)

Other unmapped streams were detected during the ground truthing and added to the revised creek data set. Details of which streams were added and removed can be found in the the Riparian Corridor Consistency Report (Eco Logical 2010).

The revised creek lines where then allocated a Strahler classification (consistent with the guidelines published under the WM Act) based on the Strahler method and observations made in the field. A comparison between the LPMA Strahler Classifications and the revised ground-truthed classifies steams is provided **Figure 10**.

Strahler stream ordering (after Strahler, 1964) is a hierarchical numbering system based on the degree of branching within a waterway catchment. The numbering starts at the top of the catchment with the headwater streams (called first order streams) and increase in a downstream direction, increasing by one unit at each confluence of two streams of the same order. This allows the distinction between drainage lines, minor and major waterways.

It is noted that the Strahler Stream Order classifications are alternative classification system to that used under the Riparian Corridor Management Study (DIPNR, 2004) and unpublished DECCW mapping for Macquarie Rivulet. The justification for using this stream classification is provided in the Riparian Corridor Consistency Report (Eco Logical, 2010). Essentially, the Strahler classification is a much more widely used and recognized method of stream classification and less subjective than the allocation of the classifications used under the RCMS viz;

- Category 1 - an environmental corridor
- Category 2 - terrestrial and aquatic habitat
- Category 3 - bed and bank stability/water quality

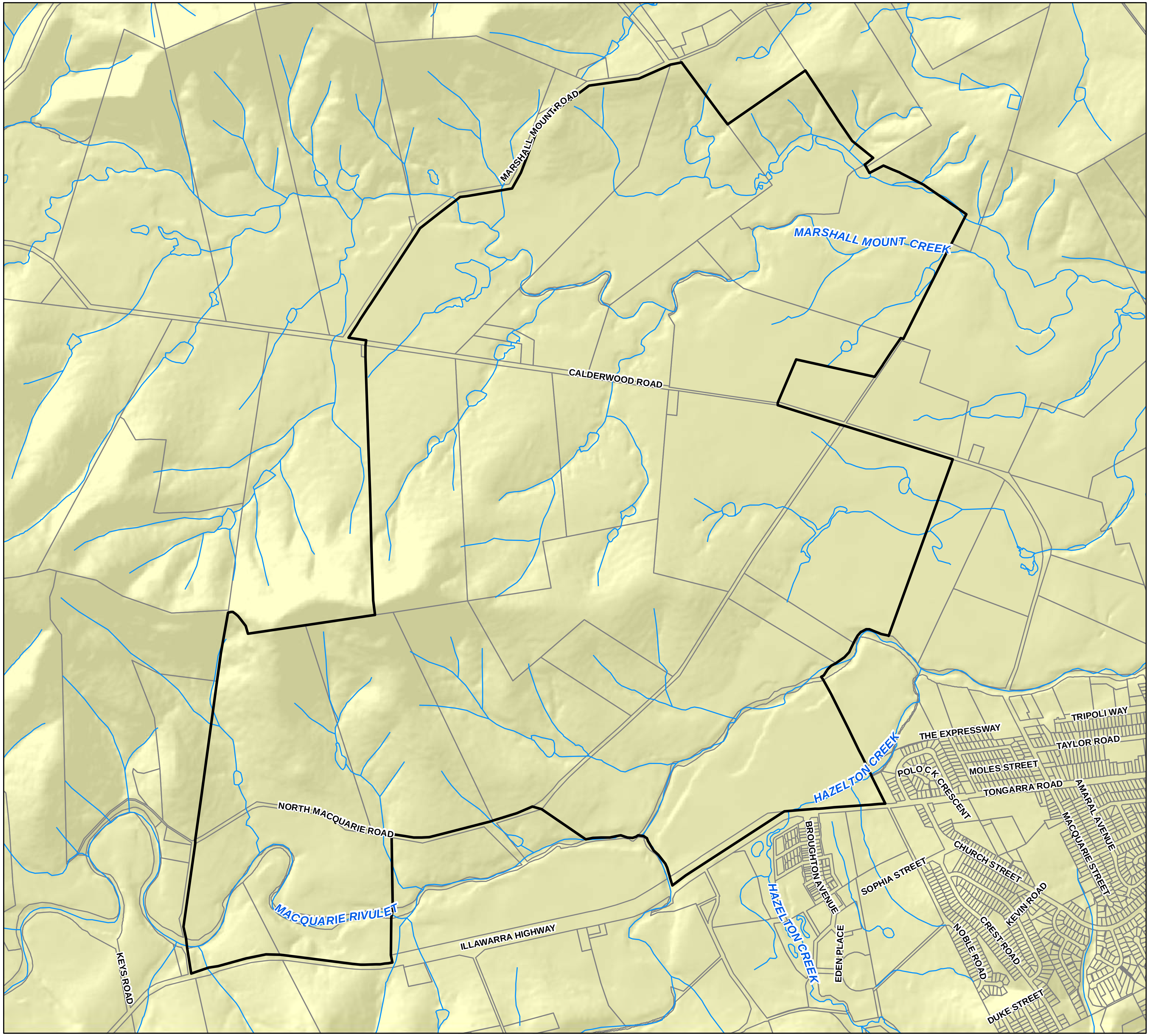
Once the streams had been classified, corridor widths were allocated to them in line with the corridor with proposed in the Riparian Corridor Management Study (RCMS) (Wollongong City Council, 2004) for the equivalent stream type (refer **Figure 11**). Existing watercourses were allocated riparian corridor widths based on their Strahler Classification as follows:

| Strahler Stream Order | RCMS Stream Classification equivalent | Core Riparian Zone (CRZ) | Riparian Corridor Width |
|---|---|---|---|
| 1 | Category 3 | 10m from TOB | 24m |
| 2 | Category 2 | 20m from TOB | 48m |
| 3 and above | Category 1 | 40m from TOB | 92m |

Although the corridor widths remain the same there were changes to the classification of streams, in accordance with the hydrologic assessment detailed above and habitat assessment undertaken by Eco Logical (2010). According to the Riparian Corridor Consistency Report, this resulted in;

- 28 stream segments consistent with the RCMS
- 8 stream segments removed
- 5 stream segments in a lesser category than the RCMS
- 18 stream segments in a higher category than the RCMS

The proposed development has taken these riparian corridors into consideration in the Masterplan as demonstrated in **Figure 12**. As part of the design works there are also two changes proposed to the existing riparian corridors detailed above. These changes include the removal of one section of creek, which will diverted into the Village Centre Lakes and the addition of a Riparian Corridor along Hazelton Creek.

