YARRABILBA PRECINCT 3

WATERWAY STABILITY ASSESSMENT

VERSION 1

PLANS AND DOCUMENTS
referred to in the PDA
DEVELOPMENT APPROVAL

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1 INTRODUCTION

The Yarrabilba Priority Development (PDA) is located within the Logan City Council area and occupies a former pine plantation south of Logan Village. The Yarrabilba PDA was declared by regulation under the Economic Development Act (2012). Yarrabilba is part of a regional growth area identified in the South East Queensland Regional Plan, which identifies a need for a further 70,000 dwellings across a number a localities in the Logan council area by 2031. The Yarrabilba development aims to provide approximately 17,000 dwellings for a population of 45,000.

Precinct 3 covers an area of approximately 245 ha which includes approximately 137ha of development (lots, road, schools, parks) and approximately 108ha of environmental and conservation land.

This document presents the waterway stability assessment and strategy for Yarrabilba Precinct 3 to meet the requirements required by the State Planning Policy, *Yarrabilba Total Water Cycle Management Strategy* (DesignFlow, 2012) and *Yarrabilba Stormwater Infrastructure Master Plan* (DesignFlow, 2012). This report provides details of waterway buffers, management of waterway stability flows and waterway stabilisation measures to protect the form and function of the waterways within the site. The assessments were made based on field visits, desktop review of soils and LIDAR survey and historic aerial imagery. In addition, review of expected bed shear stresses as a result of development were competed.

The strategy presented in this report is to be refined as part of design development for each stage. Separate reports detail the stormwater quality and flood management strategies and can be read in conjunction with the information presented herein.

2 SITE CHARACTERISTICS

2.1 SITE LOCALITY

Precinct 3 (subject of this report) is the third major development area to be released at Yarrabilba and lies in the north eastern portion of the Lend Lease site extending from Precinct 2 across to the eastern site boundary adjoining Plunkett Reserve as shown in Figure 1. The precinct covers a total area of 254 ha which includes a significant proportion of waterway and conservation open space (approximately 157 ha or 60% of Precinct 3) as well as a major powerline easement buffer bordering the southern edge of the precinct.

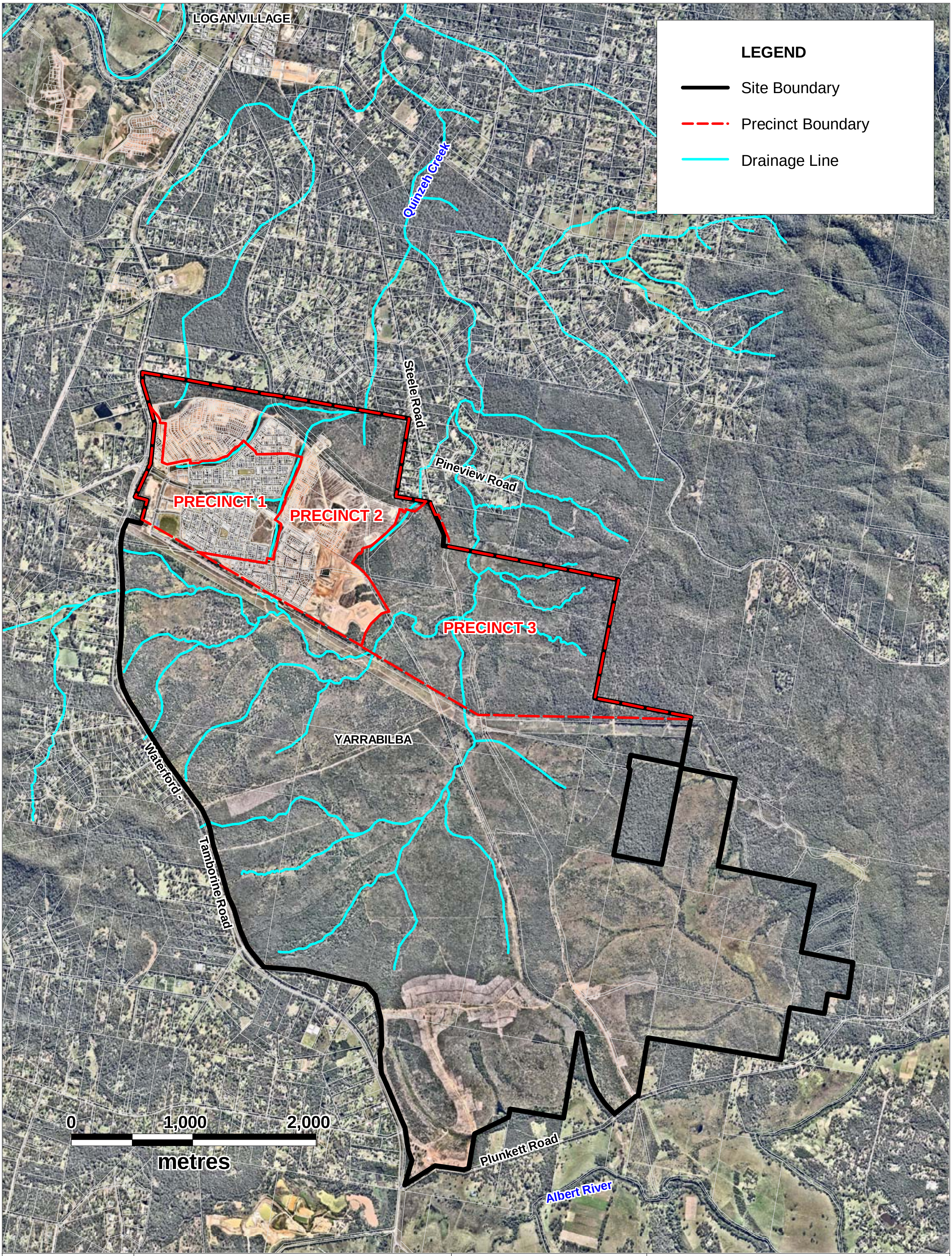
2.2 TOPOGRAPHY, CATCHMENTS AND DRAINAGE

The general topography across the site ranges from moderate grades (generally typically 2-6%) with broad flat zones along Quinzeh Creek (0.5%). Elevations range from 100m AHD at the south eastern corner of the site area to approximately 23mAHD at the northern boundary at the discharge of Quinzeh Creek. The eastern part of the site is very steep up to 25%.

As illustrated in Figure 2, the majority of Precinct 3 development drains toward Quinzeh Creek (Stream 2), which discharges north of the site. At the north-west corner of the development approximately 20ha of Precinct 3 combines with a further 27ha from Precinct 2 to drain via a flat wide depression to the northern boundary of the size.

Figure 3 illustrates the topography for Precinct 3 and identifies the streams of interest. These stream identifications are used throughout the remainder of this document.

Three stream exist (Streams 3 to 5) in the eastern half of the development area will receive drainage from Precinct 3B and C, prior to discharge to Quinzeh Creek. At the southern end of Precinct 3, a natural wetland area has been mapped and will be protected.



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Project: 4316

Yarrabilba Precinct 3
Waterway Stability Assessment

Client: Lend Lease

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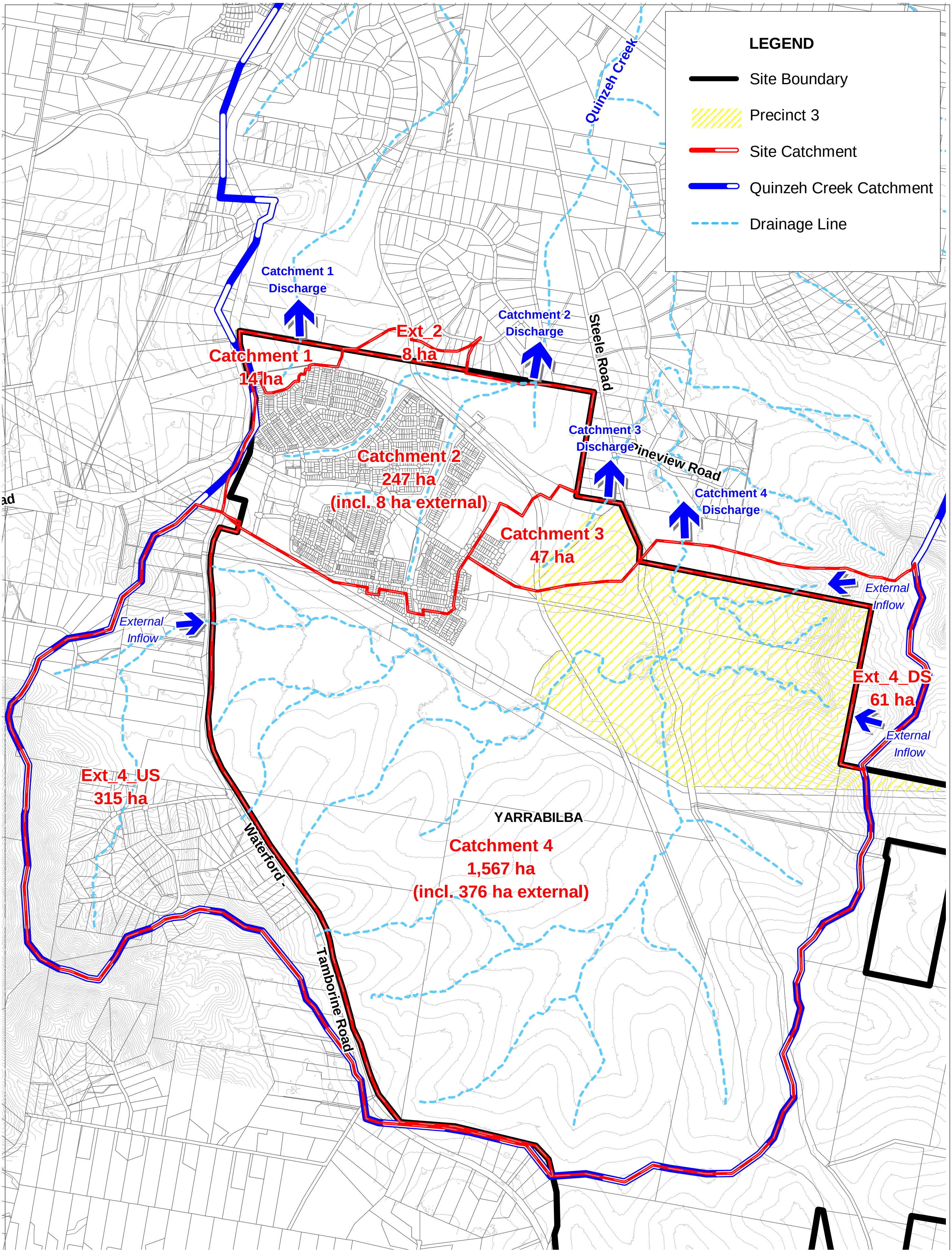
FIGURE 1

Site Location



Prepared by: DesignFlow For: lendlease	Project: 4316 Yarrabilba Precinct 3 Waterway Stability Assessment	N W E S Scale: 1 : 30,000 (A4)	**FIGURE 2** **Topography, Catchments and Drainage**
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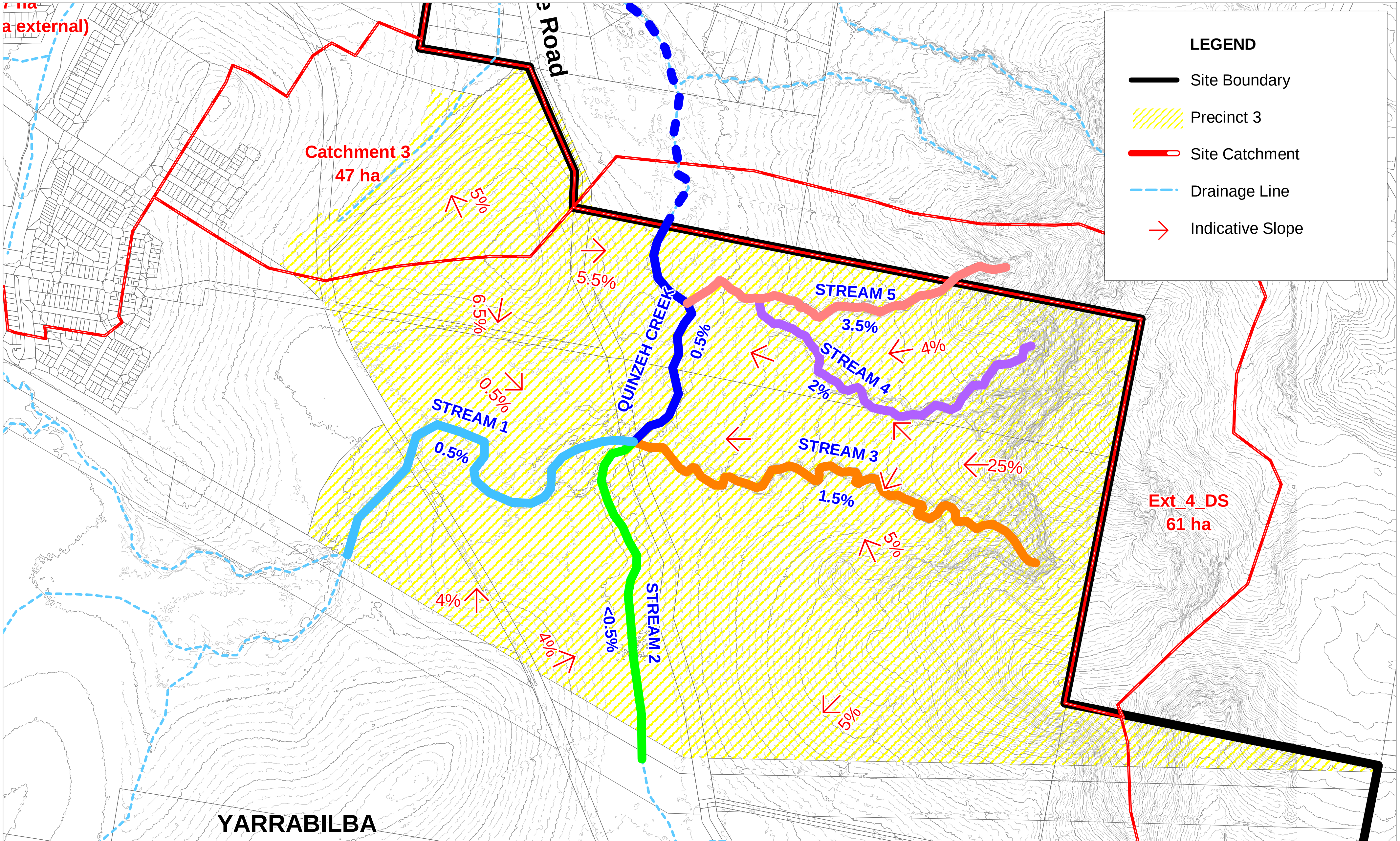

1.0m Contour Interval

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Yarrabilba Precinct 3
Waterway Stability Assessment

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FIGURE 3

Topography and Stream Identification

2.3 SOILS AND VEGETATION

Geological mapping indicates Precinct 3 is located across two geological units:

- Woogaroo sub-group (R-Jo) -Precinct 3A; and
- Ispwich Coal measure (Ri) – Precinct 3b and c

Broad scale geotechnical investigations completed across the site (Bowler, 2004) indicate subsurface soils are typically sands overlying silty clays and weathered sandstones. Soils are typically dispersive across the site. The soil conditions for Precinct 3, particularly Precinct 3A, are not expected to vary significantly from those encountered for Precincts 1 and 2. Some variances may occur, particularly in the eastern side of the Precinct (Precincts 3B and C) where geology changes to Ipswich Coal measures. In this instance higher strength rock and more saturated deep sand profiles may occur, mainly along drainage lines, although in general areas where development will occur for Precincts 3B and C are likely to be similar to Precinct 3A conditions. Further site specific geotechnical investigations will occur to confirm soil conditions.

