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Environmental Impact Statement – Appendix N2: Geomorphology Technical Assessment

Warragamba Dam Raising

Reference No. 30012078
Prepared for WaterNSW
10 September 2021

SMEC INTERNAL REF. 30012078

Warragamba Dam Raising EIS

Geomorphology Technical Assessment

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Executive Summary

A Geomorphological Technical Impact Assessment was undertaken for the Warragamba Dam Raising Project (or 'the Project'), a project to provide additional water storage capacity in the Lake Burragorang catchment dedicated to flood mitigation. To investigate baseline conditions and impact assessment, the Geomorphology Investigation Area (GIA) has been divided into three main zones (upstream, lake and downstream) as shown conceptually in **Figure 1**. Potential impacts on soils in the construction area around the dam wall are addressed in Chapter 22 and Chapter 27 of the Environmental Impact Statement (EIS).

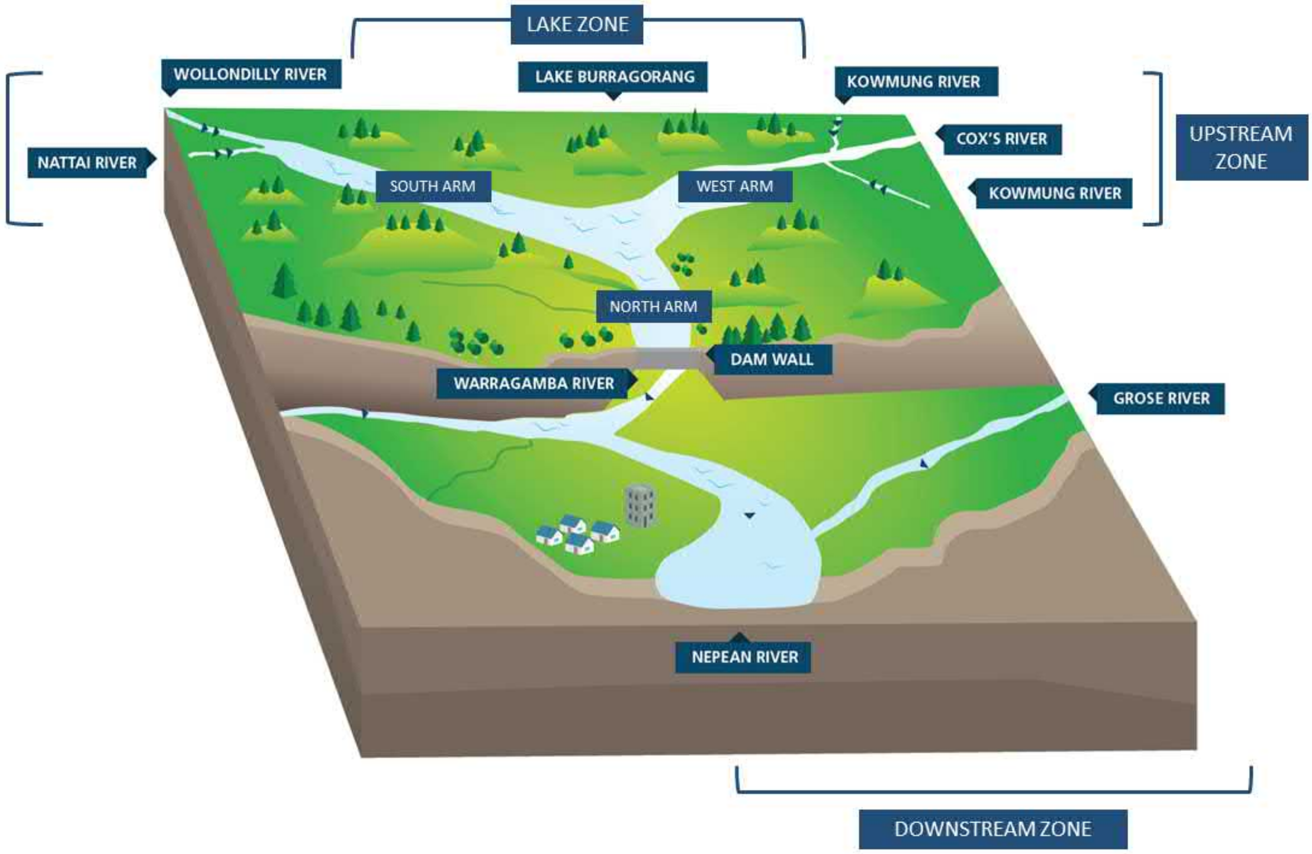


Figure 1 Conceptual division of the GIA into three zones

Extensive desktop and site investigations have been conducted to understand current conditions in these GIA watercourses. A range of semi-quantitative approaches were then used to assess the potential impacts of the Project including:

- Bank Erosion Index (Downstream Zone)
- Hicken Curve motion analysis (Downstream Zone)
- Hjulström Curve sensitivity analysis (Upstream Zone)
- Erosion hotspot modelling using a GIS raster tool (Upstream and Lake Zones)
- Turbidity overlays on Flood Mitigation Zone (FMZ) discharge flood extent and critical infrastructure / land use mapping.

There are uncertainties regarding this semi-quantitative analysis due to the lack of suitable hydrological modelling and findings should be considered indicative rather than holding any inherent magnitude / spatial accuracy. Notwithstanding this the results are considered adequate to define the likely effects of the Project, and the mitigation measures required.

The Project has been designed to avoid or minimise potential impacts on natural geomorphological processors. Key mitigation measures that achieve these outcomes are as follows:

- Geomorphic stability assessment in the Downstream Zone that assesses specific areas which may be vulnerable to changes in flow regime caused by the project.
- Targeted stability improvement measures for areas identified as being vulnerable to erosion
- Existing mitigation measures that WaterNSW have full / partial responsibility for delivering and will successively benefit current geomorphological condition in the catchment but which are independent of the Project
- Mitigation measures addressed in the Biodiversity, Heritage, Flooding and Hydrology and Water Quality Chapters
- National Parks Environmental Management Plan
- Outside scope mitigation measures for which WaterNSW have no responsibility but will benefit current geomorphological condition in the catchment.

Aspects of the Project which have potential to impact on geomorphology are shown conceptually in **Figure 2**.

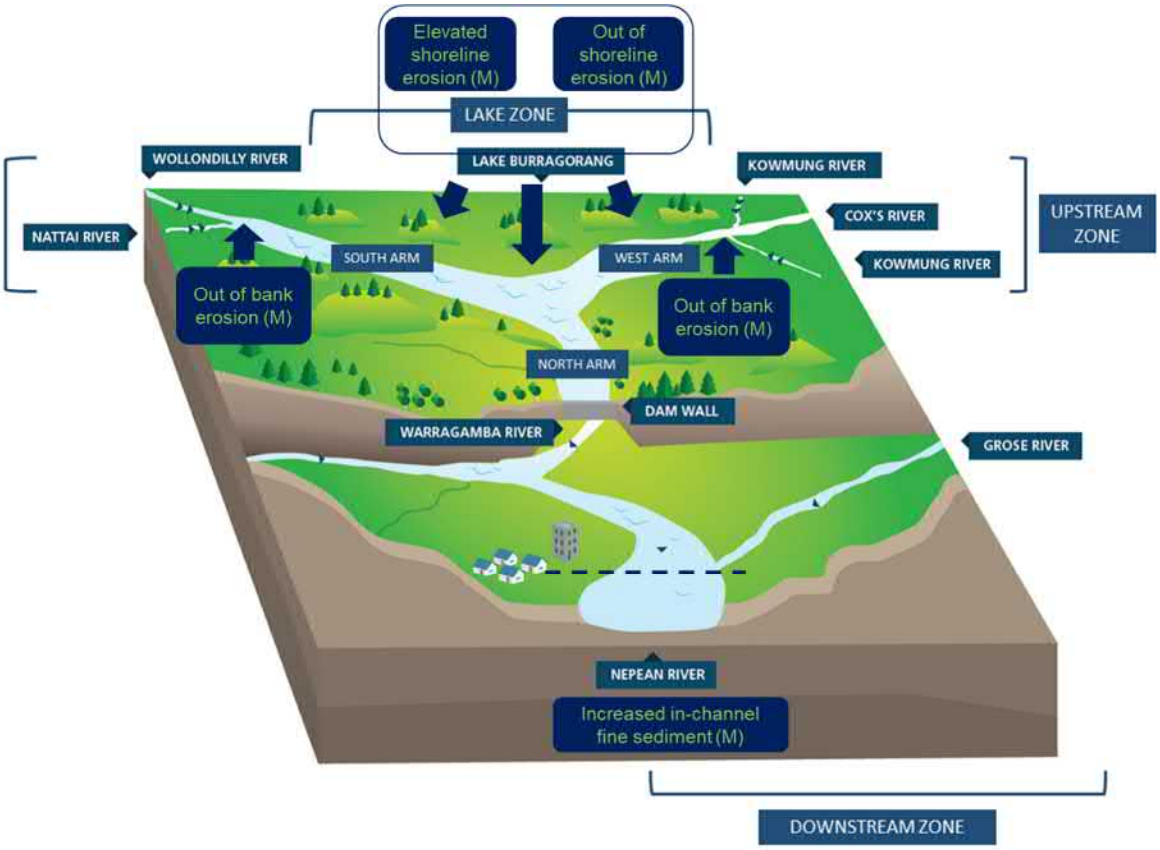


Figure 2 Medium (M) assessed residual impacts from the Project

The main risk to Upstream Zone watercourses was from elevated erosion of terrace deposits during inundation events with a 'medium' residual risk. To an extent this will be controlled by upstream activities and any impacts will be short-lived, during low frequency flood events. Sediment delivery to the lake will decrease, with translocation of sediment deposition features further upstream.

Presence of rockfall avalanches adjacent to the foreshore of Lake Burragorang, especially in the Nattai Valley, was noted as a risk for supply of erodible sediment into the lake, if this coincided with an inundation event. Elevated erosion of shoreline banks as a function of the larger area of inundated land in the With

Project Scenario compared to Existing Scenario resulting in a higher mass of eroded soil (not a change in rates of erosion), would be focussed on north, west and south arms. A combination of more easily erodible soil, larger fetch and exposed locations on the lake foreshore would result in a 'medium' residual risk.

Some impacts were spatially variable. For instance, the risk of erosion in the downstream reaches varied between Medium and High. Once mitigation measures have been successfully identified and completed however, we expect the residual risk of bank erosion caused by the FMZ discharge release to be low. This assumes that successful pre-emptive mitigation measures are adopted. Sedimentation of terrestrial riparian environments caused by inundation of water were assessed to be a 'negligible' residual risk for the Upstream Zone watercourses and 'low' residual risk for both Lake Burragorang and the Hawkesbury-Nepean.

Abbreviations

List of Abbreviations	
AEP	Annual Exceedance Probability
D_{50}	The intercepts for 50% of the cumulative mass from a sediment particle size distribution
DP&E	Dept. of Planning and Environment (now Dept.of Planning, Industry and Environment)
EIS	Environmental Impact Statement
EMP	Environmental Management Plan
EP&A	*Environmental Planning and Assessment Act 1979*
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
FMZ	Flood Mitigation Zone
FSL	Full Supply Level
GIA	Geomorphology Investigation Area - The area of land (and watercourses flowing through this land) selected to be covered by this assessment, including Upstream, Lake and Downstream Zones
m	Metre
m AHD	Metres above Australian Height Datum
km	Kilometres
km^2	Square kilometre
PMF	Probable Maximum Flood - The largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation (PMP). The PMF is often assigned a notional probability based on where the PMF would sit on the Flood Frequency Curve. A reference probability of 0.00001% AEP (1 in 100,000 AEP) has been adopted for the Hawkesbury- Nepean (WMAWater, 2018).
Project	Raising Warragamba Dam to create a Flood Mitigation Zone
SEARs	Secretary's Environmental Assessment Requirements
SSI	State Significant Infrastructure
[TSS]	Total Suspended Solids Concentration
WDR	Warragamba Dam Raising

1 Introduction

1.1 Background

The Hawkesbury-Nepean Valley (the valley) in western Sydney has the highest flood risk in New South Wales, if not Australia. The potential for significant flooding of the Hawkesbury-Nepean Valley was known by the local Aboriginal community before the first European settlement of the area in the 1790s. In the early years of European settlement, the risk of flooding was recognised and a series of proclamations were issued that warned of the risk of flooding. This high flood risk arises from the river being confined by narrow sandstone gorges, creating rapid deep backwater flooding over extensive floodplains. The floodplains are home to a large existing population who would be impacted in a major flood.

During the 1980s and 1990s updated flood investigation techniques and new geological evidence predicted that floods significantly larger than any historically recorded could occur in the Hawkesbury-Nepean Valley. The dam was raised by five metres in the late 1980s to meet modern dam safety requirements. Further investigations into flooding and flood mitigation were undertaken and culminated in 1995 in a proposal to raise Warragamba Dam by 23 metres primarily for dam safety but also to provide for flood mitigation. The 1995 proposal did not proceed. In the late 1990s, major upgrades of Warragamba Dam were undertaken to prevent dam failure during extreme flooding events, to protect Sydney's water supply, and to prevent catastrophic downstream floods from dam failure. This resulted in the construction of the auxiliary spillway. However, these works only dealt with dam safety issues and did not address the major flood risks to the people and businesses in the Hawkesbury-Nepean Valley and the NSW economy.

In 2011, an approximately 1 in 100 chance in a year flood impacted Brisbane, resulting in significant damage, economic costs, and social disruption. The substantial impacts of the 2011 Brisbane flood led the NSW Government to recommence investigations into flood mitigation options for the Hawkesbury-Nepean Valley.

In 2013, the NSW Government in response to the State Infrastructure Strategy and community concerns, initiated the Hawkesbury-Nepean Valley Flood Management Review to consider flood planning, flood mitigation and flood response in the Hawkesbury-Nepean Valley. The review found that current flood management and planning arrangements could be improved, and no single mitigation option could address all the flood risks present in the Hawkesbury-Nepean Valley. The review concluded that raising Warragamba Dam to capture inflows is the most effective infrastructure measure that could have a major influence on flood levels during those events, when most of the damages occur. Other complementary and non-infrastructure options were also identified to mitigate flood risks.

Under the direction of Infrastructure NSW (INSW), the Hawkesbury-Nepean Valley Flood Management Taskforce was established to investigate feasible flood options to reduce overall risk to the Hawkesbury-Nepean Valley. In June 2016, the former Premier and Minister for Western Sydney, Mike Baird MP, announced the NSW Government plan to raise Warragamba Dam to significantly reduce the risk of flooding in the Hawkesbury-Nepean Valley. The cost-benefit analysis demonstrated that the Warragamba Dam Raising would provide a 75 percent reduction in flood damages on average, and reduce current levels of flood damages from $5 billion to $2 billion (2016 dollars).

Raising Warragamba Dam would significantly reduce flood risk; however, it would not eliminate the risk completely. Regardless of the increase in the dam's height, flooding can be generated from catchments other than Warragamba Dam. The raising of Warragamba Dam would therefore be complemented with other non-infrastructure and policy actions. In May 2017, INSW released *Resilient Valley, Resilient Communities*, which outlines the Hawkesbury-Nepean Valley Flood Risk Management Strategy (the Flood Strategy). The Flood Strategy covers the geographic region between Bents Bridge and the Brooklyn Bridge, encompassing areas within the Local Government Areas (LGAs) of Liverpool City, Penrith City, Hawkesbury City, The Hills Shire Blacktown City, Central Coast and Hornsby Shire.

The Flood Strategy's objective is to reduce flood risk to life, property and social amenity from floods in the Hawkesbury-Nepean Valley. The strategy includes nine key outcomes; a combination of infrastructure and non-infrastructure initiatives to mitigate the flood risk to the Hawkesbury-Nepean Valley floodplain downstream of Warragamba Dam. Actions include:

- coordinated flood risk management across the Hawkesbury-Nepean Valley now and in the future
- strategic and integrated consideration of flood risk in land use and emergency planning
- engaging and providing flood risk information for an aware, prepared and responsive community.

The Flood Strategy provides the context and policy impetus to mitigate flood risk in the Hawkesbury-Nepean Valley.

1.2 Project description

Warragamba Dam Raising is a project to provide flood mitigation to reduce the significant existing risk to life and property in the Hawkesbury-Nepean Valley downstream of the dam. This would be achieved through raising the level of the central spillway crest by around 12 metres and the auxiliary spillway crest by around 14 metres above the existing full supply level for temporary storage of inflows. The spillway crest levels and outlets control the extent and duration of the temporary upstream inundation. There would be no change to the existing maximum volume of water stored for water supply.

The NSW Government announcement in 2016 proposed that the dam wall be raised by 14 metres. Subsequently, the NSW Department of Planning and Environment Secretary's Environmental Assessment Requirements (SEARs) required the project to be designed, constructed and operated to be resilient to the future impacts of climate change and incorporate specific adaptation actions in the design.

Peer reviewed climate change research found that by 2090 it is likely an additional three metres of spillway height would be required to provide similar flood mitigation outcomes as the current flood mitigation proposal. Raising the dam side walls and roadway by an additional three metres may not be feasible in the future, both in terms of engineering constraints and cost. The current design includes raising the dam side walls and roadway by 17 metres now to enable adaptation to projected climate change. Any consideration of raising spillway heights is unlikely before the mid to late 21st century and would be subject to a separate planning approval process.

The 17-metre raising height of the dam abutments (side walls) and roadway have been considered and accounted for in the EIS and design. The potential maximum height and duration of upstream inundation remains consistent with what was originally proposed in 2016.

The Project also includes providing infrastructure to facilitate variable environmental flows to be released from Warragamba Dam.

The Project would include the following main activities and elements:

- demolition or removal of parts of the existing Warragamba Dam, including the existing drum and radial gates,
- thickening and raising of the dam abutments
- thickening and raising of the central spillway
- new gates or slots to control discharge of water from the flood mitigation zone (FMZ)
- modifications to the auxiliary spillway
- operation of the dam for flood mitigation
- environmental flow infrastructure.

The Project would take the opportunity, during the construction period for the dam raising, to install the physical infrastructure to allow for management of environmental flows as outlined in the NSW Government, 2017 Metropolitan Water Plan. However, the actual environmental flow releases themselves do not form part of the Project and are subject to administration under the *Water Management Act 2000*.

1.2.1 Project location

Figure 3 shows the local and regional context of the Project. The Project site is located approximately 65 kilometres west of the Sydney Central Business District in the Wollondilly Local Government Area (LGA). To the west of the Project site are the Blue Mountains, various national parks and state conservation areas, and the Greater Blue Mountains World Heritage Area (GBMWHA), which make up part of the catchment of Lake Burragorang - the water storage formed by Warragamba Dam. To the east of the Project site are the Warragamba and Silverdale townships and surrounding rural residential areas.

1.2.2 Construction activities

Figure 4 shows the construction area for the Project including:

- Ancillary facilities such as coffer dams, batch plants, material storage areas and worker facilities
- Areas which require clearing of vegetation to allow for construction and access
- Areas directly impacted by construction works
- Areas that would be used for construction activities but would not be modified by the Project (for example, existing roads, Lake Burragorang).

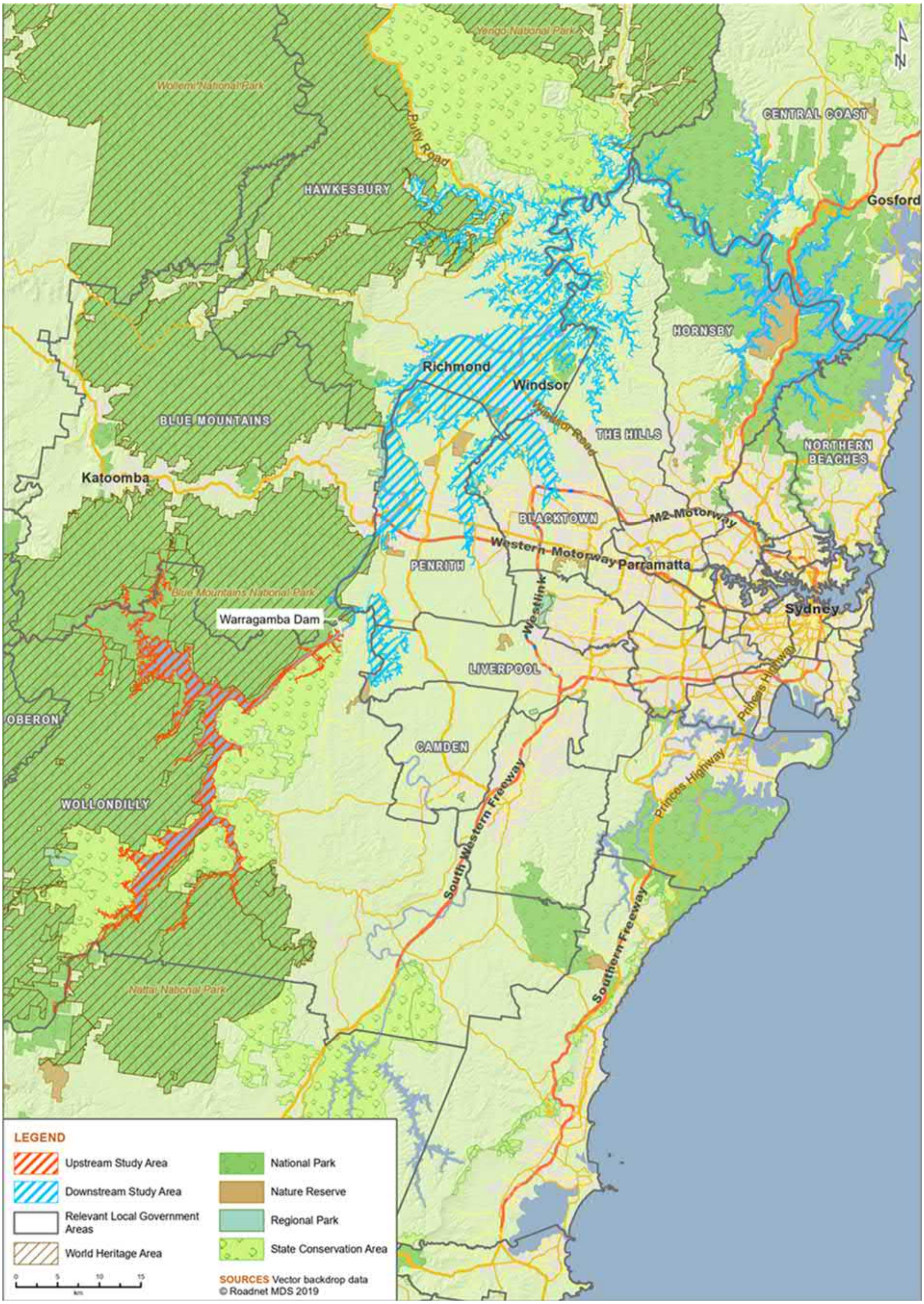


Figure 3 Warragamba dam location

Figure 4 Project Construction Area

1.2.3 Main activities and elements

Figure 5 shows the existing dam with its relevant key features. **Figure 6** shows the modified dam after the Project works have been completed. The Project works include:

- Demolition
- Thickening and raising of dam abutments
- Thickening and raising of central spillway
- Modifications to the auxiliary spillway
- Other infrastructure and elements
- Environmental flow infrastructure.

1.2.4 Operation of the dam for flood mitigation

Operational objectives in order of priority are to:

- maintain the structural integrity of the dam
- minimise risk to life
- maintain Sydney's water supply
- minimise downstream impact of flooding to properties
- minimise environmental impact
- minimise social impact.

There would be two different modes of operation for the Project: normal and flood operations. In both modes Warragamba Dam would continue to store and supply up to 80 percent of Sydney's drinking water. The storage capacity, which is the dam's full supply level, would not change. The current and future operation of the dam is shown **Figure 7** and **Figure 8**, respectively.

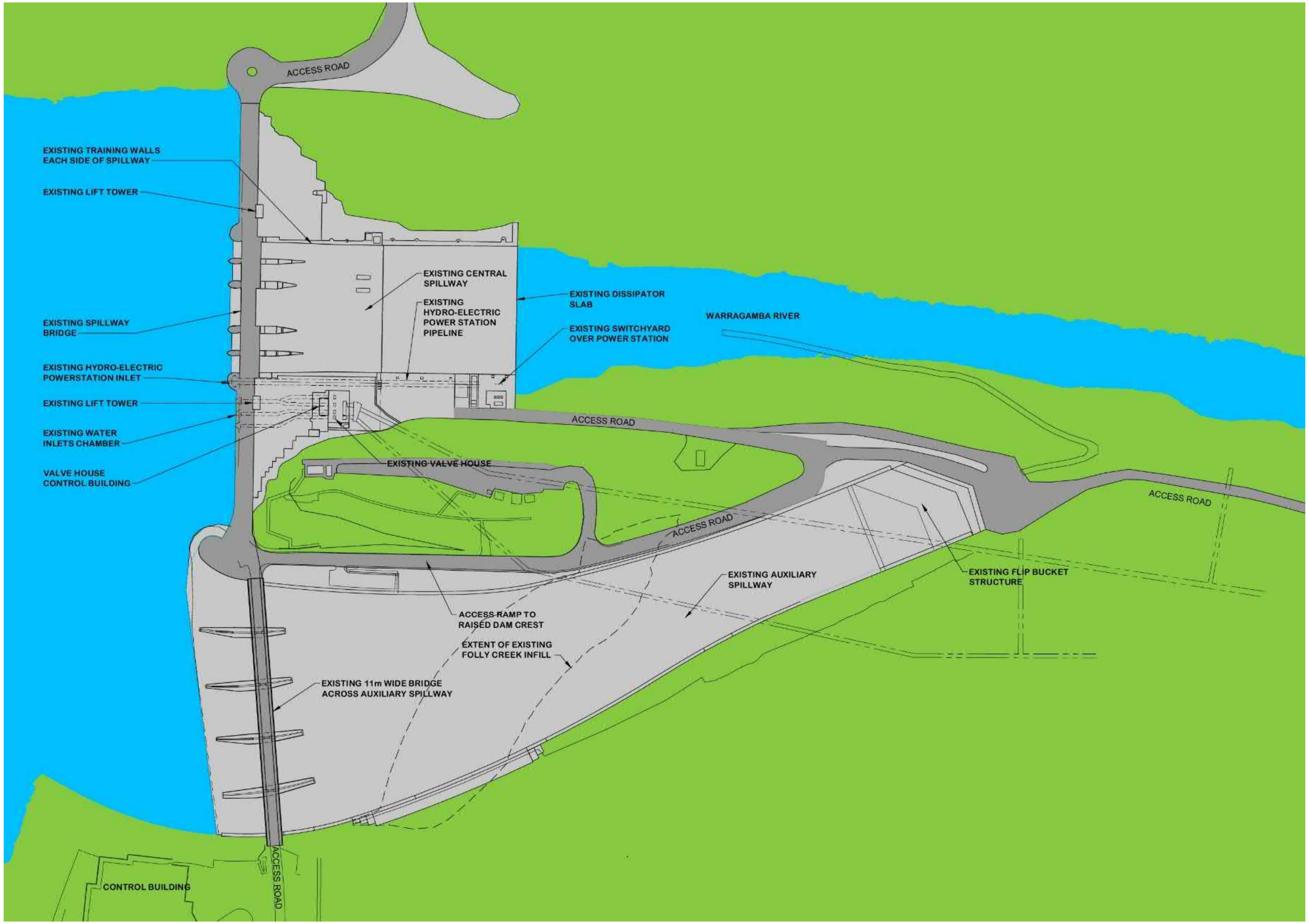


Figure 5 Aerial view of existing dam features

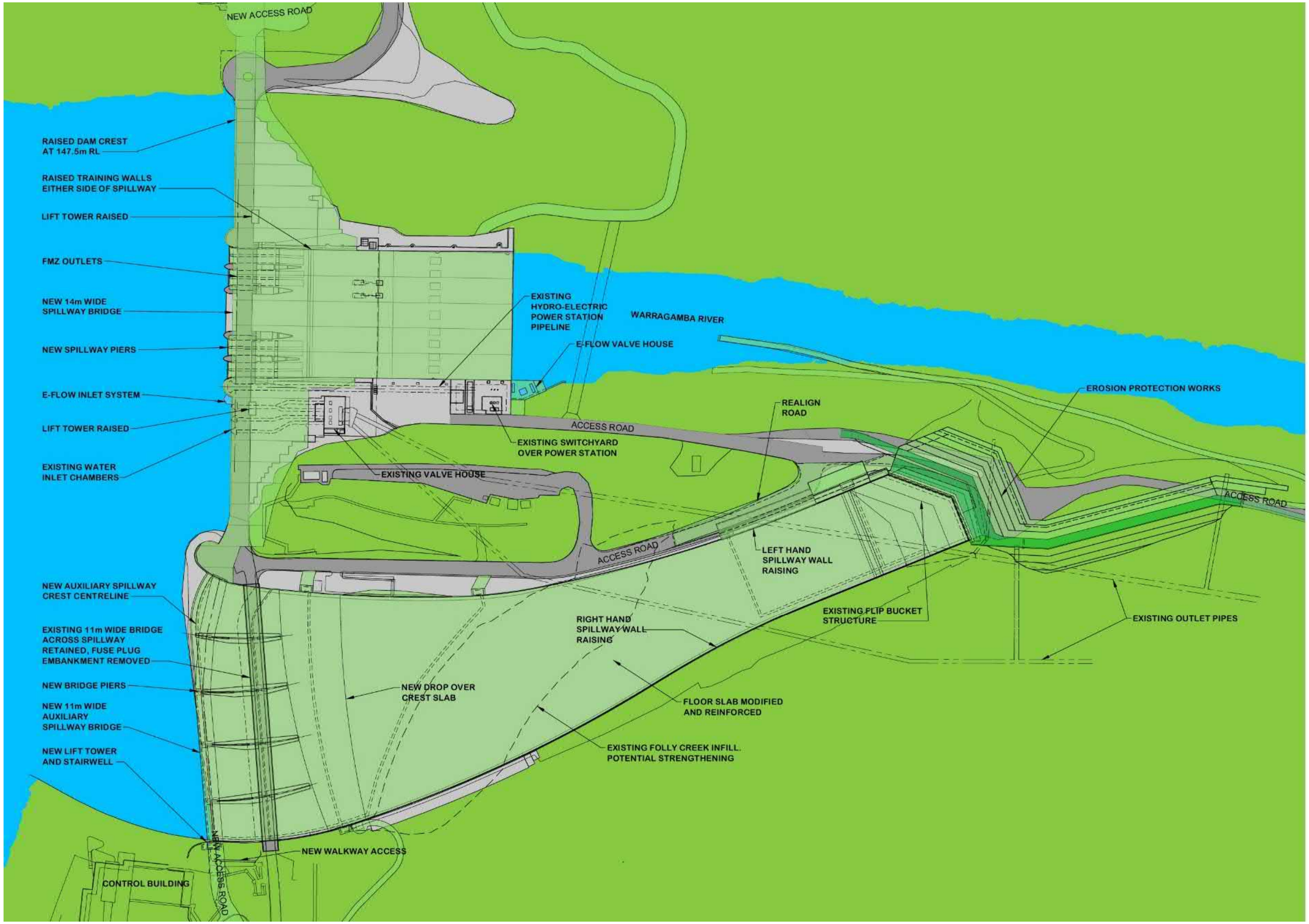


Figure 6 Aerial view of modified dam from the Project

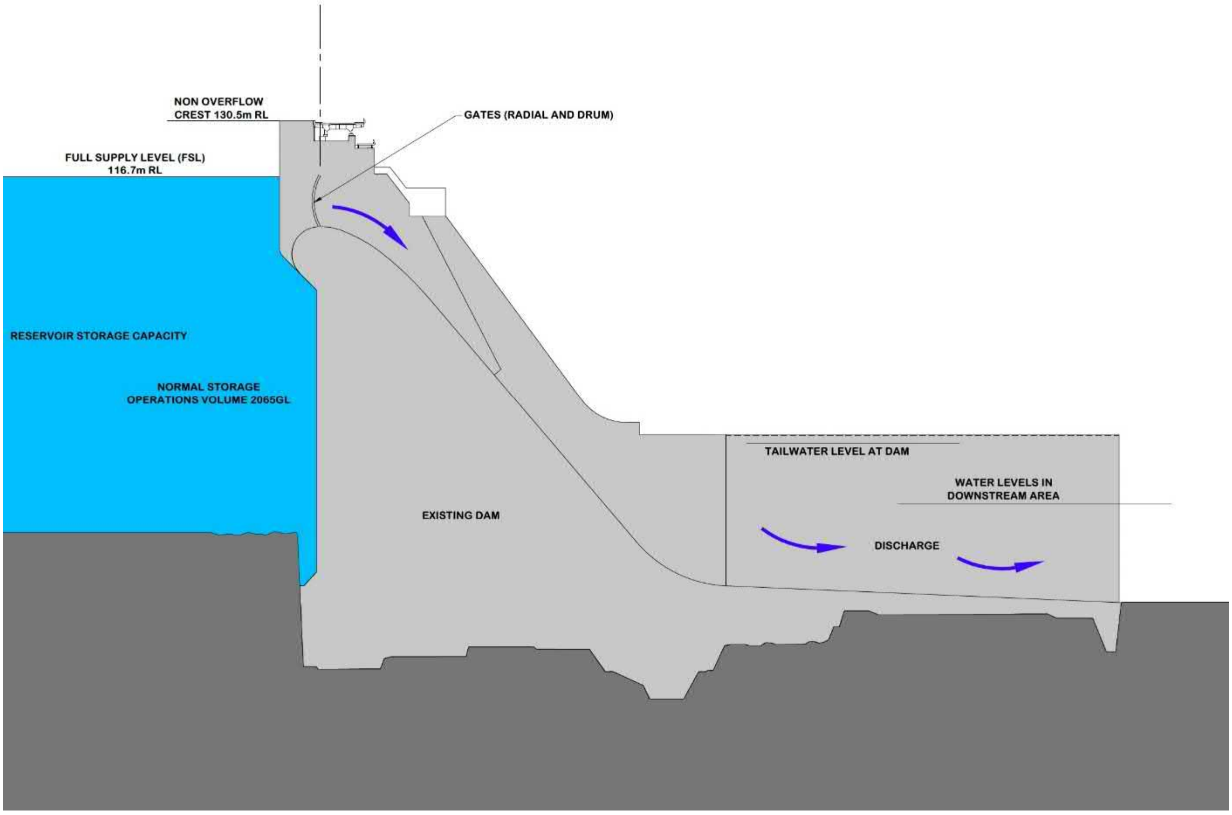


Figure 7 Existing operation of the dam

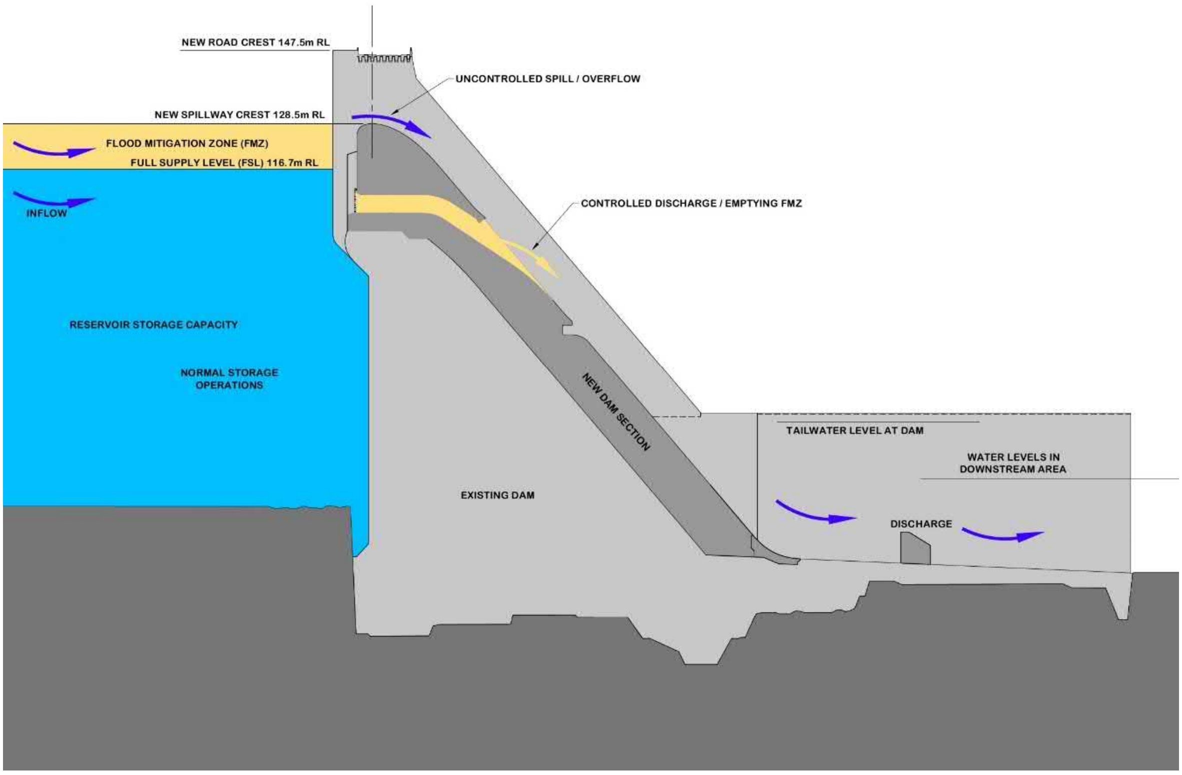


Figure 8 Future operations of the dam

a. Normal operations

Normal operations would occur when the dam storage level is at or lower than Full Supply Level.

Normal operations mode for the modified dam would be essentially the same as current operations – apart from environmental flow releases. Inflows would be captured up until the Full Supply Level after which environmental flow releases would cease and flood operation procedures would be implemented.

b. Flood operations

During large rainfall events when the storage level rises above full supply level, flood operations mode would commence. In this mode, inflows to Lake Burragorang would be captured and temporarily stored below the spillway (increasing water levels in Lake Burragorang and upstream tributaries). The raised dam would provide capacity (called a flood mitigation zone) to capture temporarily around 1,000 gigalitres of water during a flood event.

Water would be discharged in a controlled manner via the gated conduits or slots until the dam level returns to full supply level. Flood mitigation zone operating protocols would guide this process and be developed for approval by the relevant regulatory authorities.

The raised dam would not be able to fully capture inflows from all floods. For floods that exceed the capacity of the flood mitigation zone, water would spill firstly over the central spillway and then, depending on the size of the flood, the auxiliary spillway.

For more information on downstream and upstream impacts and benefits from the Project see Chapter 15 (Flooding and hydrology).

1.3 Scope items

This Geomorphological Technical Impact Assessment has been prepared to provide technical guidance and inform the broader Environmental Impact Statement (EIS) that is being prepared for the proposed dam raising project. The Warragamba Dam Raising EIS is required to be undertaken in accordance with the methodologies and guidelines required under the project SEARs. The EIS will inform assessments under the *Environmental Planning and Assessment Act 1979* (EP&A Act) and the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act). As there is an Assessment Bilateral Agreement in place between the Commonwealth and NSW Government, the SEARs for the EIS also cover EPBC Act, due to the potential for the Project to impact on Matters of National Environmental Significance (MNES).

The Project is deemed to be State Significant Infrastructure (SSI) under the EP&A Act. As such, the Secretary of the NSW Department of Planning, Industry and Environment (DPIE) has issued SEARs for the project. These set the terms of reference for preparing an EIS under the EP&A Act. **Table 1** below provides a summary of the relevant Project SEARs and where they are addressed in this report. This table demonstrates that there is not a dedicated section of the SEARs for fluvial geomorphology and instead that issues relating to fluvial geomorphology are extracted from a combination of the 'Soil' and 'Water – Hydrology' sections of the requirements. Where items have been struck through, they are outside the remit of this fluvial geomorphology report and are addressed in either the Soils or Water – Hydrology EIA chapters. Where items appear in blue font, they are partially addressed in this report but there is also cross-over to other technical EIS disciplines.

Table 1 Relevant project SEARs and relevant report section

Table notes

- Black text – indicates requirements which are addressed in this report
- Blue text – indicates requirements which are partially addressed in this report
- ~~Strike-through text~~ - indicates requirements which are not addressed in this report

SEARs	Relevant section of this report
Soil 6: The Proponent must assess the impacts on soil and land resources (including erosion risk or hazard). Particular attention must be given to soil erosion and sediment transport consistent with the practices and principles in the current guidelines.	• Bank erosion has been addressed for the Upstream Zone (**Section 5.1.1**), Lake Burragorang Zone (**Sections 5.2.1** and **5.2.2**) and Downstream Zone (**Section 5.3.1**). • Sediment transport in the Upstream Zone (**Section 5.1.2** and **5.1.3**), Lake Burragorang Zone (**Sections 5.2.3** and **5.2.4**) and Downstream Zone (**Section 5.3.2**). • Relevant guidelines have been identified in **Section 2.2** and the desktop, site and data analysis approaches used in this assessment in line with common industry practice are described in **Sections 2.3, 2.4, 2.5**, respectively.
Soil 7: Attention must also be given to direct and indirect increase in erosion, siltation, impact on riparian vegetation of increased sediment loads and reduction in stability of river banks or watercourses both upstream and downstream in the event of a flood. ~~Consideration must be given to the amount of time areas are inundated and the impact of soil during and after these events.~~	• Erosion / siltation / stability - as above • The potential for increased sediment load has been addressed in **Section 5.2.3** (Lake Burragorang Zone) and **Section 5.3.3** (Downstream Zone). • The impact of sediment load on vegetation will be assessed in the Biodiversity report.
Soil 8: Consideration should also be given to areas inundated by probable maximum flood levels and the potential for the project to impact how siltation remains deposited in these areas, as well as the potential impact on existing vegetation ~~and changes in soil characteristics. The Proponent should detail, in the event that a probable maximum flood level event occurs, how soil and areas affected by changed hydrological regimes as a result of the project will be managed and/or remediated.~~	• **Section 5.3.3** addresses how siltation remains deposited on the floodplain. • The potential for increased sediment load has been addressed in **Section 5.2.3** (Lake Burragorang Zone) and **Section 5.3.3** (Downstream Zone). • The impact of sediment load on vegetation will be assessed in the Biodiversity report.
Water – Hydrology 4: The Proponent must assess (and model if appropriate) the impact of the construction and operation of the project and any ancillary facilities (both built elements and discharges) on surface and	• Impact assessment is divided into Construction and Operation sections (**Sections 4** and **5**, respectively). • Sediment deposition changes to aquatic habitat are assessed in **Section 5.1.3** (Upstream Zone) and **Section 5.3.2** (Downstream Zone).

SEARs	Relevant section of this report
groundwater hydrology in accordance with the current guidelines, including: a) natural processes within rivers, ~~wetlands,~~ estuaries, ~~marine waters~~ and floodplains that affect the health of the fluvial, riparian, estuarine ~~or marine system and landscape health (such as modified discharge volumes, durations and velocities), aquatic connectivity~~ and access to habitat for spawning and refuge; ~~b) impacts from any permanent and temporary interruption of groundwater flow, including the extent of drawdown, barriers to flows, implications for groundwater dependent surface flows, ecosystems and species, groundwater users and the potential for settlement;~~ ~~c) changes to environmental water availability and flows, both regulated/licensed and unregulated/rules-based sources;~~ d) direct or indirect increases in erosion, siltation, destruction of riparian vegetation or a reduction in the stability of river banks or watercourses;	• Erosion / siltation / bank stability – See Soil 6 response • Destruction of riparian vegetation – See Soil 7 response
Water – Hydrology 8: ~~The Proponent must consider and discuss the rate at which flood waters would potentially recede following a probable maximum flood event, the impact on vegetation both upstream and downstream from the flood and the impact on water quality over time as flood waters are released from the dam throughout the catchment.~~ Geomorphology and river management should be taken into account.	• See Soil 6, 7 and 8 responses • See Water – Hydrology 4 response • River management (focussed on addressing the identified potential impacts) is addressed in **Section 5.4**.

1.4 Project team liaison as part of this technical note

As part of the process of investigating, assessing and preparing this technical note, the following project team liaison was completed:

- Hydrology Data Meeting - geomorphologist requirements meeting, WaterNSW, 30 November 2018
- Geomorphology handover session from Peter Johnson, 18 December 2018
- Biodiversity – Geomorphology – Soils workshop, SMEC, 19 February 2019
- Biodiversity – Geomorphology workshop, SMEC, 29 April 2019
- Hydrology model correspondence with WMA Water (via SMEC / WaterNSW), 23 April 2019, 1 July 2019 and 23 July 2019

Other informal engagement included extended periods on site with the internal EIS team including ecologists and soil scientists.

1.5 Geomorphology conceptual understanding – Stage 1

1.5.1 Conceptual understanding of hydrological functioning and reservoir operation

The hydrological functioning of the catchment, and how this changes as a result of the dam raising, influences the geomorphic processes at work which in-turn defines any changes to the landscape of the catchment as a result of the dam raising. The hydrological functioning of the catchment has been conceptualised across three areas and the geomorphic assessment of effects is also discussed across these three zones:

1. Upstream environment, the incoming rivers above the reservoir
2. The Lake Burragorang reservoir
3. Downstream environment, the Hawkesbury-Nepean Valley below the dam wall.

In the upstream environment the water impounded by the existing dam inundates the valleys of the incoming tributaries. The extent of inundation is dependent on the water level in the dam. There is evidence of sediment deposition in a number of locations around the 'typical' extent of inundation.

Within the reservoir itself the operation of the current dam results in water levels varying as flow is collected (level rise) and as water is discharged for use/environmental purposes (level fall). This results in vegetation die-off and localised shoreline erosion in the area beneath the Fully Supply Level. While in some of tributaries the area below the Full Supply level may be temporarily re-colonised by vegetation, around the main reservoir the loss of soil and vegetation below the Full Supply Level is generally permanent.

The existing dam has limited control of how flows are released, and the effects of the release on the river downstream. This results in higher peak flows with larger erosive power and ability to inundate areas of the adjacent flood plain in the downstream reaches.

The intent of the dam raising project is to reduce the incidence and severity of flooding on the downstream reaches of the river (Hydrology & Flood Assessment, Appendix H1, SMEC, 2021). The reservoir Full Supply Level (FSL) is not being changed and therefore water levels in the reservoir under normal operation will not change. Under flood events the dam raising will increase scale and duration of inundation in Lake Burragorang (**Figure 9**). This will lead to effects in the upstream environment, within the reservoir surroundings and the upstream tributaries. However, it is intended that this increased ability to manage peak inflows to the reservoir will have positive outcomes on flood risk, erosion and inundation downstream.

Due to the proposed operational regime for the raised dam there will be two sets of hydrological functioning which will occur on the downstream river during floods. Both sets of hydrological functioning will have potentially different geomorphic effects.

- **Set 1, Small floods (5% AEP)** - The flood management zone behind the raised dam would fully capture the 5% AEP event without spills over the central spillway. This assumes that the reservoir is at or below the Full Supply Level prior to the flood event. After the incoming flood peak has started to fall, the flood water retained in the reservoir is then discharged via gates in the dam at a discharge rate of approximately 1,150 m^3/s (Hydrology & Flood Assessment, Appendix H1, SMEC, 2021).

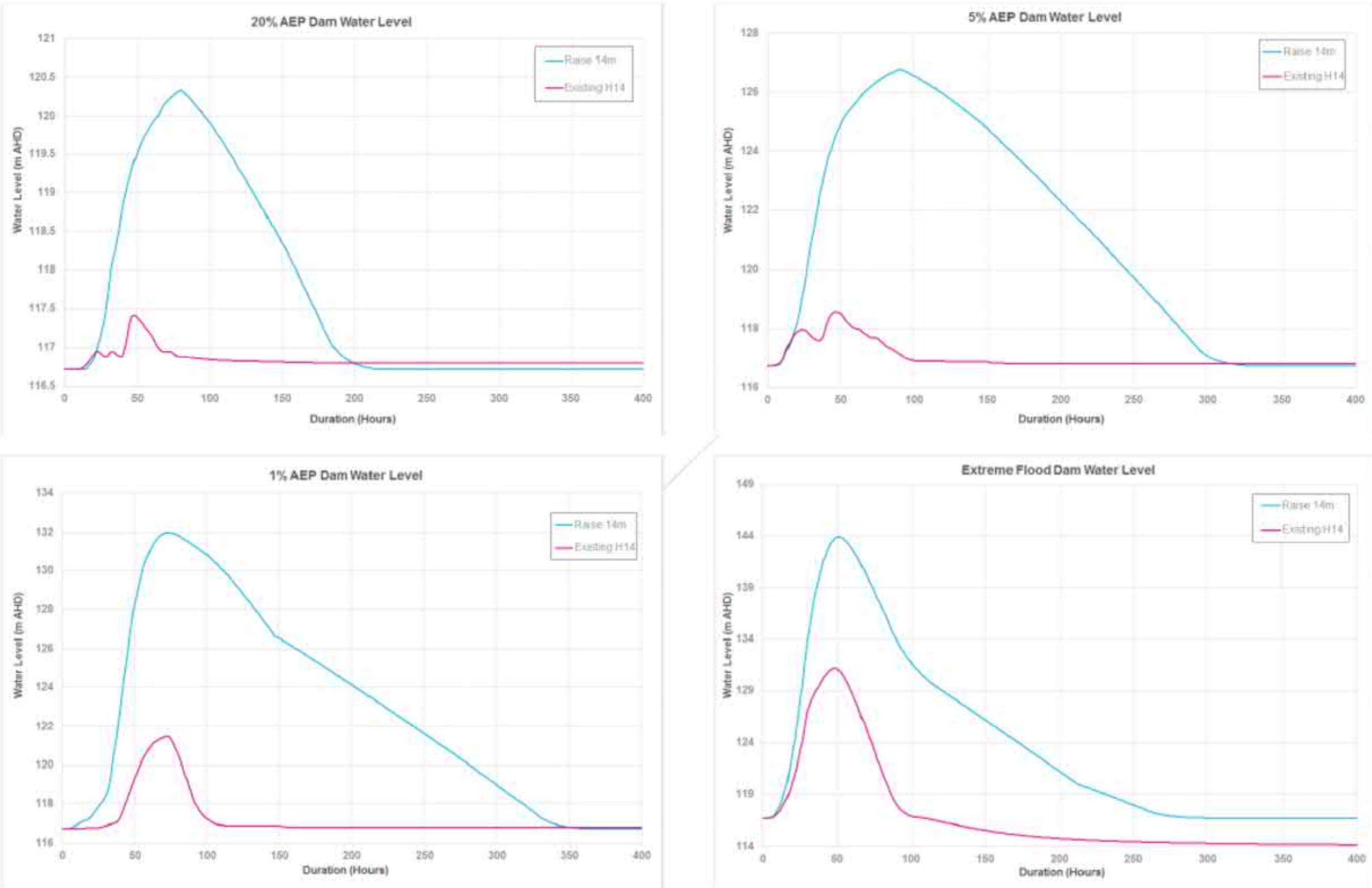
  This operational regime results in a constant flow rate hydrograph for extended periods discharged from the dam for all events up to the 5% AEP event, with the only variation between events being the duration of discharge. For the downstream reaches an overall reduction in flow peak will occur, however the river will spend longer at the fixed discharge flow. This has implications for the erosion of vulnerable bankside soils.

- **Set 2, Major floods 2% AEP and 1 % AEP and Probable Maximum Flood (PMF) –** Above the 5% AEP flood the raised dam will begin to spill over the central spillway. The operational regime for these events is to discharge an additional amount of water after flood levels downstream have receded, therefore maximising the use of the available storage and reducing peak outflows as much as possible. This is to be achieved by piggy-backing outflows onto the early part of the discharge for approximately 2 days before the release is reduced back to 1,150 m^3/s (Hydrology & Flood Assessment, Appendix H1, SMEC, 2021).

The implications of this regime are a three-stage discharge hydrograph, with the third stage being the same as that for Set 1, described above. For the downstream reaches this constant flow rate release has the potential to induce erosion in certain sediments. In upstream tributaries these events will increase the extent and duration of inundation and therefore potentially change deposition patterns. The expected water levels as a result of dam raising have been assessed to be very similar to existing water levels and therefore geomorphic changes are not likely (Hydrology & Flood Assessment, Appendix H1, SMEC, 2021).

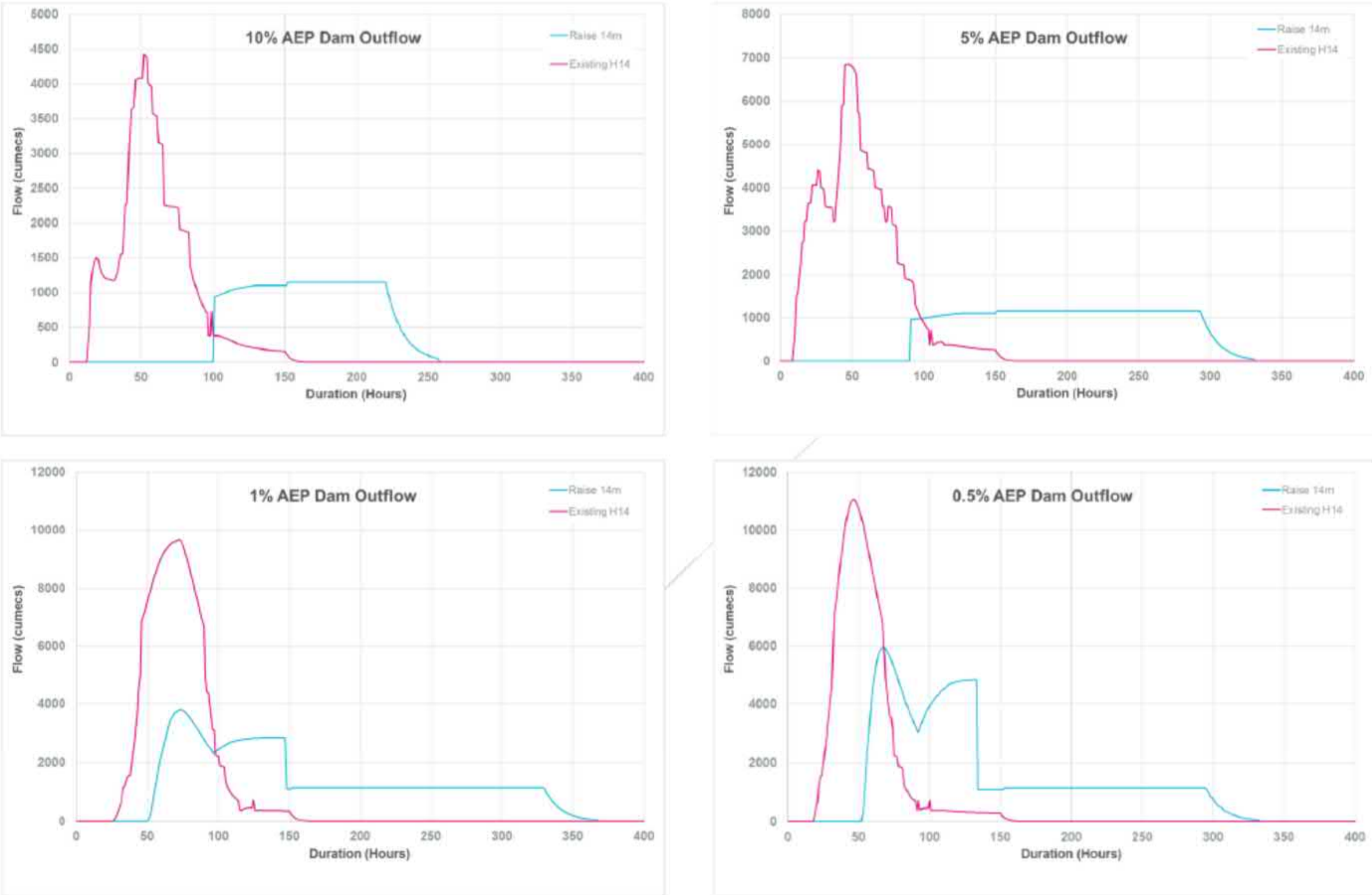
The probable maximum flood (PMF) is a hypothetical flood estimate relevant to a specific catchment whose magnitude is such that there is negligible chance of it being exceeded. It represents a notional upper limit of flood magnitude and no attempt is made to assign a probability of exceedance to such an event (Ball et al. 2019).

Figure 9 Reservoir water level changes (Hydrology & Flood Assessment, Appendix H1, SMEC, 2021)



Note: The ‘Extreme Flood’ referred to in this plot is equivalent to the PMF

Figure 10 Dam outflow changes (Hydrology & Flood Assessment, Appendix H1, SMEC, 2021)



1.5.2 Conceptual understanding of geomorphological issues

Fluvial geomorphology is the study of the form and function of streams and the interaction between streams and the landscape around them. 'Fluvial' refers to the processes associated with running waters, 'geo' refers to earth and 'morphology' refers to channel shape. To address the scope items / SEARs (**Section 1.3**), this assessment will be required to:

- Understand baseline geomorphological conditions in the GIA
- Interpret the changes to hydrological processes that are important in controlling geomorphological condition
- Assess scale and locations of geomorphological change in the GIA.

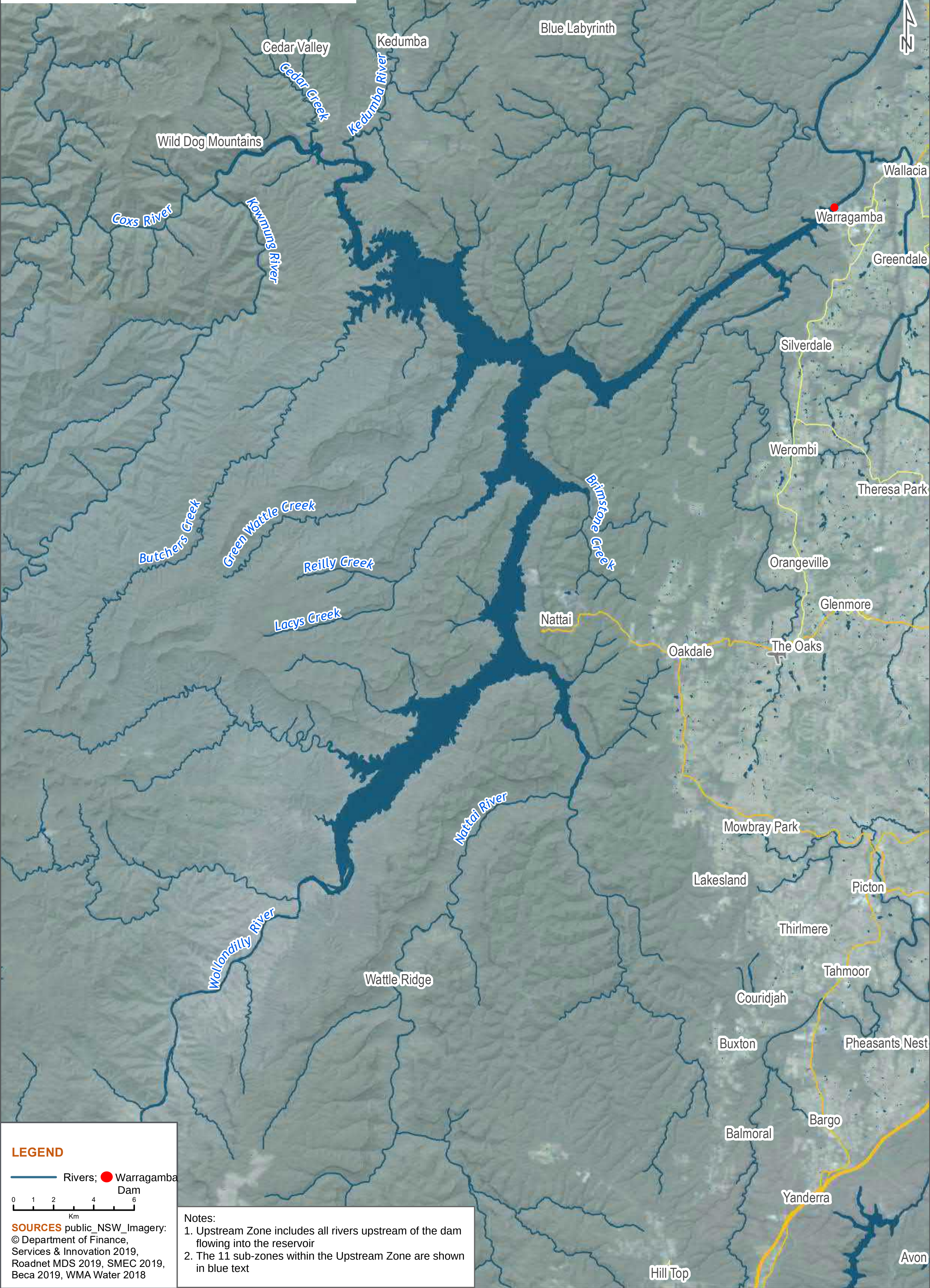
To investigate baseline conditions and impact assessment, the GIA (as defined in **Section 0**) has been divided into three main zones, with 20 sub-zones:

- Upstream watercourses, including, but not limited to:
  - Brimstone Creek
  - Butchers Creek
  - Cedar Creek
  - Coxs River
  - Green Wattle Creek
  - Kedumba River
  - Kowmung River
  - Lacys Creek
  - Nattai River
  - Wollondilly River
- Lake Burragorang
  - North Arm
  - South Arm
  - West Arm
- Downstream Watercourses, including, but not limited to:
  - Cattai Creek
  - Grose River
  - Hawkesbury River
  - Nepean River
  - South Creek
  - Warragamba River

These sub-zones are shown for the Upstream Zone (**Figure 11**), Lake Zone (**Figure 12**) and Downstream Zone (**Figure 13**). There are other watercourses within these zones, but the named watercourses were selected to target additional impact analysis work based on the following criteria:

- Located in areas of focus for other technical disciplines including flow modelling, ecology (both aquatic and terrestrial) and heritage;
- Subject to a mode of envisaged impact, based on changes in hydrological processes in the catchment
- Representative of different sizes of watercourses in the GIA
- Representative of geographical distribution within the GIA
- Watercourses with a predicted change in hydrological condition from the WDR
- Wild Rivers considerations as identified in *NPWS Act*

Figure 11 Upstream Zone and 11 sub-zones



LEGEND

Rivers; Warragamba Dam

0 1 2 4 6
Km

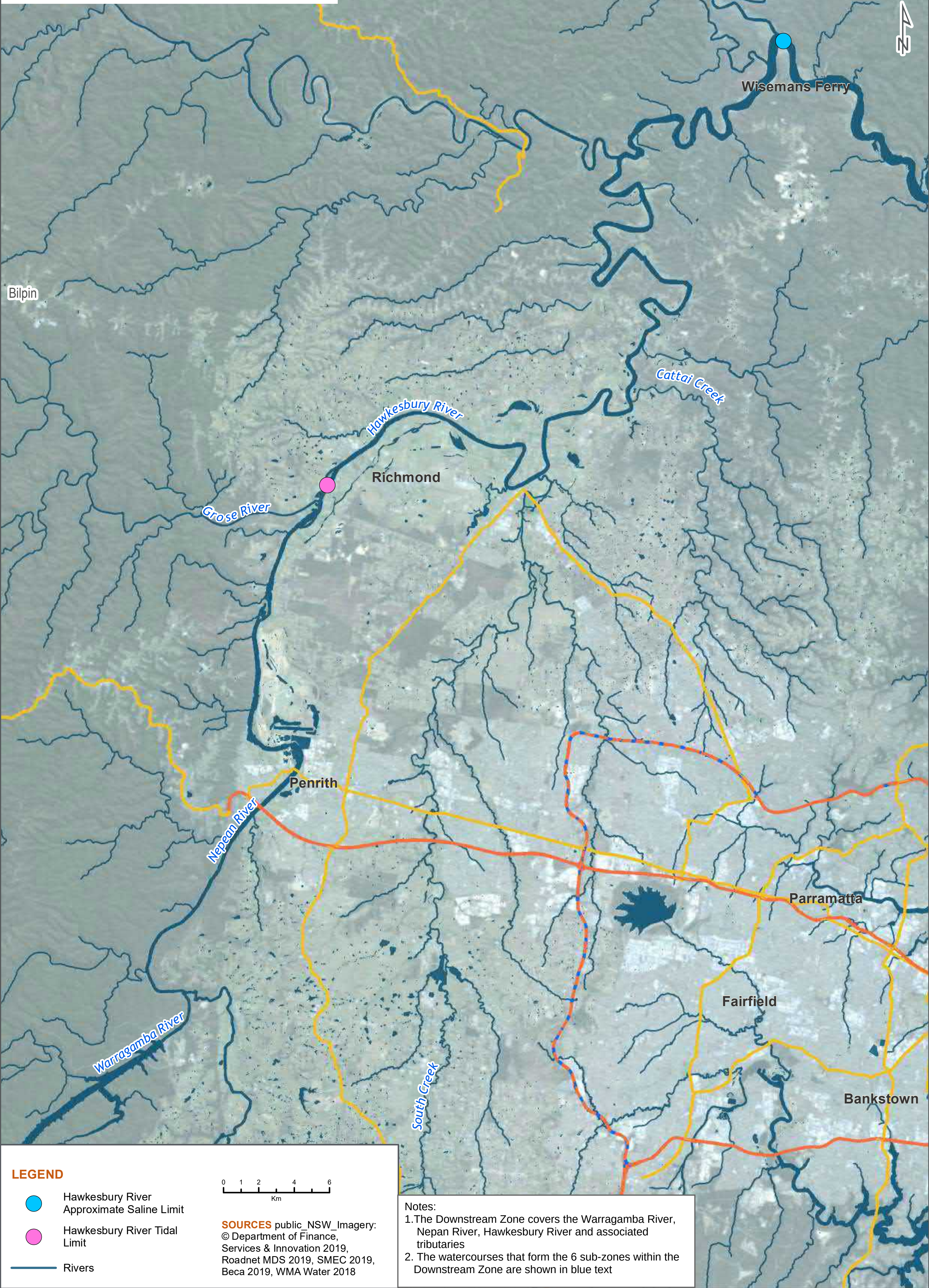
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019, SMEC 2019, Beca 2019, WMA Water 2018

Notes:
1. Upstream Zone includes all rivers upstream of the dam flowing into the reservoir
2. The 11 sub-zones within the Upstream Zone are shown in blue text

Figure 12 Lake Zone and 3 sub-zones

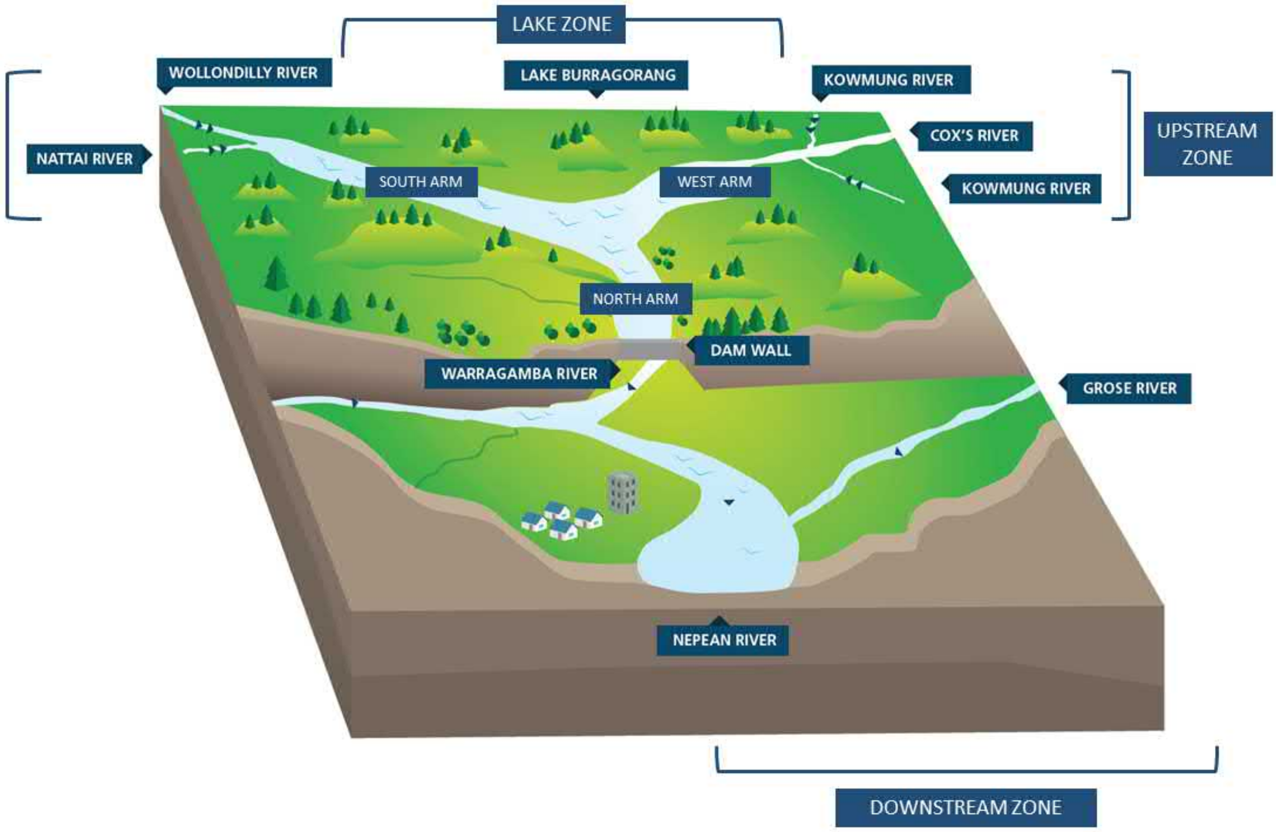
Notes:
1. The Lake Zone cover the area of water impounded behind Warragamba Dam called Lake Burragorang
2. The 3 sub-zones within the Lake Zone are shown in blue text

Figure 13 Downstream Zone and 6 sub-zones



The zones described here are also shown conceptually in **Figure 14**. This conceptual model will be updated later in this document as further detail of the system geomorphology within the GIA is provided (**Section 5.4**).

Figure 14 Conceptual representation of the important geomorphological features of the GIA



For the purposes of this geomorphology report, a GIA has been devised. Delineation of an up-gradient limit in the Upstream Zone for the Project assessment is defined by the PMF. In the Downstream Zone, tributaries are only considered in terms of the potential backflow effect during release flows from the dam. The assessment down-gradient limit stops in the Downstream Zone at Wisemans Ferry. The justification for selection of this down-gradient limit is as follows:

- The dam release flow signal will be far lower in a tidally influenced environment.
- The influence of the bi-directional flow, due to tidal influence means that the empirical assessment approach used upstream will be less applicable.
- The approximate saline limit of the Hawkesbury River occurs at the Webbs Creek confluence 5 km upstream from Hawkesbury. This is the turbidity maxima and downstream of this due to flocculation of sediments there is enhanced deposition.
- Wisemans Ferry is a well-known landmark on the Hawkesbury system.
- There is less critical infrastructure and residential properties downstream from Wisemans Ferry that might be impacted by geomorphological change to the channel.
- Flow impacts to the river are no longer apparent, with storm fluvial flows from upstream and the tidal range from downstream masking the dam release flow signal.

2 Geomorphology Assessment Approach

2.1 Impact assessment approach

The key objective of this geomorphological study is to identify and assess geomorphological impacts related to the project. The assessment outcomes will inform the WDR EIS.

The following methodology has been followed when undertaking the impact assessment:

- Identify and describe baseline conditions through a combination of desktop information (**Section 2.3**) and site-based observations (**Section 2.4**)
- Analyse physical process change and describe sensitive environmental values / receptors
- Describe potential adverse and beneficial impacts of the project on the environmental values / receptors
- Identify risk of these impacts occurring (significance vs likelihood)
- Identify mitigation measures to reduce the identified impacts / risk.

In the event that significant geomorphological impacts are identified, mitigations will be recommended.

This framework is summarised in **Figure 15** below and includes a risk score based on the likelihood and significance of an impact. The risk matrix is shown on **Figure 16.**

Figure 15 Project Impact Assessment Methodology

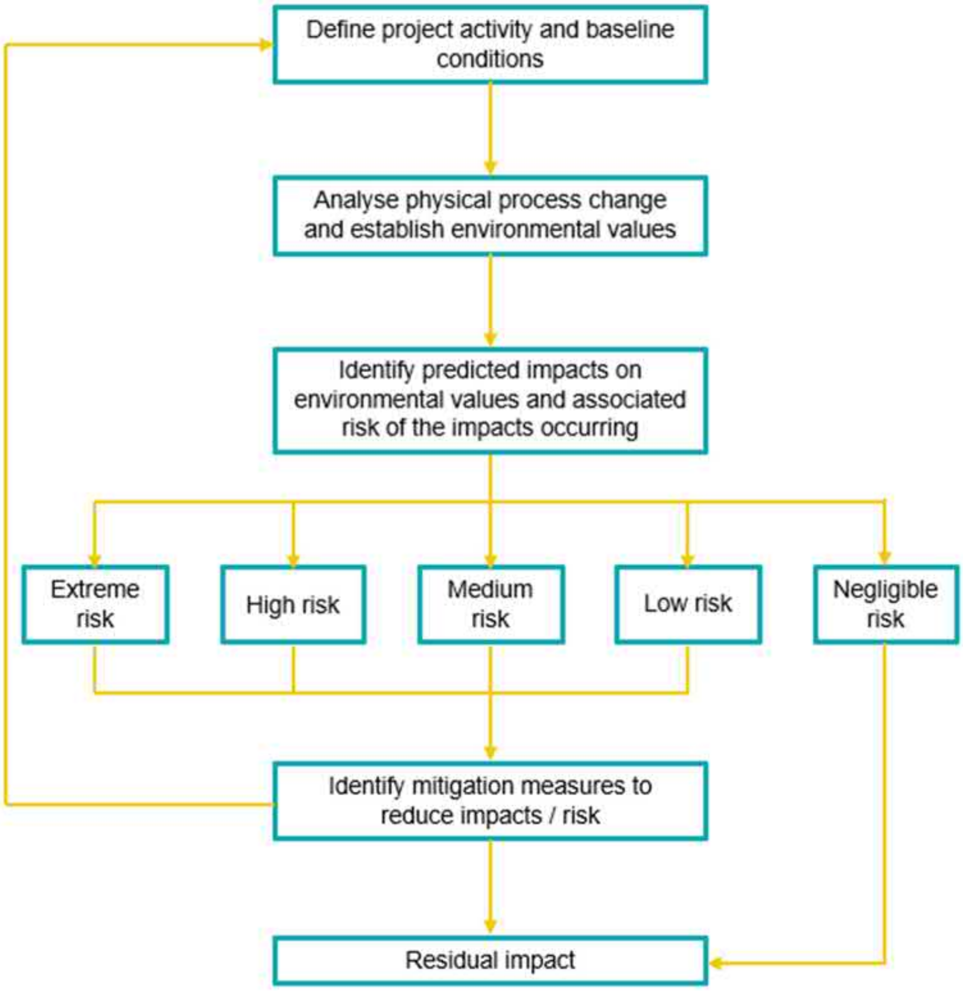


Figure 16 Risk Matrix

Likelihood	Significance				
	Negligible	Minor	Moderate	High	Very High
Highly unlikely / rare	Negligible	Negligible	Low	Medium	High
Unlikely	Negligible	Low	Low	Medium	High
Possible	Negligible	Low	Medium	Medium	High
Likely	Negligible	Medium	Medium	High	Extreme
Highly likely / almost certain	Low	Medium	High	Extreme	Extreme

The definitions for 'likelihood' and 'significance' categories are provided in **Appendix A.3.1**.

2.2 Applicable guidelines

This assessment has been prepared in accordance with the relevant commonwealth, state legislative, policy and guideline requirements, and in consultation with the relevant government agencies. Guidelines and policies considered were as follows:

- ANZECC Guidelines and Water Quality Objectives in NSW (DEC, 2006)
- A Rehabilitation Manual for Australian Streams (Cooperative Research Centre for Catchment Hydrology, 2000)
- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ ARMCANZ, 2000, revised 2018)
- Guidelines for Controlled Activities on Waterfront Land (DPI 2012)
- Guidelines of Ecologically Sustainable Management of Rivers and Riparian Vegetation (Land and Water Resources Research and Development Corporation, 1995)
- NSW State Rivers and Estuary Policy 1993
- NSW Government Water Quality and River Flow Objectives 2006. Available at: http://www.environment.nsw.gov.au/ieo/
- Managing Urban Stormwater: Soils and Construction Volume 1 (Landcom 2004)
- The River Styles Framework. Available online at: https://riverstyles.com/
- *Water Management Act* 2000

This list of guidance documents contains multiple overlaps and contradictions. Where this is the case, and because there is no definitive guidance for fluvial geomorphology assessments that would automatically take precedence, any conflicts of guidance will be identified in this document.

2.3 Desktop methodologies

A summary of desktop methodologies for characterising the baseline environment can be seen in **Table 2**.

Table 2 Desktop methodology summary

Assessment type	Data source/s	Application to this assessment
Aerial photography	Nearmap, 2019	Illustrate channel planform movements visually Quantify nett sediment input / export areas Determine lateral accretion (downstream or upstream) in geomorphic features
Data request	SMEC / WaterNSW / WMA Water	Targeted data request capturing knowledge from the analysis behind other EIS chapters
Literature review	Multiple sources – search using Google, Google Scholar and ResearchGate	Review of locally relevant ecological and water quality environmental values Locally relevant hydrological and geomorphological features
Longitudinal profiles	Nearmap, 2019	Changes in gradient at incremental distances along watercourse (Wollondilly River only) Changes in gradient for entire watercourse (all other major creeks / rivers in GIA)
Meteorological data	WaterNSW, 2019	Generation of wave height dataset for Lake Burragorang Interpretation of sediment dataset
River Styles™ framework	NSW Office of Water (2012)	Catchment-scale classifications
Sediment concentrations and flow data	WaterNSW, 2019	Sediment load calculations for the Coxs, Nattai and Wollondilly Rivers Temporal and spatial variation in sediment concentrations in both the Upstream and Downstream Zone rivers and for Lake Burragorang Variation of sediment with depth in Lake Burragorang
Topographic survey of Lake Burragorang	WaterNSW, 2019	Input dataset for the Erosion Hotspot Model Sediment deposition features in Lake Burragorang
Turbidity level long-profile of Hawkesbury-Nepean River	DECC, 2009	Input to floodplain sedimentation from out of bank flows

Further detail is provided in **Appendix A.1**. Work conducted by the project geomorphologist previously engaged by SMEC was incorporated into this section (*pers. comm.* Peter Johnston, 2018).

2.4 Site methodologies

Site visits were conducted to the Upstream Zone (3 days), Lake Zone (1 day) and the Downstream Zone (1 day). A summary of site methodologies employed for characterising the baseline environment can be seen in **Table 3**.

Table 3 Site methodology summary

Assessment type	Approach & site coverage	Application to this assessment
Bank strengths	Use of a penetrometer to measure bank strengths. Geometric mean of x18 measurements of tensile bank strength collected at each of 30 sites (14 Upstream Zone, 6 Lake Zone, 10 Downstream Zone).	• Baseline indication of bank strengths • Used to assess impacts of flow changes on bank erosion susceptibility
Rapid geomorphology walkover survey	Templates based on RiverStyles™ classification (Brierly and Fryirs 2005) were used to describe the main channel types identified in the assessment based on valley setting, channel continuity, river planform, geomorphic units and bed material texture. A total of 54 sub-sites were surveyed (including 14 coupled Upstream Zone [i.e. 28 sub-sites], 6 Lake Zone and 10 coupled Downstream Zone [i.e. 20 sub-sites]).	• Conveyance and channel adjustment characteristics. • Erosion mechanisms and depositional features • Floodplain geomorphology • River character and behaviour based on bed and bank sediment information
Sediment deposition potential	Deposition matting has been deployed at seven key locations - Kedumba River (two sites) - Lake Burragorang (four sites) - Hawkesbury River (one site)	• Potential accumulation of sediment mass on floodplain banks during inundation events • Particle size composition of deposited sediments

Further detail is provided in **Appendix A.2**.

2.5 Impact assessment analysis

Semi-quantitative impact assessment analyses of collated desktop and site investigations data was completed for the upstream, lake and downstream environments as summarised in **Table 4** below. The differences observed in the Hydrological Modelling performed for the Project could not be related solely to the dam development and therefore a meaningful quantitative difference geomorphology analysis could not be undertaken. Further information on this, along with a treatise on the hydrological understanding of the Project, can be found in **Appendix B**.

Table 4 Data analysis approaches to support impact assessment

Catchment location	Assessment approach	Application to this assessment
Upstream	• Bank erosion data (spatial variation) • Erosion hotspot model • Hjulström Curve sensitivity analysis • Literature review • Site walkover observations	This combination of analyses will be used to assess potential for out of bank erosion, translocation of sediment features upstream and in channel sediment deposition
Lake Burragorang	• Bank erosion data (spatial variation) • Erosion hotspot model • Literature review • Site walkover observations	This combination of analyses will be used to assess potential for out of shoreline erosion, elevated erosion of shoreline banks, deposition of sediments on sensitive receptors during inundation events and change in circulation patterns causing sediment redistribution
Downstream	• Bank erosion data (spatial variation) • Bank Erosion Index • Literature review • Hicken Curve motion analysis • Site walkover observations • Turbidity levels overlain on Flood Mitigation Zone (FMZ) discharge flood extent and critical infrastructure / land use mapping	This combination of analyses will be used to assess potential for cumulative bank erosion impact caused by prolonged FMZ flows, increased fine sediment content in Hawkesbury-Nepean river channel and floodplain sedimentation from out of bank flows

Further detail on these semi-quantitative approaches is provided in **Appendix A.3**.

2.6 Mitigation measures

Mitigation measures are means to prevent, reduce or control any adverse geomorphological effects of the Project, and include restitution for any damage to the environment caused by those effects through replacement, restoration, compensation or any other means.

The proposed mitigation measures for this Project follow typical industry mitigation and management practices.

Mitigation measures are the result of an iterative process that took place between the baseline condition assessment and environmental effects prediction. The proposed mitigation measures for the identified geomorphological effects are summarised in **Section 5.4**.