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# LPMA Watercourses (Pre-Ground Truthed)

CALDERWOOD
URBAN DEVELOPMENT PROJECT

**Legend**

- Site Boundary
- Watercourse (LPMA) *
- Cadastre (LPMA)

** Watercourses from the NSW Land and Property Management Authority (LPMA) have been captured as part of the Original 1:25,000 Mapping Program*

N
W E
S

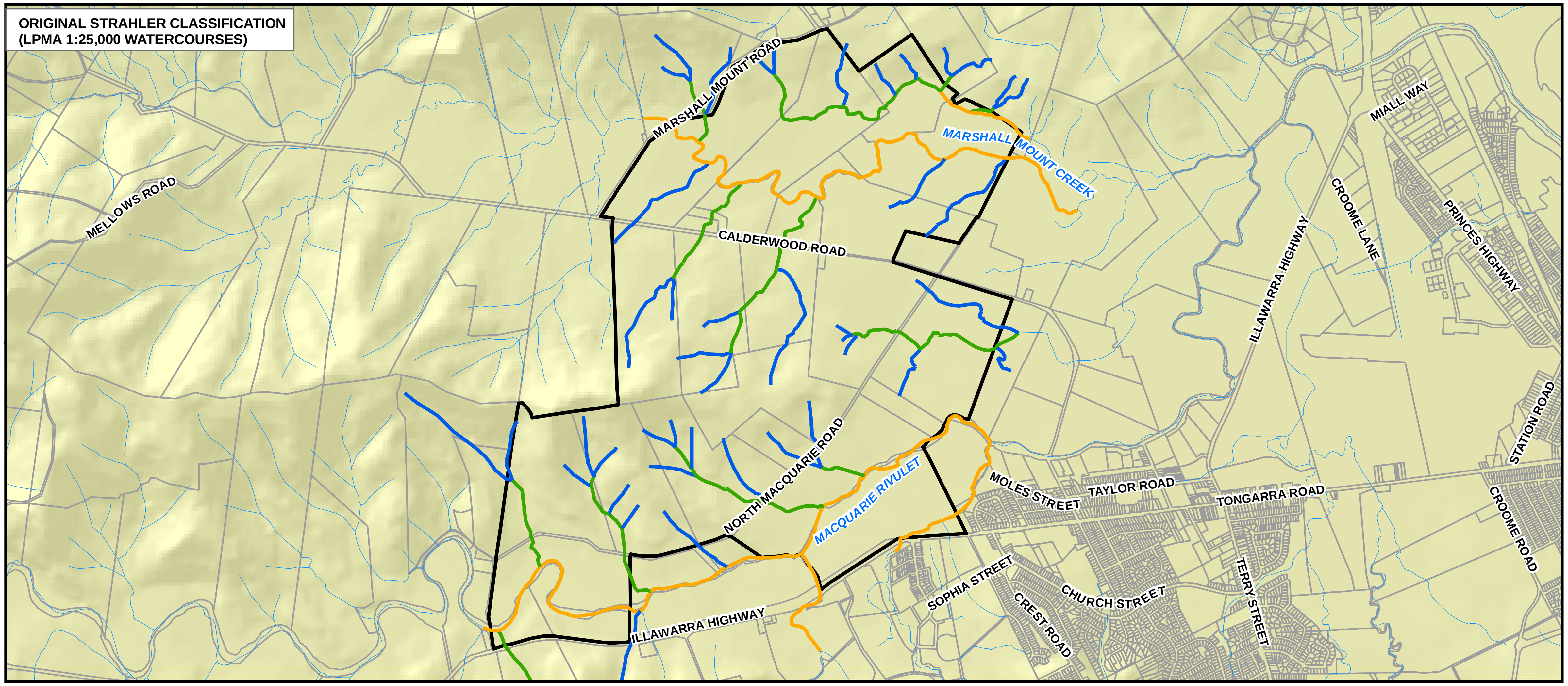
**FIGURE 9**

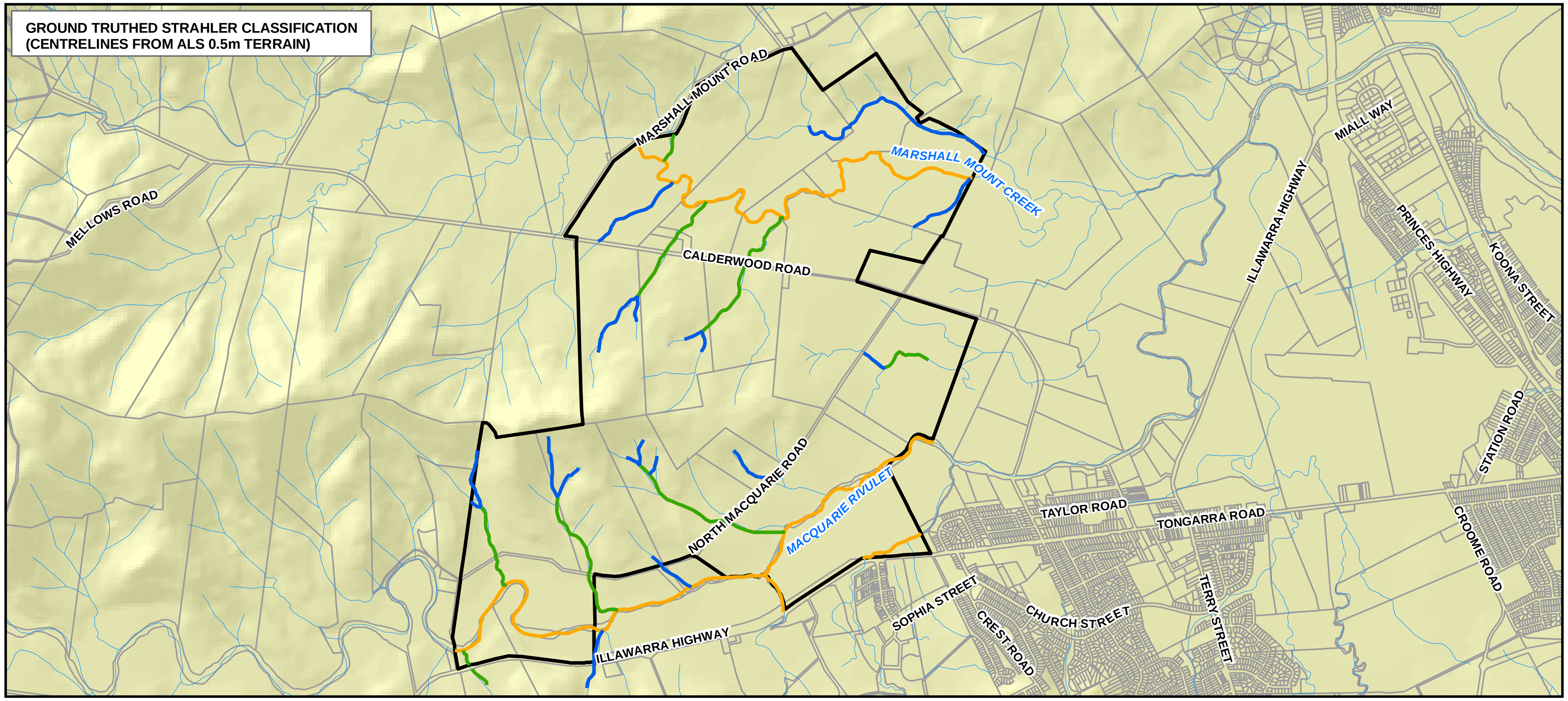
**Scale 1:15,000 (at A3)**

Metres
0 250 500 750 1,000

Cardno

Map Produced by Cardno Wollongong
Date: 11 February 2010
Coordinate System: Zone 56 MGA/GDA 94
GIS MAP REF: 110026-01_38004_LPMA_Watercourses.mxd 02

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# Strahler Classification Comparison

CALDERWOOD
URBAN DEVELOPMENT PROJECT

**Legend**

Site Boundary
Watercourse (LPMA) *
Cadastre (LPMA)

**Ground Truthed Strahler Categories (ALS) ****

Stream Order 1
Stream Order 2
Stream Order 3 +

** Watercourses from the NSW Land and Property Management Authority (LPMA) have been captured as part of the Original 1:25,000 Mapping Program*

*** ALS watercourses as part of the ground truthed classification have been captured from ALS 0.5m terrain by Cardno Forbes Rigby in conjunction with Delfin Lend Lease and show pre-development condition.*