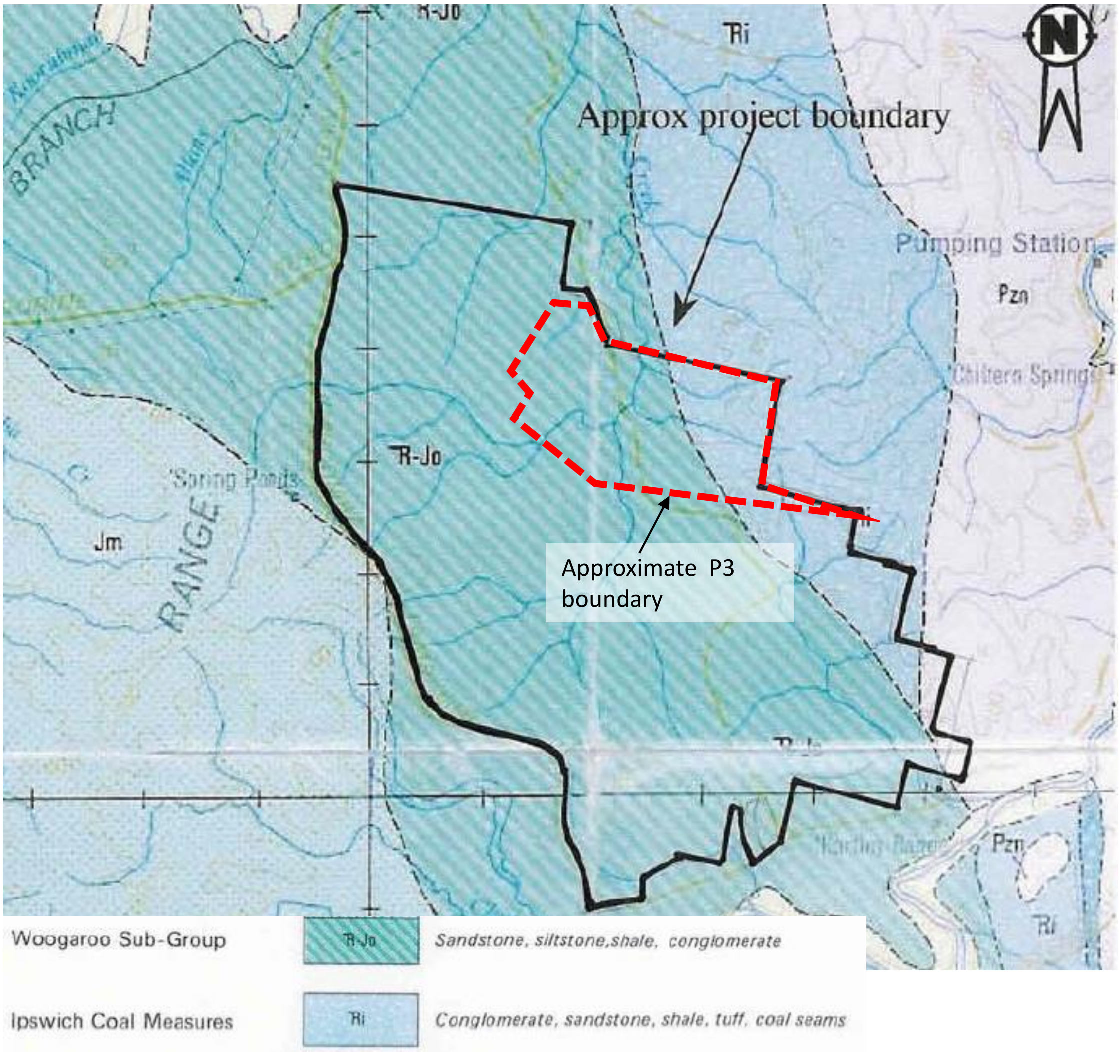


Figure 4 Geology and soils

2.4 VEGETATION

The majority of the Yarrabilba site was formerly pine plantation with current undeveloped areas of the site are now broadly associated with grassland or pine/eucalypt/acacia regrowth with local areas of higher value ecological vegetation communities as documented in the *Natural Environment Site Strategy* (Natura, 2016). Historical aerial imagery illustrates grassland and pine areas represented roughly 80% of the existing land use across the Yarrabilba site, which have subsequently been covered with regrowth (refer to DesignFlow, 2014). Dense vegetation generally occurs along drainage lines in the development area.

Vegetation management will generally be undertaken in accordance with *Yarrabilba Development: Natural Environment Site Strategy* (Natura Consulting, 2012) which highlights vegetation management procedures with regards to clearing approvals, revegetation, monitoring/compliance and design requirements.

The fauna corridor and Plunkett Conservation Park represent the main ecological constraint for development within the Precinct 3 boundary. The *Natural Environment Site Strategy (NESS)* (Natura Consulting, 2012) provides an overarching plan that pulls together the individual Infrastructure Master Plans, such as Fauna Corridor Master Plan (Natura Consulting, 2012).

The drainage lines and waterway corridors within Precinct 3 exhibit a range of conditions. Some of the riparian zones are in a healthy condition whereas others are affected by weeds and historical vegetation clearing. The vegetation directly adjacent and within the waterways of Precinct 3 is broadly described as below:

- Waterways and streams are densely vegetated.
- Ephemeral vegetation communities such as Lomandra, Xanthorea , Blady grass, Melaleuca and Eucalyptus are common throughout the waterways, with increasing grass communities in lower lying areas
- The invert of the waterways is generally sandy with minor vegetation coverage

2.5 PROPOSED DEVELOPMENT

Precinct 3 development is located at the northern end of the Yarrabilba development boundary and is bisected by Quinzeh Creek. The total area of Precinct 3 development boundary is approximately 245ha. As illustrated in Figure 5, a significant portion of Precinct 3 development is associated with fauna, waterway and conservation corridors (>50%).

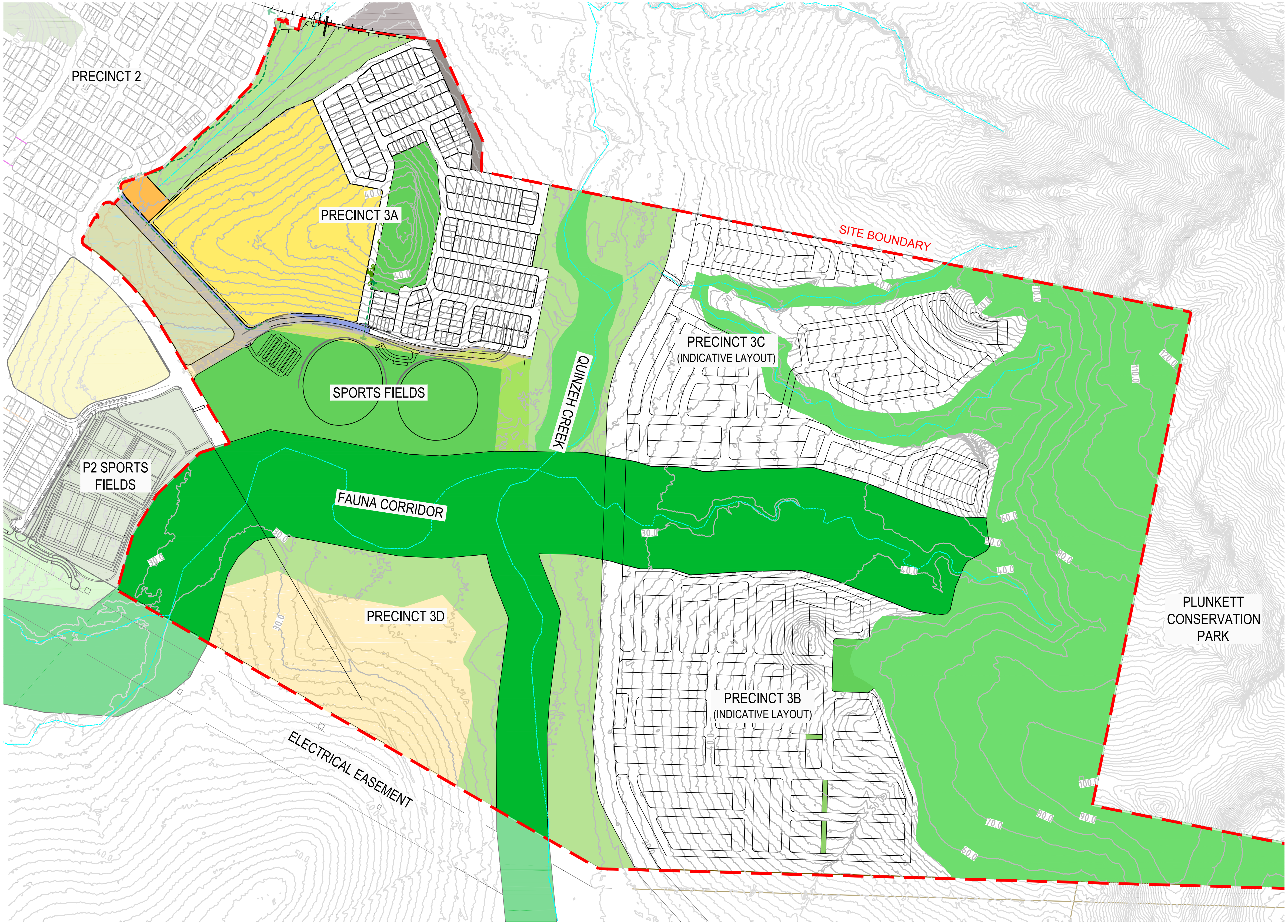
Precinct 3 is divided into 3 development zones (refer to Figure 5):

- Precinct 3A (61.4 ha)
- Precinct 3B (31.9 ha)
- Precinct 3C (24.8 ha)
- Precinct 3D (12.3ha)

Precinct 3A includes a mix of residential development (8.9 ha), roads (7.53ha), open space (18.82ha) a school site (12.34 ha) and community use (3.28 ha) and a child care centre (0.50ha)

Precincts 3B and 3C are mainly residential development areas only.

In the context of waterway stabilisation, Precinct 3A impacts mostly on Quinzeh Creek. Precinct 3B and C development potentially impacts on the lower half of stream 3-5 and Quinzeh Creek



LEGEND

PRECINCT 3 BOUNDARY

1:8,000

0 160 320 480m

REVISION	DESCRIPTION	DRAFTED BY INITS	DRAFTED BY DATE	CHECKED BY INITS	CHECKED BY DATE
D					
C					
B					
A	PRELIMINARY ISSUE	MJM	19.07.16	SL	19.07.16

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PRELIMINARY
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SCALE: 1:8,000 A3

PROJECT: YARRABILBA PRECINCT 3
DRAWING TITLE: FIGURE 5
PRECINT 3 DEVELOPMENT LAYOUT
PROJECT No: 4284
DRAWING No: FIGURE 5
REVISION: A

3 WATERWAY MANAGEMENT PRINCIPLES

Lend Lease are committed to protecting and enhancing the waterways and wetlands of Yarrabilba. Not only is this required by legislation but also from a community point of view. Healthy waterways that are integrated well into the landscape will be highly valued by the Yarrabilba community.

The waterway management principles which apply to Yarrabilba are listed below:

- Protect ecological zone - protection of significant ecological values (refer *Fauna Corridor Master Plan CPAS*)
- Stormwater quality - apply best practice stormwater management during construction and operational phase (refer *Yarrabilba Precinct 3 Stormwater Quality Management Plan* DesignFlow, 2016)
- Waterway buffers - suitable buffers to waterways are provided in the development to minimise impact on waterway vegetation and form and ensure the development edge is safe from potential hazards including landslips and dispersive soils (Section 4)
- Hydrologic management - hydrologic change is managed to minimise the risk of scour and erosion in waterways within and downstream of the site (Section 5)
- Stabilise waterways - stabilise locations within waterways which currently are prone to scour and following development of the site (Section 6).

The following sections define specific design objectives for waterway buffers, hydrologic change and waterway stabilisation and define strategies for achieving these objectives.

4 WATERWAY BUFFERS

4.1 OBJECTIVES

Waterway buffers aim to protect and enhance the ecosystem and character areas while protecting nature conservation values and physical processes within key waterways.

Buffer requirements for Yarrabilba as defined by *Yarrabilba Total Water Cycle Management Strategy* (DesignFlow, 2012) and *Yarrabilba Stormwater Infrastructure Master Plan* (DesignFlow, 2012) are presented in Table 1. Quinzeh Creek and Stream 1 are consider a Major Creek and the eastern tributaries (Streams 3-5) are Minor Creeks. The wetland in the southern section of the site is the Minor Wetland.