2.7 Exclusions

- Dynamic numerical sediment modelling was not possible to undertake with sufficient accuracy given the unavailability of data. Instead, a conceptual model(s) was developed to detail any potential changes in sediment dynamics and channel shaping processes in the different watercourses during both construction and operational phases of the project. As such, no quantitative assessment of impacts using dynamic numerical modelling was performed. Instead, empirical associations between flow and sediment transport were used which is suitably proportionate to the sediment transport issues assessed, within the context of the proposal location and the surrounding environment as per SEARs (**Section 1.3**).

- Assessment did not include consideration of climate change; this has been addressed separately in Appendix G to the EIS (Climate change risk).
- No assessment of large-scale geotechnical landslide / land stability / failure issues caused by a change in wetting of the basal surfaces and / or land surface disturbance in the Lake Burragorang Valley has been performed as they are outside the scope of a fluvial geomorphology assessment. This is addressed in the EIS (SMEC, 2020, Chapter 22, Section 22.5).
- The scope did not include any assessment of impacts on terrestrial soils which were addressed in a separate Soils and Contamination Technical Assessment (SMEC, 2020 Appendix N of the EIS).

3 Baseline characterisation – existing environment

This section is split into two sub-sections, the first reviewing existing knowledge related to geomorphology in the Hawkesbury-Nepean catchment using desktop sources of literature and data. This process identified some key information gaps. The second summarises the additional information gathered during site investigations to fill these information gaps.

3.1 Desktop review of the Hawkesbury-Nepean Catchment

The Hawkesbury-Nepean river system is one of New South Wales' most important natural assets and is one of the largest coastal river catchments along the NSW coastline (Ribbons, 2015). Its catchment covers 2.2 million hectares (22,000 km^2), framing the northern and western edges of the Sydney Basin. It is the main source of drinking water for over four million people, or 70 percent of the NSW population. Its waters also support agricultural and horticultural industries that generate more than $1 billion annually, including $259 million of irrigated agriculture which supplies much of Sydney's fresh food. Each year more than 10 million people visit the Hawkesbury-Nepean catchment to experience its natural assets including World Heritage listed wilderness, rainforests, open woodlands, wetlands and heath lands, and the spectacular Hawkesbury estuary. (NSW Government, 2013).

The catchment includes the coastal reaches from Turimetta Headland to Barrenjoey near its mouth, and catchments for Warragamba, the Upper Nepean and the Mangrove Creek dams, the main water supply reservoirs for the Sydney metropolitan area, including Gosford and Wyong (NSW DoPIE, 2019). More than 40 percent of the Hawkesbury-Nepean catchment (9,000 km^2) is upstream of Warragamba Dam. Warragamba Dam was constructed between 1948 and 1960 with the sole purpose of supplying water to the Sydney metropolitan area.

Significant alteration of the natural river flow, intensive urban and industrial development as well as numerous, competing needs for water are key water management challenges (NSW DoPIE, 2019). Specific water management issues include:

- Environmental water: sufficient flows and freshes to maintain river health
- Increasing demand for water: urban population and industry growth
- River bank management: urban and agricultural development, construction of 'instream' development such as pontoons and wharves
- Water accounting: the NSW Government is rolling out water meters to licence holders to account for water extraction
- Water quality: pollution, algae and weed growth.

The first part of this sub-section describes the characteristics of the Hawkesbury-Nepean catchment. The second part examines geomorphology studies in the three zones of the GIA study (as defined in **Section 1.5**).

3.1.1 Geology and Soils

Rock types also have a strong influence on the physio-chemical characteristics of soils and the sediment derived from soil erosion, so it is an important factor in considering sediment transport.

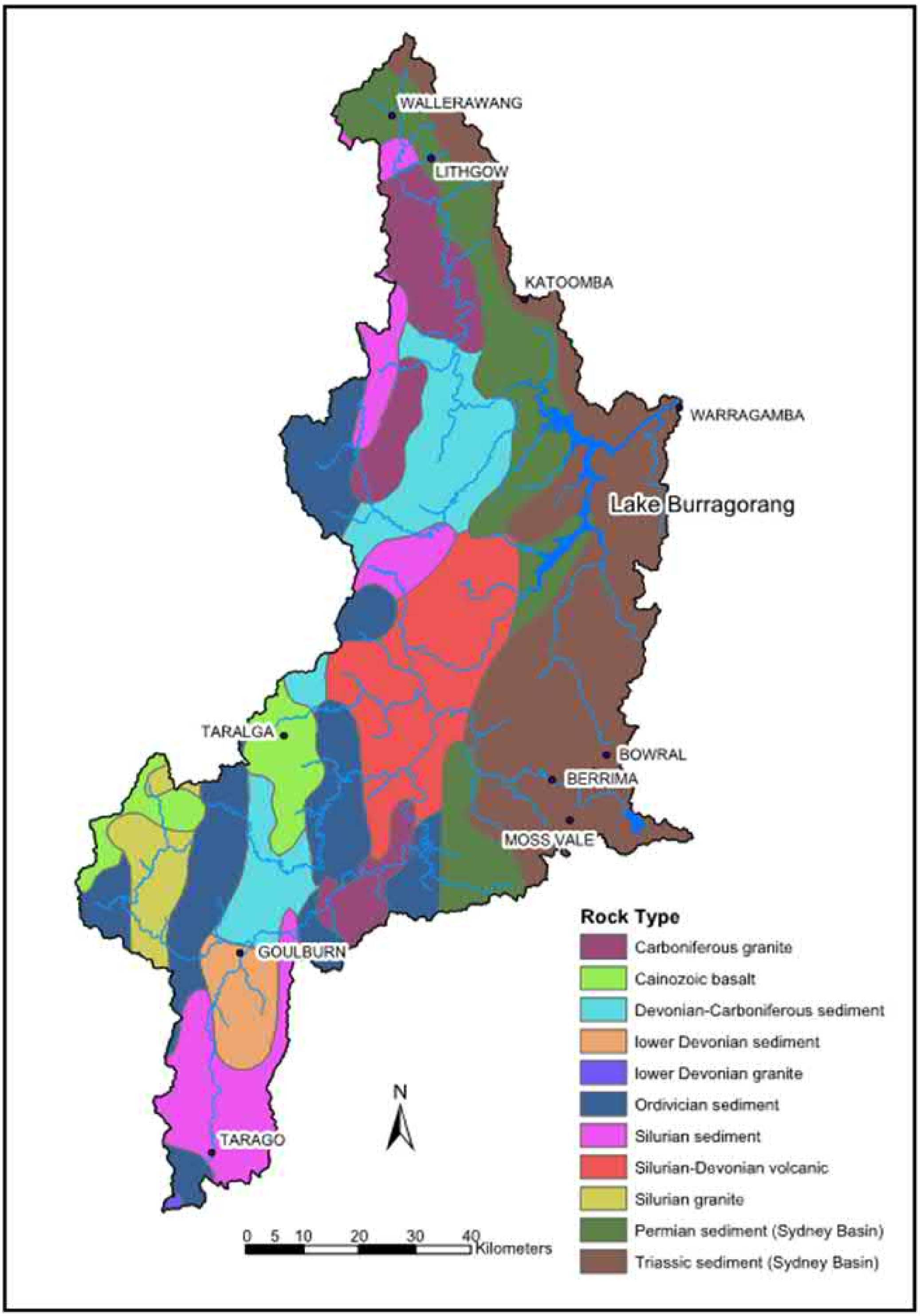


Figure 17 Geology of the Lake Burragorang Catchment (Geoscience Australia: www.ga.gov.au)

The eastern part of the Lake Burragorang catchment contains the massive sandstones that outcrop along the western edge of the Sydney Geological Basin (**Figure 17**). The Hawkesbury Sandstone, which is the dominant geological feature, has been dissected into extensive plateaus, escarpments, and gorges. Soils developed on these rocks are sandy and have low fertility (Fredericks, 1994).

The Hawkesbury Sandstone is overlain by relatively small areas of Wianamatta Shale, notably between Bowral and Moss Vale. These finer grained sedimentary rocks produce low undulating hill and swampy depression topography. Soils have a high clay content and good water holding capacity, so they have been developed for grazing, dairy farming and other more intensive forms of agriculture that can be sustained by the application of fertilizers.

Sedimentary rocks that are mainly exposed in gorges cut through the Hawkesbury Sandstone include the Narrabeen (sandstones and claystones) and Shoalhaven (sandstones and conglomerates) groups and the Illawarra Coal Measures (sandstones, claystones, coal). Mining access to the coal seams has mainly occurred in incised valleys such as the lower Nattai and parts of the upper Coxs rivers.

West of the Sydney Basin the Lachlan Fold Belt is the major geological feature that makes up the major part of the Lake Burragorang catchment. Rock types include granites, and complexes of volcanic and sedimentary rocks (**Figure 17**). The youngest rocks are Cainozoic basalt that occurs along the margin of the upper Wollondilly catchment and form gently rolling hill country, with often deep and relatively fertile soils.

Granitic rocks outcrop in the upper Wollondilly and mid to upper Coxs catchments. The soils are relatively infertile and subsoils are susceptible to gully erosion, but the generally rolling topography that forms on granite makes this country suitable for grazing.

Volcanic complex rocks make up a major part of the middle to lower Wollondilly catchment. Soils developed on these rocks are susceptible to erosion, particularly gully erosion, and have low natural fertility. All but the steepest slopes are cleared and used for grazing (Fredericks, 1994). Deep ‘v’ shaped valleys have formed in parts of this land system, particularly along the Wollondilly River. The landscape is gently to moderately rolling beyond the deep valleys.

Ancient sedimentary rock complexes (metasediments including sandstone, shale, greywacke, siltstone) occupy areas of the lower Coxs and much of the middle to upper Wollondilly catchments. Some of the sandstones of terrestrial origin are very resistant to erosion. Land occupied by marine sediments tends to be gently rolling in the upper catchments, but may also be incised into deep valleys in the lower to middle catchments. Soils have low natural fertility and are lightly textured, and so may be susceptible to surface erosion.

3.1.2 Rainfall

Rainfall in the catchment can be affected by drought and seasonal rainfall can be erratic (Sakal *et. al*., 2008). Rainfall is influenced by the southern extensions of tropical low-pressure systems while convective storms can result in localised short-duration, high intensity falls which deliver larger proportions of the annual rainfall in one event (Fredericks, 1994). Highest rainfall generally occurs in the highest parts of the catchment, notably on the high plateaus in the Coxs catchment (e.g. approximately 1,400 mm at Katoomba) and the Southern Highlands in the vicinity of Moss Vale. Conversely, the lowest rainfall area occurs on the middle to lower Wollondilly Catchment (e.g. approximately 500 mm at Goulburn). Thunderstorms often originate in response to daily heating of hills slopes to the west of Sydney in unstable air flows before drifting over adjacent lowlands and coastal areas to the east. These thunderstorms are neither spatially nor temporally uniform (Rasuly, 1996).

The implications of this rainfall pattern are rapid hydrological responses to events in the northern, Sydney Metropolitan (also due to local convection patterns and high impermeable area) and western sub-catchments. Rainfall erosivity is also highest in the northern and western parts of the catchment where the mean annual rainfall is highest (**Section 3.1.4e**). In the drier parts of the catchment gradual hillslope erosion is the dominant source of sediments to the channels (**Section 3.1.4e**).

3.1.3 Land Use

Land cover is predominantly pasture and woody vegetation (**Figure 18**). About 47% of the Lake Burragorang catchment remains as forest and woodland, mainly concentrated in the lower Coxs and Nattai catchments. These areas include National Park. Most of the cleared land is in the relatively low gradient parts of the

Wollondilly and Upper Coxs catchments. Cleared areas are mainly grassland with areas of open Eucalyptus also used for grazing. Urban areas occupy about 3% of the catchment and a similar area is used for plantations and horticulture. Mining activities occur in 1% of the catchment but can have a disproportionate impact on sediment generation (**Section 3.2.1**).

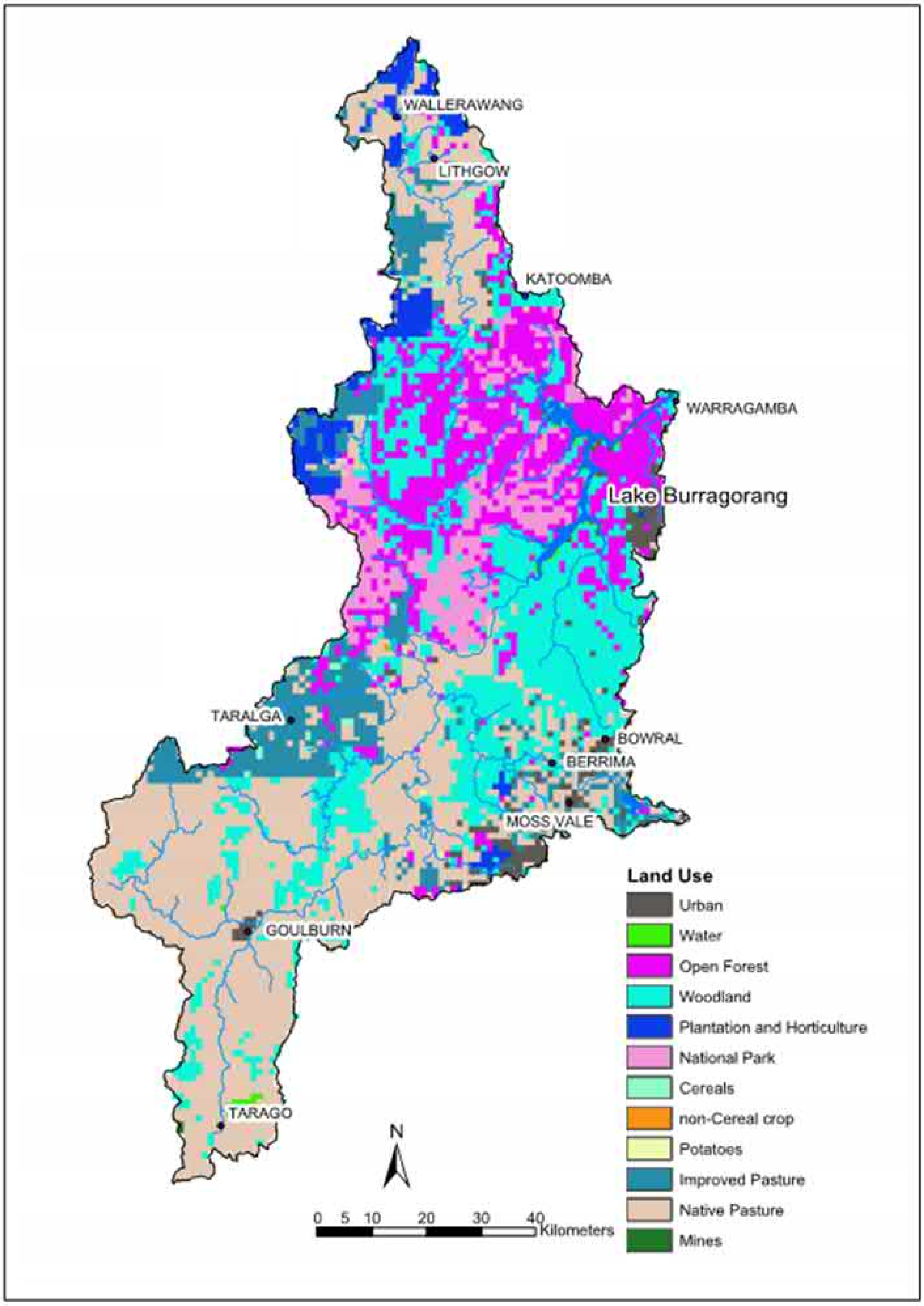


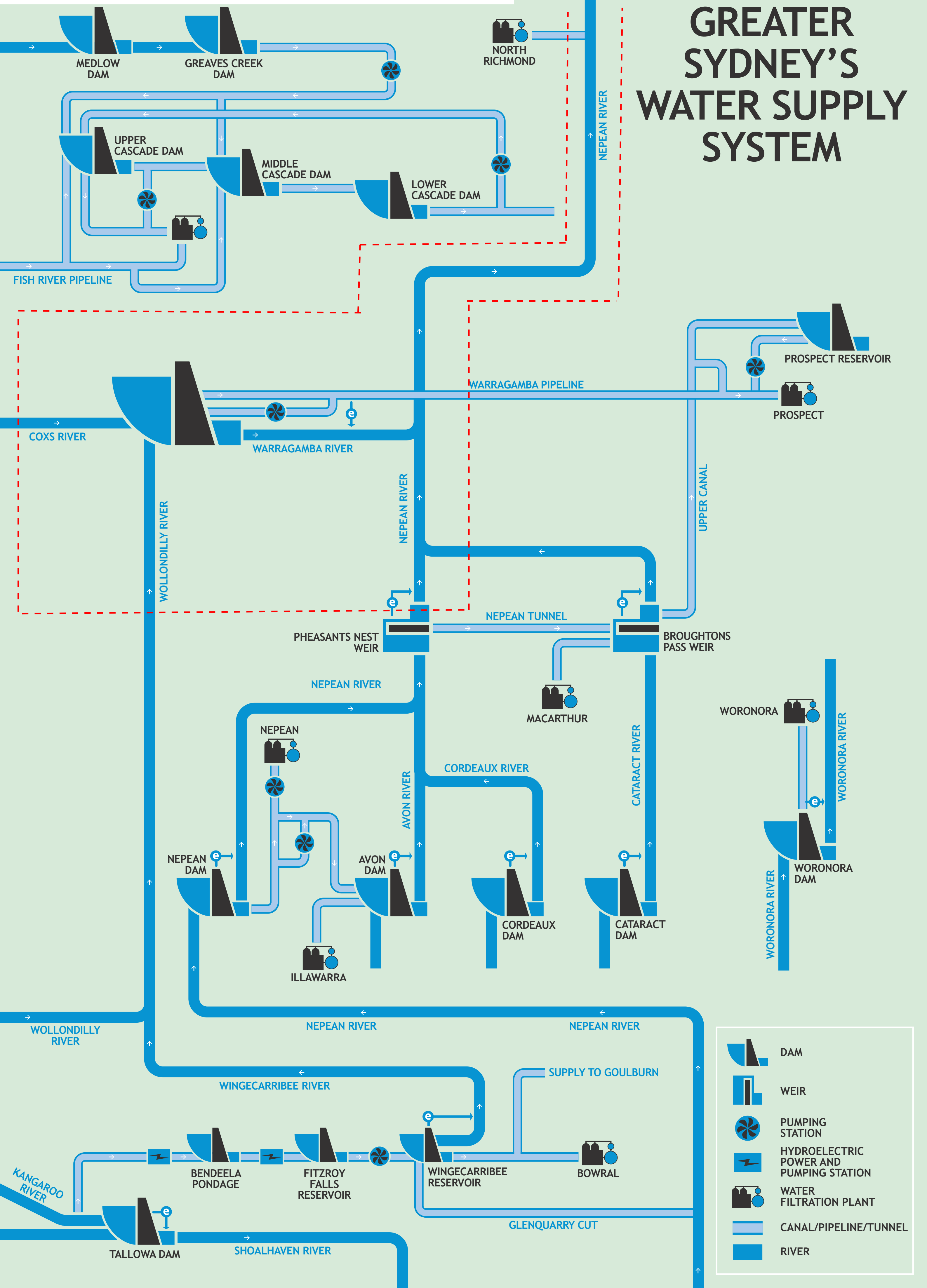
Figure 18 Land use in the Lake Burragorang catchment (Source: National Land and Water Resources Audit)

3.1.4 Waterbodies

Twelve major catchments contribute flow to Lake Burragorang. The Wollondilly catchment is the largest area (55% of the total), followed by the Coxs River (27%), the region immediately around the lake (9%) and the

Nattai River (7%). While the basin is considered unregulated, river flows within much of the Hawkesbury-Nepean catchment are heavily controlled by dams and weirs which retain river flows (NSW DoPIE, 2019). Water from river catchments to the south and west of Sydney is stored in 10 major dams, and then transported via a network of rivers, pipes and canals to water filtration plants (WaterNSW, 2016). Most of the water from Sydney's catchments is supplied to Sydney Water's nine filtration plants for treatment and distribution to customers. More than 80% of Sydney's water is treated at Prospect water filtration plant, which supplies 3.7 million people in Sydney (WaterNSW, 2016). This complex system is highly flexible and can be reconfigured during times of drought, high rainfall or during maintenance. Water is released from dams as environmental flows, to maintain the health of downstream river systems (**Figure 19**).

Figure 19 WaterNSW total system schematic (adapted from WaterNSW, 2016)



The Warragamba system is the main water supply to more than 3.4 million people living in Greater Sydney (WaterNSW, 2019). Water from the Coxs and Wollondilly rivers flows to Warragamba Dam, one of the world's largest domestic water supplies, containing four times the volume of Sydney Harbour, 2,027 GL. Water flows by gravity through two pipelines, 27km to Prospect water filtration plant, which supplies 75% of Sydney. The dam also supplies Warragamba, Penrith and the lower Blue Mountains via water filtration plants at Warragamba and Orchard Hills. Water is released into the Warragamba River to provide a secure water supply to the people of North Richmond and as environmental flows. The Warragamba system can be topped up by water from the Shoalhaven system. Water from Wingecarribee Reservoir can be released into the Wingecarribee River, which flows into the Wollondilly River and Warragamba Dam. A deep-water pumping station has been constructed at Warragamba Dam to enable continued supply if the water level falls below the outlets during a severe drought (WaterNSW, 2016).

a. Aerial photography analysis

Historic aerial images of selected sites in the Upstream, Lake and Downstream Zones are provided in **Appendix C**. A summary of changes to the geomorphological structure of the sites is provided in **Table 5**, **Table 6** and **Table 7**, respectively, below. The available photography covers varying date ranges, depending upon location. Our summary provides details of the presence of key geomorphological features in available photography. We cannot confirm the presence or absence of these features outside of the date ranges quoted.

Table 5 Historical changes in geomorphology of selected Upstream Zone sites

Site code	Watercourse	Observations
US-01	Wollondilly River	2009 onwards – Sediments of left bank pool with increasing vegetation cover in 2015-2016
US-02		Removal of vegetation and sediment deposition on left hand bank in 2014 and again in 2016 following regrowth
US-03		No changes observed over timeframe
US-04		No changes observed over timeframe
US-05		2018 re-vegetation of extensive delta
US-06	Nattai River	No changes observed over timeframe
US-07		Extensive reworking of channel on braided floodplain with eyots forming. Inundation of levee in 2013.
US-08		Transport of sand in channel evident 2006 – 2010.
US-09	Coxs River	Partial vegetation of in-channel fill in 2012 that subsequently is eroded
US-10		Partial non-vegetated sand bar deposited in the channel which appears to be either inundated or eroded downstream in 2012.

Site code	Watercourse	Observations
US-12		Sand slug evident in 2006 which subsequently is transported downstream and not evident in 2014 / 2016 images. Large area of mud-like substance deposited on near-side bank in 2017.
US-11	Reedy Creek	No changes observed over timeframe
US-13	Kedumba River	Poor resolution but a sand bar has been deposited in the downstream reach in the 2017 image.
US-14		No changes observed over timeframe clear. Vegetation partially masks channel structure.
US-16	Cedar Creek	No changes observed over timeframe

Table 6 Historical changes in geomorphology of selected Lake Zone sites

Site code	Watercourse	Observations
R-01	Lake Burragorang	Form of inlet to south remains stable. Main shoreline appears non-vegetated but progressive re-vegetation to 2019. Some rill erosion evident.
R-02		Exposed foreshore evident in 2010 and 2019 but inundated in 2013 and 2016. Vegetation evident in 2010 has disappeared. Rill erosion evident in swash zone.
R-03		Sand bypass channel in 2006 has been re-vegetated in successive 2012, 2014 and 2016 images.
R-04		No changes observed over timeframe
R-05		No changes observed over timeframe
R-06		Mud deposits along cliff-face emanating from southern inflow in 2015. These appear to be in suspension. Other tributaries in area also appear to contain silt deposits.

Table 7 Historical changes in geomorphology of selected Downstream Zone sites

Site code	Watercourse	Observations
DS-01	Warragamba River	Vegetation of mid-channel bar between 2014 and 2018.
DS-02		Highly turbid water in 2007 (fine sediments) and 2009 (algae) appear to be sourced from upstream Nepean, rather than from Warragamba. No change to channel structure.
DS-03	Nepean River	Channel inflow on left hand bank evident in 2016. Revegetation in other years.
DS-04		No changes observed over timeframe.

Site code	Watercourse	Observations
DS-06		Highly turbid water in 2006 (algae). No change to channel structure.
DS-07		Channel instream deposits evident in 2007 and 2019. No change to main channel structure.
DS-08	Grose River	Large areas of sand deposition 2002 – 2014. These appear to be partially re-vegetated in 2018.
DS-09	Hawkesbury River	No changes observed over timeframe.
DS-11		Presence of submerged macrophytes / weed growth off beach in 2007.
DS-12		Highly turbid water in 2003 and 2014 (fine sediments)

b. Wollondilly River long profile

The Wollondilly River long profile was plotted according to the procedure given in **Appendix A.1.4**. It shows a general reduction in elevation from 156 m AHD from the upstream point to 118 m AHD where the river flows into Lake Burragorang (**Figure 20**). A polynomial trendline (r^2 value of 0.95) was applied to smooth outliers in the elevation profile. Potential areas of erosion and deposition were flagged on the long profile using 10th and 90th percentile slope percent changes – i.e. rapid declines or inclines, respectively, in the profile.

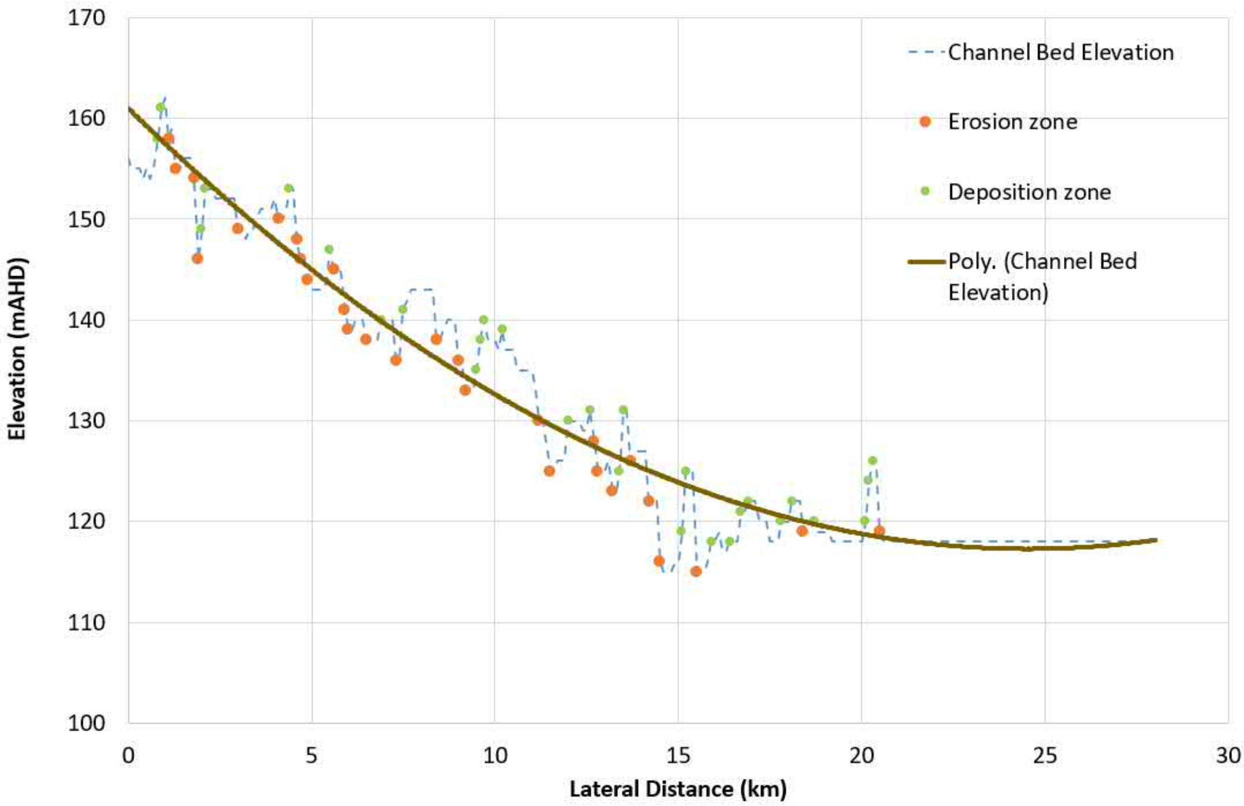


Figure 20 Wollondilly River longitudinal profile

The main findings from this assessment were that:

- Largest declines between -2 and -10 m (<10 percentile) were mapped as potential erosion zones
- Inclines of 1 – 4 m (>90 percentile) were mapped. These values have lower confidence than potential erosion zones (due to the poor vertical accuracy of the NearMap photogrammetry-based data) but may be indicative of slight increases in elevation within bed topography or the greatest positive change in decline along the profile.
- The majority of potential 'erosion zones' occurred near the top of the profile between 1,000 – 9,000 m chainage length
- The majority of potential 'deposition zones' occurred in the bottom of the profile between 10,000 – 20,000 m chainage length

The full dataset of 'erosion and 'deposition' points on the long profile are listed in **Appendix D**.

c. Coxs River long profile

The channel profile over the Cox's 50 km upstream from the Lake Burragorang was adapted from CSIRO Land & Water, 2000 and point measurements from Nearmap (**Figure 21**).

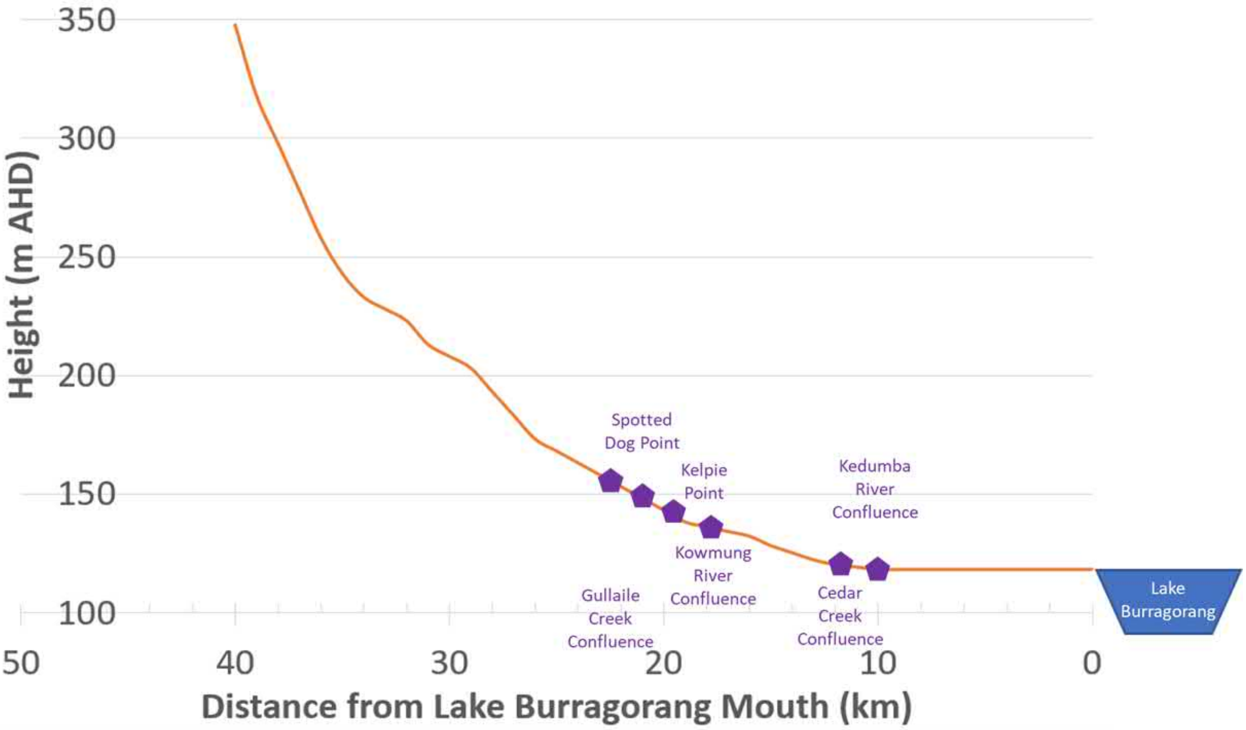


Figure 21 Coxs River longitudinal profile (Source: CSIRO Land & Water, 2000)

The lowest average gradient of 0.004 m/m occurs in the stretch immediately upstream of Lake Burragorang to the Kedumba River Confluence. The steepest stretch of the rivers occurs at 30 - 40 km upstream from the Lake Burragorang Mouth (0.019 m/m).

Other profiles with lower confidence levels are presented in **Appendix D** for completeness. No analysis of these profiles has been completed.

The gradients for major watercourses in the Hawkesbury-Nepean catchment are presented in **Table 8** below. These were calculated from the difference in height at source and end-point (in m) divided by the length of the watercourse (in km). These can be classified into three categories:

- Low slope (0-10%)
- Medium slope (11-20%)

- High slope (>20%)

The majority of short creeks which flow into Lake Burragorang have a high slope. The Coxs, Nattai and Wollondilly have very similar slope of 6 or 7%. Most of the downstream rivers have low slope, with the exception of the Grose River (18%).

Table 8 Total gradients for watercourses in the Hawkesbury-Nepean catchment

Zone	Watercourse	Total length (km)	Source altitude (m AHD)	Confluence / end point altitude (m AHD)	Total slope (m/km)
Upstream	Brimstone Creek	8.9	452	116	38
	Butchers Creek	32	674	124	17
	Cedar Creek	16.3	658	115	33
	Cox's River	155	1040	114	6
	Green Wattle Creek	26	815	115	27
	Kedumba River	20	556	120	22
	Kowmung River	74	941	125	11
	Lacys Creek	16.2	714	111	37
	Nattai River	51	452	116	7
	Reedy Creek	7.5	668	131	72
	Wollondilly River	156	993	115	6
Downstream	Cattai Creek	34	86	6	2
	Grose River	54	953	2	18
	Nepean (source – Yarramalong)	178	766	2	4
	Hawkesbury (Yarramalong – Estuary)	120	58	0	0
	South Creek	70	97	2	1
	Warragamba River	18	118	22	5

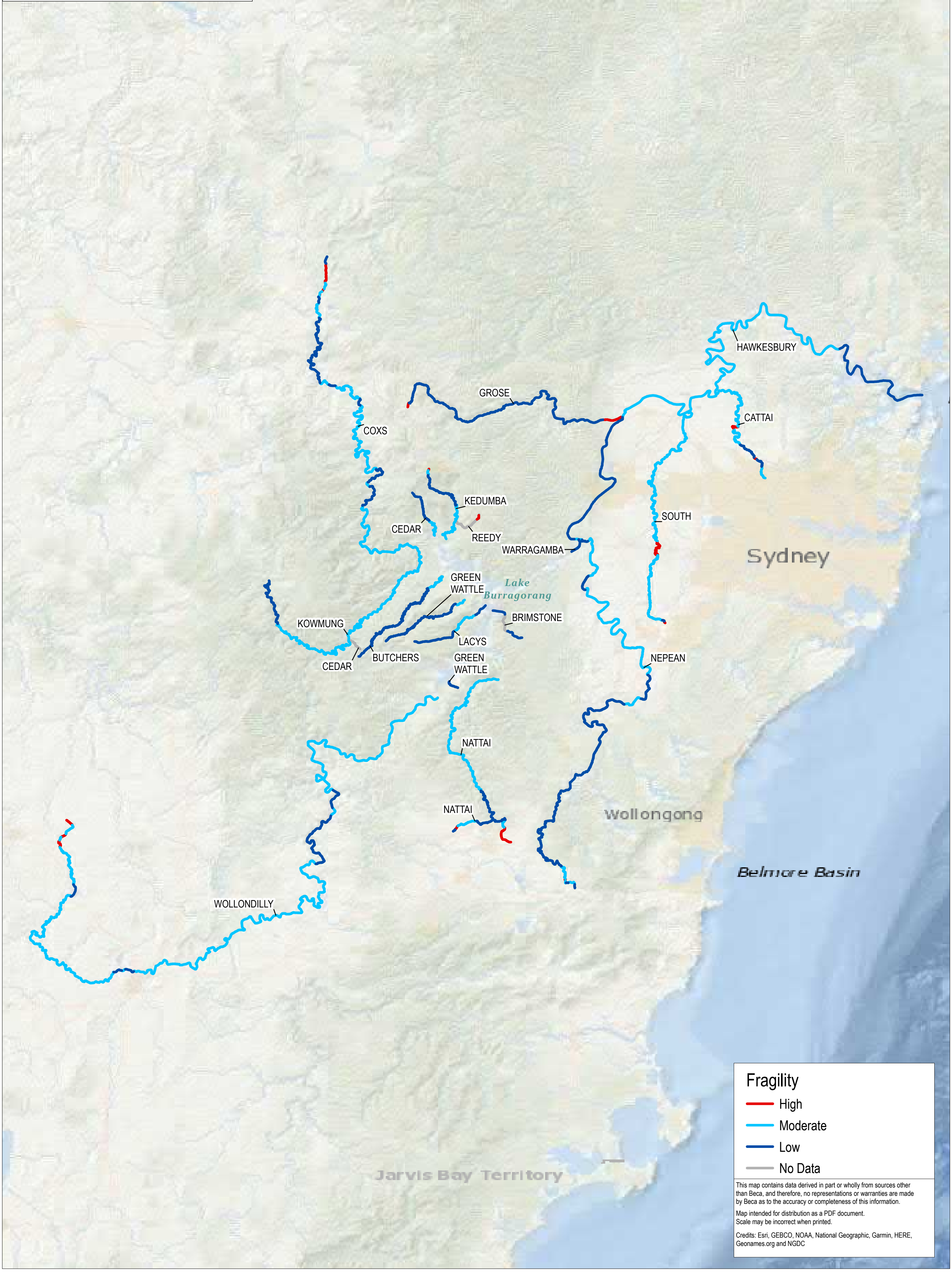
d. RiverStyles™ Framework

The Water Division of NSW Department of Planning, Industry and Environment and Macquarie University developed the NSW River Styles Database. The database was accessed to extract watercourses and other waterbodies classifications using the RiverStyles™ framework (Brierley & Fryirs 2005). Classifications found within the Upstream and Downstream Zones are presented for the following parameters:

- Fragility (**Figure 22**)
- Recovery potential (**Figure 23**)
- River Style (**Figure 24**)
- Stream condition (**Figure 25**)

A detailed breakdown of these four attributes for each reach of all the watercourse can be found in **Appendix E**.

Figure 22 RiverStylesTM Fragility



This map contains data derived in part or wholly from sources other than Beca, and therefore, no representations or warranties are made by Beca as to the accuracy or completeness of this information.

Map intended for distribution as a PDF document.
Scale may be incorrect when printed.

Credits: Esri, GEBCO, NOAA, National Geographic, Garmin, HERE, Geonames.org and NGDC

GIS@beca.com

File: \\fpsyd1\Projects\451\4512987\03_Work Process\03_2 Baseline Conditions\River Styles\NSWRiverStyles\NSWRiverStyles.aprx Date: 28/11/2019

Map Scale @ A4: 1:1,100,000

0 5 10 20
Kilometres

Revision	Author	Verified	Approved	Date
2	KRH2	HC7	DJE2	27/11/2019
1	KRH2	DRAFT	DRAFT	05/03/2019

Title:
Fragility

Client: **SMEC Australia Limited**

Project: **Warragamba Dam Raising EIS**

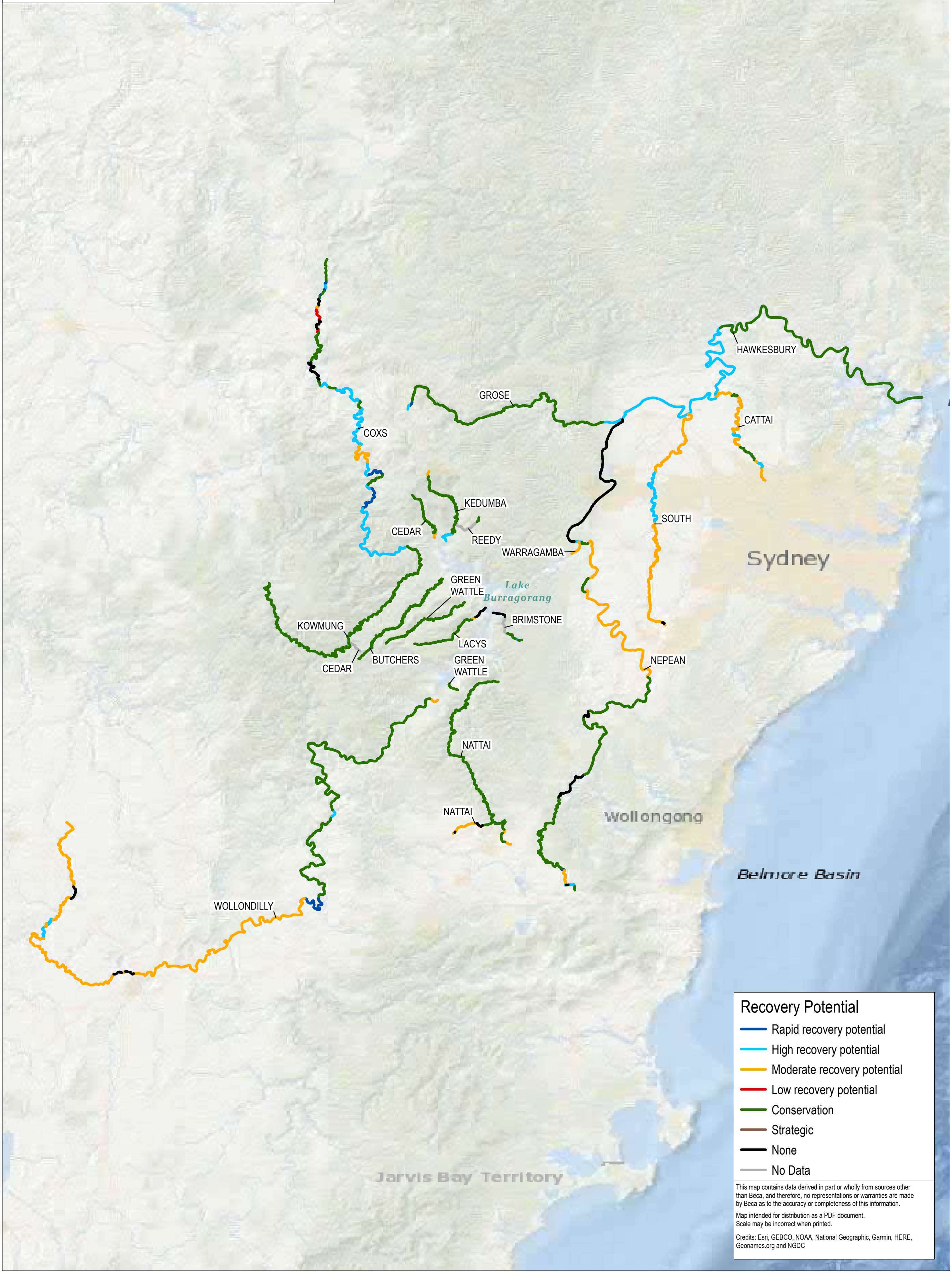
N

Beca

Discipline: **GIS**

Drawing No: **GIS-4512987-04**

Figure 23 RiverStylesTM Recovery Potential



Map Scale @ A4: 1:1,100,000

0 5 10 20
Kilometres

Revision	Author	Verified	Approved	Date
2	KRH2	HC7	DJE2	27/11/2019
1	KRH2	DRAFT	DRAFT	05/03/2019

Title:

Recovery Potential

Client: SMEC Australia Limited

Project: Warragamba Dam Raising EIS

N

Beca

Discipline: GIS

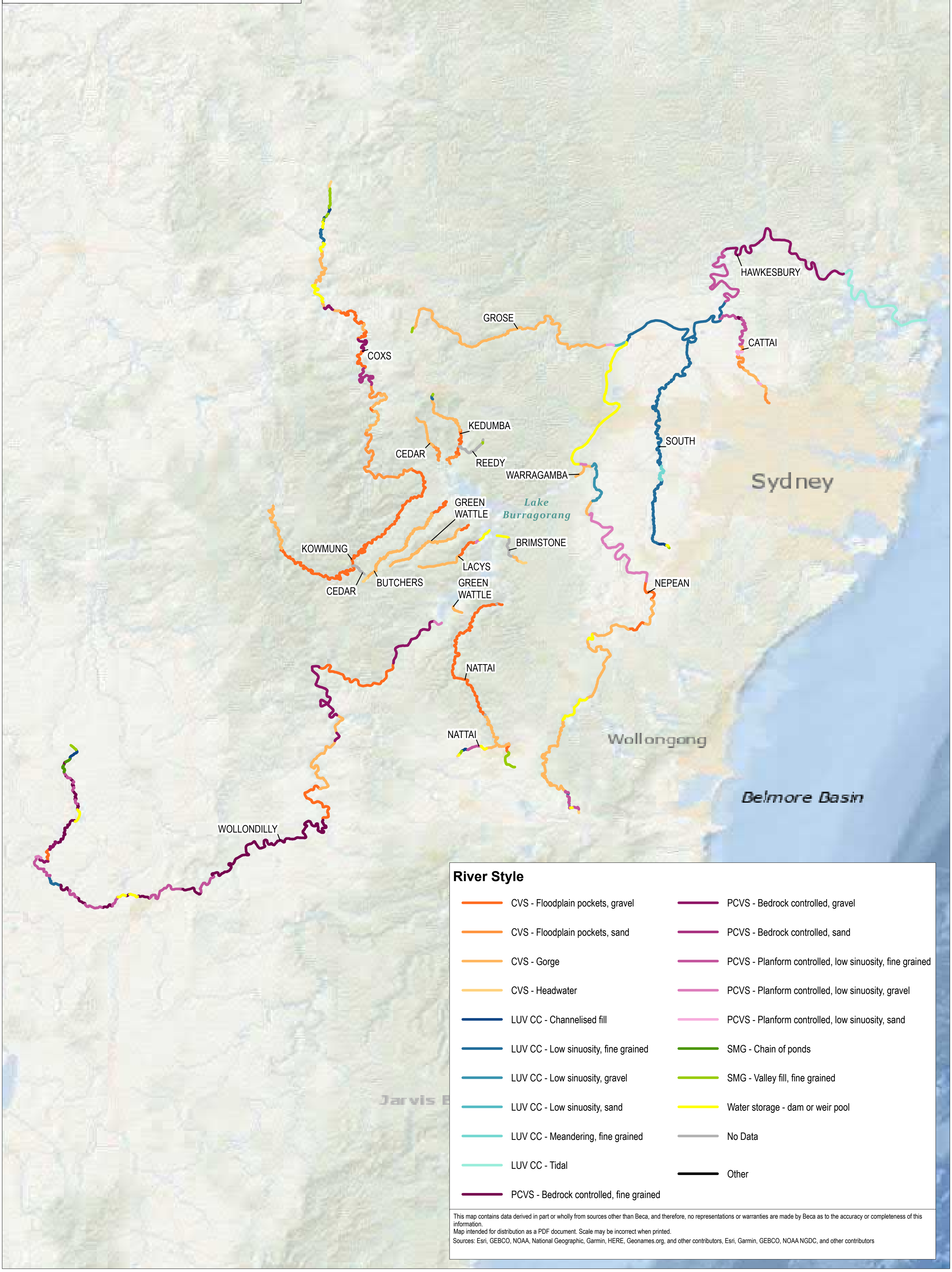
Drawing No: GIS-4512987-03

GIS@beca.com

File: \\fpsyd1\Projects\451\4512987\03_Work Process\03_2 Baseline Conditions\River Styles\NSWRiverStyles\NSWRiverStyles.aprx Date: 28/11/2019

GIS@beca.com

Figure 24 RiverStylesTM Classifications



Map Scale @ A4: 1:1,100,000

0 5 10 20

Kilometres

Revision	Author	Verified	Approved	Date
2	KRH2	HC7	DJE2	27/11/2019
1	KRH2/RSV1	DRAFT	DRAFT	05/03/2019

Title:

NSW River Styles

Client: SMEC Australia Limited

Project: Warragamba Dam Raising EIS

N

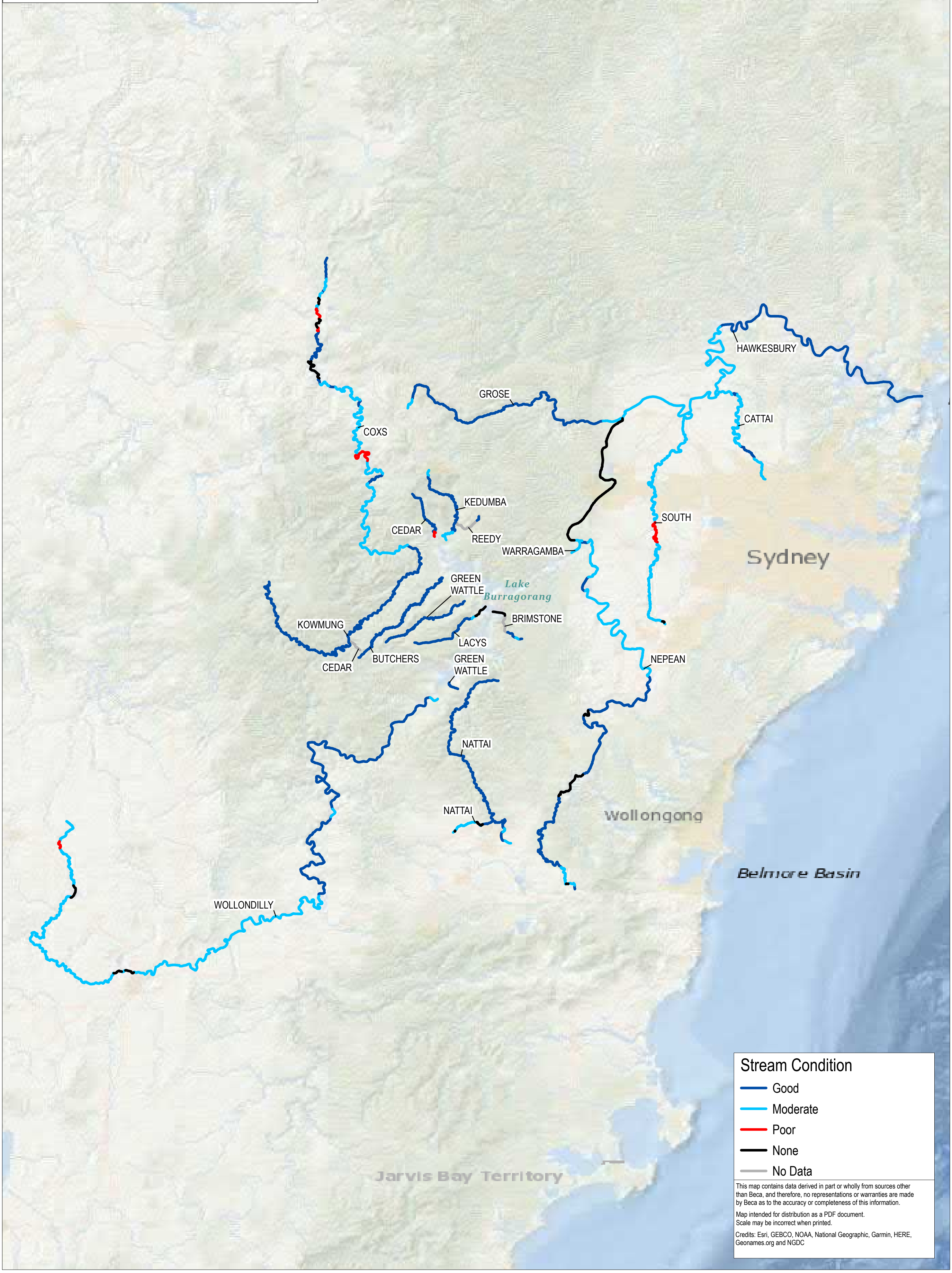
Beca

Discipline: GIS

Drawing No: GIS-4512987-01

File: \\lfpsyd1\Projects\45\4512987\03_Work Process\03_2 Baseline Conditions\River Styles\NSWRiverStyles\NSWRiverStyles.aprx Date: 28/11/2019

Figure 25 RiverStylesTM Stream Condition



This map contains data derived in part or wholly from sources other than Beca, and therefore, no representations or warranties are made by Beca as to the accuracy or completeness of this information.

Map intended for distribution as a PDF document. Scale may be incorrect when printed.

Credits: Esri, GEBCO, NOAA, National Geographic, Garmin, HERE, Geonames.org and NGDC

GIS@beca.com

File: \\fpsyd1\Projects\451\4512987\03_Work Process\03_2 Baseline Conditions\River Styles\NSWRiverStyles\NSWRiverStyles.aprx Date: 28/11/2019

Map Scale @ A4: 1:1,100,000

0 5 10 20

Kilometres

Revision	Author	Verified	Approved	Date
2	KRH2	HC7	DJE2	27/11/2019
1	KRH2	DRAFT	DRAFT	05/03/2019

Title: **Stream Condition**

Client: SMEC Australia Limited

Project: Warragamba Dam Raising EIS

N

Beca

Discipline: GIS

Drawing No: GIS-4512987-02

A summary of these attributes for the Upstream Zone follows:

- **Brimstone Creek** has a total length of approximately 9 km and is mainly characterised by good and moderate stream conditions along most of its stretch. It has a high or conservation recovery potential, with mostly low fragility.
- **Butchers Creek** has a total channel length of 32 km and is characterised by headwaters, gorges and floodplain pockets consisting of gravel. The stream condition is overall good and has a conservation recovery potential with low to moderate fragility.
- **Cedar Creek** is characterised by headwaters and gorge areas and has a total length of around 16 km. The headwaters are in good condition; however, the gorge has a poor stream condition. The stream has a conservation to moderate recovery potential as we move downstream, with a low to moderate fragility.
- **Coxs River** is one of the major streams in the area with a length of 155 km. The river is characterised by headwaters that flow into multiple gorges and low sinuosity, fine grained channels and floodplains pockets with sand and gravel. There are some areas with weir pools along the stream length. The stream condition is good in the upstream section, with some poor condition areas further downstream, however most downstream areas have a moderate stream condition. Most of the stream has low to moderate fragility, with only one section upstream with fine grained valley fill that has high fragility. The recovery potential in the upstream region is varied and ranges from conservation to low or no recovery potential. In the downstream areas, the recovery potential is mainly high with some areas of rapid, conservation or moderate recovery.
- **Green Wattle Creek** is a relatively small creek and is characterised by a gorge and floodplain pockets with gravel. The stream condition is good and has a conservation recovery potential with low to moderate fragility.
- **Kedumba River** is characterised by gorges and floodplains with sand and gravel. The stream condition is generally good with moderate condition at the mouth and source. The recovery potential of the stream is moderate or conservation with a certain region of the floodplain with high recovery potential. The fragility is mainly moderate or low with the valley fill region being of high fragility.
- **Lacys Creek** consists of gorge, floodplains and weir pool regions. The stream condition is mostly good, with conservation or moderate recovery potential. The creek generally has low or moderate fragility.
- **Nattai River** is 51 km long characterised by the source headwaters that run into fine grained valley fills, floodplains and gorges with controlled planforms having low sinuosity. The overall stream condition is moderate with downstream areas having good stream condition. The recovery potential of the stream is moderate or conservation with low or moderate fragility in most channel regions. The downstream regions with valley fills are classified as having high fragility.
- **Wollondilly River** has a total length of 156 km and mainly consists of a bedrock controlled and planform controlled, fine grained channel. The stream condition is generally moderate with downstream areas showing good stream conditions. The recovery potential is generally moderate upstream with some downstream areas consisting of a conservation recovery potential. The source of the stream has some high fragility regions but majority of the channel length has a moderate fragility with some low fragility areas including gorges and weir pools.

A summary of these attributes for the Downstream Zone follows:

- **Cattai Creek** is a 34 km long watercourse flowing into the Hawkesbury River in the tidal section. It consists of floodplains and gorge areas at the source, that flow into planform controlled, low sinuosity regions with a generally fine grained and sandy channel bed. The stream condition is mainly moderate with some areas classified as having a “good condition”. The recovery potential varies from moderate, to high and conservation. The stream has high fragility in some regions with others being moderately fragile.
- **Grose River** is a watercourse that flows into the Hawkesbury River at the tidal limit. It consists of gorges, and a low sinuosity, sandy channel bed. The channel condition is mainly moderate or good, with high

recovery potential at the source and moderate potential further downstream. The channel has both high and low fragility in various areas.

- **Hawkesbury River** consists of a tidal channel region, with bedrock and planform-controlled regions upstream with fine grained channel bed and gravel. The stream condition is good or moderate, with high or conservation recovery potential and low to moderate fragility.
- **Nepean River** is 178 km long, consisting of very diverse channel conditions. The upstream regions consist of planform-controlled channel with low sinuosity. Gorges exist further downstream, with some weir pools and floodplains. Some regions have a moderate stream condition whereas some parts of the stream are classified as being in good condition. The recovery potential is mainly conservation in most parts of the stream, with some regions having a moderate, high or rapid recovery potential. The stream generally has low to moderate fragility.
- **South Creek** is a watercourse that flows into the Hawkesbury River at Windsor. It mainly consists of low sinuosity fine grained channel, with some regions consisting of a meandering channel bed as well as a region with a weir pool. The stream condition is generally moderate with only one region identified as having poor quality. The recovery potential is moderate with moderate to low fragility.

e. Other literature reviews

Most rivers and creeks that flow directly into Lake Burragorang are in good condition. Some sections of waterways are considered poor (such as where Cedar Creek and Tonalli River join Lake Burragorang). Numerous other upstream creeks were categorised as moderate in geomorphic condition.

Geomorphic conditions of the Hawkesbury-Nepean River catchment are categorised as good, moderate or poor based on ecological diversity, the presence of catchment controls, vegetation coverage and overall geomorphic stability (GHD, 2013).

A review of the geomorphology literature can be found in **Table 9**, below.

Table 9 Literature review of geomorphological conditions in the Hawkesbury-Nepean Catchment

Author	Year	Region	Key outcomes / findings
Upstream Zone			
NPWS	2003	Upstream	The alluvial deposits found on the river flats of the Burragorang, Kedumba and Nattai Valleys vary in depth, texture and grain size. For the most part the alluvium is derived from the Triassic and Permian sediments resulting in a high proportion of sand in the soil. These flats support three major plant communities: Tablelands River Oak Forest (Map Unit 39), River Fringe Reedland (MU76), Burragorang River Flat Forest (Map Unit 23). Minor plant communities found at the catchment boundaries include Dry Alluvial Paperbark Woodland (Map Unit 49), Oakdale Alluvial Rough-barked Apple Forest (Map Unit 38), Cumberland Plain, Alluvial Woodland (Map Unit 58) and Tablelands Black Sally Woodland (MU44).
CSIRO Land & Water	2000	Upstream (Cox's)	The granite-derived soils are typically thin and highly erodible.
CSIRO Land & Water	2000	Upstream (Cox's)	Pre-European settlement, heavily forested hillslopes, opening into more open woodland and some areas of grassland in the wider valleys such as the Megalong Valley and along the River Lett have been reported. The current vegetation pattern is one of extensive pasture in the upper and mid-catchment suggesting widespread clearance, while below Island Hill the land cover is nearly entirely native timber. The effects of fire, increases in rabbit populations, and the impacts of stock, have also contributed to land degradation.
CSIRO Land & Water	2000	Upstream (Cox's)	Flow regime of the lower Coxs River affected by: (i) land clearing in the upper and central parts of the catchment; (ii) regional climatic variations; and (iii) the construction and operation of Lyell Dam, part of the Coxs River Water Supply Scheme used as cooling water to support electricity generation.
CSIRO Land & Water	2000	Upstream (Cox's)	The channel form of the lower Coxs River varies considerably over the 83 km from Lyell Dam to Kelpie Point as a function of the past and present river flow regimes, the channel gradient, and the sediment supply to the river.
CSIRO Land & Water	2000	Upstream (Cox's)	The channel gradient over the Cox's 80km downstream from Lyell Dam distance ranges from 0.0016 to 0.1. The lowest average gradient (from 6 stretches) of 0.04 occurs in the stretch immediately upstream of Lake Burragorang. The steepest stretch of the rivers occurs 20 km upstream of this point, at 50 - 60 km downstream from Lyell Dam.

Author	Year	Region	Key outcomes / findings
CSIRO Land & Water	2000	Upstream (Cox's)	Lyell Dam traps all but the finest sediment eroded from the upper catchment, and so the current sediment supply to the river below the dam and downstream to Kelpie Point is delivered from the mid-catchment tributaries. The gully networks in the mid-catchment tributaries have introduced large volumes of sand to the Coxs River channel.
CSIRO Land & Water	2000	Upstream (Cox's)	Surface erosion is also occurring in the Coxs River catchment. From Caesium-137 concentrations in the surface layers of sediment in Lake Burragorang, Fredericks (1994) estimated that as much as 25% of the contemporary sediment delivered to the Coxs River arm of the lake was derived from erosion of surface soils in the Coxs River catchment.
CSIRO Land & Water	2000	Upstream (Cox's)	The flow regime shift in the mid-1940s – from a drought-dominated to a flood-dominated regime – led to the formation of flood chutes and extensive stripping of floodplain sediments along the Coxs River. These processes delivered large volumes of alluvial sand to the main channel, as well as widening the channel. However, because the channel margins are so resistant, the dominant source of remobilised sediment was alluvium stripped from the floodplain by high flows.
CSIRO Land & Water	2000	Upstream (Cox's)	The sediment transport capacity of the Coxs River below Lyell Dam varies by nearly three orders of magnitude, mainly because of variations in channel slope rather than increases in discharge. The reductions in sediment transport capacity due to flow regime are small relative to the downstream variations due to channel slope.
CSIRO Land & Water	2000	Upstream (Cox's)	Sediment deposition occurs in the Coxs when sediment supply is in excess of sediment transport capacity. Because of a lack of detailed hydraulic data, it is not possible to compare the actual volumes of sediment supplied to the channel with actual volumes moved. However, a qualitative assessment is possible. In the steeper reaches, even the current flow regime (with its reduced transport capacity) is competent to transport the increased sediment load. In contrast, in the flatter reaches, even the without-scheme flows are not competent to transport the increased load. The reduced transport capacity in these reaches will mean a longer period will be required to flush out the sediment which has been deposited in these reaches, even though the current sediment supply is lower than during the period of most active gully erosion.
CSIRO Land & Water	2000	Upstream (Cox's)	Channel adjustment occurs in response to smaller channel-forming discharges. Tributary sediment and material from the scour zone are reworked to produce benches that may become a new “inset” floodplain.

Author	Year	Region	Key outcomes / findings
CSIRO Land & Water	2000	Upstream (Cox's)	Reach 4 is the steepest reach with a fall of 19 m/km. It is predominantly a confined bedrock-boulder channel with little or no stored alluvium. Sediment transport, particularly of sand, is expected to be highly efficient in this reach.
CSIRO Land & Water	2000	Upstream (Cox's)	Reach 5 is the second of the steeper reaches. It is characterised by some rapids and sand stores adjacent to the channel near tributary junctions.
CSIRO Land & Water	2000	Upstream (Cox's)	Reach 6 is the third of the low gradient reaches - its lowest gradients being less than 0.004. Much sand is in the channel in spite of the heavily forested nature of the surroundings.
CSIRO Land & Water	2000	Upstream (Cox's)	In the lower Coxs River catchment, changes in land use, increases in human and farm animal populations, and the presence of Lyell Dam have changed the water quality in the river.
CSIRO Land & Water	2000	Upstream (Cox's)	Turbidity and suspended particulate matter were highly variable through time and across sites, and generally indicative of a disturbed catchment. Higher values generally occurred at sites downstream of catchment disturbance including urbanisation, road construction, erosion resulting from land degradation, and grazing on river banks.
CSIRO Land & Water	2000	Upstream (Cox's)	Anecdotal accounts suggest that other fish species such as Australian bass, Macquarie perch and mullet may once have inhabited the lower reaches of the river. The presence of Warragamba Dam downstream now prevents upstream migration of Australian bass and mullet so they are not a sensitive receptor to be considered against geomorphological impacts of this Project. Macquarie perch require clean gravel for spawning and have undergone a severe decline through most of their range, although local populations appear to be thriving elsewhere in the Hawkesbury-Nepean River system.
CSIRO Land & Water	2000	Upstream (Cox's)	Many reaches below the dam are dominated by bedrock, creating long pools and stable riffles.
CSIRO Land & Water	2000	Upstream (Cox's)	The main avenues, then, by which improvements in river condition can be achieved are rural and urban catchment management, flow management at Lyell Dam to provide a more natural flow regime, and direct control of introduced species, particularly introduced riverine vegetation – willows, broom, and blackberry.

Author	Year	Region	Key outcomes / findings
CSIRO Land & Water	2000	Upstream (Cox's)	The large loads of sand in the river channel will not be removed in the short term.
DECC	2010	Upstream (Cox's)	Investing in riparian protection and riverine restoration works in the Upper Cox's Catchment through the Hawkesbury–Nepean CMA River Restoration Project according to the NSW Government endorsed Hawkesbury–Nepean River Health Strategy
BMCC	2004	Upstream (Katoomba)	The Upper Kedumba River Valley forms part of a natural drainage corridor located west of the Katoomba township in the Upper Blue Mountains, New South Wales. Katoomba Falls is a site of natural and cultural significance to the Blue Mountains, and it depends on the condition of the wetland system in the upstream reserves for its quality of water and ongoing flow through dry periods.
BMCC	2004	Upstream (Katoomba)	The soils of the study area are generally poor and highly erodible. The slopes enclosing the north south running river valley are relatively steep and subject to severe erosion in places. Disturbance of these soils has led to erosion and sedimentation of the creek, which in turn impacts on water quality.
BMCC	2004	Upstream (Katoomba)	Drainage and water quality issues include unacceptable sediment load – some entering site from upstream and some being generated on site by the concentration of stormwater flow from urban run-off. Creeklines are degraded and streambank scour and erosion continue to occur.
BMCC	2004	Upstream (Katoomba)	Valley Corridor Environment Values and Roles include: Presence of natural corridor ecosystem, Natural hydrology (Creeks / Drainage) and their storm water treatment, System of Hanging Swamps / wetland environments, Continuity of Woodland environments, Flora and Fauna habitat corridor
Shakesby *et al.*	2006	Upstream (Nattai)	Hillslope soil losses in the Nattai catchment due to forest fires have historically been high due to (i) loss of the protective vegetative layer which reduces interception, rainfall storage and exposes soil to rainsplash detachment and increases in overland flow (ii) Burning generates ash with inherent higher mobility and reduces soil aggregate stability (iii) soil water repellence is enhanced
Shakesby *et al.*	2006	Upstream (Nattai)	Erosion of the sandy sub-soil was limited to local redistribution due to litter dams acting as sediment traps and bioturbation causing surface roughness

Author	Year	Region	Key outcomes / findings
Blake *et al.*	2006	Upstream (Nattai)	Delivery of sediments from burnt areas of the Nattai catchment to downstream receivers was proven by mineral magnetic signature.
Tomkins *et al.*	2007	Upstream (Nattai)	The lack of sediment accumulation along the Nattai valley suggests that most is exported from the catchment or only temporarily stored on the lower slopes and valley floor. This implies that a significant mass movement event within the lifetime of the reservoir would produce a dramatic increase in sediment and nutrient load during the event and afterwards through reworking of any stored materials.
Tomkins *et al.*	2007	Upstream (Nattai)	Boulders in the Nattai River were found to have come from Gillans Creek, a tributary which flows into the Nattai River rather than part of a landslide. The boulders increase in size downstream, which is unlike typical landslide deposits (chaotic arrangement) or fluvial deposits (downstream fining), and instead suggests that they formed part of a large debris flow that originated in Gillans Creek and flowed down the Nattai River for a limited distance as channel slope declined. The coarsest boulders now form a lag within the river bed appearing to be beyond the competence of contemporary floods.
Tomkins *et al.*	2007	Upstream (Nattai)	Catastrophic floods are important triggers of extreme erosion events within the Nattai catchment, particularly in terms of their ability to mobilize extremely large volumes of sediment over short periods of time (measured in hours to days). The contribution of catastrophic floods to contemporary sediment yield in the Nattai catchment based on the 40-year record is estimated to be around 35 % (seven times greater than wildfire). Using the longer Hawkesbury-Nepean record of floods over 207 years the amount increases to 55 %.
Tomkins *et al.*	2007	Upstream (Nattai)	The role of wildfire as a trigger of extreme erosion-sedimentation events in the Nattai catchment compared with other triggers is substantially less (Figure 23). Instead extreme rainfall appears to be the most common trigger with severe thunderstorms and heavy rainfall events resulting in widespread impacts including rainsplash erosion, slope wash, debris flows and where large enough generation of catastrophic floods. Catastrophic floods, although less frequent, transport the largest volumes of sediment. These can result in decades worth of sediment being mobilized and exported from the catchment within a few days. Earthquakes are the least frequent trigger of extreme erosion events although the effects of such an event could be more significant depending on whether landslides result and if they occur around the foreshores of Lake Burragorang.

Author	Year	Region	Key outcomes / findings
Caitcheon *et al.*	2006	Upstream (Wollondilly)	Lake Burragorang sediment show a clear dominance of sediment from the Wollondilly in the main arm. Relative contributions from other sources such as the Coxs River were low. The dominant source areas in the Wollondilly catchment were the main lower catchment tributaries, that is the Guineacor, Wingecarribee and Tarlo Rivers. Most of this sediment originates from hillslope erosion. The steeper country in the lower catchment (e.g. Wingecarribee and Guineacor catchments) was prone to hillslope erosion. Gully erosion was the dominant source on the upper catchment (Tarlo catchment on the tablelands).
Lake Burragorang Zone			
DoL	2006	Lake Burragorang (Tonalli)	Yerranderie is an abandoned silver mining town and is located about 15 km up-gradient from Lake Burragorang. Most of the sites were not rehabilitated and active soil erosion has caused contamination of downstream water resources.
Romero & Imberger	2003	Lake Burragorang (all)	Presence of a deep underflow (20-60 m depth) with heterogenous temperature distribution during storm events was noted. Sediment entering the lake from the Cox's and Wollondilly Rivers will be trapped in the bottom layer.
Rustomji and Wilkinson	2007	Lake Burragorang (all)	Forested catchments developed upon Sydney Basin sandstones near Lake Burragorang have area specific suspended sediment yields of approximately 40 t/km2/yr. Such a yield is greater than yields generated from agricultural areas in the flatter and drier parts of the catchment, such as the Mulwaree River and upper Wollondilly River sub-catchments. The lack of gully erosion in the forests, the predominance of bedrock dominated channels and generally intact riparian vegetation suggests that these relatively high sediment yields are due to high rates of hillslope erosion during infrequent, large magnitude rainfall events. Hillslope erosion is the dominant source of sediment delivered to the river network, generating approximately seven and thirty times the mass of sediment generated by gully erosion and river bank erosion respectively. Many of the gullies in the Lake Burragorang catchment were initiated shortly after European settlement of the catchment in the mid-1800s. Sediment yields from gullied catchments of the region peaked in the late 1800s to early 1900s and have subsequently declined, due to inferred low rates of gully network extension. This pattern is reflected in reduced floodplain aggradation rates observed in agricultural catchments over the last 20 to 100 years and some gullies may also be re-aggrading, which further serves to decrease sediment yields from gullied landscapes.

Author	Year	Region	Key outcomes / findings
			Modelling predictions for the catchment indicate that river bank erosion comprises a minor component of the Lake Burragorang catchment's sediment budget.
Tomkins *et al.*	2007	Lake Burragorang (all)	Landslide around the foreshores of Lake Burragorang have been recorded with several post-European landslides related to underground coal mining and ground subsidence.
Tomkins *et al.*	2007	Lake Burragorang (all)	Mass movement seems to become a dominant process where rivers have incised through the resistant but highly jointed Hawkesbury Sandstone and into the underlying Narrabeen Group and Permian rocks. These locally weaker lithologies weather and erode more easily undermining the overlying massive sandstone rocks. The result is an abundant supply of large volumes of sediment from hillslopes.
Wilkinson *et al.*	2007	Lake Burragorang (Nattai)	There was an extensive wildfire in the Nattai River catchment in December 2001. In 2002–2003, the yields of suspended sediment and phosphorus for individual runoff events were up to two orders of magnitude greater than those pre-fire due to their greatly increased availability for transport. The actual annual post-fire sediment yields to Lake Burragorang from the Nattai River were several times higher than what would have occurred without fire in the dry post-fire conditions.
Downstream Zone			
Ribbons	2015	Downstream	The natural characteristics of the Hawkesbury-Nepean Valley make it susceptible to significant flood risk. The Hawkesbury-Nepean Valley consists of a sequence of floodplains linked by gorges. As shown on Figure 3 the combination of large upstream catchments and the narrow downstream gorges results in floodwaters backing up behind the natural 'choke points'. This 'bathtub effect' causes significant flooding in the Penrith and the Richmond-Windsor floodplains. A Plan for Growing Sydney indicates a projected population increase in the Metropolitan West subregion (most of which is located within the Hawkesbury-Nepean Valley) of nearly 90,000 people by 2031, with a target of at least 39,000 new homes and 37,000 additional jobs. The North West Growth Centre will accommodate a large proportion of these homes and jobs. Many new homes and jobs across the region will be located in the Hawkesbury-Nepean floodplain.

Author	Year	Region	Key outcomes / findings
Kuruppu K	2016	Downstream	Median turbidity values were below the ANZECC trigger value. Sampling stations N14 (Wisemans Ferry), N35 (Pitt Town Bottoms) and N64 (Warragamba River Upstream Nattai Confluence) showed comparatively high turbidity values during the considered period of study. Site N57 (Penrith Weir) has the highest observed turbidity (437 NTU) value. High turbidity values can occur in wet weather conditions. Turbidity often increases sharply during rainfall,
Birch *et al.*	1998	Downstream (tidal)	The mud content of samples increases in the tidal section of the Hawkesbury River system, and the lower estuary tributaries are mantled in almost pure mud, e.g. Berowra, Mangrove, Mooney, Mullet and Cowan Creeks, as well as Pittwater. The sand content and coarse fraction grain size increases upstream, whereas sorting declines. Textural variation increases with environmental complexity and is most prominent in the main channel upstream of Wiseman's Ferry and in fluvial tributaries.
DECC	2009	Downstream (tidal)	Differences in habitat created by tidal influences and river geomorphology downstream from Yarramundi cause differences in macroinvertebrate community structure.

3.1.5 Lake morphology

The elevation range measured using by the combined multibeam bathymetry and topographic laser scanner surveys (MGS, 2014) varied from a minimum of 18.02 m AHD to a maximum of 156 m AHD. The combined bathymetry and topographic laser scanner data are presented as an elevation map referenced to AHD (**Figure 26**).

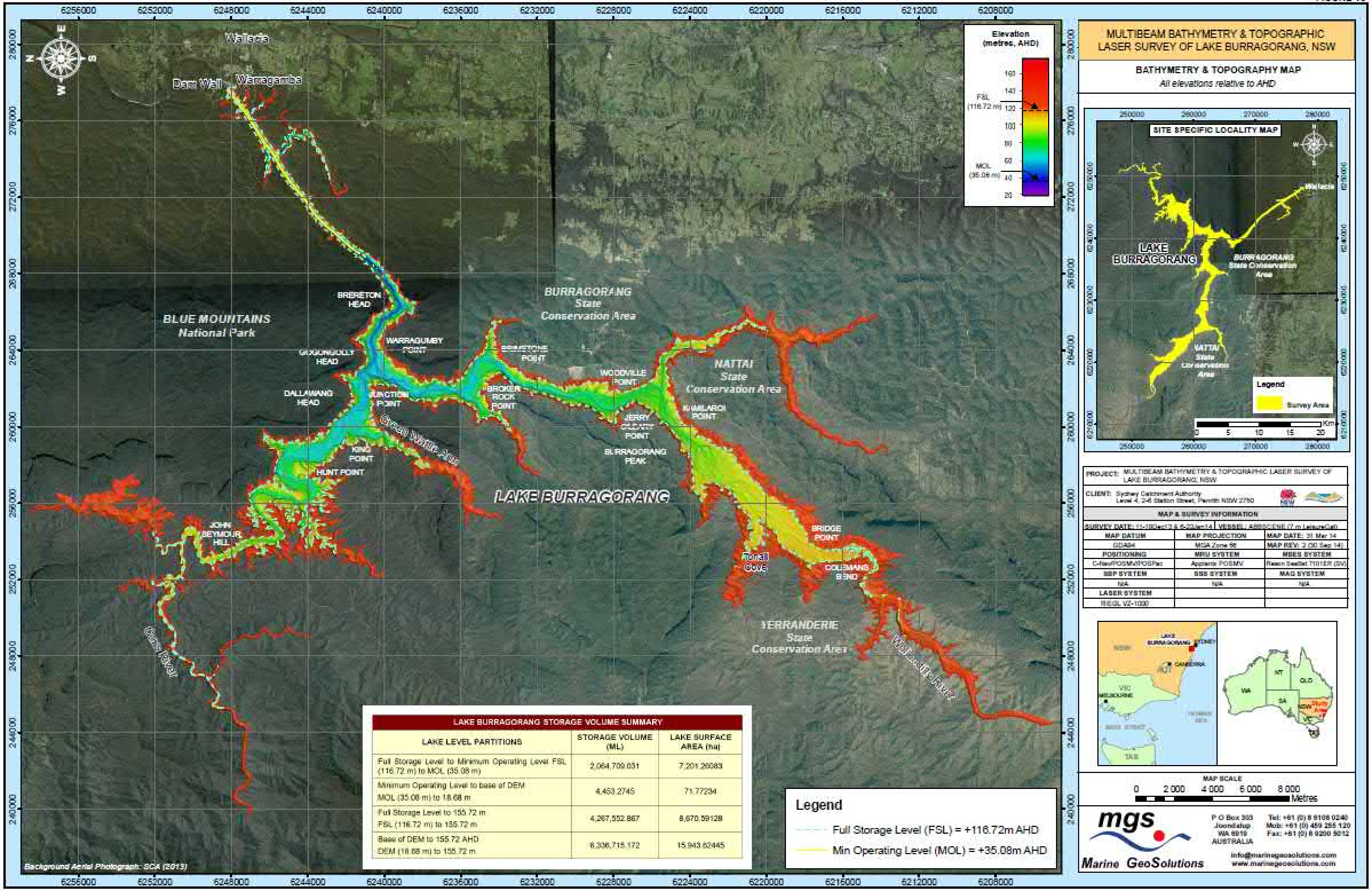
The morphology of Lake Burragorang is dominated by the flooded V-shaped river channel remnants primarily of the Cox's and Wollondilly Rivers (**Figure 26**). The main basin of the lake occurs at the confluence of these river systems in the vicinity of Junction area; however, the deepest section of the lake occurs within the steep sided Gorge that makes up the eastern arm of the Lake (between Junction Point and the Warragamba Dam wall). The final ±300 m of the Gorge before the dam wall displays the deepest bathymetry within the lake (±23.8 m AHD), however the greatest depth in this section (18.68 m AHD) occurs within a ± 60 x 80 m rectangular basin directly adjacent to the dam wall, possibly constructed to act as a sediment trap at the base of the dam wall (MGS, 2014). Conversely, the shallowest sections of the lake occur in the lower reaches of the Cox's and Wollondilly Rivers, as would be expected, where elevations of ±110 m AHD are encountered.

Some of the most prominent morphological features within the lake are listed below.

- There are numerous incisions in the steep sides of the Gorge and other steep sections of the lake, most likely the result of minor faults or joints in the underlying sandstone that have been exploited by natural drainage over time to form these small-scale erosional features (MGS, 2014).
- There are numerous fluvial-type depositional and erosion features on the lake floor in many of the shallower reaches of the lake including a network of braided channels, sediment bars and point bars. These are indicative of an area of sediment deposition on the valley floor prior to the construction of the dam wall.
- Remnants of landslides / slumping and drowned roadways from pre-dam land use are evident.
- Several raised plateau features were noted in the moderately shallow to shallow sections of the Lake, in the Junction and lower reaches of the Cox's and Wollondilly Rivers. These features are believed to be remnants of fluvial channel bars that were formed prior to the construction of the dam. The sedimentary nature of these fluvial features is evidenced by the presence of slumps/slope failures along their margins.

It is evident from the bathymetry data that there is far less sedimentation within the gorge and associated creeks, between Brereton Head and the Warragamba Dam wall (**Figure 26**) than the rest of the lake bottom. The evidence in support of this is that the channel sides, and to an extent the channel thalweg (channel base), have an uneven and rugged appearance, indicating a predominantly rocky bottom.

Figure 26 Lake Burragorang Bathymetry Survey



3.1.6 Catchment sediment loads

a. Spatial variation in suspended sediment

Spatial differences in total suspended solids concentrations ([TSS]) were analysed as per **Section 2.3** and **Appendix A.1**. These data are summarised in **Table 10** and detailed calculations are provided in **Appendix F**. The main findings were:

- Upstream river and lake minimum values were at the laboratory reportable limit of detection (1 mg/L)
- Upstream river averages and maximum [TSS] were much greater than lake [TSS]
- Upstream river [TSS] average was largest for the Wollondilly River followed by the Cox's (half the Wollondilly). The Nattai [TSS] average was lower (7 times less than Wollondilly)
- Lake [TSS] maximum was very similar for the North East, North West and Central Portion. Lake [TSS] maximum for the South Arm was lower (nearly three times) despite highest [TSS] inputs from the Wollondilly River which is only approximately 2 km to the south of the sample site.

Table 10 [TSS] summary data

Main zone	Watercourse / location (site code)	[TSS] mg/L average (min - max)	Count
Upstream	Cox's River at Kelpie Point (E083)	22 (1 – 514)	259
	Nattai River (E210)	6 (1 – 92)	71
	Wollondilly River (E488)	44 (1 – 436)	357
Lake	Burragorang North East Arm (DWA9)	2 (1 – 37)	1,362
	Burragorang North West Arm (DWA12)	2 (1 – 36)	973
	Burragorang Central Portion (DWA27)	3 (1 - 43)	1,105
	Burragorang South Arm (DWA39)	4 (1 – 15)	91

b. Depth variation in lake suspended sediment

Analysis of changes in [TSS] with depth at the four Lake Burragorang sites has been completed (**Figure 27**).