N
W E
S

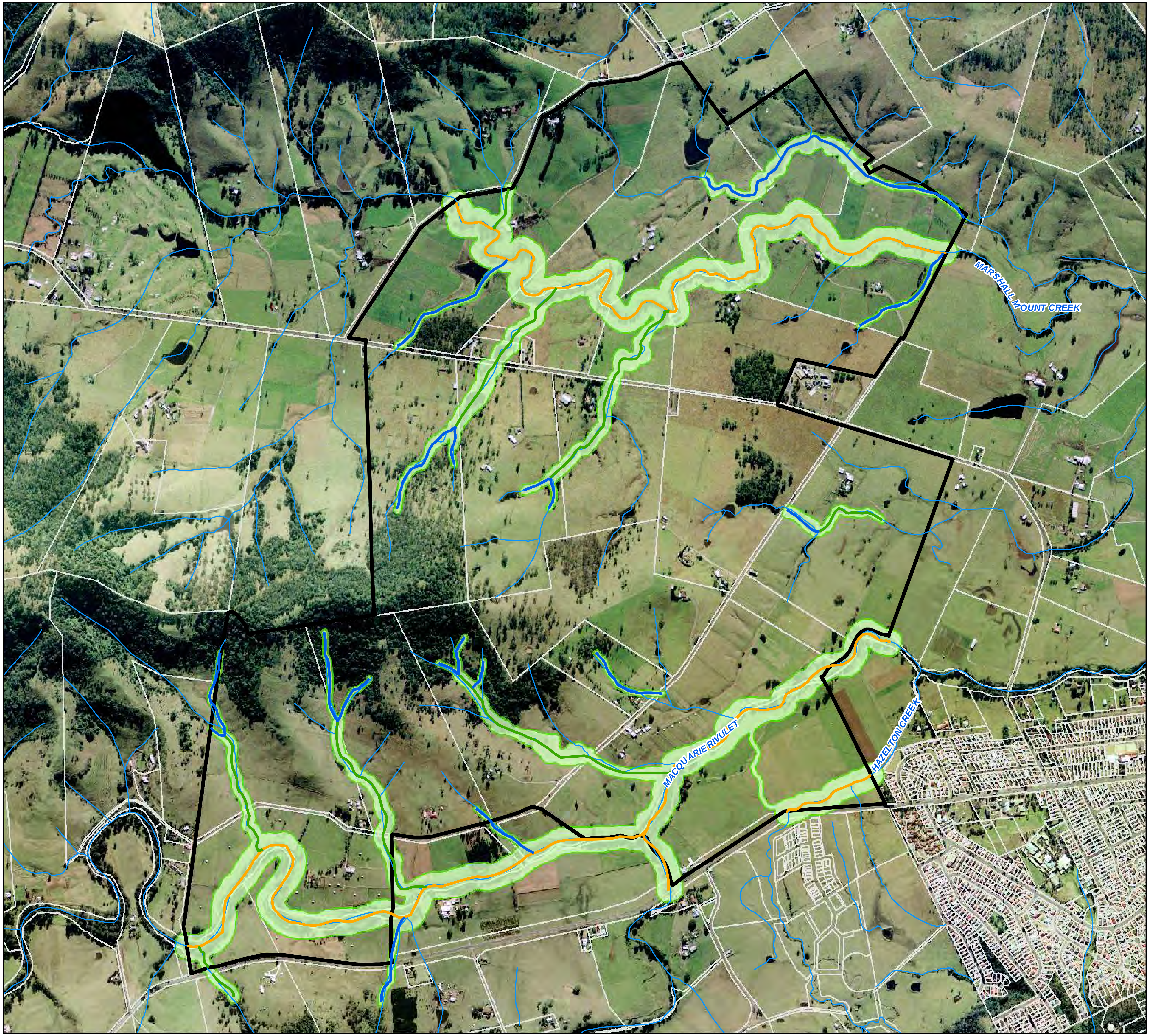
**FIGURE 10**

**Scale 1:30,000 (at A3)**

Metres
0 500 1,000 1,500 2,000

Cardno

Map Produced by Cardno Wollongong
Date: 24 February 2010
Coordinate System: Zone 56 MGA/GDA 94
GIS MAP REF: 110026-01_38008_StrahlerComparison.mxd 04

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# Riparian Zones for Existing Ground Truthed Streams

CALDERWOOD
URBAN DEVELOPMENT PROJECT

**Legend**

- Site Boundary
- Watercourses (LPMA) *
- Cadastre (LPMA)
- Riparian Corridor **

**Ground Truthed Strahler Categories (ALS) *****

- Stream Order 1
- Stream Order 2
- Stream Order 3 +

** Watercourses from the NSW Land and Property Management Authority (LPMA) have been captured as part of the Original 1:25,000 Mapping Program*

*** Design Riparian Corridor derived from buffer against Top of Bank as defined from ALS 0.5m terrain by Cardno Forbes Rigby in conjunction with Delfin Lend Lease. Design Riparian corridor incorporates proposed urban layout, creek and floodway works.*

**** ALS Watercourses captured from ALS 0.5m terrain by Cardno Forbes Rigby in conjunction with Delfin Lend Lease and are shown to incorporate proposed urban layout, creek and floodway works.*