Table 1: Waterway buffer requirements

Waterway Category	Definition	Desirable minimum buffer width from waterway centreline or defined bank / edge of wetland
Major creek	Creeks with permanent flow and defined bed and banks	30 metres
Minor creek	Creeks with defined bed and banks and either permanent or intermittent flows	15 metres
Natural drainage path	Intermittent overland flow paths with or without defined bed and banks	15 metres
Major wetland	Wetlands of regional significance*	100 metres
Minor wetland	Wetlands of local significance**	50 metres

* No regional significant wetlands at Yarrabilba
** Only 1-2 wetlands of local significance at Yarrabilba

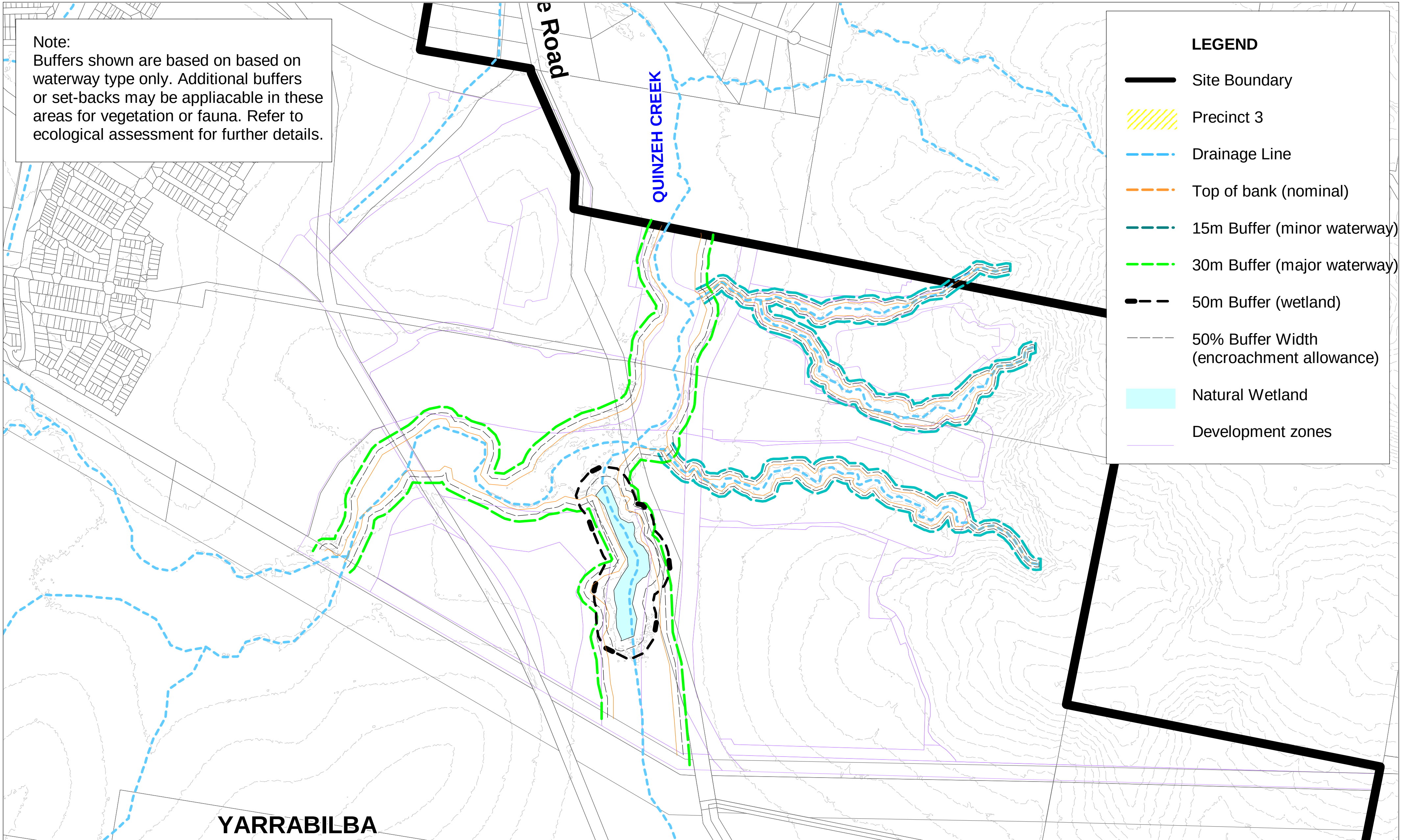
4.2 STRATEGY

The following waterway buffers have been used to inform the development layout for Precinct 3:

- 30m to Quinzeh Creek and Stream 1
- 15m to Streams 3 to 5
- 50m to the existing wetland in the south

The edge of the waterway has been mapped along with the associatd buffers with the results presented in Figure 6. Where the *Natural Environment Site Strategy and Fauna Corridor Master Plan CPAS* identifies greater setback requirements for vegetation, fauna corridors or bushfire, these will override the minimum riparian buffer widths stated above.

Where riparian buffer allowances are not constrained by other setbacks and are degraded, it may be practical to co-locate low impact uses such as vegetated stormwater treatment infrastructure or passive recreational infrastructure partly within the buffer in conjunction with rehabilitation. Figure 7 outlines the permissible uses within the defined waterway and wetland buffer widths which have been used to design the development edge for Precinct 3 and the integration with the stormwater management systems.



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Waterway Stability Assessment

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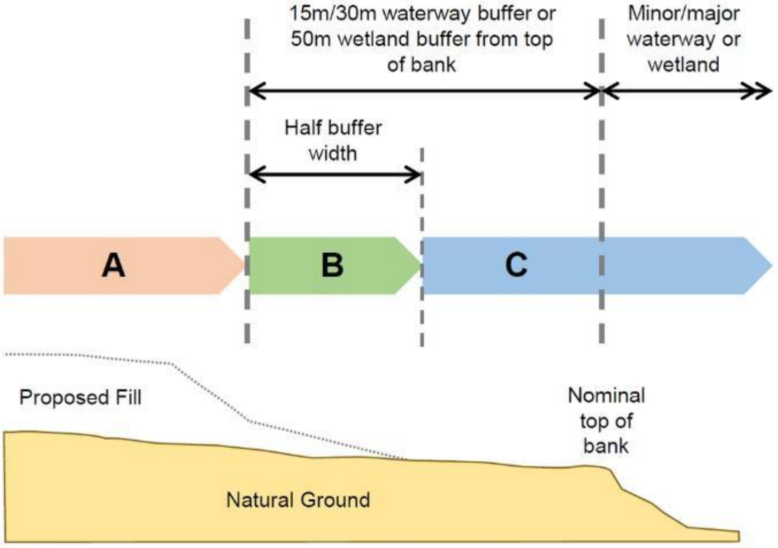
FIGURE 6

Waterway Buffers



Where a more conservative setback to earthworks or infrastructure is required for vegetation, fauna corridor or bushfire buffers, these will override the minimum buffers identified here for waterway riparian corridors. Refer to Strategy 14 for details.

Note: Buffers and permissible uses apply to land disturbing activities. Design must therefore allow for constructability to ensure encroachment/ disturbance beyond allowable zones does not occur during construction.

Permissible Uses within Waterway or Wetland Buffers:

Zone A

No restrictions to development or infrastructure from waterway/ wetland riparian buffers

Zone B

Permitted:

- Vegetated stormwater treatment systems with batters 1:4 max.
- Development batters 1:10 max. (vegetated)
- Pathways
- Zone C allowances (see below)

Not Permitted:

- Building allotments
- Road reserve (other than for waterway crossings)
- Retaining walls
- Scheduled maintenance areas of stormwater treatment systems (e.g. forebays)

Zone C

Permitted :

- Stormwater outlets/headwalls
- Waterway stabilisation works
- Riparian rehabilitation planting
- Road/water/sewer/flood bund/pathway crossings of waterway

Not Permitted:

- All other general development earthworks and infrastructure

Figure 7 Waterway Buffer Design Principles

5 WATERWAY STABILITY FLOWS

Urban development increases both the volume and frequency of stormwater runoff. An important consequence of these effects is the potential for increased erosion of the bed and banks of natural waterways downstream of urbanising areas. Without control measures in place, this increase in erosive potential typically leads to channel enlargement and a reduction in aquatic habitat value (Water by Design, 2007).

5.1 OBJECTIVES

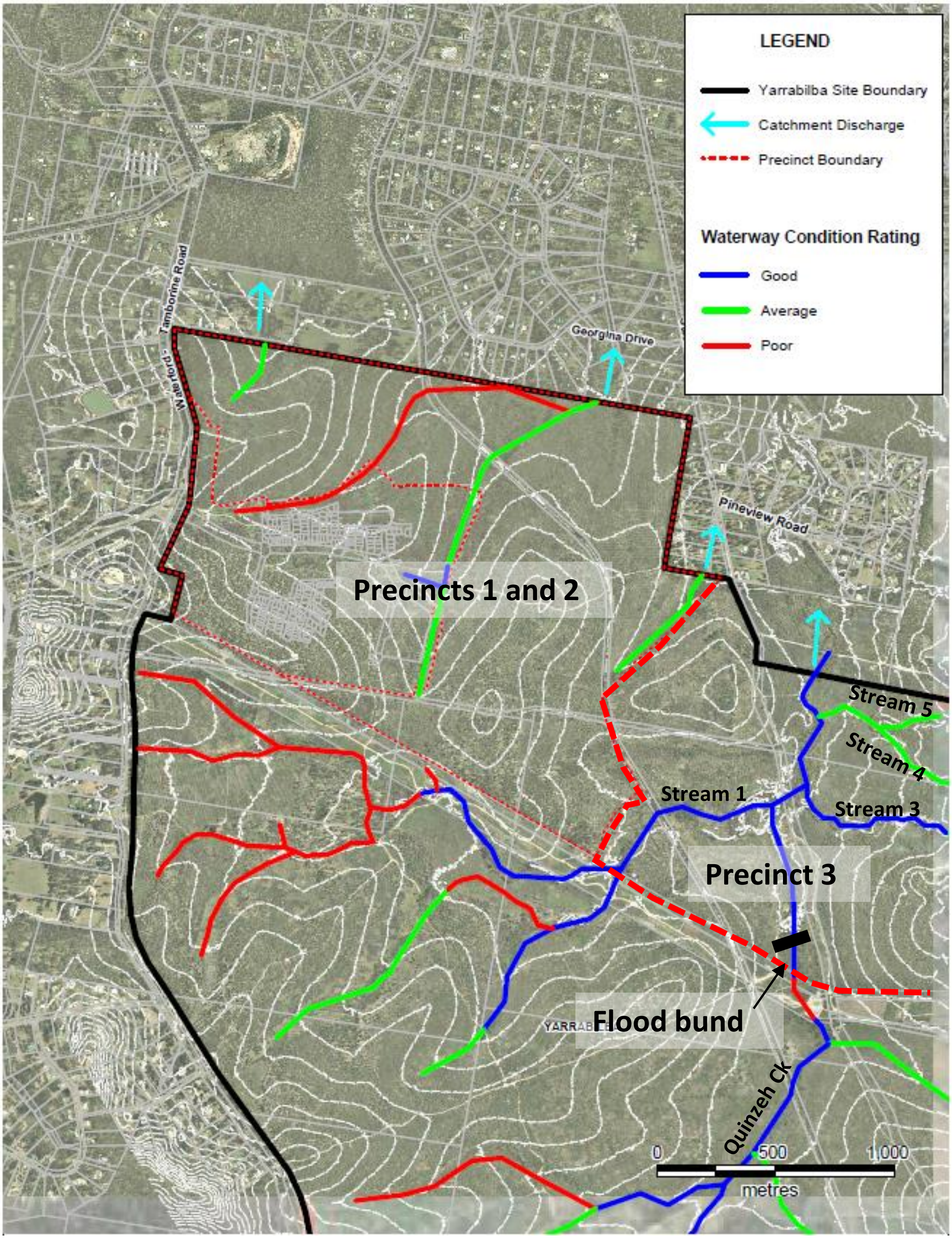
The waterway stability objectives adopted for the site are based on protecting waterways and drainage lines from erosion as a result of increased flow from urban development. This applies to waterways and drainage lines within the site as well as downstream receiving waterways beyond the development boundary. Due to the large size of the site and significant variation in waterway types and riparian and in-stream condition, the waterway stability objective has been derived for a range of situations as shown in Table 2. These objectives are consistent with the *Yarrabilba Total Water Cycle Management Strategy* (DesignFlow, 2012), *Yarrabilba Stormwater Infrastructure Master Plan* (DesignFlow, 2012) and *State Planning Policy* (DSDIP, 2016)

Table 2: Derived waterway stability objectives

Waterway classification	Waterway Stability Criteria
Site waterway reach in good condition (i.e. well vegetated and stable waterway)	Limit post development 1 year ARI flows in waterway to pre-development conditions*
Site waterway reach in poor condition (i.e. poorly vegetated or active erosion)	As per above OR Rehabilitate waterway to convey the post development 1 year ARI flows without the risk of erosion*
External waterways	Limit 1 year ARI flows at site boundary for critical duration event (60 minutes or longer) to pre-development conditions

* Localised increases in 1 year ARI flows can be accepted provided the erosion criteria for sandy vegetated soils (50% cover for native grasses) is achieved in accordance with QUDM. The objective supports the rehabilitation of degraded waterways and allows local increases in 1 year ARI provided the rehabilitation design provides an appropriately stable waterway for the increased 1 year ARI flows.

Figure 8 indicates the current condition of waterways within Precinct 3 development (ref: DesignFlow, 2014). Given the state of Precinct 3 streams are in a good to average condition managing post developed 1 year flows will important, particularly along Quinzeh Creek.



Extracted from *Yarrabilba - General Waterway Condition Assessment* (DesignFlow, 2013)

Figure 8 Precinct 3 Waterway Condition

5.2 STRATEGY

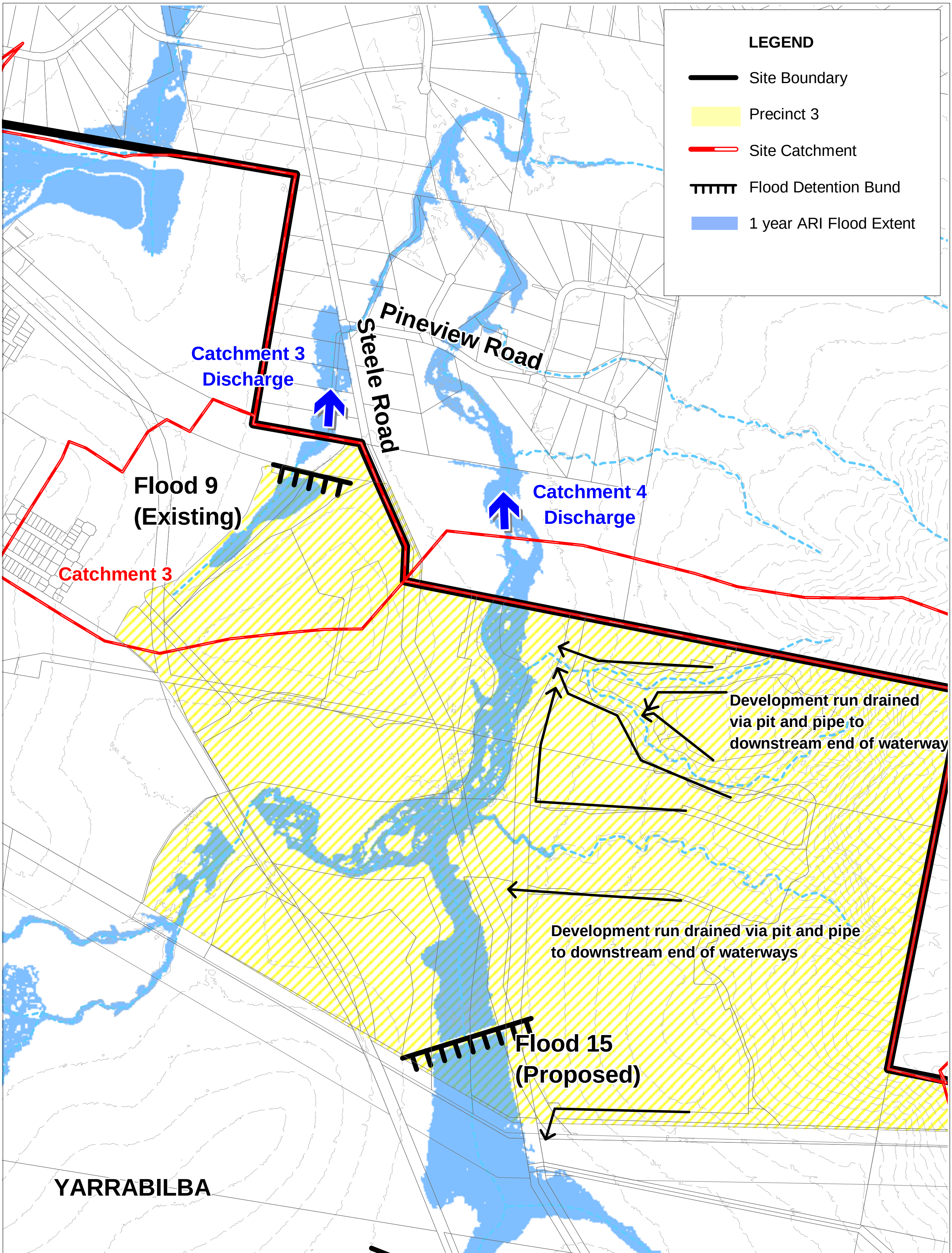
As part of the overall flood management strategy for the Yarrabilba development flood bunds are proposed in Precinct 3:

- Flood 9 – This flood detention system has been constructed at the northern western boundary of Precinct 3 to manage flood flows from Precinct 2 and Precinct 3. The detention system has been designed to ensure peak flows for the 1 to 100 year events remain at or below pre-developed levels.