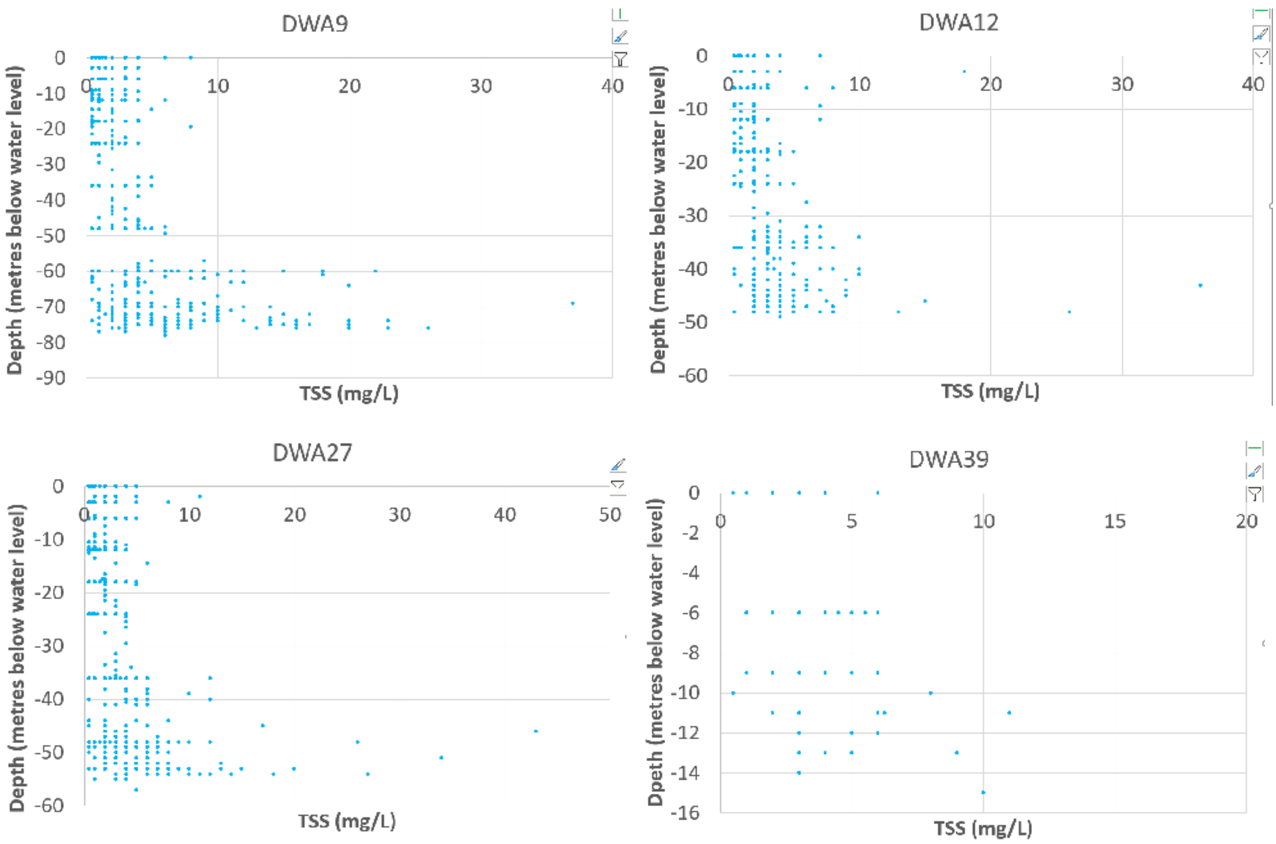


Figure 27 Variation in suspended solids with depth in Lake Burragorang

The main findings from this analysis were:

- The north east site has greatest depth (-78 m), North West and Central were similar (-49 and -56 m, respectively) and South was the shallowest (-15 m)
- All sites show a similar pattern with low concentration variance in shallow waters (typically 1- 10 mg/L) and high variance in deep waters (approximately 1 – 40 mg/L). The [TSS] range was lower at the shallowest North East site (1 – 11 mg/L).
- The ratio of step-change depth (i.e. the transition point from shallow waters with low variance in [TSS] to deeper water with higher variance in [TSS]) to total depth is lower for the Central portion site (0.6) than at the other sites (0.7 – 0.8). That is, higher [TSS] variance occurs at slightly shallower relative depths at the Central portion site.
- The high outliers occurred mainly during the winter period but could not be attributed directly to antecedent rainfall or high winds in the area.

c. Temporal variation in suspended sediment

Marked changes in [TSS] over time were recorded at all sites. For the river sites (Figure 28):

- Peaks in [TSS] (> 50 mg/L) generally occurred during January – March and coincided with flow peaks in the Cox's and Wollondilly River. Correlation coefficients for the two rivers were r^2 0.53 and 0.35 (at the 95% significance level) indicating weak-moderate relationships.
- [TSS] appears unresponsive to flow peaks on the Nattai – this could be due to the channel not containing stored sediment or that flows were not competent at entraining the particle calibre present in the channel.
- Small peaks in [TSS] in the Nattai (10-20 mg/L) during low flow conditions may have been due to in-situ production of algae, rather than due to inorganic sediments.

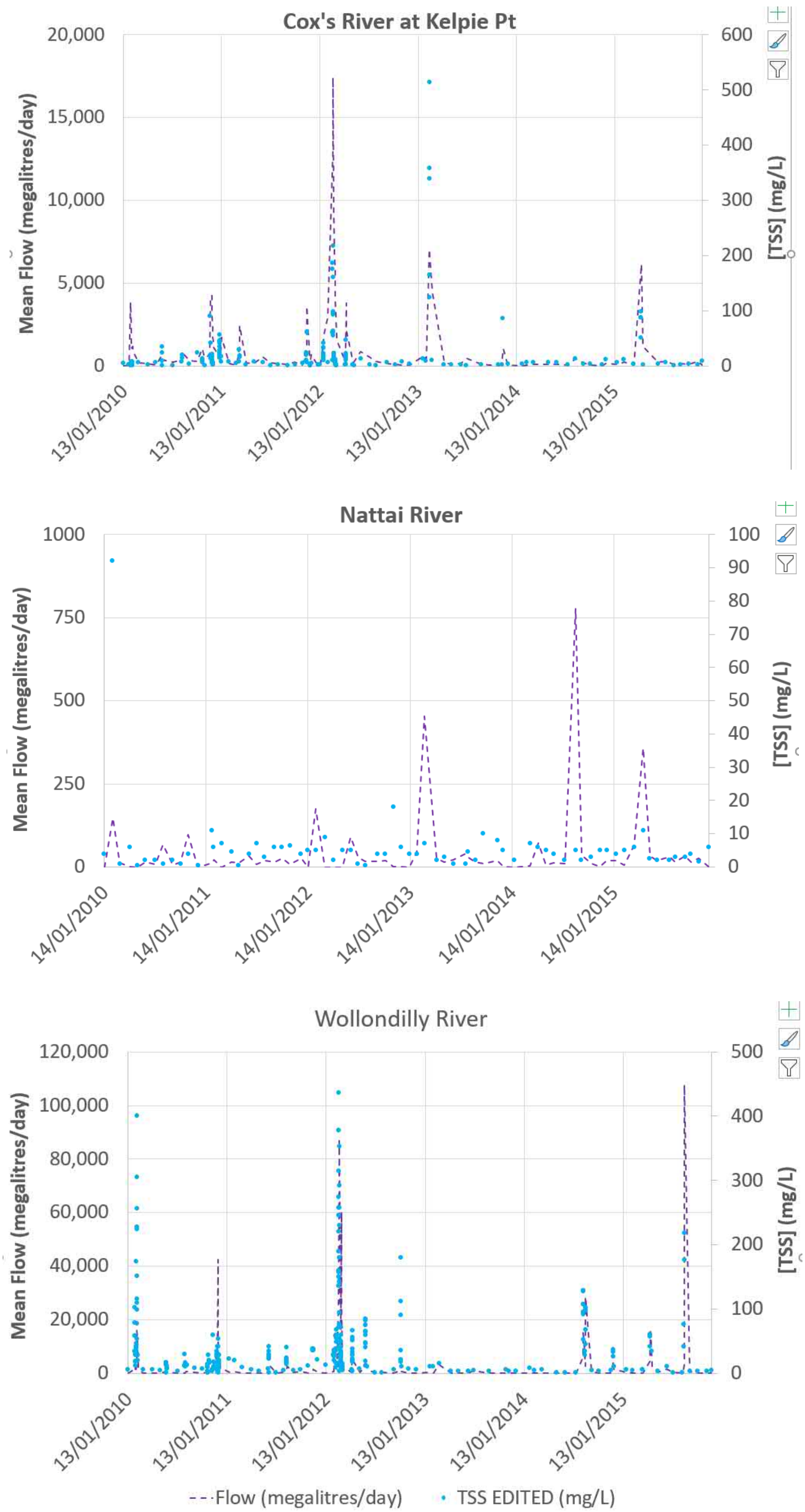


Figure 28 Temporal variation in flow and suspended sediment in Upstream Zone rivers

For the lake sites (**Figure 29**):

- Higher [TSS] coincided with the June – September period, possibly coinciding with high flows in upstream catchments which would carry a higher [TSS] (see rivers commentary above).
- Initial outlier analysis does not suggest that high [TSS] were caused by either high antecedent rainfall (previous 24 hours) or wind speed directly in the lake. This might be because localised conditions are not controlling suspended sediment but rather the inlet rivers, with associated lag-time in delivery, are transporting high sediment into the lake. A detailed analysis of the causative factors of high [TSS] in the lake is beyond the remit of this technical note.
- The DWA39 sample site (south arm) has lowest peaks in [TSS] despite the Wollondilly River which flows into the lake at this location having demonstrable suspended sediment response to increasing flow.

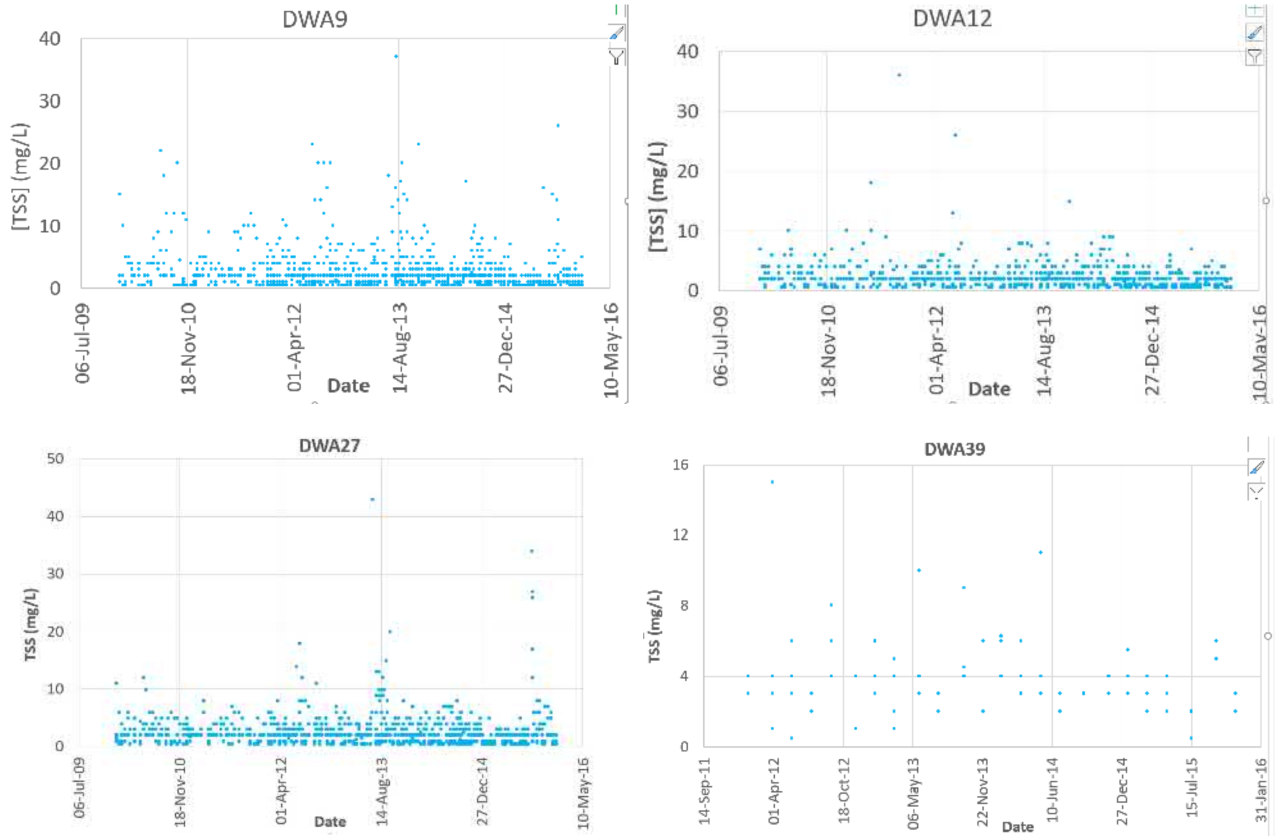


Figure 29 Temporal variation in suspended sediment in Lake Burragorang

d. Sediment loads

Insufficient data was available to create a sediment budget for the Lake Burragorang catchment, as discussed in **Appendix A.1.7**. Sediment loads have been computed for the three rivers where aligned [TSS] and flow data was available (**Table 11**). Data contributing to this load calculation included continuous flow gauging (presented as a volume per unit time) and spot readings for [TSS] which appear to cover the range of flows monitored during the period and as such were deemed to be representative on a temporal basis. In addition to the estimates we have made using TSS and flow data we have also reported estimates from an erosion model reported in Rustomji (2006). This model assessed the sediment budget for the Lake Burragorang catchment. From Table 11 it can be seen that estimate produced by the two methods vary. We have not investigated the reason for this variance, however, it does serve to highlight the likely uncertainty associated with such estimates. The lack of agreement does not affect the outcome of this study, as the estimates are not used in further analysis.

Table 11 Estimated suspended sediment loads for rivers in the Lake Burragorang catchment (Estimates from Rustomji P (2006) provided in brackets)

River	Suspended sediment load (tonnes / annum)	Catchment area (km^2)	Catchment factored load (tonnes / annum / km^2)
Cox's	54,822 (60,800)	2,630	21 (23)
Nattai	154 (15,000)	446	0.3 (34)
Wollondilly	496,983 (123,000)	2,699	184 (45)

3.1.7 Turbidity profile for the Hawkesbury-Nepean River

Figure 30 illustrates the changes in turbidity as you move from the mouth of the Hawkesbury River at Broken Bay upstream. These figures include historic turbidity data from a more extensive network of sites than is being monitored or identified for monitoring in the current DPI Water Program and values are based on long-term medians (DECC, 2009).

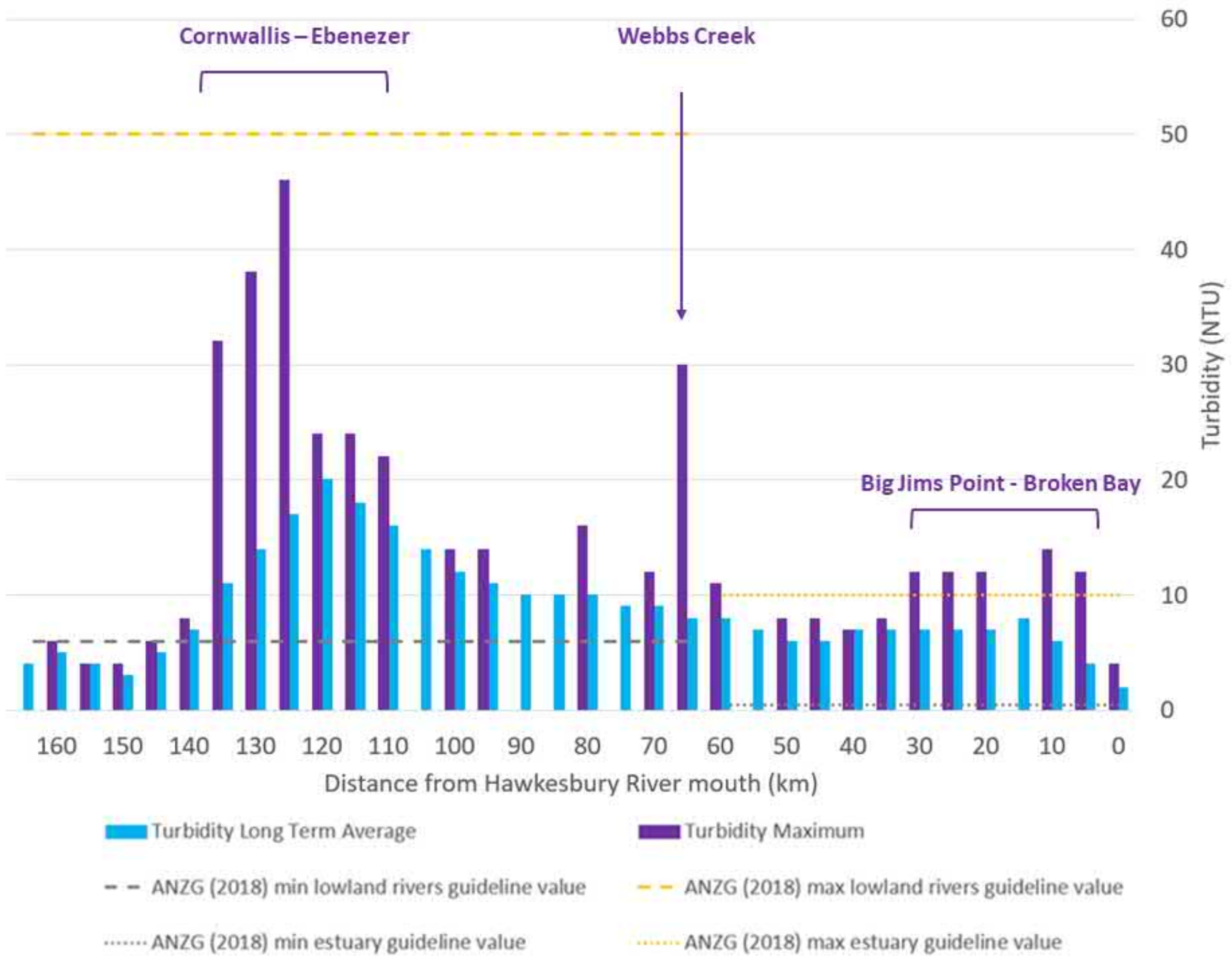


Figure 30 Hawkesbury-Nepean River turbidity profile

Long-term median turbidity levels generally remain relatively low in the freshwater section between Penrith and North Richmond. These levels are below the minimum ANZG 2018 guidance level for lowland rivers (South Australia, including NSW, aquatic ecosystem generic guideline) and could be due to lack of sediment supply caused by the dam and / or the depositional conditions in the area. Between Cornwallis and Ebenezer where the Rickaby's and South Creek confluences enter the Hawkesbury, there is a peak in turbidity medians. Following this, a gradual reduction back to low levels occurs close to the mouth of the Hawkesbury River, because ocean water is usually clearer than freshwater due to the effect of salinity on suspended solids - salt ions can cause suspended particle to aggregate and settle at the bottom of a body of water (Fondriest Environmental, 2014). There are two exceptions to this pattern of decreasing turbidity in the Hawkesbury River towards the Tasman Sea:

- Elevated turbidity at Webbs Creek. This 'turbidity maximum' occurs in many coastal waterways, caused by the trapping and flocculation of sediment at the wedge (e.g. salinity discontinuity) between freshwater and seawater (Jassby *et al*., 1995; Uncles *et al*, 2002)
- Consistent maximum levels above the ANZG (2018) estuary guidelines between Big Jims Point and Broken Bay. Tide-dominated coastal waterways are naturally turbid because strong tidal currents resuspend fine sediment (Heap *et al*., 2001; Porter-Smith *et al*., 2004). Tidal currents have the capacity to mobilise fine sediments and turbidity levels can vary considerably due to the spring-neap cycle of high and low tidal ranges and the daily cycle of high and low tides.

3.1.8 Water and adjacent land environmental values

The Secretary's Environmental Assessment Requirements (SEARs) have set the terms of reference for an assessment under the EPBC Act as there is potential for the Project to impact on certain Matters of National Environmental Significance (MNES). This sub-section identified the environmental values in the catchment that could be impacted by changes in geomorphology.

a. Sensitive aquatic habitats

i. Upstream environment

Several wetlands listed as Important Wetlands in Australia (the Directory) exist in the catchment including Boyd Plateau Bogs, Lowbidgee Floodplain, Wingecarribee Swamp and Thirlmere Lakes. These all lie greater than 50 km from Lake Burragorang and have been listed below. No Ramsar or State Environment Protection Policy (Coastal Management) listed wetlands exist within the upstream environment.

- Boyd Plateau Bogs is small wetland that drains to Kowmung River within the Kanangra-Boyd National Park more than 60 km upstream of the Coxs River.
- Lowbidgee Floodplain is situated near Belangalo State Forest, more than 100 km upstream of the inlet point of the Wollondilly River into Lake Burragorang.
- Wingecarribee Swamp lies in a gently sloping upper catchment valley of Wingecarribee River near the town of Robertson (over 100 km upstream of the inlet point of the Wollondilly River into Lake Burragorang). The swamp is the largest and one of the best examples of a montane peatland in NSW.
- The Thirlmere Lakes situated near Camden Park drain to the Nepean River, although are only noted here due to their relative proximity to the dam and upstream study area.

Of the wetland areas listed in the directory, four are considered nationally significant wetland areas within the Warragamba sub-catchment:

- The Wingecarribee Swamp in the Wingecarribee River sub-catchment (NSW093);
- Long, Hanging Rock, Mundego and Stingray Swamps (Paddys River Swamps) in the Wollindilly River sub-catchment (NSW082);
- Boyd Plateau Bogs in the Kowmung River sub-catchment (NSW074); and
- Lake Bathurst in the Mulwaree River sub-catchment (NSW066).

The nationally significant wetlands in the Wollondilly-Mulwaree-Wingecarribee river sub-catchment provide a number of key functions for the region, namely fish passage, fish nursery areas and dry season refuge areas for aquatic species.

The channels upstream and downstream of the dam provide valuable aquatic and terrestrial habitat with broad environmental value. WaterNSW (2015) report states that Lake Burragorang supports an abundance of aquatic flora and fauna including macroinvertebrates, molluscs, fish, reptiles and mammals.

Other noteworthy surface water features include the Jumping Rock Swamp (Paddys River catchment, Wollondilly River sub-catchment) and Paddys River Swamps (including Hanging Rock Swamp, Mundego Swamp, Long Swamp and Stingray Swamp in the upper reaches of Paddys River catchment) complex, located approximately 58 km south of the GIA. Additionally, the swamps on the Newnes Plateau (some of which occur in the headwater tributaries of the Coxs River), located approximately 46 km northwest of the GIA. Both complexes are examples of Temperate Highland Peat Swamps on Sandstone and are listed as an Endangered Ecological Community (EEC) under both state and federal legislation.

The most well developed aquatic macrophyte beds were found in the lower Wollondilly River, however aquatic weeds were dominant. Some small macrophyte meadows occur in shallow areas immediately upstream of Warragamba Dam wall near the auxiliary spillway. These meadows would be subject to periodic wetting and drying with variations in dam water levels. No threatened aquatic flora or communities are likely to occur in the upstream environments of the project.

ii. Downstream environment

Downstream of the dam, the river system includes both freshwater and estuarine waters between the Warragamba River directly downstream of the dam wall and Wisemans Ferry. The system does not include the reach of the Nepean River upstream of its junction with the Warragamba River. The natural characteristics of the Hawkesbury-Nepean Valley make it susceptible to significant flood risk. The Hawkesbury-Nepean Valley consists of a sequence of floodplains linked by gorges. The combination of large upstream catchments and the narrow downstream gorges results in floodwaters backing up behind the natural ‘choke points’ (**Figure 31**). This ‘bathtub effect’ causes significant flooding in the Penrith and the Richmond-Windsor floodplains.

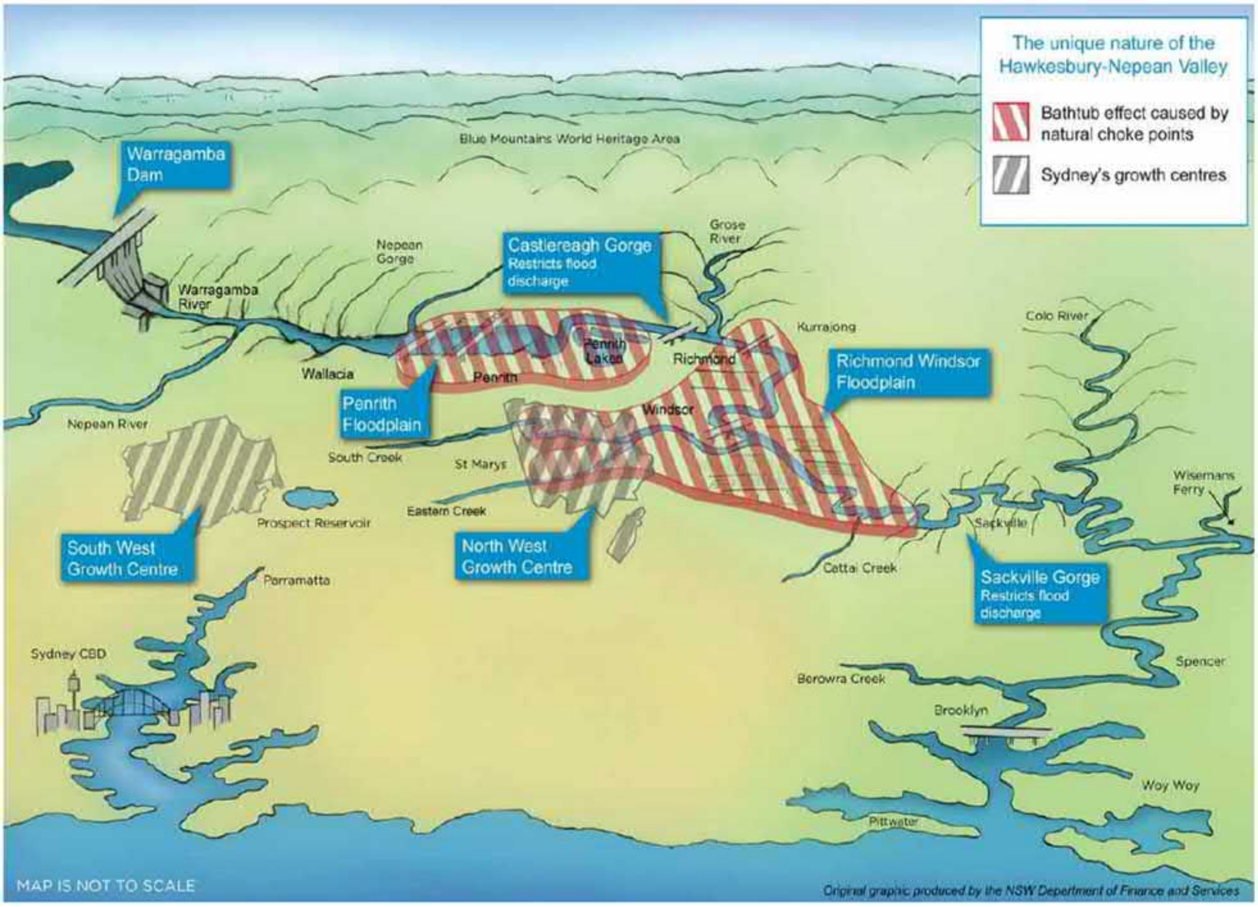


Figure 31 The bathtub effect of flooding in the Hawkesbury-Nepean Valley (Ribbons, 2015)

The Hawkesbury-Nepean region includes upland lakes, wetlands, coastal swamps and coastal floodplains. Wetlands listed in the Directory as Important Wetlands in Australia include Pitt Town Lagoon located off Bardenarang Gully and Longneck Lagoon located off Longneck Creek near Pitt Town. Both wetlands are examples of the Endangered Ecological Communities (EEC) Freshwater Wetlands on Coastal Floodplains of New South Wales North Coast, Sydney Basin and South-East Corner Bioregions. No Ramsar or coastal wetlands are located within the downstream study area.

The downstream environment includes waterways and their associated riparian zones as well as floodplain and wetland waterbodies adjacent to the main rivers. According to the Hawkesbury-Nepean State of the Catchments (SOC) 2010 report, wetlands in the region are in very poor condition overall (DECCW, 2010c), with altered hydrology already considered to have a moderate disturbance impact on both wetlands.

These floodplain wetlands include flood lakes, backswamps, ponded tributaries and creek swamps (ERM Mitchell McCotter, 1995). They provide important habitat for migratory water birds. While they are predominantly invaded by carp, they have potential to provide native fish habitat (BMT WBM, 2014a).

Wetland mapping studies show 50 floodplain wetlands with regional conservation significance associated with the Hawkesbury-Nepean River downstream of Pheasants Nest and Broughtons Pass Weirs to the confluence of the Colo River, with the majority found from Richmond to Wisemans Ferry.

Other floodplain wetlands exist on the Richmond Lowlands including Irwins Swamp, Yarramundi Lagoon, Bakers and Triangle Lane Lagoons (both in private ownership), and Pughs and Bushells Lagoons spanning both public and private property.

b. Aquatic ecology

This sub-section summarises the detailed treatise provided in the Aquatic Ecology Assessment Report Appendix F4 (SMEC, 2019). Of relevance to this report are the sensitivities of identified species to geomorphological changes.

The catchment upstream of Warragamba Dam is predominantly surrounded by protected areas. It is therefore not subject to the level of anthropogenic influence as the catchment downstream of Warragamba Dam, which is surrounded a variety of land uses including urban and heavy industrial. This land use influence in the downstream catchment has led to significant alterations to aquatic habitats, largely driven by habitat modification, and changes to water quality. This difference in anthropogenic influence is somewhat reflected in the respective habitat conditions; however, because of the sheer scale of downstream the catchment, and the myriad surrounding land uses, there are many streams within the downstream catchment that display excellent habitat condition.

The potential impacts posed to aquatic habitats by the Project relate to changes in water quality. Direct impacts to aquatic ecosystems or threatened species are not anticipated. During operation of, and release of stored flood waters from the flood mitigation zone, the largest / least frequent flood events are less likely (compared with the Existing Scenario) to cause bank erosion. However, the intermediate / more frequent (e.g., 1 in 20-year) releases from the flood mitigation zone may cause erosion risks. The potential impact this may have on aquatic ecology is difficult to quantify. Sedimentation of aquatic habitats, including filling of rocky areas, riffles and smothering of benthic habitats are potential impacts to aquatic life. However, much of the habitat change would be in areas that are already heavily modified such as Penrith Weir.

Threatened aquatic species are present in the study area and include the Macquarie Perch, Australian Grayling, Trout Cod, Murray Cod, Silver Perch, Black Rockcod, Adam's Emerald Dragonfly and Sydney Hawk Dragonfly (GHD, 2013, Alluvium, 2016, Knight, 2010; SMEC, 2019). There is the potential for at least two threatened fish species that are indigenous to the Hawkesbury-Nepean catchment to occur in the GIA. These are the Macquarie Perch (*Macquaria australasica*), listed as Endangered under both the EPBC Act and Fisheries Management Act (1994), and the Australian Grayling (*Prototroctes maraena*), listed as Vulnerable under the EPBC Act and Endangered under the Fisheries Management Act (1994). Aquatic flora assemblages exist throughout the Hawkesbury-Nepean system, however no comprehensive studies exist upstream of the Warragamba River confluence. A habitat assessment for Macquarie Perch showed most sites had sparse to moderate (<10%) aquatic macrophyte cover over multiple sites in the Lake Burragorang catchment, including Coxs, Kedumba, Wollondilly, Nattai and Little rivers (BMT WBM, 2017). Green filamentous algae were abundant at sites with low riparian cover. Furthermore, the NSW Department of Primary Industries (2006) indicate at least three other threatened species occur in the catchment: Trout Cod (*Maccullochella macquariensis*), Murray River Cod (*Maccullochella peelii peelii*) and Silver Perch (*Bidyanus bidyanus*). These species are not locally indigenous but have been translocated. The preferred habitat of Murray Cod and Trout Cod include deep water holes in the main channel of the Hawkesbury River. As there are no recent records of these species in the catchment, it is possible that these introductions have failed (DPI, 2006).

Distribution modelling under the Commonwealth Protected Matters Search Tool indicates the Black Rockcod (*Epinephelus daemelii*) could occur in the lower reaches of the study area, although there have been no confirmed sightings. This species is listed as Vulnerable under both the EPBC Act and Fisheries Management Act (1994). The river is also a corridor for the movement of fish, aquatic fauna or species of direct fisheries significance, including catadromous species that migrate from freshwater habitats to marine environments to breed. These catadromous species include, but are not limited to, eels, Australian bass and mullet. Additionally, the estuary within the study area supports the feeding and nursery habitats, and movement corridors of fish such as bream, mulloway, flathead, whiting and shellfish such as prawns and crabs that are of direct economic significance. There is the potential for other marine species to occur, however these are considered likely to remain in more suitable estuarine habitat downstream of the study area.

Many of these species are not known to exist in the vicinity of hydrological flow impact zones e.g. the Macquarie Perch favours secluded streams, with complex in-stream habitats. This type of habitat is generally not present on the main stem of the river system below the dam.

c. Terrestrial ecology

This sub-section summarises the detailed treatise provided in the Upstream and Downstream Biodiversity Assessment Report, Appendix F1 and F2, respectively (SMEC, 2019). Of relevance to this report are the sensitivities of identified species to geomorphological changes.

i. Upstream environment

The upstream catchment immediately around Lake Burragorang primarily consists of intact native vegetation, generally eucalypt dominated woodlands. There are some areas along the Wollondilly River which were cleared for agriculture, however this a relatively small proportion of the immediate catchment. There has been some historical disturbance in some areas through selective logging, mining and agriculture, however, generally the vegetation is good condition with minimal weed infestation. Over 20 different Plant Community Types (PCTs) were identified within the PMF level of the Project, with four of PCTs listed or threatened or endangered. Both threatened flora and fauna species occur in the catchment with the most notable being the Camden white gums in the Kedumba River catchment

The area surrounding Lake Burragorang is contained in National Parks and State Conservation Areas. It is also a Schedule 1 Special Area which restricts public access.

The upper catchments of the Nattai River, Kedumba River and Kowmung River are largely contained in National Parks and are heavily vegetated. The upper catchments of the main tributaries of Lake Burragorang, the Wollondilly River and the Coxs River, have experienced significant clearing for agriculture, mining and power generation.

ii. Downstream environment

Within the downstream environment, there are a number of National Parks and State Conservation Areas within the Greater Blue Mountains World Heritage Area. These areas are located primarily on the western and northern borders of the study region where rivers including the Grose, Colo and Macdonald Rivers flow toward the Hawkesbury-Nepean River.

Between the dam wall and Lapstone the catchment either side is generally heavily vegetated and the Warragamba River and Nepean River is contained with a gorge. Between Lapstone and Cattai Creek, the catchment has largely been cleared for agricultural and urban development (apart from the western bank between Penrith and Richmond). Downstream of Cattai Creek, the catchment is heavily vegetated.

d. Water quality

This sub-section summarises the detailed treatise provided in the Water Quality EIS Appendix Q (SMEC, 2019). Of relevance to this report are the sensitivities of identified species to geomorphological changes.

i. Upstream environment

The Warragamba Dam is the largest raw water supply in Australia. It controls 40% of the total area of the Hawkesbury-Nepean River catchment.

Part of the Kowmung River within the upstream catchment is declared a wild river under the National Parks and Wildlife Act 1974 (NPW Act). It is considered in near-pristine condition in terms of both ecology and water flow and is free of the unnatural rates of siltation or bank erosion affecting other Australian rivers (OEH, 2015). In accordance with the NPW Act, the river must be maintained to ensure restoration and maintenance of natural biological, hydrological and geomorphological processes associated with wild rivers and their catchments. Much of the Kowmung River lies within the Kanangra-Boyd National Park, while its lower reaches occur within the Blue Mountains National Park. The River Styles™ in the sub-catchment were predominantly gorge (70%), with confined and partly confined types also common and therefore relatively resilient to geomorphic disturbances (DECC, 2005). The topography of the upper section of the river is relatively steep, a fact that would help the river to recover from any major erosion events upstream. All of the Kowmung River was found to be in good geomorphological condition (DECC, 2005). The reason/s behind lower condition categorisation in a previous study was not recorded (DLWC, 1999) but authors of the 2005 study postulated that it could be the presence of sand slugs created by disturbance and erosion upstream.

A study by Young *et al.* (2000) on the Coxs River found that there was no downstream trend in water quality. However, the highest water quality was considered to be at Kelpie Point and in the river's headwaters. Nutrient concentrations and faecal coliform counts vary across the downstream reach of the Coxs River. They have been recorded to be higher than ANZECC water quality guideline levels for primary contact recreation. Influencing factors in the variance exhibited along the river are likely to include varying tributary inflow quality, which is in turn related to the level of natural vegetation disruption and land use in each catchment. High levels of total phosphorus have been recorded at Kelpie Point at concentrations considered to have contributed to excessive algal growth in the river. High nutrient concentrations have been recorded during high flows and were attributed to agricultural land use (non-point source) and sewage treatment effluents (point source). However, since this study, sewage treatment effluent has been diverted away from Coxs River to Winmalee STP.

Within the Lake Burragorang water quality is generally good with low levels of nutrients, suspended sediments and other pollutants. After rainfall higher concentrations of nutrients, suspended sediments and other pollutants are recorded in Lake Burragorang, however, water quality is generally considerably better than downstream of the dam in the Hawkesbury-Nepean River.

ii. Downstream environment

The river condition downstream of Warragamba Dam has been modified significantly since European settlement. Human impacts now dominate some channel and catchment processes with flow regimes altered contributing to accelerated erosion, increased runoff and diminishing water quality. Water quality in the river varies with both location and weather condition. Generally wet weather water quality in the river is very poor due to the impact of runoff from agricultural and urban lands. In dry weather, particularly downstream of Penrith, water quality is impacted by discharges from numerous sewage treatment plants. Algal blooms and excessive growth of aquatic weeds have occurred regularly over the past 30 years due to the high nutrient levels in the river.

The major uses of the Hawkesbury-Nepean River include water supply, wastewater disposal, irrigated agriculture, tourism, commercial fishing and oyster farming. Recreational water users include recreational fishing, swimming and water skiing.

Two declared wild rivers exist in the downstream environment. These include the Colo River and the Grose River, both of which are major tributaries to the Hawkesbury-Nepean River.

The Colo River flows through the Greater Blue Mountains World Heritage Area and consists of four sub-catchments, Colo, Wolgan, Capertee and Wollemi across the Blue Mountains and Wollemi National Parks. These are largely and relatively undisturbed catchments. Human impacts in these catchments are namely the historical mining that occurred at the headwaters of Wollangambie Creek within the Colo sub-catchment.

The Grose River flows through the Blue Mountains National Park, however it has had historical impacts of grazing, logging and mining within its catchment. No lasting major impacts are considered to exist from the historical logging and grazing, and the mine that had been located at the headwaters of the Grose River is no longer operational. A geomorphic assessment of the Grose River indicate that it is in good geomorphic condition. The majority is classified as a gorge river (more than 94%) with a few 'Confined' reaches which are both relatively resilient to geomorphic changes (DECC, 2008). Sand slugs are present in the lower / eastern reaches which have potential to alter natural processes. These are being flushed out in high flows.

The tidal limit of the Hawkesbury River occurs near Yarramundi, approximately 140 km upstream of the river mouth (Department of Natural Resources, 2006; Krogh *et al*., 2009).

3.2 Site investigations

3.2.1 Rapid geomorphological assessments

Sites for the walkover survey were selected to be representative of larger scale reaches in which they are located (Upstream Zone and Lake Zone in **Figure 32** and Downstream Zone in **Figure 33**).

Figure 32 Location of rapid geomorphological sites in the Upstream Zone and Lake Zone

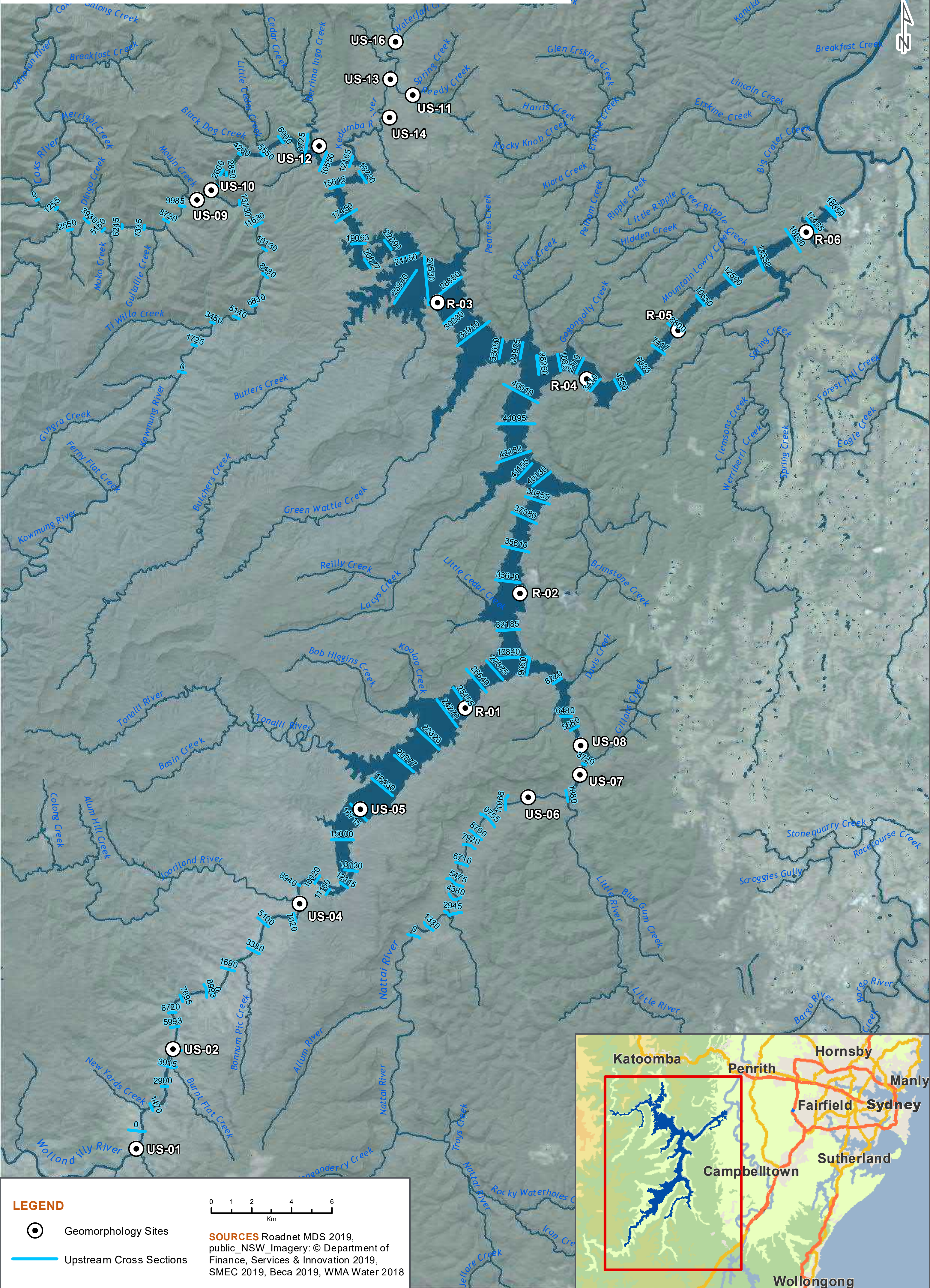
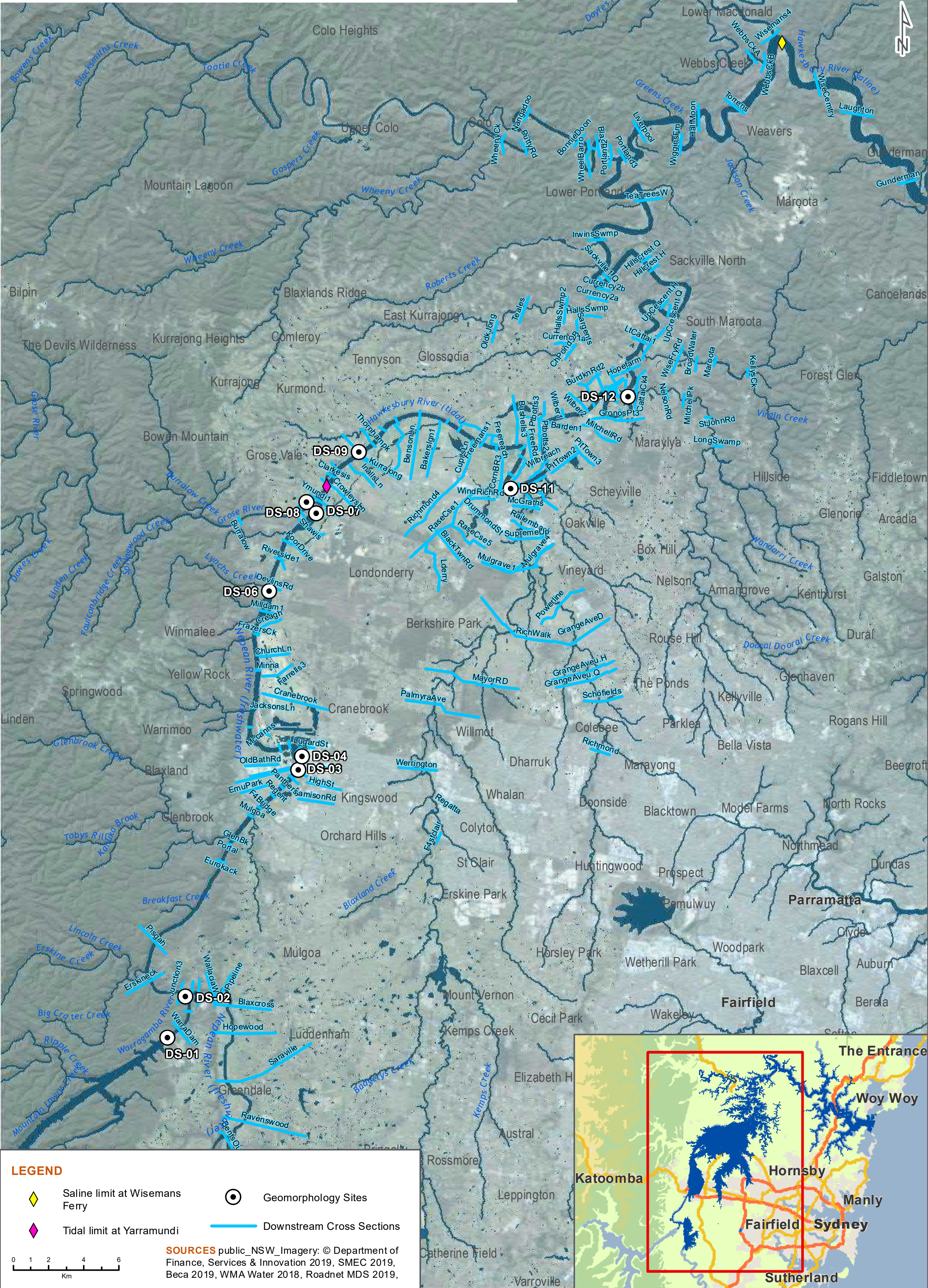


Figure 33 Location of the rapid geomorphological sites in the Downstream Zone



Completed walkover survey sheets are provided in **Appendix G**. The text below provides a brief summary of geomorphological conditions in selected reaches.

a. Upstream Zone

The Coxs River upstream extent of this assessment is set in valley fill floodplain with steep forested terracing. The channel can be anabranching and multiple mid-channel islands which store gravels and sands are present (**Figure 34**). The channel has a pool and riffle structure and there is slight meander formation within the confines of the fill allowing lateral accretion. A relatively straight 'flood runner' depression at a raised level relative to the permanent channel occasionally conveys floodwaters has formed on the adjacent side of the mid-channel bars. This is relatively homogenous and contains higher calibre cobble materials, reflecting the increased competence for transport in high flow events.

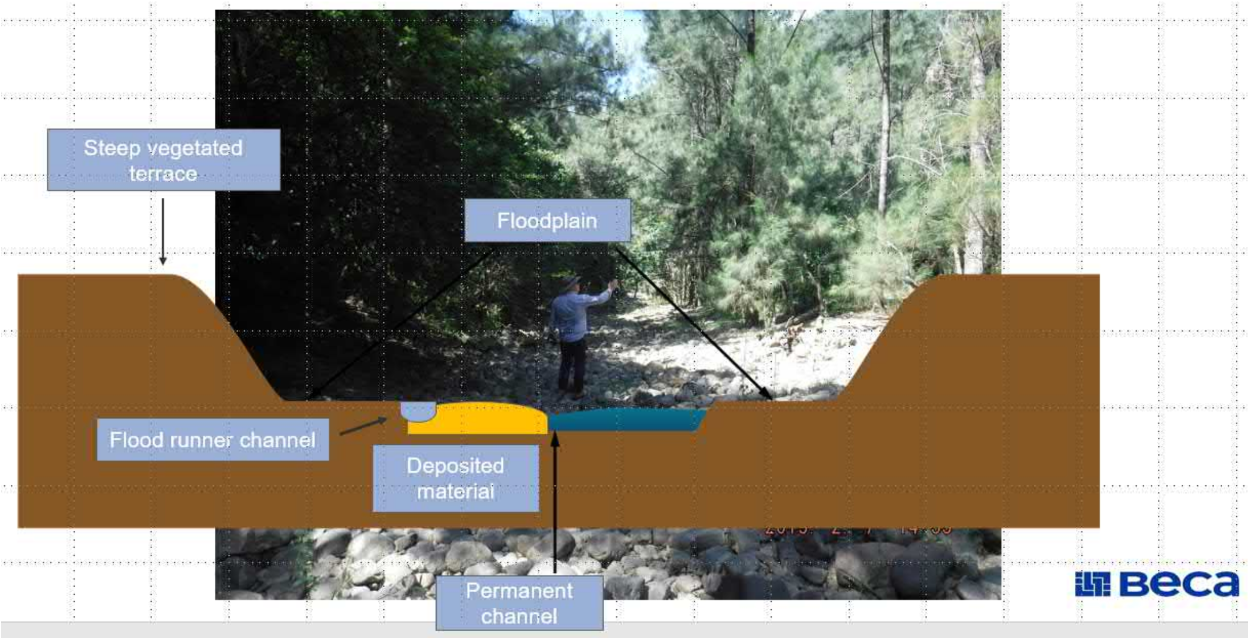


Figure 34 Typical structure of Coxs River upstream

Sediment calibres present in the mid-channel islands are not present in the permanently wetted channel nor in the paleo-channel which contain coarser pebbles and cobbles, respectively. As such, this structure acts as a storage mechanism for gravels / sands which will be eroded in high flow events, travel stochastically downstream and then deposit.

The Coxs River downstream extent has a lower gradient and a sand bed. The channel is this area has high organic loading, with hydrogen sulphide bubbling observed during disturbance (**Figure 35a**). Point bars form on the inside of meander bends and a small 2-4m strip of non-vegetated bank is exposed on the outside of meander bends before dense vegetation in the open u-shaped valley (**Figure 35b**). Rill erosion has been initiated in these deposits, presumably from runoff channels sourced on adjacent terracing.

(a) Hydrogen sulphide rich sediments	(b) Rill erosion on non-vegetated bank

Figure 35 Coxs River downstream features

The Kedumba River is a valley-fill fine-grained channel with multiple well-developed levees. These raised elongated asymmetrical ridges borders the Kedumba channel (i.e. along the proximal floodplain). The channel margin is steeper than the floodplain margin. Levee crests here are relatively shallow, laterally extensive features. They are composed almost entirely of suspended load sediments (dominantly silt, often sandy) deposited at high flood stage. Highly developed levees along extensive fine-grained floodplains such as these infer a laterally fixed channel zone and well-defined segregation of water and sediment transfer between the channel and flood basin. Overlying this material, a dark black thin layer of organic material was observed. It is postulated that this was sourced from recent wildfires in the catchment.

(a) Primary levee with stable fill material

(b) Black organic matter overlying sandy deposits

Figure 36 Kedumba Valley features

The Nattai River is also set in valley fill floodplain with forested terracing. The upstream site contains elongated bedrock ridge over which finer sediments have been draped and colonised by vegetation (**Figure 37a**). These sediments were deposited on top of the instream bedrock ridge during the waning stages of flood events. As they have become colonised by vegetation, additional sediment has been trapped and accumulated on top of the bedrock core. Over time these bars have built both vertically and longitudinally as sediments are trapped in the wake of vegetation. At the two downstream sites, relatively homogeneous, uniform, tabular 'sand sheet' deposits cover the entire bed (**Figure 37b**).

(a) In channel bedrock ridges

(b) Sand sheets

Figure 37 Nattai River channel features

An array of bedforms are present in this downstream section, reflecting riffle, dune or plane-bed sedimentation. These were formed when transport capacity was exceeded and / or competence was decreased and bedload deposition has occurred across the bed. This feature generally reflects transport capacity-limited conditions due to an oversupply of sediment. Bedforms appear to be subject to frequent removal and replacement by floods as the sand sheet moves downstream as a pulse.

b. Lake Zone

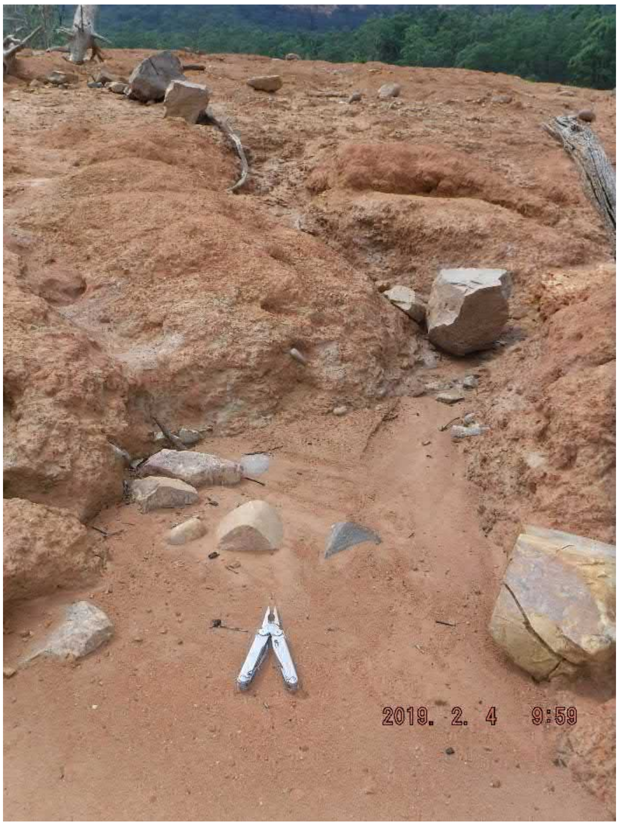
A roughly triangular (in map view) and wedge-shaped (in cross section) delta, approximately 5 km in length, has formed at the inlet point of the Wollondilly River into Lake Burragorang (**Figure 38a**). This is located at the point that velocities from the river have decreased below their conveyance capacity for the bedload and subsequently suspended load to the extent that a depositional environment predominates. This feature was not present at any other inlet points such as for the Coxs or Nattai Rivers. Bedding of materials (as is typical of deltas) was not observed with homogenous sediment composition generally comprising fine sands and silts. This was interspersed with gravels and cobble materials along the edge of the river channel (**Figure 38b**). The smoothed angle of the delta bank at the channel mouth and presence of lobate 'fingers' to the west suggests that delta morphology is influenced predominantly by the Wollondilly River current, and associated distributary channels, as opposed to wave action.

(a) Looking north west down onto the delta top

(b) Sediment composition along the delta edge

Figure 38 Wollondilly Delta

Lake Burragorang sites have larger exposed foreshores due to the current low water level conditions (site assessments undertaken 04/02/19 at a water level of 105.019 m). In the southern, central and both-west arms, well developed and extensive (circa 100m) partially vegetated shorelines with approximately 20 percent gradients are present. These contain incised rills with concentrated runoff lines developing into gullies (**Figure 39a**). Further up the shoreline above the mean water level, berms are often present protecting a backshore with more stable vegetation. These berms appear subject to infrequent wave action, causing bank erosion. In some instances, this wave undercutting has led to exposure of sheer cliff faces of unstable soil, revealing tree roots and causing vegetation mat collapse and cantilever failure of the bank (**Figure 39b**).



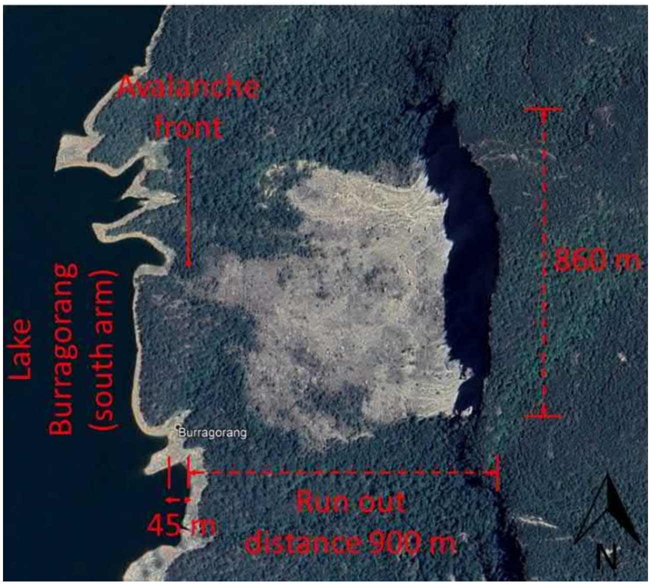
(a) Gully formation on the foreshore

(b) Wave undercutting exposing tree roots

Figure 39 Lake Burragorang Foreshore

The gorge area in the north east arm is markedly different, with bedrock constrained near-vertical valley. Some rockfall failures were observed, with blocks of sandstone becoming detached from the main body of the cliff-face at weaker joints and falling directly into the lake. Limited opportunities for vegetation colonisation exist in this area.

A mass movement deposit is visible by aerial photography on the foreshores of Lake Burragorang - this is referred to in the erosion hotspot model as the North Nattai rockfall avalanche. The landslide is a composite feature consisting of a rock avalanche (or sturzstrom) sitting on top of multiple rotational slumps.



(a) Aerial view (b) View from the lake

Figure 40 North Nattai Rock Avalanche

The rock avalanche is composed of chaotically arranged sandstone boulders sourced from the failure of an 860 m long section of cliff face. The deposit has a runout distance of 900 m and is within 45 m of the full supply level of Lake Burragorang. The rock avalanche itself has several lobes or mounds of deposits giving rise to an undulating surface topography with tens of meters of relief including a steep (35–55˚), thick (5–15 m) leading edge. The avalanche appears to have preferentially flowed down and infilled prior drainage lines and depressions. This avalanche, and similar mass movement events in the Nattai catchment, have been attributed to long-wall mining in the area (Cunningham, 1998; Tomkins *et. al.*, 2007). Material is available for transport into the lake if this area of land is inundated and the stability of the feature would need to be assessed further.

c. Downstream Zone

The ‘Warragamba Dam to Nepean River Junction’ reach (incorporating the walkover site DS-01) is influenced by hard metamorphic and granitic rocks with gravels and boulders forming the bed of the stream in most places and the lower parts of the alluvial banks. Bedload contains well-rounded river gravels and boulders, which have been transported by fluvial action from the west and southwest of the 9,050km^2 Warragamba catchment. Lateral movement of the channel allows the deposition of in-channel coarser sediments, while the finer ‘top-stratum’ deposits are generally attributed to vertical accretion processes, such as from floods and high-stage flows. This 3.3 km reach has incised into the lower Burragorang gorge, which is at least 100m deep near the dam and increases to about 130m at the junction. The fall is about 100m but most of that is in the dam wall. Water level at the junction is approximately 14.3 m. Since it is less than 20m below the dam and there is a former storage weir some 1.2km downstream gradients in this gorge are low, with a mean gradient of approximately 0.0030. The gorge is narrow, about 250m wide at the top, and more like a stepped slot. On the remnants of lower sandstone steps and in the bed some coarse bedload survives, together with fallen sandstone blocks. However, it is more than evident that most of this load has been removed by sediment-deficient flows from the dam since 1960. Some of it forms a riffle just downstream of the pool at the junction of the two rivers. This, together with a slight lowering of Penrith Weir, means that the peak water level is now just downstream of the junction, where some of this gravel has accumulated.

The 'Warragamba River Junction to the end of the Fairlight Gorge' reach (incorporating the walkover site DS-02) is located at the junction of the Nepean and Warragamba Rivers (located at the site of a magmatic plug, which has weathered into a broad basin), the drainage area has increased to about 10,800 km^2. This 12.7 km reach is known as the Fairlight or Penrith Gorge. The channel is incised between 130 and 230 m below the undulating plateau of the left bank and the east-dipping cuesta on the right bank. At the junction the gorge is over 600 m wide but downstream it narrows to 500 m. The water surface width widens from only 20 or 30 m adjacent to the alluvia in the basin near the junction to between 100 and 125 m between Euroka Creek and the end of the gorge. This is only just over 1 m above sea level, which is unusual for a site so far inland (about 170 km). There is no gradient in this reach because all but the top 100 m or so are part of the Penrith Weir peak water level. A block delta up to 3 m high, spreads 100 m across the weir pool and is about 200 m long. Nepean floods have changed the shape of the delta (Warner, 2002), but it has not been moved downstream. These floods have deposited boulders and gravels from the bed of the gorge. Downstream there is evidence for subsequent bed scouring because the delta has acted as a barrier to flows and sediment movement.

The 'End of Fairlight Gorge to Penrith Weir' reach (incorporating the walkover site DS-03) is a 5.4 km straight channel and is the lower part of the long Penrith weir pool. It has no gradient and at cease-to-flow stage, the water level is just over 14 mAHD. At the weir, the channel is about 120m wide; this increases to 200m at the Victoria Bridge. Upstream it is 130 to 150m wide. Sediment starvation induced by Warragamba dam has allowed the bed of the gorge to erode nearly 1.36m since 1900 (Warner, 2002). The channel lies in the alluvia for the first time from the dam. However, the channel is inset into the fossil floodplain (Castlereagh Terrace), with a sandstone shoal in the bed upstream of the Motorway Bridge on the left bank. The terrace dates back to about 26,000 years ago, with lateral migration of the channel inhibited by the bedded gravels and boulders in the lower part of the alluvial beds (Warner, 2002). Modern sands and finer alluvia have been deposited adjacent to the lower terrace slopes. Boulders move along the floor of the pool and some are now trapped behind the weir wall. Sediment-deficient flows over the Warragamba dam have moved this bedload along the gorge, over the Glenbrook delta and up to, as well as over, the weir. The alluvial surface is occupied by Penrith and Emu Plains urban areas and is only flooded by the 1 in 100 year and greater floods. Left- and right-bank areas are greatly modified by rural and urban settlements. Banks have been engineered.

The 'Penrith Weir to Grose River Junction' 18.9 km reach (incorporating the walkover sites DS-04, DS-06 and DS-07) is the only alluvial section which is not affected by weirs and has a mixed load. In general, the floodplain is fairly narrow incised into the sandstones of the lower Blue Mountains on the left bank and inset below the Castlereagh terrace and lower floodplains on the right. Where the major floodplain widens, as at the northern end of the Penrith Lakes and opposite the Grose junction, linear lagoons mark the back of the floodplain. The channel has been widened, deepened and generally cut up by sand and gravel operations in the bed and on adjacent banks, particularly near Penrith, Mill Dam Falls and above Yarramundi Bridge. Such increases in cross sections reduce the incidence of flooding, greatly increase the capacity of the channel and reduce discharge velocities to levels well below the threshold of motion for most of the time.

The Grose River Junction to Wilberforce reach (incorporating the walkover sites DS-09 and DS-11) reach is the tidal limit. Below the Grose junction, the river becomes the Hawkesbury. This reach is tidal rather than a saline estuary (this point is located downstream of Wisemans Ferry). This 24.8 km reach is for the most part an alluvial channel with predominantly sandy benches and higher more cohesive alluvium. The exception is the Terrace, a shale capped cliff extending between 6 and 10 km on the left bank. However, the coarse bedload found above the Grose junction is absent / smothered from the channel bed, which becomes sand dominant. The gravels probably pass beneath the sand and were part of the steeper (higher energy) sub-alluvial channel, which prevailed in the late Pleistocene (Warner, 2002). Infill at lower levels is mainly estuarine clays but the present channel is cut in silt-rich sands, which form fairly cohesive banks, with inset sandy deposits of post-settlement alluvium. The upper 6 km of this reach are barely sinuous but east of the

Terrace, the channel meanders. Near Windsor the channel also meanders and the floodplain has widths of up to 6 km that have high storage capacity for overbank flows (BMT WBM, 2013). This section is also characterised by lagoons and floodplain swamp wetlands with low elevations as a result of more rapid sedimentation in the main channel compared to the smaller tributaries. The main channel on this reach has been dredged from time to time (BMT WBM, 2013). Levees are sandy and between 8 and 10 m high. Behind the levees, the toe of the levee slopes steeply into marginal (rather than tributary) back swamps and lagoons with elevations not much above sea level. On the right bank are Pughs, Bakers and Pitt Town Lagoons, whilst on the left bank is Bushells Lagoon. The wide flat banks around Windsor are cleared, cultivated, usually weed infested and often eroding.

The Wilberforce to the Colo River Confluence channel reach (incorporating walkover site DS-12) is set in a partially submerged gorge. This reach is 37km long with a fairly even mix of bedrock and alluvial banks. On the outside of meander bends, bedrock is usually found, sometimes in near vertical cliffs. In this reach the Hornsby Plateau has no great elevation. Near Wilberforce sandstone elevations are about 20m; they increase to 30 or 40 m at Ebenezer at 10km; whilst at Sackville, heights reach 50 m. At the Colo junction the dissected plateau reaches over 100 m. Widths in this reach vary between 100 and 250 m. There are a series of 'turbulence holes' near steeper cliff sections and several of these exceed 30 m below present sea level. These increase sub-tidal capacities which in-turn lowers the effectiveness of tidal flushing. A 30 m 'hole' at walkover site DS-12 near New Hope Farm in the Cattai National Park is 5m deeper than the predicted gradient. Sub-aerial and sub-aqueous sedimentation have been more rapid in the main channel and consequently drowned tributary valleys have been dammed by Hawkesbury levees, leaving lagoons and swamps as wetlands in the slower in-filling tributary valleys.

The Colo River Confluence to Wisemans Ferry reach marks the end of this assessment extent. This 20 km reach is in a deeper, partially submerged gorge and is characterised by bedrock and alluvial banks. Bedrock typically occurs on the outside of meander bends. The dissected Hornsby Plateau is now 200 to 230 m above the river. Channel widths vary from 100 to 400 m. There are a number of deep holes near steeper cliff sections that are up to 30 m below sea level (BMT WBM, 2013). Pool depths vary from 7.9 to 35.7 m and they entirely cut in bedrock (Dury, 1970). The Colo River, Macdonald River and Webbs Creek maintain open entrances to the Hawkesbury River because of their larger size and flows, relative to other minor tributaries.

3.2.2 Bank strengths

Bank strengths for the selected Upstream and Lake Zones sites is shown in **Figure 41** and for the Downstream Zone site is shown in **Figure 42**. The full dataset is provided in **Appendix H**.

Maximum recorded bank strengths over the instrument measuring range of 5 kg/m^2. were recorded at:

- The upstream sites US-05 (Wollondilly River at inlet to lake) and US-09 (Coxs River at Kelpie Point)
- The lake sites R-05 and R-06; and
- The downstream sites DS-01, DS-02 (both Warragamba River) and DS-03 (Nepean River at Penrith).

The lowest recorded bank strength was 0.1 kg/m^2, which was recorded at:

- The upstream sites US-02 (Wollondilly River), US-07 (Nattai River at Iron Bridge) and US-14 (Kedumba River)
- The lake sites R-01 (southern arm) and R-02 (central), and
- The downstream sites DS-06 (Nepean at Devlins Bridge), DS-08 (Grose River at Yarramundi) and DS-11 (Hawkesbury River at Windsor).

The strongest and the weakest bank regions were spread over the length of the lake and rivers, including the downstream and upstream areas, with no clear spatial pattern. The aerial imagery of the river indicates that the highest bank strengths are associated with the narrow regions of the river and the gorge area in the north-east arm of the lake.

Average bank strength decreased in the Downstream Zone, the further downstream travelled. For the upstream locations the average bank strength as well as the maximum bank strength was higher at locations closer to the reservoir, such as US-04 and US-05.

Figure 41 Bank strengths in the Upstream Zone and Lake Zone

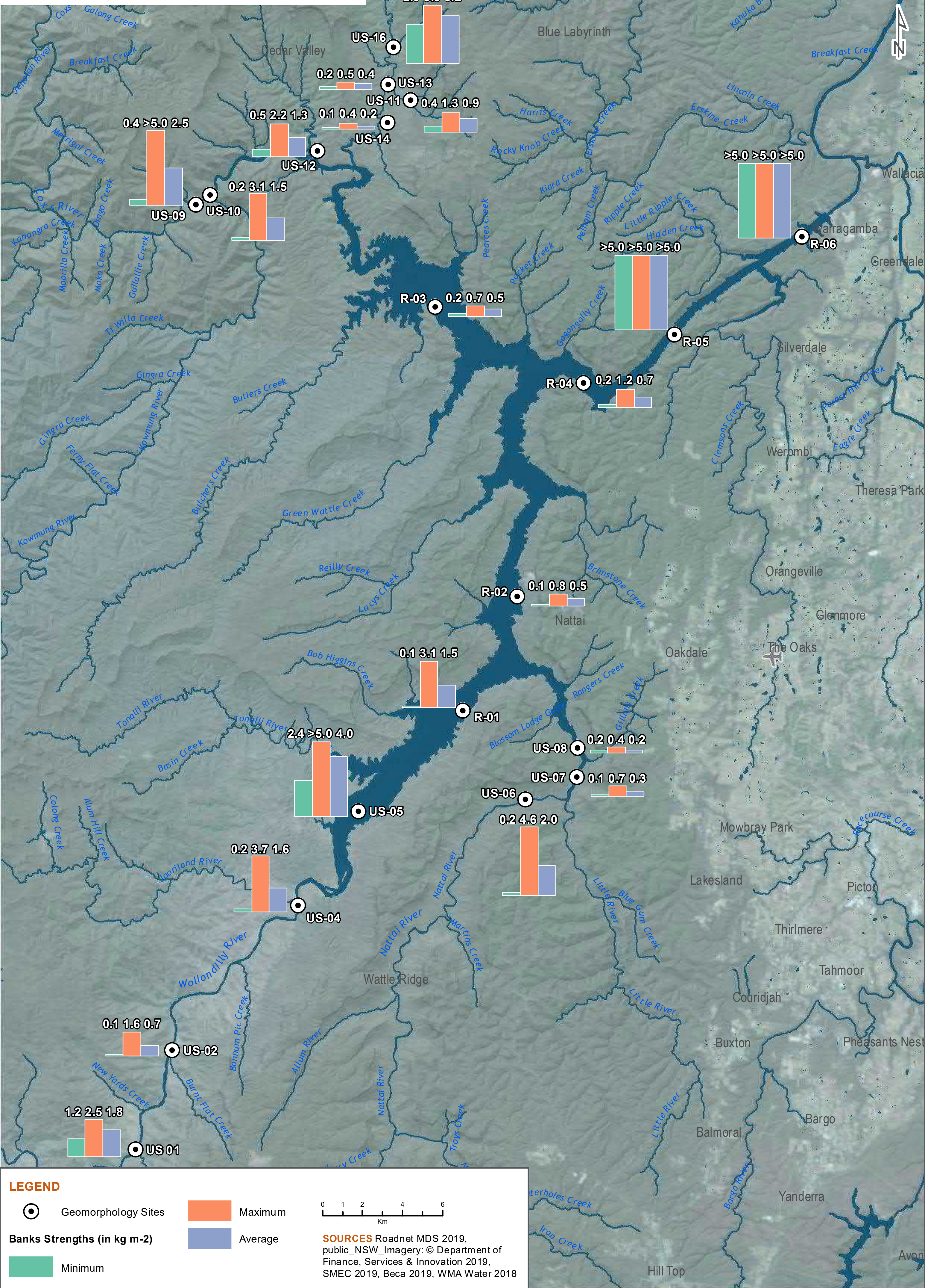
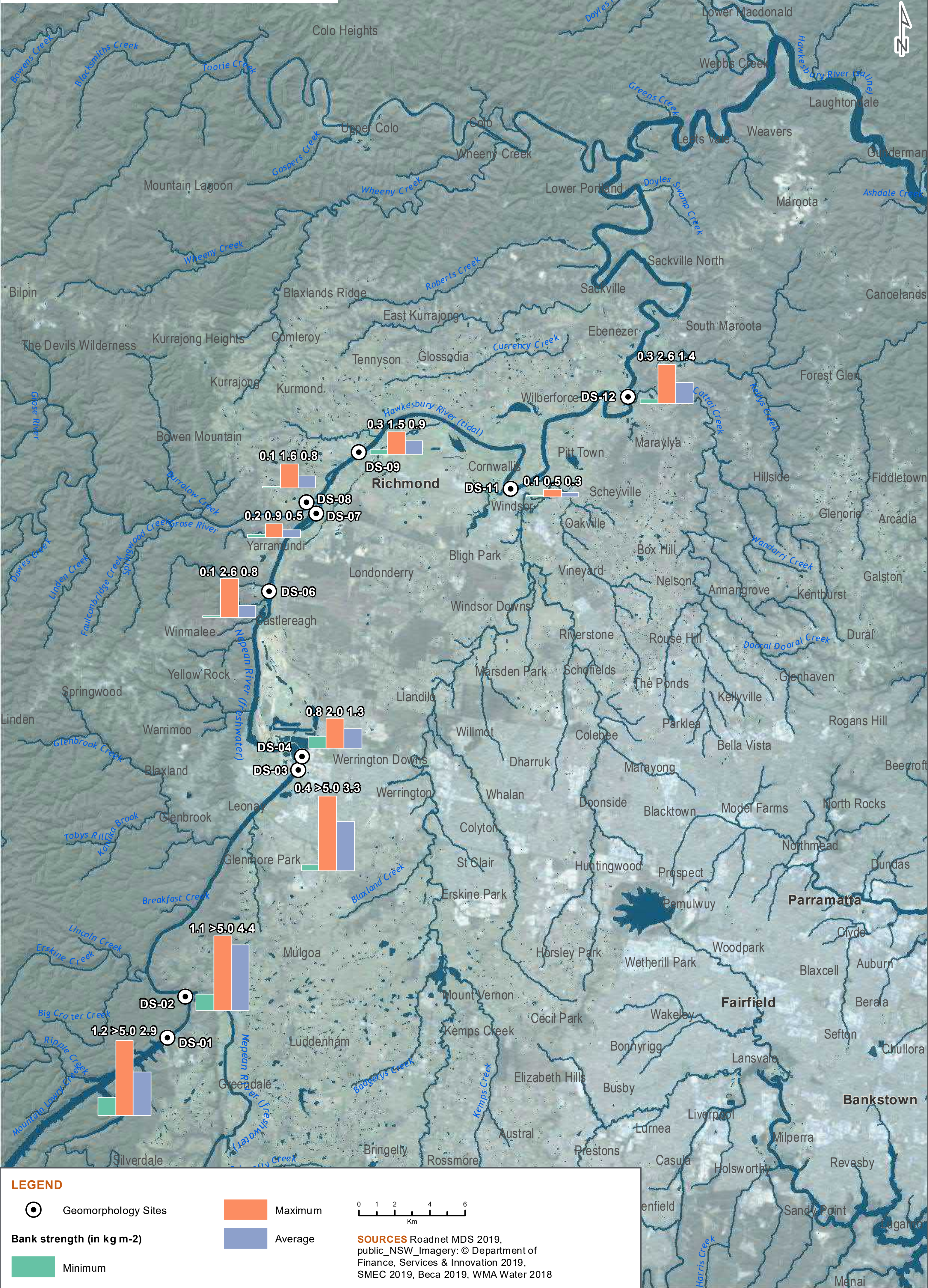


Figure 42 Bank Strengths in the Downstream Zone



3.2.3 Bed sediment composition

Bed sediment composition for the selected Upstream and Lake Zones sites is shown in **Figure 43** and for the Downstream Zone site is shown in **Figure 44**. The full dataset is provided in **Appendix I**. Relevant observations of bed sediment composition were:

- The locations in the Nattai River contained sand as the predominant sediment type with other types of sediments present in smaller quantities. The Kedumba and Coxs Rivers contained a mix of larger and finer sediments like cobble and sand, with upstream regions of the stream made up mainly of cobbles, and downstream regions at the confluence made up of finer particles like gravel, sand and silt. The Wollondilly River consisted of a variety of sediment sizes, and the percentages varied at different locations.
- At the Upstream Zone sites US-01, US-04, US-09, US-10, US-11 and US-16 cobbles were found to be the predominant bed sediment material, with other types of sediments present in lesser percentages.
- Some Upstream Zone sites contained finer sediments in larger proportions than the others, including US-02, US-05, US-06, US-07, US-08, US-12, US-13 and US-14.
- At the Lake Zone, including sites R-01, R-02, R-04, the predominant bed sediment types were found to be sand, gravel and fine sand.
- The reservoir sites lying within the gorge before the dam, including R-05 and R-06, reported higher proportions of larger sediment types like boulders and cobbles.
- The only Downstream Zone sites containing larger sediments such as boulders and cobbles were DS-01, DS-02 and DS-07. All other sites lying in the downstream region contained finer sediment like sand, fine sand and gravel.
- Warragamba River, in its upper regions mainly consisted of boulders, which were replaced with finer gravel, sand and fine sand in its lower reaches. The Nepean River and Hawkesbury River contained finer particles including sand and fine sand with some gravel in the section between Penrith Weir and the Grose River Junction.

Bed surface sediment characteristics in the tidal Hawkesbury River from the Grose River junction to Wisemans Ferry have been studied previously (NSW Public Works, 1987). The main findings were:

- The riverbed is comprised of clean sands to muddy sands, with the sand content being of medium grain size, typically 0.3 to 0.5 mm.
- The sand fraction is of uniform mean grain size along the channel centre.
- Grain size variations did not appear to vary in a consistent fashion along the 80 km length of river sampled
- The fines content is very small (i.e., clean sands) in the upper tidal reaches from Freemans Reach to Windsor
- Immediately downstream of South Creek the sediments are muddy sands to sandy muds and remain silty until York Reach where they are clean.
- The sands remain clean to the vicinity of Colo River, downstream from which the mud content progressively increases. The Colo River confluence is near to the limit of marine saline intrusion, and the presence of salinity in the water acting to flocculate the fines probably explains the increasing mud content of the sediments.