N
W E
S

**FIGURE 11**

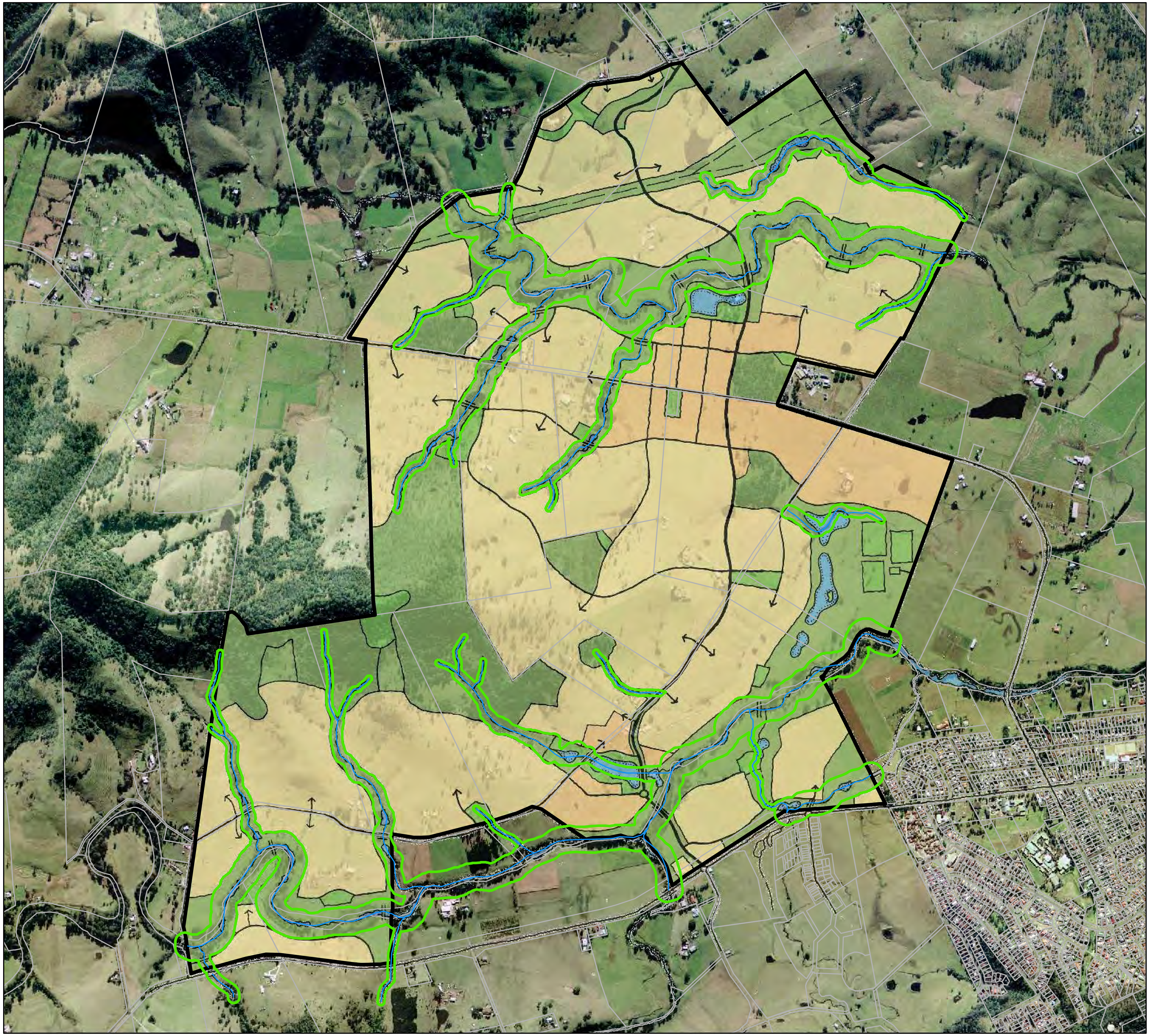
**Scale 1:15 000 (at A3)**

Metres
0 250 500 750 1,000

Cardno

Map Produced by Cardno Wollongong
Date: 24 February 2010
Coordinate System: Zone 56 MGA/GDA 94
GIS MAP REF: 110026-01_38060_ALS_StrahlerRiparian.mxd 03

Aerial imagery supplied by AAM Hatch (2001)



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# Proposed Development Riparian Corridors

CALDERWOOD
URBAN DEVELOPMENT PROJECT

**Legend**

- Site Boundary
- Watercourse (ALS) *
- Cadastre (LPMA)
- Design Riparian Corridor **

** Watercourses captured from ALS 0.5m terrain by Cardno Forbes Rigby in conjunction with Delfin Lend Lease and are shown to incorporate proposed urban layout, creek and floodway works*

*** Design Riparian Corridor derived from buffer against Top of Bank as defined from ALS 0.5m terrain by Cardno Forbes Rigby in conjunction with Delfin Lend Lease. Design Riparian Corridor incorporates proposed urban layout, creek and floodway works.*

**FIGURE 12**

N
W E
S

**Scale 1:15 000 (at A3)**

Metres
0 250 500 750 1,000

Cardno

Map Produced by Cardno Wollongong
Date: 24 February 2010
Coordinate System: Zone 56 MGA/GDA 94
GIS MAP REF: 110026-01_38059_RiparianConceptLayout.mxd 04

Aerial imagery supplied by AAM Hatch (2001)
Concept Base Plan from Delfin Lend Lease - February 2010

# 4 Potential Impacts

As discussed in **Chapter 1** the CUDP involves the construction of approximately 4,800 dwellings over an area of 700ha in the Calderwood Valley. This valley is located on the boundary of the Shellharbour and Wollongong LGAs and is encompassed by the Macquarie Rivulet Catchment (also flowing into the Marshall Mount sub-catchment in the north).

## 4.1 Generally

In relation to geomorphology, the proposed development will involve a number of changes to the catchment and floodplain which have the potential to alter the geomorphologic conditions at the site. These include:

- **Changes to Catchment Land Use (i.e., from Rural to Urban)** – Several hundred hectare of urban area is proposed on the development site, the vast majority of which is rural land under existing site conditions. This change in land use from rural to urban will alter the nature and quantity of stormwater runoff from the development site from that of existing conditions.
- **Construction of WSUD Features** – The development proposes a number of WSUD features including wetlands, swales, and conveyance channels in riparian and floodplain areas. These features are required to convey and treat stormwater runoff from the development site and discharge to Macquarie Rivulet or Marshall Mount Creek. These features will be designed to treat stormwater runoff in low flow conditions only (i.e., up to a 3 month ARI flows), and will divert higher flows directly into their respective creeks.
- **Re-grading of Floodplain and Riparian Areas** – The development proposes re-grading and earthworks in some floodplain areas along the Macquarie Rivulet and Marshall Mount Creek. These works are required for flood mitigation purposes to improve conveyance through the development site.
- **Construction of Access Bridges** – The development proposes access bridges across the Macquarie Rivulet and Marshall Mount Creek to provide flood free access to the development site. These bridges will be designed such that they are traversable in the 1% AEP flood event, and that they do not result in any increase in flood levels outside the development site. In order to achieve this, construction of these bridges will require some in channel earthworks to locally widen and armour the stream channel at the bridge locations.
- **Establishment of Riparian Vegetation** – The development proposes the retention and establishment of vegetated riparian corridors along the Macquarie Rivulet and Marshal Mount Creek and other creeks within the catchment of the development site. These riparian corridors are proposed in order to provide bank stability and reduce bank erosion, improve water quality, provide diversity of habitat for terrestrial, riparian, and aquatic flora and fauna species, provide connectivity between wildlife habitats, and allow for conveyance of flood flows through the development site. Riparian corridors will be appropriately planted out and establishment of vegetation in these areas may result in an acceptable increase in roughness on the floodplain (refer to the FPRMS (Cardno, 2010)) for further detail.

## 4.2 Potential Geomorphological Impacts

The development proposes to change rural landuse to urban landuse. This change in landuse is often associated with decreased lag time of runoff due to an increase in impervious area. Runoff that would otherwise become infiltrated and join groundwater flows in rural landuse is more likely to remain as surface flow, and enter the surface drainage system as surface runoff. This increase in surface runoff is associated with a potential for increased erosion in the surface drainage network.
Increased flow duration due to increased impervious areas can result in channel changes due to increased scour of the bed and banks of downstream creek channels. For example, in an

undeveloped state a 500-ha catchment would experience flows > $1m^3/s$ over about 120 hours in any one 'average' rainfall year. When urbanised this (or higher) flows would be experienced for 210 hours per 'average' year, resulting in increased potential erosion and channel change.

The quantum of this erosional impact is dependent on:

- The scour resistance of the material which makes up the bed and banks of the creek (eg. alluvium would be much more susceptible to scour than bedrock)
- Size of the channel (larger channels have an increased capacity to accommodate changes in low flows)
- Bed grade (e.g. with flat bed grades on the lower reaches of a creek flow velocities are generally low compared to a high energy mountain stream which has a steep bed grade).

Direct changes in physical geometry of the creek can also occur in and around proposed bridge crossings or where creek diversion/piping is proposed.

Development can also change the quantum of sediment which is available within a catchment. Long-term increases in sediment load can cause accretion of sediment within pools, whilst long term decreases in sediment can cause bed lowering by starving the creek of natural bed load materials.

Once erosion occurs, the channel changes character, and needs to readjust to reach equilibrium between deposition and erosion. For instance, if a channel becomes eroded, and the cross-sectional area of the channel becomes increased, the channel can then contain more discharge before water is spilt onto the floodplain. This results in further adjustment of the channel.