- Flood 15 – This flood detention system is proposed at the southern boundary of Precinct 3 along Quinzeh Creek (Streams 1 and 2) as part of Precinct 3 works. The operation of this flood basin will ensure peak flows for the 1 to 100 year events remain at or below pre-developed levels along Quinzeh Creek within Precinct 3 boundary.

For the eastern tributaries (Streams 3 to 5) the stormwater runoff for the development is proposed to be directed to the downstream ends of these streams via the pit and pipe drainage system. This will minimise and/or avoid any increase flow impacts along the length of the streams by keeping flows within the majority of the streams below pre-developed levels.

Figure 9 illustrates the important aspects of the waterways stability flood management strategy.



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Yarrabilba Precinct 3 Flood Study

Client: Lend Lease

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Date: 11 July 2016

FIGURE 9

Precinct 3 Waterway Stability and Flow Management Strategy

5.3 MODELLING

The Yarrabilba flood model (TUFLOW) used as part of *Yarrabilba Precinct 3 Flood Study* (DesignFlow, 2016) was utilised to simulate the 1 year ARI waterway stability flow strategy. Pre and post development 1 year ARI events for a range of durations where simulated and the peak flows and velocities extracted. The results are presented in Table 3 for a number of reporting locations within Precinct 3 and immediately downstream as shown in Figure 10. The table illustrates that the 1 year ARI flows and velocities are reduced in Quinzeh Creek and Stream 1 where has they are the same in Streams 3-5.

The underlying waterway mapping in Figure 10 shows the peak velocity mapping for the post development scenario only as they are very similar or lower than the pre development velocities. The velocities through the main drainage line and Quinzeh Creek are typically very low at <0.5 m/s with isolated pockets reaching 0.5-1.0 m/s. The velocities in the eastern tributaries are higher at 0.5-1.0m/s with pockets of 1-1.5m/s which is not surprising given the grade of these waterways. Managing new inflow locations to these eastern waterways will be important.

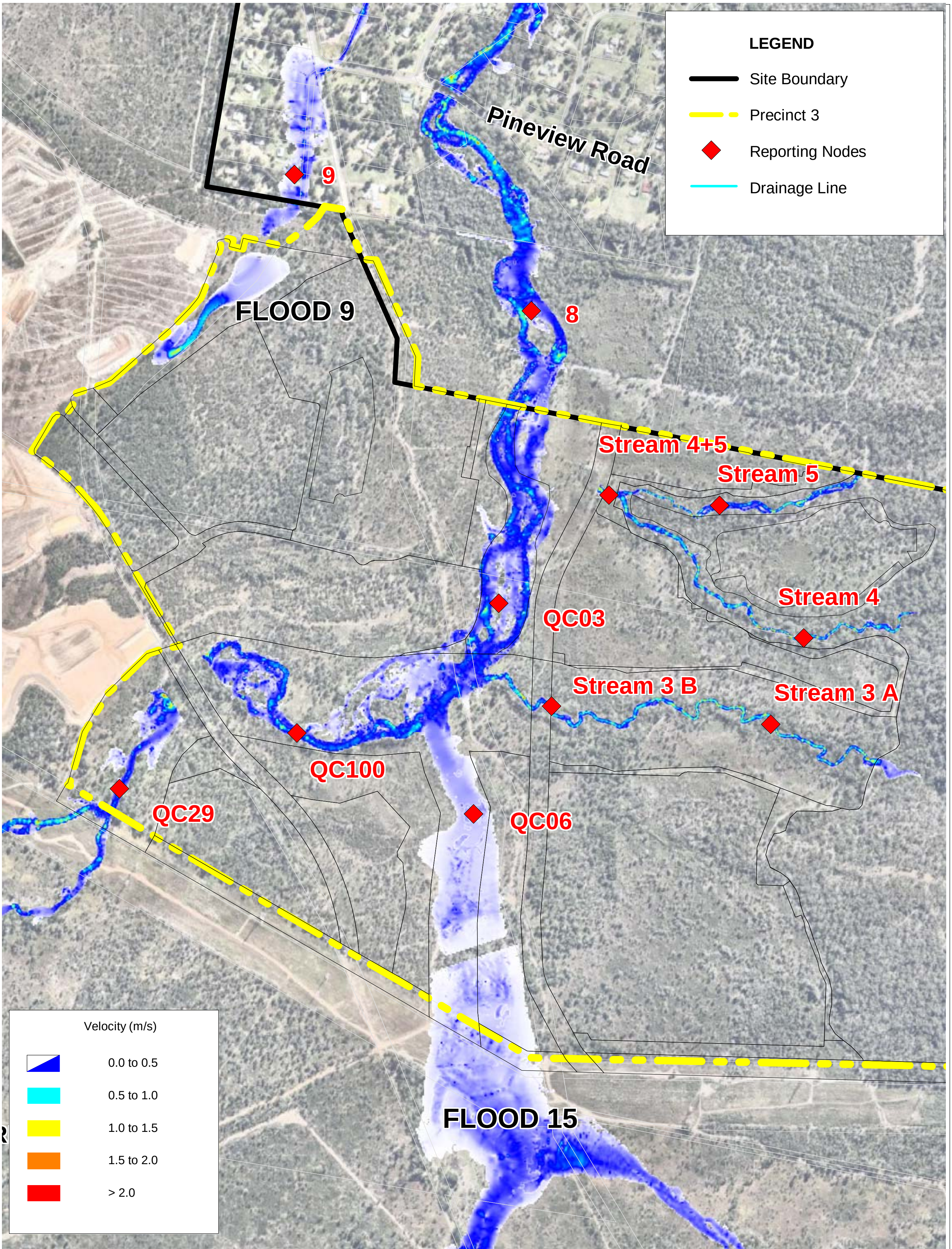
Table 3: 1 year ARI peak flow and velocity

Reporting Node ID	Peak Flow (m^3/s)		Peak Velocity (m/s) [2]	
(refer Figure 10)	PRE	DEV	PRE	DEV
QC29	9.9	9.8	0.8	0.5
QC100	9.7	8.8	1.2	1.2
QC06	9.7	6.1	0.3	0.2
QC03	19.9	14.4	0.8	0.7
8	20.4	14.8	1.4	1.2
9	0.9	0.5	0.9	0.5
Stream 3 A	3.0	3.0	1.1	1.1
Stream 3 B	4.0	3.7	0.9	0.9
Stream 4	2.4	2.1	1.3	1.3
Stream 5	1.8	1.3	0.8	0.8
Stream 4+5	4.8	5.0	1.0	1.0

Notes:

1. PRE = pre-development, DEV = Precinct 3 post development mitigated
2. Velocities will vary across the width of any channel section and these peak velocities are therefore point maximums only for the purposes of comparison and not representative of uniform channel velocity.
3. Velocity variations beyond 1 decimal place are not shown as they are not significant to inform changes in waterway stability at this scale of modelling

The results above demonstrate the Precinct 3 waterway stability flow strategy is effective at ensuring the objectives in Section 5.1 are achieved.



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Scale: 1 : 12,500 (A4)

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FIGURE 10

1 year ARI Peak Flow and Velocity Reporting Locations

6 WATERWAY STABILISATION

Even with the adoption of waterway buffers and management of waterway stability flows, there is potential for portions of the Precinct 3 waterways to erode. The following subsections provide preliminary assessment of waterway stability for Precinct 3 and presents a waterway stabilisation strategy. This strategy is to be refined as part of design development and detailed design for each development stage. The assessments were made based on field visits and desktop review of historic aerial imagery. In addition, review of expected bed shear stresses as a result of development were competed.

6.1 WATERWAY STABILISATION OBJECTIVE

Identify current instability in waterways and locations where instability may occur as a result of the development through geomorphological assessment and identify a stabilisation for these locations.

6.2 GEOMORPHIC APPRAISAL

A geomorphic appraisal was undertaken to assess the current state of Quinzeh Creek and associated streams within the Precinct 3 development site boundary. The aim was to assess the current geomorphic condition of the site and potential impacts on geomorphology resulting from altered morphology and hydrology associated with the development.

Site visits were completed by DesignFlow with Ben Pearson (Hydrobiology). Geomorphic assessments were completed by Hydrobiology (Hydrobiology, 2016). Hydraulic 2D modelling was completed by DesignFlow.

The geomorphic assessment included several desktop and field tasks:

- A review of aerial imagery to identify whether there had been major changes in channel condition and any major catchment changes that may have influenced current channel form/process. Imagery was sourced from Google Earth and DNRM;
- A review of soils and geology information to understand natural drivers behind the channel condition;
- A review of Lidar data to understand site topography;
- A review of 2D hydraulic model outputs to understand potential in-stream locations where issues may arise;
- Two site visits walking the length of all the waterways within the study area to provide an overall understanding of waterway behaviour on the site. Active processes and channel characteristics were noted, with particular emphasis

placed on any bed/bank instabilities (selected photographs are provided in Appendix A);

- Use of the above information to break the waterways into zones characterised by different geomorphic features and processes; and

- Identification of specific geomorphic issues / concerns in the waterways.

6.2.1 Historical changes

Any historical changes along the lengths of the waterways were masked by dense vegetation along the channel margins. As such, little could be deduced about their long-term stability. One section of Stream 5 downstream of its confluence with Stream 4 was visible in multiple images with different acquisition dates (2003, 2009, 2015). These are shown in Figure 11. They show a small meandering stream across an unconfined landscape. It is also evident from the sequence of photographs that the channel has been in a phase of degradation/deepening (2003-2009) and combined degradation/deepening and widening (2009-2015), suggesting that there has been upstream migration of incision, since 2003 at least. The channel appears to have incised into an 'outwash' zone at the base of the Stream 5 valley. Lidar analysis and field assessments support the incision theory, with multiple head cuts and over-steepened sections observed. These are discussed further in ensuing sections.

Figure 11 Historical aerial imagery Stream 5 (source: Google Earth)

6.2.2 Geomorphic characterisation

6.2.2.1 Quinzeh Creek (Streams 1 and 2)

Photographs of Quinzeh Creek and Stream 1 are shown in Appendix A (Photos 27-30). The reaches of Quinzeh Creek and Stream 1 that flow through the study area have a gradual slope (0.5%) and are set within a narrow floodplain that is partly confined by a moderately sinuous valley of low relief and gradual slope. The channel consists of a sandy bed and banks and an anastomosing plan form that is typical of a valley that has undergone historical aggradation (sourced from Streams 3-5 and other tributaries further upstream). The anastomosing channel consists of moderately stable irregular meanders. Isolated examples of bank scour and failure are evident and may worsen with altered hydrology. Flood chutes and channels will also pose an avulsion risk.

A large waterhole has formed along Quinzeh Creek near the southern boundary of Precinct 3. This is probably anthropogenic in origin, but the aggradation within the Quinzeh floodplain has probably also assisted in its development.

6.2.2.2 Tributaries east of Quinzeh Creek (Streams 3-5)

Selected photographs of Streams 3-5 are shown in Appendix A and referred to where relevant herein. The three tributaries can be broadly described as incised, headward eroding, sandy bed gullies that are confined by the valley margins (and ridges) that divide them and consist of occasional flood pockets where valley width allows.

The downstream reaches of the streams consist of 'outwash zones' that are gradually sloped towards Quinzeh Creek. Velocities decrease markedly in this area and historically aggradation has occurred. The streams are currently incising into these zones.

Due to their headward eroding nature, the active channels in all of the streams are generally more 'developed' in the downstream reaches (at least until they flow into the 'outwash zone') and less defined in the upstream reaches (as expected). Headward erosion is likely to continue over time leading to development of more defined low flow channels (bed incision, bank instabilities) further upstream.

Figure 12 shows the longitudinal profiles of the three streams. It is evident that slopes vary considerably along the lengths of the streams, with extremely steep upper reaches (up to 25%), variable middle reaches (1% - 10%) depending on valley confinement and the degree of active channel incision and moderately flat lower reaches within the 'outwash zones' (0.6% - 1%). Note: the steep upper reach zone is generally outside of the influence of Precinct 3 development.