Figure 43 Bed sediment composition in the Upstream Zone and Lake Zone

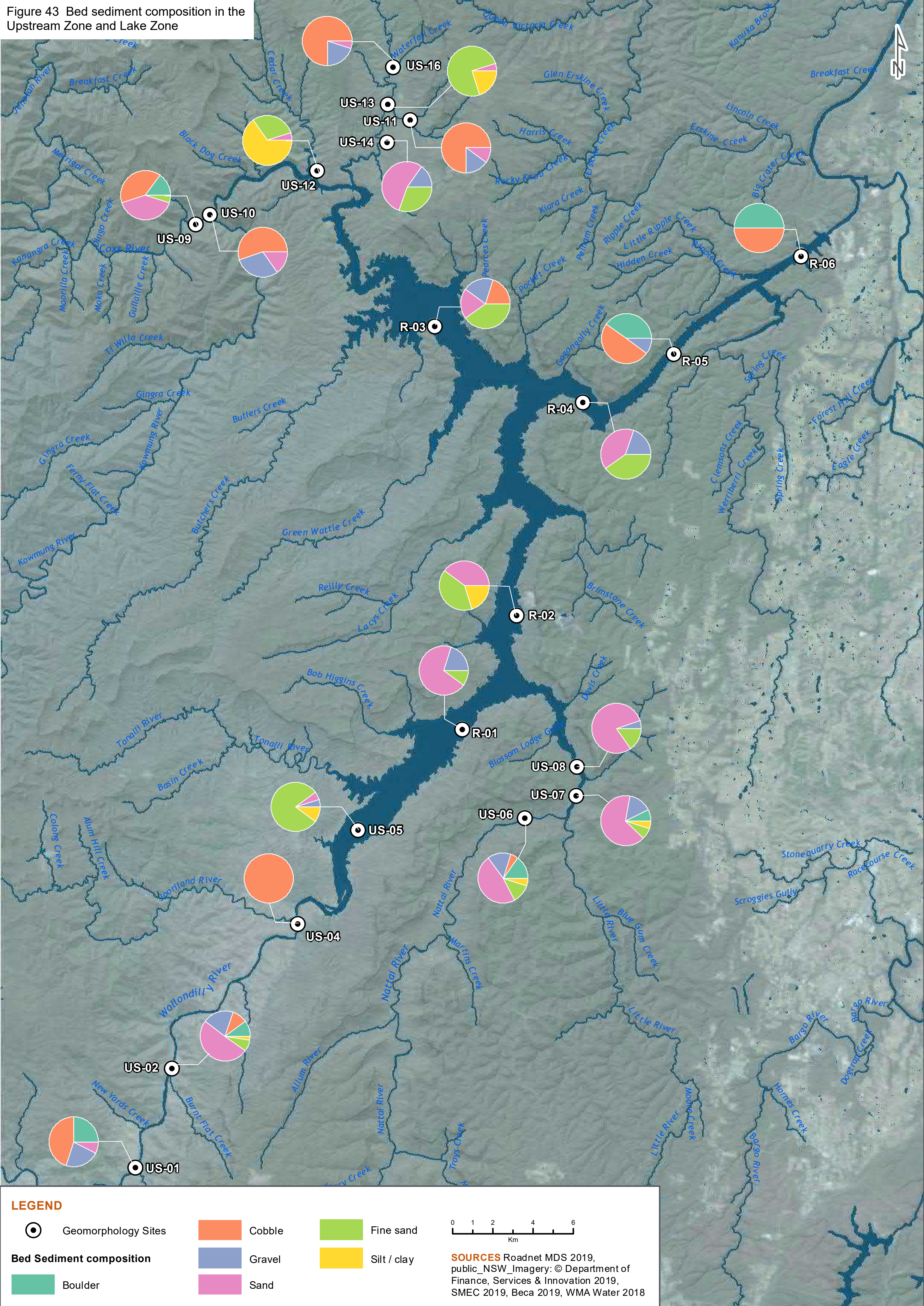
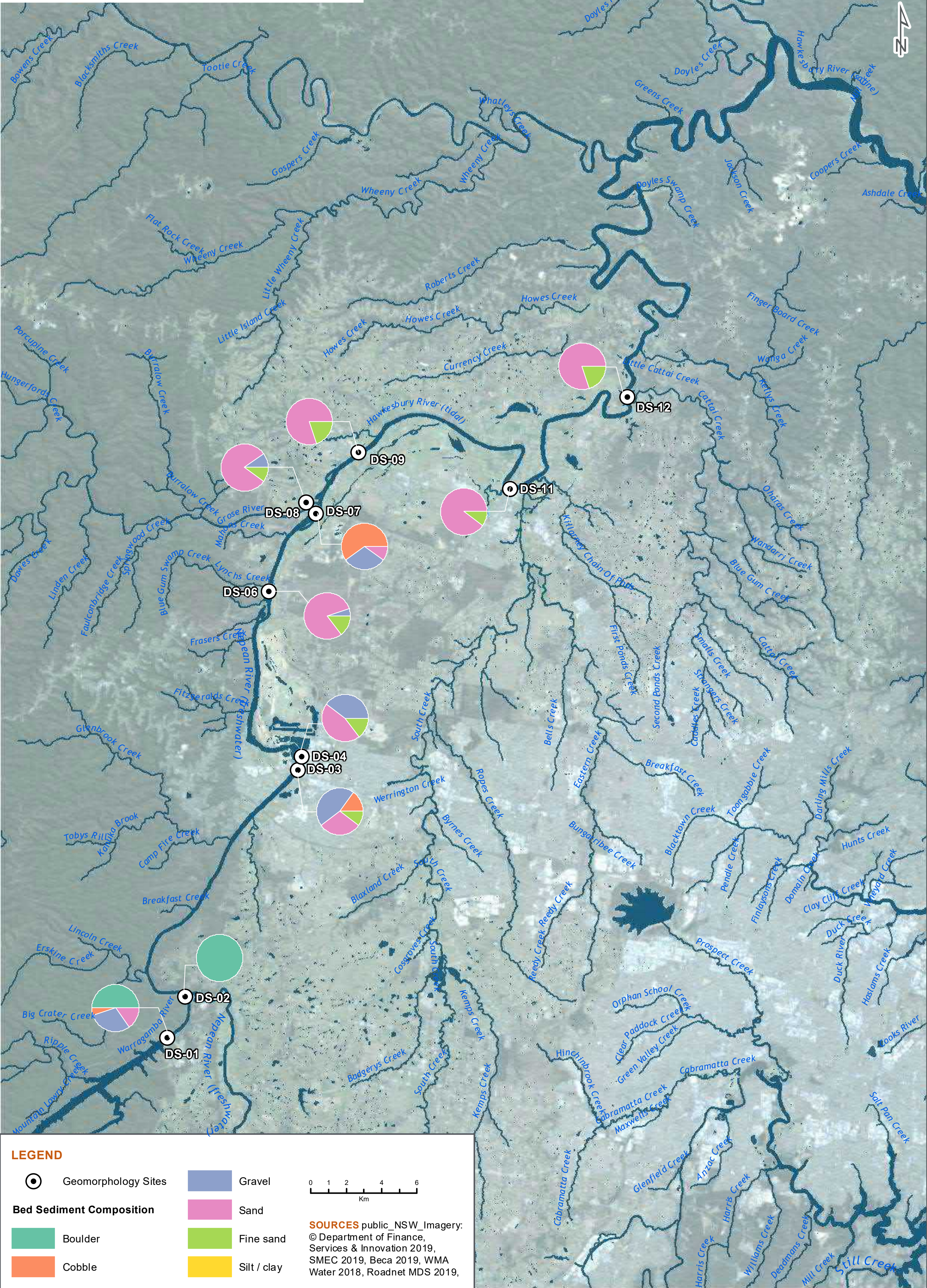


Figure 44 Bed sediment composition in the Downstream Zone



3.2.4 Sediment deposition

Since deployment of the sediment mats in the Lake Burragorang catchment in early February 2019, water levels have steady declined (from 60 to 50% storage) and there has been no observed inundation of any of the deployed mats (**Figure 45**). As such, no sediment deposition data can be reported in this technical assessment.

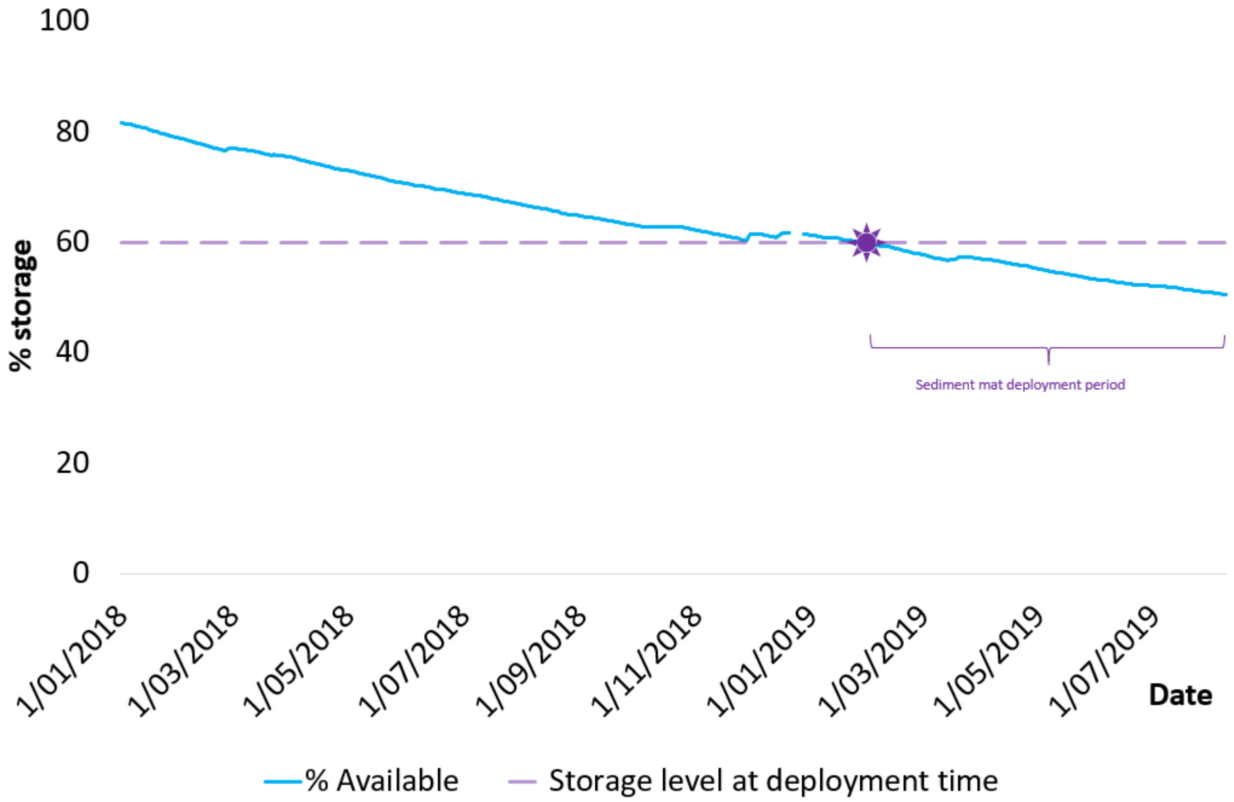


Figure 45 Sediment mat deployment comparison to water levels

The above data was collected and written up prior to the February 2020 rainfall event and therefore has not considered any deposition that may have occurred during this event. The mats have been left in the catchment in the event that other parties wish to assess deposition in future studies.

4 Environmental assessment – construction phase

The potential impacts and mitigation measures relating to erosion during the construction phase are covered extensively in Chapter 22- Soil and Chapter 27 - Water Quality of the EIS (SMEC, 2019). The key to managing geomorphological impacts will be to minimise water runoff and associated sediments from leaving the site using typical good practice construction erosion and sediment control procedures.

5 Environmental assessment – operation phase

This section reviews operation phase potential impacts for the Upstream, Lake and Downstream Zones. Fluvial processes are complex, and it is unlikely that precise impact predictions are possible, but a combination of semi-quantitative approaches used in this section provide indicative predictions that are appropriate in this assessment to support the Project EIS process.

5.1 Upstream Zone potential impacts

This sub-section assesses the potential changes to the Upstream Zone (as defined in **Section 1.5.2**) arising from the Project. This includes the following watercourses and their tributaries:

- Coxs River
- Kedumba River
- Kowmung River
- Nattai River
- Wollondilly River

The sub-section addresses the following identified potential impacts:

- Out of bank erosion (**Section 5.1.1**)
- Translocation of sediment features upstream (**Section 5.1.2**)
- In-channel sediment deposition (**Section 5.1.3**)

A summary of these impacts and associated mitigation measures to address the issues identified is provided in **Section 5.4**.

5.1.1 Out of bank erosion

This section summarises the findings of the erosion hotspot modelling for the upstream environment (as described in **Appendix A.3.2**). The Erosion Hotspot Model is a set of raster images mapping relative potential erosion, hosted in a GIS platform with buffer rings around watercourses based on existing flood levels and predictions of with Project flood levels. The model contains the following input layers:

- Gradient
- Land cover
- Soil type / erodibility factor
- Maximum in channel velocity derived from the Project flood model (WMA Water, 2018)

When combined, these factors produce a comparison of erosion potential, by land area, in the Upstream Zone catchments for both the current erosion risk(herein referred to as the Existing Scenario) and also the predicted erosion risk with the dam raising Project (herein referred to as the With Project Scenario) flood regime.

Data extracted from the model is presented in **Figure 46** below and the detailed visual mapping is presented in in **Appendix J**. For the purposes of this assessment, out of bank erosion is defined as any erosion driven by fluvial processes during events larger than the existing FSL that is not confined to the existing river channel. As such, it assesses the erosion impact of back-up of flows in the lower sections of the Upstream Zone.

In general, the erosion hotspot modelling shows that total area of land within the buffers decreases gradually as the magnitude of flood increases, reflecting a reduction in the river floodplain with a low gradient up to the vertical banks of the FSL. Conversely, however, the 1% AEP and PMF events show an increase in floodplain land area, due to overtopping of the river terraces onto adjacent relatively flat land areas.

Existing Scenario erosion risk classifications range from negligible to high (**Table 12** and **Figure 46**). The vast majority of the land in the upstream rivers GIA, however, lies in the 'slight' (37 - 72 % of total land area) and 'low' (27 – 57 % of total land area) range categories. The With Project Scenario erosion risk classifications range from slight to high (**Table 13** and **Figure 46**). The vast majority of the land in the upstream rivers GIA, however, lies in the 'low' range category (57 - 75% of the total land area) with a greater proportion in the 'intermediate' range category than for the Existing Scenario.

Table 12 Upstream Zone erosion risk classification per land area – Existing Scenario

Erosion Potential Risk	20% AEP Existing		10% AEP Existing		5% AEP Existing		1% AEP Existing		PMF Existing	
	Area (m^2)	%	Area (m^2)	%	Area (m^2)	%	Area (m^2)	%	Area (m^2)	%
0 – Negligible	719	0.0%	1,015	0.2%	1,025	0.2%	4,744	0.3%	1,634	0.0%
1 – Slight	1,195,572	71.5%	412,148	64.7%	238,456	42.2%	515,772	36.6%	2,166,572	41.0%
2 – Low	447,963	26.8%	202,353	31.8%	299,012	52.9%	798,127	56.6%	2,504,601	47.4%
3 – Intermediate	27,660	1.7%	21,083	3.3%	26,356	4.7%	92,402	6.5%	593,177	11.2%
4 – High	0	0.0%	0	0.0%	0	0.0%	14	0.0%	21,048	0.4%
5 – Very High	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
6 - Extreme	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total Area (m^2)	**1,671,914**		**636,599**		**564,849**		**1,411,059**		**5,287,032**	

Table 13 Upstream Zone erosion risk classification per land area – With Project Scenario

Erosion Potential Risk	20% AEP Project		10% AEP Project		5% AEP Project		1% AEP Project		PMF Project	
	Area (m^2)	%	Area (m^2)	%	Area (m^2)	%	Area (m^2)	%	Area (m^2)	%
0 – Negligible	1,016	0.0%	1,113	0.1%	757	0.0%	571	0.0%	426	0.0%
1 – Slight	25,859	1.0%	26,237	1.9%	406,124	22.9%	527,278	17.4%	2,118,040	26.8%
2 – Low	1,892,763	75.3%	1,022,644	74.4%	1,149,957	64.9%	2,019,997	66.7%	4,516,787	57.1%
3 – Intermediate	542,021	21.6%	281,318	20.5%	201,273	11.4%	448,140	14.8%	1,194,981	15.1%
4 – High	50,483	2.0%	43,211	3.1%	15,045	0.8%	34,317	1.1%	74,404	0.9%
5 – Very High	-	0.00%	-	0.00%	-	0.0%	-	0.0%	-	0.0%
6 - Extreme	-	0.00%	-	0.00%	-	0.0%	-	0.0%	-	0.0%
Total Area (m^2)	**2,512,142**		**1,374,523**		**1,773,156**		**3,030,303**		**7,904,638**	

The 10% and 20% AEP storm events represent the largest proportion of change in erosion class between Existing Scenario and With Project Scenario:

- Shifts up one erosion class of 84% and 89% of the total land area, respectively
- Shifts up two erosion class of 2% and 3% of the total land area, respectively

These changes in class indicate an incremental increase in the likelihood of erosion but give no quantitative indication of the spatial nor the volumetric extent of that change in erosion.

Conversely, the majority of land stays in the same erosion class between Existing Scenario and With Project Scenario for 5%, 1% and PMF events. This lack of change to erosion class indicates that the likelihood of erosion is similar, but there could still be a quantitative change in the spatial extent or the volumetric extent of erosion within the area.

Creeks flowing into the lake from the east and south (e.g. Little River, Nattai River, Werriberri Creek, Wollondilly River) have similar erosion classification for the With Project Scenario to the north-east arm of the lake (**Section 5.2.1**), with slight - low erosion risk predominating (**Appendix J**). However, the creeks to the west of the lake (e.g. Cedars Creek, Cox's River, Kedumba River, Kowmung River) have noticeably higher erosion risk classification in the With Project Scenario, with the intermediate category predominating (**Appendix J**). This could be due to increased land gradient.

Studies have shown that sediment has accumulated in the Wollondilly River (Pittock 1975; Cornish 1977; Warner, 1987; Belland & Erskine, 1981; Erskine, 1992), above its gorge reach (starting approximately 25 km from the Lake Burragorang mouth). These out of bank post-settlement alluvial deposits have persisted as stable sediment storage sites in the decades since their deposition, having revegetated with grass and other riparian vegetation. Indeed, many have persisted despite substantial variations in rainfall (Pittock 1975; Cornish 1977) and flood magnitude (Belland & Erskine, 1981; Erskine, 1992) where some models of fluvial behaviour would have suggested their erosion (Warner, 1987). There remains the potential for these sediment deposits to be destabilised and be made available for downstream transport during inundation event floods.

Studies have shown that there has been a dramatic reduction in sediment deposition across the catchment over at least the last 20 years. Younger deposits clearly cannot represent a major component of the deposited sediments. This supports the conclusion that catchment sediment yields in the major river systems over the last 20 to 40 years have declined substantially below their initial post-settlement peak (Wasson *et al*., 1998; Olley & Wasson, 2003). Better management of vegetation cover more broadly across the catchment is also likely to be influencing lowered sediment yields today compared to a century ago. This downward trend may be slightly reversed in the With Project Scenario, with mobilisation and transport of the terrace deposits described earlier.

This analysis has shown that erosion risk classification increases for all storm events for the With Project Scenario, but that the most marked changes between Existing Scenario and With Project Scenario occur during 10 and 20 % AEP events. In addition, the erosion risk for the vast majority of land only changes by one or two classes, demonstrating that the potential for increase in erosion is low.

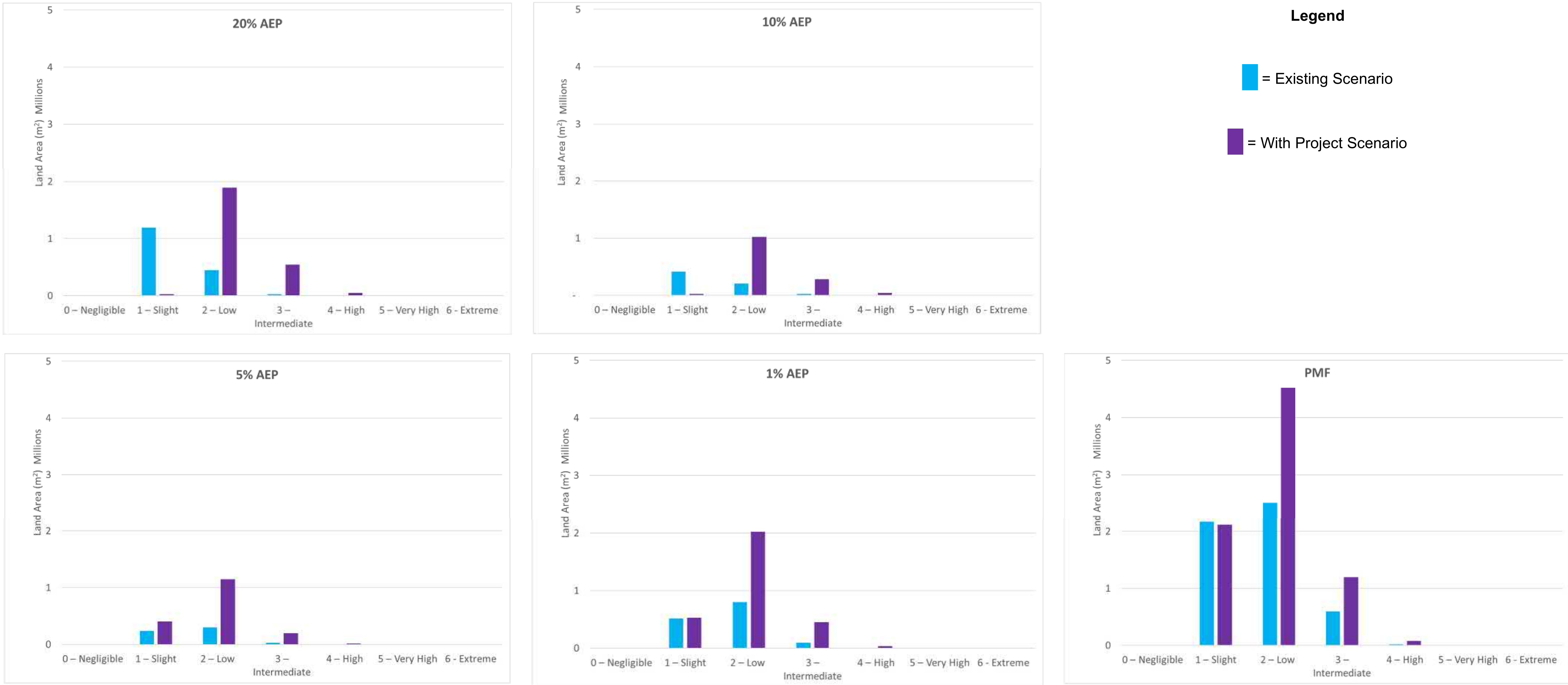


Figure 46 Erosion Hotspot Tool Classifications comparison for the Existing Scenario and With Project Scenario in upstream creeks / rivers

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5.1.2 Translocation of sediment features upstream

The movement of sediment features up-gradient in river systems flowing into Lake Burragorang is considered in this sub-section with reference to the Coxs, Kedumba and Wollondilly Rivers. Other river systems may experience similar patterns of deposition and these sites are used as a reflection of wider-scale trends. The trigger for this sediment feature translocation would be backing up of flows in the existing river mouths due to rising water levels. This would cause a decrease in channel velocity further up the river leading to lower competence to transport sediments, in-turn leading to enhanced deposition. The scale of this translocation is difficult to analyse without quantitative hydrological data, but long-sections of the Coxs and Wollondilly Rivers are used to provide indicative estimates.

For the Coxs River, the difference in peak water levels caused by the Project will lead to stagnant water conditions in the vicinity of the Kedumba River confluence (**Figure 47**). The deposited organic material noted in **Section 3.2.1** will be deposited throughout this reach during low flow conditions. It is thought that these low-density sediments would be entrained and flushed out of the reach in the next high flow event.

As an example of effects in an extreme flood, the PMF event spatial extent runs to the stretch of the Coxs between Kelpie Point and the Kowmung River Confluence (**Figure 47**). This reach is a supply and storage zone for gravels and sands currently, by virtue of the reach upstream in the vicinity of Spotted Dog Point having steep gradient. Lower competence to transport this calibre of sediment may further denude the downstream reach to the Kedumba River confluence. This would lead to a further increase in the percentage of fines in the bed material and may lead to lateral accretion / bank erosion within the floodplain fill structure. The PMF, however, will be extremely infrequent occurrence and the duration of inundation would be so short-lived that any reduction in supply of coarse sediments will be minimal on a longer-term basis. The With Project Scenario PMF has been used here, however a very similar pattern is evident under the Existing Scenario PMF. Given the rarity of PMF events any reference to this level should be treated as indicative only.

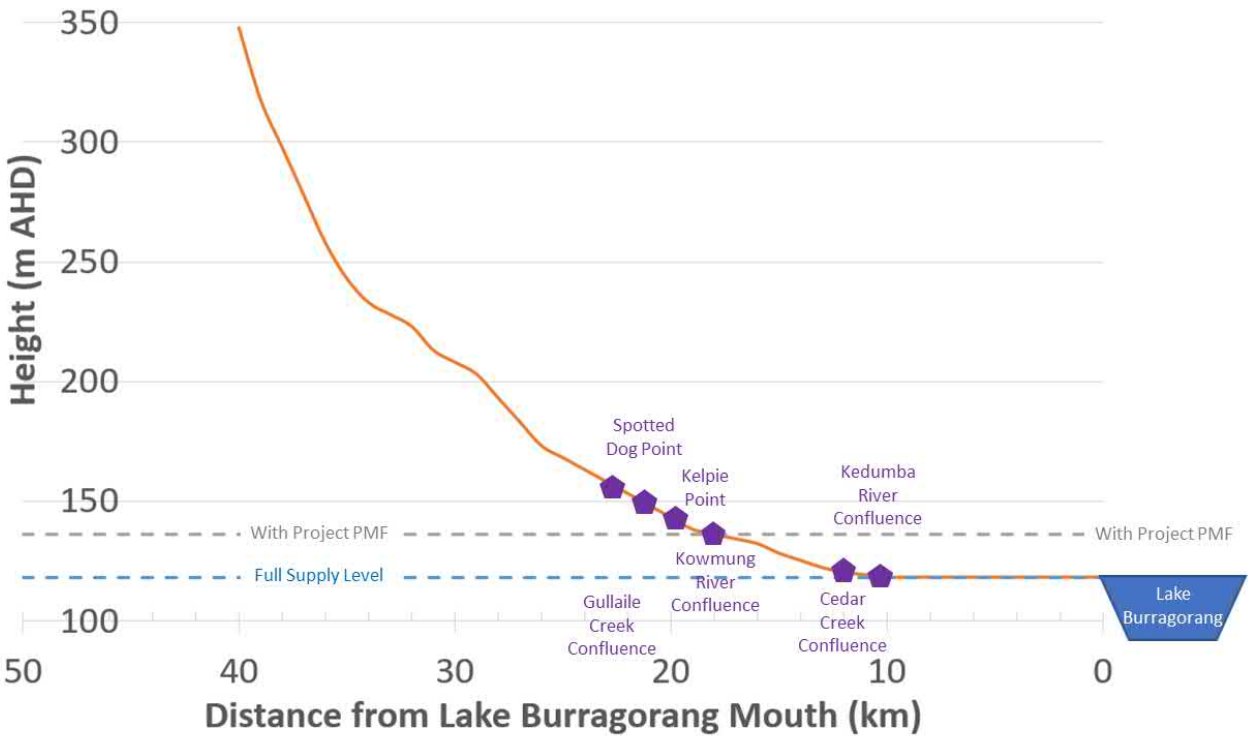

Figure 47 Coxs River Long Profile Features (adapted from CSIRO Land & Water, 2000)

Both the Kedumba River and Kowmung River flow into the Coxs River in an area predicted to be inundated at times. This will lead to a burial of tributary confluence bars which have formed at, and immediately downstream of, the mouth of tributaries. The features currently comprise poorly sorted gravels and sands with complex and variable internal sedimentary structures. Flow separation and generation of secondary currents in the backwater zones promote sedimentation in sheltered areas under low flow velocity conditions and add to habitat diversity. These bars represent a form of slackwater deposit (interbedded sands and mud) that is not elevated above the channel and thus would only be prone to reworking during high flow events. The magnitude of this change is, therefore, considered to be extremely small.

Further up the Kedumba River, the presence of levees (as noted in **Section 3.2.1**) suggest that bank overtopping is a reasonably common occurrence. No sediment yield data was found for this river from extensive literature searches. Using the presence of a thin layer of organics thought to be sourced from recent wildfires as an alternative, it is evaluated that the deposition depth of sediments during inundation events into these levees would be small.

The Kowmung River benefits from a steep gradient and the PMF event extent into the reach is therefore limited to approximately 200 m. The rare frequency of this event in combination with the likely competence of any storm flows in this high-gradient stretch to flush fine sediments down into the Coxs mean that impacts here would be negligible.

For the Wollondilly River, the presence of delta deposits at the river mouth to the lake is noted (**Section 3.2.1**). This stretches for almost 5 km, from 3 km within the lake itself to 2 km up the river, to a sharp meander bend which is thought to limit further deposition.

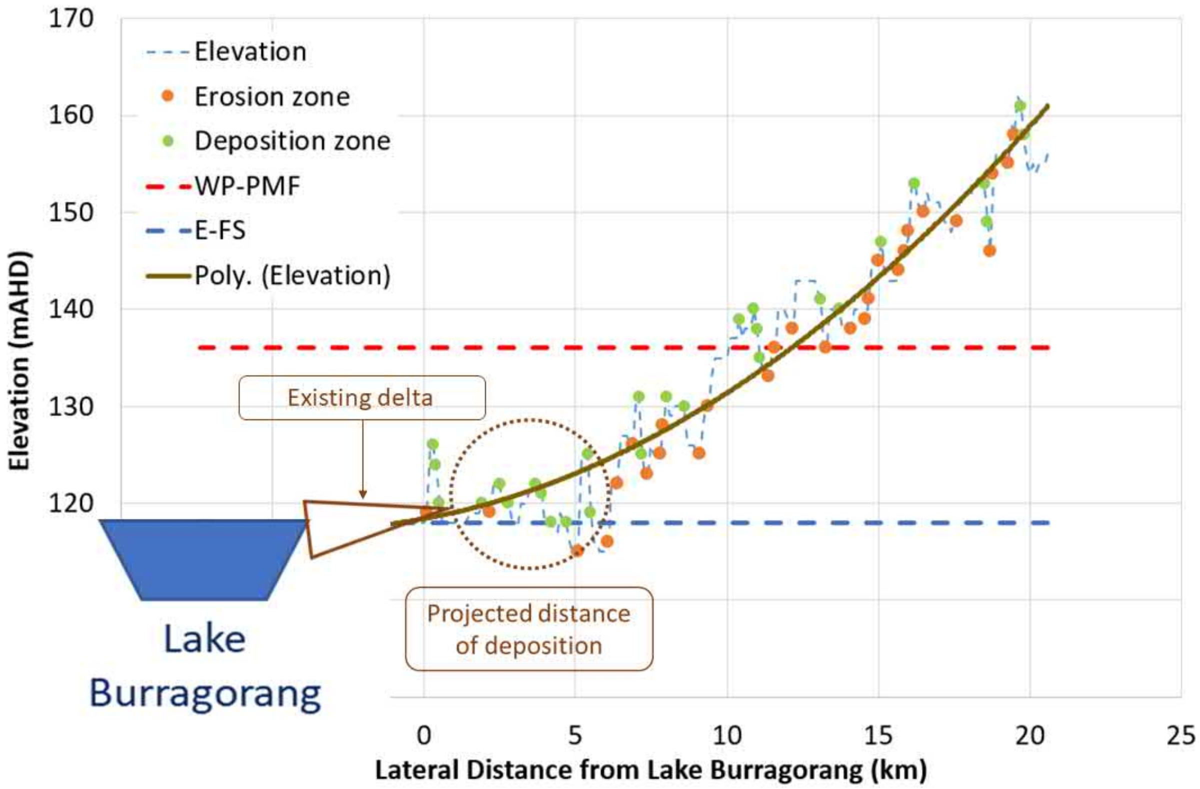

Figure 48 Wollondilly River Long Profile Features

It is anticipated that this delta zone, or at least an enhanced deposition zone, will stretch further up river. Based on extension of the deposition points (green dots on **Figure 48**) this could lie in the area between 2 and 6 km (i.e. about a 4 km extension upstream). As for Coxs River, it is thought that these fine sediments would be entrained and flushed out of the reach in the next high flow event, especially as the floodplain width is partially constrained in this section.

In summary, the effect of the project on sediment features within the tributaries to the reservoir will be minor to negligible. They are not expected to result in a significant change of channel form in any of the tributaries but will result in existing bed forms typically extending over a longer length of some channels, with greater temporal variability in form in the upper parts of the directly affected reaches as sediment is deposited in smaller events, then washed through in larger events.

5.1.3 In channel sediment deposition

Sediment loads for the upstream rivers were reported in **Section 3.1.6**. This showed that suspended sediment transport into Lake Burragorang was dominated by the Wollondilly River (496,983 tonnes per annum / 184 tonnes per annum per km^2) with Coxs (54,822 / 21 tonnes per annum per km^2) and Nattai (154 tonnes per annum / 0.3 tonnes per annum per km^2) delivering successively lower loads.

Excessive sediment deposits on the river / stream beds are attributed to alteration and degradation in habitat. This is shown conceptually in **Figure 49**.

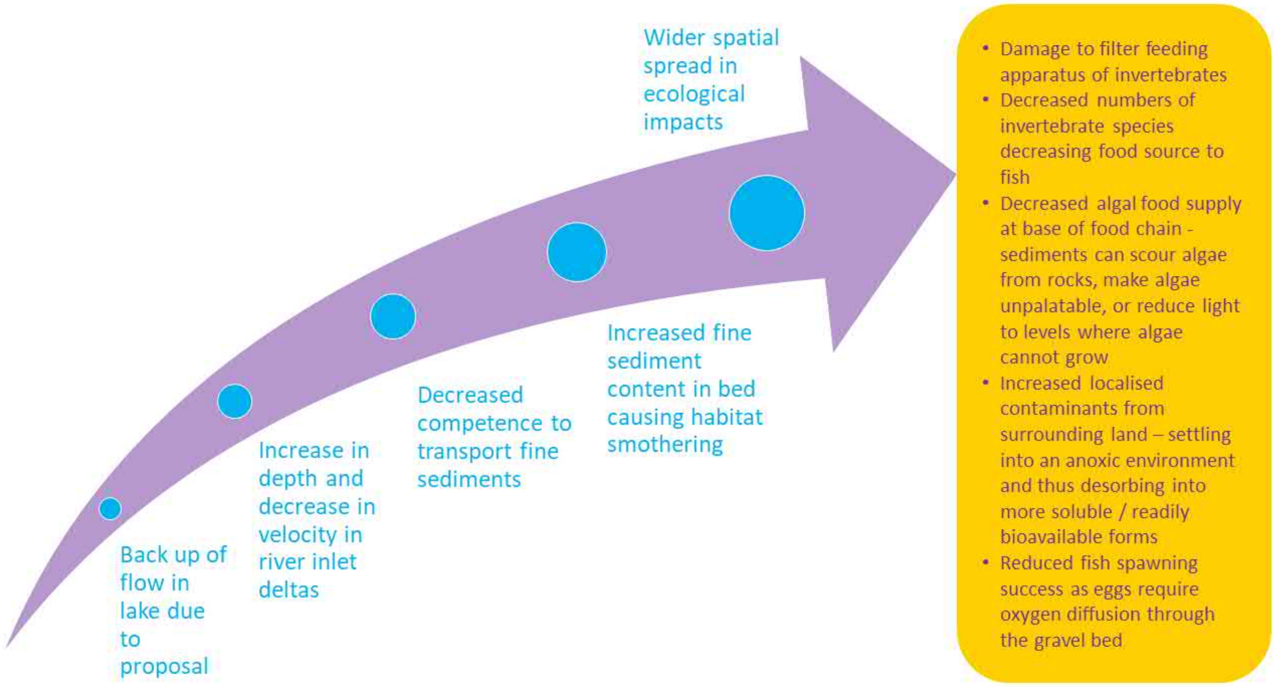

Figure 49 Potential impacts to fine sediment deposition in the upstream rivers

Hjulström Curve Sensitivity Analysis

The Hjulström Curve was used to predict conditions that would cause a change in sediment transport conditions (**Appendix A.3.3**). Upstream Zone river sites using cross-section averaged velocities measured during the walkover survey (**Appendix A.2.2**) rather than modelling results were super-imposed onto the curve to examine current sediment transport status (**Figure 50**). All sites lay under the critical deposition curve, suggesting that bed sediment would not move under the existing flow regime. This was partly due to relatively large D_{50} sediment size at all the sites with a lack of sand size material present (which is transported in lowest critical velocities due to a combination of low size and lack of cohesiveness). Absence of erosion and transport was supported by observations of water clarity, slow moving flows and lack of stochastic bed material saltation during site walkover surveys.

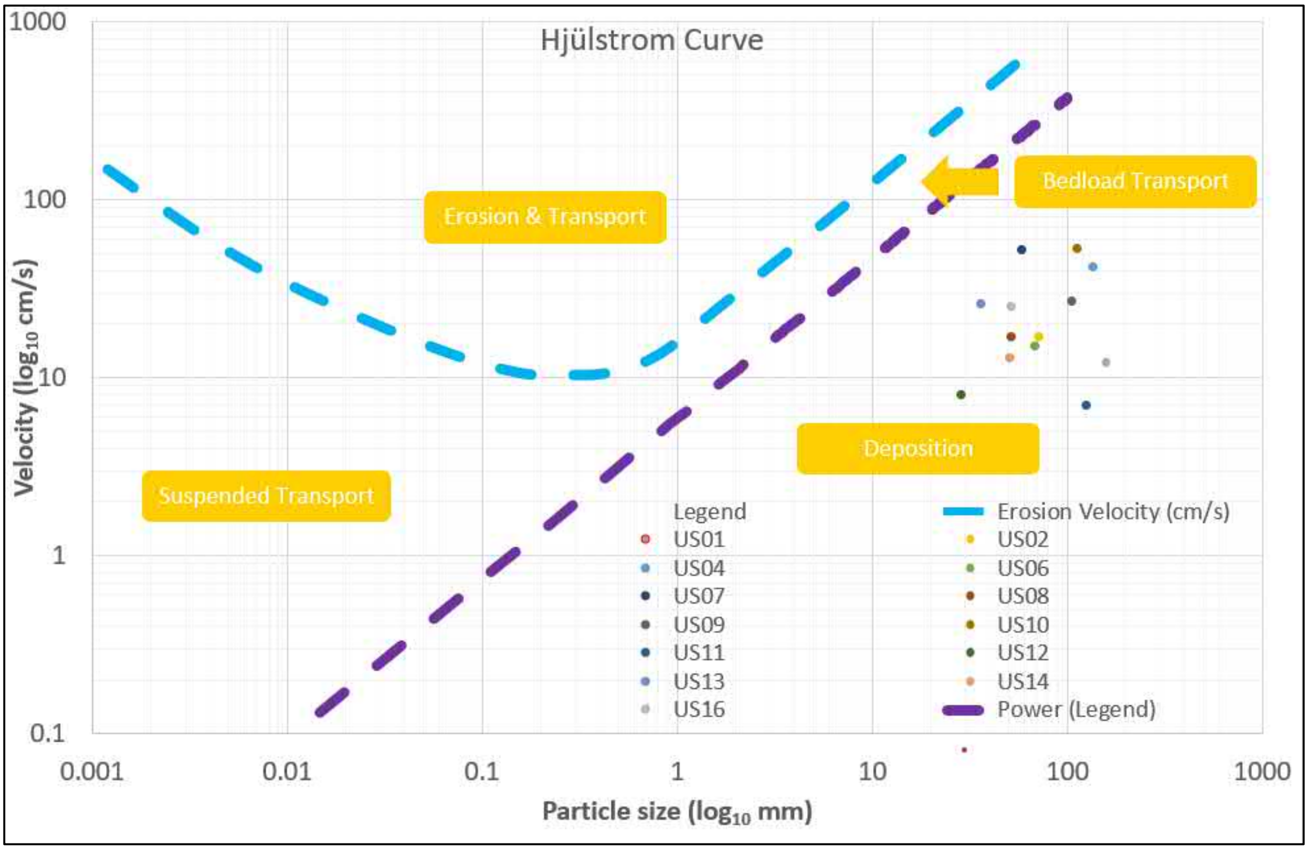

Figure 50 Hjulström Curve with Upstream Zone river sites

This observation was not surprising given the dry hydrological conditions during the time of the survey. Because this empirical model is based on site measured velocities and no modelling data to predict changes in velocities under the With Project Scenario were available, the second stage of the Hjulström Curve analysis involved forecasting velocities required to change points from the deposition classification (**Table 14**).

Table 14 Hjulström Curve Sensitivity Analysis

Site	D50 Sediment Size (mm)	Average flow velocity (m/s)	Current Sediment Zone	Velocity increase required Transport-Bedload (m/s)	Velocity increase required Erosion & Transport (m/s)
US-01	159.18	0.12	Deposition	5.38	N/A
US-02	71.115	0.17	Deposition	2.73	7.83
US-04	135	0.42	Deposition	4.53	N/A
US-05	38.214	0.00	Deposition	1.40	4.35
US-06	67.815	0.15	Deposition	2.35	7.15
US-07	58.52	0.52	Deposition	1.53	5.88

Site	D50 Sediment Size (mm)	Average flow velocity (m/s)	Current Sediment Zone	Velocity increase required Transport-Bedload (m/s)	Velocity increase required Erosion & Transport (m/s)
US-08	51.77	0.17	Deposition	1.83	5.83
US-09	104.775	0.27	Deposition	3.53	N/A
US-10	111.93	0.53	Deposition	3.47	N/A
US-11	125.155	0.07	Deposition	4.03	N/A
US-12	28.628	0.08	Deposition	1.07	3.22
US-13	35.976	0.26	Deposition	1.04	3.79
US-14	50.44	0.13	Deposition	1.87	5.67
US-16	51.77	0.25	Deposition	1.75	5.75

N/A = Outside the prediction curve for the empirical relationship

Sites requiring a velocity threshold <2 m/s to transition from a deposition regime to a bedload transport regime included:

- Cedar Creek (US-16)
- Cox's River adjacent to the lake inlet (US-12)
- Kedumba River (US-13 and US-14)
- Nattai River adjacent to the lake inlet (US-8)
- Nattai River at Iron Bridge (US-7)
- Wollondilly River adjacent to the lake inlet (US-5)

What these sites share in common was that they were low energy environments with relatively finer sediment within channel storage and available for transport. These include the reservoir-dominated transitional zones on the Cox's, Nattai and Wollondilly Rivers as well as Cedar Creek and Kedumba River which had a marked lower gradient and bed sediment size than neighbouring rivers (Section 3.2.3). The remaining sites requiring velocity increases of between 2 – 6 m/s to transition from a deposition to a bedload transport regime were on the Cox's River (US-9 and US-10), Nattai River (US-6), Reedy Creek (US-11) and Wollondilly River (US-1, US-2, US-4). These sites all had larger sediment size and faster flow velocities.

The same trend was observed for transition from a deposition regime to an erosion and transport regime with velocity thresholds between 3 – 6 m/s for low energy sites and 7 – 8 m/s for high energy sites.

All upstream sites consist of average particle sizes of 50 to 160 mm. Under Existing Scenario conditions, erosion is likely to occur at sites US-02, US-05, US-06, US-07, US-08, US-12, US-13, US-14 and US-16. This is due to presence of larger proportions of finer particles in these locations. The upstream locations including US-01, US-04, US-09, US-10 and US-11 all consist of larger sediment compositions, hence are unlikely to undergo erosion at higher velocities.

Highest Existing Scenario site measured velocities were found at upstream sites US-04, US-07, US-10. Of these, US-07 has the highest potential for erosion due to presence of finer sediment particles. Downstream sites generally have lower velocities, which could attribute to the deposition of finer sediments in these reaches.

Sites allocated an ‘N/A’ status in **Table 14** fall outside the curve for the empirical relationship. What this means in reality is that this calibre of material will not be expected to be eroded from a natural channel under the range of flood flows modelled by Hjülstrom but may be transported downstream in a stochastic fashion as bedload.

The Project is unlikely to increase velocities in the Upstream Zone rivers. Conversely, velocities are predicted to decrease for the With Project Scenario. It is clear that the regime in dry season for the rivers will not change from the Existing Scenario because, based on bed material calibre, it is already a depositional environment. What cannot be established quantitively at present given current data is if the sediment transport regime for high flow events will change and if so at what locations and if the magnitude of change would be great enough to alter regime from one of an erosion and transport mode to bedload transport mode to depositional mode. However, it is likely that the depositional zone will extend further upstream when lake levels are higher for flood storage purposes, then the finer fractions of that deposited sediment would progressively move downstream in subsequent smaller runoff events.

Overall, the effects will be a limited increase in the extent and lateral width of deposition in all of the upstream rivers, within the increased length of river or stream that sees intermittent inundation when the water level is elevated for flood management purposes.

5.2 Lake Zone potential impacts

This sub-section assesses the potential changes to the Lake Zone (as defined in **Section 1.5.2**) arising from the Project.

The sub-section addresses the following identified potential impacts:

- Out of shoreline erosion (**Section 5.2.1**)
- Elevated erosion of shoreline banks (**Section 5.2.2**)
- Deposition of sediments on sensitive receptors during inundation events (**Section 5.2.3**)
- Change in circulation patterns causing sediment redistribution (**Section 5.2.4**)

A summary of these impacts and associated mitigation measures to address the issues identified is provided in **Section 5.4**.

5.2.1 Out of shoreline erosion – Erosion Hotspot Modelling

This section summarises the findings of the erosion hotspot modelling for the Lake Zone (as described in **Appendix A.3.2**). The Erosion Hotspot Model is a set of raster images mapping relative potential erosion hosted in a GIS platform with buffer rings around Lake Burragorang based on existing flood levels and predictions of with Project flood levels. The model contains the following input layers:

- Gradient
- Land cover
- Soil type / erodibility factor
- Shoreline exposure to wave erosion based on surrogate of relative exposure index derived from effective fetch lengths – these were estimated using the Mason *et al.* (2018) procedure (see below for detail explanation) - this process was applied on Lake Burragorang only

When combined, these factors produce a comparison of erosion potential in the Lake Zone catchment for both the Existing Scenario and also the new flood regime imposed by the Project.

SMEC have advised that the change in Land Cover assumes a worst case long-term change in vegetation for all flood events apart from the 20% AEP. The actual change in land cover for these events is unknown and would be subject to an adaptive monitoring and management program.

Data extracted from the model is presented in **Figure 52** and the detailed visual mapping is presented in **Appendix J**.

In general, the erosion hotspot modelling shows that total area of land within the buffers decreases gradually as the magnitude of flood increases, reflecting a reduction in the shoreline with a low gradient up to the vertical banks of the FSL (**Figure 52**) Conversely, however, the PMF event shows an increase in land area, due to overtopping of the FSL vertical banks onto adjacent relatively flat land areas.

Existing Scenario erosion risk classifications range from negligible to high (**Figure 52**). The vast majority of the land, however, lies in the slight (53 – 67 % risk range) and low (32 – 46% risk range) categories for Lake Burragorang.

As for the Upstream Zone (**Section 5.1.1**), the 10% and 20% AEP storm events represent the largest proportion of change in erosion class between Existing Scenario and With Project Scenario:

- Shifts up one erosion class of 78% and 76% of the total land area, respectively
- Shifts up two erosion class of 17% and 19% of the total land area, respectively

Conversely, the majority of land stays in the same erosion class for 5%, 1% and PMF events (30, 35 and 34% of the total land area, respectively).

However, the creeks to the west of the lake (e.g. Cedars Creek, Cox's River, Kedumba River, Kowmung River) have noticeably higher erosion risk, with the intermediate category predominating (**Appendix J**). This could be due to increased land gradient.

The north-east arm of the lake is generally in the negligible – low risk range, presumably by virtue of the geomorphological structure of this section with vertical bed rock banks predominating (**Section 3.2.1b**). Sheltered inlets throughout the lake also fall within this range. The mid-lake, south-east arm and north-east arm have a larger proportion of intermediate erosion risk land (**Appendix J**)., due to effective fetch indices being higher than the sheltered areas and soil types having higher propensity to erode than for the north-east arm. Creeks flowing into the lake from the east and south (e.g. Little River, Nattai River, Werriberri Creek, Wollondilly River) have a similar erosion range to the north-east arm of the lake, with slight - low erosion risk predominating.

Known landslides along the immediate foreshores and adjacent slopes of Lake Burragorang are an important source of sediment to be considered in this out of shoreline erosion assessment. Their positioning may be coincidence because these areas are more accessible by road and form the focus of this investigation. The evidence from the North Nattai site however, suggests that the landslides are directly linked to exposure of the Permian strata. The geology of the Sydney Basin has been well mapped and shows that most of Lake Burragorang (including the lower Coxs, lower Wollondilly and Nattai Rivers) is located within the Permian Illawarra Coal Measures and Berry Formation. In these locations rotational slumping, rock fall and rock avalanching has led to the development of the broad valleys, compared with for example, the Warragamba gorge, which flows through Hawkesbury and Narrabeen Group strata. The exposed Permian strata around the foreshores of Lake Burragorang, means that landsliding would be expected to continue in the Existing Scenario. The implications of such an event on sediment influx, dam capacity and wave generation have been well documented from examples of landslide failures into reservoirs in Italy (Vajont Dam, Pontesei Reservoir) (e.g. Panizzo *et al*. 2005) and more recently associated with the Three Gorges Dam in China (e.g. Liu *et al*. 2004). Plotting of Existing FSL and Project PMF water levels on the profile of the current rockfall avalanche (as reported in **Section 3.2.1b**) show that neither event reaches the 'cliff face' of the rockfall nor do they differ in terms of the proportion of length inundated compared to the total run length (approximately 3% difference).

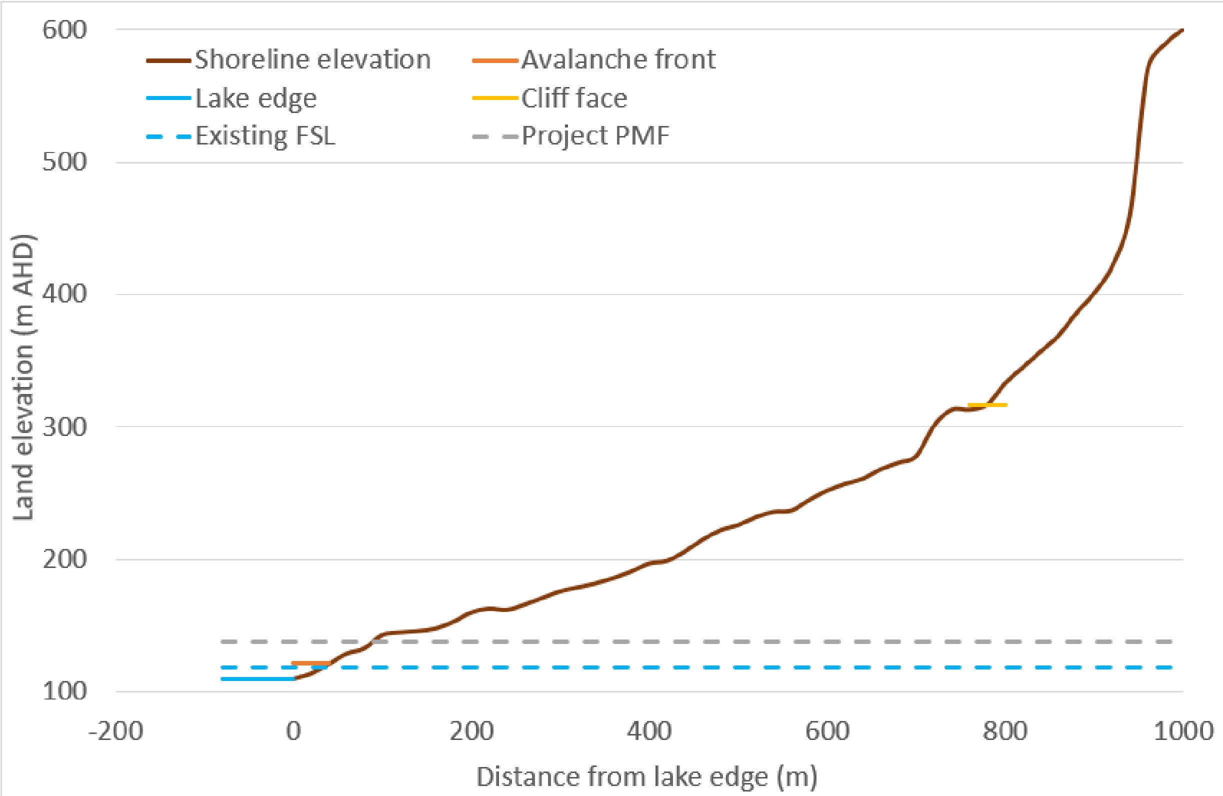

Figure 51 Flood inundation at the existing rockfall avalanche

However, there are many unknowns regarding the existing landslides around the foreshores of Lake Burragorang including whether inundation predicted for the With Project Scenario would increase the frequency of failure, if the prevailing climate conditions or other triggers (earthquakes are often suggested) play a role and thresholds which lead to collapse.

Further investigation is also warranted to establish the frequency and rates of rotational slumping, as well as the effects of reservoir impoundment on pore-water pressure within the Permian bedrock and older landslides which extend below maximum water level. It is possible that all the currently preserved landslides occurred at similar times or under similar conditions such as during a period of enhanced fluvial activity or as a result of a high magnitude earthquake. Alternatively, it is possible that landslides occur randomly throughout time depending on internal thresholds and forces and only the most recent are still preserved in the landscape today. The role of debris flows in transporting sediment into the major rivers is also an issue for sediment supply and water quality. To date, the importance of these processes has been poorly recognised compared with, for example, post-wildfire erosion.

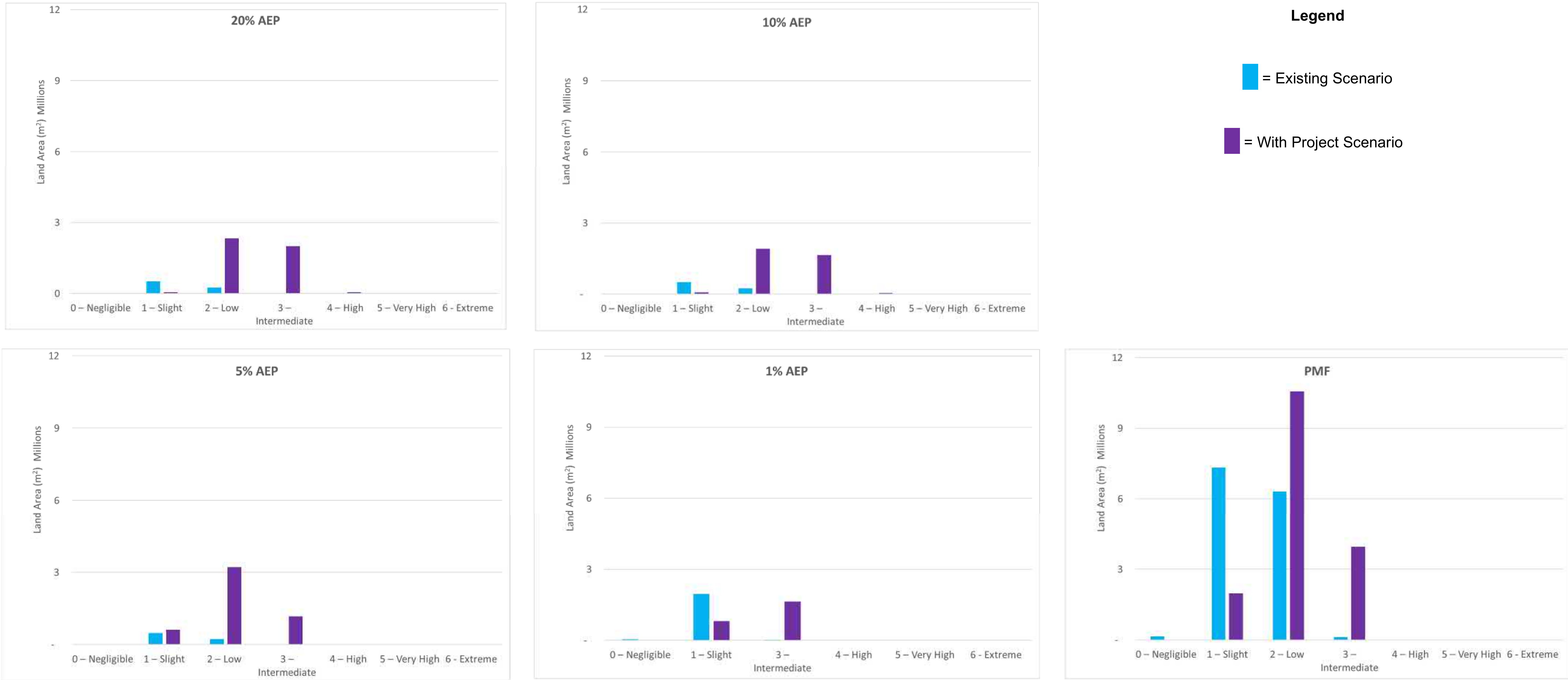

Figure 52 Erosion Hotspot Tool Classifications comparison for the Existing Scenario and With Project Scenario around Lake Burragorang

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5.2.2 Elevated erosion of shoreline banks

The specific erosion of berms / banks on the shoreline of Lake Burragorang has been separated from the wider-scale erosion of the foreshore / inundated areas discussed above.

Wave undercutting will cause damage to berms / banks due to the more frequent water contact time for the With Project Scenario to these points further up the foreshore. Eroded material will be transported away from the localised site by preferential flow in the rills and gullies that have formed on the foreshore.

The highest risk areas for erosion have the following characteristics:

- Banks with lower tensile strength in the exposed part of the soil profile at depth which have the potential to be undermined (**Section 3.2.2**)
- Exposed points of the bank that protrude out from the shoreline
- Banks that are in line with dominant wind directions (south easterly and westerly) (**Appendix J**)
- Large fetch, producing higher energy wave action (**Appendix J**)

Sites that fit this profile are generally in the central and southern arms of Lake Burragorang. The primary events of concern for the potential erosion impact from wave undercutting are those that reach the existing FSL as these banks already have denuded profiles with low vegetation cover (**Section 3.2.1b**).

5.2.3 Deposition of sediments on sensitive receptors during inundation events

The potential for inundation events to transport sediment-laden water and then deposit these on sensitive receptors, such as riparian vegetation and heritage items, within the lake storage zone as flood waters subside are considered here.

Analysis of the suspended sediment record for the lake (**Section 3.1.6**) showed that shallow waters contained very low [TSS] (1-10 mg/L). It was the deeper water that exhibits larger temporal variation in [TSS] considered to be due to a combination of:

- Disturbance of the bed material by underlying currents
- Input of sediment from inflows at depth due to stratification (as covered in **Section 5.2.4**).
- Proximity of deep water to the lake bed which contains existing deposited material

This trend with water depth is likely to increase, if anything, due to deeper water and enhanced stratification being predicted for the With Project Scenario (**Section 5.2.4**). Shallow water [TSS] data is predicted to remain low and spatially consistent so no differences in the level of risk of deposition on sensitive receptors in different areas of the lake are envisaged.

A component of the suspended load transported up the shoreline will subsequently be washed back into the main body of the lake as floodwaters recede. This will further reduce the impact on sensitive receptors. It would be too complex to estimate the likely thickness of sediment deposition, especially as no sediment mat deposition data was available at the time of writing this report (**Section 3.2.4**). Furthermore, the size fraction likely to be transported up the foreshore to locations containing sensitive receptors is likely to be silts / clays and organic matter. The density of sands and gravels will mean these fractions are unlikely to be present in lake sediments, being deposited instead in the mouths of the inlet rivers. The main area of sediment deposition is likely to be on the Existing foreshore up to the FSL, which is already denuded and contains little vegetation. This input of nutrient-rich particulates may actually benefit plant growth. Thus we consider that the effect is likely to be minor in terms of risk of smothering of vegetation, and potentially of some benefit to plant growth.

5.2.4 Change in circulation patterns causing sediment redistribution

Stratification impacts in reservoirs are well documented (e.g. Ellis and Jones, 2013; Fassnacht *et al.*, 2014). The deeper water with the Project is unlikely to result in a greater chance of stratification as the Flood Mitigation Zone would be operational rarely and for a short period of time. However, Lake Burragorang is often stratified (**Section 3.1.4e**). Significant inflows into the Lake Burragorang generally occur in the colder months, when East Coast Lows are more common. These colder inflows enter the reservoir at the base of the water column and consequently poorer water quality in the deeper sections of the lake is common.

This desktop review has noted that:

- The north east arm of the lake, closest to the dam, forms a gorge and unconsolidated sediment is thought to be absent from this area (**Section 3.1.5i**)
- [TSS] concentrations in the deeper lake water can at times be elevated compared to lake shallow waters (**Section 3.1.6**)
- Sediment loads into the lake are considerable, especially from the Wollondilly River (**Section 3.1.6**).

Based on this combination of facts, we do not expect any material change in the existing circulation patterns as a result of the Project, and therefore do not expect sediment redistribution to vary from existing conditions. We also do not expect that there would be any change to the quantity of fine sediment from upstream rivers increasing sedimentation in the lake body. Increased contributions from shoreline erosion will be minor in the context of total influent sediment loads, and in the long term will not make a material difference to total sediment deposition in the lake, or to near surface turbidity, compared to the Existing Scenario.

5.3 Downstream Zone potential impacts

5.3.1 Cumulative bank erosion caused by prolonged FMZ flows

Riverbank erosion and bank slumping can be exacerbated by higher river flows (flood events and FMZ releases). An investigation by the Queensland Department of Science, Information Technology and Information as reported in the Wivenhoe and Somerset Dams Optimisation Study concluded that release strategies that maintain a constant water level for long durations are likely to have a greater impact on downstream bank erosion than a slightly varied flow level (Department of Energy and Water Supply, 2014). This study suggested that a fixed release discharge may cause notching or undercutting at low levels, or completely saturate the bank (increasing susceptibility to mass failure erosion) at higher levels (Department of Energy and Water Supply, 2014). Often banks collapse when they are saturated with water.

To investigate this potential impact in the Hawkesbury and Nepean Rivers, plots of bank erosion index for different storm events at the selected sites are shown in **Figure 53** (please note logarithmic-scale on y-axis). Important observations from these plots include:

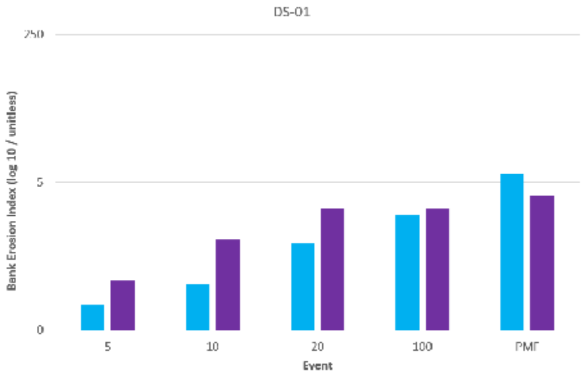
- Contrary to the Existing Scenario, wherein the bank erosion index generally increased with an increase in the magnitude of the flood event, the With Project Scenario generally indicated a high bank erosion index for the intermediate 1 in 20-year event and lower bank erosion index values for events of all other magnitudes.
- At Warragamba (DS-01) With Project Scenario bank erosion index was higher than Existing Scenario bank erosion index apart from under the PMF event.
- At Penrith Rail Bridge (DS-03) Existing and With Project bank erosion index was very low, except for the PMF event where the Existing Scenario was higher.
- At Penrith Weir (DS-04) With Project bank erosion index was consistently higher than Existing bank erosion index. This site also had a higher bank erosion index than any of the other selected sites.

- At Devlins Road (DS-06) With Project bank erosion index was consistently lower than Existing bank erosion index.
- At Shaw Island (DS-07) With Project bank erosion index was higher, except for the 1 in 5-year event where the Existing Scenario was higher.

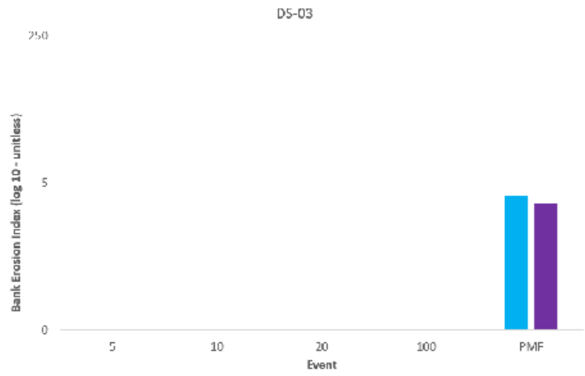
The assessment has drawn particularly on the geomorphological assessment as described in some detail in section 3.2.2(c), as well as taking account of the River Styles Framework. It has considered the combined implications of river fragility and recovery potential, and the hydrological change that could affect the river bank erosion. In terms of River Styles:

- The reach from Warragamba Dam to the confluence with the Nepean will see the greatest relative hydrological change, and has low fragility and moderate recovery potential
- From the Nepean River to the Grose River has low fragility and rapid recovery potential
- From Grose River to the tidal reaches the relative influence of the hydrological change is reduced due to other inflows, and the reach has moderate fragility and high recovery potential, apart from the lower reach downstream of Sackville) having conservation values.
- Stream condition is moderate immediately downstream of the dam, “none” to the Grose River confluence, moderate to just upstream of Wisemans Ferry, then good from there to the coast.

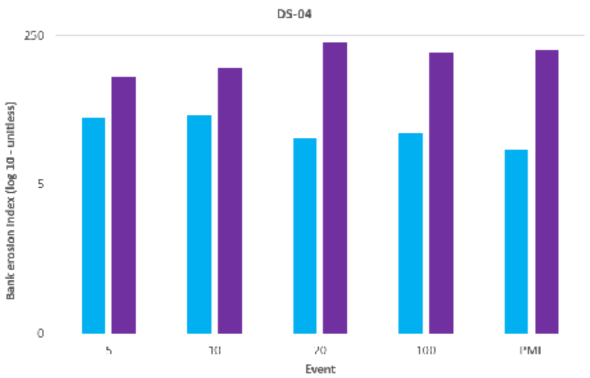
Figure 53 Bank Erosion Index plots for selected sites



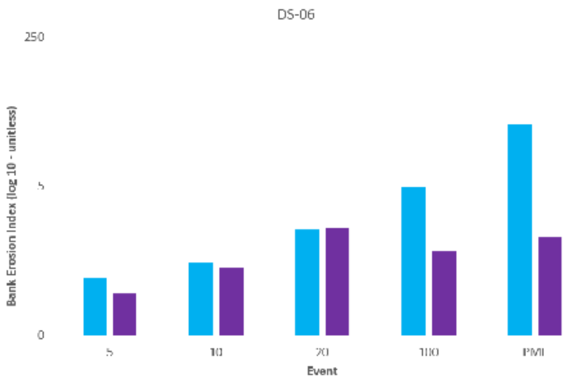
DS-01 Warragamba River upstream of Nepean Confluence



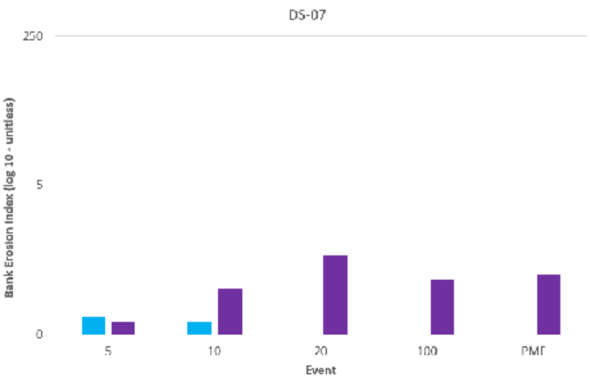
DS-03 Nepean River at Penrith Rail Bridge



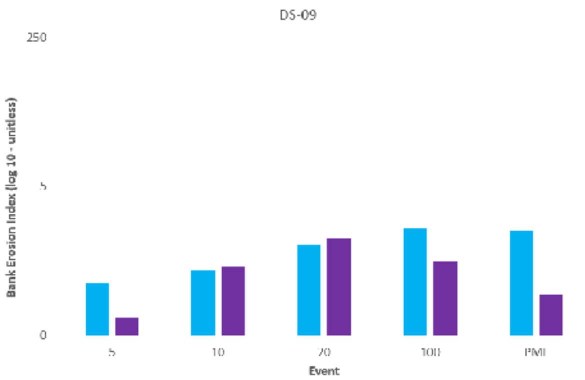
DS-04 Nepean River downstream from Penrith Weir



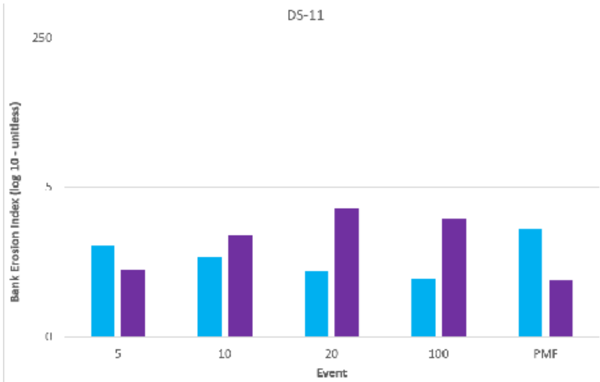
DS-06 Nepean River at Devlins Road



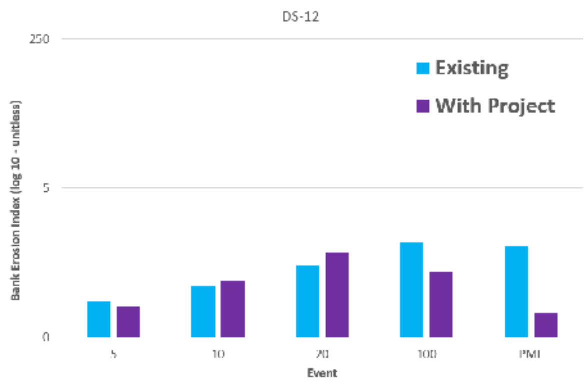
DS-07 – Nepean River at Shaw Island



DS-09 – Hawkesbury River at North Richmond



DS-11 Hawkesbury River at Windsor



DS12 Hawkesbury River at Cattai National Park

The increasing erosion index trend for Existing Scenario is not surprising as the stream power comparison is a function of attritional bank scour and reflects the direct removal of bank materials by the physical action of flowing water and the sediment that it carries. The relationship between increasing flow speed and the erosive power of flowing water has been frequently reported (e.g. Aktar, 2013; Bartley, 2006; Dragicevic, 2017; NRW, 2006). The implications of the With Project observations for bank stability are that the largest / least frequent events are less likely to cause bank erosion (unlike the Existing Scenario) and instead the intermediate / more frequent 1 in 20-year FMZ discharge will cause greater erosion risks.

However, it should be made clear that actual bank erosion can be caused by a whole range of complex factors not associated with changing stream power that would not be detected by this simple treatise including:

- Soil characteristics such as poor drainage or seams of readily erodible material within the bank profile
- Excessive or inappropriate sand and gravel extraction
- Intense rainfall events (e.g. cyclones)
- Inundation of bank soils followed by rapid drops in flow after flooding
- Redirection and acceleration of flow around infrastructure, obstructions, debris or vegetation within the stream channel
- Removal or disturbance of protective vegetation from stream banks as a result of trees falling from banks or through poorly managed stock grazing, clearing or fire
- Saturation of banks from off-stream sources
- Stream bed lowering or infill
- Wave action generated by wind or boat wash

The responses to these changes can be complex, often resulting in accelerated rates of erosion and sometimes affecting stability for decades. Mass failure or collapse / slumping of banks can be caused by a combination of these various mechanisms and the causes of these types of failures are often difficult to determine. Furthermore, this comparison only holds for circumstances when the volume of water discharged under the Existing hydrograph is the same as that discharged for the FMZ discharge. The bank erosion data presented here is therefore just indicative, and the scale of change / flood event patterns should not be treated as an absolute indicator of change in bank erosion risk.

This desktop review has noted that:

- Existing (without project) patterns of susceptibility to erosion in the Hawkesbury-Nepean River are likely to continue into the future, with some potential changes in erosion rates.
- Reaches downstream of Sackville Ferry where the river bank is comprised of steep sandstone cliffs and where the riparian vegetation is in good condition are less likely to be adversely affected by higher flow rates in the river.
- The rate of bank erosion is likely to increase for the With Project Scenario in the Penrith and Windsor – Sackville (upstream of Sackville Ferry) areas of the Nepean and Hawkesbury Rivers. At Penrith, this is probably by virtue of a much more sustained period of flow associated with the FMZ discharge, exerting a greater cumulative force onto the banks.
- The rate of bank erosion is likely to increase for the With Project Scenario in the Warragamba River, but to a lesser extent than the Hawkesbury-Nepean. As for Penrith, erosion is probably by virtue of a much more sustained period of flow associated with the FMZ discharge, exerting a greater degree of force onto the banks.

  Land clearing and / or extraction of sand and gravel from the riverbed has been extensive in the Penrith and Windsor – Sackville (upstream of Sackville Ferry) areas. These sections of the river bank typically have little or no riparian vegetation and often have steep slopes. The 1 in 20-year flows have a combination of high stream power and intermediate duration here, resulting in higher bank erosion.

5.3.2 Increased fine sediment content in Hawkesbury-Nepean river channel

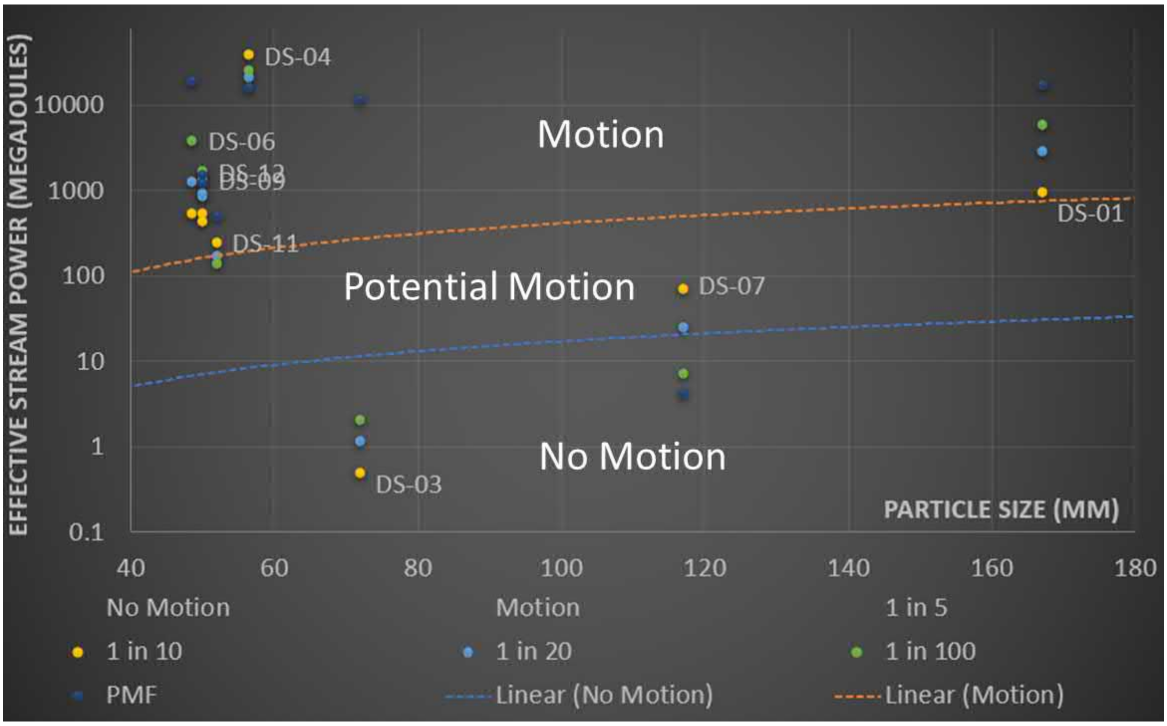
The competence of the FMZ to transport sediments that are already in the channel to reaches that would be sensitive to elevated sediment deposition is considered in this sub-section. To do this, a Hicken Curve analysis was used according to the procedure in **Appendix A.3.4**. The resulting stream power motion curves for Existing Scenario and With Project Scenario are shown below (**Figure 54**).

The two curves look similar. ‘Motion’ / ‘potential motion’ is likely to occur for the majority of flood events at the majority of sites under both Existing Scenario and With Project Scenario. Exceptions to this occur for the Hawkesbury River at Penrith Rail Bridge site (DS-03) which is below the ‘no motion’ line for all events other than the PMF for the Existing Scenario and With Project Scenario. It is clear that this site is a depositional environment with an over-widened channel (**Section 3.2.1c**). In addition, the Grose River site above the confluence with the Hawkesbury River (DS-07) is located under the ‘no motion’ line for 1% AEP and PMF.

Generally, motion is more likely to occur with smaller particle sizes (particularly those associated with DS-04, 06, 09, 11 and 12). Flow releases will assist in flushing of fine sediments from pools and riffles in the Warragamba River and in initiating bedload transport in the Warragamba River Junction to Penrith Weir and Penrith Weir to Grose River junction reaches of the Nepean River.

With higher flows, the sediment compositions at the sites where finer particles were found predominantly will change so as to consist of larger sediments such as sands and gravels. This is mainly applicable to downstream sites in the Penrith – Windsor section where finer particles were present in larger proportions but are underlain by coarser material. Fassnacht *et al.* (2014) found similar results with minor downstream impact on bed sediment calibre. A degrading system is more likely to therefore occur in the lower reaches of the rivers due to transportation of particles as a result of higher stream velocities and higher stream power. This includes locations DS-01, DS-04, DS-06, DS-09, DS-11 and DS-12. Large stable substrates directly below the dam in the Warragamba River from the release of clear water from the release flow removing fine sediment has been noted in previous work (e.g. Ellis and Jones, 2013).

(a) Existing Scenario



(b) With Project Scenario

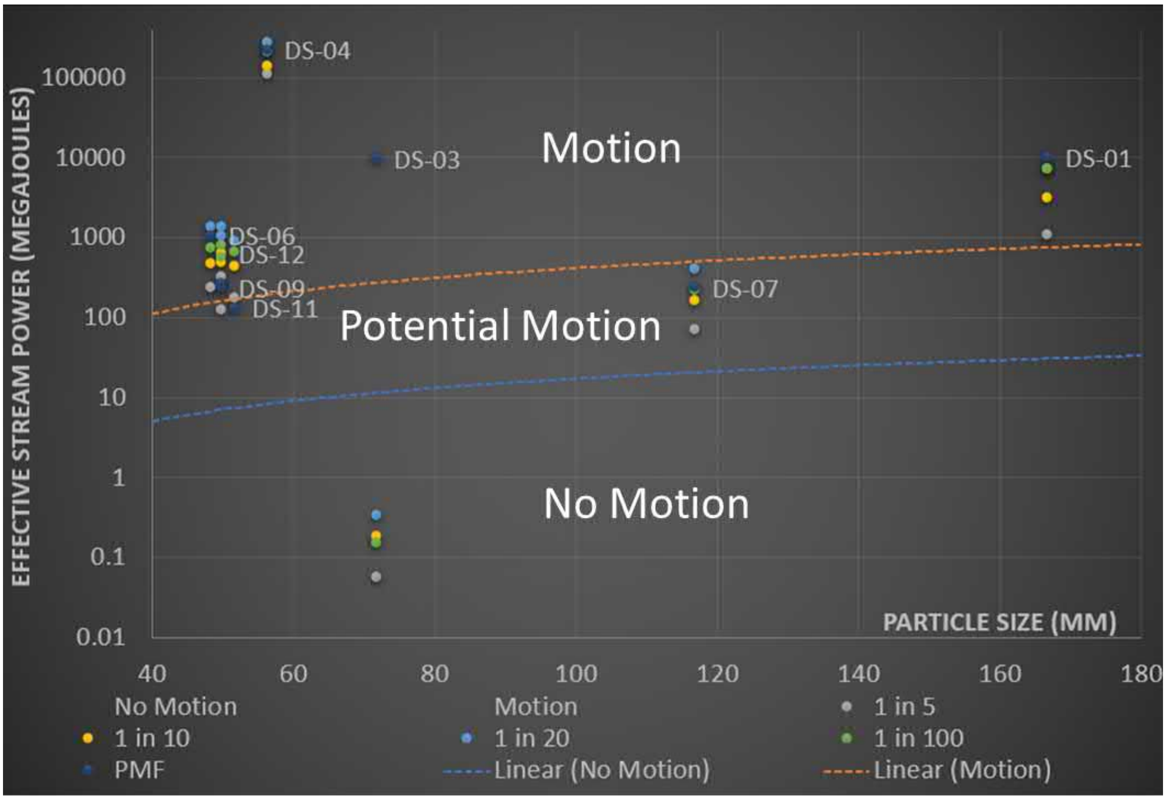


Figure 54 Stream power motion curves

The implications of long-profile turbidity observations (**Section 3.1.7**) for the geomorphology of the Hawkesbury River in the With Project Scenario are that:

- The 'turbidity maximum' observed currently at Webbs Creek may migrate further downstream towards Wisemans Ferry. This pattern would be particularly marked during FMZ discharges occurring concurrently with weak neap incoming tides. It is predicted that this turbidity increase would not lead to a greater risk of sediment deposition within this stretch of water, as the fine sediment would be suspended in the water column and the events would be relatively short-lived. Aquatic vegetation within this stretch may decline, however, due to the high suspended solids concentrations causing lower light penetration (Fondriest Environmental, 2014).
- The peaks in turbidity noted in the Hawkesbury River Estuary between Big Jims Point and Broken Bay may increase. This pattern would be particularly marked during FMZ discharges occurring concurrently with spring tides. In these instances, the larger tidal force would have higher competence to transport sand and sediment from the shoreline and the greater turbulent mixing caused by the fluvial freshwater input would resuspend bottom sediments. It is unlikely that the scale of this change would have an impact on aquatic habitat as the mixing period would be short-lived and organisms in this environment are already adapted to high turbidity.

5.3.3 Floodplain sedimentation from out of bank flows

The extent of inundation of agricultural land and other sensitive land has been identified on flood extent maps for the Downstream Zone (**Appendix K**). To capture the risk of out of bank and pooled water impacting these sites these maps have been overlain with long-term turbidity data (**Section 2.5**) to produce sedimentation surrogate maps for critical infrastructure and land uses. The main findings from this mapping exercise are that:

- Flow peaks will be lower, so less extensive inundation will occur
- FMZ flows were designed to be largely within the banks, so the proposal results in a net reduction in out of bank sedimentation risk
- Critical infrastructure that could be affected by elevated sedimentation include tourist parks in the Wisemans Ferry area and community facilities/ tourist parks in the Windsor – Pitt Town area
- Land use that could be affected by elevated sedimentation include grazing and urban areas in the Wisemans Ferry area and horticulture, grazing and urban areas in the Cornwallis - Windsor – Pitt Town area

Inundation of agricultural land can result in the loss of crops. The impact of inundation on agriculture located on the floodplain arising from higher flow rates in the river is determined by the area of land inundated and the duration of that inundation. As an example of this impact, informal advice from turf farmers suggests that there is minimal impact if the turf is inundated for less than two days. However, damage may occur after turf is inundated for more than two days, and it can take several weeks for the turf to recover. The recovery period is dependent on the duration of inundation. Inundation of more than one-week could result in a major loss of turf crops. However, this is thought to be more a function of water inundation rather than sediment inundation.

Recreation related open space is an appropriate use of flood prone land, and golf courses are often located on flood prone land. It is possible that such uses could be impacted in terms of inundation duration and possibly limited sediment deposition. A number of courses are located within the area likely to be inundated by the FMZ discharge.

In all cases, small amounts of sediment are expected to be transported with flood flows onto the identified sites. A component of the suspended load transported out of bank will subsequently be washed back into the main body of the Hawkesbury River as floodwaters recede. This will further reduce the impact on sensitive receptors. It would be too complex to estimate the likely thickness of sediment deposition, especially as no sediment mat deposition data was available at the time of writing this report (**Section 3.2.4**). Furthermore, the size fraction likely to be transported up the foreshore to locations containing sensitive receptors is likely to be silts / clays and organic matter. The density of sands and gravels will mean these fractions are deposited in buffer / riparian land adjacent to the main river channel. This input of nutrient-rich particulates may benefit plant growth.

In summary, the inundation and sedimentation effects are likely to be limited in location and extent and would occur in areas already subject to flooding under the Existing Scenario.