## 4.3 Likelihood of Impacts

The case study presented in **Section 4** demonstrates that impacts of past urban development in the catchment have not led to significant changes in the geomorphology of Macquarie Rivulet. It is expected that the CUDP will also have minimal impact on the geomorphology of Macquarie Rivulet Delta and Marshall Mount Creek, especially considering the WSUD measures to be undertaken part of the development.

As part of their geotechnical assessment of the site, Douglas Partners (2010) assessed the potential effect of the development on erosional processes and of natural erosional processes on the potential development. Douglas Partners (2010) assess the erosion potential of the site as being restricted to the banks and beds of streams. As the alluvial flats are generally well vegetated they anticipate volumes of slumped or eroded materials to be in the range of a few cubic meters.

Douglas Partners (2010) anticipate that the development will have minimal effect on the erosion potential of the current stream courses, providing for the sound engineering of stormwater disposal methods. Proposed mitigation measures include the appropriate orientation of structures and services to minimise the requirements for excavation, the minimal removal of vegetation and the programming of works to minimise erosion. Progressive remediation of disturbed areas, especially those excavated for the purposes of re-profiling the floodplain, is recommended.

## 4.4 Potential Mitigation Measures

In order to mitigate the impacts of this land use change, the development will also incorporate onsite detention (OSD) and a number of water sensitive urban design (WSUD) features to limit maximum discharge rates and improve the water quality of stormwater runoff from the development site.

During regrading of the floodplain all final landforms will be designed to be stable and sustainable, and to ensure that there are no significant impacts on the geomorphologic conditions in the Macquarie Rivulet or Marshall Mount Creek.

All earthworks associated with the construction of bridges and other creek crossings will be designed to achieve a sustainable channel bed and minimise geomorphologic impacts.

As well as being a requirement of the development for ecological reasons the rehabilitation and revegetation of the Riparian Corridor will serve as a mitigation measure against future erosion of the stream banks and will assist in returning the watercourses to a more natural state.

Further details of these, and other mitigation measures, designed to minimise the impacts of the development on hydrology and to protect the development against natural hydrological occurrences, can be found in the Floodplain Risk Management Study (Cardno, 2010a), the Water Cycle Management Study (Cardno, 2010b) and the Geotechnical Investigation (Douglas Partners, 2010).

# 5 Case Study – Development of Albion Park

In assessing the proposed geomorphologic impacts of the CUDP there is a unique opportunity to undertake a Case Study, comparing the proposed development to the existing development of Albion Park. Albion Park is a similar sized development to Calderwood (refer **Table 5.1**) and is located in the same floodplain downstream of the subject site, with similar historic land uses. However, as Albion Park was developed in the mid 1900's there has been sufficient time to determine if the development has had any mid-long term impacts on the local geomorphology.

Albion Park is a development of approximately 3,000 houses and is home to 11,000 people. The suburb is located south of Wollongong and downstream from the Calderwood site on the Macquarie Rivulet. Prior to its development into an urban centre, Albion Park was comprised primarily of farmland.

The area was first colonised after being cleared as part of the Red Ceder forestry industry in the early 1800's. The first bridge over Macquarie Rivulet (Albion Park Rail) was constructed in 1858 and by the early 1900's Albion Park was coming to be known as a lucrative beef and dairy cattle district (Shellharbour Council, 2010). Urban development of the area commenced in the mid 1950s and has continued in earnest ever since.

It is noted that riparian corridor and WSUD measures were not undertaken in the development of Albion Park to control sediment and nutrient laden runoff.

**Table 5.1 – Comparisons between Albion park & the Calderwood UDP**

| | Albion Park | Calderwood |
|---|---|---|
| **Site Area** | 500 ha | 700 ha |
| **Houses** | 3,000 | 4,800 |
| **Population** | 11,000 | 12,400 |
| **Catchment** | Macquarie Rivulet | Macquarie Rivulet |
| **Catchment Size** | 7,500 ha | 6,000 ha |
| **Current land uses** | Cleared/Rural/Urban | Cleared/Rural/Farming |

## 5.1 Potential Impacts to be examined

The urban intensification of an area previously used for farming changes a range of hydrological processes. The increase in impervious areas increases the amount of surface water runoff entering watercourses. A consequence of this is erosion within the watercourse, if not appropriately managed. The increased surface runoff also has the capacity to increase flow volumes and velocities in the stream, this may in turn lead to increased bank erosion, or the altering of the streams path. The conversion of farming land to urban land may also lead to some benefits for stream health, such as a decrease in the amount of suspended sediment and nutrients being transported into the stream.

Possible changes to Macquarie Rivulet since the construction of Albion Park, which will be examined below, include:

- Effects of increase in impervious area (increased volumes and velocities of runoff)
- Mobilisation of fine sediments on the floodplain
- Bed and bank erosion
- Lateral movement of the channel

- Increasing channel depth
- Revegetation of the riparian corridor.

## 5.2 Impact Assessment

To be able to quantify the impact of the development of Albion Park on Macquarie Rivulet, comparisons have been made between aerial photographs from before Albion Park was fully developed (LPMA, 1949) and aerial photography from well after Albion Park was developed (Hatch, 2001). Statements made about the geomorphological condition of Macquarie Rivulet, and impact of any development are also supported by published literature, where available and appropriate.

### 5.2.1 Urban Development

Initial comparisons between 1948/49 and 2001 aerial photography show that significant development has occurred around Albion Park during the 52 year period between the photographs (refer **Figure 13**). Development in Albion Park was not carried out all at once, but in staged land releases as the need arose. This is similar to the manner in which Calderwood is proposed to be developed. Macquarie Rivulet can be seen running along the top of the photographs in **Figure 13**.

**Figure 13 – Comparison of Development at Albion Park between 1949 (Left) & 2001 (Right)**

Nanson and Young (1981) describe the deepening of urban channels in the Illawarra as a consequence of urban development. Although none of the channels studies were mechanically enlarged, maintenance has been undertaken in the form of channel straightening and the removal of vegetation. Under theses disturbed conditions flood discharges have scoured away the unprotected banks. Nanson and Young (1981) also note the example of Cabbage Tree Creek, which although it has widened, is still significantly smaller than equivalent rural streams. This has been attributed to the lack of maintenance undertaken in the stream, and hence the retention of dense, mat like vegetation on the banks, which has prevented them from eroding. This example shows that the retention or reestablishment of vegetation along creek lines can offset the effects of urban development.

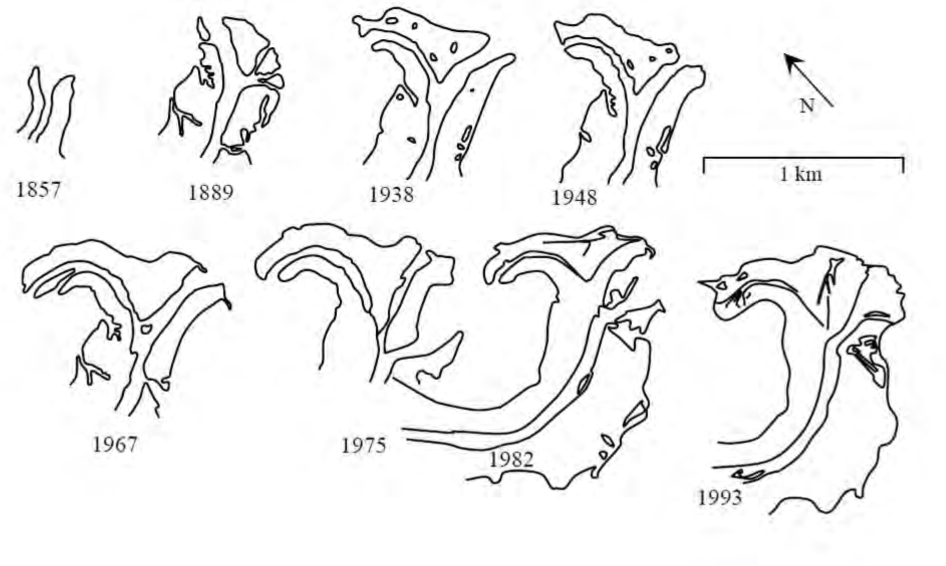
### 5.2.2 Sedimentation and Erosion

The sedimentation of Lake Illawarra has been studied extensively by researchers at the University of Wollongong. A range of papers have been published on the topic (see Sloss *et al,.* 2004; Chenhall *et* *a.l,* 1995 and Young, 1986), and most discuss the role played by Macquarie Rivulet, which is the Lake's main tributary.