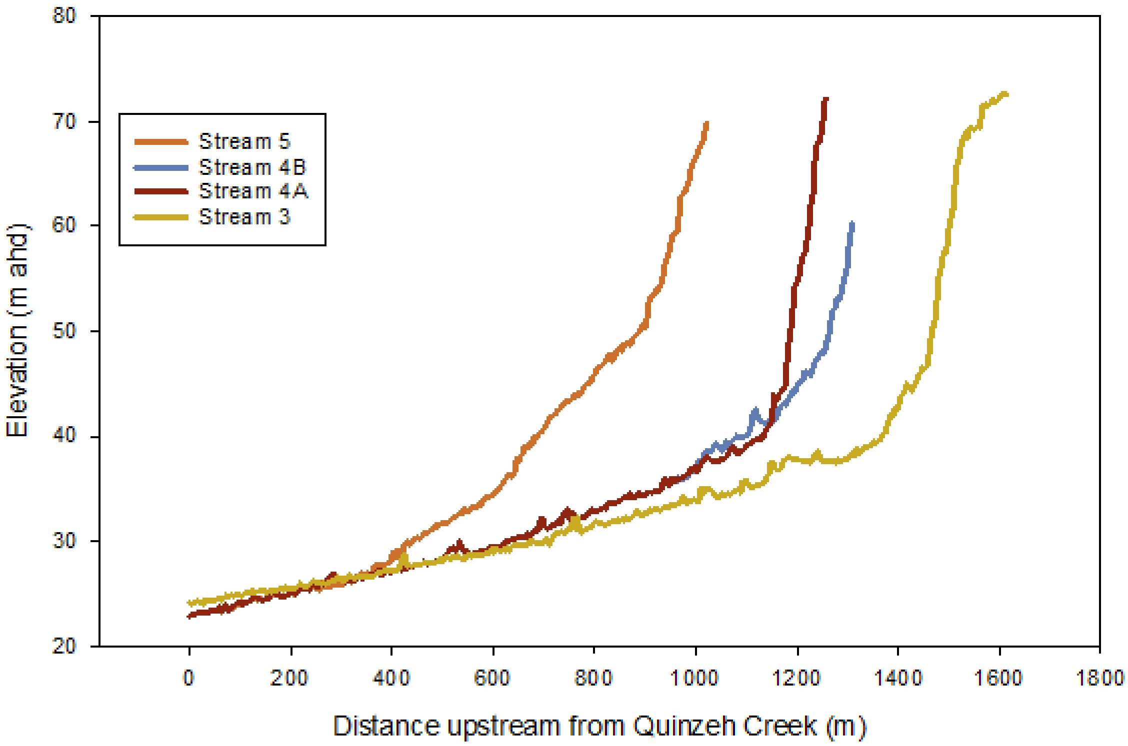


Figure 12 Longitudinal profiles of Streams 3-5

Each of the streams were divided into geomorphologically discrete zones. These zones are shown Figure 13. There were 13 zones identified throughout all of the streams which were defined by valley confinement, incision driven by headcuts and bed controls. The zones are described below:

- *Zone 1* – Consisted of an outwash zone sloping gradually towards Quinzeh Creek. Channels were incised into the surrounding topography, were unconfined and were active (Photos 1 and 2). Channels varied in size (Stream 5 – 1-5 m wide; Stream 3 – ~20 m wide);

- *Stream 5, Zone 2* – The channel was meandering in form, consisted of incised, steep banks, and was confined by steep valley margins. Isolated, low-risk bank scour and failures were evident. Several headcuts were observed and associated with channel deepening and isolated bank instabilities. These headcuts appeared to be migrating upstream, particularly the one located at the upstream extent of Zone 2 (Headcut 1). Headcut 1 was located adjacent to the confluence of a small gully draining from the north and had initiated headward erosion of this gully (Photos 3 and 4);

- *Stream 5, Zone 3* – Consisted of a broad flat channel with gradually sloped bed and banks set within a depositional environment. Headcut 1 demarcated Zone 2 and 3, suggesting that Zone 3 used to extend further downstream and will likely undergo further incision during future runoff events (Photos 5 and 6);

- *Stream 5, Zone 4* – Consisted of a stable, bedrock confined, steep bed set within a very narrow valley. Banks were steep but also contained bedrock. Regardless of future incision within Zone 3, this zone should limit further upstream deepening (Photos 7 and 8);

- *Stream 5, Zone 5* – Consisted of a broad channel with gradually sloped banks and a flattening of the bed compared with Zone 4 and upstream reaches. Its upstream extent was defined by a 4WD track and sedimented runoff from this track appeared to be contributing to the flattening of this section. The broader channel and downstream control (Zone 4 bedrock) were also likely to be contributing to its gentle slope (Photos 9 and 10);

- *Stream 4, Zone 6* – Characterised by a flat depositional zone with a broad low flow channel in an inset floodplain confined by gradually sloped valley margins (Photos 11 and 12);

- *Stream 4, Zone 7* – Consisted of a meandering low flow channel set within inset flood pockets confined by a narrow valley. The low flow channel size was dictated largely by the degree of valley confinement (Photos 13 and 14);

- *Stream 4, Zone 8* – Sedimented runoff from a 4WD track and the steep upstream gullies had resulted in considerable historical deposition within this zone. It consisted of a broad valley with steep but stable high banks. A low flow channel was meandering within a gradually sloped inset flood pocket. Isolated bank instabilities were observed. The low flow channel was headward eroding and increased in size downstream. A headcut was observed at the upstream extent of the zone (Headcut 2) (Photos 15 and 16);

- *Stream 4, Zone 9 and Stream 3, Zone 13* – Incised, steep gullies, very high banks/valley margins. These zones are upstream of the development zone but were contributing significant volumes of sediment to the downstream reaches, particularly from the access track (Photos 17, 18, 25 and 26);

- *Stream 3, Zone 10* – Consisted of a meandering low flow channel set within gradually sloped meandering valley margins. The channel was incised into an inset flood pocket, and increased in size in a downstream direction. Isolated instabilities and headcuts were observed (Photos 19 and 20);

- *Stream 3, Zone 11* – Consisted of steep, very high valley margins that would be susceptible to erosion, although were generally stable at the time. Bedrock provides additional stability to the bed and banks within the reach and has probably been exposed by the headcut. No distinct channel was evident within the valley margins. The bed of the valley was flat and of variable width associated with valley width. A headcut was observed at the upstream margin (Headcut 3) (Photos 21 and 22); and

- *Stream 3, Zone 12* – Characterised by a depositional outwash zone created by sedimented runoff from the upstream gullies. No low flow channel was evident, although a headcut appeared to be forming downstream (Photos 23 and 24).

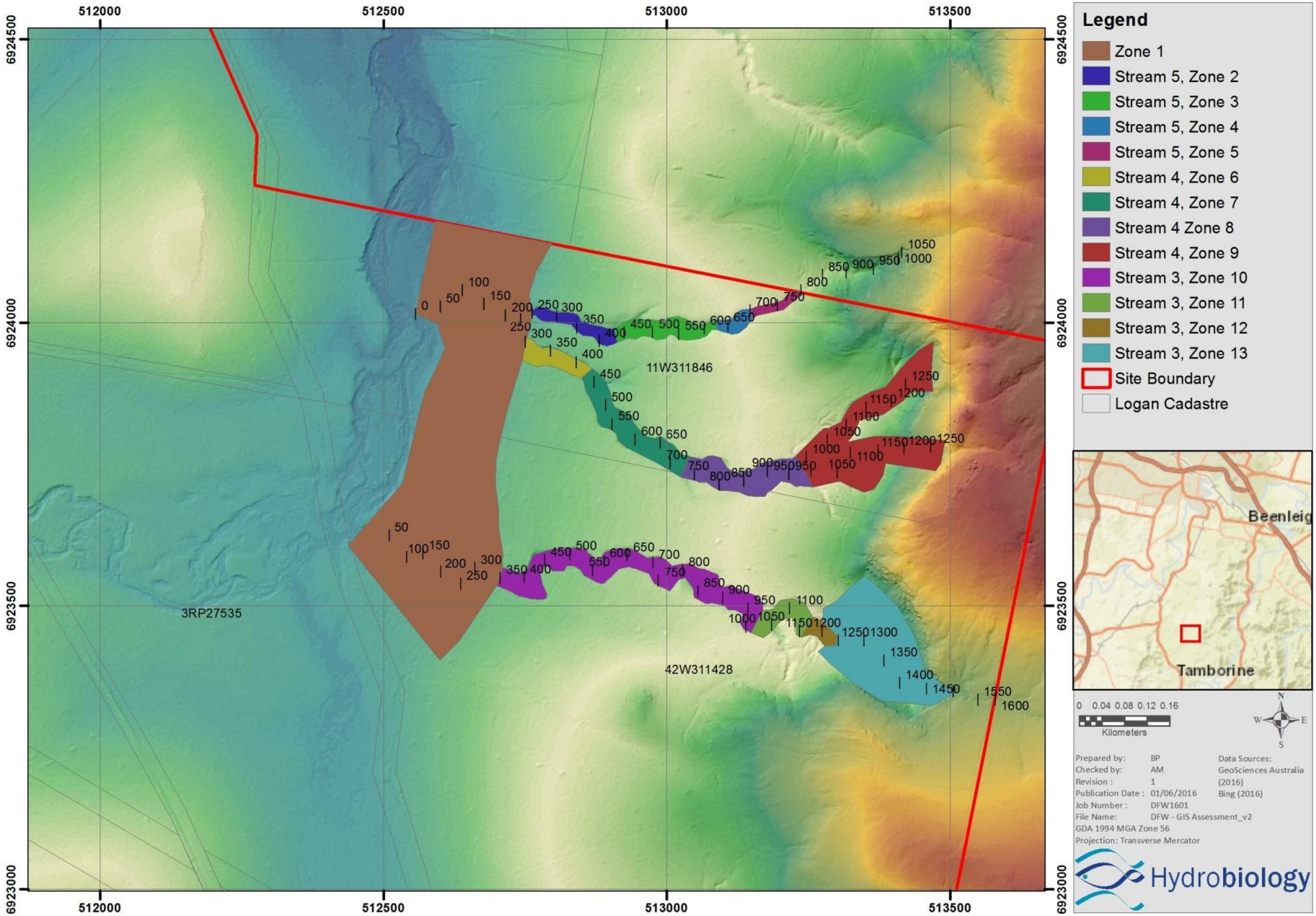


Figure 13: Stream 3 to 5 Geomorphic Zones

6.2.3 Modelling

An assessment of bed shear stress has been undertaken to review the pre and post developed bed shear levels with relation to potential erosions and stability. Outputs from TUFLOW flood modelling for Quinzeh Creek and the eastern tributaries have been assessed. Assessment of bed shear stress values were preferred instead of velocity/stream power as they are a better indicator of potential erosion.

Model resolution is generally too coarse to make assessments regarding localised erosion, however the general spatial trends in shear stress could be interpreted from the outputs, which together with observations from site visits help inform targeted stabilisation areas.

Figure 14 and Figure 15 shows the model outputs for bed shear stress for Quinzeh Creek, Stream 1 and Streams 3-5 for the post development 2 year and 50 year ARI events (Annual Exceedance Probability (AEP) of 50% and 2%).

<u>Quinzeh Creek (Streams 1 and 2)</u>

The majority of the length of Quinzeh Creek and Stream 1 experienced shear stresses within acceptable limits for both the 2 year event (<50 N m^{-2}) and 50 year event (<100 N m^{-2}). However, there are several locations where the hydraulic model results suggests there may be erosion issues develop post development. These include:

- High shear stresses immediately downstream of the easement crossing of Stream 1 for both the 2 year and 50 year ARI events;
- High shear stresses (>100 N m^{-2}) at isolated locations within the main channel of Stream 1 and Quinzeh Creek downstream of its confluence with Stream 1. These locations tend to be adjacent to the outside bank of meander bends; and
- Low shear stresses (depositional) throughout much of the Quinzeh Creek and Stream 1 floodplains for both the 2 year and 50 year ARI events. This is partly influenced by the proposed flood basin on Quinzeh Creek.

It must be noted that these shear stress outputs do not take into account vertical flows (i.e. flows entering the multi-thread channels over the top of their banks) and may underestimate stresses in these locations.

<u>Steams 3-5</u>

It is evident that natural shear stresses were extremely high in Stream 3-5, which can be attributed to the high slopes throughout much of the lengths of the streams and the high level of confinement. Of particular note were the following locations:

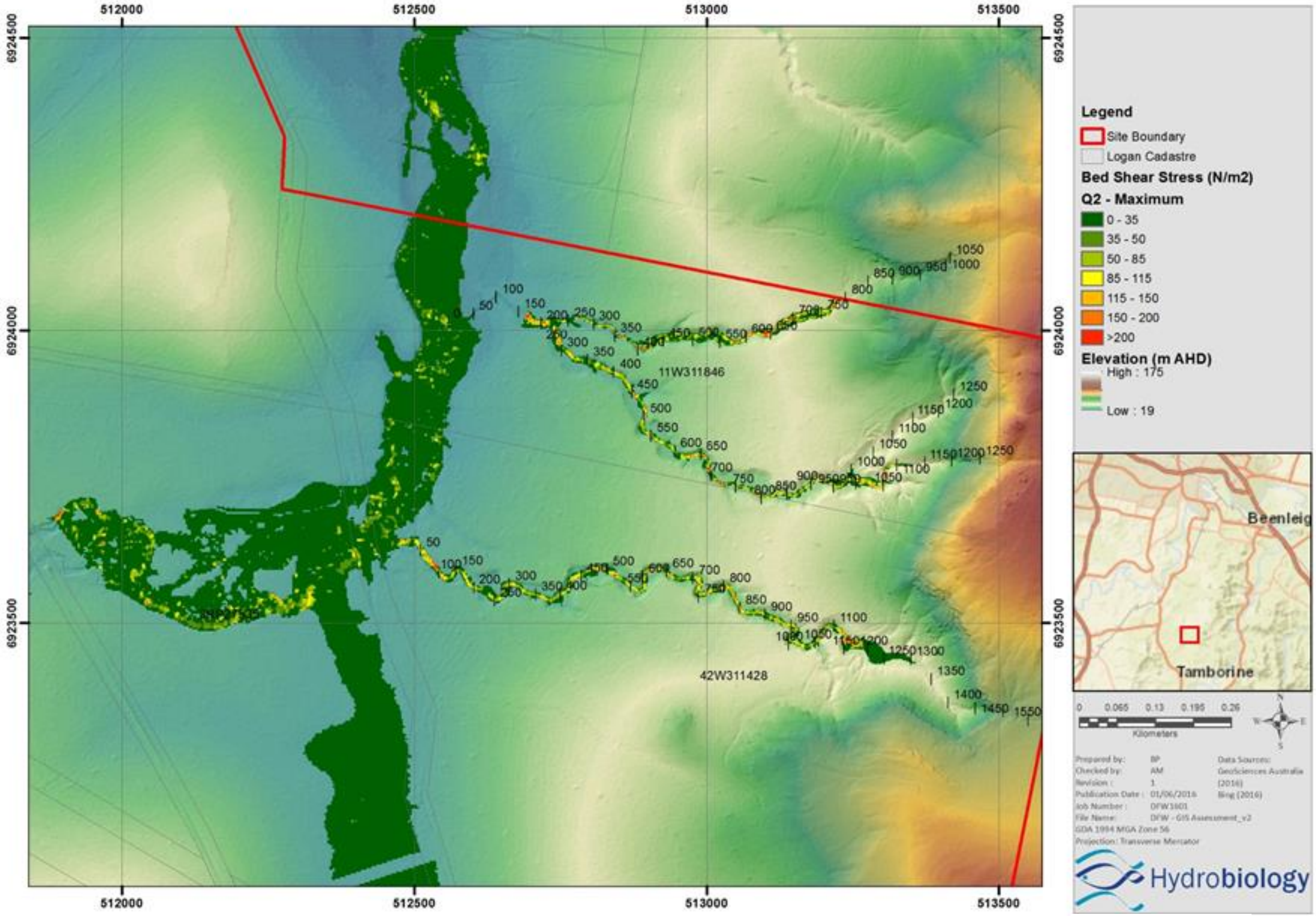
- Very high shear stresses for the 1 in 2 year (>250 N m^{-2}) at about 350-400 m and 650 m upstream of the confluence of Stream 5 and Quinzeh Creek. These were associated with Headcut 1 and the bedrock section in Stream 5;

- Very high shear stresses for the 1 in 2 year event (>250 N m^{-2}) at about 1150 m upstream of the confluence of Stream 3 and Quinzeh Creek. This was associated with Headcut 3;

- High shear stresses for the 1 in 50 year event (>150 N m^{-2}) throughout all streams; and

- Numerous hotspot locations scattered throughout all the streams associated with local shifts in bed slope and confinement. These areas are likely to be more susceptible to erosion in the future and can be identified in Figure 14 as those areas exceeding 100N/m2 for the 2 year ARI event (50% AEP).