5.4 Summary of geomorphology changes and mitigation measures

Table 15 summarises the potential operation impacts identified in **Section 5** and the associated pre-mitigation risk rating as per the procedure in **Section 2.1**. Construction risks and mitigation measures have been comprehensively addressed in the Water Quality Assessment (Appendix Q, SMEC, 2019) and are not considered here.

5.4.1 Pre-mitigation risks

A summary of pre-mitigation risks is provided below:

- A total of sixteen potential impacts from the Project have been identified (Table 15). This includes four potential impacts in the Upstream Zone, four potential impacts in the Lake Zone and, eight potential impacts in the Downstream Zone.
- The Project is likely to result in the following low risk impacts to Geomorphology as follows:
  - Translocation of sediment features upstream – Coxs and Wollondilly Rivers
  - Floodplain sediment deposition – Kedumba and Wollondilly Rivers
  - Deposition of sediments on sensitive ecological / heritage receptors during inundation events – Lake Burragorang North, South and West arms
  - Change in Lake Burragorang circulation patterns causing sediment redistribution
- The Project is likely to result in the following medium risk impacts to Geomorphology as follows:
  - Out of bank erosion – Brimstone Creek, Green Wattle Creek, Nattai River, Tonalli Creek, Wollondilly River
  - Out of shoreline erosion – Lake Burragorang North, South and West Arms
  - Increased fine sediment content in Hawkesbury-Nepean River channel
  - Floodplain sedimentation from out of bank flows in the Downstream Zone
  - Cumulative bank erosion impact caused by prolonged FMZ flows and susceptibility of the river form based on River Styles – Warragamba Dam to Nepean River confluence, Nepean River confluence to Fairlight Gorge, Fairlight Gorge to Penrith Weir, Devlins Road to Grose confluence, Windsor to Colo River, Colo Ricer to Wiseman Ferry.
- The Project is likely to result in the following high risk impacts to Geomorphology as follows:
  - Out of bank erosion in the Upstream Zone
  - Elevated erosion of shoreline banks in the Lake Zone
  - Cumulative bank erosion impact caused by prolonged FMZ flows and susceptibility of the river form based on River Styles - Nepean River, Penrith Weir to Devlins Road, and Hawkesbury River, Grose River Junction to Windsor.

Mitigation measures were applied to these potential geomorphological risks as described below in **Section 5.4.2**.

5.4.2 Mitigation measures

Mitigation measures were proposed to reduce the potential impacts of the above risks. A post-mitigation risk rating was then assigned to the various risks identified. The proposed mitigations have been divided into the following broad categories:

- **Geomorphology stability assessment –** A detailed assessment of potential geomorphological issues would be undertaken. This would identify specific areas which may be susceptible to bank erosion and/or changes to bed profiles as a result of the Project. The outcomes of this work would direct mitigation measures to reduce the scale of predicted effects.
- **Existing mitigation measures** that WaterNSW have partial/full responsibility for under existing plans and agreements. These measures are intended to benefit the catchment independently of the Project. Further details are provided in Appendix L
- Mitigation measures addressed in the Biodiversity Chapters (**Mitigation Measures – Ecology**)
- Mitigation measures addressed in the Heritage Chapter (**Mitigation Measures – Heritage**)
- Mitigation measures addressed in the Flooding and Hydrology Chapter (**Mitigation Measures – Hydrology**)
- Mitigation measures addressed in the Water Quality Chapter (**Mitigation Measures – Water Quality**)
- National Parks Environmental Management Plan (**National Parks EMP**)
- **Outside scope mitigation measures** for which WaterNSW have no responsibility but will benefit current geomorphological condition in the catchment

The 65 mitigation measures recommended for this Project are provided in full in **Appendix L.**

Table 15 Geomorphology risk matrix

Zone	Potential impact	Pre-mitigation			Mitigation measure/s (see Appendix L)	Post-mitigation		
		Likelihood	Significance	Risk		Likelihood	Significance	Risk
Upstream	Out of bank erosion – Brimstone Creek, Green Wattle Creek, Nattai River, Tonalli Creek, Wollondilly River	P	Mo	M	• Existing mitigation measures • National Parks EMP	P	Mo	M
Upstream	Out of bank erosion – Butchers Creek, Coxs River, Kedumba River, Kowmung River (lower), Laceys Creek	HL	Mo	H	• Existing mitigation measures • National Parks EMP	L	Mo	M
Upstream	Translocation of sediment features upstream – Coxs and Wollondilly Rivers	HL	N	L	• National Parks EMP	L	N	N
Upstream	Floodplain sediment deposition – Kedumba and Wollondilly Rivers	HL	N	L	• Existing mitigation measures • Outside scope mitigation measures	L	N	N
Lake Burragorang	Out of shoreline erosion – Central, South and West Arms	L	Mo	M	• Existing mitigation measures • Outside scope mitigation measures	P	Mo	M
Lake Burragorang	Elevated erosion of shoreline banks – North, South and West Arms	HL	Mo	H	• Existing mitigation measures • National Parks EMP	L	Mo	M
Lake Burragorang	Deposition of sediments on sensitive ecological / heritage receptors during inundation events - North, South and West Arms	HL	N	L	• Existing mitigation measures • Outside scope mitigation measures	HL	N	L
Lake Burragorang	Change in circulation patterns causing sediment redistribution	HL	N	L	• Mitigation measures - Water Quality	H	N	L
Downstream	Cumulative bank erosion impact caused by prolonged FMZ flows - Warragamba River, Dam to Nepean River confluence - Nepean River, Warragamba River confluence to Fairlight Gorge	HL	Mi	M	• Audit and investigation used to direct erosion mitigation measures	U	Mi	L
Downstream	Cumulative bank erosion impact caused by prolonged FMZ flows - Nepean River, Devlins Road to Grose Confluence - Hawkesbury River, Windsor to Colo River	L	Mo	M	• Audit and investigation used to direct erosion mitigation measures	U	Mi	L
Downstream	Cumulative bank erosion impact caused by prolonged FMZ flows - Nepean River, Fairlight Gorge to Penrith Weir	P	Mo	M	• Audit and investigation used to direct erosion mitigation measures	U	Mi	L
Downstream	Cumulative bank erosion impact caused by prolonged FMZ flows - Hawkesbury River, Grose River to Windsor	HL	Mo	H	• Audit and investigation used to direct erosion mitigation measures	U	Mi	L
Downstream	Cumulative bank erosion impact caused by prolonged FMZ flows - Hawkesbury River, Colo River to Wisemans Ferry	Po	Mo	M	• Audit and investigation used to direct erosion mitigation measures	U	Mi	L
Downstream	Cumulative bank erosion impact caused by prolonged FMZ flows (including damage to existing erosion protection measures) - Nepean River, Penrith Weir to Devlins Road	HL	Mo	H	• Audit and investigation used to direct erosion mitigation measures	U	Mi	L
Downstream	Increased fine sediment content in Hawkesbury-Nepean River channel	P	H	M	• Mitigation measures - Water Quality • Outside scope mitigation measures	P	H	M
Downstream	Floodplain sedimentation from out of bank flows	L	Mo	M	• Mitigation measures - Ecology • Mitigation measures - Heritage • Outside scope mitigation measures	U	Mi	L

For Likelihood; U = Unlikely; P = Possible; L = Likely; HL = Highly Likely / For Significance; N = Negligible, Mi = Minor, Mo = Moderate; H = High; VH = Very High / For Risk;

N = Negligible	L = Low	M = Medium	H = High	Ex = Extreme

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5.4.3 Residual risk

Sixteen (16) environmental risks were identified for the Project. Following the successful implementation of the mitigation measures proposed in **Section 5.4.2** the following residual risks are likely to remain:

- No ‘Extreme’ rated risks will remain
- No ‘High’ rates risk will remain
- Five ‘Medium’ rated risks will remain
- Nine ‘Low’ rated risks will remain
- Two ‘Negligible’ rated risks will remain

The medium residual risk scores are listed in **Figure 55** below.

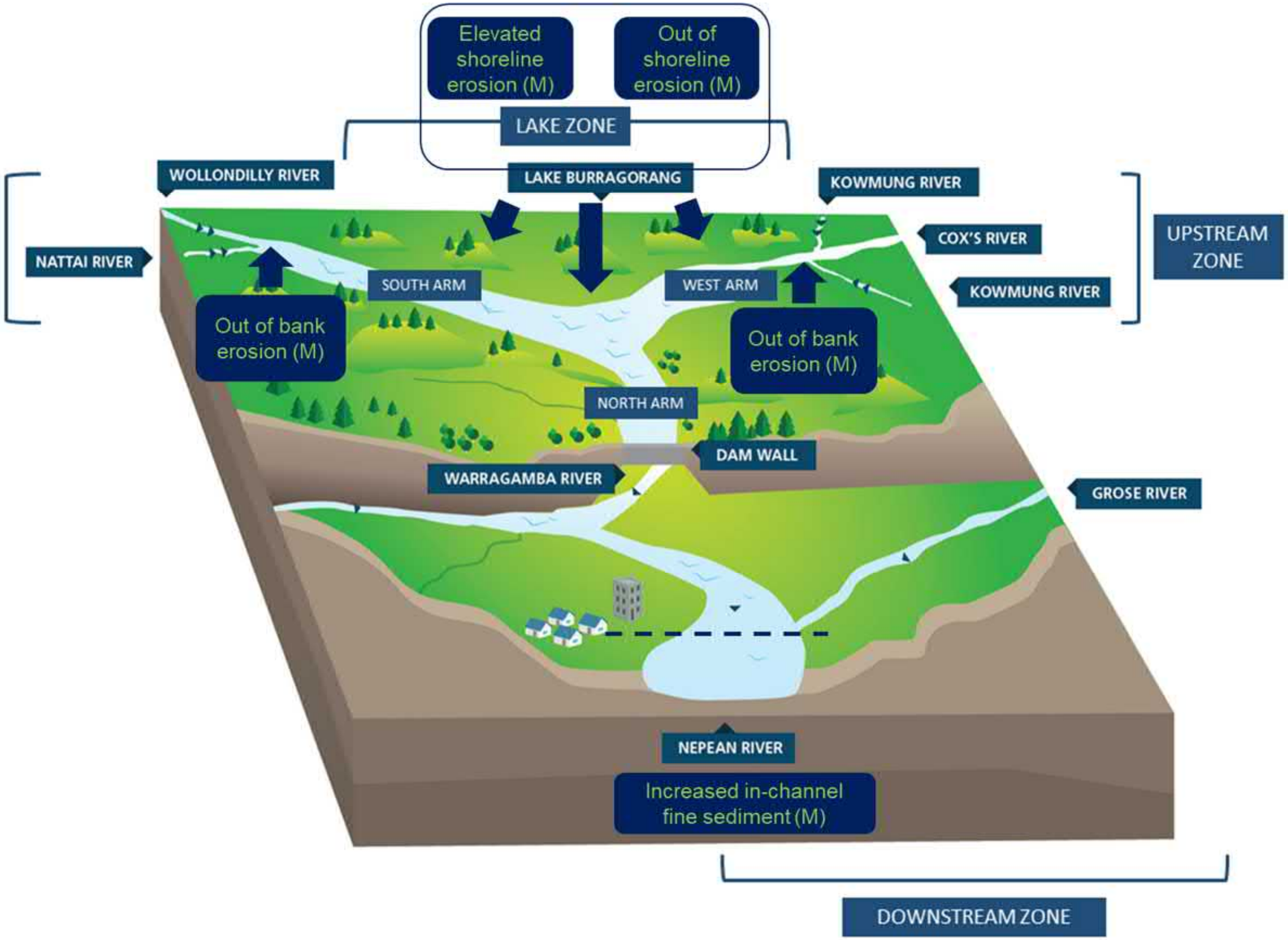

Figure 55 Medium (M) and High (H) residual Project risks

6 Conclusions

This geomorphology technical assessment provides a summary of the proposed WDR which is required to water storage capacity in the Lake Burragorang catchment, New South Wales, to facilitate flood mitigation in the downstream river reaches. This report includes a description of the existing fluvial geomorphological environment, using both a desktop and site investigation approach.

The potential risks associated with the Project have been assessed, and mitigation measures proposed to reduce the potential impacts of the project. Five 'medium' rated residual impacts remain after mitigation, including:

- Out of bank erosion in the Upstream Zone, including Brimstone Creek, Green Wattle Creek, Nattai River, Tonalli Creek, Wollondilly River
- Out of bank erosion in the Upstream Zone, including Butchers Creek, Coxs River, Kedumba River, Kowmung River (lower), Laceys Creek
- Out of shoreline erosion in the Lake Zone, at the Central, South and West Arms
- Elevated erosion of shoreline banks in the Lake Zone, at the North, South and West Arms
- Cumulative bank erosion impact in the downstream reaches caused by prolonged FMZ flows, It is recommended that 65 mitigation measures are applied to minimise impacts including:
- Geomorphic stability investigations to identify specific locations where the project may effect change stability and to direct infrastructure improvements required prior to the Project commissioning. Appropriate mitigation or remedial measures would be determined as part of this further assessment.
- Existing mitigation measures that WaterNSW have full / partial responsibility for delivering and will successively benefit current geomorphological condition in the catchment but which are independent of the Project.
- Mitigation measures addressed in the Biodiversity, Heritage, Flooding and Hydrology and Water Quality Chapter.
- National Parks EMP.
- Outside scope mitigation measures for which WaterNSW have no responsibility but will benefit current geomorphological condition in the catchment.

The scope of each measure is listed in **Appendix L**.

While it is clear that there will be unavoidable geomorphological impact on bank erosion in the system, the assessment indicates that changes to sediment deposition on sensitive receptors in the Upstream Zone and on floodplains in the Downstream Zone when flows are backed up will be minor. Indeed, constraining flows within the downstream channel will lead to a net reduction in overbank flows in the downstream river reaches, leading to a reduced likelihood of sediment deposition. There will undoubtedly be a transition towards deposition conditions during flood storage events (upstream rivers) and increased risk of erosion during FMZ discharges (downstream rivers). The long-term effect of these events, however, appear to be short-lived and covering a limited spatial scale. There are uncertainties regarding the semi-quantitative analyses in this report due to the lack of suitable hydrological modelling data and findings should be considered indicative rather than holding any inherent magnitude / spatial accuracy. Effects are expected, but they are likely to be relatively minor in the context of an active river channel at a reach scale where there are multiple interrelated influences on erosion. That said, there remains the potential for significant effects in shorter, more discrete lengths of river, and mitigation in the form of necessary infrastructure improvements needs to be identified through more detailed investigations.

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Appendices

A

Appendix A – Assessment Methodologies

Appendix A.1. Desktop Methodologies

A.1.1 Aerial photography

Satellite imagery over the Lake Burragorang catchment is poor with low resolution and short-period records. Acknowledging this, aerial images of selected watercourse sections (circa 200 m length) were captured using the NearMap Vertical Historical Imagery Tool with the following criteria:

- Clearest four images on record and if possible;
  - The most current image
  - The oldest image on record
  - Two intermediate images

The approach advocated by Downward *et al.* 1994 was then used to assess channel change in order to:

- Illustrate channel planform movements visually
- Quantify nett sediment input / export areas
- Determine lateral accretion (downstream or upstream) in geomorphic features

A.1.2 Data request

A request for Information was lodged with SMEC on 6th February 2019. A total of 40 items was requested. The full list can be seen in **Figure 56**.

Figure 56 *Request for Information Log*

BECA REQUEST FOR INFORMATION LOG TEMPLATE

PROJECT NAME	Geomorphology Impact Assessment - WDR	PROJECT MANAGER	Dan Evans

RFI #	CURRENT STATUS	PRIORITY	REQUEST DESCRIPTION	ASSIGNED TO	DATE REQUESTED	DATE REQUIRED	DATE SAVED	NOTES
GEOM-01	CLOSED	EXPEDITED	Aquatic ecology locations where there are geomorphology concerns	BMT	6-Feb-19	11-Feb-19	29-Mar-19	Provide mapping output to SMEC GIS team.
GEOM-02	CLOSED	EXPEDITED	Total suspended solids (5 years time series data at all Lake Burragorang sites plus inflows). Associated flow gauging volumes for inflows to allow load calculations. If not available, turbidity record instead.	BMT	6-Feb-19	11-Feb-19	13-Feb-19	Excel friendly format preferred
GEOM-03	CLOSED	Not available	Total suspended solids - modelling runs for WDR scenarios for inflows and Lake Burragorang.	BMT	6-Feb-19	11-Feb-19	N/A	Excel friendly format preferred
GEOM-04	CLOSED	Not available	Impact of increasing dam height on stratification from water quality assessment	BMT	6-Feb-19	13-Feb-19	N/A	Comparison of cold water inflow deposition potential versus warm water inflow promoting turbidity
GEOM-05	CLOSED	EXPEDITED	Heritage locations where there are geomorphology concerns	Niche	6-Feb-19	11-Feb-19	24-Apr-19	Provide mapping output to SMEC GIS team.
GEOM-06	CLOSED	CRITICAL	Draft soils, terrestrial ecology chapters	SMEC	6-Feb-19	7-Feb-19	3-Jul-19	
GEOM-07	CLOSED	CRITICAL	Scanned copies of WaterNSW yellow book geomorphology locations	SMEC	6-Feb-19	8-Feb-19	6-Feb-19	Joel replied to request on 01/02/2019 but no attachment was provided; in addition extend to all locations in reservoir and
GEOM-08	CLOSED	CRITICAL	EIS writing style guide (for report consistency)	SMEC	6-Feb-19	8-Feb-19	14-Feb-19	
GEOM-09	CLOSED	EXPEDITED	Ecology locations where there are geomorphology concerns	SMEC	6-Feb-19	11-Feb-19	29-Apr-19	Provide mapping output to SMEC GIS team
GEOM-10	CLOSED	EXPEDITED	Socio-economic locations where there are geomorphology concerns (e.g. agricultural land, bushwalks, camp grounds, infrastructure, look-out points, commercial / residential property)	SMEC	6-Feb-19	11-Feb-19	28-Apr-19	Provide mapping output to SMEC GIS team
GEOM-11	CLOSED	Not available	Soil lithology cores for areas in the inflow, Lake Burragorang and Hawkesbury-Nepean inundation zone	SMEC	6-Feb-19	12-Feb-19	N/A	
GEOM-12	CLOSED	EXPEDITED	Weekly verified storage reports (full operating storage (ML), storage level (m), available storage (ML & %). Converted to Excel data & plot. From 10 Feb 2018 - 10 Feb 2019).	SMEC	6-Feb-19	12-Feb-19	6-Feb-19	Excel friendly format preferred
GEOM-13	CLOSED	EXPEDITED	Various GIS mapping outputs as discussed with Fadhillah Norzahari (05/02/2019)	SMEC	6-Feb-19	15-Feb-19	13-Aug-19	
GEOM-14	CLOSED	STANDARD	Notice of any rises in Lake Burragorang water depth >0.2m, >0.4m, >0.6m relative to 04/02/2019	Water NSW	6-Feb-19	Ongoing	N/A	Notification by text (0406650661) or e-mail (dan.evans@beca.com) preferred
GEOM-15	CLOSED	CRITICAL	Current & future dam operation rules description (full supply level, spillway levels, spillway operations)	Water NSW	6-Feb-19	7-Feb-19	8-Feb-19	
GEOM-16	CLOSED	Not available	Wave height data (5 years record, time series, all Lake Burragorang sites)	Water NSW	6-Feb-19	11-Feb-19	N/A	Excel friendly format preferred
GEOM-17	CLOSED	EXPEDITED	If GEOM-16 is not possible, wind speed and direction data (5 years record, time series, all sites)	Water NSW	6-Feb-19	11-Feb-19	15-Feb-19	Excel friendly format preferred
GEOM-18	CLOSED	EXPEDITED	Bathymetry data for Lake Burragorang (both water column depth and sediment depth, if available).	Water NSW	6-Feb-19	12-Feb-19	26-Feb-19	Plotted image files and Excel friendly format preferred
GEOM-19	CLOSED	Not available	Any historic high res aerial photography of inflow delta areas and Warragamba River below dam release flow	Water NSW	6-Feb-19	15-Feb-19	N/A	Image files
GEOM-20	CLOSED	EXPEDITED	Any sediment composition information for Lake Burragorang (margins, bed & suspended sediment)	Water NSW	6-Feb-19	15-Feb-19	22-Feb-19	
GEOM-21	CLOSED	EXPEDITED	Any other geomorphology reports commissioned by WaterNSW in the Warragamba catchment	Water NSW	6-Feb-19	15-Feb-19	22-Feb-19	
GEOM-22	CLOSED	CRITICAL	Definition of initial conditions used for the modelling runs (unless covered in GEOM-23)	WMAWater	6-Feb-19	7-Feb-19	8-Feb-19	
GEOM-23	CLOSED	CRITICAL	WMA draft modelling report	WMAWater	6-Feb-19	7-Feb-19	8-Feb-19	
GEOM-24	CLOSED	Not available	Longitudinal profiles for Cox's, Hawkesbury-Nepean, Kedumba, Kowmung, Nattai, Wollondilly (limit to PMF inundated areas only)	WMAWater	6-Feb-19	13-Feb-19	n/a	Excel friendly format preferred; vertical resolution <1m AHD if possible
GEOM-25	CLOSED	EXPEDITED	Flow model outputs for the Cox's, Kedumba, Kowmung, Nattai, Wollondilly*	WMAWater	6-Feb-19	13-Feb-19	3-Jun-19	1 in 5, 1 in 10, 1 in 20 & 1 in 100 year and the PMF. Existing base case and dam raising scenarios. Excel format preferred.
GEOM-26	CLOSED	EXPEDITED	Flow model outputs for the Hawkesbury-Nepean*	WMAWater	6-Feb-19	13-Feb-19	3-Jun-19	1 in 5, 1 in 10, 1 in 20 & 1 in 100 year and the PMF. Existing base case and dam raising scenarios. Excel format preferred.
GEOM-27	CLOSED	EXPEDITED	Key to flow model transects (location codes)	WMAWater	6-Feb-19	13-Feb-19	12-Feb-19	
GEOM-28	CLOSED	EXPEDITED	Velocity profiles for Cox's, Kedumba, Kowmung, Nattai, Wollondilly*	WMAWater	6-Feb-19	13-Feb-19	21-Mar-19	1 in 5, 1 in 10, 1 in 20 & 1 in 100 year and the PMF. Existing base case and dam raising scenarios. Excel format preferred.
GEOM-29	CLOSED	EXPEDITED	Velocity profiles for Hawkesbury-Nepean*	WMAWater	6-Feb-19	13-Feb-19	8-Feb-19	1 in 5, 1 in 10, 1 in 20 & 1 in 100 year and the PMF. Existing base case and dam raising scenarios. Excel format preferred.
GEOM-30	CLOSED	EXPEDITED	Stream power profiles for Cox's, Kedumba, Kowmung, Nattai, Wollondilly*	WMAWater	6-Feb-19	13-Feb-19	18-Apr-19	1 in 5, 1 in 10, 1 in 20 & 1 in 100 year and the PMF. Existing base case and dam raising scenarios. Excel format preferred.
GEOM-31	CLOSED	EXPEDITED	Stream power profiles for Hawkesbury-Nepean*	WMAWater	6-Feb-19	13-Feb-19	18-Apr-19	1 in 5, 1 in 10, 1 in 20 & 1 in 100 year and the PMF. Existing base case and dam raising scenarios. Excel format preferred.
GEOM-32	CLOSED	EXPEDITED	Level duration inundation curves for Cox's, Kedumba, Kowmung, Nattai, Wollondilly*	WMAWater	6-Feb-19	13-Feb-19	8-Feb-19	1 in 5, 1 in 10, 1 in 20 & 1 in 100 year and the PMF. Existing base case and dam raising scenarios. Excel format preferred.
GEOM-33	CLOSED	EXPEDITED	Level duration inundation curves for Lake Burragorang*	WMAWater	6-Feb-19	13-Feb-19	8-Feb-19	1 in 5, 1 in 10, 1 in 20 & 1 in 100 year and the PMF. Existing base case and dam raising scenarios. Excel format preferred.
GEOM-34	CLOSED	EXPEDITED	Level duration inundation curves for Hawkesbury-Nepean*	WMAWater	6-Feb-19	13-Feb-19	8-Feb-19	1 in 5, 1 in 10, 1 in 20 & 1 in 100 year and the PMF. Existing base case and dam raising scenarios. Excel format preferred.
GEOM-35	CLOSED	EXPEDITED	Flood extents Wollondilly Nattai Rivers (inc. Lake Burragorang south)	WMAWater	6-Feb-19	13-Feb-19	11-Feb-19	1 in 5, 1 in 10, 1 in 20 & 1 in 100 year and the PMF. Existing base case and dam raising scenarios. ArcView shapefile to be provided to SMEC GIS team and PDF preferred.
GEOM-36	CLOSED	EXPEDITED	Flood extents Richmond Windsor	WMAWater	6-Feb-19	13-Feb-19	11-Feb-19	1 in 5, 1 in 10, 1 in 20 & 1 in 100 year and the PMF. Existing base case and dam raising scenarios. ArcView shapefile to be provided to SMEC GIS team and PDF preferred.
GEOM-37	CLOSED	EXPEDITED	Flood extents Penrith Castlereagh	WMAWater	6-Feb-19	13-Feb-19	11-Feb-19	1 in 5, 1 in 10, 1 in 20 & 1 in 100 year and the PMF. Existing base case and dam raising scenarios. ArcView shapefile to be provided to SMEC GIS team and PDF preferred.
GEOM-38	CLOSED	EXPEDITED	Flood extents Warragamba Wallacia (inc. Lake Burragorang north)	WMAWater	6-Feb-19	13-Feb-19	11-Feb-19	1 in 5, 1 in 10, 1 in 20 & 1 in 100 year and the PMF. Existing base case and dam raising scenarios. ArcView shapefile to be provided to SMEC GIS team and PDF preferred.
GEOM-39	CLOSED	EXPEDITED	Flood extents Cox's Kowmung Kedumba Rivers (inc. Lake Burragorang west)	WMAWater	6-Feb-19	13-Feb-19	11-Feb-19	1 in 5, 1 in 10, 1 in 20 & 1 in 100 year and the PMF. Existing base case and dam raising scenarios. ArcView shapefile to be provided to SMEC GIS team and PDF preferred.
GEOM-40	OPEN	EXPEDITED	Conversation with flow modellers	WMAWater	6-Feb-19	15-Feb-19	n/a	Additional questions following supply of modelling report / outputs

A.1.3 Literature review

Relevant studies and investigations were reviewed and captured in a literature review. Search engines used to source literature included:

- Google
- Google Scholar
- ResearchGate
- SMEC Request for Information GEOM 19 - 21

The following search terms were used in isolation and in combination with 'geomorphology' and 'sediment' as part of this process:

- Coxs
- Hawkesbury-Nepean
- Lake Burragorang
- Nattai
- Wollondilly

In addition to this, the following publicly available datasets were accessed:

- RiverStyles^{TM} Framework
- Soil lithology cores using the NSW E-Spade tool

A.1.4 Longitudinal profiles

Long profiles (i.e. change in river channel elevation with distance) were constructed for the following watercourses:

- Coxs River
- Kedumba River
- Kowmung River
- Nattai River
- Nepean River
- Reedy Creek
- Warragamba River
- Wollondilly River

Starting points for profiling were defined as the furthest upstream rapid geomorphological walkover survey point (**Appendix A.2.2**). Using Nearmap for best possible resolution and up-to-date images, line segments of each river channel were created using the Inline Elevation Profile tool. Care was taken to ensure the lines were marked at the channel thalweg where possible, whilst avoiding overhanging branches and instream deposition features that may have affected readings.

Using the Nearmap elevation profiles, the river elevation was noted and the change in slope as a percentage between each point calculated at approximately 100 m intervals along the line segment. The horizontal distance and elevation data for each river were used to produce line graphs.

Trendlines with the highest correlation coefficient were selected. Percentile analysis was then performed on the datasets, calculating the 10th and 90th percentiles of slope percentage. The points on each river profile that were identified within the 10th percentile (indicating potential areas of erosion) and 90th percentile (indicating potential areas of deposition) were then plotted on the river profile graphs.

There was an inherent inaccuracy with the elevation data obtained from Nearmap with large unexplained increases and decreases in elevation that could not be attributed to a physical onsite feature. LIDAR data would have been preferred for this task and due to the inaccuracy in elevations along the river profiles only the

Wollondilly River profile has been reported in the front-end of this assessment as the data captured could not be relied upon. We have used professional judgement to identify those areas where there were apparent errors, and to compensate for errors as we interpreted and applied the data. We do not consider that the inaccuracies have materially affected the reliability of this assessment. For completeness, all river profiles are included in **Appendix C**.

A.1.5 Meteorological data

Rainfall intensity and wind speed / direction data was provided by WaterNSW from the Lake Burragorang AWS, mounted on a pontoon in the north east arm of Lake Burragorang at approximately 1.5 m above water level. This data were used to interpret temporal trends in sediment (**Section 3.1.6c**) and generate wave heights for the erosion hotspot model (**Section 5.2.1**).

When this data record was not sufficient to cover spatial or temporal requirements, the BoM weather station at Badgerys Creek (#67108) was used as it contains a long-term record and is only 12 km from the dam wall, albeit at a lower altitude of 80 m AHD, compared to approximately 140 m AHD at Warragamba.

A.1.6 River Styles™ framework

The River Styles Framework was used in this assessment to form both a description of rivers with similar channel forms and processes, and to incorporate the condition of the river reach and its likely recovery potential, based on the fragility of the river and its geomorphic condition (Brierley and Fryirs 2005).

The River Styles® classification is based on valley setting, level of floodplain development, bed materials and geomorphic units. Characterisation of the fluvial geomorphology of the study area was approached at two measurement scales:

- Catchment scale – desktop assessment of the study area and downstream to the Hawkesbury-Nepean River (100s to 1,000s of m).
- Reach scale – field verification and assessment at geomorphology survey locations (10s to 100s of m).

Procedures to identify river styles were broadly based on the following parameters:

- Degree of valley confinement;
- Presence and continuity of a channel;
- Channel planform (number of channels, sinuosity); and
- Geomorphic units and features.

The River Styles framework provides a consistent way to define river character and behaviour.

Figure 57 provides the six levels of descriptors used to identify specific River Styles and then place them in the continuous pattern of river shape and complexity progressing downstream.

Figure 57 River Styles Descriptors

Once the River Styles of a set of reaches are determined and included in the database, additional information relating to the target reach is assessed and included. The key information that is appended to the River Styles classification is:

- River styles – detail the physical setting in which the stream occurs. It includes four main groups comprising the swampy meadow group, confined valley setting, partially confined valley setting, and unconfined valley setting,
- Fragility – refers to the susceptibility or sensitivity of certain geomorphic categories to physical adjustments and changes when subjected to degradation or certain threatening activities,
- Geomorphic condition – a measure of departure from a natural or expected state and can be defined as the ability of a river or reach to perform functions expected for a specific river type,
- Recovery potential – provides the potential of the river reach to return to good condition, through the consideration of existing physical disturbance threats.

Prioritisation of management actions, including bed and bank stabilisation engineering options, revegetation and other measures are derived from the recovery potential and fragility of the river, as well as upstream and downstream values and risks to the reach. This is conducted in a qualitative way, to allow more detailed quantitative assessments to be undertaken.

For the desktop assessment, watercourses and other waterbodies were classified into groups of similar geomorphic characters using the River Styles® NSW GIS layer available online (Nov, 2012). These characterisations are then verified for selected sites as part of the site investigation described in **Appendix A.2.2**.

A.1.7 Sediment concentrations / load calculation

Lake Burragorang Concentrations

Four locations were selected within Lake Burragorang to obtain spatial coverage and quality and quantity of the data at each site:

- North-east arm approximately 12 km from dam (Sample point #DWA09)
- North-west arm approximately 25 km from dam (Sample point #DWA12)
- Central portion approximately 23 km from dam (Sample point #DWA27)
- South arm approximately 43 km from dam (Sample point #DWA39)

Upstream Zone River Sediment Concentrations / Loads

River sites were selected primarily based on data availability. Three river locations contained matching records for both flow and total suspended solids concentrations ([TSS]) data. These are shown in **Figure 58** and located at:

- Cox's River at Kelpie Point (site code 212250)
- Nattai River at The Causeway (site code 212280)
- Wollondilly River at Jooriland (site code 212270)

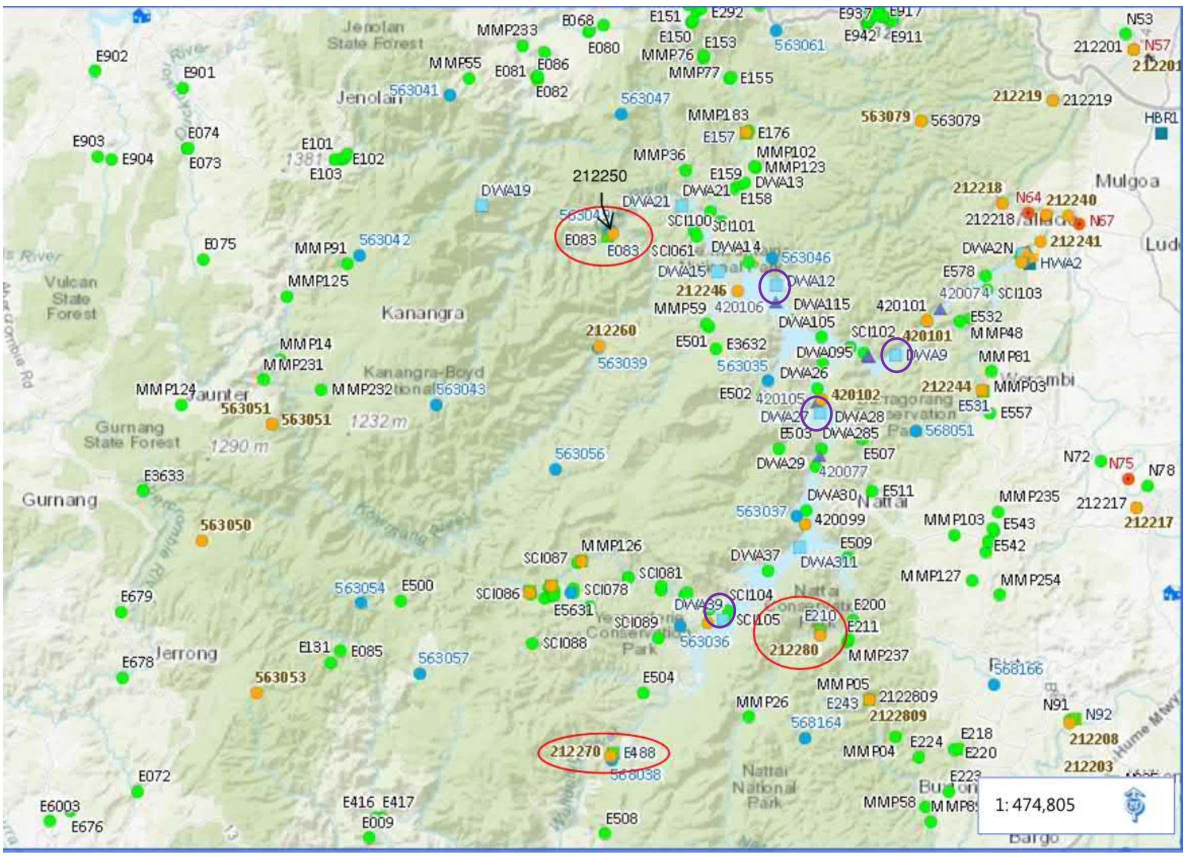

Figure 58 Sample locations analysed. Red – Both TSS and flow, Purple – TSS in lake.

Aligned TSS and flow data was not available for the majority of inflows to Lake Burragorang (e.g. Butchers, Cedar, Kedumba, Green Wattle Creeks) and as such a complete 'catchment sediment budget' was not able to be computed.

The procedure for calculation of sediment load at the three nominated river sites was as follows:

- TSS concentrations in mg/L were divided by 1,000 to convert to tonnes / megalitre
- The converted TSS concentrations were then multiplied by the flow, to obtain daily sediment loads (in tonnes / day)
- The daily TSS load values were multiplied by 365 to obtain the estimated annual loadings in tonnes / year.

A.1.7 Topographic survey of Lake Burragorang

A high resolution bathymetric and shoreline topographic survey of Lake Burragorang was undertaken by Marine GeoSolutions Pty Ltd (MGS, 2014). The survey was undertaken between 11th December 2013 and 22nd January 2014 using a high specification multibeam echosounder, topographic laser scanner and inertial navigation system. Mapping was produced in the GDA94 MGA Zone 56 coordinate system and bathymetric and topographic elevations are referenced to AHD.

Appendix A.2. Site Methodologies

A.2.1. Bank erosion

A Controls Model 16-T0171 pocket penetrometer (**Figure 59**) was used to measure river bank unconfined compressive strength (in kg cm^{-2}).

Figure 59 Pocket penetrometer for measuring bank strength

Logging was undertaken on dynamic samples (i.e. undisturbed and in-situ). Selection of measurements points were on a random basis but stones, tree roots and other obstructions were avoided. Eighteen readings were taken and recorded at each test site corresponding to different parts of the bank (i.e. toe, mid-wall and surface) and values were expressed to the nearest 0.1 kg cm^{-2}. Test refusals were reported as > 4.5 kg cm^{-2}.

Tests were carried out consistently according to the following guidance:

- Use the same force and angle of penetration (perpendicular to the bank) for all readings
- Measurements were conducted by one geomorphologist for consistency
- Condition of the instrument was maintained throughout

A geometric mean, minimum and maximum were calculated for each sample location. Due to the inherent inaccuracy in the device, pocket penetrometer results were used in this investigation for cross-checking purposes only (i.e. they provide a relative value of bank strength not absolute).

A.2.2. Rapid geomorphology site walkover

A baseline geomorphology review was conducted to provide a snapshot of current fluvial geomorphic condition. The walkover observations and subsequent classifications were conducted in accordance with the RiverStyles™ approach (Thompson *et al.* 2001), recognised Australia-wide as an effective, simple step-by-step procedure that ensures consistent and comparable results. It assesses river character and behaviour based on bed and bank sediment information, detail on erosion mechanisms and depositional features, floodplain geomorphology, conveyance and channel adjustment characteristics. The Framework applies a set of hierarchical principles to differentiate reaches, interpret their process-based behaviour and examine interactions between patterns of reaches at the catchment scale. A field form (**Figure 60**), general site photos and a field sketch were completed for each site. This approach is more applicable to riverine environments but for consistency a modified field form (**Figure 61**) was also used to capture lake geomorphological conditions.

Selection of appropriate and accessible sites for a rapid geomorphological walkover assessment involved a pre-site selection screening. Sites were selected where flow modelling transects, potentially ecologically sensitive receptors and spatial representation of different stream types were identified using aerial photography and longitudinal profiles. Additional criteria were then reviewed to select a list of 24 locations within and surrounding Lake Burragorang on the following watercourses:

- Cedar Creek (one site)
- Cox's River (three sites)
- Grose River (one site)
- Hawksbury River (three sites)
- Kedumba River (two sites)
- Lake Burragorang (six sites)
- Nattai River (three sites)
- Nepean River (four sites)
- Reedy Creek (one site)
- Warragamba River (two sites)
- Wollondilly River (four sites)

The location of these sites are provided in maps for the Upstream and Lake Zone (**Figure 32**) and the Downstream Zone (**Figure 33**).

Figure 60 Rapid geomorphological walkover survey template

Project	WDR EIS (Beca reference # 4512987)					**Date**	
Surveyor		**Reach code:** XX-XX				**Time**	
Drainage channel		**Creek**	**River**	**Estuary**	**Pond**	**Wetland**	**Lake**

Weather conditions		**U-S elevation**		**D-S elevation**	
Upstream grid reference		**Downstream grid reference**			

Watercourse attributes

Dimensions	**Width**		**Max. depth**		**Average velocity (ms^{-1})**		
Shape description			**Max. Roughness Height**		**Bank erosion**		
Instream vegetation (% cover [emergent, floating, submerged, algae, moss])		**Bank vegetation**		**Bench vegetation**		**Organic matter**	

Flow type

Smooth surface flow [H1]	Broken standing waves [H2]	Unbroken standing waves [H3]	Chute [H4]	Rippled [H5]	Scarcely perceptible flow [H6]	Upwelling [H7]	Free fall [H8]	Standing water [H9]

Channel Planform

Sinuosity (straight, low, intermediate, high)		***Form***	**Single**	**Forked**	**Braided**		**Open**
Sand bars	**Gravel bars**		**Rock outcrops**		**Riparian strip**	**Floodplain connectivity**	
Floodplain land use			**Bank Strength (kg/cm^2)**			**Bank structure & angle**	

Bed character

	Boulder		Cobble		Gravel		Sand		Fine sand		Silt / clay	
% composition	U-S	D-S	U-S	D-S	U-S	D-S	U-S	D-S	U-S	D-S	U-S	D-S

Bed stability		**Supply**	**Deposition**	**Erosion**	**Conveying**

*DWF = Dry weather flow, BF = Bankfull flow, RHB = Right hand bank, LHB = Left hand bank, U-S = Upstream location of selected stretch, D-S = Downstream location of selected stretch

Rapid geomorphological walkover survey template (continued)

<<INSERT IMAGE>>

<<INSERT IMAGE>>

Cross-section XX-XX

<<INSERT IMAGE>>

<<INSERT IMAGE>>

Historic Aerial | MM / YYYY	**Upstream XX-XX**	**Downstream XX-XX**

Figure 61 Modified rapid geomorphological walkover survey for lacustrine environments - template

Project	WDR EIS (Beca reference # 4512987)				**Date**	
Surveyor	**Reach code:** R-XX				**Time**	
Drainage channel	**Creek**	**River**	**Estuary**	**Pond**	**Wetland**	**Lake**
						X
Weather conditions				**Land use**		
Grid reference				**Elevation**		
Bank attributes						
Wave height			**Bank structure and angle**			
Bank strength (kg/cm^2)	SL FSL		**Bank erosion**			
Aquatic vegetation		**Bank vegetation**		**Bench vegetation**	**Organic matter**	
Bed character						
% composition	**Boulder**	**Cobble**	**Gravel**	**Sand**	**Fine sand**	**Silt / clay**

***SL = Shoreline, FSL = Full Supply Level**

<<INSERT IMAGE>>	<<INSERT IMAGE>>	<<INSERT IMAGE>>
Aerial view of RXX site | January 2019	**Interest feature #1**	**Interest feature #2**

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A.2.3. Sediment deposition potential

At each site, AstroTurf mats were installed in order to sample the potential deposition of inundation water on the lake foreshore / river floodplain and thereby estimate the retention and smothering potential of sediment on terrestrial vegetation. Mats were composed of commercially available UV stable lightweight polypropylene grass tiles with 8 mm pile height, cut into 50 x 50 cm squares. They were secured onto the bank using 20 mm two-pronged metal stakes in each corner of the square.

Mats were deployed at the following sites:

- Lake Burragorang – R-01, R-02, R-03, R-04
- Kedumba River – US-13, US-14
- Hawkesbury River – DS-12

Typical arrangements are shown in **Figure 62**.

Lake Burragorang foreshore	Kedumba River floodplain

Figure 62 Deployment array for sedimentation AstroTurf mats

For the lake foreshore sites, mats were located in a transect, at the water's edge, placed at the upslope leading edge, mid-buffer and downslope edge of the buffer, and where possible downslope of the buffer feature, usually at two contrasting locations within each field (i.e. mats were positioned along two transects). For the river floodplain sites, mats were placed at strategic locations on the wetland/flood plain surface in order to document spatial patterns of sediment accumulation.

Mats were installed in early February 2019 and water level change was checked weekly using the weekly verified storage reports.

Although it is recognised that there may be problems with the use of the mats, such as the potential for wash-off of previously trapped sediment due to the long periods that the traps remain in the fields, such effects are believed to be minimal and the use of AstroTurf mats is now a reasonably established method to collected sediment due to overland flow on hillslopes and overbank flows on flood plains (Owens *et al*., 2006).

Mats that were inundated by encroaching waters and contained sediment would be removed and transferred in plastic bags to the laboratory, where the sediment would be air-dried at room temperature for a minimum of 48 hours. The sediment would then carefully be removed and the total dry weight obtained. Astroturf grass fibres dropping off the mat into the sediment would be identified and removed from the sample. An aerial deposition mass (g/m^2) and rate ($g/m^2/d^{-1}$) would then be calculated. The particle size distribution (total range 63 µm–2 mm) would be determined by mechanical sieving. The cumulative particle size distribution was determined, from which the median grain size (D50) could be calculated, from the percentages of gravel (>2mm), coarse sand (>0.5mm), medium sand (>0.25mm), fine sand (>63 µm) and silt / clay (<63 µm).

Appendix A.3. Impact Assessment Methodologies

A.3.1. Project Risk Assessment Methodology

7.1.1 Introduction

A risk assessment methodology was developed, which is generally aligned with the requirements of AS/NZS ISO 14001:2016. This standard defines risk in terms of potential probability and consequence. The magnitude of a risk was assessed on the basis of information collected from baseline studies and the types and scale of activities that will be undertaken. Risk was determined by assigning scores to the likelihood (probability) and consequence, as shown below:

$$\boldsymbol{Risk = Likelihood \times Consequence}$$

Once risks were identified and the inherent risk estimated, decisions were made on how best to minimise the risks. The choices to reduce risk were considered in the context of the benefits and costs of each course of action to the Project, the receiving environment, and sensitive receptors.

Mitigation measures are actions that can be implemented to reduce the level of risk associated with an activity. As risk is defined as a product of likelihood and consequence, mitigation measures work by either reducing the likelihood of a negatively impacting event occurring, or minimising the consequences should the event occur. The overall effect of reducing one or both components is to minimise the residual risk associated with the Project.

7.1.2 Risk assessment procedure

A GIA specific risk matrix was developed (**Figure 63**) and risk evaluated by considering:

- the likelihood of an impact occurring over the life of the Project, or after the Project has been decommissioned
- the severity or consequence of the impact in a biophysical and/or socio-economic context, with consideration of:
  - whether the impact will be in breach of regulatory or policy requirements
  - the sensitivity of receptors
  - resilience or tolerance to disturbance, that is whether the impact is permanent or temporary
  - the areal extent of the impact and/or the magnitude of the impact on receptors.

Once the consequence and likelihood of an impact are assessed, the risk matrix provides an associated ranking of risk significance: **Negligible; Low**; **Moderate**; **High** or **Extreme** for both before and after the application of mitigation measures. Risk definitions are given in **Table 16**.

Where the risk after the application of mitigation measures (residual risk) was assessed as high or very high, mitigation options were reviewed to ascertain whether any further mitigation could be employed to further reduce potential impacts.

Table 16 Risk Definitions

Extreme	Widespread and diverse primary and secondary impacts with significant long-term effects on the Widespread and diverse primary and secondary impacts with significant long-term effects on the environment, livelihood and quality of life. Those affected will have irreparable impacts on livelihoods and quality of life.
High	Significant resources and/or Project modification would be required to manage potential environmental damage. These risks can be accommodated in a project of this size, however comprehensive and effective monitoring measures would need to be employed such that Project activities are halted and/or appropriately moderated. Those impacted may be able to adapt to change and regain their livelihoods and quality of life with a degree of difficulty.
Medium	Risk is tolerable if mitigation measures are in place, however management procedures will need to ensure necessary actions are quickly taken in response to perceived or actual environmental damage. Those impacted will be able to adapt to changes.
Low	On-going monitoring is required however resources allocation and responses would have low priority due to higher ranked risks. Those impacted will be able to adapt to change with relative ease.
Negligible	Impacts do not require further consideration

Key issues were further categorised per Project elements and phases, for example upstream/downstream and construction/operation. For each issue a level of assessment was undertaken commensurate with the potential degree of impact the Project may have on that issue. This included an assessment of whether the identified impacts could be avoided or minimised (for example, through design amendments). Where impacts could not be avoided, environmental management measures have been recommended to manage impacts to acceptable levels. Both environmental and health and safety[1] aspects were assessed for each of the identified issues.

Environmental management measures will be implemented through the management frameworks put in place by the Construction Environmental Management Plan (CEMP), Operational Environmental Management Plan (OEMP) and relevant sub-plans. In addition to incorporating management measures, these plans will include details of how the measures will be implemented, monitored and audited for compliance.

[1] Health and safety has not been assessed as a stand-alone issue, but rather is incorporated in assessments of individual issues.

Figure 63 Risk matrix

			Significance				
			Localised (on-site), short-term impact on habitat, species or environmental media	Localised or widespread medium-term impact to habitat, species or environmental media	Localised degradation of sensitive habitat or widespread long-term impacts on habitat, species or environmental media. Possible contribution to cumulative impacts.	Widespread and long-term changes to sensitive habitat, species diversity or abundance or environmental media. Temporary loss of ecosystem function at landscape scale. Moderate contribution to cumulative impacts.	Loss of a nationally or internationally recognised threatened species or vegetation community. Permanent loss of ecosystem function on a landscape scale. Major contribution to cumulative effects
			Negligible	**Minor**	**Moderate**	**High**	**Very High**
Likelihood	Rare or previously unknown to occur	**Highly unlikely / rare**	Negligible	Negligible	Low	Medium	High
	Unlikely to occur during the Project	**Unlikely**	Negligible	Low	Low	Medium	High
	Possible under exceptional circumstances	**Possible**	Negligible	Low	Medium	Medium	High
	May occur during the Project or beyond the Project	**Likely**	Negligible	Medium	Medium	High	Extreme
	Expected to occur during the Project or beyond the Project	**Highly likely / almost certain**	Low	Medium	High	Extreme	Extreme

A.3.2. Erosion Hotspot Model

An erosion hotspot model was generated for the Upstream and Lake Burragorang Zones following a procedure documented in Evans *et al*., 2006 and Yang *et al*, 2018.

This erosion hotspot tool combines multiple parameters which contribute to erosional processes within GIS and derives the risk of erosion that the specific combination of parameters at each site presents. This approach allows a comparative assessment of the erosion risk resulting from the Existing Scenario and the With Project Scenario, and as such is useful as a relative assessment of the project impacts rather than to provide an absolute assessment of erosion impacts.

Whilst this approach does not provide absolute values its benefit lies in accounting for parameters which are known to contribute to erosion in a logical and repeatable way. Whilst a subjective appraisal of the method outputs is still required it remains more robust than a purely subjective assessment.

All computations and associated mapping were hosted in an ArcMap (version 10.4) platform with Spatial Analyst Tools (including Extract by Mask, Raster Calculator and Reclassify) and Conversion Tools (including Polygon to Raster). A Spatial Analyst license / extension was also required.

Delineation of spatial extent

Firstly, buffers were created using the following flood extents:

Existing:

(i) FSL (100% storage) to 1 in 5 Existing => **1 in 5 Existing Case**

(ii) 1 in 5 Existing to 1 in 10 Existing => **1 in 10 Existing Case**

(iii) 1 in 10 Existing to 1 in 20 Existing => **1 in 20 Existing Case**

(iv) 1 in 20 Existing to 1 in 100 Existing => **1 in 100 Existing Case**

(v) 1 in 100 Existing to PMF Existing => **PMF Existing Case**

With Project:

(i) FSL (100% storage) to 1 in 5 With Project => **1 in 5 Dam Raising Case**

(ii) 1 in 5 with Project to 1 in 10 With Project => **1 in 10 Dam Raising Case**

(iii) 1 in 10 with Project to 1 in 20 With Project => **1 in 20 Dam Raising Case**

(iv) 1 in 20 with Project to 1 in 100 With Project => **1 in 100 Dam Raising Case**

(v) 1 in 100 with Project to PMF With Project => **PMF Dam Raising Case**

In addition to this, the North Nattai rockfall avalanche, caused by the North Nattai Colliery longwall mining, was added as a 'special case' area (**Section 3.2.1b**). These buffers defined the spatial extent of the erosion tool – no land outside these extents was modelled.

Input parameters

The following attributes were incorporated as raster map layers in the model:

- Gradient derived from the Project GIS dataset with 1 m resolution contour generated from 1m DEM (Source: Department Finance, Services and Innovation)
- Land cover derived from the National Dynamic Landcover dataset – existing case only (Geoscience Australia, 2005)
- The Land Cover data used in the processing of Erosion Hotspot Model was sourced from the SMEC Biodiversity Assessment Report Appendix F1 (**Table 17**).
- For the Existing Scenario, Plant Community Types were matched to a Land Cover Type
- For the With Project Scenario, percentage changes to these Plant Community Types were inferred (based on likely dieback due to inundation) to a revised Land Cover Type.
- For detailed information on which PCT being assigned with which Land Cover type, please refer to separate spreadsheet as attached.
- Soil type / erodibility factor derived from Blue Book 'k' values sourced from eSpade (2019)
- Shoreline exposure to wave erosion based on surrogate of relative exposure index derived from effective fetch lengths – these were estimated using the Mason *et al.* (2018) procedure (see below for detail explanation) - this process was applied on Lake Burragorang only
- Maximum in channel velocity derived from the Project flood model (WMA Water, 2018) – this process was applied to the upstream creeks / rivers only

These features were allocated a nominal ranking, using equal distribution divisions, with larger rankings reflecting an increased capacity to control erosion potential as shown in **Table 18**.

Rainfall intensity was not used as a variable for the erosion mapping tool because the catchment area over which impacts from the dam raising may be experienced was small and insufficient data resolution was available within this area (i.e. multiple tipping bucket rain-gauges would be required at representative locations through the catchment).

Effective fetch length distance calculations

Effective fetch length (i.e. the maximum distance on the lake for predominant wind directions over which waves could develop) was estimated using the following 6-step approach:

- Derivation of a wind rose based on WaterNSW AWS data supplied from the surface of Lake Burragorang (**Figure 64**)
- Classification of wind speeds into 3 categories (0 – 5 equals 'low', 5 – 20 equals 'medium', < 20 m/s equals 'high') from the wind rose
- Transposition of the travel direction of this wind speed category onto the outline of Lake Burragorang to estimate lines of maximum length from wind hitting the water surface on one side of the lake to hitting the bank on the opposite side of the lake
- Delineation of x19 zones around Lake Burragorang that would be exposed to each class of wind speed
- Measuring ±45° 'cones of influence' to hit the banks of prominent points derived from the lines of maximum length and then back-calculating the length of the dam over which a wave could travel before it reached this point to derive an effective fetch index (**Figure 66**)
- Multiplying wind speed and direction classification with effective fetch index to derive a relative exposure index (**Table 19**).

Land Cover Type change for the With Project Scenario

Existing Plant Community Types (x24 present) were aligned to the following associated Land Cover Types (x4 present):

- Woody Trees (Closed)

- Woody Trees (Open)
- Woody Trees (Sparse)
- Herbaceous Graminoids Tussock Grasses (Open)
- Predicted changes in these Land Cover Types (x6 present), sourced from the SMEC Biodiversity Assessment Report Appendix F1 (SMEC, 2019), were then assigned a percentage change:
- Woody Trees (Closed)
- Woody Trees (Open)
- Woody Trees (Sparse)
- Woody Shrubs (Scattered)
- Herbaceous Graminoids Tussock Grasses (Open)
- Cultivated & Managed Lands Pasture (Rainfed Graminoids)

Detailed information on Plant Community Type-Land Cover type associations and predicted changes for different flood events in the With Project Scenario are provided in **Table 17** below.

SMEC have advised that the change in Plant Community Type-Land Cover type for the various flood events are the worst-case predictions and apart from 20% AEP, may not occur as a result of the Project. It also be should be recognised that the frequency of the flood event needs to be considered in assessing longer terms erosion risks.

Combining rankings into an erosion risk classification

Rankings for individual attributes were summed to produce a maximum possible score range of 1 – 47 (**Table 18**). These combined rankings were then classified according to the following system:

- Negligible erosion risk – ranking range 1 - 7
- Slight erosion risk – ranking range 8 - 14
- Low erosion risk – ranking range 15 - 21
- Intermediate erosion risk – ranking range 22 - 28
- High erosion risk – ranking range 29 - 35
- Very high erosion risk – ranking range 36 - 42
- Extreme erosion risk – ranking range 43 – 47.

Table 17 Predicted changes in land cover

PCT_NAME	Existing Land Cover	20% AEP Land Cover	20% AEP % Change	10% AEP Land Cover	10% AEP % Change	5% AEP Land Cover	5% AEP % Change	1% AEP Land Cover	1% AEP % Change	PMF Land Cover	PMF % Change
Coachwood - Lilly Pilly warm temperate rainforest in moist sandstone gullies, Sydney Basin Bioregion	Woody Trees (Closed)	Woody Shrubs (Scattered)	71-80	Woody Shrubs (Scattered)	71-80	Woody Shrubs (Scattered)	71-80	Woody Shrubs (Scattered)	41-50	Woody Trees (Open)	41-50
Forest Red Gum - Narrow-leaved Ironbark open forest of the southern Blue Mountains gorges, Sydney Basin Bioregion	Woody Trees (Open)	Woody Trees (Sparse)	71-80	Woody Trees (Sparse)	71-80	Herbaceous Graminoids Tussock Grasses (Open)	11-20	Herbaceous Graminoids Tussock Grasses (Open)	11-20	Herbaceous Graminoids Tussock Grasses (Open)	11-20
Forest Red Gum - Yellow Box woodland of dry gorge slopes, southern Sydney Basin Bioregion and South Eastern Highlands Bioregion	Herbaceous Graminoids Tussock Grasses (Open)	Herbaceous Graminoids Tussock Grasses (Open)	11-20	Herbaceous Graminoids Tussock Grasses (Open)	11-20	Herbaceous Graminoids Tussock Grasses (Open)	11-20	Herbaceous Graminoids Tussock Grasses (Open)	11-20	Herbaceous Graminoids Tussock Grasses (Open)	11-20
Forest Red Gum - Yellow Box woodland of dry gorge slopes, southern Sydney Basin Bioregion and South Eastern Highlands Bioregion	Woody Trees (Sparse)	Woody Trees (Sparse)	71-80	Woody Trees (Sparse)	71-80	Herbaceous Graminoids Tussock Grasses (Open)	11-20	Herbaceous Graminoids Tussock Grasses (Open)	11-20	Herbaceous Graminoids Tussock Grasses (Open)	11-20
Grey Gum - Broad-leaved Ironbark dry open forest on gorge slopes on the Blue Mountains, Sydney Basin Bioregion	Woody Trees (Open)	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20
Grey Gum - Hard Leaved Scribbly Gum woodland of the Cox River Valley	Woody Trees (Open)	Cultivated & Managed Lands Pasture	11-20	Cultivated & Managed Lands Pasture	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20

PCT_NAME	Existing Land Cover	20% AEP Land Cover	20% AEP % Change	10% AEP Land Cover	10% AEP % Change	5% AEP Land Cover	5% AEP % Change	1% AEP Land Cover	1% AEP % Change	PMF Land Cover	PMF % Change
		(Rainfed Graminoids)		(Rainfed Graminoids)							
Grey Gum - Thin-leaved Stringybark grassy woodland of the southern Blue Mountain gorges, Sydney basin Bioregion	Woody Trees (Open)	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20
Grey Gum shrubby open forest on gorge slopes of the Blue Mountains, Sydney Basin Bioregion	Woody Trees (Open)	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20
Grey Myrtle - Lilly Pilly dry rainforest in dry gullies of the Sydney Basin Bioregion and South East Corner Bioregion	Woody Trees (Closed)	Woody Trees (Closed)	1-10	Woody Trees (Closed)	1-10	Woody Trees (Closed)	1-10	Woody Trees (Closed)	1-10	Woody Trees (Closed)	1-10
Grey Myrtle dry rainforest of the Sydney Basin Bioregion and South East corner Bioregion	Woody Trees (Closed)	Woody Trees (Closed)	1-10	Woody Trees (Closed)	1-10	Woody Trees (Closed)	1-10	Woody Trees (Closed)	1-10	Woody Trees (Closed)	1-10
Mountain Blue Gum - Thin-leaved Stringybark open forest on river flat alluvium in the Sydney Basin Bioregion	Woody Trees (Open)	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20
Narrow-leaved Ironbark - Broad-leaved Ironbark - Grey Gum open forest on the edges of the Cumberland Plain,	Woody Trees (Open)	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20

PCT_NAME	Existing Land Cover	20% AEP Land Cover	20% AEP % Change	10% AEP Land Cover	10% AEP % Change	5% AEP Land Cover	5% AEP % Change	1% AEP Land Cover	1% AEP % Change	PMF Land Cover	PMF % Change
Sydney Basin Bioregion											
Narrow-leaved Ironbark - Forest Red Gum on rocky slopes of the lower Burragorang Gorge, Sydney Basin Bioregion	Woody Trees (Open)	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20
No PCT assigned. MU: Escarpment Mountain Grey Gum Forest	Woody Trees (Open)	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20
No PCT assigned. MU: Exposed Devonian Grey Gum Forest	Woody Trees (Open)	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20
No PCT assigned. MU: Sheltered Sandstone Smooth-barked Apple Forest	Woody Trees (Open)	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20
No PCT assigned. MU: Upland Swamps Tea Tree Thicket	Woody Trees (Open)	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20
Red Bloodwood - Grey Gum woodland on the edges of the Cumberland Plain, Sydney Basin Bioregion	Woody Trees (Open)	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20

PCT_NAME	Existing Land Cover	20% AEP Land Cover	20% AEP % Change	10% AEP Land Cover	10% AEP % Change	5% AEP Land Cover	5% AEP % Change	1% AEP Land Cover	1% AEP % Change	PMF Land Cover	PMF % Change
Red bloodwood - scribbly gum heathy woodland on sandstone plateaux of the Sydney Basin Bioregion	Woody Trees (Open)	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20
Red Bloodwood - Sydney Peppermint - Blue-leaved Stringybark heathy forest of the southern Blue Mountains, Sydney Basin Bioregion	Woody Trees (Open)	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20
River Oak open forest of major streams, Sydney Basin Bioregion and South East Corner Bioregion	Woody Trees (Open)	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20
Sydney Peppermint - Grey Gum shrubby open forest of the western Blue Mountains, Sydney Basin Bioregion	Woody Trees (Open)	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20
Turpentine - Grey Ironbark open forest on shale in the lower Blue Mountains, Sydney Basin Bioregion	Woody Trees (Open)	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20
Turpentine - smooth-barked Apple moist shrubby forest of the lower Blue Mountains, Sydney Basin Bioregion	Woody Trees (Closed)	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20	Woody Shrubs (Scattered)	11-20

PCT_NAME	Existing Land Cover	20% AEP Land Cover	20% AEP % Change	10% AEP Land Cover	10% AEP % Change	5% AEP Land Cover	5% AEP % Change	1% AEP Land Cover	1% AEP % Change	PMF Land Cover	PMF % Change
Water Gum - Coachwood riparian scrub along sandstone streams, Sydney Basin Bioregion	Woody Trees (Sparse)	Woody Shrubs (Scattered)	21-30	Woody Shrubs (Scattered)	21-30	Woody Shrubs (Scattered)	21-30	Woody Shrubs (Scattered)	21-30	Woody Shrubs (Scattered)	21-30

Table 18 Erosion hotspot model input variable ranking matrix

Ranking (for all parameters)	Slope range (%)	Land cover type*	Soil / k value	Effective fetch index (m) ¥	Maximum velocity (ms^{-1}) ¥¥
0	No value	Woody Trees (Closed)	Bedrock (<0.029)	0 – 4,256	0 - 0.70
1	0 - 4.83	Woody Trees (Open)	Faulconbridge (0.029)	4,257 – 8,514	0.71 - 1.40
2	4.84 - 10.56	Woody Trees (Sparse)	Gymea (0.035)	8,515 – 12,771	1.41 - 2.10
3	10.57 - 16.60	Woody Shrubs (Scattered)	Medlow Bath (0.035)	12,772 – 17,028	2.11 - 2.80
4	16.61 - 22.34	Herbaceous Graminoids Tussock Grasses (Open)	Round Mount (0.039)	17,029 – 21,286	2.81 - 3.50
5	22.35 - 27.77	Herbaceous Graminoids Tussock Grasses (Sparse)	Hassans Walls (0.044)	21,287 – 25,543	3.51 - 4.20
6	27.78 - 33.21	Cultivated & Managed Lands Pasture (Rainfed Graminoids)	Kedumba (0.046)	25,544 – 29,800	4.21 - 4.90
7	33.22 - 39.55	No value	Wollangambe (0.054) No data (0.054)	29,801 – 34,058	4.91 - 5.60
8	39.56 - 50.72	No value	Cedar Valley (0.055)	34,059 – 38,315	5.61 - 6.30
9	50.73 - 76.98	No value	Warragamba (0.058)	38,316 – 42,573	6.31 - 7.00
10	>76.99	No value	Hawkesbury (0.06)	No value	> 7.01
11	No value	No value	Cox's River (0.061)	No value	No value
12	No value	No value	Kanangra Gorge (0.077)	No value	No value

Key

* Existing and With Project (see Table 19)

¥ Lake Burragorang only

¥¥ Upstream creeks / rivers only

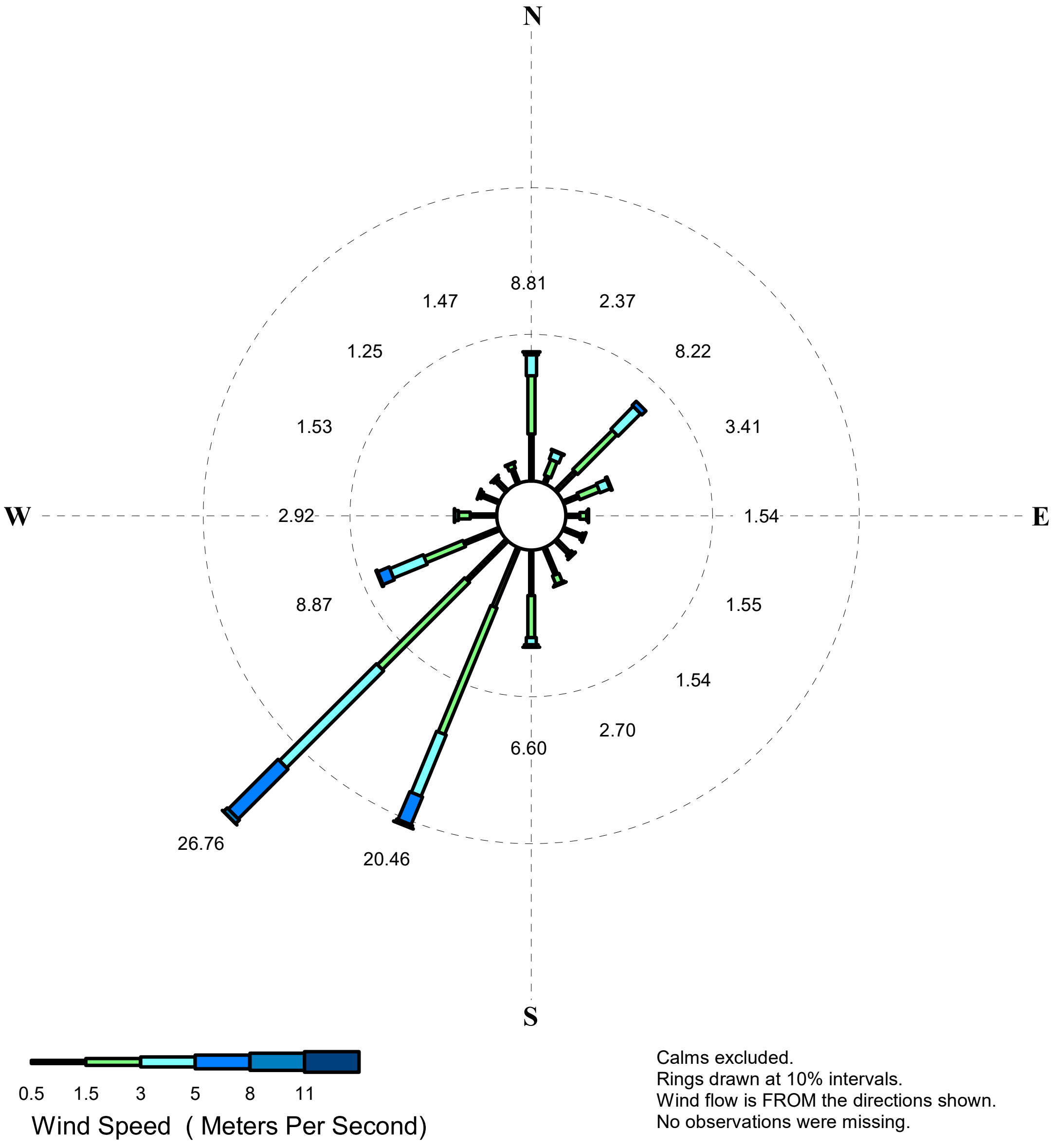
Erosion Hotspot Model outputs

Three raster map outputs were produced combining these layers to provide a visual representation of erosion risk in the study area:

- Existing Scenario mapping
- With Project Scenario mapping
- ‘Comparison’ scenario mapping (change in erosion risk class between Existing Scenario and With Project Scenario)

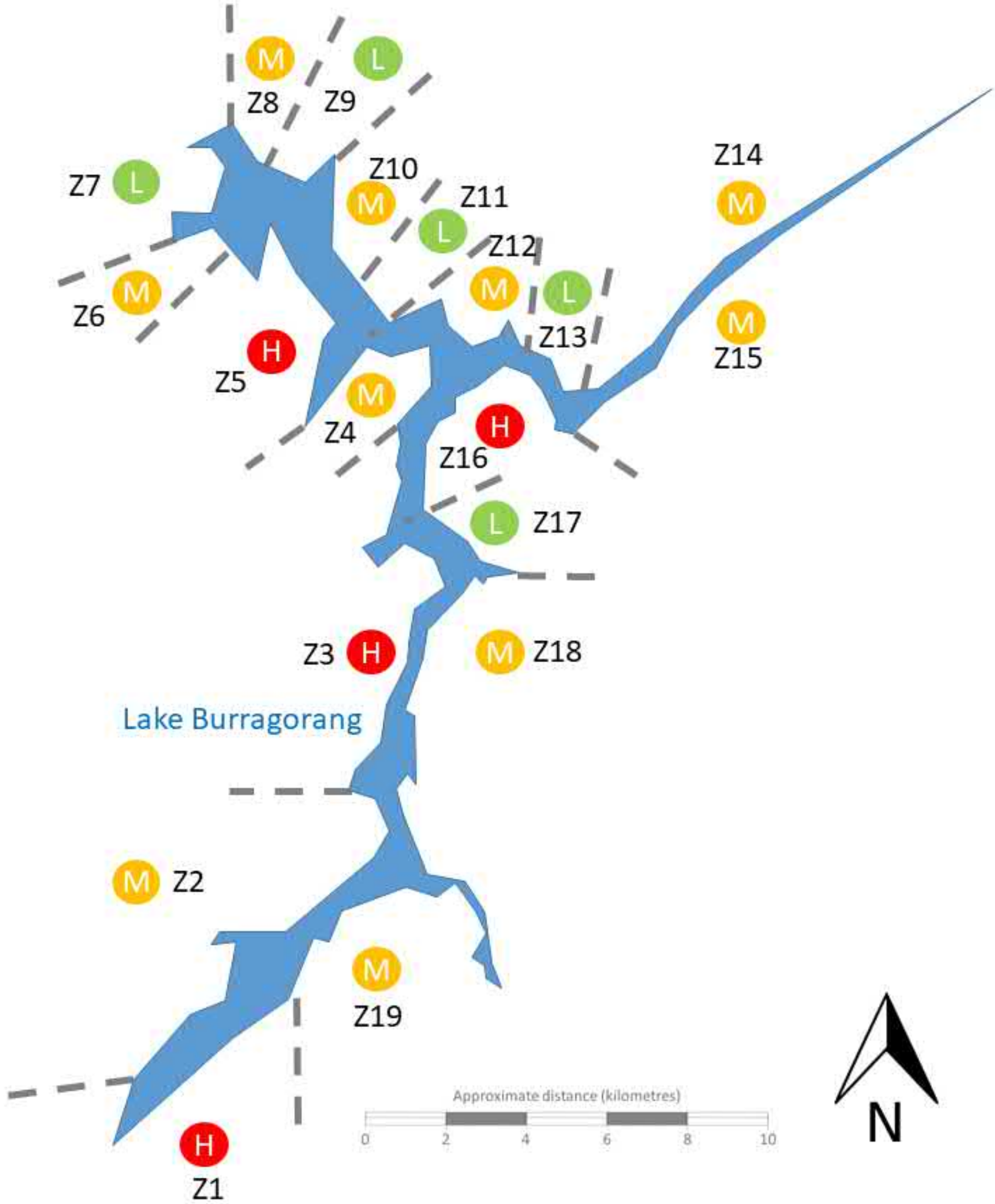
In addition, a spreadsheet was produced showing land areas and percentage of land per erosion class.