A characteristic of Macquarie Rivulet is the delta that has formed at its entry into the lake. The delta has been formed by the accumulation of sediments entering the Lake from Macquarie Rivulet. The extent of the progradation and development of the birdsfoot delta is evident by observing morphological change that has occurred since initial mapping of the delta in 1857 and compared with aerial photographs from 1982. **Figure 14** shows this progression.

Sloss *et. al.* (2004) undertook radiocarbon and aspartic acid analysis of the sediments present in Macquarie Rivulet Delta, where Macquarie Rivulet enters the lake and found it to be a relatively recent deposit (approximately 350 years old). The rate of this sedimentation was then determined from aspartic acid derived ages obtained from fossil molluscs and $^{137}Cs$ data. It was determined that the rate of sedimentation has increased in the last 40 years from a rate of approximately 4.5 mm/yr to a rate of 31 mm/yr in the pro-delta region (based on an aspartic acid derived age of *ca*. 40 yr on *N. trigonella* at a core depth of 125 cm).

**Figure 14 – Evolution of Sediment at Macquarie Rivulet Delta (Sloss *et. al.* 2004)**




Sloss *et. Al.* (2004) conclude that:

***"Accelerated sedimentation associated with deforestation and rural expansion, as well as the development of industrial and urban areas around Lake Illawarra, has had a dramatic affect on sedimentation rate and deltaic development associated with fluvial runoff. This accelerated sedimentation poses significant environmental problems, particularly in the regions of Macquarie Rivulet, Duck Creek and Hooka Creek where bay-head delta progradation has resulted in sedimentation rates up to 7 mm/yr."***

According to Chenhall *et al* (1995) rates of sediment accretion, prior to catchment clearing, urbanization, and industrialization have been estimated at less than 1 mm $yr^{-1}$, thus indicating a general tenfold increase in sediment accumulation adjacent to the western foreshore caused by catchment development.

The is no doubt that there has been increased sedimentation at the Macquarie Rivulet Delta in the last 50 years, however, it is unknown what percentage of this is due to urban development. As shown in **Figure 14** the sedimentation of the delta began long before the development of the township of Albion Park in the mid 1950s. Although there have been increased levels of sedimentation in the last 200 years, there is no evidence that sedimentation rates have increased since the development of

Albion Park. Once the vegetation has been cleared, stream velocities will not return to their previous state without active revegetation, and hence the effects will continue into the future rather than ceasing when the clearing stops.

Increased sediment loads in streams where the catchment has been subject to land clearing are well documented, with loads increased by an order of magnitude in some cases (e.g. Milliman *et al.* 1987). Fryirs and Brierley, (1999) examined the changing nature of sediment sources since European settlement in the Wolumla catchment, near Bega, and found that vegetation clearance and dairy faming triggered the major changes to sediment delivery in the catchment. In the period post 1944, when most urban development is assumed to have occurred (and the effects of clearance minimised), there was very little geomorphic change in the catchment and minor rates of sediment release noted. The clearance of 70% of the 1040km$^2$ Bega River Catchment has also been implicated in significant changes in the River's morphology. The clearance in association with the addition of stock grazing and the introduction of stock grazing has lead to bank destabilisation, channel expansion and increased levels of sedimentation (Brooks and Brierley, 1997).

In comparison with the effects of clearing and rural use, sedimentation loading in relation to urban development is a two stage process. There may be increased sediment loadings during construction and earthworks, where bare ground is exposed. This mobilisation is often large (1 to 2 orders of magnitude) but then often decreases to levels less than those seen for forested areas (Brierley and Fryirs, 2005). The trade off may be increased velocities on channels as a result of stormwater discharge and associated channel erosion. These potential impacts are discussed in the following sections.

### 5.2.3 Lateral Movement

The historic form and development of Macquarie Rivulet is described by Neller (1979). By examining the ages and forms of the alluvial terraces (which he found to be much younger than the last major flow reduction), Neller (1979) found that, prior to the last incision (approximately 2000 years ago), the channel pattern would have been more sinuous than it is now. According to Neller (1979) Macquarie Rivulet is in an equilibrium form and is not currently susceptible to large channel movements.

In relation to the current morphology of the channel, Neller (1979) determined that the Osage steam style meanders seen in Macquarie Rivulet are not the consequence of underfittness, which often causes meanders to be wider the required by the active channel and would have been caused by a recent reduction in stream flow.

Neller (1979) also found that bedrock control does not affect the form of the channel, with the area around the active channel being comprised mainly of alluvium and bedrock outcrops. Outcrops of Budgong Sandstone and Berry Siltstone offer little resistance to flow and the Latite outcrops being comprised of resistant, well jointed rock that does not affect channel alignment.

Neller (1979) instead concluded that, rather than being in a state of flux, or responding to historical conditions, the current form of Macquarie Rivulet is in equilibrium, with the wide meanders and terracing a result of infrequent, but intense flooding that is characteristic in the catchment. The main alluvial channel is therefore not the channel which has given Macquarie Rivulet its current shape.

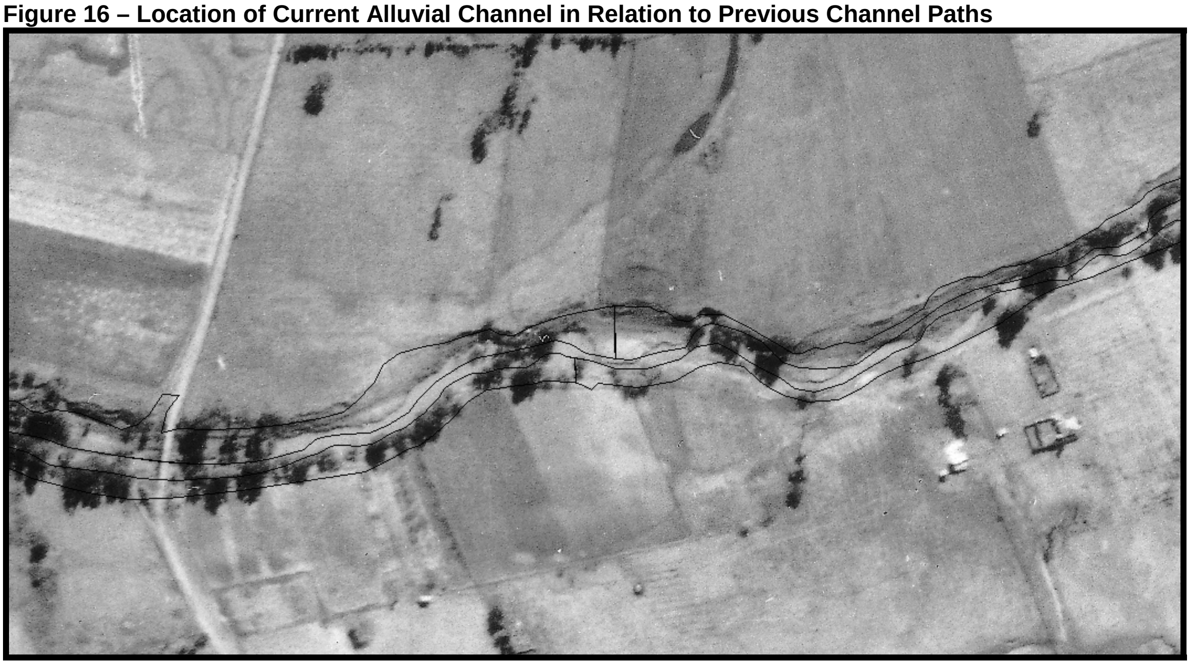
In **Figure 15** a false colour version of the historic aerial (1948 and 1949) are displayed with the true colour current aerial (2001). In the false colour imagery the vegetation along the creek line stands out. It can be seen from this comparison that the path of Macquarie Rivulet has not changed in the 50 years since the devolvement of Albion Park.