Note: Hydraulic modelling of the post developed case showed negligible impacts to shear stresses from the pre-developed case. In Quinzeh Creek and Stream 1, the proposed flood detention systems are effective in preserving flows at pre development rates. In Streams 3-5, bed shear does not change because most runoff generated from the development will be diverted to the downstream end of the waterways meaning no increase in flows along the waterways. It must be noted that negligible impacts to shear stresses do not necessarily translate to negligible geomorphological impacts, as existing issues are likely to continue within the waterways despite the low impacts to hydraulics.



DesignFlow

Figure 14: Bed Shear Stress – 2 year ARI post development

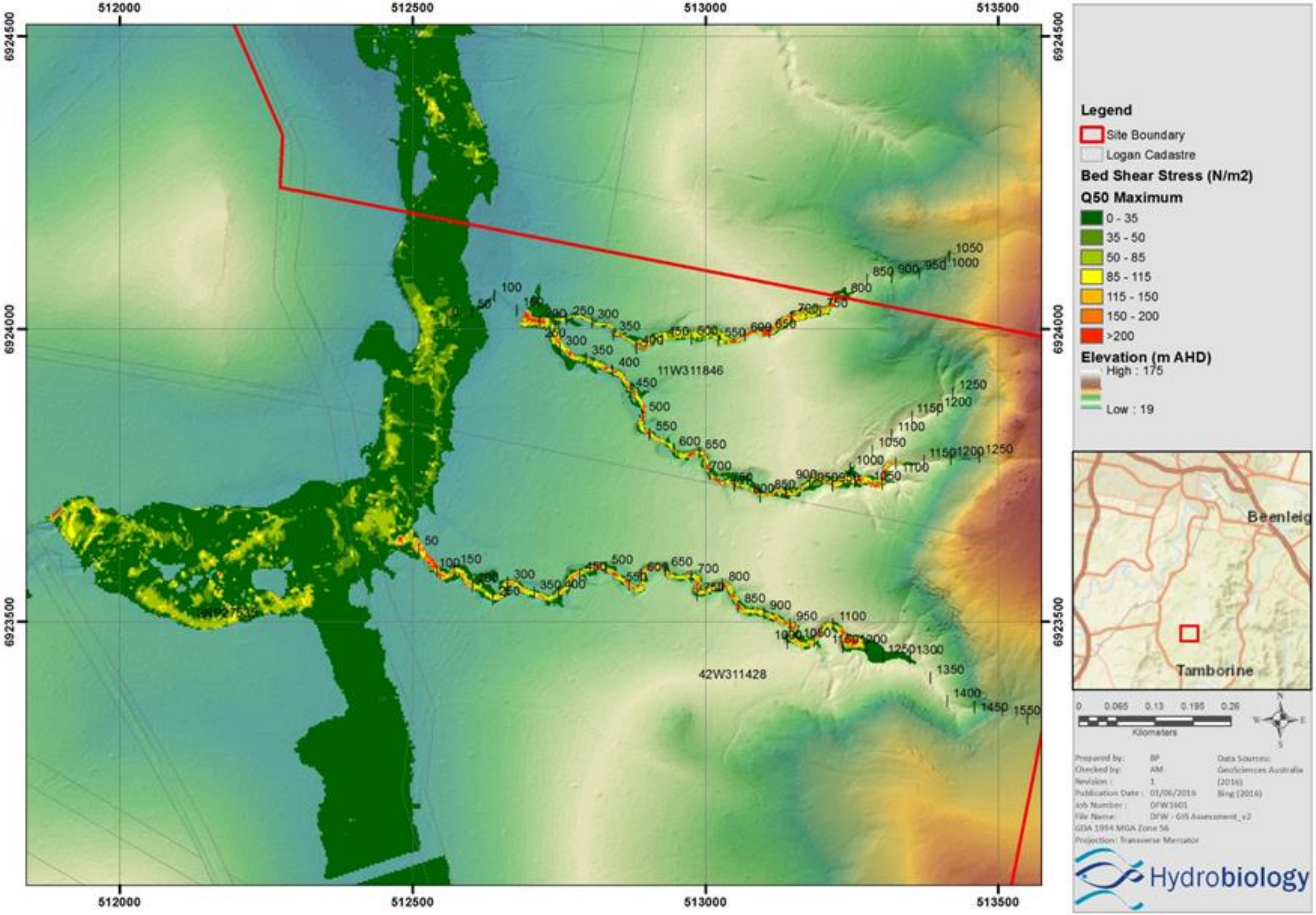


Figure 15: Bed Shear Stress – 50 year ARI post development

6.2.4 Findings

Figure 16 provides a summary of the geomorphic appraisal. The waterways are generally in a stable condition, however, there are reaches of the waterways which are actively eroding and will continue to erode.

6.2.4.1 Quinzeh Creek and Stream 1

The main potential threats to Quinzeh Creek resulting from the development will be associated with altered hydrology as a result of urbanisation of the catchment, increased sediment delivery from its tributaries and their associated impacts on channel stability. It is anticipated that aggradation of the floodplain (low shear stress environments) and scour of channel banks (higher shear stress environments) is likely to occur to some degree, particularly given the sandy channel boundary material. Aggradation may impact on flood levels, whilst scour may impact on infrastructure.

In addition, some migration and/or avulsion of the channel across the floodplain would be expected to occur under current conditions. Regardless, it will be important to manage runoff volumes, velocities and duration to ensure that impacts are moderated. Appropriate buffer zones and regular monitoring should ensure channel migration does not impact on infrastructure. Sediment delivery to the channel should be minor provided Streams 3-5 are appropriately managed and construction sediment management measures are properly managed.

6.2.4.2 Streams 3 to 5

It is evident despite the steepness of the bed of Streams 3-5 and general stable nature of the waterways, lateral instability is the main risk throughout much of the lengths of the three tributaries. A number of headcuts also indicate that the streams are in a cutting phase in their evolution and are migrating upstream. These are likely to pose issues to bank stability in the future. The major geomorphic issues that will need to be addressed are related to the following:

- Migration of identified headcuts, particularly where bed shear stresses are noted to be high.
- Stability of gully confluences are of concern given the steepness of some section of the valley margins
- Mobilisation of sediments as a result of headcut migration
- Sediment runoff from gullies and existing 4WD tracks
- Isolated existing bank instabilities and steep, high valley sides and banks have the potential to be susceptible to erosions, particularly associated with bed incision. These should not pose a major risk provided an effective riparian buffer is retained, overland flows are controlled and upstream headcut migration is managed.

The following sections provides details of strategies to manage the above issues.

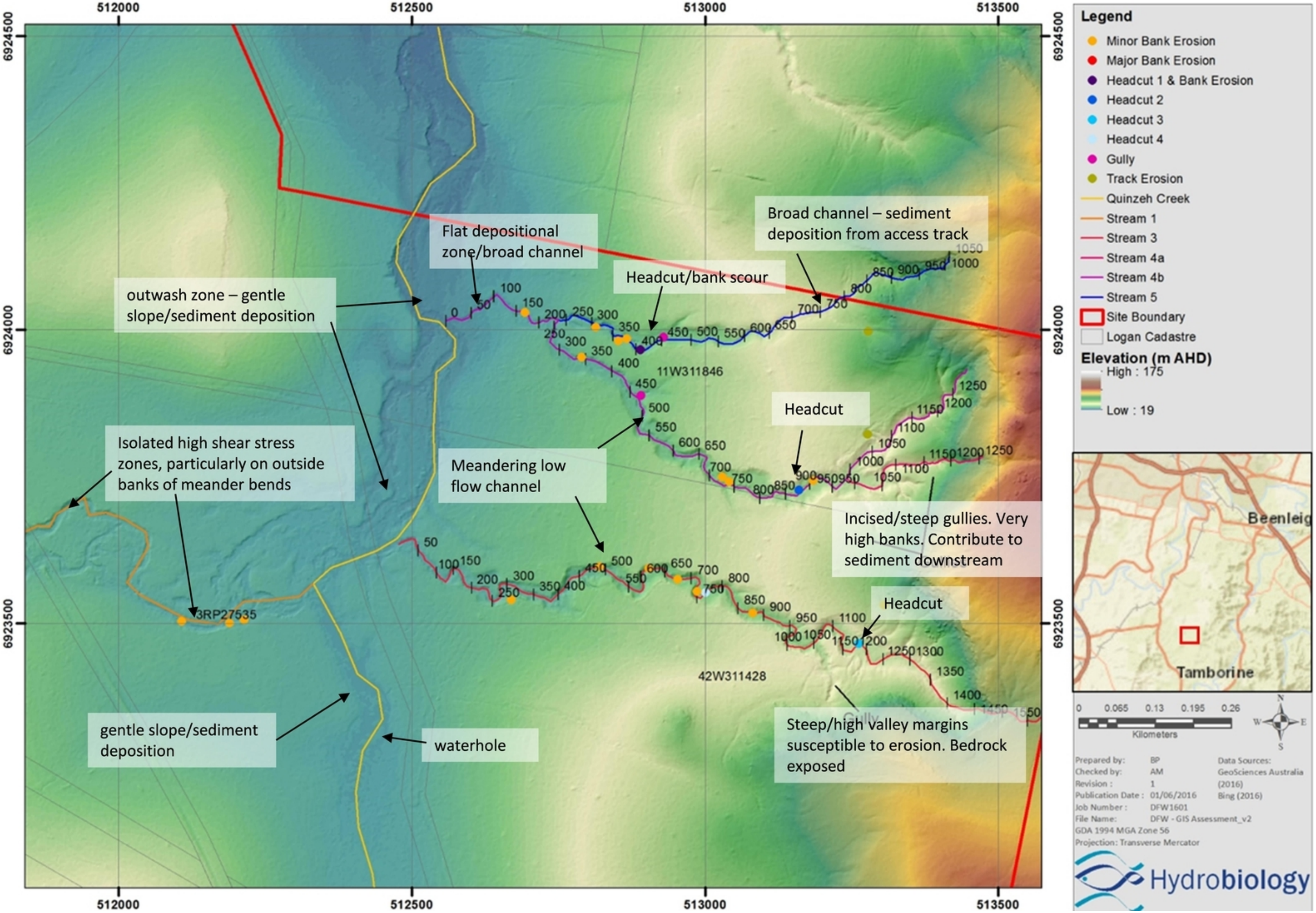


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Figure 16: Summary of Site Appraisal

6.3 WATERWAY STABILISATION STRATEGY

As mentioned in Section 6.2.4 overall Quinzeh Creek and associated streams within the Precinct 3 boundary are currently relatively stable. However, stabilisation of the waterways is required in a number of locations particular in Streams 3 to 5. The following provides the recommended waterway stability strategy for Precinct 3 and is broadly summarised in Figure 17. The main items include:

- Stabilisation of identified head cuts (refer to Figure 16 previously) within the three tributaries east of Quinzeh Creek (Streams 3-5), particularly the steeper stream 5, to arrest their upstream migration. This includes the installation of rock drop/bed control structures at each head cut location.

- Stabilisation of gully confluences and other flow entry locations to ensure their stability. This includes a combination of bank battering, revegetation and rock protection and flow dissipation structures.

- Monitoring of channel stability as development proceeds to guide reactive management of channel stability. Particular attention should be placed on those areas identified as currently eroding, those adjacent to infrastructure (particularly instream infrastructure such as flood basins and crossings) and aggradation of the floodplain of Quinzeh Creek

- A combination of bank battering, revegetation and rock protection of banks at locations identified as unstable or requiring stabilisation

- Limit development discharge points into streams, preferably at downstream locations of streams, or at locations where stabilisation works are proposed (eg at gully confluences/headcuts) and include appropriate scour protection at outfalls

- Provide appropriate erosion protection at in-stream structures such as road crossings and flood basin outfalls

- Direct overland flows from the development to controlled discharge points, preferably at downstream ends of stream. The use of flow diversion bunds may be required where flow is discharging over the top of banks and causing rilling and gullying

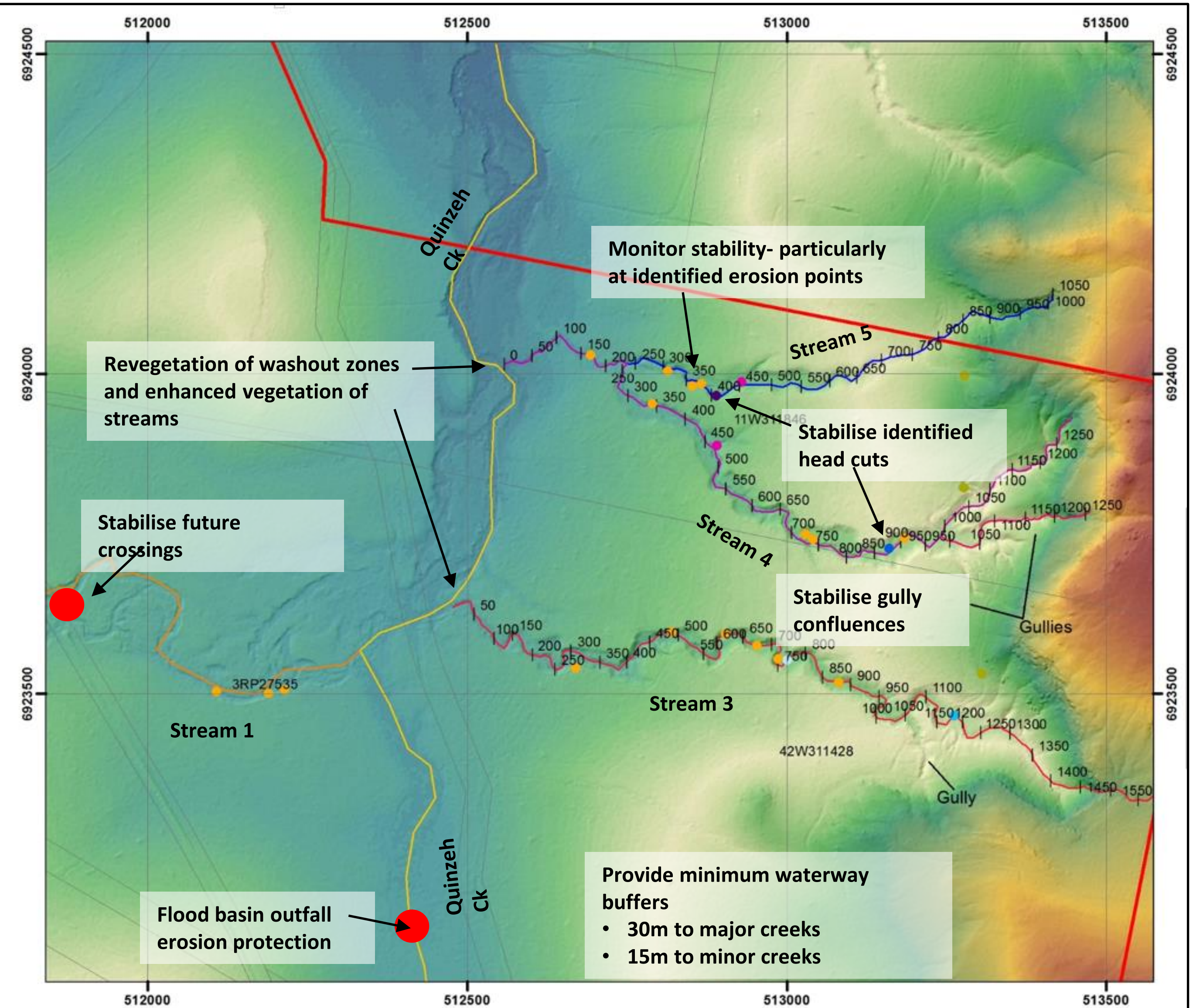
- Vegetation management that encourages revegetation of the downstream ‘outwash zones” and enhances the existing communities within stream 3-5

- Consideration for grading/removal of existing 4WD tracks that are acting as major source of sediment, particularly to Streams 3-5

The strategy elements described will need to be investigated further as part of a detail design of each stage of development. It is important to note that any stabilisation strategy should be developed in conjunction with the stormwater management strategy and flood management strategy to ensure that concentrated inflows to streams (from stormwater outlets or overland flow paths) is appropriately managed with scour protection and energy dissipation where required.