Figure 64 Windrose for Lake Burragorang



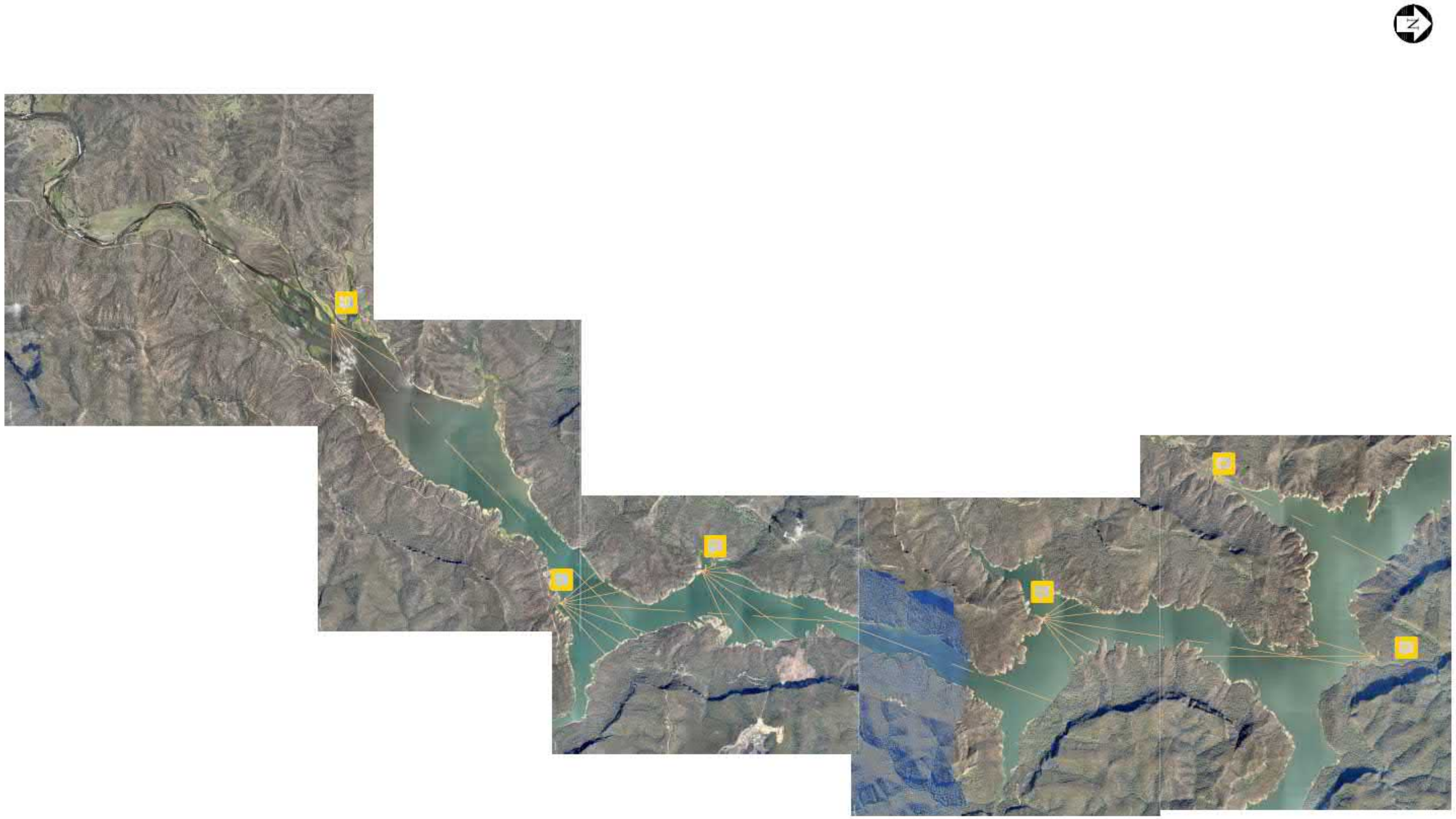
Beca

Figure 65 Land division zones based on wind speed and direction



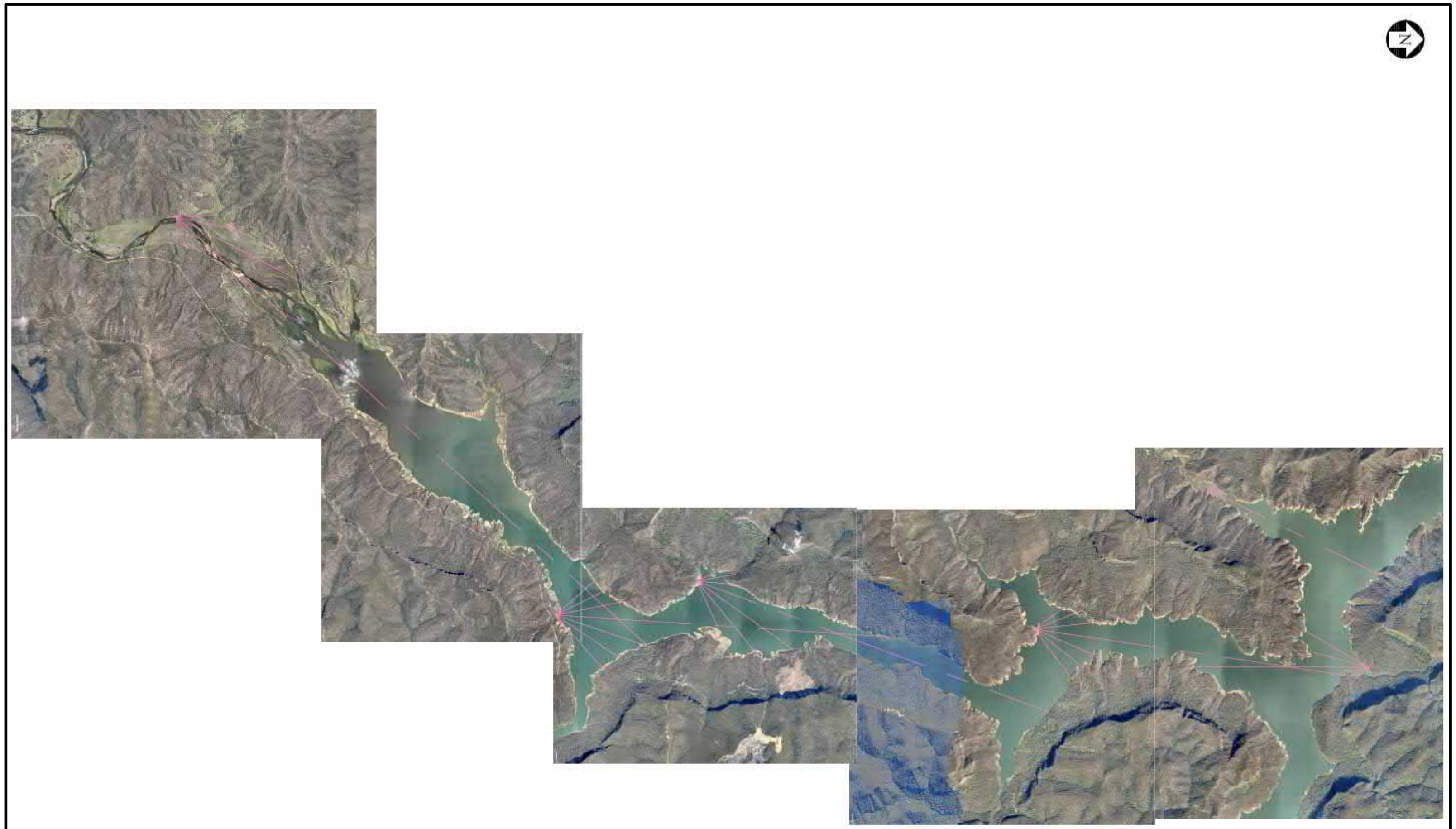
Legend	
H	High
M	Medium
L	Low
— —	Zone Boundary
Z?	Zone number (refer to Fetch lengths.xls – EFI worksheet for effective fetch index values)

Figure 66 Cones of influence measurement



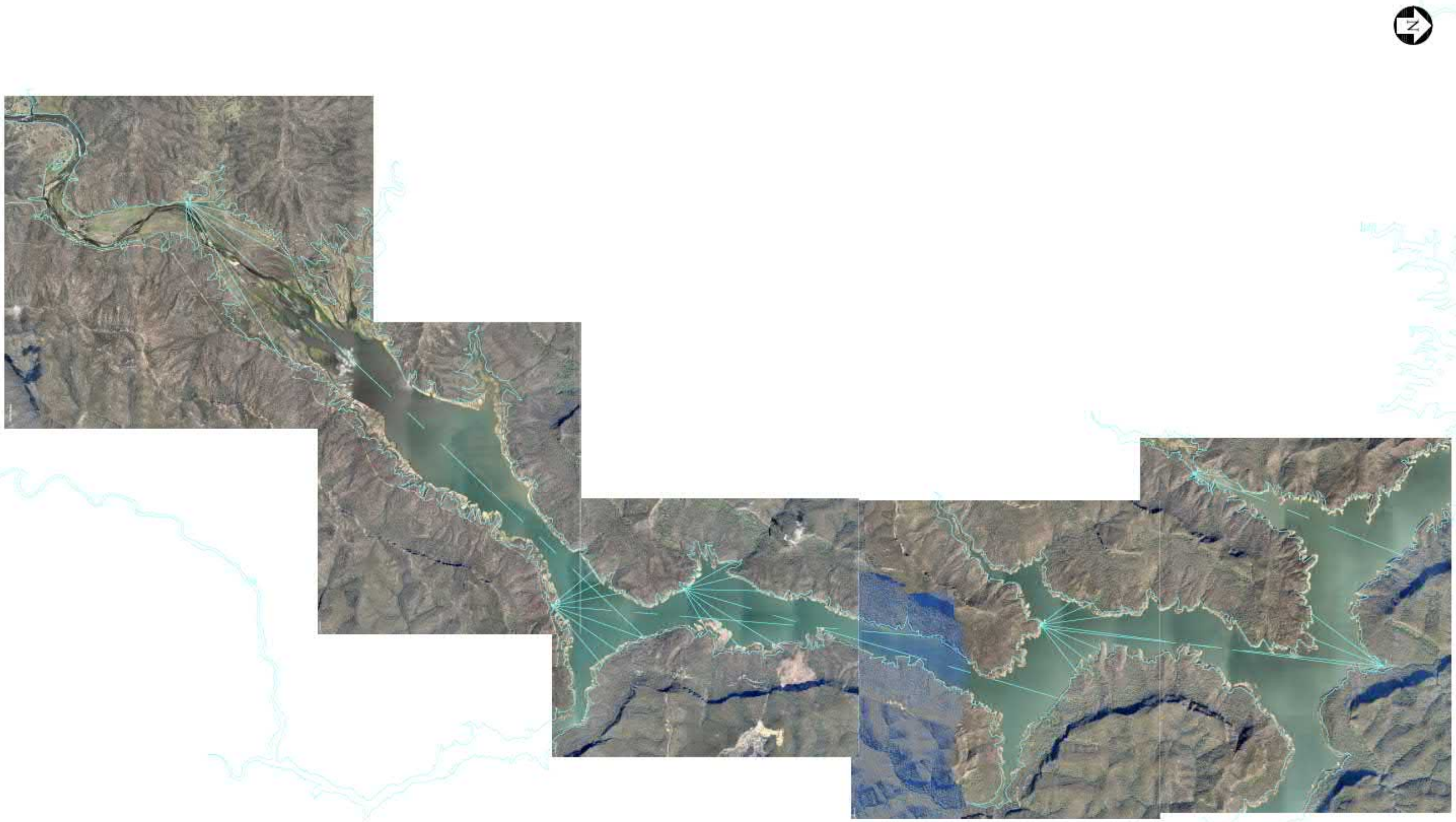
PLAN - CURRENT WATER LEVELS
SCALE 1:75000

Cones of influence measurement (continued)



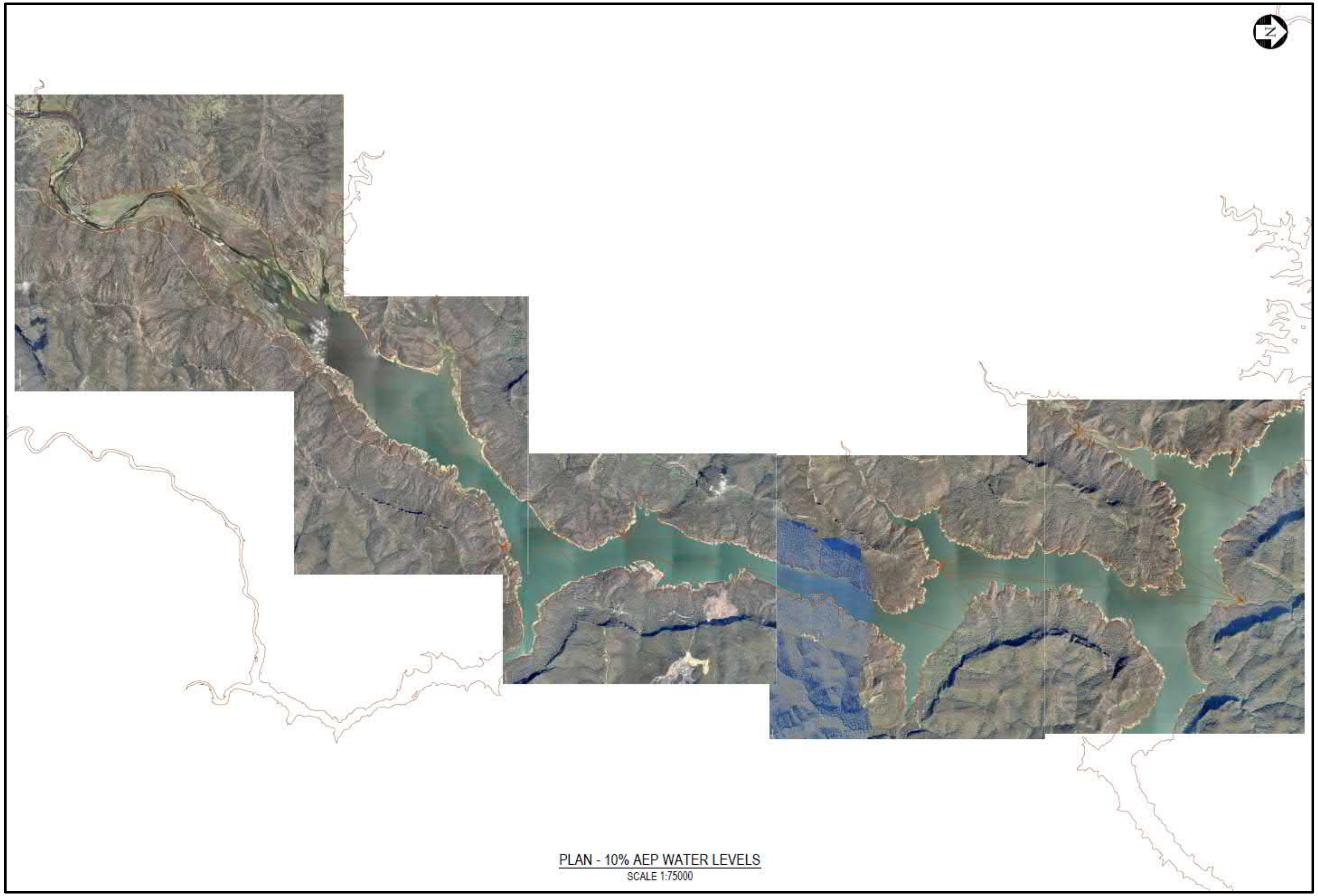
PLAN - EXISTING 100% WATER LEVELS
SCALE 1:75000

Cones of influence measurement (continued)

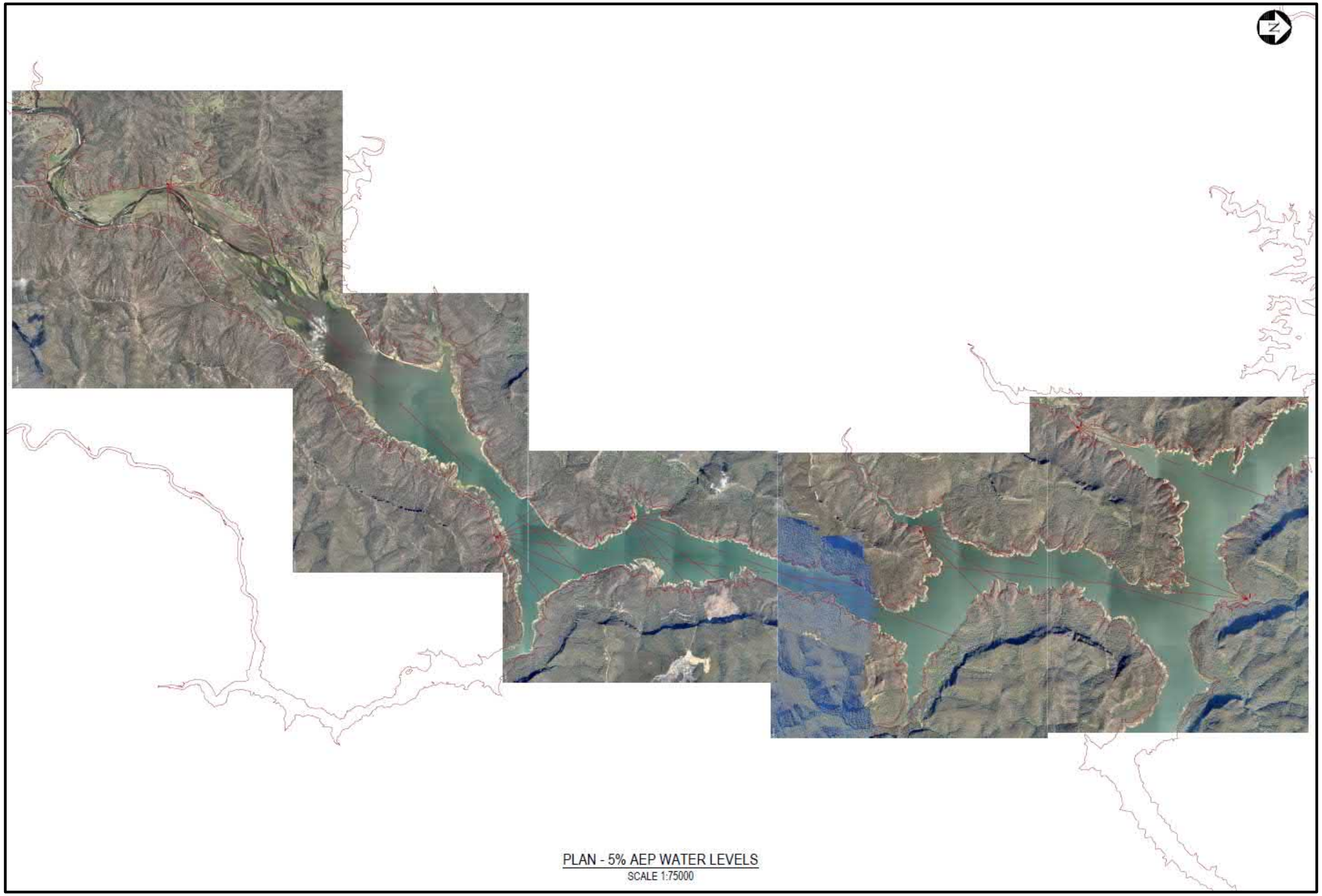


PLAN - 20% AEP WATER LEVELS
SCALE 1:75000

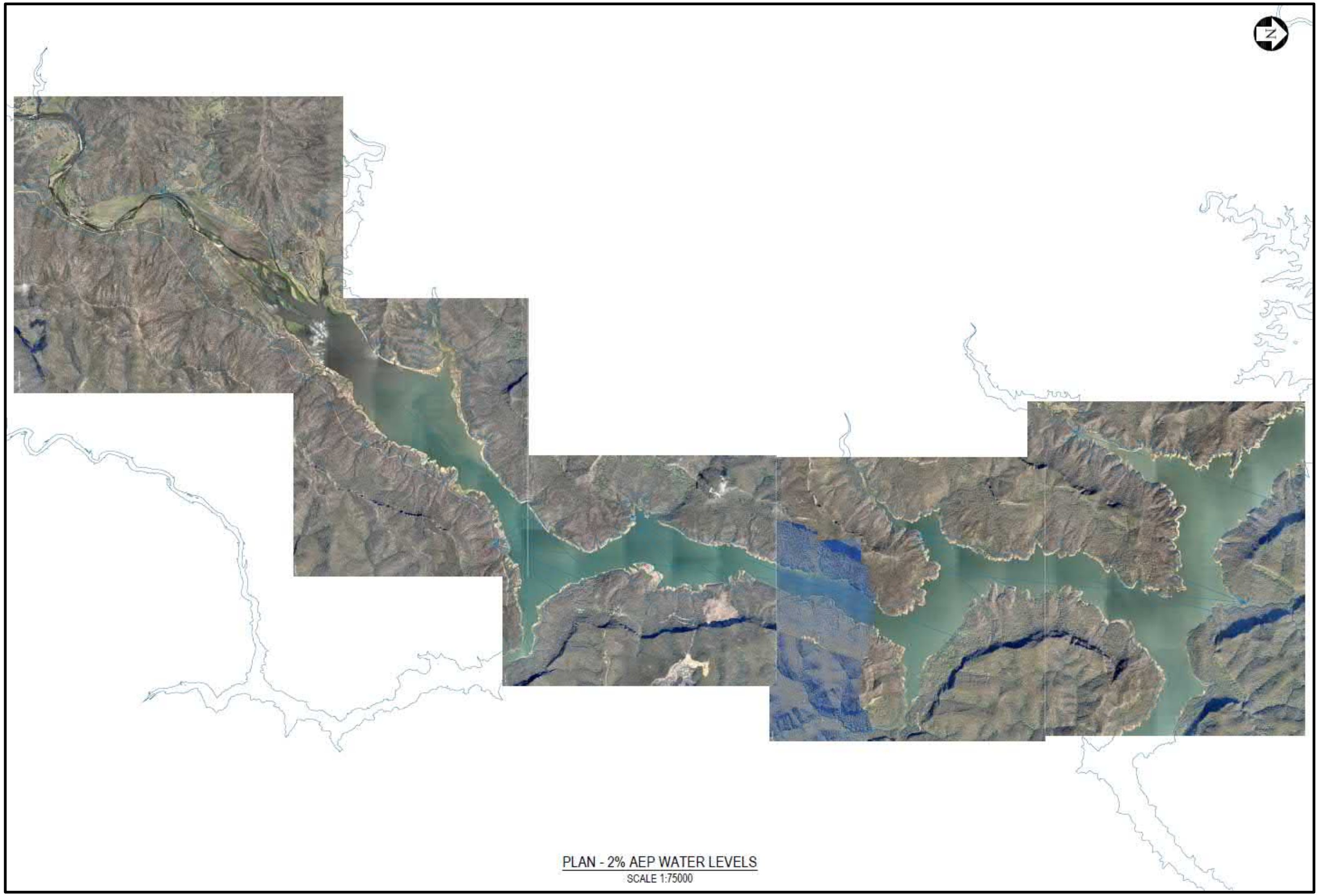
Cones of influence measurement (continued)



Cones of influence measurement (continued)



Cones of influence measurement (continued)



Cones of influence measurement (continued)

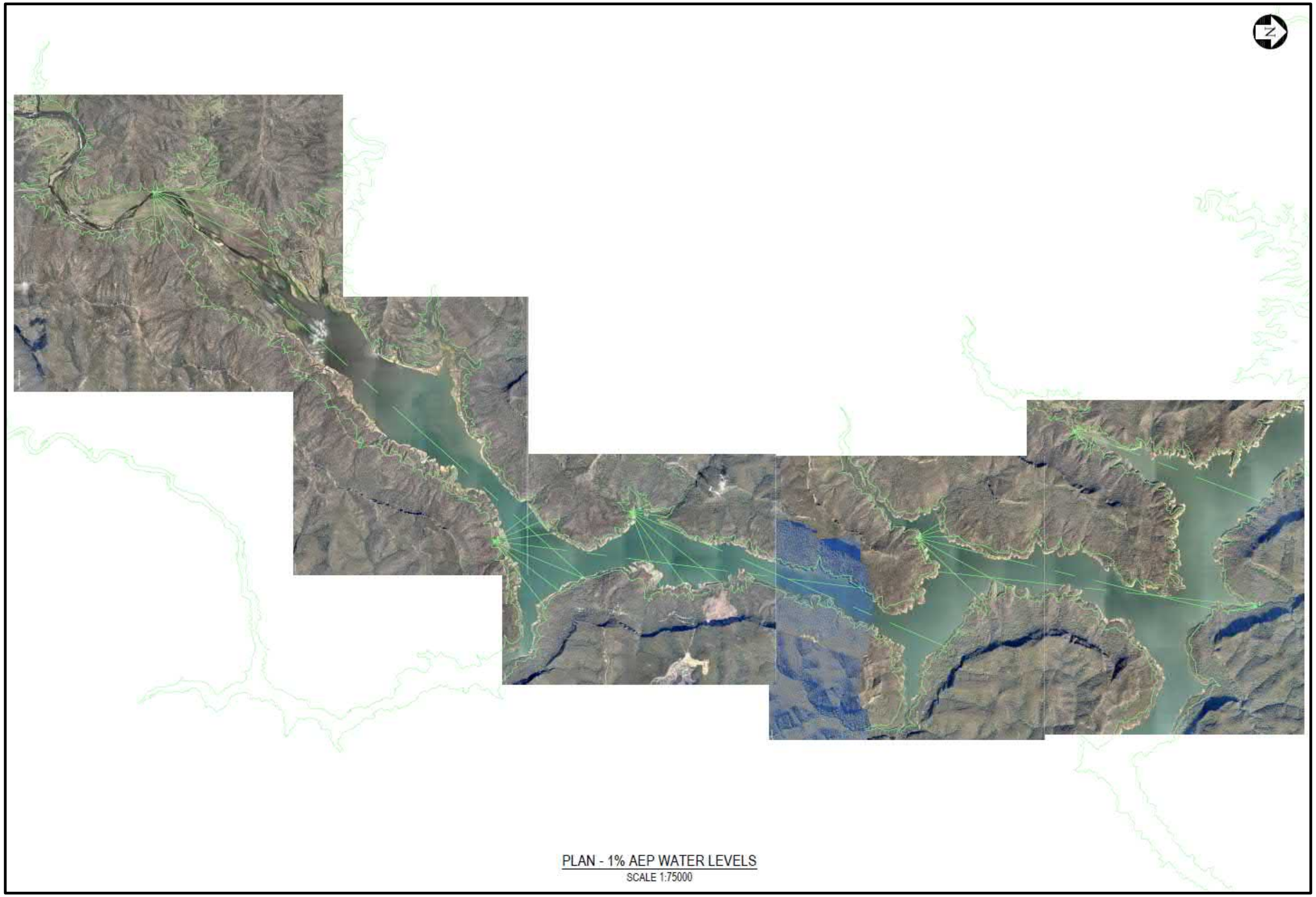


Table 19 Effective fetch distance and Relative Exposure Index estimation

Zone number	Wind speed & direction classification	Rank	Effective Fetch Distance (m)	Relative Exposure Index
Existing (1 in 5, 1 in 10, 1 in 20 AEP)				
Z1	High	3	7,219	21,657
Z2	Medium	2	7,850	15,700
Z3	High	3	7,850	23,550
Z4	Medium	2	1,280	2,561
Z5	High	3	4,063	12,188
Z6	Medium	2	1,280	2,561
Z7	Low	1	7,850	7,850
Z8	Medium	2	1,280	2,561
Z9	Low	1	1,280	1,280
Z10	Medium	2	1,280	2,561
Z11	Low	1	1,280	1,280
Z12	Medium	2	1,280	2,561
Z13	Low	1	1,280	1,280
Z14	Medium	2	7,850	15,700
Z15	Medium	2	7,850	15,700
Z16	High	3	7,850	23,550
Z17	Low	1	1,281	1,281
Z18	Medium	2	7,850	15,700
Z19	Medium	2	7,219	14,438
Existing (1 in 100 AEP)				
Z1	High	3	7,279	21,838
Z2	Medium	2	7,850	15,700
Z3	High	3	7,850	23,550
Z4	Medium	2	1,553	3,106
Z5	High	3	4,063	12,188
Z6	Medium	2	1,553	3,106
Z7	Low	1	7,850	7,850
Z8	Medium	2	1,553	3,106
Z9	Low	1	1,553	1,553
Z10	Medium	2	1,553	3,106
Z11	Low	1	1,553	1,553
Z12	Medium	2	1,553	3,106
Z13	Low	1	1,553	1,553
Z14	Medium	2	7,850	15,700
Z15	Medium	2	7,850	15,700
Z16	High	3	7,850	23,550
Z17	Low	1	1,300	1,300

Zone number	Wind speed & direction classification	Rank	Effective Fetch Distance (m)	Relative Exposure Index
Z18	Medium	2	7,850	15,700
Z19	Medium	2	7,279	14,559
Existing (1 in 100 AEP) and Dam Raising (20% AEP)				
Z1	High	3	13,241	39,723
Z2	Medium	2	8,198	16,395
Z3	High	3	8,198	24,593
Z4	Medium	2	1,829	3,659
Z5	High	3	4,689	14,066
Z6	Medium	2	1,829	3,659
Z7	Low	1	8,198	8,198
Z8	Medium	2	1,829	3,659
Z9	Low	1	1,829	1,829
Z10	Medium	2	1,829	3,659
Z11	Low	1	1,829	1,829
Z12	Medium	2	1,829	3,659
Z13	Low	1	1,829	1,829
Z14	Medium	2	8,198	16,395
Z15	Medium	2	8,198	16,395
Z16	High	3	8,198	24,593
Z17	Low	1	1,342	1,342
Z18	Medium	2	8,198	16,395
Z19	Medium	2	13,241	26,482
Dam Raising (10% AEP)				
Z1	High	3	13,353	40,059
Z2	Medium	2	8,212	16,425
Z3	High	3	8,212	24,637
Z4	Medium	2	1,789	3,578
Z5	High	3	4,603	13,809
Z6	Medium	2	1,789	3,578
Z7	Low	1	8,212	8,212
Z8	Medium	2	1,789	3,578
Z9	Low	1	1,789	1,789
Z10	Medium	2	1,789	3,578
Z11	Low	1	1,789	1,789
Z12	Medium	2	1,789	3,578
Z13	Low	1	1,789	1,789
Z14	Medium	2	8,212	16,425
Z15	Medium	2	8,212	16,425
Z16	High	3	8,212	24,637

Zone number	Wind speed & direction classification	Rank	Effective Fetch Distance (m)	Relative Exposure Index
Z17	Low	1	1,370	1,370
Z18	Medium	2	8,212	16,425
Z19	Medium	2	13,353	26,706
Existing (PMF) and Dam Raising (5% AEP)				
Z1	High	3	13,416	40,247
Z2	Medium	2	8,031	16,063
Z3	High	3	8,031	24,094
Z4	Medium	2	1,645	3,291
Z5	High	3	4,738	14,214
Z6	Medium	2	1,645	3,291
Z7	Low	1	8,031	8,031
Z8	Medium	2	1,645	3,291
Z9	Low	1	1,645	1,645
Z10	Medium	2	1,645	3,291
Z11	Low	1	1,645	1,645
Z12	Medium	2	1,645	3,291
Z13	Low	1	1,645	1,645
Z14	Medium	2	8,031	16,063
Z15	Medium	2	8,031	16,063
Z16	High	3	8,031	24,094
Z17	Low	1	2,388	2,388
Z18	Medium	2	8,031	16,063
Z19	Medium	2	13,416	26,831
Dam Raising (1% AEP)				
Z1	High	3	13,658	40,975
Z2	Medium	2	8,098	16,195
Z3	High	3	8,098	24,293
Z4	Medium	2	1,801	3,601
Z5	High	3	4,903	14,710
Z6	Medium	2	1,801	3,601
Z7	Low	1	8,098	8,098
Z8	Medium	2	1,801	3,601
Z9	Low	1	1,801	1,801
Z10	Medium	2	1,801	3,601
Z11	Low	1	1,801	1,801
Z12	Medium	2	1,801	3,601
Z13	Low	1	1,801	1,801
Z14	Medium	2	8,098	16,195
Z15	Medium	2	8,098	16,195

Zone number	Wind speed & direction classification	Rank	Effective Fetch Distance (m)	Relative Exposure Index
Z16	High	3	8,098	24,293
Z17	Low	1	2,481	2,481
Z18	Medium	2	8,098	16,195
Z19	Medium	2	13,658	27,317
Dam Raising (PMF)				
Z1	High	3	14,188	42,564
Z2	Medium	2	8,178	16,356
Z3	High	3	8,178	24,534
Z4	Medium	2	2,391	4,782
Z5	High	3	4,650	13,950
Z6	Medium	2	2,391	4,782
Z7	Low	1	8,178	8,178
Z8	Medium	2	2,391	4,782
Z9	Low	1	2,391	2,391
Z10	Medium	2	2,391	4,782
Z11	Low	1	2,391	2,391
Z12	Medium	2	2,391	4,782
Z13	Low	1	2,391	2,391
Z14	Medium	2	8,178	16,356
Z15	Medium	2	8,178	16,356
Z16	High	3	8,178	24,534
Z17	Low	1	3,288	3,288
Z18	Medium	2	8,178	16,356
Z19	Medium	2	14,188	28,376

Table 20 Combined rankings matrix

Summed score minimum	Summed score maximum	Erosion potential rank	Erosion potential classification
1	7	0	Negligible
8	14	1	Slight
15	21	2	Low
22	28	3	Intermediate
29	35	4	High
36	42	5	Very high
43	47	6	Extreme

A.3.3. Upstream Hjulström curve sensitivity analysis

The Hjulström curve (Hjulström, 1935) is used in this analysis to hindcast what velocity changes at upstream sites would be required to alter the current bed sediment composition and thus whether that section of river will erode, transport, or deposit sediment. The graph takes sediment particle size and water velocity into account (**Figure 67**).

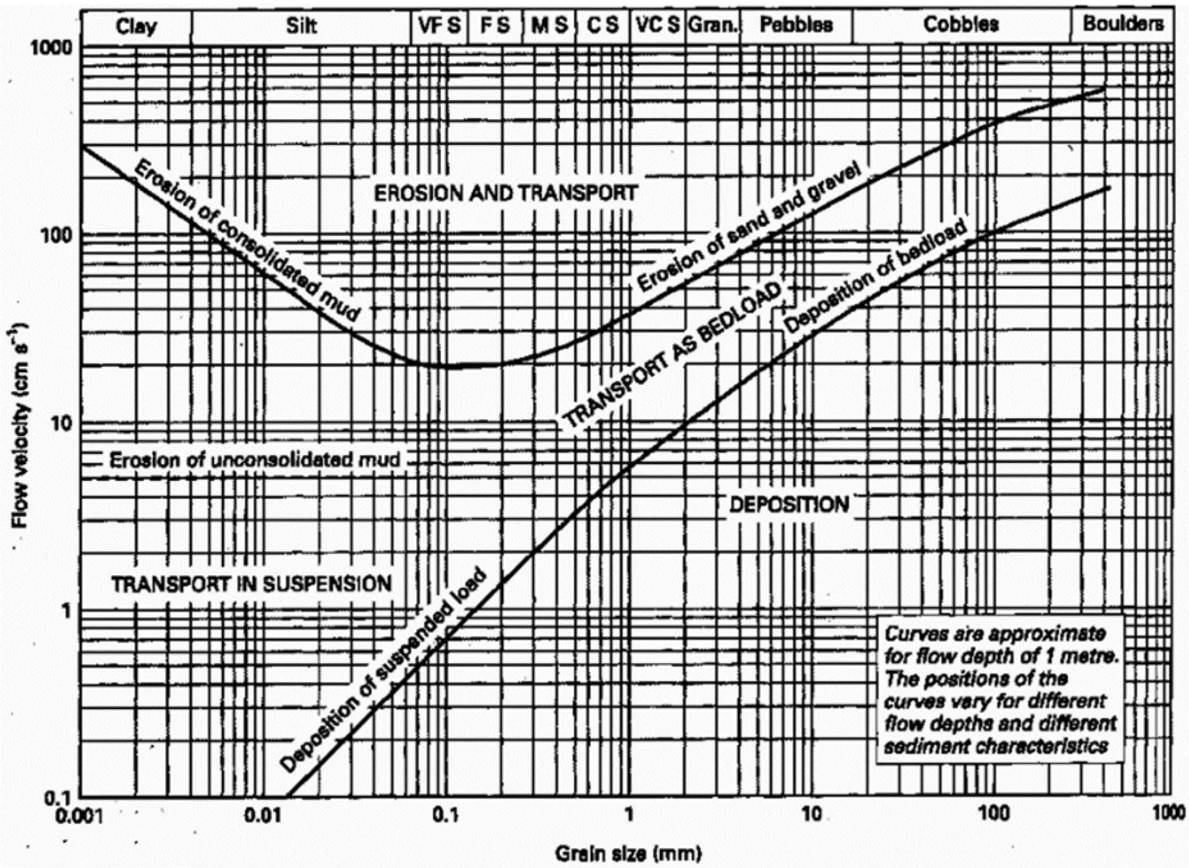


Figure 67 Hjulström curve

The upper curve shows the critical erosion velocity in cm/s as a function of particle size in mm, while the lower curve shows the deposition velocity as a function of particle size. Note that the axes are logarithmic.

For upstream sites where only one-off velocity measurements collected during the geomorphology walkover survey (**Appendix A.2.2**) were available for analysis, the current status of the channel was noted and a hindcasting approach was used to estimate velocity changes required to change status from a depositional-transport-erosion status. The following procedure was used:

- Calculate sediment D_{50} size for all the upstream sites
- Calculate cross-sectional average velocity data for the same sites
- Superimpose these data onto the Hjulström Curve
- Classify the sediment zone for the point in the 'Data' worksheet
- Record the velocity change required to shift the sediment zone by 1, 2 or 3 steps (Erosion – Transportation [suspension] – Transportation [bedload] – Deposition)

This analysis is simplistic due to the heterogenous nature of bed sediments in the upstream rivers and combinations of cohesive and non-cohesive sediments. In addition, it does not account for water depth variation nor does it show that sedimentation is caused by flow velocity deceleration and erosion is caused by flow acceleration. The analysis also assumes a linear relationship between variables, when in reality non-linear relationships may exist in some instances.

These limitations and assumptions are commensurate with the level of detail considered in the geomorphic study as a whole and are not likely to impact the findings and subsequent mitigation measures proposed. Given that the hydrological modelling output limits the ability to undertake a robust analysis of Existing Scenario and With Project Scenario erosive forces there is limited opportunity to undertaken more detailed assessment. Whilst the Hjulström Curve approach is simplistic, it is a practical response to assessing the data available.

A.3.4 Downstream comparisons of stream power

Bank Erosion Index

To assess the impact of increased flows on downstream environment bank erosion, changes in stream power were assessed. Stream power data was extracted from the WMA Water hydrological model. The hydrograph peak was identified on the 'existing' curve and the FMZ discharge was identified on the With Project curve (**Figure 68**).

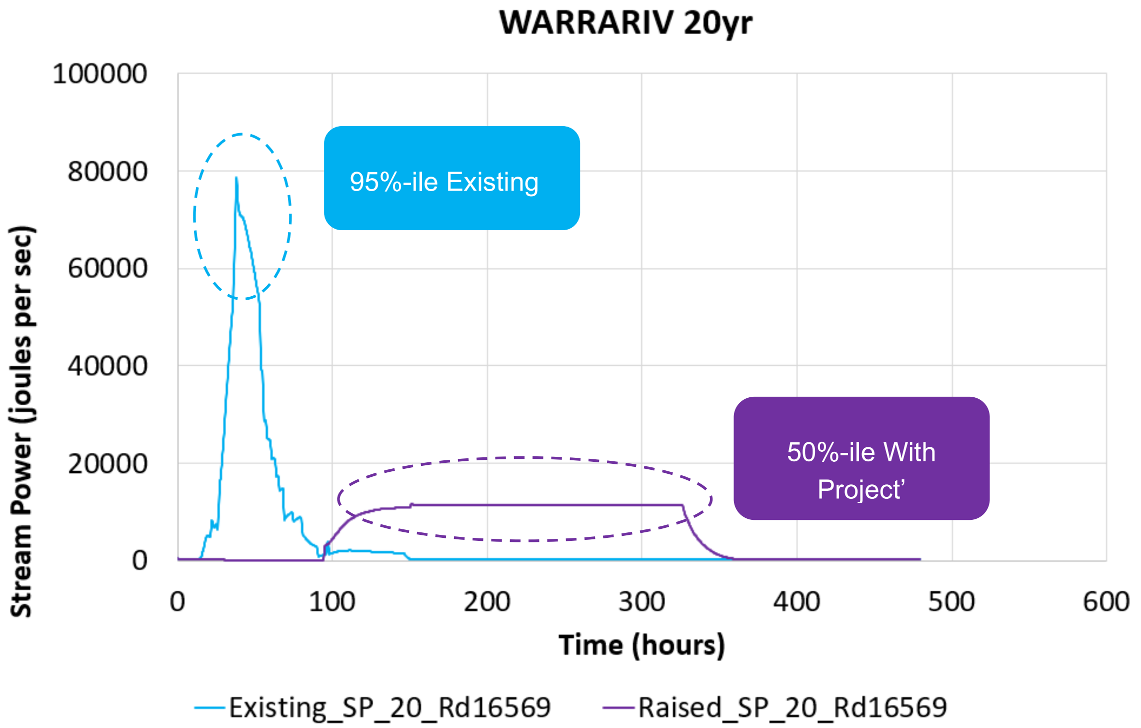


Figure 68 Identification of stream power events for Existing Scenario and With Project Scenario

The data for these two specific periods was then extracted from stream power plots for the flood events - 1 in 5, 1 in 10, 1 in 20, 1 in 100 and PMF.

- Calculation of 95%-ile 'existing' stream power value
- Extrapolation of the duration that the 'existing' hydrograph equals or exceeds this value (start and end time in hours)
- Calculation of the average stream power for the FMZ discharge plateau for the With Project curve
- Extrapolation of the duration of the discharge for the With Project curve (start and end time in hours)
- Multiplication of stream power (existing 95%-ile and With Project average) by the duration of the event to give Effective Stream Power Index'
- Normalisation of the Effective Stream Power Index by the geometric-average bank strength at that particular site, giving a Bank Erosion Index

This process was completed for the following sites that had all the data required (**Table 21**).

Table 21 Stream power comparison sites

Location description	Geomorphology study code	WMA Water cross-section transect code
Warragamba River upstream from Nepean River confluence	DS-01	WarraIV
Nepean River at Penrith Rail Bridge	DS-03	USRailE
Nepean River downstream from Penrith Weir	DS-04	BelowWr
Nepean River at Devlins Road	DS-06	DevlinsD

Nepean River at Shaw Island	DS-07	ShawIS
Hawkesbury River at North Richmond	DS-09	NthRich
Hawkesbury River at Windsor	DS-11	WindsorR
Hawkesbury River at Cattai National Park	DS-12	HillCret

Bank erosion index was then plotted onto bar charts to show Existing and With Project changes for different storm events. It should be noted that for a comparison between Existing Scenario and With Project Scenario, we have assumed that the total volume of discharge water is the same.

Motion states analysis

The mean state for incipient motion of in-channel sediments has been estimated here using an adapted form of the Shields Curve and Hjulström Curve (Hicken, 1997). This uses empirical relationships between stream power and sediment size to estimate the degree of sediment transported down-gradient.

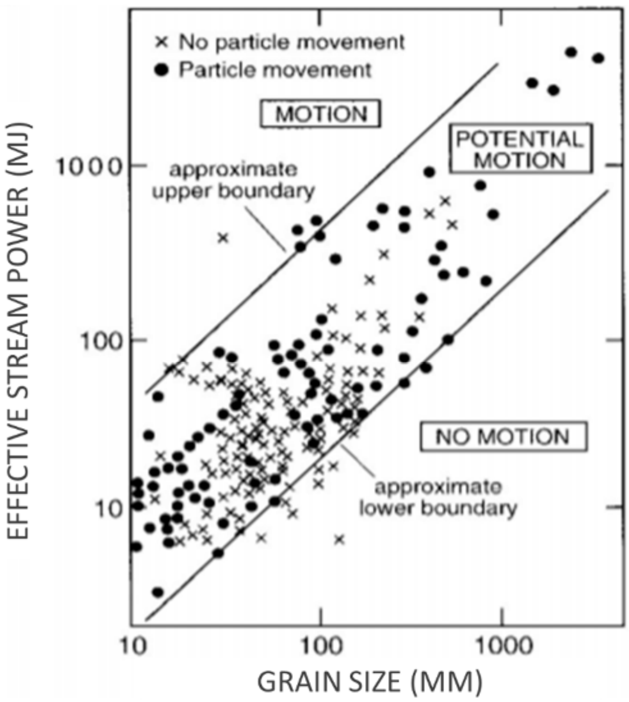


Figure 69 Sediment motion states in relation to stream power / grain size domain (Hicken, 1997)

Effective stream power was plotted against the mean sediment particle size (D_{50}) for the sites listed in **Table 21** and super-imposed onto the Hicken Motion States Curve. The process for this analysis was as follows:

- Extract 95%-ile existing effective stream power for each event (1 in 5, 1 in 10, 1 in 20, 1 in 100 and PMF events)
- Extract mean With Project effective stream power for each event (1 in 5, 1 in 10, 1 in 20, 1 in 100 and PMF events)
- For each site, create a plot of stream power values against sediment D50 values
- Extrapolate points with ‘no motion’, ‘potential motion’ and ‘motion’

Unlike Shields Curve and Hjulström Curve, the ‘Potential Motion’ area of the Hicken curve demonstrates that for mixed-size sediment, the change from stability to motion is not abrupt as a single curve implies but rather is a transitional state. Use of the Hicken curve therefore reflects the natural variability in the impelling and inertial forces involved in transport.

B

Appendix B – Correspondence with WMA Water

Memorandum

To:	Jonas Ball	**Date:**	23 April 2019
From:	Dan Evans	**Our Ref:**	4512987
Copy:	Graham Levy, Patrick Mackay, Mark Megaughin		
Subject:	Review of flood model data		

Please find attached a gap analysis / list of further questions regarding flood modelling.

1 Review of downstream stream power

Purpose: To assess changes to likely erosion patterns as a result of the dam raise

a) Beca has reviewed the information provided in Request For Information ('RFI') GEOM-30 and GEOM-31 which includes stream power data, as well as a summary of maximums for the existing situation. This is suitable for our analysis.

b) We require the following to undertake the analysis of stream power changes in the downstream environment

i. Data for the dam raising scenario, in the same format as the existing scenario data provided

ii. For the avoidance of doubt, confirmation of units used in spreadsheet

iii. Confirmation on how the modellers have dealt with the main tributary flows which join the river downstream of the dam. We can only locate outflow hydrographs from the dam and cannot locate information on the tributaries in the reports. We need this to understand the results we have been provided.

2 Review of downstream flood levels

Purpose: To assess changes to inundation extents/durations/levels as a result of the dam raise

a) Beca has reviewed the information provided in RFI GEOM-32 to GEOM-34. It provides level duration information which could be used to check for impacts at key structures which cross the river, or are located on the banks

b) We require the following to undertake the analysis:

i. An explanation of the different terms used in the curves: Existing Dam, Dam Raising +14m, Existing Dam (at spillway), Dam Raising +14m (at spillway)

ii. Invert / deck level data for structures and other sites of interest (cross-reference RFI GEOM-10).

c) The second part of our downstream level analysis would involve assessing the difference in inundation extent under the two scenarios (RFI GEOM-35 to GEOM-39) and postulating what geomorphological impacts this might have based on our knowledge of suspended sediment, bank strength and soil properties in the inundated area.

i. The mapping provided is insufficient for us to do this. We would use pre and post inundation extent data to quantify the spatial difference at each event, noting where significant sites are/are not flooded in those events and the associated geomorphological change. However, we only have mapping in pdf format and it often has no legend. What events do the blue and red line correspond to?

ii. To undertake the analysis we would request that the SMEC GIS team create flood extent overlay maps for us and report the difference in inundation area at critical locations (cross-reference RFI GEOM-10) for each event. For usability this could be done between significant bridges / highways which may create physical barriers for areas of inundation / overland flow.

3 Review of upstream velocities

Purpose: To assess changes to the depositional environment in upstream tributaries as a result of the dam raise

a) Beca has reviewed the information provided in RFI GEOM-28 and GEOM-29. It provides an average velocity and velocity cross-section for given inputs of level, flow and MIKE11 grid point. This is suitable for our analysis.

b) We require the following to be confirmed in order to undertake the analysis:

i. An explanation of the process to complete a velocity derivation such that we can perform the calculations with confidence that we are completing correctly.

ii. Given the velocity data has been provided separately from the stream power and level data can we have it confirmed that they are derived from the same model runs, using the same cross-section references?

4 Additional questions for WMA Water

Outstanding questions are:

- How the tributary flow is dealt with in the model, downstream of the dam?
- An explanation of the reservoir inundation duration curves, such that we can interpret them properly.

It might be easiest if we could call WMA Water directly (Monique Retallik) to discuss these two points?

Regards,

Dan Evans
Senior Associate - Environmental Science
Direct Dial: +61 2 8216 4648
Email: dan.evans@beca.com

Memorandum

To:	Jonas Ball (SMEC)	**Date:**	1 July 2019
From:	Mark Megaughin	**Our Ref:**	4512987
Copy:	Dan Evans, Graham Levy		
Subject:	Warragamba Dam | Issues using supplied flow data for Geomorphology Study		

1 Introduction

The flow, level and stream power data supplied by SMEC contains temporal and scale patterns which we cannot explain. Because of this uncertainty we cannot undertake a robust or meaningful analysis of the elements of the geomorphology study which rely on difference assessments as it appears that the dam raise is not the only variable changing. We have compared data for 'Existing' and 'Raise14' scenarios and have found changes between, and within, cross-sections which we cannot explain if the only variable being changed is the height and operational patterns of the dam. We believe that there are differences in the base hydrology used for the 'Existing' and 'Raise14' scenarios, and that there may be some model instabilities which are affecting the results provided. Before we can finalise our geomorphology assessment we need confirmation from WMA that the results provided are accurate and reliable and that the patterns with which we have concerns have a basis in reality.

2 Our work so far

We undertook two difference assessments. The first compared velocities in upstream rivers for the 'Existing' and 'Raise14' model runs, and the second compared stream power in downstream rivers (those below Warragamba Dam) for the 'Existing' and 'Raise14' model runs. In both assessments we focused on rivers and reaches which we expected to be influenced by the dam raising, however, it also included some river reaches and tributaries which are unlikely to be influenced by the dam raising. Our consideration of areas unlikely to be influenced was a key part of our data checking as these areas should be the same under 'Existing' and Raise14' scenarios.

The purpose of the difference assessment is to determine the changes to upstream velocity and downstream stream power as a result of the 14 m dam raise. For our assessment to produce correct results the only variable between the 'Existing' and 'Raise14' scenarios can be the dam raise.

2.1 Upstream velocities

Beca requested velocity data for tributaries upstream of Warragamba Dam. Our work required that for each cross-section we compare 'Existing' and 'Raise14' velocities to assess the effects of the dam raising on velocity, and by extension how sediment deposition might change. We were informed by SMEC that these data were not available. As a surrogate we were provided flow and level data and a spreadsheet model which used the cross-section profile to convert flow and level data into velocity. To handle the large number of scenarios which result from the number of cross-section and model runs we automated the process to derive velocity long-sections for each upstream tributary. The automated process had two steps:

1. Identify the peak flow and level in each cross section, for each model run and pass this data through the spreadsheet provided to generate a velocity.
2. Plot the velocities for each model as long-sections and compare the ‘Existing’ and ‘Raise14’ profiles to identify where they are different.

For the difference assessment to generate useable results the only variable which can change between ‘Existing’ and ‘Raise14’ should be the dam height. If any other variables change then we cannot use the output of the difference assessment.

2.2 Downstream stream power

Beca requested stream-power data for the all rivers modelled by WMA downstream of Warragamba Dam. Our work required that for each cross-section we compare ‘Existing’ and ‘Raise14’ stream power to assess the effects of the dam raising on erosion potential. SMEC provided timeseries which show water level, flow, stream-power and unit stream-power for each cross section under ‘Existing’ and Raise14’.

Again, for the difference assessment to generate useable results the only variable which can change between ‘Existing’ and ‘Raise14’ should be the dam height. If any other variables change then we cannot use the output of the difference assessment.

3 The issues we have identified

3.1 Upstream velocities

We undertook a difference assessment of the ‘Existing’ and ‘Raise14’ velocities. Our recommendation remains that velocity data should be extracted directly from the hydraulic model for use in this assessment, however to date this has not been possible. As a surrogate to having velocity data available we have used the level and flow data provided and processed it through the velocity spreadsheet also supplied. There are risks associated with this approach as it adds an additional step into the process through which errors can be introduced.

Based on our understanding of the proposed dam raise our basis for assessing the velocity long-sections is that in all cases the velocities in the ‘Raise14’ scenario should be the same as or lower than in the ‘Existing’ scenario. Where the dam raise increases the water level the velocity would be lower, and where the river is beyond the influence of the dam raise then the velocities would be the same.

If we plot the long sections for the 0.1 event **(Figure 1)** we can see that the ‘Raise14’ velocities are higher than for ‘Existing’ in Nattai River upstream, Nattai River and Wollondilly River. For the 0.2 event **(Figure 2)** there are parts of the long sections for Coxs River, Nattai River and Wollondilly River that are higher in the ‘Raise14’ scenario when compared to ‘Existing’. Similar issues were identified in the 0.05 **(Figure 3)** and 0.01 events.

Figure 1 – 0.1 event

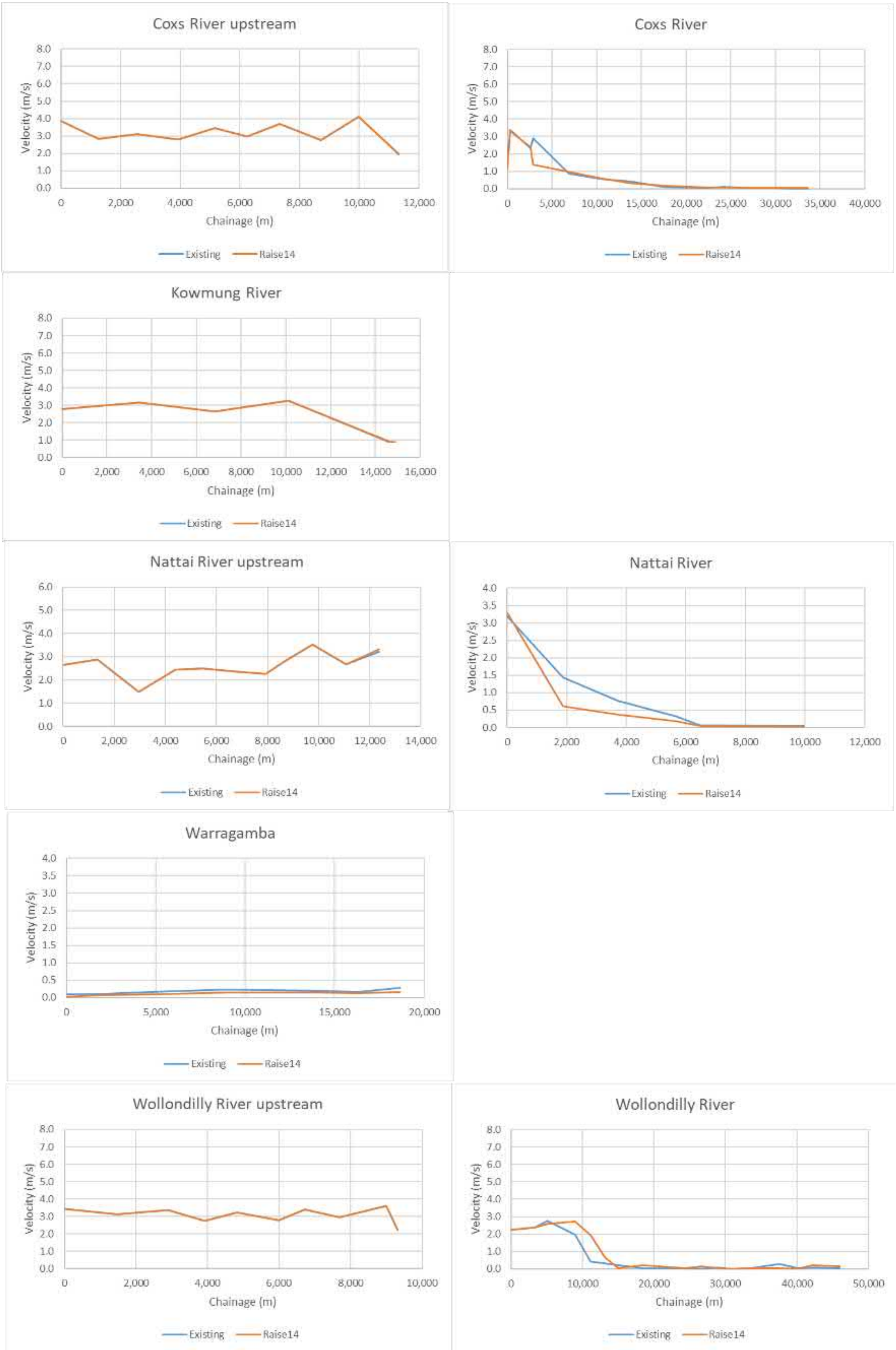
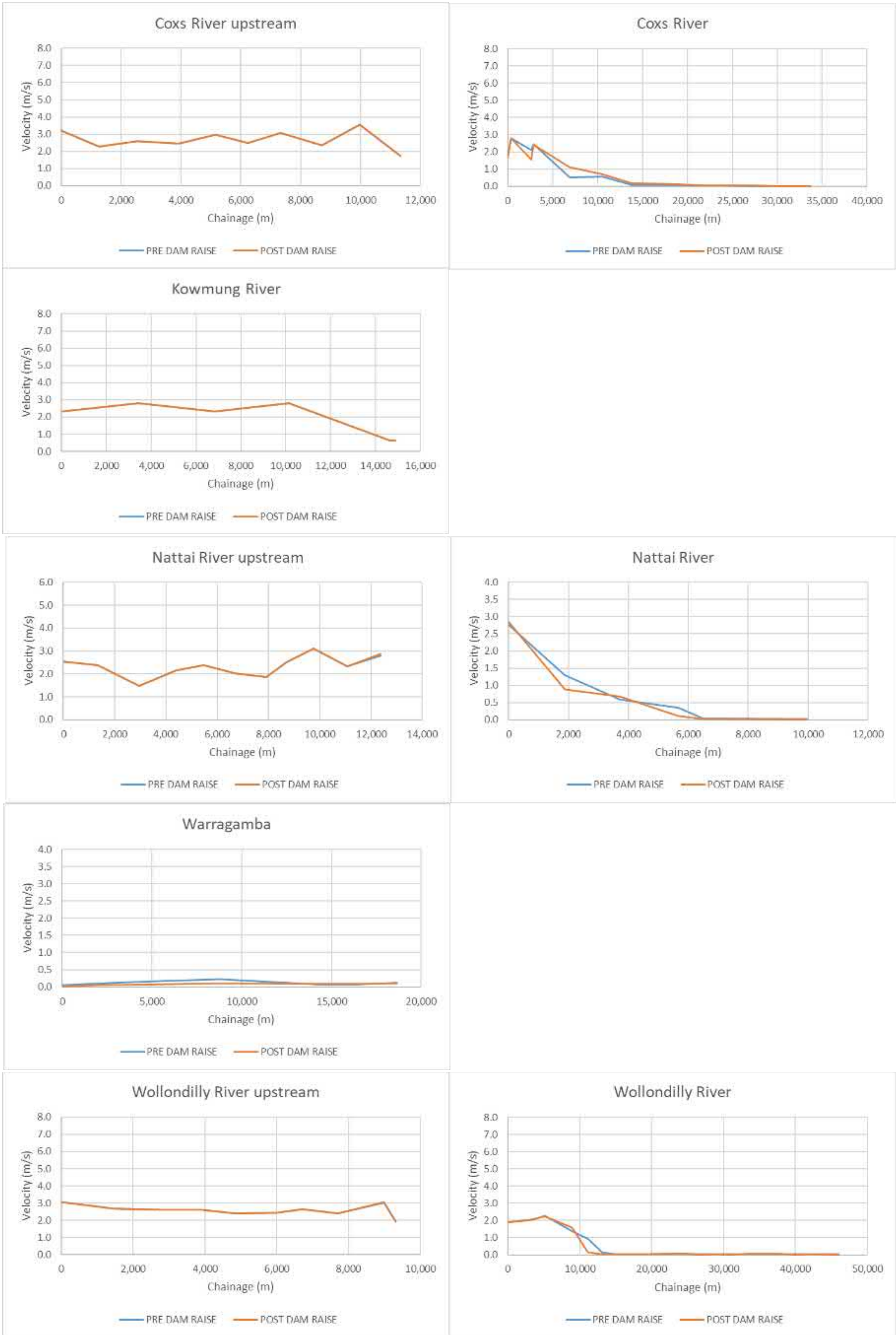
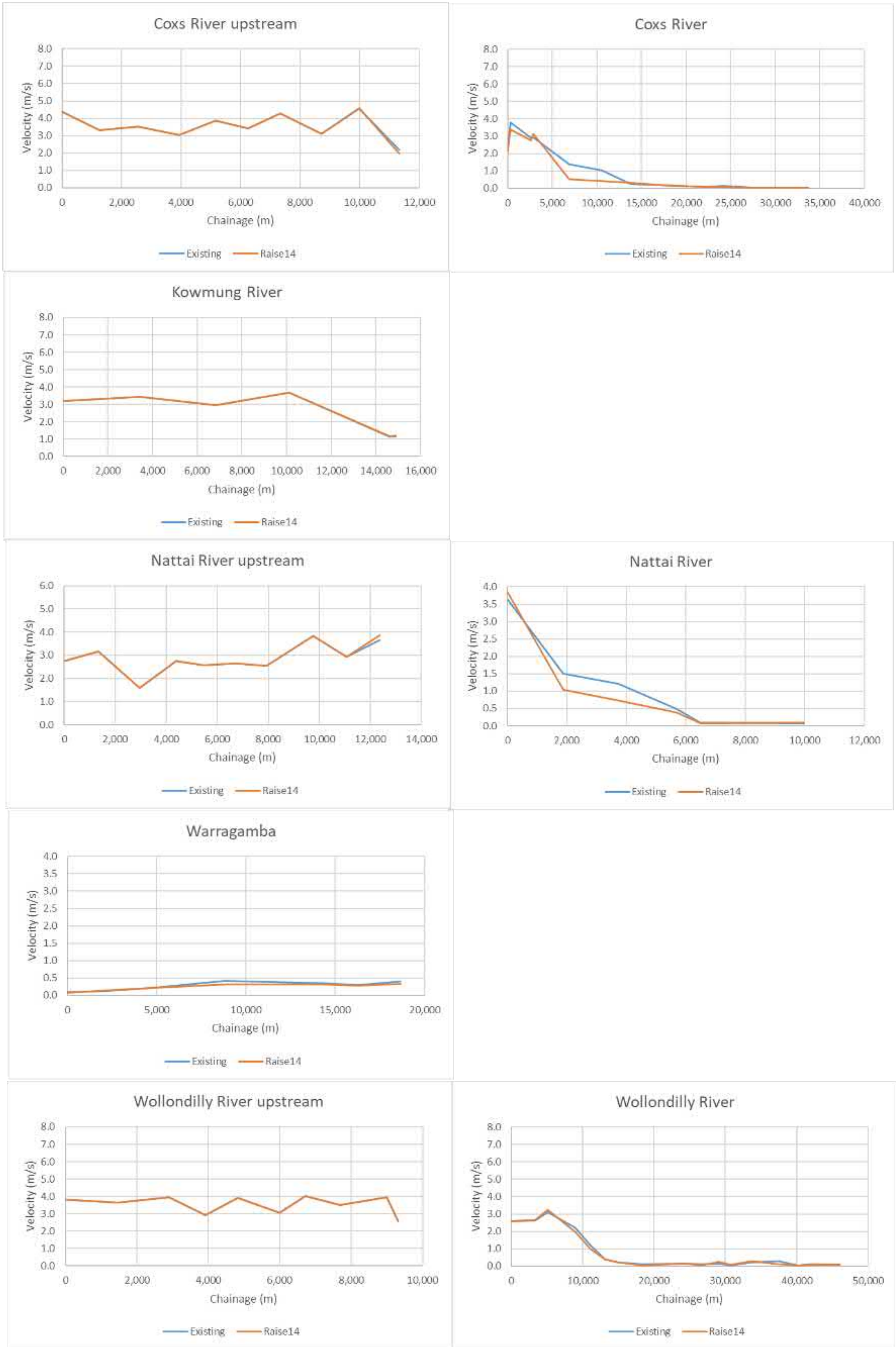


Figure 2 – 0.2 Event



Memorandum

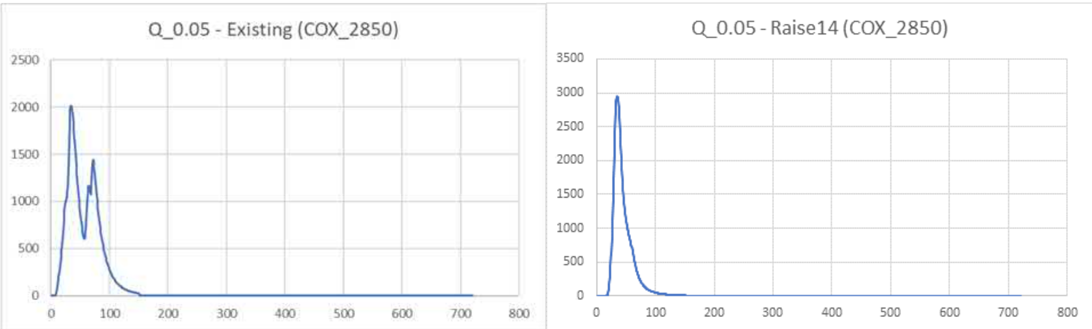
Figure 3 – 0.05 event



We explored the possible reasons for this using the flow and level data we had available. We have used the cross-section COX_2850 as an example (Map 1, see attachments).

Figure 4 shows the 0.05 event at cross-section COX_2850 for both the 'Existing' and 'Raise14' scenarios. In the long section this cross-section shows a higher velocity in the "Raise14' scenario when compared to the 'Existing' scenario. We understand that this cross section is at the upper extent of influence for the existing dam. This cross section shows that under 'Existing' the hydrograph has a double peak, but under 'Raise14' there is a single peaked hydrograph. The peak flow also differs by 1,000 m^3/s. We cannot understand how this can be the case when the event has not changed. It would however go some way to explain why the velocities are higher under the 'Raise14' scenario in the 0.05 event.

Figure 4 – Cross-section COX_2850 under the 0.05 event



Summary: We have found several data points which do not align with our understanding of the modelling undertaken and which violate the requirements of a difference assessment; that being that the dam raise is the only variable being changed. We believe that this is being caused by the differences in flow as shown in example cross section COX_2850. For us to be able to continue we need confirmation from WMA as to what is driving the issues found, and whether they represent the actual conditions in the reservoir pre and post dam raise.

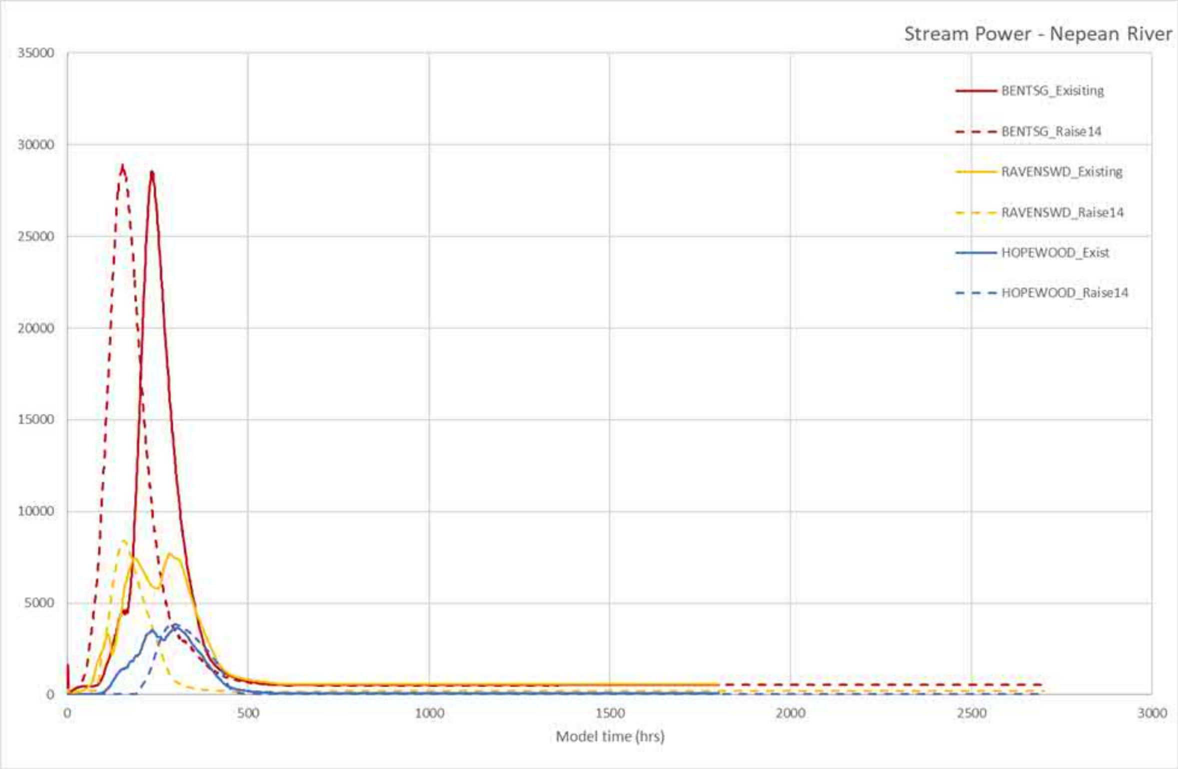
In addition, we consider that manually deriving the velocity data via the supplied spreadsheet is adding unnecessary complication and risk into the process and recommend that velocity data be supplied directly from the hydraulic model for us to undertake a revised assessment of effects.

3.2 Downstream stream power

We undertook a difference assessment of the 'Existing' and 'Raise14' stream power data. Before investigating the effects of the dam raising on the downstream reach of the Nepean River we looked at the supplied model results from the upper Nepean River, above its confluence with the Warragamba River. Our assumption (considering the grade and relative water levels between the sites considered and the main river) was that the upper Nepean River should not be impacted by the dam raising and hence flows and levels, and therefore stream power, should be the same in the 'Existing' and 'Raise14' scenarios.

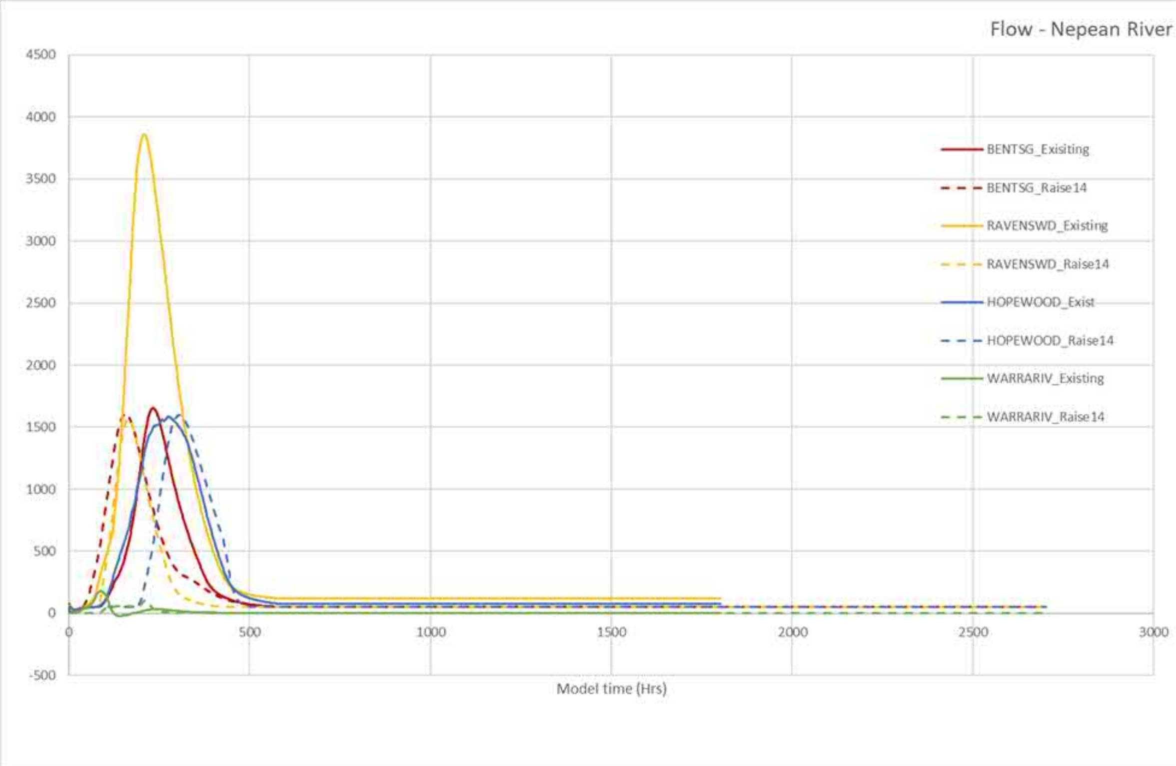
We plotted the stream power for three representative cross-sections on the Upper Nepean River **(Figure 5 + Map 2, see attachments**). For cross-section BENTSG stream power peaks at similar levels, however there is a shift in the timing of the peak. We cannot determine what would cause this shift in timing and this could impact results in the downstream reach of the river due to a difference in the summing of the two hydrographs. For cross-section RAVENSWD and HOPEWOOD we see a change from a double peak stream power profile to a single peak. Again, these raises concerns that the base data for 'Existing' and 'Raise14' are not the same.

Figure 5 – Upper Nepean River | Stream power



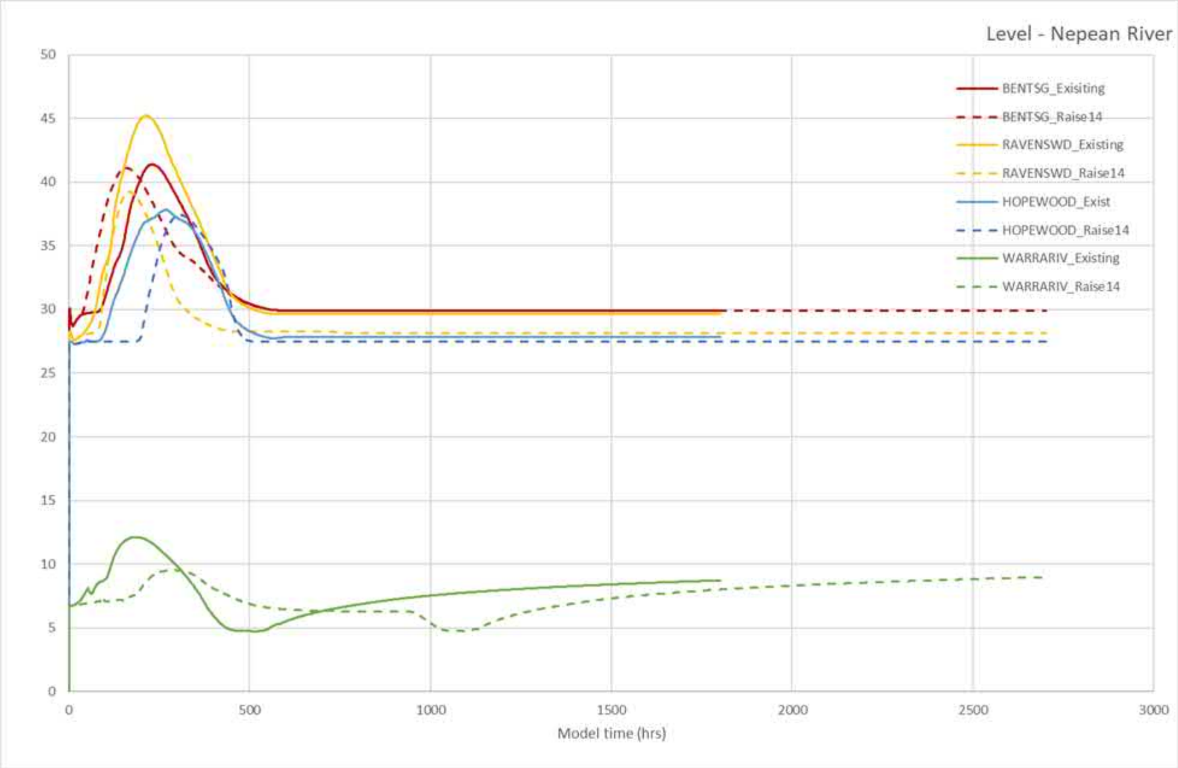
For the same cross-sections we also plotted flow **(Figure 6)**. For flow we observed similar peak flows for 'Existing' and 'Raise14' but again the timings were different. This has the potential to impact the results of a difference assessment undertaken further downstream. The flow results from cross-section RAVENSWD were of concern given the scale of change in the peak flows.

Figure 6 – Upper Nepean River | Flow



Finally, we plotted the water level at these cross sections, along with the water level for WARRARIV, the closest Warragamba River cross-section to the confluence with the Upper Nepean River **(Figure 7)**. Based on the relative levels between the Upper Nepean River and the Warragamba River it does not appear likely that water levels in the Warragamba River influence the levels and flow character of the Upper Nepean River. If this assumption is correct then there is a further variable which is impacting the flow regime of the upper Nepean River, and this violates the terms of our difference assessment.

Figure 7 – Upper Nepean River | Level



Summary: We have found that the stream power, level and flow plots for the Upper Nepean River differ between the 'Existing' and 'Raise14' scenarios and that water levels in the Warragamba River do not appear to be a driving factor.

Given the flow appears to be varying between the 'Existing' and 'Raise14' scenarios in the Upper Nepean River this violates the terms of our proposed difference assessment. We are therefore unable to proceed with our difference assessment for stream power in the lower Nepean River.

For us to continue our work we require feedback from WMA regarding the patterns we have described above.

4 Required next steps

We have found a number of issues with the supplied data. These issues relate to patterns in flow, level, velocity and stream power which we cannot explain, which do not appear to represent the expected change between existing and future conditions, and which are therefore critical to meaningful interpretation of the effects of the dam on geomorphology. The result of this is that we are unable to use the data for the difference assessments we require to complete our geomorphic assessments. We require feedback from WMA regarding the issues we have identified, and confirmation as to whether these patterns are correct. We also recommend that the velocity data be supplied directly from the hydraulic model and that the spreadsheet step in velocity estimation be removed.

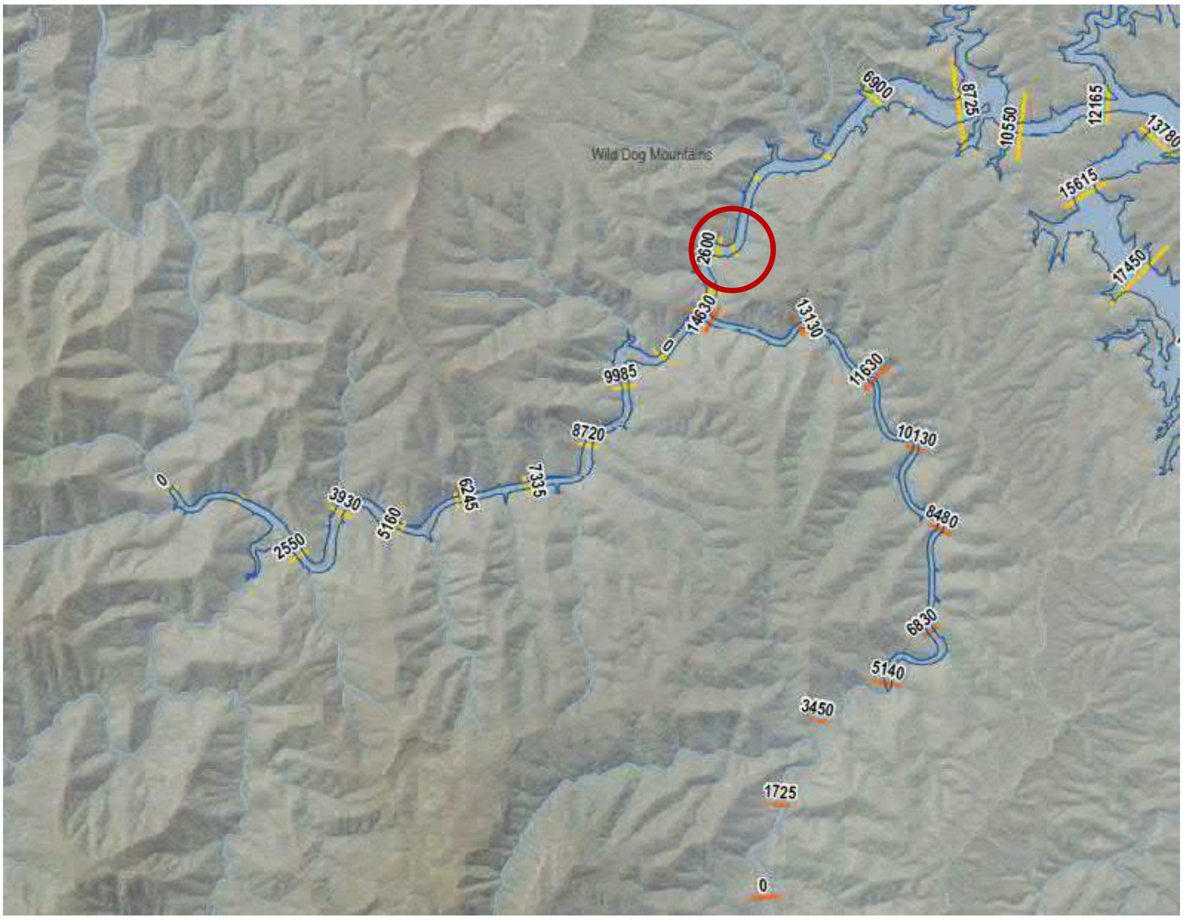
If WMA can confirm the data as being correct, or can supply corrected data, then we will be able to finalise our quantitative assessment based on analysis of the data. If this is not the case, then we will be able to complete the Geomorphic Assessment in a qualitative manner only.

Once you have had a chance to review this information we would appreciated having a discussion with yourselves and WMA to find way to finalise the geomorphology report in a satisfactory manner.

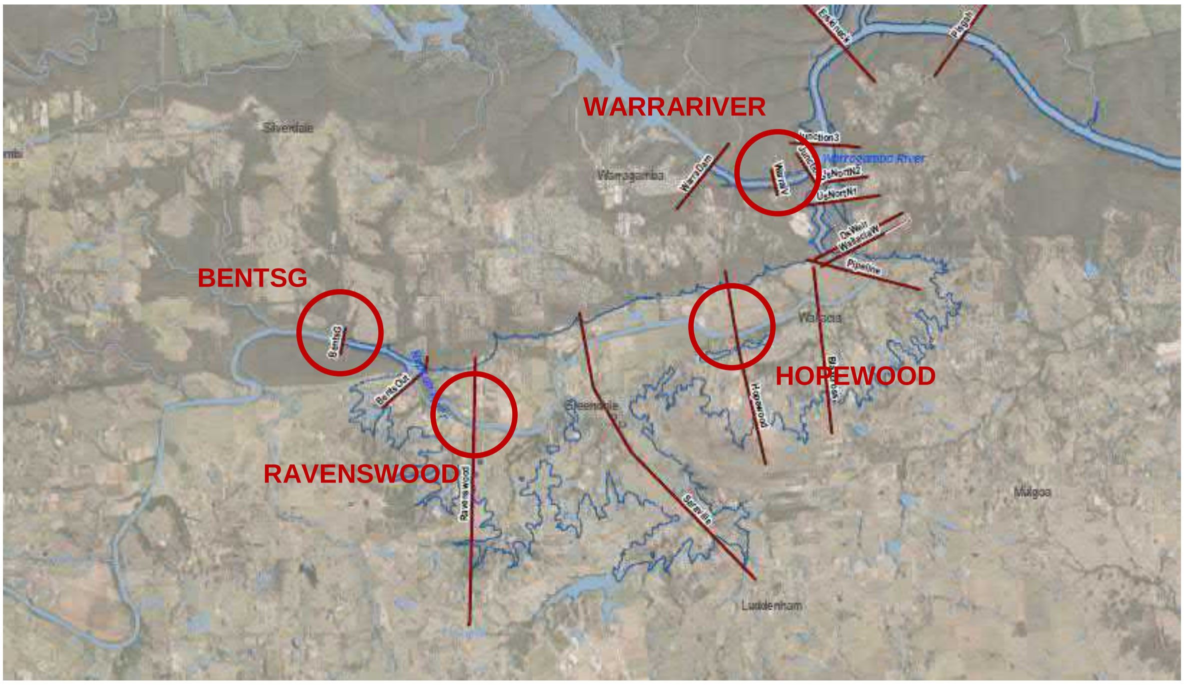
M. Meg

Mark Megaughin
Associate - Water Resources
Phone Number: +64 3 366 3521
Email: mark.megaughin@beca.com

Map 1 – COX_2085 location



Map 2 – Upper Nepean River location



Memorandum

TO: Brian Simmons
FROM: WMAwater
DATE: 23 July 2019
SUBJECT: Upstream Hydrological Dataset Enquiry
PROJECT NUMBER: 113031-08

1. INTRODUCTION

This memorandum has been written to address the Memo from Beca dated 1 July 2019, related to issues they encountered using the supplied upstream hydrological data.

We have found no issues with the data we provided, however we agree that more information in regards to how it was developed will be of more use to Beca in determining the data that best fits their analysis, and how they can use the data already provided.

2. UPSTREAM MODELLING

The Mike-11 hydraulic model has only been used to provide rating curves based on different dam starting levels at each cross section upstream of the dam. The RORB hydraulic model flows combined with a level have been used to determine the flow hydrographs for each of the 20,000 events in the monte carlo and the relevant rating curve has been used to generate the levels. Beca can refer to our Memorandum dated 11 March 2019 for further details on the use of the rating curves for the generation of water level hydrographs.

The AEPs for the water level and flow hydrographs provided have been ranked based on the level at each cross section, scenario independent. Therefore the 1 in 5 AEP will not be achieved by the same event in both the existing and raised scenarios, resulting in different shaped hydrographs as seen in Figure 4 of Beca's memo.

Therefore, due to a range of factors including the level of the dam, the volume in the curve in each particular event, the maximum flow will not always result in the same AEP between scenarios. i.e. flows for a 1 in 5 AEP for the existing dam may not be the same as flows in a 1 in 5 AEP for the raised dam.

3. UPSTREAM VELOCITY CALCULATION

While MIKE-11 is able to output average velocity at a cross section, as the hydraulic model has not been used to output results for each event, velocity has been calculated based on the flow and the cross-sectional area (a function of the level). With events varying on a scenario and cross section basis, comparing velocities in scenarios based on the AEP of the level may not be a fair comparison.

A clearer comparison of the impact of the raised dam on event velocities is illustrated in Figure 1. We have calculated the maximum velocity for all monte carlo events at the Cox 2850 cross section. The 1:1 line is where the velocities between the existing and raised dam is equal. It is expected that the raised dam will reduce velocities through the reservoir and tributaries. This is true for cross section 2850 on the Coxs River Branch (Figure 1), where the majority of data points fall below the 1:1 line.

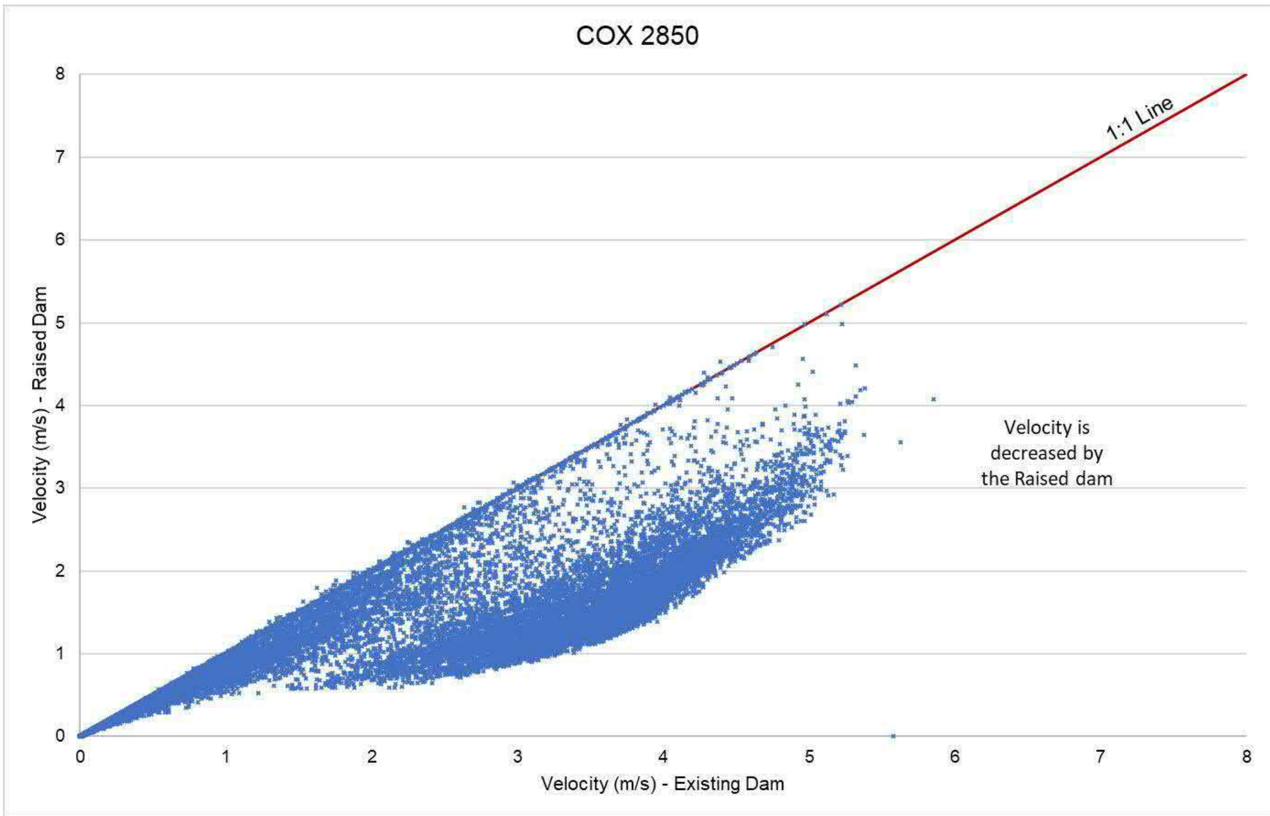


Figure 1: Monte carlo maximum velocities at cross section 2850 on the Coxs River branch

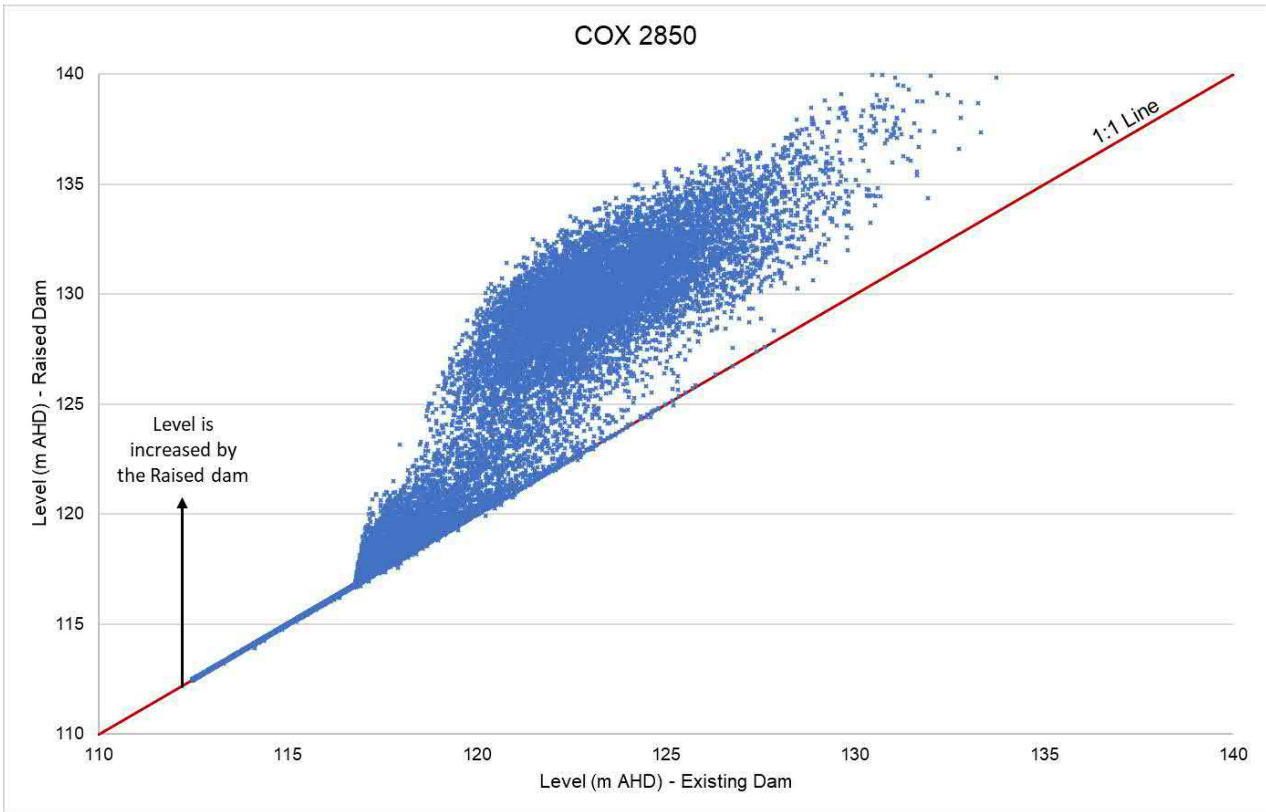


Figure 2: Monte carlo maximum levels at cross section 2850 on the Coxs River branch

As such the analysis could be undertaken by comparing identical events directly between the two scenarios. In this case, the change in dam design would be the only variable, as assumed by Beca. If this type of analysis is used however, it will be important to note that the AEP of the event of interest will not be the same between scenarios, and therefore the comparison may not be able to be reported on the basis of frequency or AEP.