**Figure 15 – Comparison of Macquarie Rivulet between 1948/1949 (False Colour) & 2001 (True Colour)**

**Figure 16** shows the current location of the channel and banks as digitised from ALS (AAM Hatch, 2001) data (the black lines). These lines are displayed on top of 1949 (LPMA, 1949) aerial photography.

As can be seen, there are very few differences between the historic channel (as shown in the photos) and the current channel. There has been very little lateral movement of the banks, and minor movement of the low flow channel during this period.

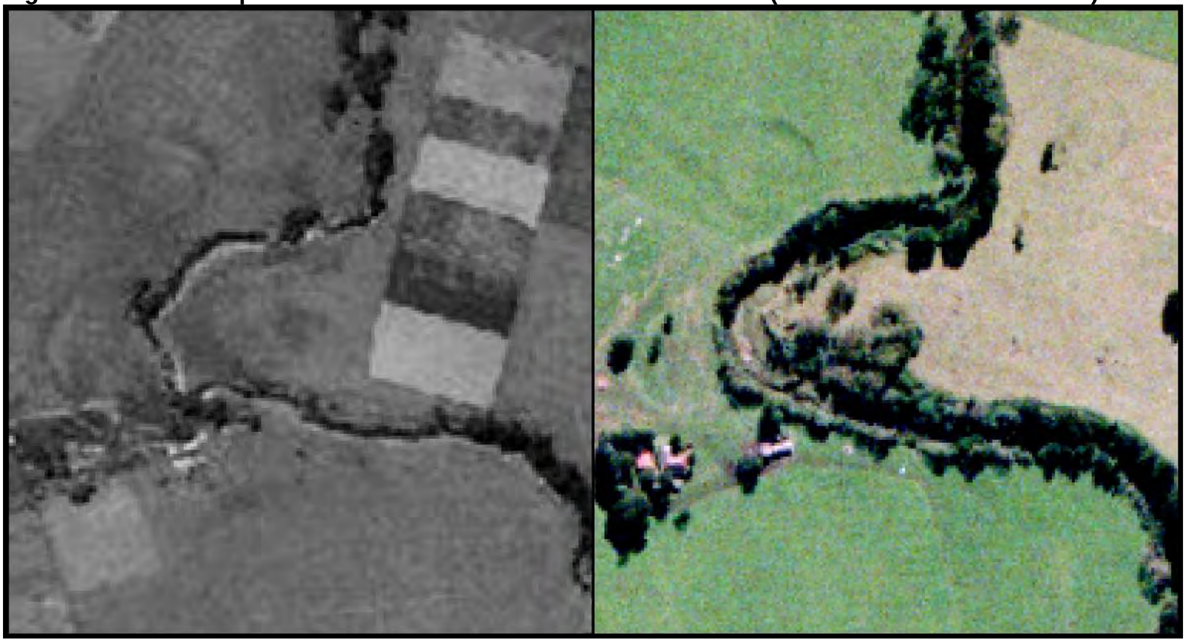
**Figure 16 – Location of Current Alluvial Channel in Relation to Previous Channel Paths**



### 5.2.4 Depth

In the 52 years between 1948/49 and 2001 Macquarie Rivulet has deepened with the main channel becoming more incised. This can be seen in the aerial photography comparisons, such as the example on this bend in **Figure 17**.

**Figure 17 – An Example of Channel Inclusion between 1948 & 2001 (Downstream of Albion Park)**



This incision of the alluvial channel and resultant terracing of the floodplain is to be expected in an area that has been subject to such extensive clearing. The removal of vegetation from the catchment has lead to increases velocities of flow in Macquarie Rivulet. These increased velocities would, in tern have lead to bed erosion, and potential bank collapse, leading to the more deeply incised form of the creek. In addition to the clearing of the catchment the introduction of cattle to the landscape may have exacerbated this process. In many places along Macquarie Rivulet access to the channel is uncontrolled and it is able to be crossed by stock. This is evidenced in photographs of Marshall Mount Creek showing the channel devoid of vegetation. The provision of stock access to the creek is likely to have significantly increases levels of bed erosion and bank collapse in the catchment. This is also evidenced by the increased sedimentation rates observed at the delta which are likely due to increased stream velocities and the mobilisation of stream bottom sediments.

Although the channel has obviously deepened in the last 50 years, this is likely a continuation of an earlier process, started when the land in the catchment was cleared of ceder trees in the 1800s. As stated this process would have also been exacerbated by the conversion of the catchment for cattle farming. Most historic stream incision in SE Australia was caused by humans due to influences such as land use changes and disturbance of local vegetation (Rutherford, 2000). As processes such as land clearing decrease, so is the impact on erosion and deposition in channels on SE Australia, however there are also many secondary effects of past change still occurring today (Rutherford, 2000).

On top of the attributable to land clearing and rural use impacts, the addition of urban development to the catchment and the associated impacts on geomorphology are thought to be minor. Evidence of the minimal impacts of the urban development can be found by comparing sites upstream of the development, which would have not been subject to these impacts to those downstream.

The incision of Macquarie Rivulet upstream of where any development has occurred, is comparable to that downstream, indicating that the clearing of forested land and conversion to rural use was the primary factor leading to increased bed erosion of the channel, and increased sedimentation in Lake Illawarra.

### 5.2.5 Revegetation of the Riparian Corridor (and other WSUD measures)

The development of Albion Park did not include the addition of WSUD features to control the quality and volumes of stormwater running off from the site.

An example of a development in the catchment which did include control measures similar to these proposed at Calderwood is the development of Tullimbar (Barthelmess, 2007). As well as incorporating a range of WSUD measures into the urban design to control the duration and velocity of stormwater outflows, the development of Tullimbar also included the rehabilitation of the riparian corridor, along Hazelton and Cooback Creeks, which discharge into Macquarie Rivulet just upstream of Albion Park.

Using the underlying geomorphological "style" as a template, these ephemeral streams were reconstructed to mirror their original state, prior to the modification of the catchment during forestry and farming and the subsequent introduction of cattle, which lead to problems such as increased bank erosion.