It is critical to ensure the design of in-stream structures such as bridges, major road crossings etc carefully consider the location of these in relation to the stream stability strategy elements as they can have major impacts on the local stream hydraulics and stability.

The following sections outline specific measures for each stage of development.



STABILISATION STRATEGY

Provide minimum waterway buffers (from top of bank)

- 30m to major creeks
- 15m to minor creeks
- 50 m to wetlands of local significance

Stabilise identified headcuts

- Install rock drop structure/bed control structure

Stabilise gully confluences

- A combination of bank battering, revegetation and rock protection
- Stabilise minor gullies using methods such as revegetation and rock protection or creating stable accesses using timber/stone stairs

Erosion protection at future crossings and flood basin outfall

- Rock protection and outfalls

Development runoff

- Minimise development discharges to streams, preferably at downstream locations and include appropriate scour protection at outfalls
- Direct overland flows to stabilised downstream zones to minimise bank instability – use flow diversion berms where necessary.

Monitor channel and stability

- Monitor channel stability to guide reactive management
- A combination of bank battering, revegetation and rock protection at locations identified as unstable or requiring stabilisation

Vegetation

- Revegetation of downstream “washout zones”
- Enhancement of existing in-stream communities

Figure 17: Waterway stabilisation strategy

6.3.1 Precinct 3A strategy

Figure 18 illustrates the waterway stability measures applicable to Precinct 3A development which include:

- Management of drainage outfalls to Quinzeh Creek from the stormwater management systems (wetland and bioretention systems)
- Provide scour protection and bank stabilisation at culvert crossing
- Revegetation in accordance with *Yarrabilba Development: Natural Environment Site Strategy* (Natura Consulting, 2012)
- Monitor Quinzeh Creek channel stability as the development proceeds and respond to instability where required.

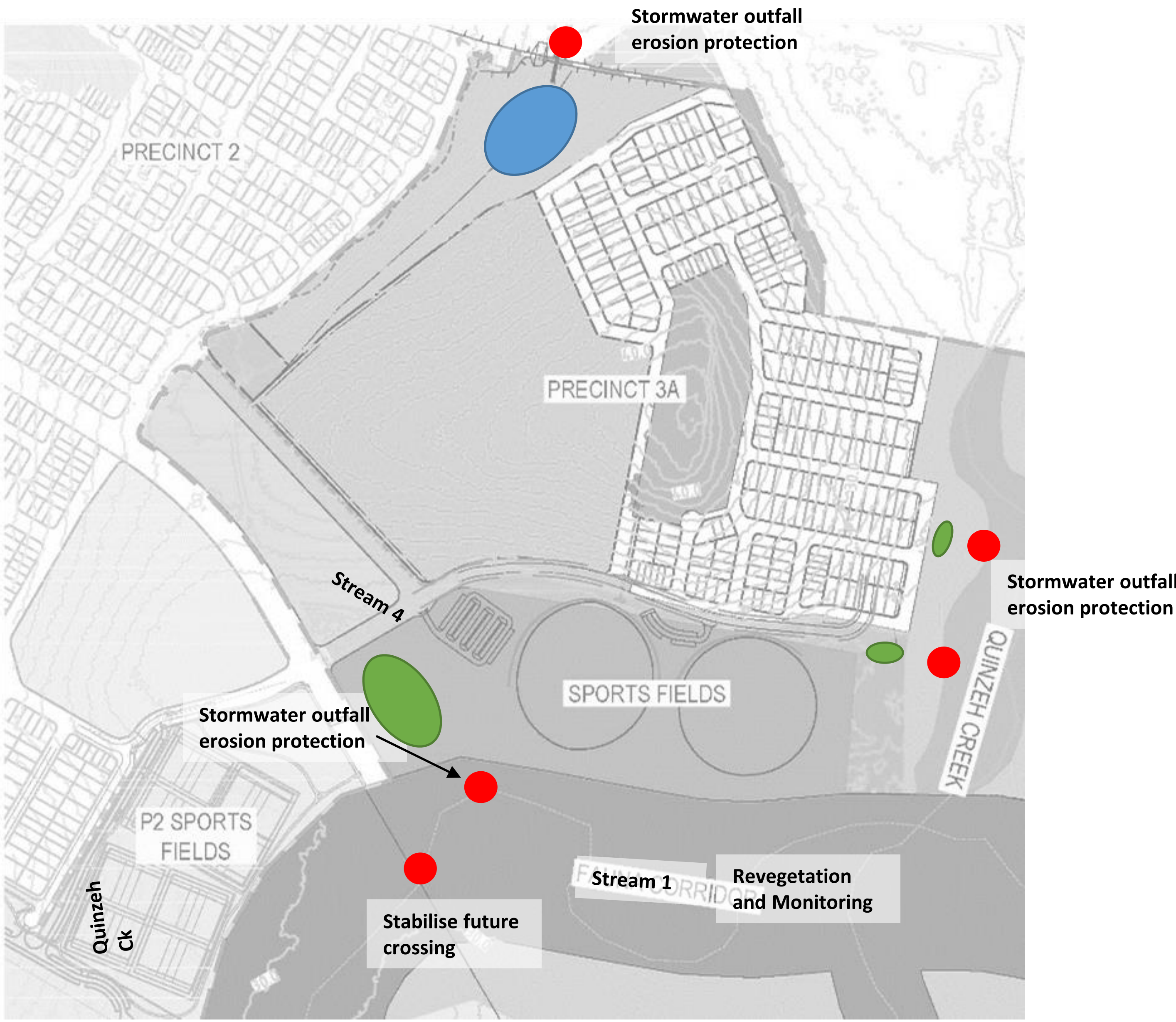


Figure 18: Precinct 3A waterway stability measures

6.3.2 Precinct 3B and C strategy

Figure 19 illustrates the waterway stabilisation strategy for Precinct 3B and C. The main waterway stability measures related to Precinct 3B and C include:

- Direct development drainage to downstream end of streams via the pit and pipe drainage. In some cases this may require diversion of overland flows as well in critical zones of the waterway through the use of the use of diversion bunds or oversized pipe for overland flows.

- Provide scour protection at drainage outfalls, including outfalls from bioretention basins (refer to *Precinct 3 Stormwater Quality Management Plan* (DesignFlow, 2016) for further details.

- Stabilise identified head cuts. For stream 4 preference is for the proposed development road crossing to align with the stabilisation required at the identified head cut and gully confluence

- Stabilise gully confluences, where applicable

- Grading or removal of the 4WD access track at the eastern end of Precinct 3B/C

- Provide scour protection at culvert crossings.

- Provide scour protection at Flood 15 flood detention basin

- Revegetation in accordance with *Yarrabilba Development: Natural Environment Site Strategy* (Natura Consulting, 2012)

- Monitor Quinzeh Creek channel stability as the development proceeds and respond to instability where required.

Note: As part of Precinct 3B and C development, construction of the main flood detention basin along Quinzeh Creek will occur (Flood 15), together with construction of a road crossing over stream 1 (refer to Figure 17, previously). Outfall erosion protection will be required at these locations to maintain stability. Where necessary, there may be advantages to complete re-alignments of Stream 1 downstream of the road crossing to improve channel stability, particularly in areas where high bed shear stresses currently occur.

It is recommended that stream stability is monitored as development proceeds to guide any reactive management of stream stability issues. Reactive management is likely to include techniques such as bank battering, revegetation and rock protection, as applicable.

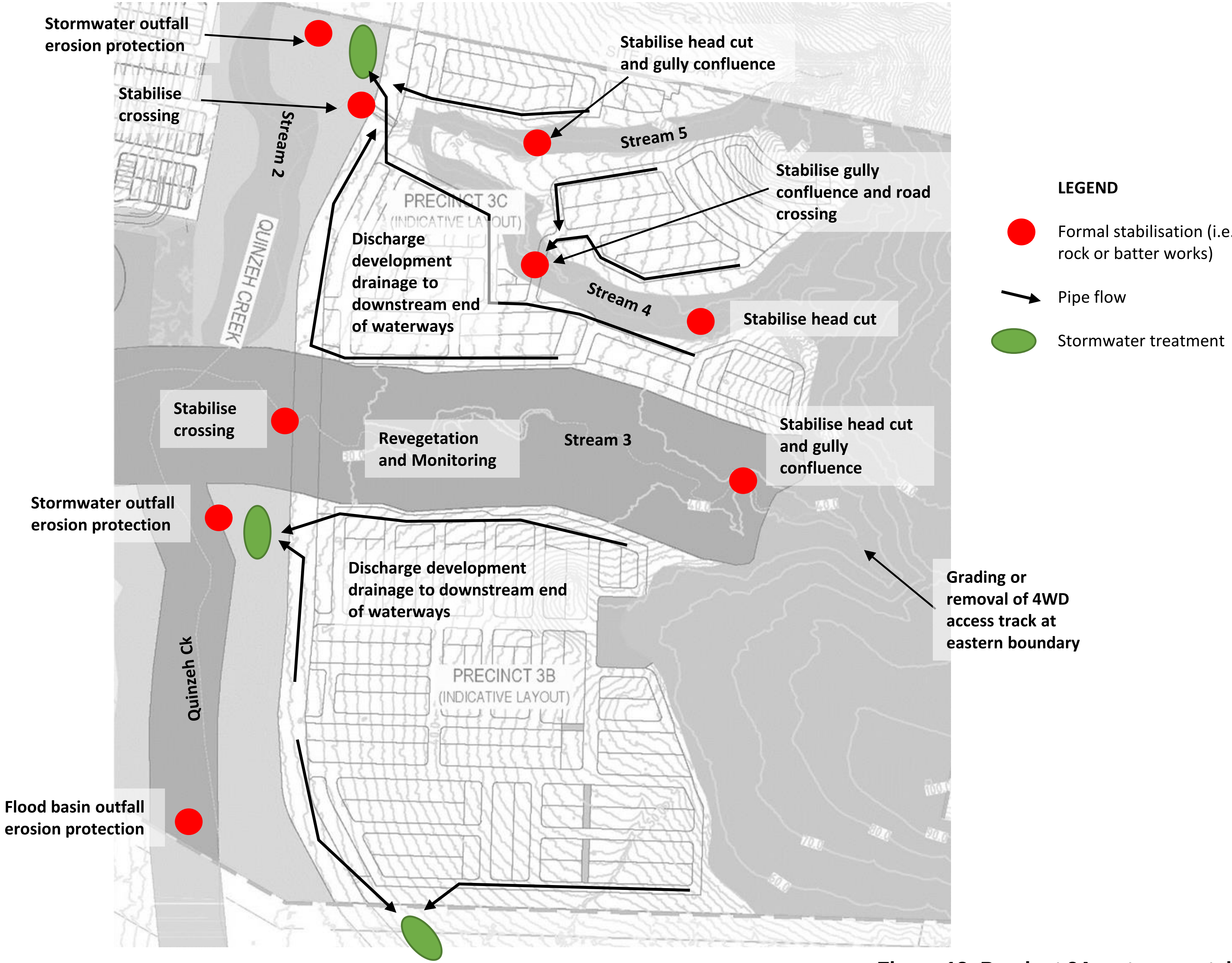


Figure 18: Precinct 3A waterway stability measures

6.3.3 Stabilisation techniques

The following provides typical stabilisation techniques that will be applicable to the streams and waterways of Precinct 3 including stabilising headcuts, gullies and banks. For full details and indicative designs for each treatment, refer to *Erosion Treatments for Urban Creeks (*BCC, 2004). The information provided below is a summary of the details presented in this Brisbane City Council document.

All techniques will involve treatment of dispersive soils with gypsum and covering the dispersive soils with non-dispersive topsoil to minimise the contact of water with the soils.

6.3.3.1 Rock chutes/drop structures

This technique involves constructing a rock structure across the full width of the channel with a rock cascade immediately downstream. This structure prevents the migration of head cut erosion upstream and avoids further scour hole creation at the change in bed level.

The rock downstream of the structure provides a stabilised flow path for relatively steep or concentrated flow paths. The selection of rock size and grading is critical in the success of these systems to ensure both conveyance and energy dissipation is sufficient while avoiding localised scour in in rock voids. It is important that rock stabilisation is recessed into the bank to finish flush with adjacent ground level and rock voids are backfilled with non-dispersive soils. These can then be planted with sedges and grasses to further improve overall long term stability and aesthetics.

Rock drop structures can be used where head cuts have been identified to limit the risk of future head cut or bed incision (refer to Figure 17). When rock chutes are used for bed control (e.g. steep gullies) they may comprise one or more steps depending on the channel slope and depth of existing head cut. Typically steps are limited to 0.5-1.0m vertical drop.