An alternate approach may be to determine the 50th percentile event within an AEP bin. Figure 3 shows the spread of events at each cross section between a 1 in 4.5 AEP and a 1 in 5.5 AEP. In Figure 3 there is some cross over at the 90th percentile line between the velocities of the raised dam and the existing dam near cross section 2600 and 2860. These are the cross sections on the Coxs River located just downstream of the confluence with the Kowmung River, as illustrated on Figure 4. The Kowmung River flows may have an influence on the spread at this location.

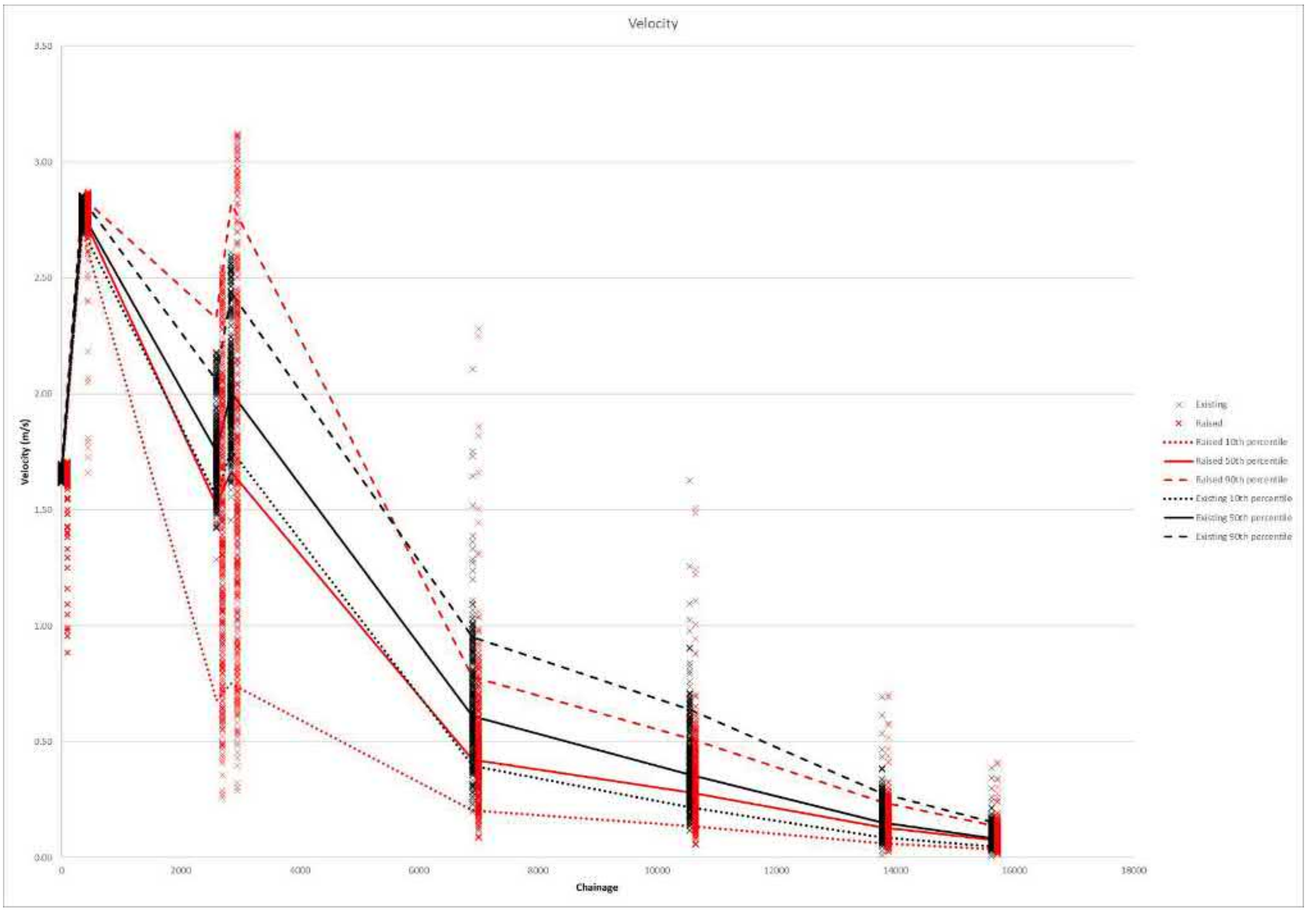


Figure 3: Coxs River Profile - Velocities for the AEP level bin between 1 in 4.5 AEP and 1 in 5.5 AEP

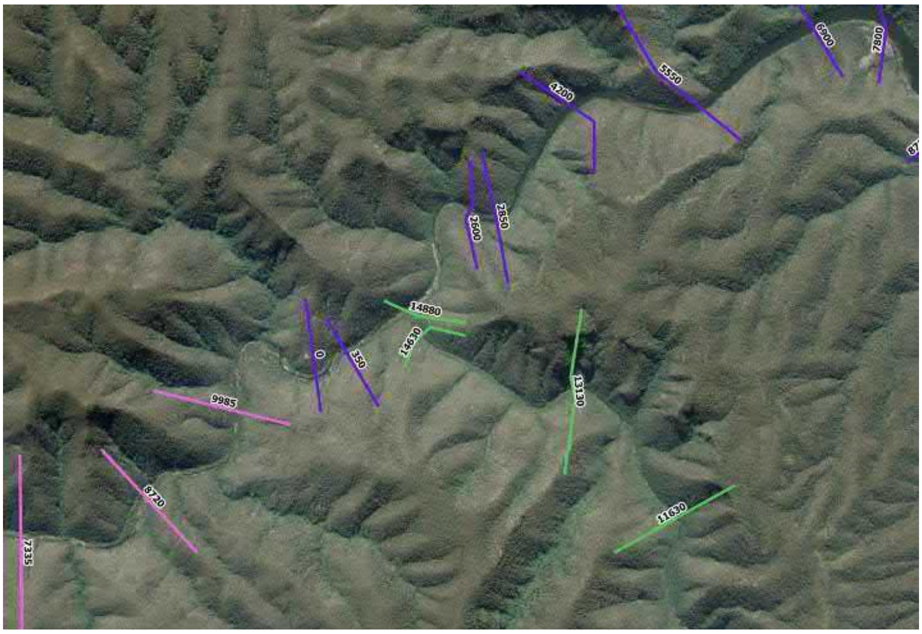


Figure 4: Cross Section layout near the confluence of the Coxs River and the Kowmung River

The level at the dam wall between different events influences the rating curve that is adopted for the conversion of flow to level and thus the estimation of velocity.

Figure 5 shows an event that has been selected as it results in a velocity at the upper limit of the 4.5 to 5.5 AEP bin in Figure 3. For the Existing Dam, the same event results in a 1 in 9.6 AEP based on the maximum level reached at the cross section. In both cases the velocity is 3.1m/s, the maximum level of roughly 120.8m AHD simply occurs more frequently in the raised dam scenario. This influences the spread of results within an AEP bin and can alter the trend of events on the outer limits of the AEP bin as seen with the 90th percentile lines on Figure 3.

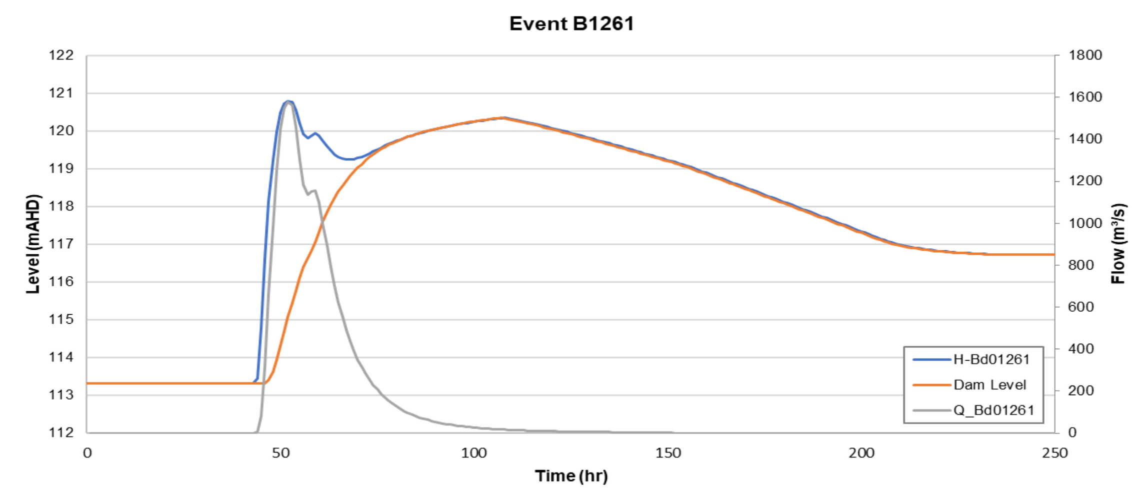


Figure 5: Raised dam, upper limit event at cross section COX 2850

Figure 3 also illustrates that for both the 50th percentile and the 10th percentile, the velocity results are as expected with the 50th percentile velocities of the raised dam AEP bin trending below those for the existing dam AEP bin. This may be a more appropriate approach for determining the impact on velocity between different scenarios within a Monte Carlo Framework. The maximum velocities for the 1 in 5 AEP bin in Figure 3 are listed in Table 1 below.

Table 1: Velocity Percentiles for the 1 in 5 AEP bin

Cross Section Chainage – Coxs River Branch	Existing Dam Velocity by Percentile (m/s)			Raised Dam Velocity by Percentile (m/s)		
	10th	50th	90th	10th	50th	90th
0	1.63	1.66	1.68	1.62	1.65	1.69
350	2.71	2.78	2.84	2.70	2.77	2.85
2600	1.56	1.75	2.06	0.68	1.52	2.33
2850	1.76	2.01	2.44	0.75	1.66	2.82
6900	0.40	0.61	0.95	0.20	0.42	0.78
10550	0.22	0.36	0.64	0.14	0.28	0.51
13780	0.09	0.15	0.28	0.06	0.13	0.24
15615	0.05	0.08	0.15	0.04	0.08	0.14

3.1. Summary – Upstream Velocities

It appears that there is a misunderstanding with regards to how events are being selected and therefore, the potential variables included in the assessment. As the selection is based on events from the monte carlo framework being ranked independent of scenario, different events and flow patterns are selected for the same AEP, between the existing and raised dam cases. Different events will also likely be selected at different cross sections.

Beca raised the issue that the differences in flow seen between the two scenarios invalidate them for use in their assessment. WMAwater suggest that instead the median velocity within an AEP bin is a better measure of the impact of the dam. While the flow hydrographs will again not be equal between the two cases, this will be a better representation of velocity impact. Alternatively, on a larger scale of all 20,00 events, Figure 1 and Figure 2 both adequately show the effect of the dam raising, at an event basis on velocities and levels.

Beca have also expressed issue with the use of a velocity spreadsheet, used to convert flows to velocities at a cross section. The methodology used to calculate upstream hydraulic properties using of rating curves is explained in Section 2, and the WMAwater memo supplied with the data. It is not feasable for this project to extract velocities for all 20,000 events in the monte carlo from the Mike 11 hydraulic model and even so, the velocities for particular AEPs will not be from identical events.

4. STREAM POWER

WMAwater wrote a memo in Feburary 2019 detailing our approach for the calculation of stream power, which was approved by Beca. As a general overview however, the stream power equation adopted is as follows:

$$SP = S.Q.\rho.g$$

Where
SP = stream power
S = water level slope (m/m)
Q = flow (m^3/s)
ρ = density (1000 kg/m^3)
g = gravity (9.81m/s^2)

Slope has been calculated as the average of the water level slope in the upstream direction and the downstream direction at each cross section. The AEP was then extracted by ranking the maximum stream power value from all monte carlo results at each cross section.

4.1. Upper Nepean - Stream Power between the Existing and Raised Scenarios

The assumption made by Beca that stream power will not be impacted in the upper Nepean is not correct. There is significant backwatering up to Wallacia in the existing dam scenario. Figure 6, Figure 7, and Figure 8 show the water level impact of the raised dam on a range of events. In Wallacia, water levels are reduced by up to 6m in the 1 in 5000 AEP event. This reduction in backwater level will affect the water level slope, and therefore the stream power is expected to be higher in the raised dam scenario due to an increase in slope. This is clear in Table 2 and Table 3, where the same event (the 1 in 100 AEP representative event) produces notably higher stream power values in the raised scenario.

Table 2: Stream Power based on an event - Upper Nepean, Event R8858, Raised Dam

Cross Section	Flood Level (m AHD)	Chainage (m)	Ave Slope (m/m)	Flow (m^3/s)	Stream Power
BENTSGORGE	45.03	19380			
BENTSG	**44.93**	**19400**	**0.00332**	**3682**	**119920**
BENTSOUT	43.89	19980			
RAVENSWD	**43.17**	**21380**	**0.00038**	**3661**	**13781**
SARAVILLE	42.39	24480			
HOPEWOOD	**41.95**	**27380**	**0.00014**	**3567**	**4859**
BLAXCROSS	41.77	28780			

Table 3: Stream Power based on an event - Upper Nepean, Event R8858, Existing Dam

Cross Section	Flood Level (m AHD)	Chainage (m)	Ave Slope (m/m)	Flow (m^3/s)	Stream Power
BENTSGORGE	46.20	19380			
BENTSG	**46.12**	**19400**	**0.00251**	**3679**	**90715**
BENTSOUT	45.44	19980			
RAVENSWOOD	**45.09**	**21380**	**0.00017**	**3667**	**6064**
SARAVILLE	44.82	24480			
HOPEWOOD	**44.67**	**27380**	**0.00005**	**3730**	**1763**

BLAXCROSS	44.60	28780			

4.2. Impact of water level slope on hydrograph selection

Beca has observed that the shape and timing of hydrographs of events of a given AEP are not the same for flow or level between the existing and raised scenarios. This is to be expected as different events out of the monte carlo may produce a certain AEP of stream power within each scenario. It is also to be expected that the peak flow for these events may be different. The outflows of the dam and slope of the water level through Wallacia will affect the stream power and therefore the upper Nepean flow that produces, say a 1 in 5 AEP stream power will vary.

Table 4: 1 in 5 AEP stream power variable comparison based on AEP, Existing versus Raised Dam scenarios

	Slope (m/m)			Flow (m³/s)			Stream Power at Max Height	
	Existing	**Raised**	**Change in Slope**	**Existing**	**Raised**	**Change in Flow**	**Existing**	**Raised**
BENTSG	0.0015	0.0015	0.0000	1032	1126	94	15029	17076
RAVENSWD	0.0001	0.0005	0.0004	2700	1143	-1557	2875	6052
HOPEWOOD	0.0003	0.0003	0.0000	999	1113	114	2591	2893

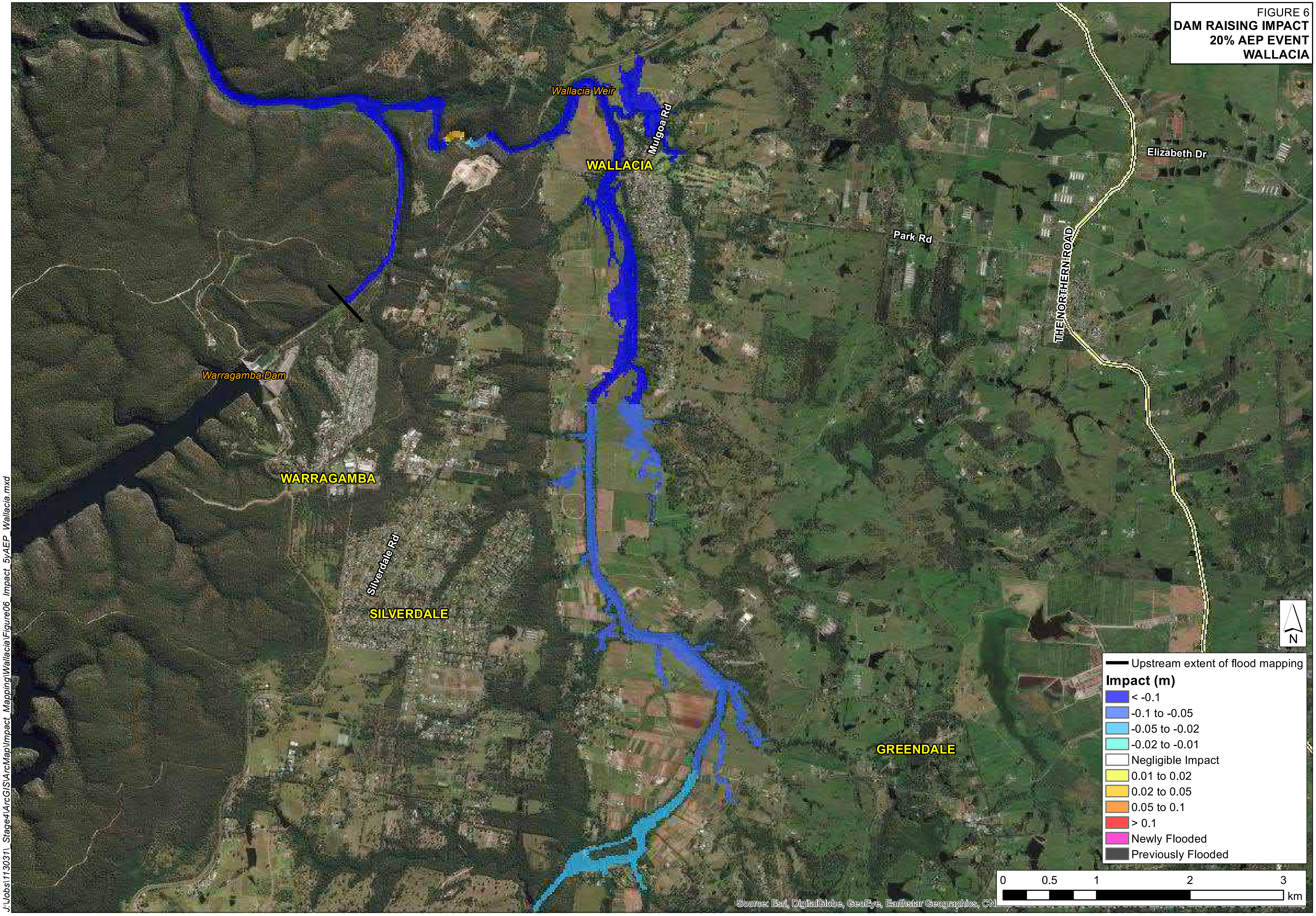
While Table 2 and Table 3 compare stream power results for a particular event ID, Table 4 compares Stream power for a single AEP. Thus, the event ID selected to represent a 1 in 5 AEP stream power is different for each scenario.

Table 4 shows that between the two scenarios, the event that produces a 1 in 5 AEP stream power has a very similar slope at the BENTSG cross section. It is likely that the reduction in backwater at Wallacia due to the raised has a negligible effect at cross section BENTSG. Again, the water level slope at the HOPEWOOD cross section is similar in both scenarios indicating that it is equally affected by backwater from the dam releases. RAVENSWD in this scenario is the location where the slope is most impacted by the reduction in levels caused by the raised dam. It is therefore expected that an event with a significantly higher flow can produce an equivalent AEP of stream power at a particular cross-section.

4.3. Summary – Upper Nepean Stream Power

Our review does not reveal any problems with the data provided to SMEC and Beca. It is acknowledged that the use of a Monte Carlo assessment however, means that the event will change between cross sections and scenarios, and thus there are variables beyond the dam design that are evident in the results.

A decision on the required data moving forward would benefit from further discussion with Beca.



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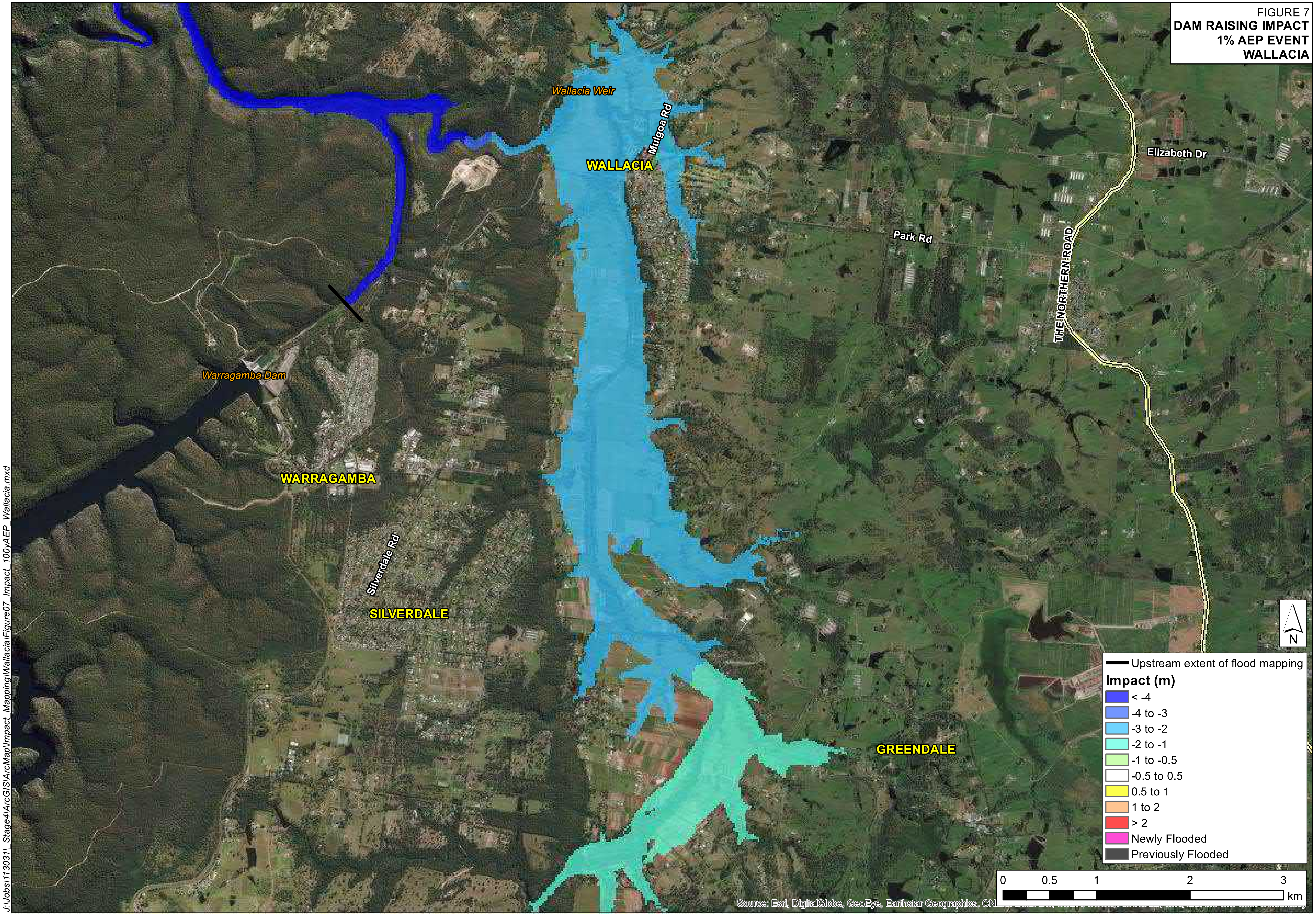

FIGURE 7
DAM RAISING IMPACT
1% AEP EVENT
WALLACIA

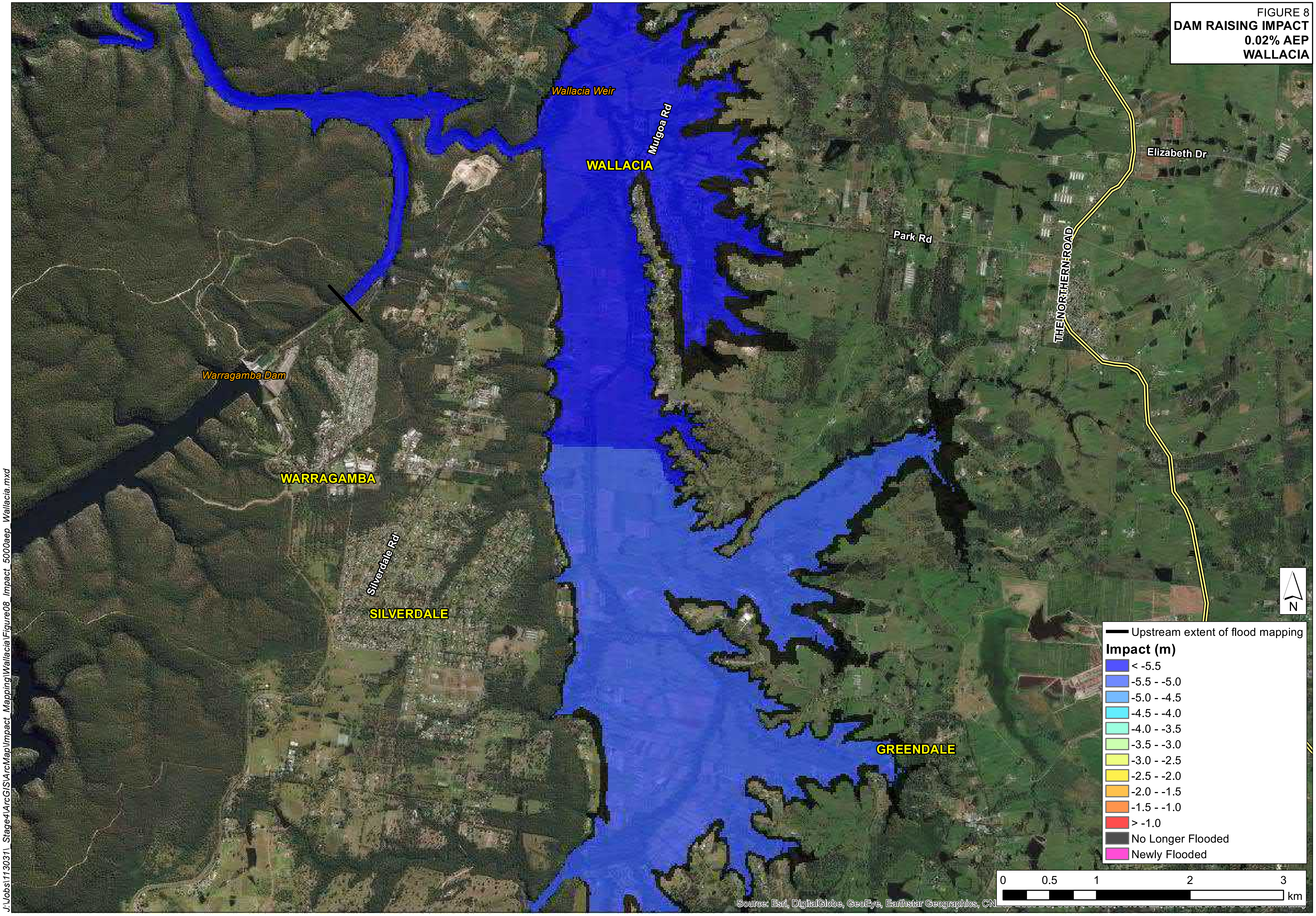
FIGURE 8
DAM RAISING IMPACT
0.02% AEP
WALLACIA
Wallacia Weir
Mulgoa Rd
WALLACIA
Elizabeth Dr
Park Rd
THE NORTHERN ROAD
Warragamba Dam
WARRAGAMBA
Silverdale Rd
SILVERDALE
GREENDALE
Upstream extent of flood mapping
Impact (m)
< -5.5
-5.5 - -5.0
-5.0 - -4.5
-4.5 - -4.0
-4.0 - -3.5
-3.5 - -3.0
-3.0 - -2.5
-2.5 - -2.0
-2.0 - -1.5
-1.5 - -1.0
> -1.0
No Longer Flooded
Newly Flooded
N
0 0.5 1 2 3
km
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CN
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C

Appendix C – Aerial Photography Analysis

C.1 Upstream Zone

WDR EIS (Beca reference # 4512987) – US01

			
10/2009	01/2014	07/2015	10/2016

WDR EIS (Beca reference # 4512987) – US02

10/2009

03/2014

05/2016

10/2016

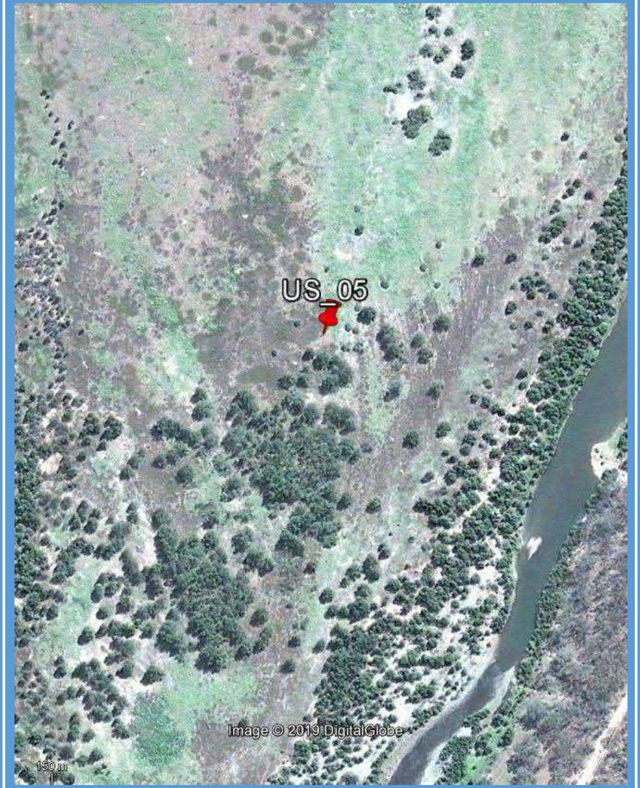
WDR EIS (Beca reference # 4512987) – US03

10/2009	03/2014	12/2015	12/2018

WDR EIS (Beca reference # 4512987) – US04

10/2009	03/2014	05/2016	12/2018

WDR EIS (Beca reference # 4512987) – US05

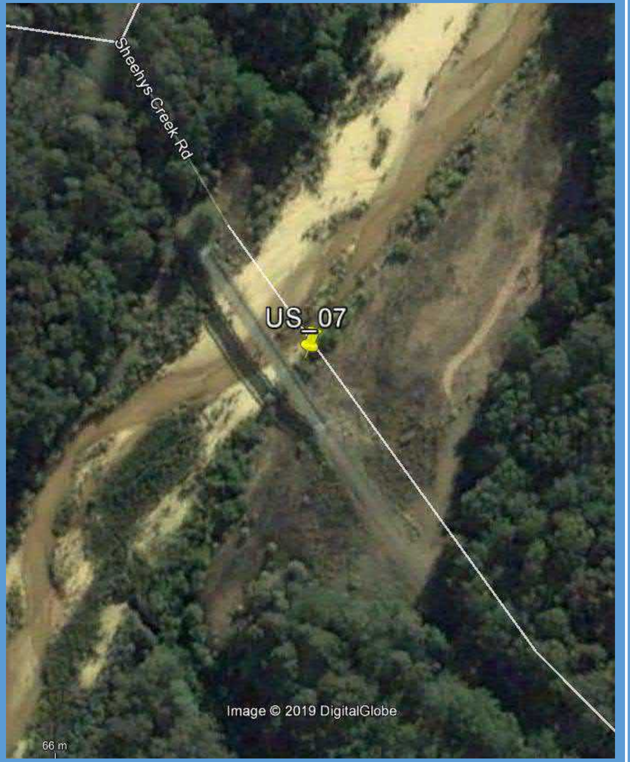


01/2002	10/2009	12/2015	12/2018

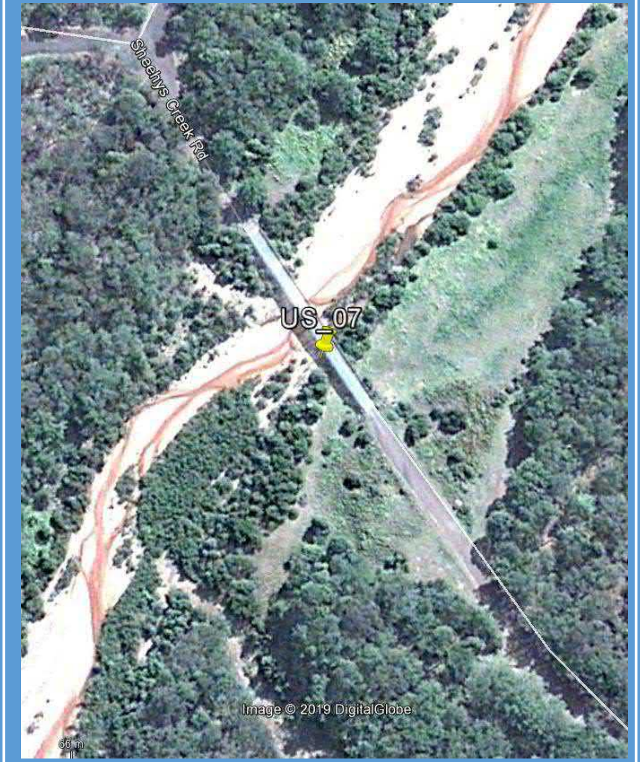
WDR EIS (Beca reference # 4512987) – US06

01/2002	10/2009	05/2016	01/2019

WDR EIS (Beca reference # 4512987) – US07



07/2006

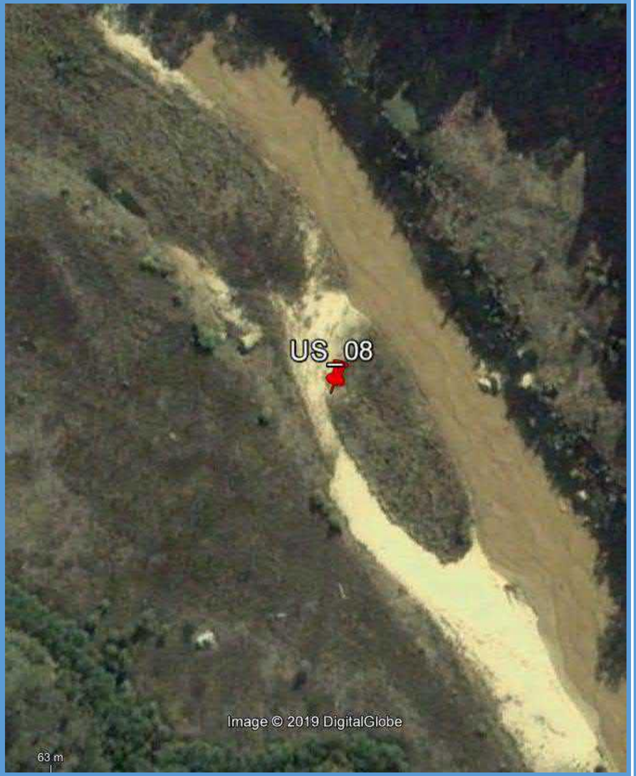


10/2009

11/2013

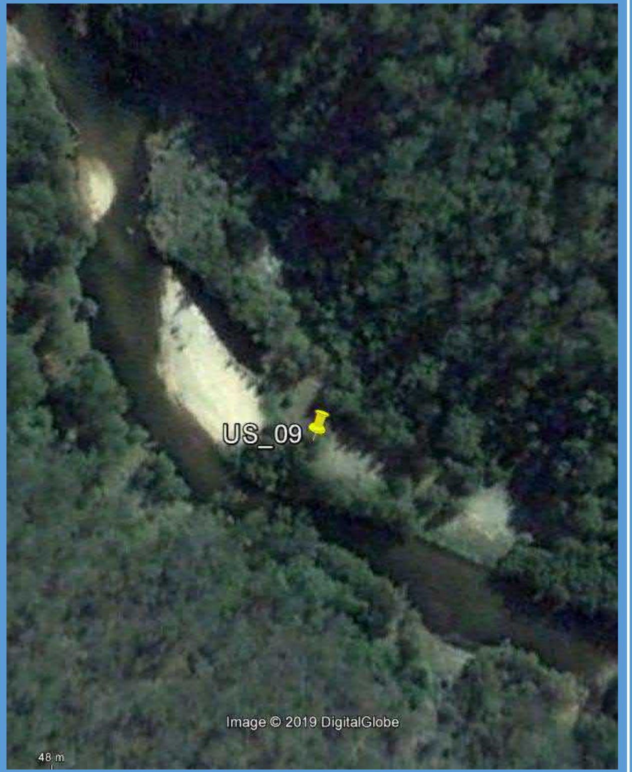
01/2019

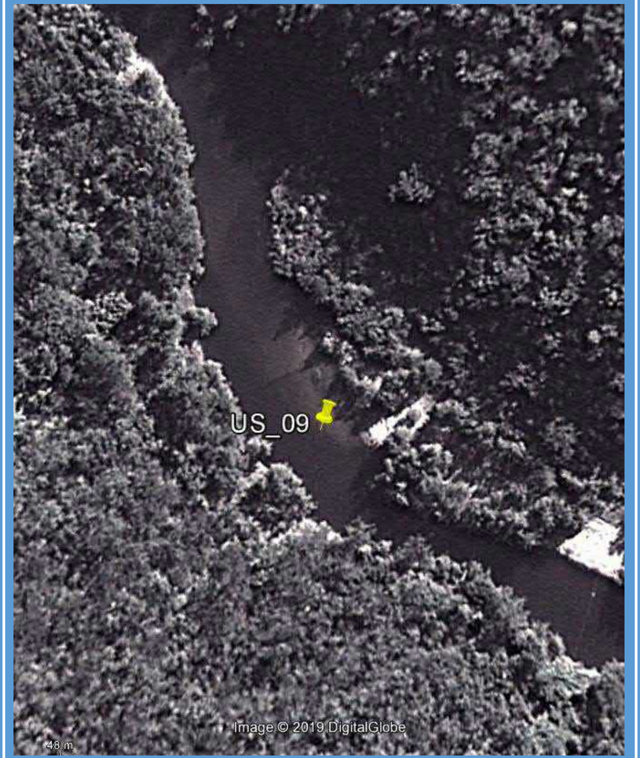
WDR EIS (Beca reference # 4512987) – US08

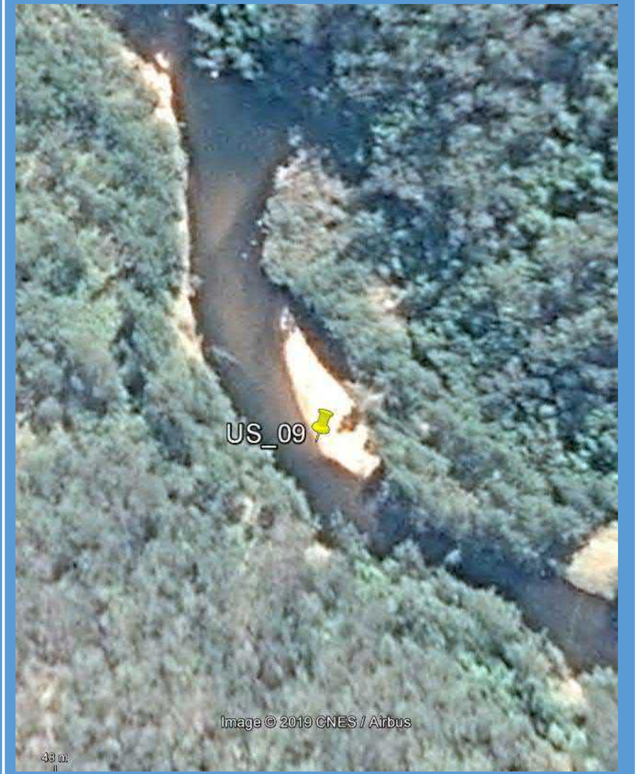


07/2006	01/2010	11/2013	01/2019

WDR EIS (Beca reference # 4512987) – US09







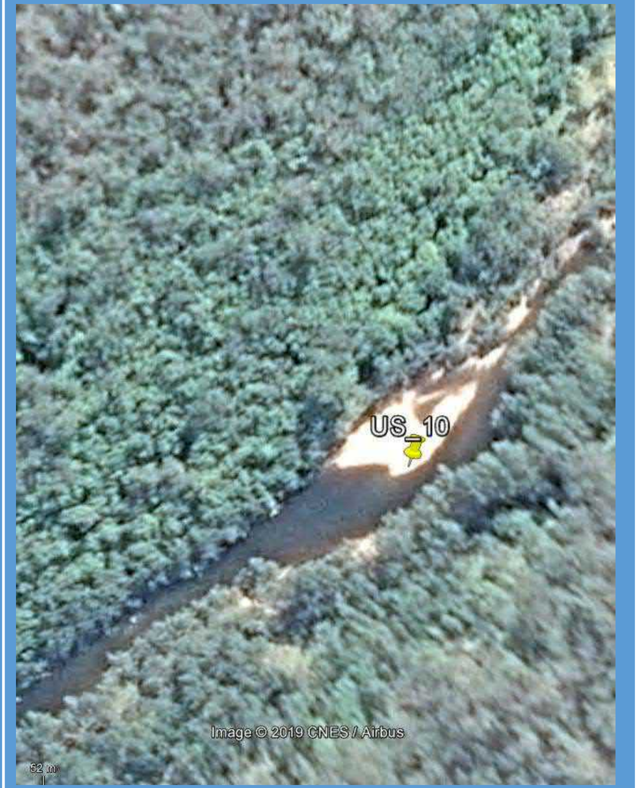
03/2006	03/2012	03/2014	10/2016

WDR EIS (Beca reference # 4512987) – US10

03/2006

03/2012

03/2014



10/2016

WDR EIS (Beca reference # 4512987) – US11

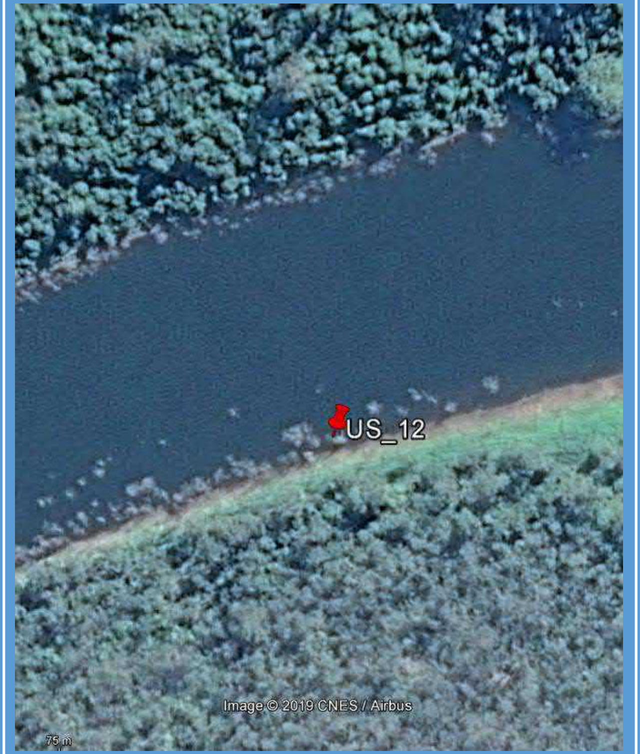
03/2006

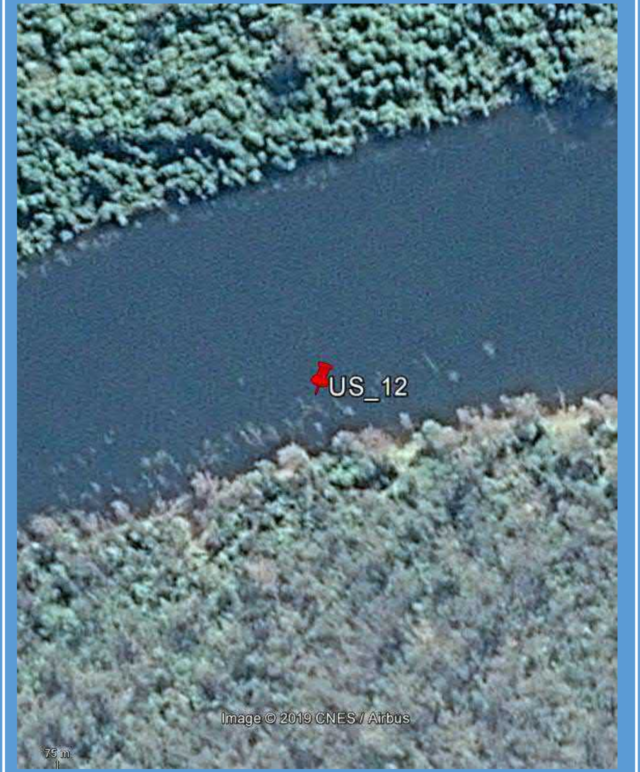
10/2013

12/2015

07/2017

WDR EIS (Beca reference # 4512987) – US12





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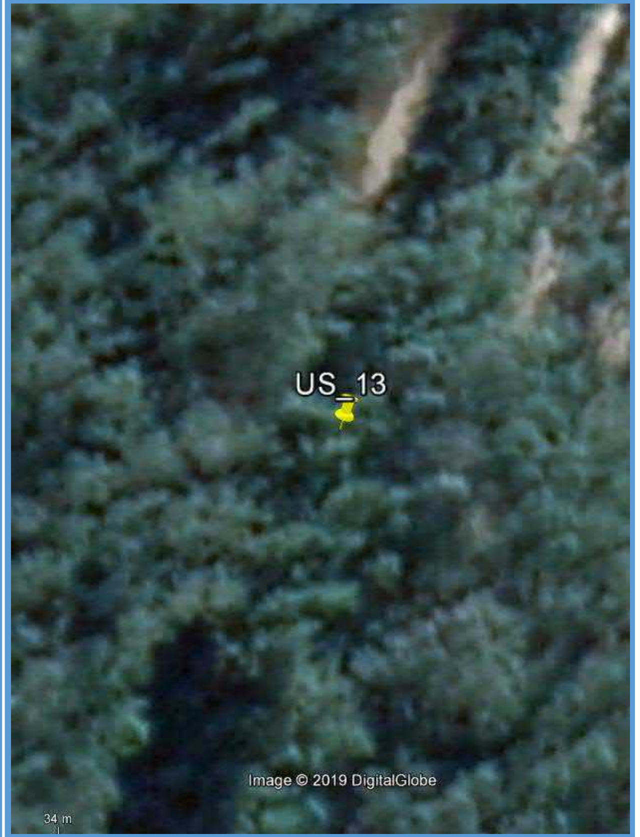
WDR EIS (Beca reference # 4512987) – US13

			
03/2006	02/2013	12/2015	07/2017

WDR EIS (Beca reference # 4512987) – US14

03/2006

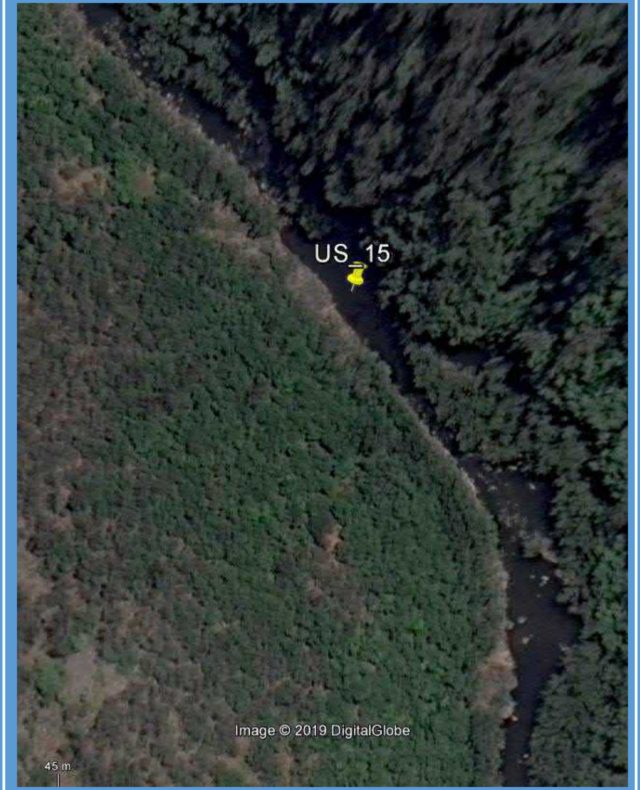
03/2014

10/2016

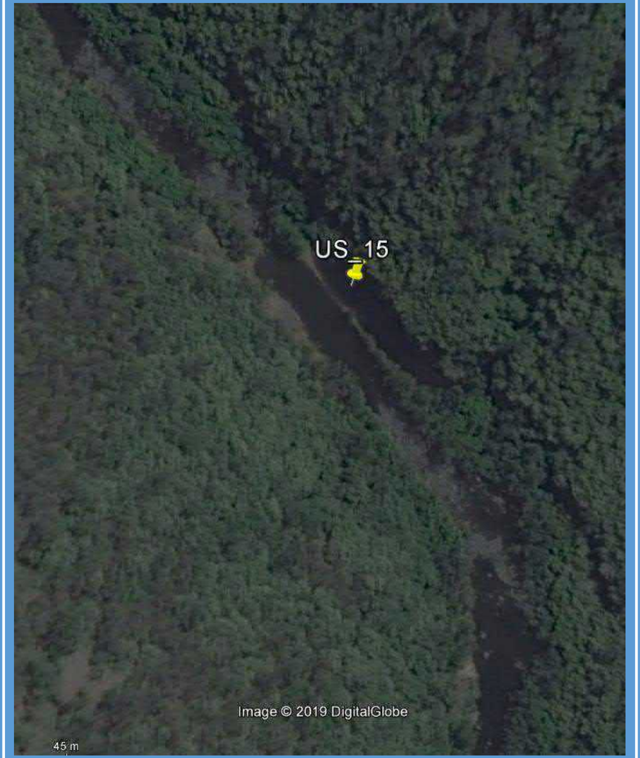
07/2017

WDR EIS (Beca reference # 4512987) – US15

03/2006



10/2014



12/2015

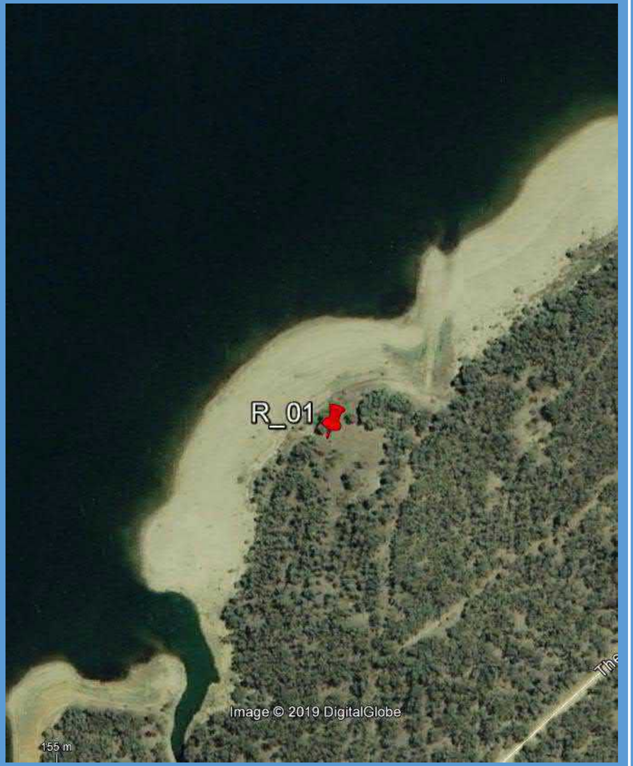
07/2017

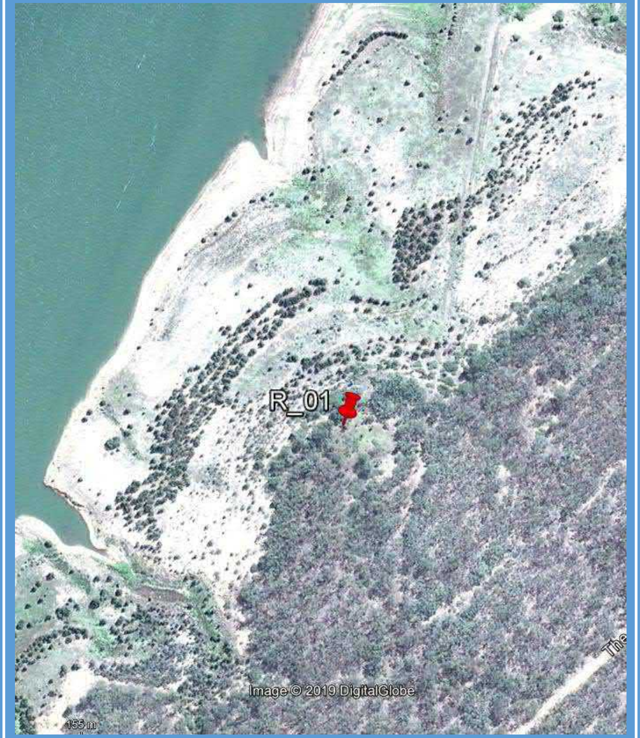
WDR EIS (Beca reference # 4512987) – US16

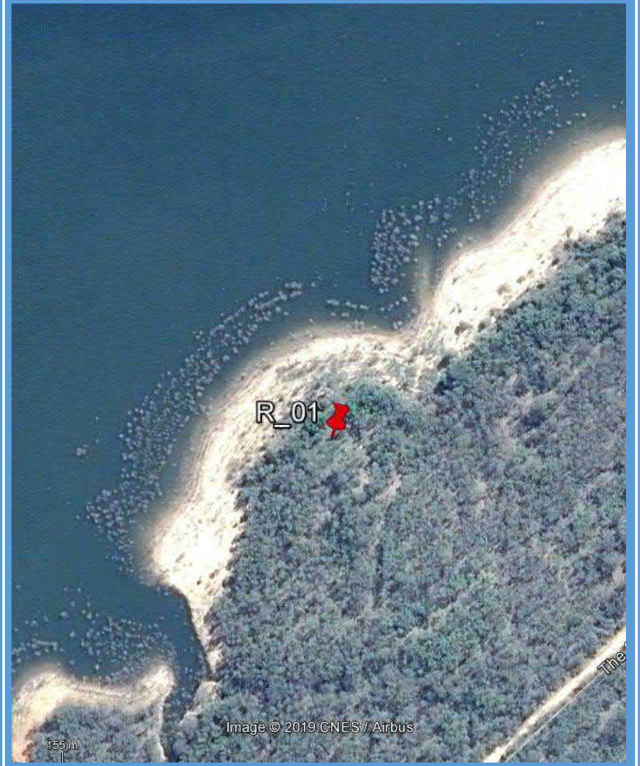
03/2006	10/2014	12/2015	07/2017

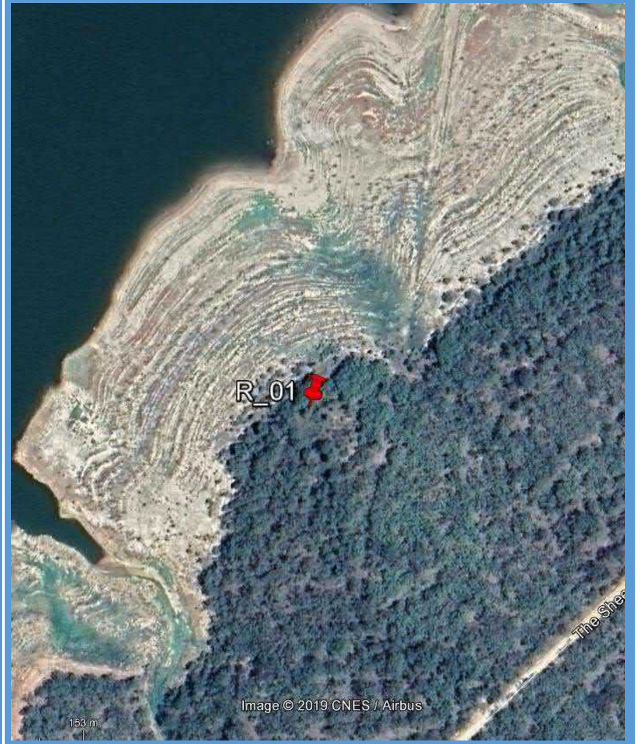
C.2 Lake Zone

WDR EIS (Beca reference # 4512987) – R01



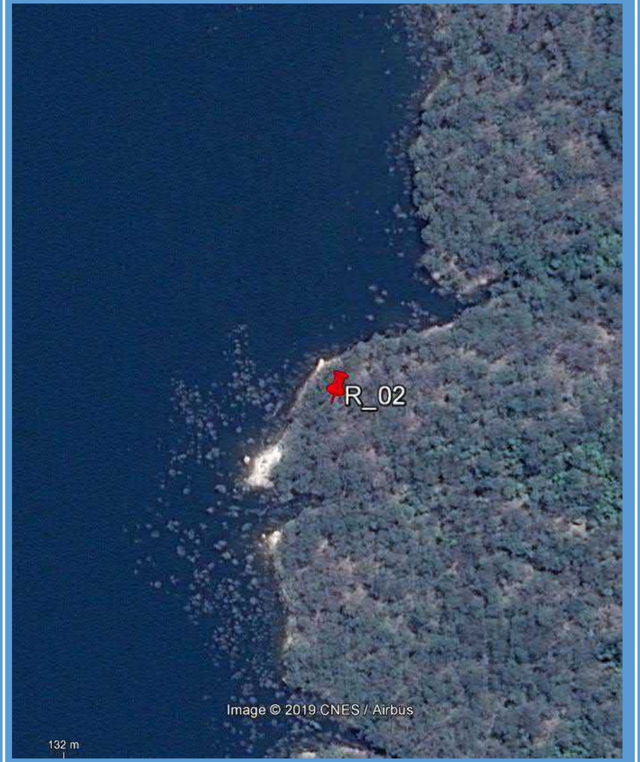


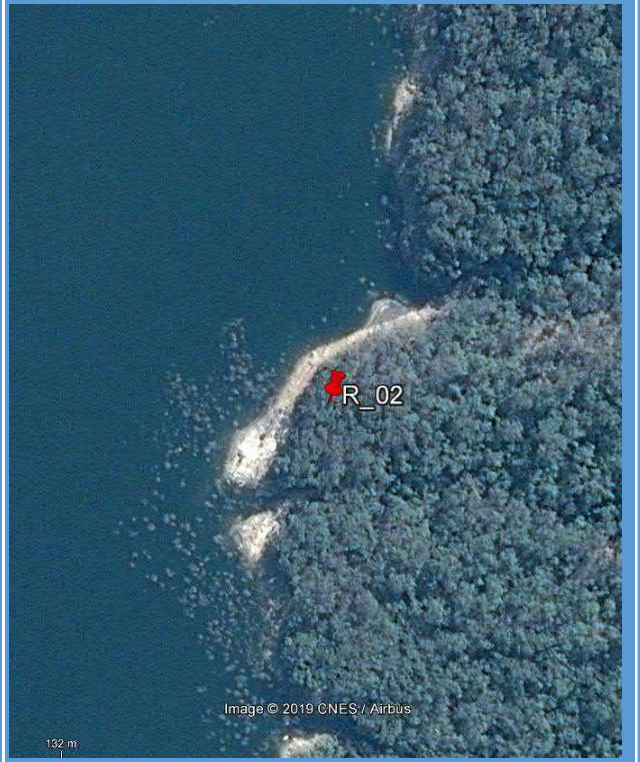




01/2002	10/2009	03/2014	01/2019

WDR EIS (Beca reference # 4512987) – R02

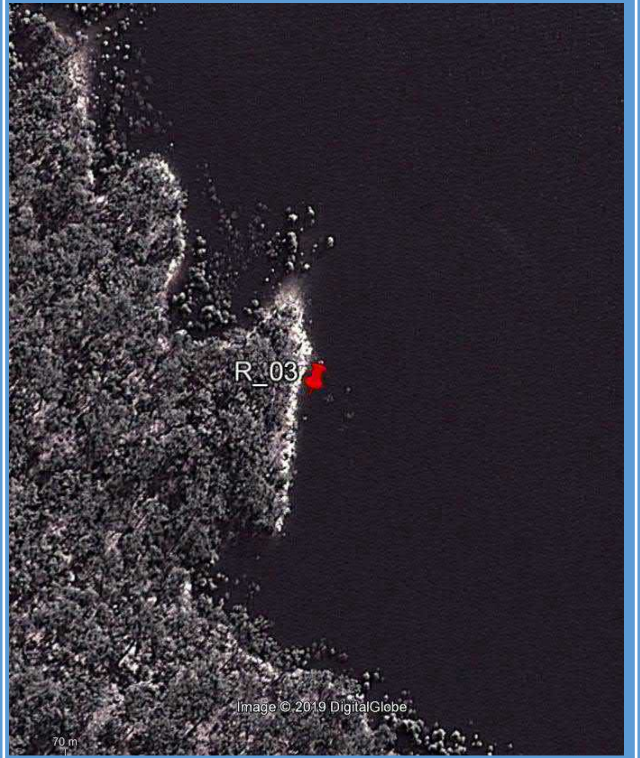




01/2010	11/2013	05/2016	03/2019

WDR EIS (Beca reference # 4512987) – R03

03/2006

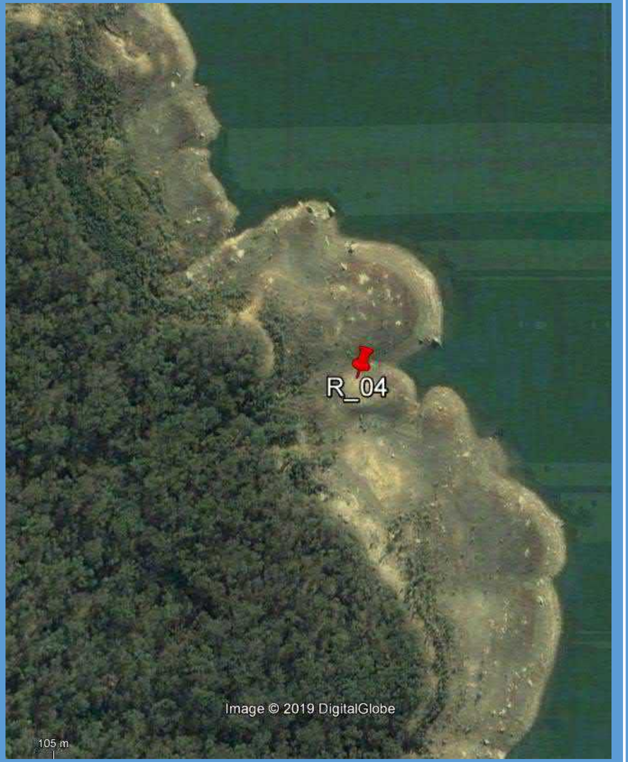


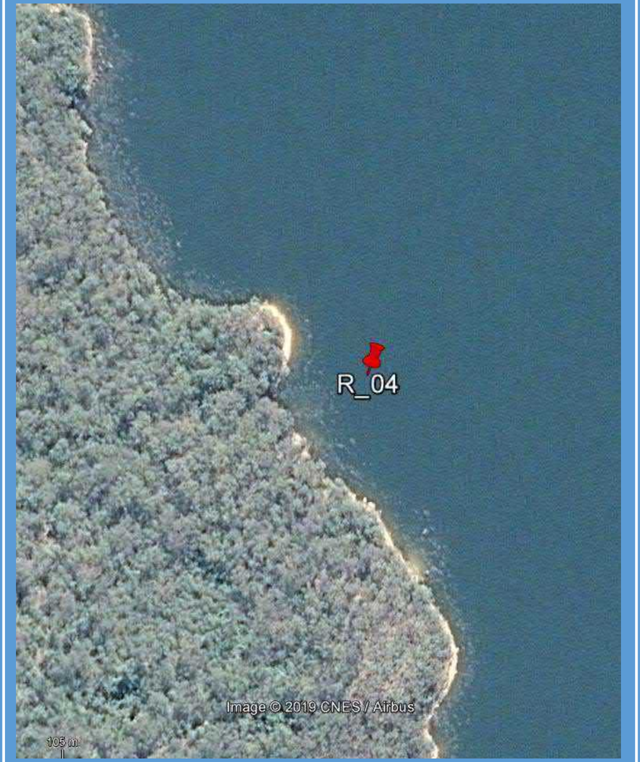
03/2012

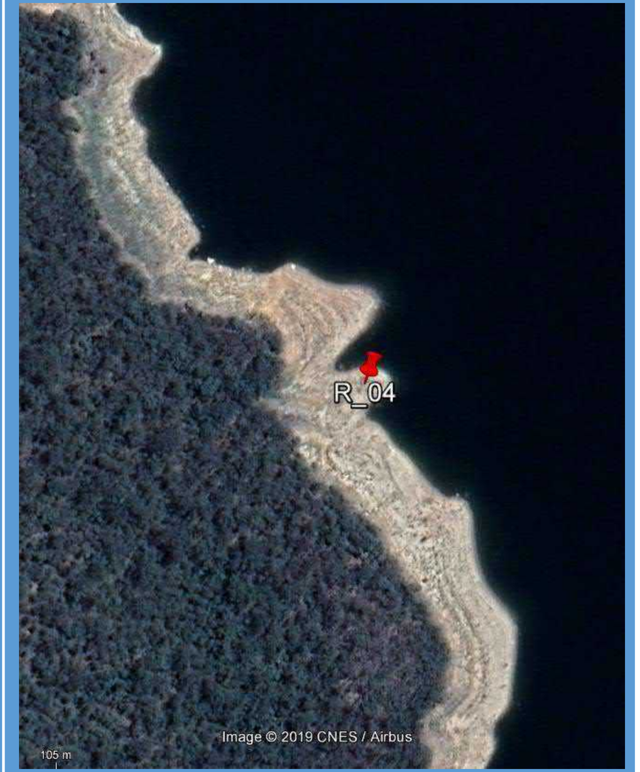
10/2014

10/2016

WDR EIS (Beca reference # 4512987) – R04







07/2006	02/2013	10/2016	10/2018

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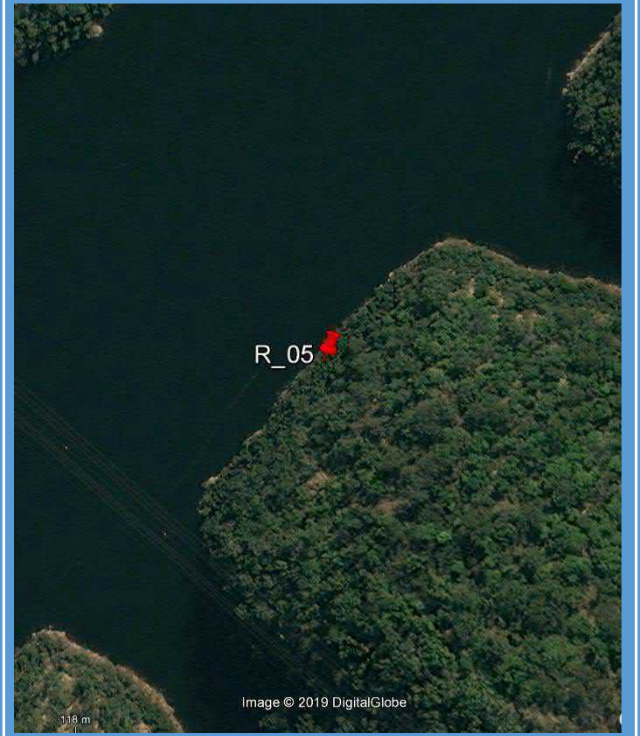

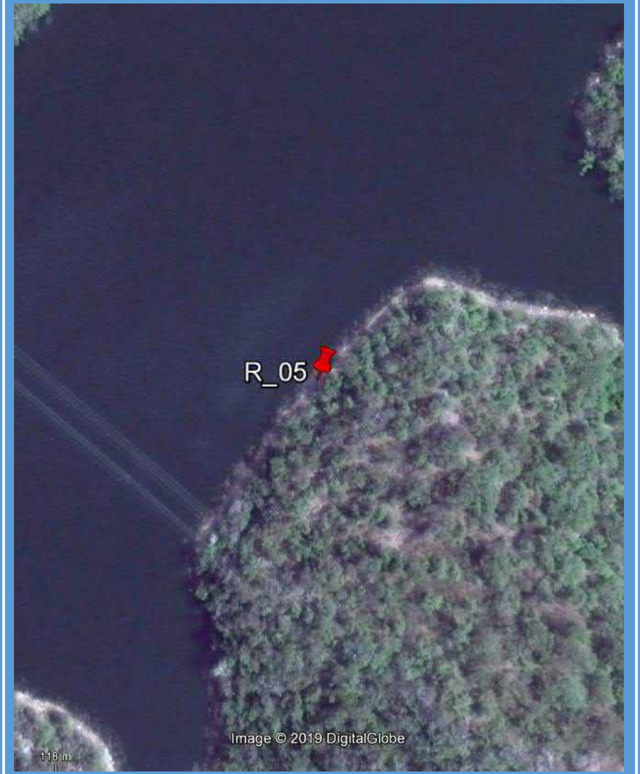

07/2006	04/2010	11/2014	10/2018

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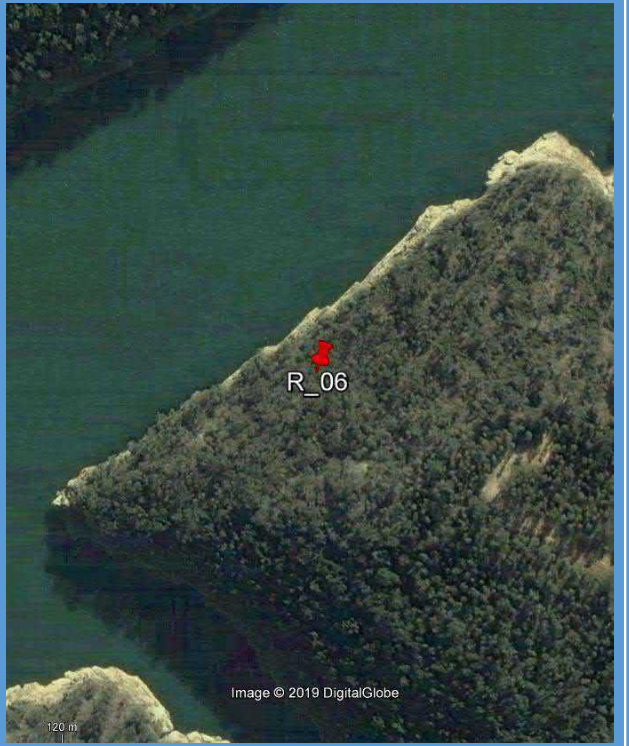
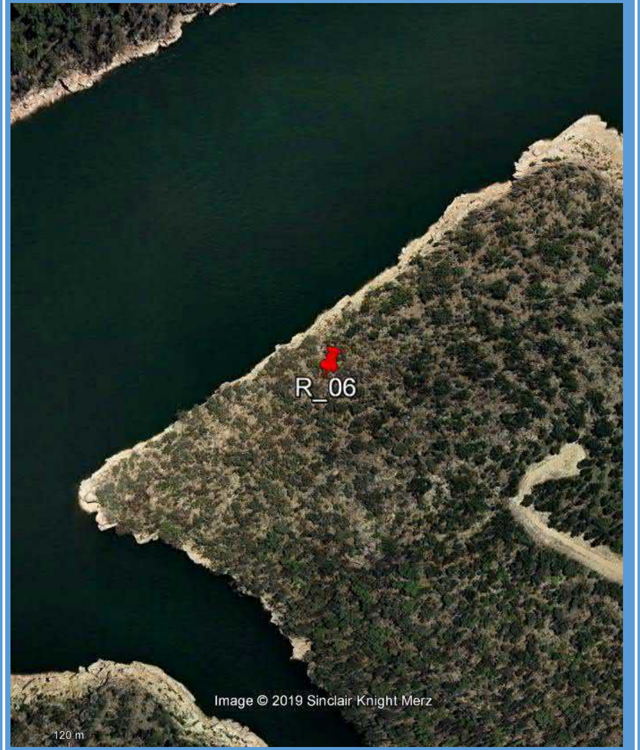
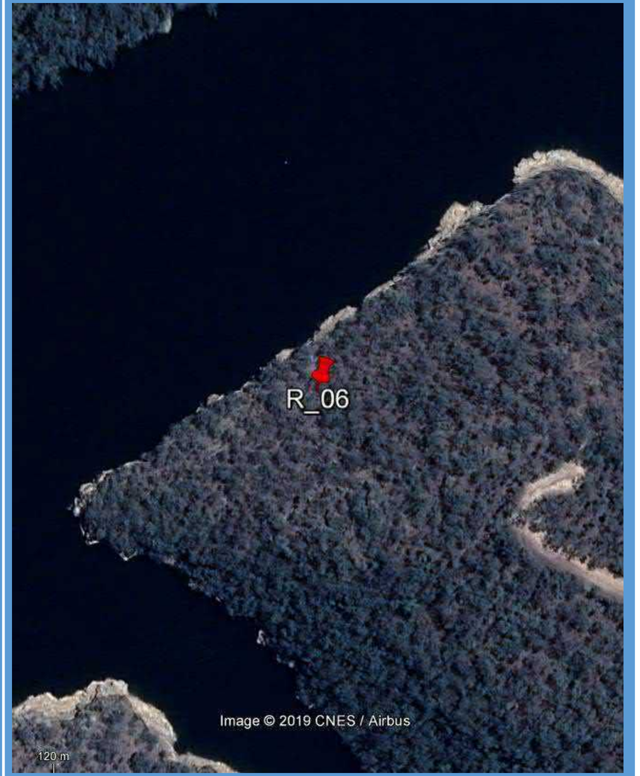
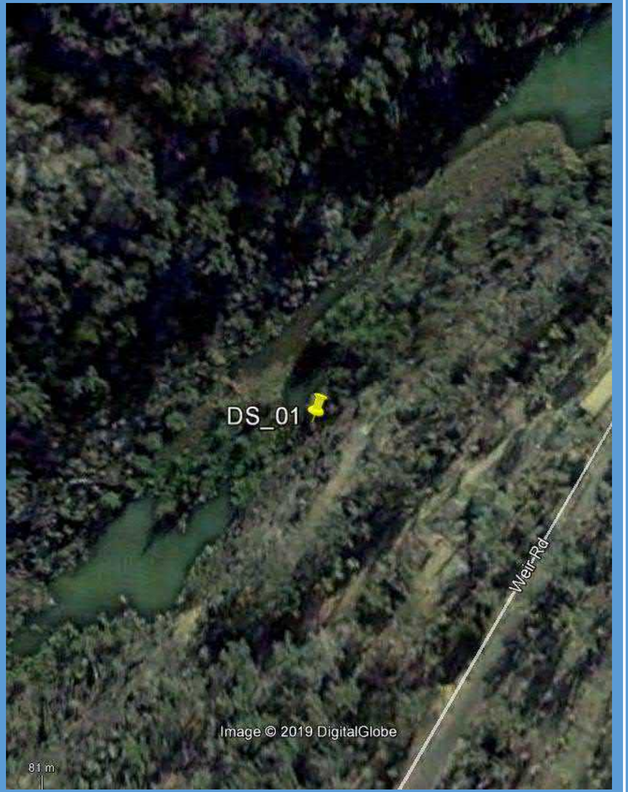
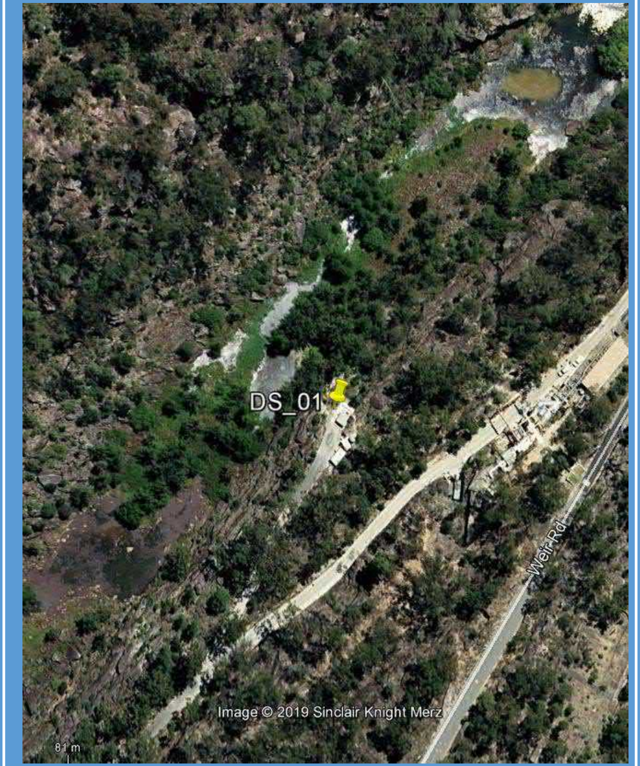
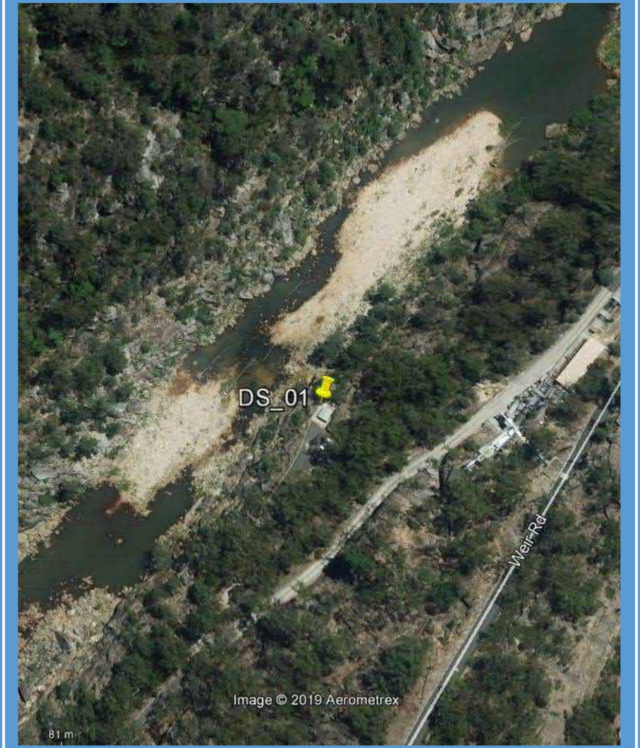
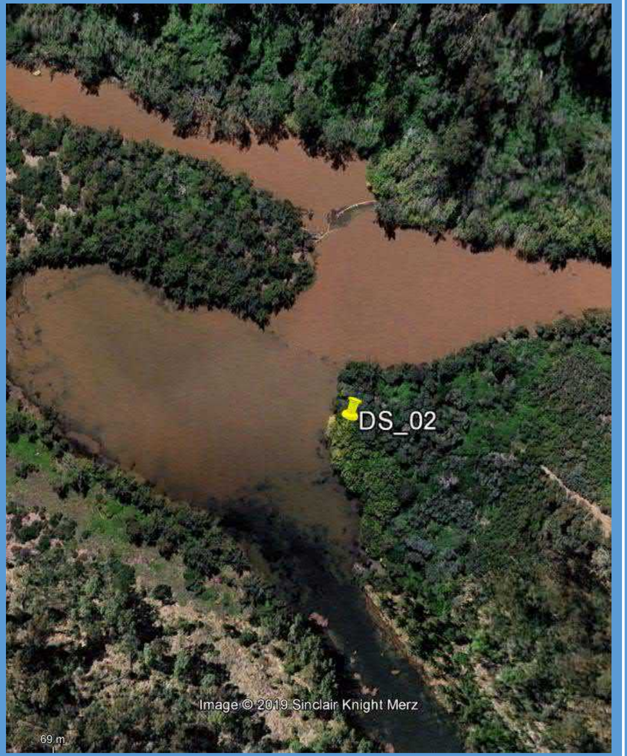
			