In the five years since the construction of Tullimbar and the creek rehabilitation there have been several 5+ year ARI floods. The site performed as designed and did not result in any significant geomorphic failures. This case shows that with implementation of effective WSUD measures and watercourse rehabilitation can prevent the development from having any off site impacts.

## 5.3 Summary

Geomorphologic processes are slow and caused over long time periods. The effects of the clearing of the land in the Macquarie Rivulet catchment are still manifesting themselves and shaping the form of the delta. The increasing depth of Macquarie Rivulet, which can be attributed in increasing stream causing bed erosion via sediment mobilisation (and deposition of this sediment at the delta) are evidence of this process.

The development of Albion Park reflects a significant change in land use in the catchment, however this development did not appear to have any significant effect on, nor exacerbate existing erosion processes in the catchment.

Relative to forest clearance the impacts of urbanisation tend to be relatively localised (Brierley and Fryirs, 2005). The biggest change in the catchment in recent time (i.e. the last 200 years) has been the clearing of trees. According to Smith (1976) (in Knighton,1998) bank Sediment with a root volume of 16-18 percent and 5 cm root mat is 20,000 times more protected from erosion than comparable sediment without vegetation.

The removal of trees has the dual effect of increasing the velocity of runoff and removing the cohesive capacity of the root systems in the soil. Both of these effects are capable of causing the increased erosion and mobilisation of sediment in the floodplain, on the creek banks and within the stream. Albion Park is also known dairy country and the erosion impacts of stock, due to disruption of the topsoil and degrading of creek-banks is also well documented in this catchment (Barthelmess, 2007) as well as being acknowledged in as a more widespread problem (Rutherfurd *et al* 2000).

The best demonstration of the minimal impact of the Albion Park development on Macquarie Rivulet is to undertake comparisons in both time and space (i.e. between current and historical aerial photos and between areas upstream and downstream of the recent development). In all instances Macquarie Rivulet shows little evidence of significant lateral movement. Changes in depth of the creek are very similar both upstream and downstream of the development and there is no evidence of increasing rates of sedimentation at the delta since the development of Albion Park.

Therefore, it can be seen from the above case study that urban development can be undertaken without significant adverse impacts on geomorphology. More specifically, the development of the CUDP would be anticipated to have as little as affect as the Albion Park Development on the Macquarie Rivulet. It is also noted that the development of Albion Park was undertaken without the stringent WSUD measures that are incorporated into modern developments. Such measures were shown to be effective in the Macquarie Rivulet Catchment during the recent development or Tullimbar Village. The development of the Calderwood Valley will include a range of engineered stormwater measures, as well as man-made protection of the watercourses and the revegetation of riparian corridors.

**Table 5.2 – Summary of Impact Assessment**

| Potential Impact | Case Study Example | Calderwood Assessment |
|---|---|---|
| Effects of increase in impervious area (increased volumes and velocities of runoff) | There are no observable changes in Macquarie Rivulet attributable to increased runoff volumes and velocities, and the morphology of this stream is such that it is able to accommodate large flow variations. | Negligible impact. Both Macquarie Rivulet exhibit characteristics of streams which are adapted to carry variable flows (Osage meanders and terracing) .<br><br>Flow variations due to the development are also likely to be minimal due to the implementation of WSUD and other mitigation measures. |
| Bed and Bank Erosion | Deemed to be primarily caused by the clearing of the land for forestry and agriculture and the subsequent cattle access to the channel. Negligible impact from Urban Development. | Negligible Impact. The revegetation of the riparian corridors should actually assist in improving in stream habitat and minimising both bed an beak erosion which causes this deepening. |
| Increasing channel depth | Linked to the bad and bank erosion mentioned above. This was also deemed to be mostly due to the clearing of the catchment and the trampling of vegetation by cattle. | Negligible impact. The revegetation of the riparian corridors should actually assist in improving in stream habitat and minimising both bed an beak erosion which causes this deepening |
| Lateral movement of the channel | There is no evidence of the lateral movement of Macquarie Rivulet channel in recent times, indicating that the stream is in an equilibrium state. | Negligible impact. Both Macquarie Rivulet exhibit characteristics of streams in an equilibrium state. |
| Mobilisation of fine sediments on the floodplain | Negligible increase in sedimentation which can be liked to urban development. In fact the conversion of rural land to urban uses is known to reduce fine sediment loadings. | The conversion of agricultural land to urban land should decrease levels of fine sedimentation.<br><br>Further the addition of mitigation measures, such as OSD ponds, will minimise the impact of urban stormwater on the natural systems. |
| Revegetation of the Riparian Corridor | No significant geomorphic failures reported during flood events. The rehabilitation of the riparian corridor and exclusion of cattle has also improved stream habitat. | No adverse impact. In fact, as the catchment was naturally covered in vegetation these works will assist in returning Marshall Mount Creek and Macquarie Rivulet to more natural states. |

# 6 Conclusions and Recommendations

In this report it has been shown that the major changes in the geomorphology of both Macquarie Rivulet and, by virtue of its similarities in location and structure, Marshall Mount Creek, have been caused by the clearing of the catchment for forestry and its subsequent use for dairy farming applications. Urban development within the catchment was shown to have negligible effect on geomorphology.

The clearing and rural land uses have also had an effect on the smaller tributaries within the catchments and so an assessment was also undertaken to determine the condition and relative hydrological value of the smaller creeklines in the site, along with the geomorphology of Macquarie Rivulet and Marshall Mount Creek. This process resulted in a number of changes in the classifications of the streams on the site and provides an accurate assessment of the hydrology and stream structure within the site. These classifications were then used to inform the allocation of riparian corridors widths and their inclusion into the Masterplan.

If a development the size of Albion Park can be shown to have negligible effect on geomorphology, without the implementation of mitigation measures, a development of a similar size with mitigation measures would also be expected to have negligible impact. With the use of appropriately engineered stormwater control measures the development is not expected to have an adverse impact on the morphology of Macquarie Rivulet or Marshall Mount Creek.

During construction the appropriate mitigation measure will be put in place to ensure minimal impact to geomorphology. This may include the use of the appropriate sediment and erosion controls, timely revegetation to ensure minimal time of soil exposure during any excavation works and the adoption of industry best practice for the installation of culverts, outlets and crossings. Post development and with the implementation of the appropriate stormwater control measures including OSD, there should be no increase in flow volumes into either catchment due to the proposed development. Details of the water management measures to be implemented art the site can be found in the Water Cycle Management Study (Cardno 2010a).

Notwithstanding the above, there are some natural features of both Macquarie Rivulet and Marshall Mount Creek which makes them resilient to any potential change in flow regime. These include, gentle bed grades, large channel with self-armoured bed, high channel stability attributed to the generally cohesive nature of surface floodplain sediments. Further, due to the nature of their catchments, these stream have developed under naturally variable flow regimes and therefore should be able accommodate some increase in low flow due to an increase in impervious areas.

The retention and rehabilitation of riparian corridors associated with the development, including revegetation and exclusion of cattle, may in fact lead to improved geomorphological outcomes, returning the major and minor watercourses to a more natural state and protecting them from erosion. An example of such an improved stream system can be found at the Tullimbar development, which is also located in the Macquarie Rivulet Catchment (Barthelmess, 2007).

Further details of the proposed WSUD measures to be implemented in association with the development, as well as a detailed description of the riparian corridor rehabilitation can be found in the Floodplain Risk Management Study (Cardno 2010a) and the Water Cycle Management Study (Cardno 2010b) prepared to support this application.

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