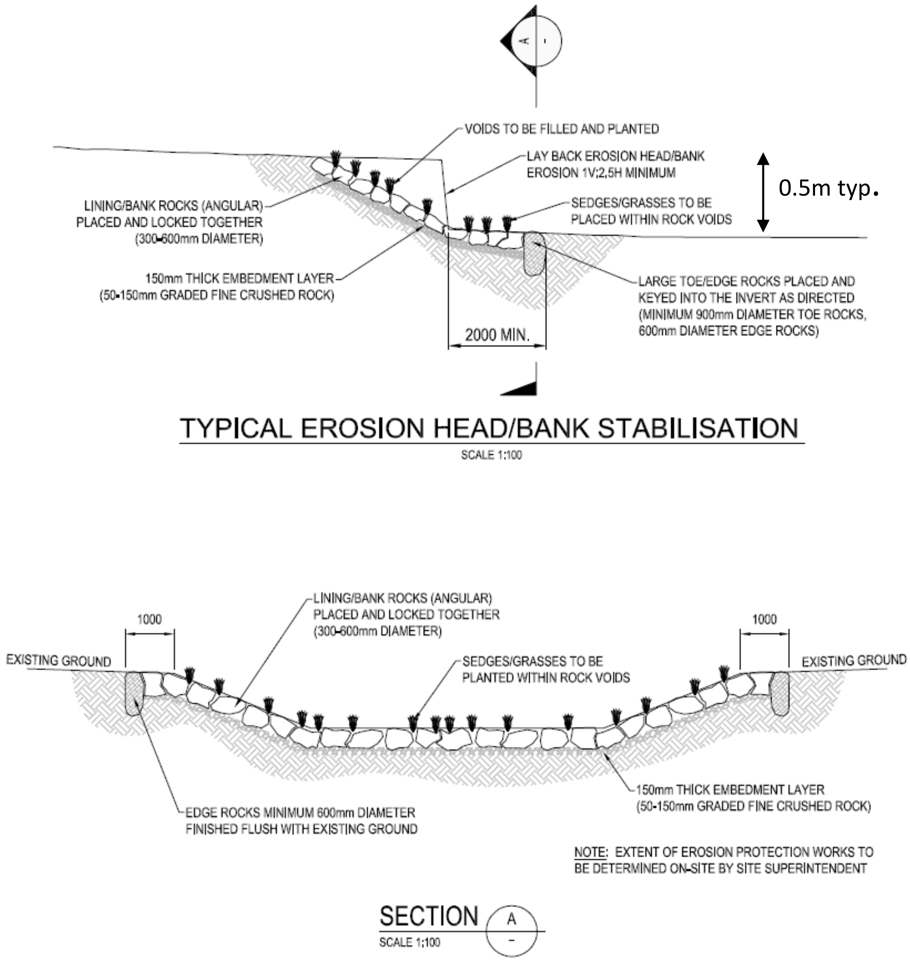


Figure 20 Typical erosion head stabilisation

6.3.3.2 Bank Stabilisation

In general the banks along the streams within Precinct 3 are relatively stable and there are only likely to be isolated areas of bank instability. An observational approach is initially proposed, monitoring stability as development occurs.

Note: Field observations indicated little evidence of bank undercutting along the length of streams within the study area. This indicates that future bank stability risks are most likely related to unmanaged overland flows, that subsequently erode dispersive soils, causing rilling and unstable banks. Management of overland flows will be critical to minimising future bank stability issues. Retention of minimum waterway buffer widths from top of bank will also play a significant role in retaining bank stability.

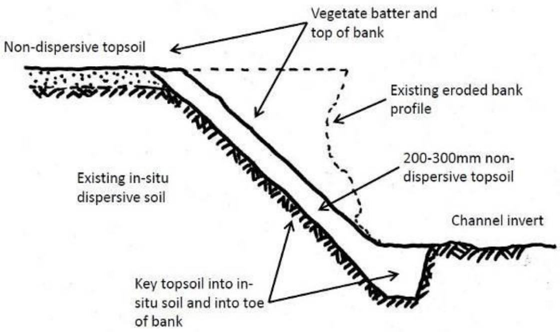
Figure 21 Example of low flow channel with stable adjacent bank along Precinct 3 streams

Battering and revegetation

Where bank erosion has resulted in steep or vertical slopes, this is usually accompanied by loss of vegetation and further susceptibility to erosion. By laying back the banks (through earthworks) and providing dense vegetation, the stability of the banks can be improved. Vegetation selection on the lower bank (and into channel edge) is important to promote additional protection during flow (such as grasses and sedges that lay over during flows and protect soils).

The following provides a summary of the steps involved in battering and revegetation techniques:

- over-excavation to form stable batter e.g. 2H:1V maximum
- treatment of the dispersive soils (e.g. gypsum). This should be ripped into the newly formed stable batter
- placement of non-dispersive topsoil (200-300 mm minimum) over exposed dispersive soils
- vegetation installation and establishment.



(photo: BCC, 2004)

Figure 22 Battering and revegetation

Note on minor gullies

There are a few minor gullies that are noted discharging to streams within the study area. Over time these areas, if not adequately stabilised, can erode and cause stability issues. Simple stabilisation techniques can be used such as capping with non-dispersive soils and vegetating. An alternative approach could be to convert these areas into stabilised paths to allow access from the development. Use of timber steps with gravel, for example, would provide a suitable stable solution.

Rock stabilisation

Bank stabilisation (comprising rock beaching) specifically targets bank erosion at either the toe of bank (low flows) or full height of bank (high flows). The rock beaching acts as an armour to erosive flows and must be constructed on an appropriately graded batter to avoid structural stability issues and to promote (where desirable) vegetation growth within rock voids.

Where bank stabilisation is proposed on the outside bends of waterways, particular attention must be given to the high velocity flows in these areas and the potential that deflection of flows from beaching can have immediately downstream of rock areas and on opposite banks (in tight meanders). Rock beaching can be used in conjunction with rock chutes where both channel and bank stability is at risk.

Based on field observations it is unlikely full height rock stabilisation will be required as part of any bank stabilisation works. Partial rock stabilisation in combination with battering and revegetation is likely to be adopted in selected areas with high velocity flow or observed scour to manage potential erosion at the toe of batters. Figure 23 provides a typical detail.

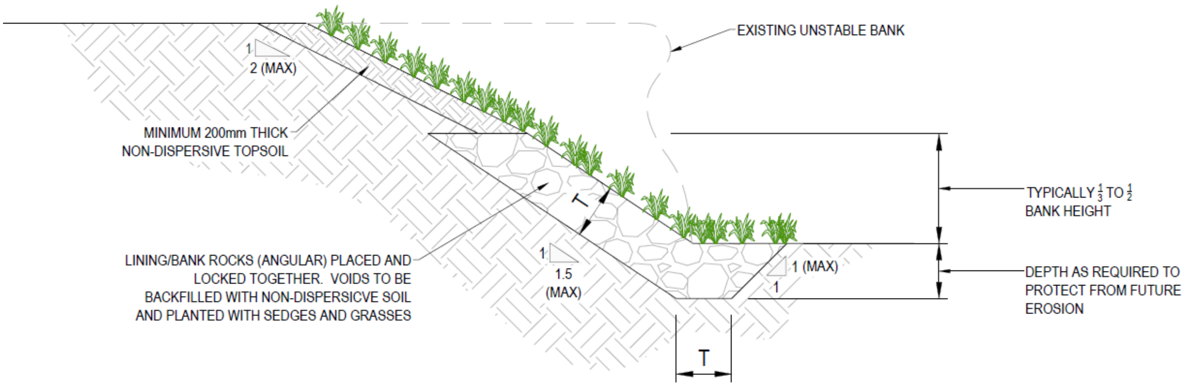


Figure 23 Typical bank stabilisation with rock

It is important that rock stabilisation is recessed into the bank and rock voids are backfilled with non-dispersive soils. These can then be planted with sedges and grasses to further improve overall long term stability and aesthetics.

6.3.3.3 Stormwater outfall protection

The location of stormwater outfalls (including future crossings and flood basin outfalls) and discharges to the streams from the development needs to be carefully considered to avoid local scour of the bank and bed of the waterway. The following will provide a basis for the design of the stormwater outfalls for the development:

- Minimise the number of stormwater outfalls to the waterway.
- The pipe or drain should be angled to generally follow the waterway flow direction.
- The invert of the pipe and drain should match the invert of the waterway.
- Appropriate rock protection and/or rock chute provided at the stormwater outfall. Where possible discharge to stable areas such as exposed bedrock locations
- Co-locate the stormwater outfalls with existing tributaries or scour points in the waterway. This means the stabilisation of these tributaries and the stormwater outfalls can be provided in a single location (dual use of rock protection).
- Provide appropriate flow diversion and energy dissipation as per standard outfall measures as described in QUDM.

6.3.3.4 Vegetation management

Vegetation management will generally be undertaken in accordance with *Yarrabilba Development: Natural Environment Site Strategy* (Natura Consulting, 2012) which highlights vegetation management procedures with regards to clearing approvals, revegetation, monitoring/compliance and design requirements. For Precinct 3 development, vegetation management is mostly connected to, and integrates with waterway setbacks, passive/recreational space and Koala habitat.

6.3.3.5 Monitor channel stability

A number of locations have been identified where minor erosion has occurred or where potential higher risk scour areas may occur based on high bed shear values (refer to Figure 16, previously). No stabilisation actions are proposed in these areas. An approach to monitor creek stability as development proceeds is proposed, and complete reactive stabilisation as required. This approach is suggested given other management approaches such as retaining waterway buffers, limiting drainage discharge points to streams and managing overland flows are expected to retain current stability of the streams.

Learnings from Precinct 1 and 2 development indicate there is merit in limiting the intervention in degraded and disturbed waterways until development within the catchment has neared completion (unless major issues are evident prior). Allowing natural regeneration and succession of vegetation species within waterways (including weeds initially) has been shown to represent a beneficial and cost effective outcome for particular waterways. However, where overriding requirements for other fauna/flora management exist, these must be taken into consideration and adopted where necessary.

7 CONCLUSION

This document presents the findings of the waterway stability assessment for Quinzeh Creek and associated tributaries within the Precinct 3 development boundary. This assessment is provided to support the development application for the Precinct 3 development.

Streams at the eastern side of the development (Streams 3-5), are relatively steep and exhibit high natural shear stresses. The streams are ephemeral, characterised by sandy beds and dense vegetation cover. Geomorphic assessments indicate that soils are dispersive, streams are incised and currently in a cutting phase which are migrating upstream. Field observations observed a number of active headcuts and a number of hotspot scour locations scattered throughout the streams. Some isolated examples of bank scour and failure were evident that may worsen with altered hydrology.

In spite of this the streams remain relatively stable but potentially pose issues to bank and bed stability in the future, particularly given the dispersive nature of soils.

Active sediment deposition and subsequent erosion is still occurring along streams within the Precinct 3 development. Sediment transport from active upstream migration, from local gully's and from unstable access tracks appear to contribute significantly to sediment in the streams.

The downstream reaches of the streams, including Quinzeh Creek are broader and flatter (typically 0.5%) outwash zones where velocities decrease markedly and aggradation occurs.

Recommended approaches

The following management strategies were identified for the streams in Precinct 3 to retain stability and minimise sediment transport downstream:

- Ensure minimum riparian buffer zones from top of bank are implemented to minimise the likelihood of impact to/from infrastructure adjacent to the waterways

- Manage hydrologic change to minimise the impact on waterways within the site and downstream (manage 1 year ARI flows).

- Stabilisation of identified head cuts within the three tributaries east of Quinzeh Creek (Streams 3-5), particularly the steeper Stream 5, to arrest their upstream migration. This includes the installation of rock drop/bed control structures at each head cut location.

- Stabilisation of gully confluences and other flow entry locations to ensure their stability. This includes a combination of bank battering, revegetation and rock protection and flow dissipation structures.

- Monitoring of channel stability as development proceeds to guide reactive management of channel stability. Particular attention should be placed on those areas identified as currently eroding, those adjacent to infrastructure (particularly instream infrastructure such as flood basins and crossings) and aggradation of the floodplain of Quinzeh Creek

- Limit development discharge points into streams, preferably at downstream locations, or at locations where stabilisation works are proposed (eg at gully confluences/headcuts) and include appropriate scour protection at outfalls

- Provide appropriate erosion protection at in-stream structures such as road crossings and flood basin outfalls

- Direct overland flows from the development to controlled discharge points, preferably at downstream locations. The use of flow diversion bunds may be required where flow is discharging over the top of banks and causing rilling and gullying

- Vegetation management that encourages revegetation of the downstream 'outwash zones" and enhances the existing communities within streams. Vegetation management will generally be undertaken in accordance with Yarrabilba Development: Natural Environment Site Strategy (Natura Consulting, 2012)

- Consideration for grading/removal of existing 4WD tracks that are acting as major source of sediment, particularly to Streams 3-5

The strategy elements described in this report will need to be investigated further as part of a detail design of each development stage. It is important to note that any stabilisation strategy will be developed in conjunction with the stormwater management strategy and flood management strategy to ensure that concentrated inflows to streams (from stormwater outlets or overland flow paths) are appropriately managed with scour protection and energy dissipation, where required.

8 REFERENCES

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APPENDIX A PHOTOGRAPHS

	
1. Stream 5, Zone 1 - ~50m chainage	2. Stream 5, Zone 1 - ~200m chainage
	
3. Stream 5, Zone 2 - ~300m chainage	4. Stream 5, Zone 2, 450m chainage (Headcut 1)
	
5. Stream 5, Zone 3 - ~475m chainage	6. Stream 5, Zone 3 - ~475m chainage
	
7. Stream 5, Zone 4 - ~575m chainage	8. Stream 5, Zone 1 - ~575m chainage

9. Stream 5, Zone 5 - ~725m chainage

10. Stream 5, Zone 5 - ~800m chainage

11. Stream 4, Zone 6 - ~350m chainage

12. Stream 4, Zone 6 - ~375m chainage

13. Stream 4, Zone 7 - ~450m chainage

14. Stream 4, Zone 7 - ~700m chainage

15. Stream 4, Zone 8 - ~900m chainage

16. Stream 4, Zone 8 - ~850m chainage

17. Stream 4, Zone 9 - ~1050m chainage

18. Stream 4, Zone 9 - ~1000m chainage

19. Stream 3, Zone 10 - ~600m chainage

20. Stream 3, Zone 10 - ~750m chainage

21. Stream 3, Zone 11 - ~1100m chainage

22. Stream 3, Zone 11 - ~1150m chainage (Headcut 3)

23. Stream 3, Zone 12 - ~1175m chainage

24. Stream 3, Zone 12 - ~1175m chainage

25. Stream 3, Zone 13 - ~1250m chainage

26. Stream 3, Zone 13 - ~1250m chainage

27. Quinzeh Creek (downstream of Stream 5)

28. Quinzeh Creek floodplain upstream Stream 2

29. Quinzeh Creek channel Upstream Stream 2

30. Stream 2