07/2006	03/2007	10/2015	10/2018

C.3 Downstream Zone

WDR EIS (Beca reference # 4512987) – DS01

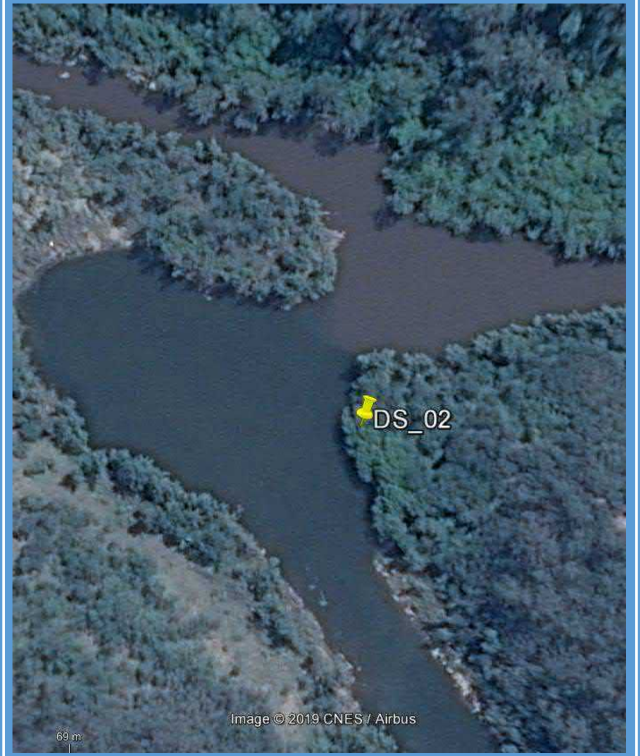
			
07/2002	03/2007	01/2014	10/2018

WDR EIS (Beca reference # 4512987) – DS02



03/2007

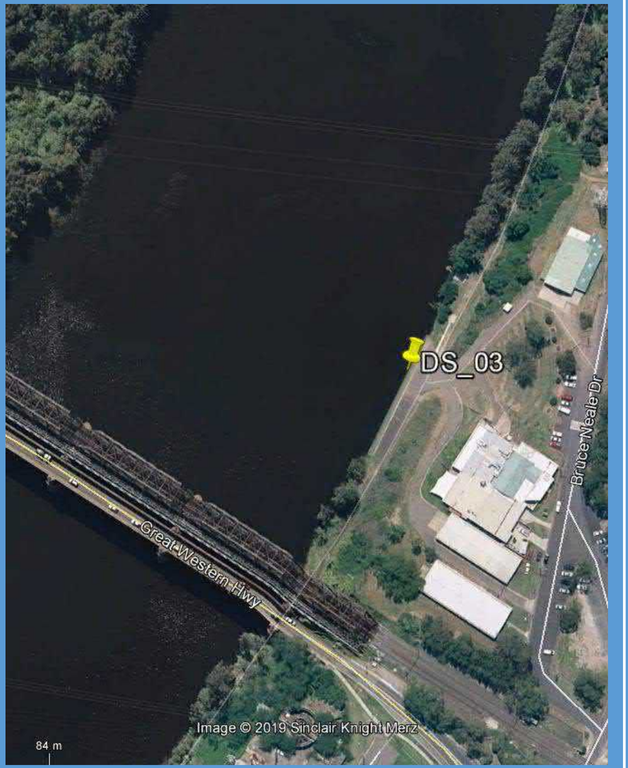
06/2009



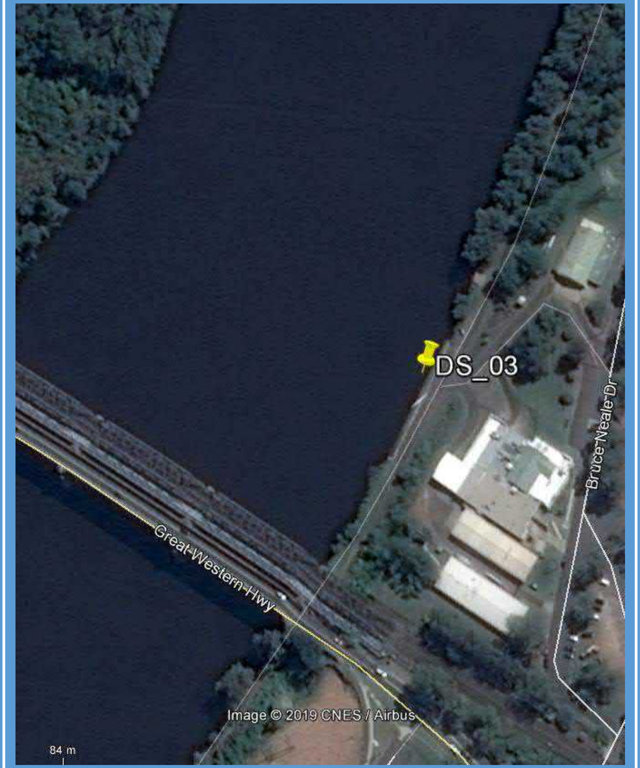
02/2013

10/2018

WDR EIS (Beca reference # 4512987) – DS03

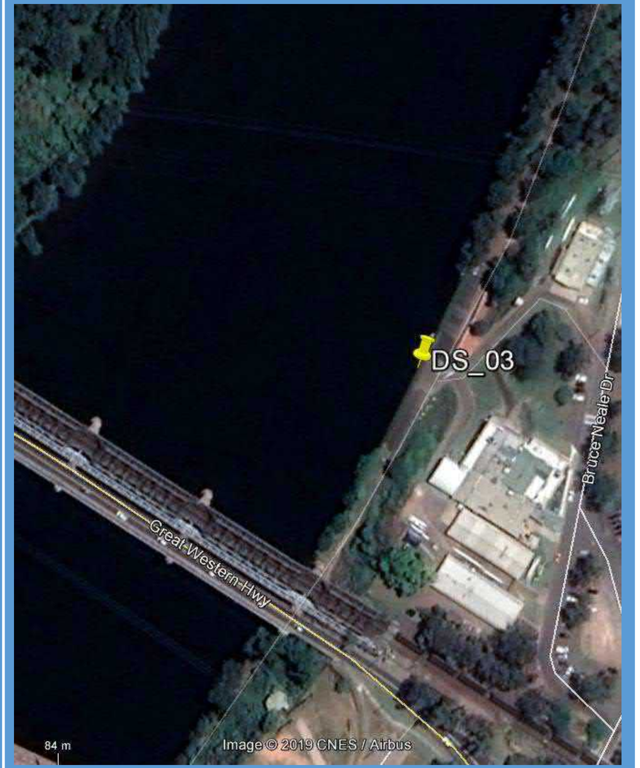


04/2007



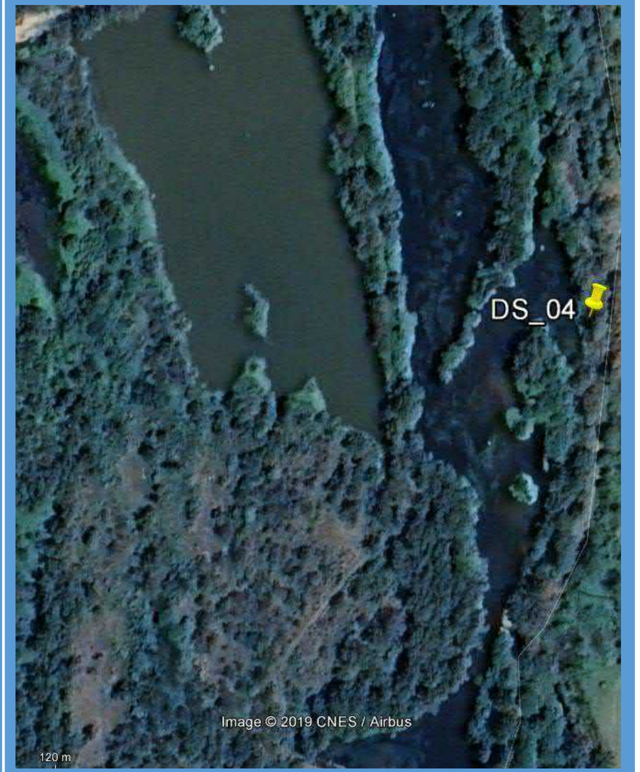
02/2013

05/2016



10/2018

WDR EIS (Beca reference # 4512987) – DS04

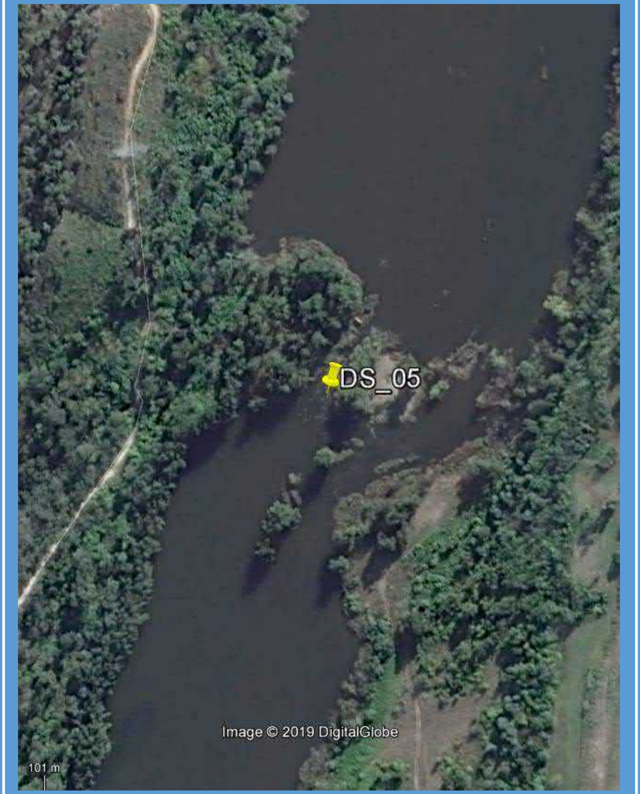


07/2002	04/2006	02/2016	01/2019

WDR EIS (Beca reference # 4512987) – DS05

07/2002

04/2010



11/2015

01/2019

WDR EIS (Beca reference # 4512987) – DS06

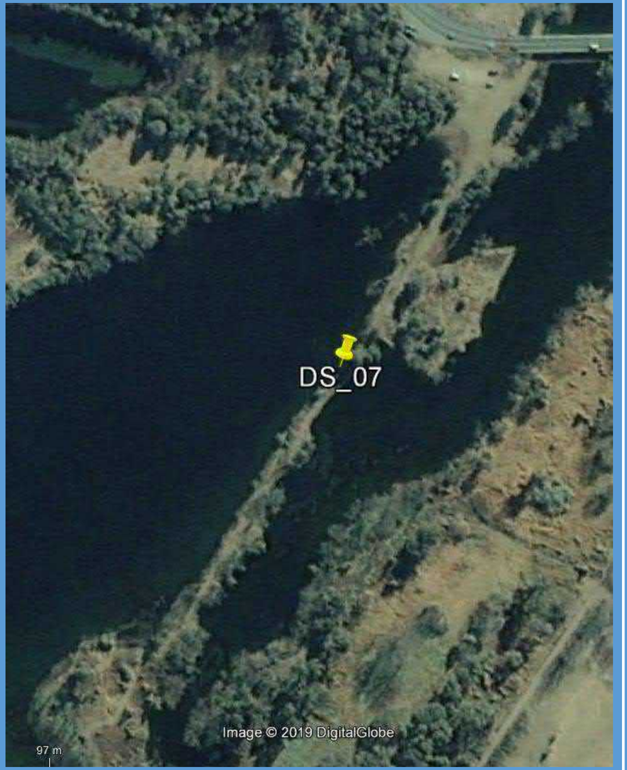
08/2002

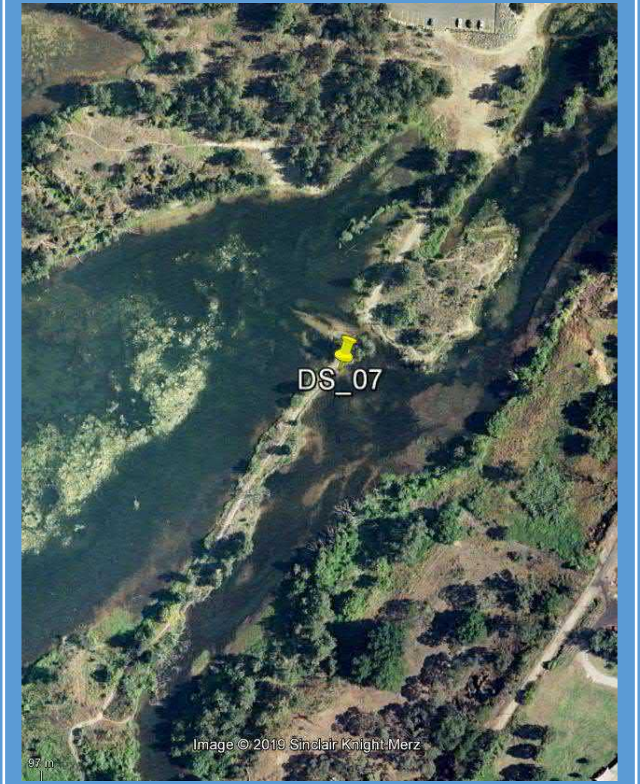
04/2006

02/2013

01/2019

WDR EIS (Beca reference # 4512987) – DS07

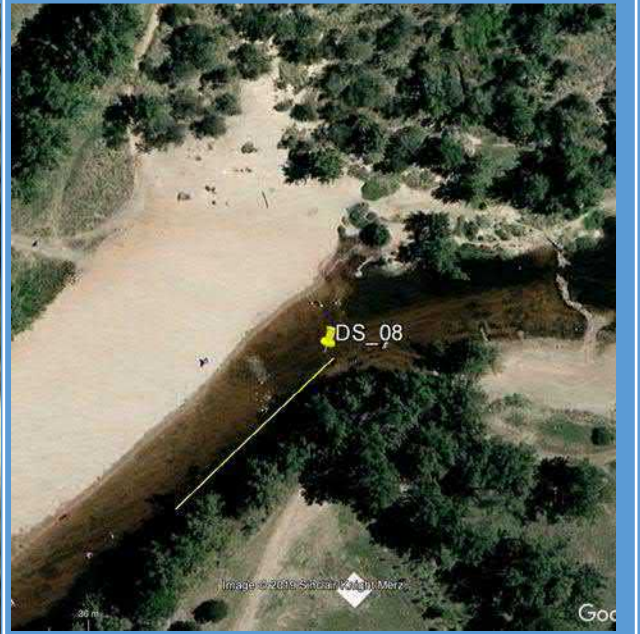




08/2002	03/2007	02/2013	01/2019

WDR EIS (Beca reference # 4512987) – DS08

08/2002



06/2009

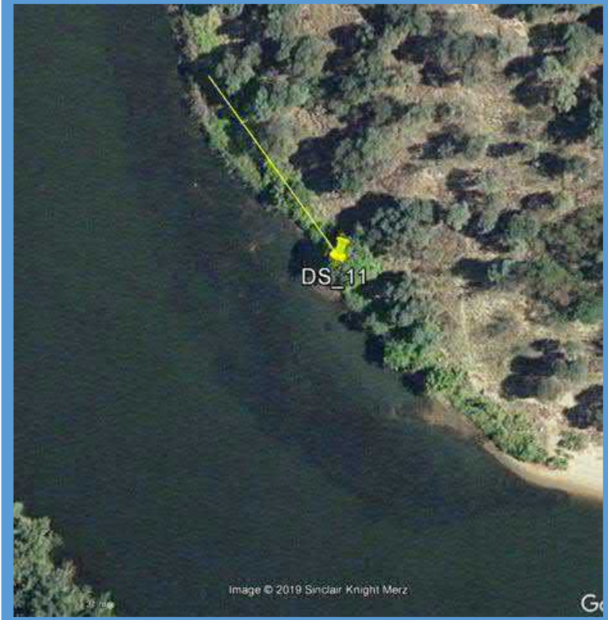
01/2014

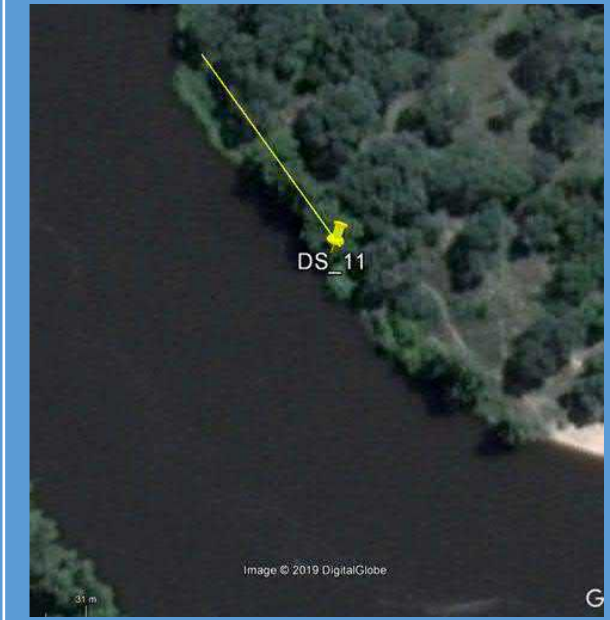
10/2018

WDR EIS (Beca reference # 4512987) – DS09

			
08/2002	03/2007	10/2015	10/2018

WDR EIS (Beca reference # 4512987) – DS11





03/2007	02/2013	10/2015	10/2018

WDR EIS (Beca reference # 4512987) – DS12

06/2003

05/2010

05/2014

10/2017

D

Appendix D – Longitudinal Stream Profile Analysis

D.1 Long Profile Analysis – Wollondilly deposition and erosion zone points

<10% Percentile- Erosion			>90% Percentile - Deposition		
Distance (m)	Elevation (m AHD)	Slope (%)	Distance (m)	Elevation (m AHD)	Slope (%)
15500	115	-10	16400	118	1
1900	146	-8	16900	122	1
20500	119	-7	18700	120	1
14500	116	-6	4400	153	2
4600	148	-5	6900	140	2
8400	138	-5	9500	135	2
13700	126	-5	9700	140	2
14200	122	-5	10200	139	2
1100	158	-4	12600	131	2
1300	155	-4	13400	125	2
5900	141	-4	15900	118	2
7300	136	-4	17800	120	2
9000	136	-4	18100	122	2
3000	149	-3	20100	120	2
9200	133	-3	20300	126	2
11200	130	-3	800	158	3
11500	125	-3	900	161	3
12700	128	-3	2000	149	3
12800	125	-3	5500	147	3
13200	123	-3	9600	138	3
18400	119	-3	15100	119	3

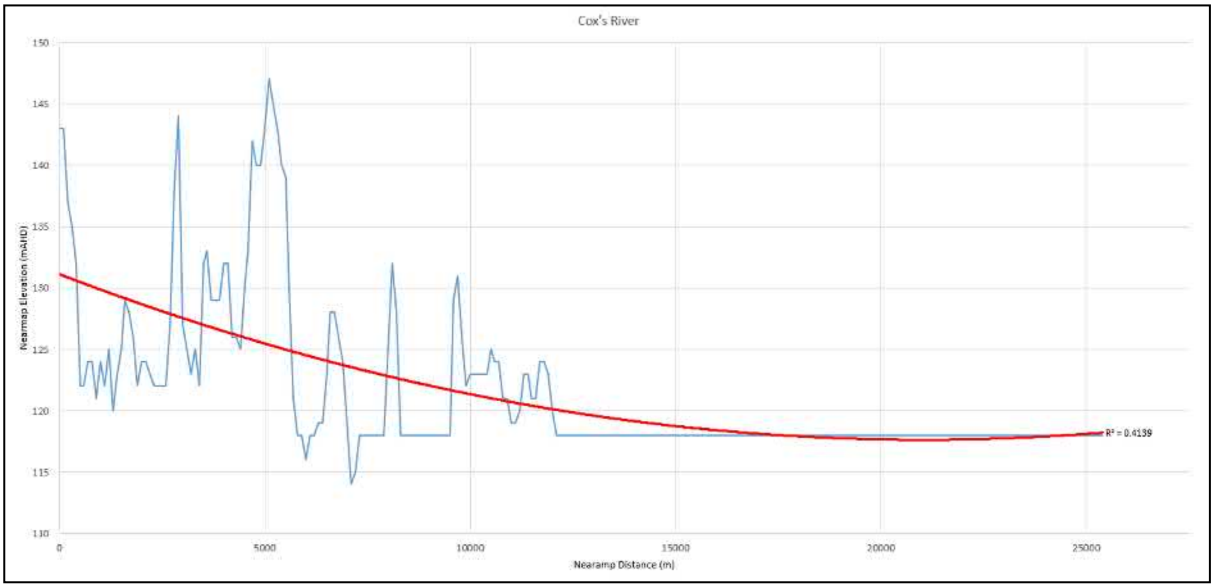
<10% Percentile- Erosion			>90% Percentile - Deposition		
1800	154	-2	16700	121	3
4100	150	-2	2100	153	4
4700	146	-2	12000	130	4
4900	144	-2	20200	124	4
5600	145	-2	7500	141	5
6000	139	-2	13500	131	6
6500	138	-2	15200	125	6

D.2 Long Profile Analysis – non-reported profiles

Long profiles of watercourses in the GIA are shown below generated according to the method reported in **Appendix A.1.4**. None of these profiles are reported with high confidence levels as the data is not considered accurate and consequently, the elevation profiles have not been analysed to identify potential areas of erosion or deposition.

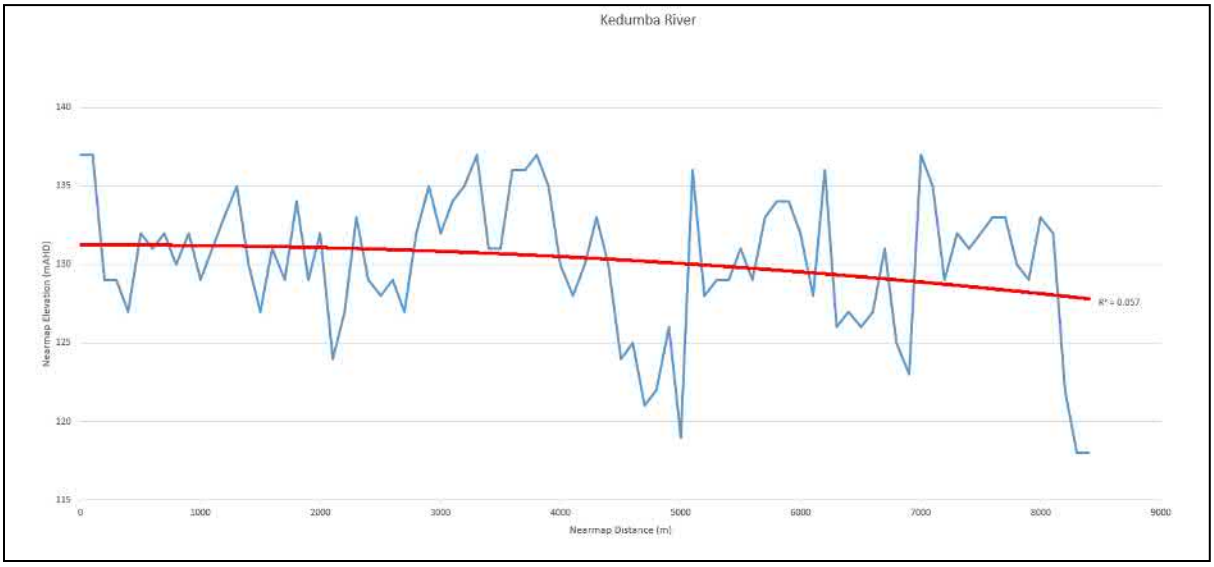
Cox's River

- Cox's River shows a general reduction in elevation from 143 m AHD from the identified upstream point to an elevation of 118 m AHD at a distance of 12,100 m from the start of the river profile. The river elevation then remained constant at 118 m AHD for 13,300 m until the river entered the reservoir.
- A polynomial trendline shows correlation coefficient value of 0.41.



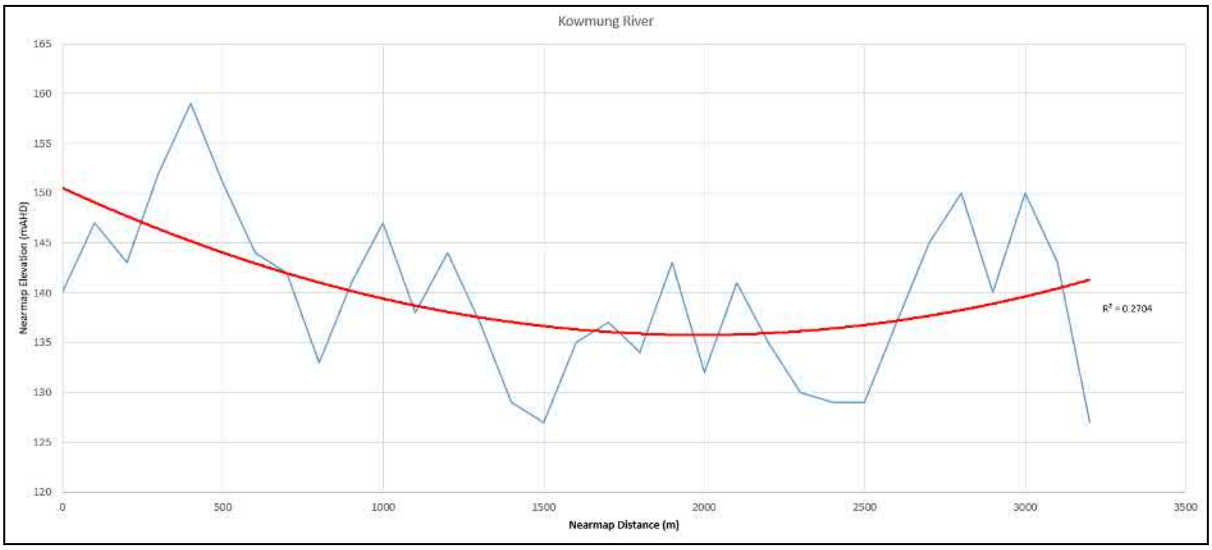
Kedumba River

- The elevation profile of the Kedumba River was recorded from the identified upstream point to the confluence with Cox's River, 8,300 m downstream of the starting point.
- A polynomial trendline shows a correlation coefficient of 0.06.



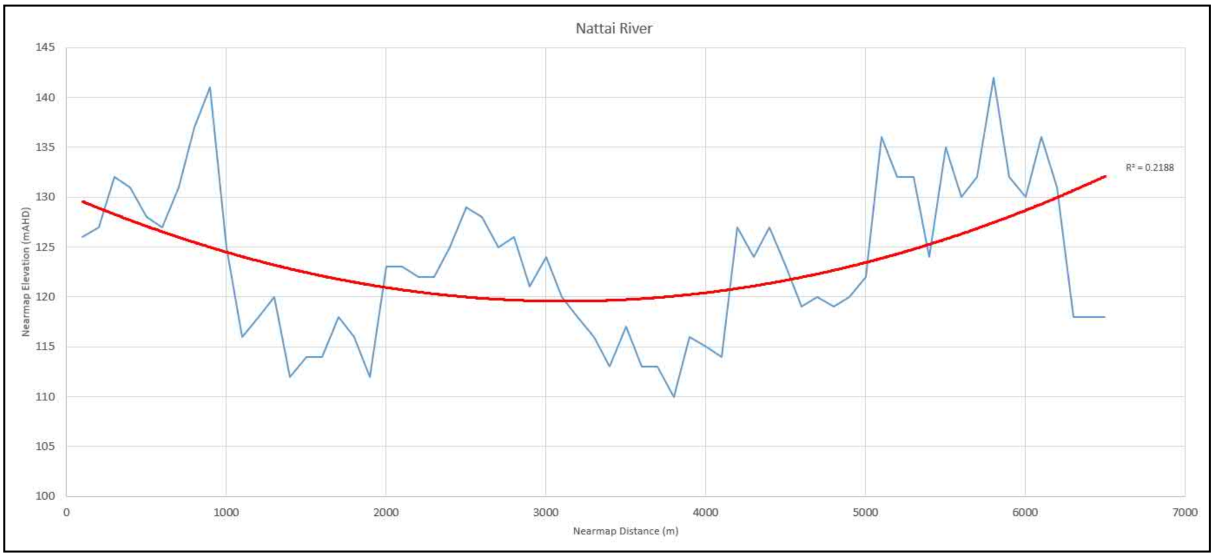
Kowmung River

- The elevation profile of the Kowmung River was recorded from the identified upstream point to the confluence with Cox's River, 3,200 m downstream of the starting point.
- A polynomial trendline shows a correlation coefficient of 0.27.



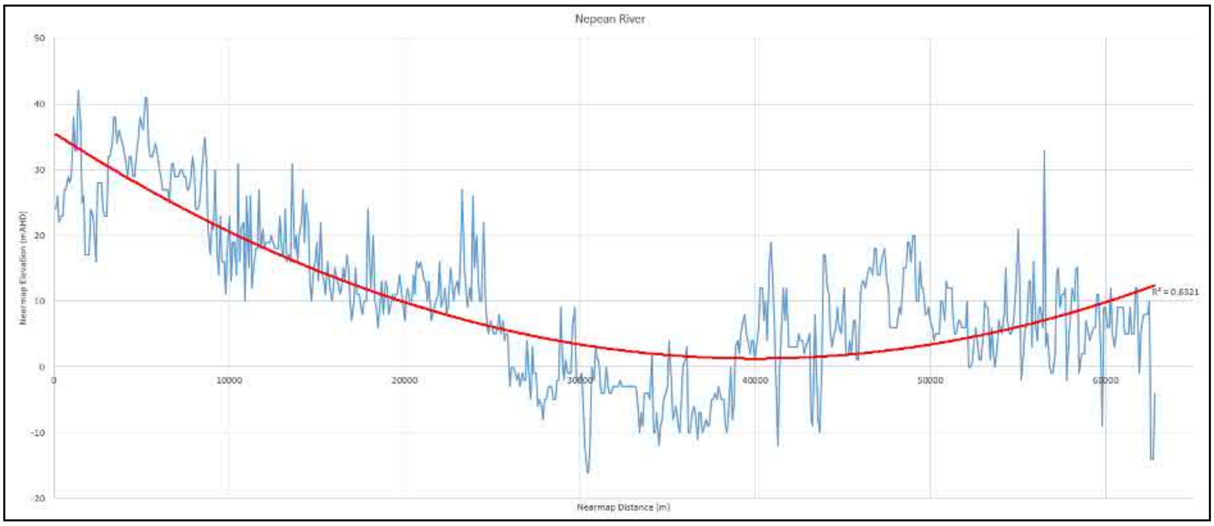
Nattai River

- The elevation profile of the Nattai River was recorded from the identified upstream point to where the river enters the reservoir.
- A polynomial trendline shows a correlation coefficient value of 0.22.



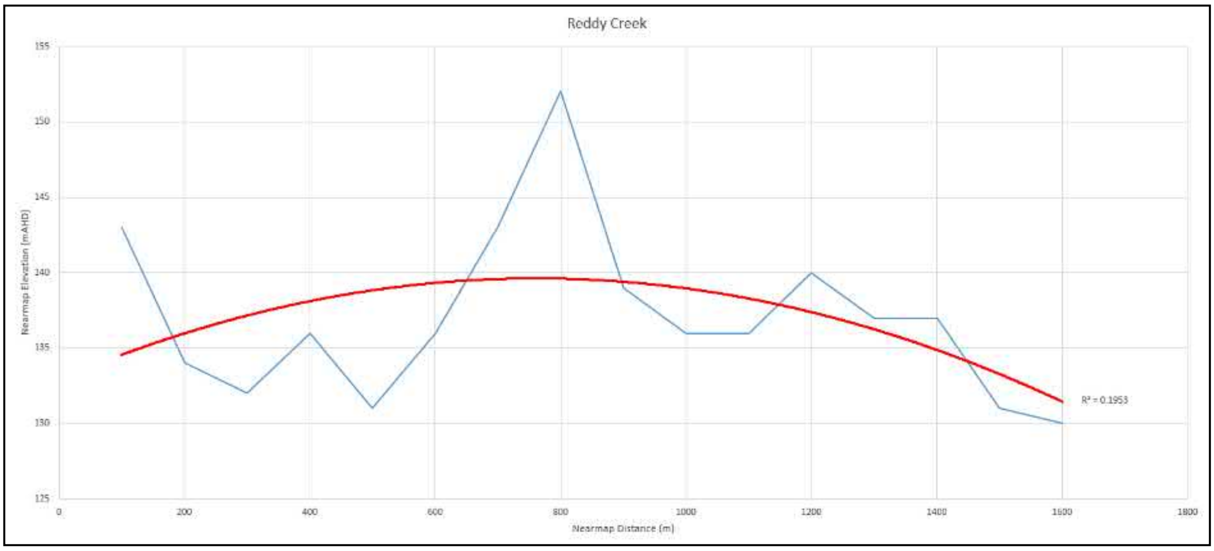
Nepean River

- The Nepean River from the confluence of the Warragamba River to the tidal limit at Yarramundi was plotted.
- A polynomial trendline shows a correlation coefficient of 0.63.



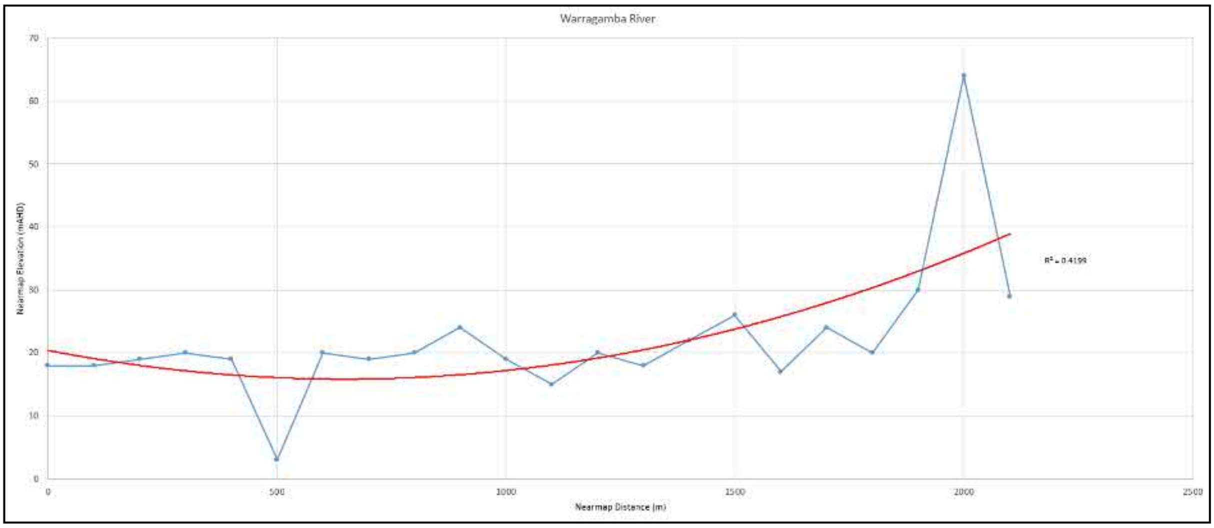
Reedy Creek

- The elevation profile of Reedy Creek was recorded from an identified upstream point (rapid geomorphology point US-11) to the confluence with the Kedumba River, 1,600 m downstream.
- A polynomial trendline shows a correlation coefficient of 0.20.



Warragamba River

- The elevation profile of the Warragamba River was recorded from the dam wall to the confluence with the Nepean River, 2,100 m downstream of the starting point.
- A polynomial trendline shows a correlation coefficient of 0.20.



E

Appendix E – River Styles^{TM} Classifications

Table 22 RiverStyles for the Upstream Zone

GIA watercourse/s	Watercourse stretch	River Style	Stream condition	Recovery potential	Fragility
Brimstone Creek	BR1	CVS Headwater	Good	Conservation	Low
	BR2	CVS Headwater	Moderate	High	Low
	BR3	CVS Gorge	Good	Conservation	Low
	BR4	No data	No data	No data	No data
	BR5	Water storage - dam or weir pool	None	None	Low
Butchers Creek	BU1	CVS Headwater	Good	Conservation	Low
	BU2	CVS Gorge	Good	Conservation	Low
	BU3	CVS Floodplain pockets gravel	Good	Conservation	Moderate
Cedar Creek	CE1	CVS Headwater	Good	Conservation	Low
	CE2	CVS Gorge	Poor	Moderate	Moderate
	CE3	No data	No data	No data	No data
Coxs River	CO1	CVS Headwater	Good	Conservation	Low
	CO2	SMG - Valley fill, fine grained	Good	Conservation	High
	CO3	LUV CC - Channelised fill	Moderate	Rapid	Moderate
	CO4	SMG - Valley fill, fine grained	Moderate	High	High
	CO5	LUV CC - Channelised fill	Moderate	Rapid	Moderate
	CO6	SMG - Valley fill, fine grained	Moderate	Conservation	Moderate
	CO7	Water storage - dam or weir pool	None	None	Low
	CO8	LUV CC - Low sinuosity, fine grained	Poor	Moderate	Moderate
	CO9	LUV CC - Low sinuosity, fine grained	Poor	Low	Moderate
	CO10	Water storage - dam or weir pool	None	None	Low
	CO11	CVS Gorge	Poor	Low	Low
	CO12	CVS Gorge	Good	Conservation	Low
	CO13	Water storage - dam or weir pool	None	None	Low
	CO14	CVS Gorge	Good	Conservation	Low
	CO15	PCVS - Bedrock controlled, gravel	Moderate	High	Moderate
	CO16	CVS Gorge	Good	Conservation	Low
	CO17	CVS Floodplain pockets gravel	Moderate	High	Moderate
	CO18	CVS Gorge	Good	Conservation	Low
	CO19	CVS Floodplain pockets gravel	Moderate	High	Moderate
	CO20	PCVS - Bedrock controlled, gravel	Moderate	High	Moderate
	CO21	CVS Floodplain pockets gravel	Moderate	High	Moderate
	CO22	PCVS - Bedrock controlled, Sand	Poor	Low	Moderate
	CO23	CVS Floodplain pockets sand	Moderate	High	Moderate
	CO24	CVS Gorge	Moderate	Rapid	Low
	CO25	CVS Gorge	Good	Conservation	Low
	CO26	CVS Floodplain pockets gravel	Moderate	High	Moderate
	CO27	CVS Gorge	Moderate	Rapid	Low
	CO28	CVS Floodplain pockets sand	Moderate	High	Moderate

GIA watercourse/s	Watercourse stretch	River Style	Stream condition	Recovery potential	Fragility
Green Wattle Creek	GW1	CVS Gorge	Good	Conservation	Low
	GW2	CVS Floodplain pockets gravel	Good	Conservation	Moderate
Kedumba River	KE1	SMG - Valley fill, fine grained	Moderate	Moderate	High
	KE2	LUV CC - Low sinuosity, fine grained	Moderate	Moderate	Moderate
	KE3	CVS Gorge	Good	Conservation	Low
	KE4	CVS Floodplain pockets gravel	Good	Conservation	Moderate
	KE5	CVS Floodplain pockets sand	Moderate	High	Moderate
Kowmung River	KO1	CVS Gorge	Good	Conservation	Low
	KO2	CVS Floodplain pockets gravel	Good	Conservation	Moderate
Lacys Creek	LA1	CVS Gorge	Good	Conservation	Low
	LA2	CVS Floodplain pockets gravel	Good	Conservation	Moderate
	LA3	PCVS - Planform controlled, low sinuosity, gravel	Moderate	Moderate	Moderate
	LA4	Water storage - dam or weir pool	None	None	Low
Nattai River	NA1	CVS Headwater	Moderate	Moderate	Low
	NA2	Water storage - dam or weir pool	None	None	Low
	NA3	SMG - Valley fill, fine grained	Moderate	Moderate	High
	NA4	LUV CC - Channelised fill	Moderate	Moderate	Moderate
	NA5	PCVS - Planform controlled, low sinuosity, fine grained	Moderate	Moderate	Moderate
	NA6	Water storage - dam or weir pool	None	None	Low
	NA7	CVS Gorge	Good	Conservation	Low
	NA8	CVS Floodplain pockets gravel	Good	Conservation	Moderate
	NA9	SMG - Valley fill, fine grained	Moderate	Moderate	High
	NA10	SMG - Valley fill, fine grained	Good	Conservation	High
	NA11	SMG - Valley fill, fine grained	Moderate	Moderate	High
	NA12	CVS Floodplain pockets gravel	Good	Conservation	Moderate
Reedy Creek	RE1	No data	No data	No data	No data
	RE2	SMG - Valley fill, fine grained	Good	Conservation	High
	RE3	No data	No data	No data	No data
Wollondilly River	WO1	SMG - Valley fill, fine grained	Moderate	Moderate	High
	WO2	LUV CC - Channelised fill	Moderate	Moderate	Moderate
	WO3	SMG - Chain of ponds	Poor	Moderate	High
	WO4	PCVS - Bedrock controlled, fine grained	Moderate	Moderate	Moderate
	WO5	SMG - Chain of ponds	Moderate	Moderate	High
	WO6	PCVS - Planform controlled, low sinuosity, fine grained	Moderate	Moderate	Moderate

GIA watercourse/s	Watercourse stretch	River Style	Stream condition	Recovery potential	Fragility
Wollondilly River (continued)	WO7	PCVS - Bedrock controlled, fine grained	Moderate	Moderate	Moderate
	WO8	PCVS - Planform controlled, low sinuosity, fine grained	Moderate	Moderate	Moderate
	WO9	PCVS - Bedrock controlled, fine grained	Moderate	Moderate	Moderate
	WO10	PCVS - Planform controlled, low sinuosity, fine grained	Moderate	Moderate	Moderate
	WO11	PCVS - Bedrock controlled, fine grained	Moderate	Moderate	Moderate
	WO12	PCVS - Planform controlled, low sinuosity, fine grained	Moderate	Moderate	Moderate
	WO13	PCVS - Bedrock controlled, fine grained	Moderate	Moderate	Moderate
	WO14	Water storage - dam or weir pool	None	None	Low
	WO15	PCVS - Bedrock controlled, fine grained	Moderate	Moderate	Moderate
	WO16	PCVS - Bedrock controlled, gravel	Moderate	Moderate	Moderate
	WO17	CVS Floodplain pockets gravel	Moderate	High	Moderate
	WO18	PCVS - Bedrock controlled, gravel	Moderate	Moderate	Moderate
	WO19	PCVS - Planform controlled, low sinuosity, gravel	Moderate	Moderate	Moderate
	WO20	PCVS - Planform controlled, low sinuosity, fine grained	Moderate	Moderate	Moderate
	WO21	LUV CC - Low sinuosity, fine grained	Moderate	Moderate	Moderate
	WO22	PCVS - Bedrock controlled, fine grained	Moderate	Moderate	Moderate
	WO23	PCVS - Planform controlled, low sinuosity, fine grained	Moderate	Moderate	Moderate
	WO24	PCVS - Bedrock controlled, fine grained	Moderate	Moderate	Moderate
	WO25	PCVS - Planform controlled, low sinuosity, fine grained	Moderate	Moderate	Moderate
	WO26	PCVS - Bedrock controlled, fine grained	Moderate	Moderate	Moderate
	WO27	PCVS - Planform controlled, low sinuosity, fine grained	Moderate	Moderate	Moderate
	WO28	Water storage - dam or weir pool	None	None	Low
	WO29	PCVS - Bedrock controlled, fine grained	Moderate	Moderate	Moderate
	WO30	PCVS - Planform controlled, low sinuosity, fine grained	Moderate	Moderate	Moderate
	WO31	PCVS - Bedrock controlled, fine grained	Moderate	Moderate	Moderate

GIA watercourse/s	Watercourse stretch	River Style	Stream condition	Recovery potential	Fragility
Wollondilly River (continued)	WO32	PCVS - Planform controlled, low sinuosity, fine grained	Moderate	Moderate	Moderate
	WO33	PCVS - Bedrock controlled, fine grained	Moderate	Moderate	Moderate
	WO34	PCVS - Bedrock controlled, fine grained	Moderate	Rapid	Moderate
	WO35	CVS Floodplain pockets gravel	Good	Conservation	Moderate
	WO36	CVS Gorge	Good	Conservation	Low
	WO37	PCVS - Bedrock controlled, fine grained	Moderate	High	Moderate
	WO38	CVS Gorge	Good	Conservation	Low
	WO39	PCVS - Bedrock controlled, fine grained	Good	Conservation	Moderate
	WO40	CVS Floodplain pockets gravel	Good	Conservation	Moderate
	WO41	PCVS - Bedrock controlled, fine grained	Good	Conservation	Moderate
	WO42	PCVS - Planform controlled, low sinuosity, gravel	Moderate	Moderate	Moderate

Table 23 RiverStyles for the Downstream Zone

GIA watercourse/s	Watercourse stretch	River Style	Stream condition	Recovery potential	Fragility
Cattai Creek	CA1	CVS Floodplain pockets sand	Moderate	Moderate	Moderate
	CA2	CVS Gorge	Moderate	High	Low
	CA3	PCVS - Planform controlled, low sinuosity, sand	Moderate	Moderate	High
	CA4	CVS Gorge	Good	Conservation	Low
	CA5	CVS Floodplain pockets sand	Moderate	Moderate	Moderate
	CA6	PCVS - Planform controlled, low sinuosity, sand	Moderate	High	High
	CA7	CVS Floodplain pockets sand	Moderate	Moderate	Moderate
	CA8	PCVS - Planform controlled, low sinuosity, fine grained	Moderate	Moderate	Moderate
	CA9	PCVS - Bedrock controlled, fine grained	Good	Conservation	Moderate
	CA10	PCVS - Planform controlled, low sinuosity, fine grained	Moderate	Moderate	Moderate
Grose River	GR1	SMG - Valley fill, fine grained	Moderate	High	High
	GR2	CVS Gorge	Good	Rapid	Low
	GR3	CVS Gorge	Good	Conservation	Low

GIA watercourse/s	Watercourse stretch	River Style	Stream condition	Recovery potential	Fragility
Grose River (continued)	GR3	PCVS - Planform controlled, low sinuosity, sand	Moderate	Moderate	High
	GR4	LUV CC - Low sinuosity, sand	Moderate	Moderate	High
Hawkesbury River	HA1	LUV CC - Tidal	Good	Conservation	Low
	HA2	PCVS - Bedrock controlled, gravel	Good	Conservation	Moderate
	HA3	PCVS - Planform controlled, low sinuosity, fine grained	Moderate	High	Moderate
	HA4	LUV CC - Low sinuosity, fine grained	Moderate	High	Moderate
Nepean River	NE1	CVS Headwater	Good	Conservation	Low
	NE2	PCVS - Planform controlled, low sinuosity, fine grained	Moderate	High	Moderate
	NE3	Water storage - dam or weir pool	None	None	Low
	NE4	PCVS - Planform controlled, low sinuosity, fine grained	Moderate	High	Moderate
	NE5	LUV CC - Meandering, fine grained	Moderate	Moderate	Moderate
	NE6	PCVS - Planform controlled, low sinuosity, fine grained	Moderate	Moderate	Moderate
	NE7	LUV CC - Low sinuosity, fine grained	Moderate	Rapid	Moderate
	NE8	PCVS - Planform controlled, low sinuosity, fine grained	Moderate	Rapid	Moderate
	NE9	CVS Gorge	Good	Conservation	Low
	NE10	Water storage - dam or weir pool	None	None	Low
	NE11	CVS Gorge	Good	Conservation	Low
	NE12	Water storage - dam or weir pool	None	None	Low
	NE13	CVS Gorge	Good	Conservation	Low
	NE14	CVS Floodplain pockets gravel	Good	Conservation	Moderate
	NE15	CVS Gorge	Good	Conservation	Low
	NE16	CVS Floodplain pockets gravel	Moderate	Moderate	Moderate
	NE17	PCVS - Planform controlled, low sinuosity, gravel	Moderate	Moderate	Moderate
	NE18	CVS Gorge	Good	Conservation	Low
	NE19	LUV CC - Low sinuosity, gravel	Moderate	Moderate	Moderate
	NE20	CVS Gorge	Good	Conservation	Low

GIA watercourse/s	Watercourse stretch	River Style	Stream condition	Recovery potential	Fragility
Nepean River (continued)	NE21	PCVS - Planform controlled, low sinuosity, gravel	Moderate	High	Moderate
	NE22	Water storage - dam or weir pool	None	None	Low
South Creek	SC1	SMG - Valley fill, fine grained	Moderate	Moderate	High
	SC2	Water storage - dam or weir pool	None	None	Low
	SC3	LUV CC - Channelised fill	Moderate	Moderate	Moderate
	SC4	LUV CC - Low sinuosity, fine grained	Moderate	Moderate	Moderate
	SC5	LUV CC - Meandering, fine grained	Moderate	Moderate	High
	SC6	LUV CC - Low sinuosity, fine grained	Poor	Moderate	Moderate
	SC7	LUV CC - Low sinuosity, fine grained	Moderate	High	Moderate
	SC8	LUV CC - Low sinuosity, fine grained	Moderate	Moderate	Moderate
Warragamba River	WA1	CVS Gorge	Moderate	Moderate	Low

F

Appendix F – Sediment Load Calculations

Appendix A.1.7 describes the process of converting flow and [TSS] records to a sediment load. The data below was derived from this process for the Coxs River (**Appendix F.1.**), Nattai River (**Appendix F.2.**) and Wollondilly River (**Appendix F.3.**).

F.1. Cox's River Kelpie Pt

Date	TSS (mg/L)	Flow (megaL/day)	TSS (tonnes/megaL)	TSS loading (tonnes/day)
3/12/2015	9	53.02	0.009	0.477
18/11/2015	3	267.633	0.003	0.803
15/10/2015	4	104.816	0.004	0.419
15/09/2015	2	153.081	0.002	0.306
20/08/2015	0.5	106.076	0.0005	0.053
22/07/2015	6	277.442	0.006	1.665
22/06/2015	4	232.472	0.004	0.930
28/04/2015	3	1159.781	0.003	3.479
21/04/2015	51	6163.523	0.051	314.340
21/04/2015	88	6163.523	0.088	542.390
21/04/2015	98	6163.523	0.098	604.025
21/04/2015	88	6163.523	0.088	542.390
25/03/2015	4	68.252	0.004	0.273
17/02/2015	12	239.429	0.012	2.873
23/01/2015	6	77.073	0.006	0.462
10/12/2014	12	136.304	0.012	1.636
28/11/2014	3	12.49	0.003	0.037
14/10/2014	4	71.309	0.004	0.285
18/09/2014	4	168.838	0.004	0.675
20/08/2014	13	468.237	0.013	6.087
23/07/2014	2	69.686	0.002	0.139
11/06/2014	6	101.856	0.006	0.611
12/05/2014	6	81.685	0.006	0.490
18/03/2014	7	102.965	0.007	0.721
20/02/2014	7	55.407	0.007	0.388
2/02/2014	4	10.284	0.004	0.041
12/12/2013	4	43.057	0.004	0.172
23/11/2013	86	1041.842	0.086	89.598
19/11/2013	3	201.991	0.003	0.606
7/11/2013	3	29.058	0.003	0.087
4/09/2013	2	94.172	0.002	0.188
10/07/2013	0.5	469.293	0.0005	0.235
20/06/2013	3	131.434	0.003	0.394
14/05/2013	2	108.04	0.002	0.216
18/04/2013	2	213.88	0.002	0.428
5/03/2013	10	4463.302	0.01	44.633
23/02/2013	514	7026.599	0.514	3611.672
23/02/2013	339	7026.599	0.339	2382.017
23/02/2013	358	7026.599	0.358	2515.522
23/02/2013	165	7026.599	0.165	1159.389

Date	TSS (mg/L)	Flow (megaL/day)	TSS (tonnes/megaL)	TSS loading (tonnes/day)
23/02/2013	124	7026.599	0.124	871.298
11/02/2013	9	414.176	0.009	3.728
30/01/2013	13	604.971	0.013	7.865
11/12/2012	4	33.207	0.004	0.133
13/11/2012	8	52.665	0.008	0.421
18/10/2012	2	116.852	0.002	0.234
18/09/2012	7	136.033	0.007	0.952
7/08/2012	0.5	257.828	0.0005	0.129
17/07/2012	2	486.072	0.002	0.972
13/06/2012	12.5	869.436	0.0125	10.868
18/05/2012	0.5	235.536	0.0005	0.118
15/05/2012	3	247.261	0.003	0.742
20/04/2012	2	2143.718	0.002	4.287
19/04/2012	10	3800.935	0.01	38.009
19/04/2012	15	3800.935	0.015	57.014
19/04/2012	18	3800.935	0.018	68.417
19/04/2012	17	3800.935	0.017	64.616
19/04/2012	14	3800.935	0.014	53.213
19/04/2012	22	3800.935	0.022	83.621
19/04/2012	47	3800.935	0.047	178.644
18/04/2012	4	1052.839	0.004	4.211
16/04/2012	3	306.631	0.003	0.920
15/03/2012	2	1598.564	0.002	3.197
15/03/2012	0.5	1598.564	0.0005	0.799
15/03/2012	2	1598.564	0.002	3.197
15/03/2012	0.5	1598.564	0.0005	0.799
15/03/2012	2	1598.564	0.002	3.197
15/03/2012	2	1598.564	0.002	3.197
15/03/2012	0.5	1598.564	0.0005	0.799
14/03/2012	1	1834.772	0.001	1.835
14/03/2012	2	1834.772	0.002	3.670
14/03/2012	2	1834.772	0.002	3.670
10/03/2012	8	4040.754	0.008	32.326
10/03/2012	5	4040.754	0.005	20.204
10/03/2012	6	4040.754	0.006	24.245
10/03/2012	4	4040.754	0.004	16.163
10/03/2012	3	4040.754	0.003	12.122
10/03/2012	4	4040.754	0.004	16.163
10/03/2012	12	4040.754	0.012	48.489
10/03/2012	7	4040.754	0.007	28.285
9/03/2012	11	5720.736	0.011	62.928

Date	TSS (mg/L)	Flow (megaL/day)	TSS (tonnes/megaL)	TSS loading (tonnes/day)
9/03/2012	8	5720.736	0.008	45.766
9/03/2012	13	5720.736	0.013	74.370
6/03/2012	10	6711.306	0.01	67.113
6/03/2012	16	6711.306	0.016	107.381
6/03/2012	12	6711.306	0.012	80.536
6/03/2012	14	6711.306	0.014	93.958
6/03/2012	12	6711.306	0.012	80.536
6/03/2012	22	6711.306	0.022	147.649
6/03/2012	23	6711.306	0.023	154.360
6/03/2012	19	6711.306	0.019	127.515
5/03/2012	22	9429.62	0.022	207.452
5/03/2012	22	9429.62	0.022	207.452
5/03/2012	18	9429.62	0.018	169.733
5/03/2012	22	9429.62	0.022	207.452
2/03/2012	218	17426.48	0.218	3798.972
2/03/2012	98	17426.48	0.098	1707.795
2/03/2012	96	17426.48	0.096	1672.942
2/03/2012	63	17426.48	0.063	1097.868
2/03/2012	55	17426.48	0.055	958.456
2/03/2012	61	17426.48	0.061	1063.015
2/03/2012	93	17426.48	0.093	1620.663
2/03/2012	161	17426.48	0.161	2805.663
1/03/2012	187	13080.02	0.187	2445.964
1/03/2012	175	13080.02	0.175	2289.003
1/03/2012	60	13080.02	0.06	784.801
1/03/2012	10	13080.02	0.01	130.800
12/02/2012	6	2919.968	0.006	17.520
27/01/2012	10	1897.403	0.01	18.974
27/01/2012	10	1897.403	0.01	18.974
27/01/2012	14	1897.403	0.014	26.564
27/01/2012	15	1897.403	0.015	28.461
26/01/2012	12	1405.175	0.012	16.862
26/01/2012	14	1405.175	0.014	19.672
26/01/2012	18	1405.175	0.018	25.293
26/01/2012	22	1405.175	0.022	30.914
26/01/2012	32	1405.175	0.032	44.966
26/01/2012	34	1405.175	0.034	47.776
26/01/2012	41	1405.175	0.041	57.612
13/01/2012	2	0	0.002	0.000
11/01/2012	2	0	0.002	0.000
7/01/2012	2	0	0.002	0.000

Date	TSS (mg/L)	Flow (megaL/day)	TSS (tonnes/megaL)	TSS loading (tonnes/day)
7/01/2012	3	0	0.003	0.000
7/01/2012	2	0	0.002	0.000
13/12/2011	5	670.248	0.005	3.351
8/12/2011	0.5	378.337	0.0005	0.189
8/12/2011	0.5	378.337	0.0005	0.189
8/12/2011	1	378.337	0.001	0.378
8/12/2011	2	378.337	0.002	0.757
7/12/2011	2	347.612	0.002	0.695
7/12/2011	0.5	347.612	0.0005	0.174
7/12/2011	0.5	347.612	0.0005	0.174
7/12/2011	2	347.612	0.002	0.695
26/11/2011	62	3621.682	0.062	224.544
26/11/2011	60	3621.682	0.06	217.301
26/11/2011	23	3621.682	0.023	83.299
26/11/2011	6	3621.682	0.006	21.730
25/11/2011	8	1219.689	0.008	9.758
25/11/2011	10	1219.689	0.01	12.197
25/11/2011	20	1219.689	0.02	24.394
25/11/2011	24	1219.689	0.024	29.273
9/11/2011	5	75.425	0.005	0.377
12/10/2011	3	220.812	0.003	0.662
14/09/2011	1	115.465	0.001	0.115
9/08/2011	3	149.449	0.003	0.448
13/07/2011	0.5	183.961	0.0005	0.092
15/06/2011	6	555.574	0.006	3.333
12/05/2011	8	141.83	0.008	1.135
13/04/2011	3	179.53	0.003	0.539
21/03/2011	19	2446.619	0.019	46.486
21/03/2011	16	2446.619	0.016	39.146
20/03/2011	8	1081.843	0.008	8.655
20/03/2011	29	1081.843	0.029	31.373
9/03/2011	5	66.918	0.005	0.335
9/02/2011	8	123.214	0.008	0.986
12/01/2011	17	1737.314	0.017	29.534
11/01/2011	17	911.591	0.017	15.497
10/01/2011	8	622.066	0.008	4.977
7/01/2011	22	1662.795	0.022	36.581
7/01/2011	15	1662.795	0.015	24.942
7/01/2011	18	1662.795	0.018	29.930
7/01/2011	24	1662.795	0.024	39.907
7/01/2011	28	1662.795	0.028	46.558

Date	TSS (mg/L)	Flow (megaL/day)	TSS (tonnes/megaL)	TSS loading (tonnes/day)
7/01/2011	46	1662.795	0.046	76.489
7/01/2011	35	1662.795	0.035	58.198
7/01/2011	57	1662.795	0.057	94.779
6/01/2011	42	496.495	0.042	20.853
13/12/2010	5	1144.309	0.005	5.722
12/12/2010	7	1473.259	0.007	10.313
12/12/2010	4	1473.259	0.004	5.893
12/12/2010	7	1473.259	0.007	10.313
12/12/2010	5	1473.259	0.005	7.366
12/12/2010	4	1473.259	0.004	5.893
12/12/2010	6	1473.259	0.006	8.840
12/12/2010	6	1473.259	0.006	8.840
11/12/2010	4	1707.461	0.004	6.830
11/12/2010	2	1707.461	0.002	3.415
11/12/2010	4	1707.461	0.004	6.830
11/12/2010	6	1707.461	0.006	10.245
11/12/2010	2	1707.461	0.002	3.415
9/12/2010	8	2392.222	0.008	19.138
9/12/2010	10	2392.222	0.01	23.922
9/12/2010	8	2392.222	0.008	19.138
9/12/2010	5	2392.222	0.005	11.961
9/12/2010	8	2392.222	0.008	19.138
9/12/2010	8	2392.222	0.008	19.138
9/12/2010	6	2392.222	0.006	14.353
8/12/2010	10	3042.826	0.01	30.428
8/12/2010	11	3042.826	0.011	33.471
8/12/2010	9	3042.826	0.009	27.385
8/12/2010	9	3042.826	0.009	27.385
8/12/2010	16	3042.826	0.016	48.685
8/12/2010	21	3042.826	0.021	63.899
8/12/2010	17	3042.826	0.017	51.728
8/12/2010	16	3042.826	0.016	48.685
7/12/2010	16	4263.479	0.016	68.216
7/12/2010	18	4263.479	0.018	76.743
7/12/2010	15	4263.479	0.015	63.952
7/12/2010	14	4263.479	0.014	59.689
7/12/2010	19	4263.479	0.019	81.006
3/12/2010	13	4219.616	0.013	54.855
3/12/2010	42	4219.616	0.042	177.224
30/11/2010	90	652.025	0.09	58.682
30/11/2010	18	652.025	0.018	11.736

Date	TSS (mg/L)	Flow (megaL/day)	TSS (tonnes/megaL)	TSS loading (tonnes/day)
10/11/2010	1	525.445	0.001	0.525
2/11/2010	12	1056.604	0.012	12.679
2/11/2010	12	1056.604	0.012	12.679
2/11/2010	11	1056.604	0.011	11.623
2/11/2010	13	1056.604	0.013	13.736
2/11/2010	12	1056.604	0.012	12.679
2/11/2010	11	1056.604	0.011	11.623
2/11/2010	11	1056.604	0.011	11.623
2/11/2010	12	1056.604	0.012	12.679
2/11/2010	12	1056.604	0.012	12.679
2/11/2010	12	1056.604	0.012	12.679
2/11/2010	6	1056.604	0.006	6.340
13/10/2010	24	260.402	0.024	6.250
15/09/2010	4	308.565	0.004	1.234
19/08/2010	20	837.544	0.02	16.751
19/08/2010	14	837.544	0.014	11.726
18/08/2010	8	369.077	0.008	2.953
15/07/2010	1	229.772	0.001	0.230
7/06/2010	1	356.157	0.001	0.356
5/06/2010	24	639.098	0.024	15.338
5/06/2010	9	639.098	0.009	5.752
5/06/2010	35	639.098	0.035	22.368
12/05/2010	7	53.477	0.007	0.374
14/04/2010	3	122.775	0.003	0.368
10/03/2010	6	186.909	0.006	1.121
16/02/2010	6	902.143	0.006	5.413
15/02/2010	4	1177.574	0.004	4.710
15/02/2010	4	1177.574	0.004	4.710
15/02/2010	5	1177.574	0.005	5.888
15/02/2010	6	1177.574	0.006	7.065
15/02/2010	4	1177.574	0.004	4.710
15/02/2010	3	1177.574	0.003	3.533
15/02/2010	5	1177.574	0.005	5.888
14/02/2010	0.5	1147.794	0.0005	0.574
14/02/2010	4	1147.794	0.004	4.591
14/02/2010	2	1147.794	0.002	2.296
14/02/2010	5	1147.794	0.005	5.739
14/02/2010	3	1147.794	0.003	3.443
14/02/2010	4	1147.794	0.004	4.591
14/02/2010	8	1147.794	0.008	9.182
14/02/2010	3	1147.794	0.003	3.443

Date	TSS (mg/L)	Flow (megaL/day)	TSS (tonnes/megaL)	TSS loading (tonnes/day)
12/02/2010	3	1045.833	0.003	3.137
11/02/2010	8	1417.448	0.008	11.340
11/02/2010	4	1417.448	0.004	5.670
11/02/2010	4	1417.448	0.004	5.670
11/02/2010	6	1417.448	0.006	8.505
11/02/2010	7	1417.448	0.007	9.922
10/02/2010	5	2309.91	0.005	11.550
10/02/2010	0.5	2309.91	0.0005	1.155
10/02/2010	0.5	2309.91	0.0005	1.155
10/02/2010	5	2309.91	0.005	11.550
10/02/2010	3	2309.91	0.003	6.930
9/02/2010	5	3834.212	0.005	19.171
1/02/2010	3	34.614	0.003	0.104
13/01/2010	5	14.109	0.005	0.071

Average TSS loading (tonnes/day)	Estimated TSS loading (tonnes/annum)
150.2	54,822

F.2. Nattai River

Date	TSS (mg/L)	Flow (megaL/day)	TSS (tonnes/megaL)	TSS loading (tonnes/day)
18/12/2015	6	0.235	0.006	0.001
13/11/2015	1.5	26.079	0.0015	0.039
16/10/2015	4	15.146	0.004	0.061
25/09/2015	3	33.705	0.003	0.101
21/08/2015	3	14.072	0.003	0.042
31/07/2015	2	29.828	0.002	0.060
17/06/2015	2	19.844	0.002	0.040
22/05/2015	2.5	32.034	0.0025	0.080
28/04/2015	11	358.288	0.011	3.941
27/03/2015	6	64.422	0.006	0.387
20/02/2015	5	6.687	0.005	0.033
20/01/2015	4	19.826	0.004	0.079
19/12/2014	5	20.142	0.005	0.101
25/11/2014	5	1.233	0.005	0.006
24/10/2014	3	9.84	0.003	0.030
19/09/2014	2	36.37	0.002	0.073
29/08/2014	5	778.533	0.005	3.893
21/07/2014	2	9.791	0.002	0.020
12/06/2014	4	12.938	0.004	0.052
15/05/2014	5	6.547	0.005	0.033
16/04/2014	6	71.129	0.006	0.427
19/03/2014	7	4.253	0.007	0.030
21/01/2014	2	0	0.002	0.000
12/12/2013	5	1.82	0.005	0.009
22/11/2013	8	20.192	0.008	0.162
2/10/2013	10	9.415	0.01	0.094
4/09/2013	2	13.886	0.002	0.028
9/08/2013	4.5	28.013	0.0045	0.126
31/07/2013	1	39.093	0.001	0.039
17/06/2013	1	20.651	0.001	0.021
15/05/2013	3	15.692	0.003	0.047
18/04/2013	2	26.221	0.002	0.052
6/03/2013	7	454.099	0.007	3.179
6/02/2013	4	43.472	0.004	0.174
10/01/2013	4	0	0.004	0.000
11/12/2012	6	2.283	0.006	0.014
14/11/2012	18	1.703	0.018	0.031
17/10/2012	4	20.533	0.004	0.082
19/09/2012	4	17.698	0.004	0.071
6/08/2012	0.5	16.385	0.0005	0.008

Date	TSS (mg/L)	Flow (megaL/day)	TSS (tonnes/megaL)	TSS loading (tonnes/day)
11/07/2012	1	28.956	0.001	0.029
15/06/2012	5	89.46	0.005	0.447
16/05/2012	5	0	0.005	0.000
13/04/2012	2	0	0.002	0.000
14/03/2012	9	0	0.009	0.000
10/02/2012	5	175.679	0.005	0.878
13/01/2012	5	0	0.005	0.000
19/12/2011	4	27.178	0.004	0.109
10/11/2011	6.5	8.898	0.0065	0.058
13/10/2011	6	25.314	0.006	0.152
15/09/2011	6	15.094	0.006	0.091
11/08/2011	3	18.328	0.003	0.055
14/07/2011	7	7.17	0.007	0.050
16/06/2011	4	33.993	0.004	0.136
11/05/2011	0.5	13.664	0.0005	0.007
14/04/2011	4.5	15.432	0.0045	0.069
10/03/2011	7	0	0.007	0.000
10/02/2011	6	21.779	0.006	0.131
4/02/2011	11	12.006	0.011	0.132
16/12/2010	0.5	0	0.0005	0.000
11/11/2010	4	97.298	0.004	0.389
14/10/2010	1	15.303	0.001	0.015
16/09/2010	2	6.518	0.002	0.013
13/08/2010	1	68.338	0.001	0.068
15/07/2010	2	7.372	0.002	0.015
10/06/2010	2	14.201	0.002	0.028
12/05/2010	0.5	0	0.0005	0.000
15/04/2010	6	1.338	0.006	0.008
11/03/2010	1	12.326	0.001	0.012
12/02/2010	92	146.453	0.092	13.474
14/01/2010	4	0	0.004	0.000

Average TSS loading (tonnes/day)	Estimated TSS loading (tonnes/annum)
0.4	154

F.3. Wollondilly River

Date	TSS (mg/L)	Flow (megaL/day)	TSS (tonnes/megaL)	TSS loading (tonnes/day)
3/12/2015	5	24.235	0.005	0.121
18/11/2015	3	186.674	0.003	0.560
15/10/2015	4	168.837	0.004	0.675
15/09/2015	3	568.051	0.003	1.704
26/08/2015	218	107,830.672	0.218	23507.087
26/08/2015	176	107,830.672	0.176	18978.198
25/08/2015	76	3,179.905	0.076	241.673
25/08/2015	42	3,179.905	0.042	133.556
20/08/2015	0.5	212.909	0.0005	0.106
16/07/2015	1	447.83	0.001	0.448
22/06/2015	11	1,576.816	0.011	17.345
20/05/2015	3	449.055	0.003	1.347
28/04/2015	34	2,606.686	0.034	88.627
23/04/2015	42	15,580.562	0.042	654.384
22/04/2015	61	4,484.152	0.061	273.533
22/04/2015	59	4,484.152	0.059	264.565
22/04/2015	57	4,484.152	0.057	255.597
25/03/2015	6	75.952	0.006	0.456
17/02/2015	5	147.69	0.005	0.738
23/01/2015	6	319.99	0.006	1.920
10/12/2014	11	1,598.934	0.011	17.588
8/12/2014	37	4,790.916	0.037	177.264
8/12/2014	26	4,790.916	0.026	124.564
8/12/2014	33	4,790.916	0.033	158.100
28/11/2014	5	7.751	0.005	0.039
14/10/2014	4	131.16	0.004	0.525
18/09/2014	5	789.8	0.005	3.949
27/08/2014	102	28,649.353	0.102	2922.234
27/08/2014	99	28,649.353	0.099	2836.286
27/08/2014	98	28,649.353	0.098	2807.637

Date	TSS (mg/L)	Flow (megaL/day)	TSS (tonnes/megaL)	TSS loading (tonnes/day)
27/08/2014	68	28,649.353	0.068	1948.156
27/08/2014	45	28,649.353	0.045	1289.221
26/08/2014	28	2,578.769	0.028	72.206
26/08/2014	34	2578.769	0.034	87.678
20/08/2014	52	12,354.419	0.052	642.430
19/08/2014	107	15,332.888	0.107	1640.619
19/08/2014	129	15,332.888	0.129	1977.943
18/08/2014	129	5,974.094	0.129	770.658
18/08/2014	107	5,974.094	0.107	639.228
18/08/2014	92	5,974.094	0.092	549.617
18/08/2014	128	5,974.094	0.128	764.684
18/08/2014	95	5,974.094	0.095	567.539
23/07/2014	1	106.361	0.001	0.106
11/06/2014	0.5	126.944	0.0005	0.063
12/05/2014	0.5	80.858	0.0005	0.040
18/03/2014	6	0	0.006	0
20/02/2014	5	0	0.005	0
2/02/2014	8	0	0.008	0
12/12/2013	3	15.376	0.003	0.046
19/11/2013	4	122.801	0.004	0.491
7/11/2013	6	9.588	0.006	0.058
4/09/2013	3	203.667	0.003	0.611
10/07/2013	5	987.031	0.005	4.935
20/06/2013	3	165.009	0.003	0.495
14/05/2013	3	74.421	0.003	0.223
18/04/2013	4	119.104	0.004	0.476
5/03/2013	15	3,282.819	0.015	49.242
11/02/2013	10	35.949	0.01	0.359
30/01/2013	11	403.688	0.011	4.441
11/12/2012	6	21.366	0.006	0.128
13/11/2012	7	30.23	0.007	0.212

Date	TSS (mg/L)	Flow (megaL/day)	TSS (tonnes/megaL)	TSS loading (tonnes/day)
18/10/2012	11	812.72	0.011	8.940
16/10/2012	18	1,316.93	0.018	23.705
16/10/2012	36	1,316.93	0.036	47.409
16/10/2012	21	1,316.93	0.021	27.656
16/10/2012	90	1,316.93	0.09	118.524
16/10/2012	112	1,316.93	0.112	147.496
16/10/2012	180	1,316.93	0.18	237.047
19/09/2012	6	180.671	0.006	1.084
6/08/2012	1	305.237	0.001	0.305
11/07/2012	0.5	465.944	0.0005	0.233
13/06/2012	11	1,190.668	0.011	13.097
7/06/2012	64	5,150.165	0.064	329.611
7/06/2012	60	5,150.165	0.06	309.010
7/06/2012	85	5,150.165	0.085	437.764
7/06/2012	66	5,150.165	0.066	339.911
7/06/2012	75	5,150.165	0.075	386.262
7/06/2012	82	5,150.165	0.082	422.314
6/06/2012	40	2,697.44	0.04	107.898
6/06/2012	12	2,697.44	0.012	32.369
6/06/2012	19	2,697.44	0.019	51.251
6/06/2012	46	2,697.44	0.046	124.082
6/06/2012	48	2,697.44	0.048	129.477
6/06/2012	75	2,697.44	0.075	202.308
16/05/2012	7	294.417	0.007	2.061
20/04/2012	29	5,391.508	0.029	156.354
20/04/2012	4	5,391.508	0.004	21.566
20/04/2012	18	5,391.508	0.018	97.047
20/04/2012	28	5,391.508	0.028	150.962
20/04/2012	38	5,391.508	0.038	204.877
20/04/2012	20	5,391.508	0.02	107.830
20/04/2012	33	5,391.508	0.033	177.920

Date	TSS (mg/L)	Flow (megaL/day)	TSS (tonnes/megaL)	TSS loading (tonnes/day)
19/04/2012	51	7,838.116	0.051	399.744
19/04/2012	56	7,838.116	0.056	438.934
19/04/2012	22	7,838.116	0.022	172.439
19/04/2012	52	7,838.116	0.052	407.582
19/04/2012	67	7,838.116	0.067	525.154
16/04/2012	6	334.147	0.006	2.005
15/03/2012	7	2,431.416	0.007	17.012
15/03/2012	5	2,431.416	0.005	12.157
15/03/2012	7	2,431.416	0.007	17.012
15/03/2012	8	2,431.416	0.008	19.451
15/03/2012	8	2,431.416	0.008	19.451
15/03/2012	8	2,431.416	0.008	19.451
15/03/2012	8	2,431.416	0.008	19.451
14/03/2012	6	3,083.218	0.006	18.499
14/03/2012	10	3,083.218	0.01	30.832
14/03/2012	10	3,083.218	0.01	30.832
14/03/2012	7	3,083.218	0.007	21.583
14/03/2012	15	3,083.218	0.015	46.248
10/03/2012	21	25,533.468	0.021	536.203
10/03/2012	27	25,533.468	0.027	689.404
10/03/2012	26	25,533.468	0.026	663.870
10/03/2012	19	25,533.468	0.019	485.136
10/03/2012	40	25,533.468	0.04	1021.339
10/03/2012	33	25,533.468	0.033	842.604
10/03/2012	17	25,533.468	0.017	434.069
10/03/2012	30	25,533.468	0.03	766.004
9/03/2012	60	60,151.358	0.06	3609.081
9/03/2012	34	60,151.358	0.034	2045.146
9/03/2012	72	60,151.358	0.072	4330.898
9/03/2012	50	60,151.358	0.05	3007.568
6/03/2012	28	16,075.811	0.028	450.123

Date	TSS (mg/L)	Flow (megaL/day)	TSS (tonnes/megaL)	TSS loading (tonnes/day)
6/03/2012	29	16,075.811	0.029	466.199
6/03/2012	30	16,075.811	0.03	482.274
6/03/2012	24	16,075.811	0.024	385.819
6/03/2012	24	16,075.811	0.024	385.819
6/03/2012	28	16,075.811	0.028	450.123
6/03/2012	42	16,075.811	0.042	675.184
6/03/2012	41	16,075.811	0.041	659.108
5/03/2012	30	27,430.042	0.03	822.901
5/03/2012	10	27,430.042	0.01	274.300
5/03/2012	30	27,430.042	0.03	822.901
5/03/2012	28	27,430.042	0.028	768.0412
4/03/2012	12	31,268.046	0.012	375.217
4/03/2012	15	31,268.046	0.015	469.021
4/03/2012	4	31,268.046	0.004	125.072
4/03/2012	37	31,268.046	0.037	1156.918
4/03/2012	16	31,268.046	0.016	500.289
4/03/2012	54	31,268.046	0.054	1688.474
4/03/2012	26	31,268.046	0.026	812.969
3/03/2012	76	46,116.655	0.076	3504.866
3/03/2012	72	46,116.655	0.072	3320.399
3/03/2012	42	46,116.655	0.042	1936.900
3/03/2012	46	46,116.655	0.046	2121.366
3/03/2012	73	46,116.655	0.073	3366.516
3/03/2012	94	46,116.655	0.094	4334.966
2/03/2012	142	86,816.984	0.142	12328.012
2/03/2012	180	86,816.984	0.18	15627.057
2/03/2012	230	86,816.984	0.23	19967.906
2/03/2012	292	86,816.984	0.292	25350.560
2/03/2012	353	86,816.984	0.353	30646.395
2/03/2012	258	86,816.984	0.258	22398.782
2/03/2012	143	86,816.984	0.143	12414.829

Date	TSS (mg/L)	Flow (megaL/day)	TSS (tonnes/megaL)	TSS loading (tonnes/day)
1/03/2012	136	77,295.603	0.136	10512.202
1/03/2012	157	77,295.603	0.157	12135.410
1/03/2012	160	77,295.603	0.16	12367.296
1/03/2012	189	77,295.603	0.189	14608.869
1/03/2012	257	77,295.603	0.257	19864.970
1/03/2012	220	77,295.603	0.22	17005.033
1/03/2012	246	77,295.603	0.246	19014.718
1/03/2012	315	77,295.603	0.315	24348.115
1/03/2012	436	77,295.603	0.436	33700.883
29/02/2012	378	25,510.381	0.378	9642.924
29/02/2012	274	25,510.381	0.274	6989.844
29/02/2012	150	25,510.381	0.15	3826.557
29/02/2012	72	25,510.381	0.072	1836.747
21/02/2012	55	3569.07	0.055	196.299
21/02/2012	60	3,569.07	0.06	214.144
21/02/2012	59	3,569.07	0.059	210.575
21/02/2012	60	3,569.07	0.06	214.144
21/02/2012	38	3,569.07	0.038	135.625
21/02/2012	49	3,569.07	0.049	174.884
20/02/2012	68	1,221.429	0.068	83.057
19/02/2012	35	1,457.139	0.035	50.100
19/02/2012	38	1,457.139	0.038	55.371
18/02/2012	58	1,383.646	0.058	80.251
18/02/2012	9	1,383.646	0.009	12.453
18/02/2012	16	1,383.646	0.016	22.138
12/02/2012	31	1,108.013	0.031	34.348
11/02/2012	36	1,905.024	0.036	68.581
11/02/2012	26	1,905.024	0.026	49.531
11/02/2012	36	1,905.024	0.036	68.581
11/02/2012	28	1,905.024	0.028	53.341
11/02/2012	20	1,905.024	0.02	38.100

Date	TSS (mg/L)	Flow (megaL/day)	TSS (tonnes/megaL)	TSS loading (tonnes/day)
11/02/2012	29	1,905.024	0.029	55.246
10/02/2012	28	718.145	0.028	20.108
11/01/2012	13.5	98.315	0.0135	1.327
13/12/2011	21	350.579	0.021	7.362
27/11/2011	36	1,618.699	0.036	58.273
27/11/2011	38	1,618.699	0.038	61.511
27/11/2011	37	1,618.699	0.037	59.892
26/11/2011	38	877.399	0.038	33.341
26/11/2011	36	877.399	0.036	31.586
9/11/2011	12	84.744	0.012	1.017
12/10/2011	6	591.378	0.006	3.548
14/09/2011	5	342.9	0.005	1.715
22/08/2011	24	2,675.849	0.024	64.220
22/08/2011	22	2,675.849	0.022	58.869
22/08/2011	17	2,675.849	0.017	45.489
21/08/2011	14	2,351.26	0.014	32.918
21/08/2011	19	2,351.26	0.019	44.674
21/08/2011	21	2,351.26	0.021	49.376
21/08/2011	20	2,351.26	0.02	47.025
21/08/2011	21	2,351.26	0.021	49.376
21/08/2011	19	2,351.26	0.019	44.674
21/08/2011	21	2,351.26	0.021	49.376
21/08/2011	24	2,351.26	0.024	56.430
20/08/2011	40	1,237.238	0.04	49.490
9/08/2011	5	488.248	0.005	2.441
13/07/2011	1	153.309	0.001	0.153
17/06/2011	24	2,891.296	0.024	69.391
17/06/2011	28	2,891.296	0.028	80.956
17/06/2011	35	2,891.296	0.035	101.195
16/06/2011	0.5	2,934.832	0.0005	1.467
16/06/2011	23	2,934.832	0.023	67.501

Date	TSS (mg/L)	Flow (megaL/day)	TSS (tonnes/megaL)	TSS loading (tonnes/day)
16/06/2011	26	2,934.832	0.026	76.306
16/06/2011	42	2,934.832	0.042	123.263
16/06/2011	29	2,934.832	0.029	85.110
16/06/2011	24	2,934.832	0.024	70.436
16/06/2011	30	2,934.832	0.03	88.045
15/06/2011	7	191.583	0.007	1.341
12/05/2011	4	70.287	0.004	0.281
13/04/2011	6	86.188	0.006	0.517
9/03/2011	9	53.362	0.009	0.480
9/02/2011	20	612.804	0.02	12.256
21/01/2011	22	371.412	0.022	8.171
15/12/2010	16	2,255.32	0.016	36.085
15/12/2010	8	2,255.32	0.008	18.043
15/12/2010	10	2,255.32	0.01	22.553
14/12/2010	14	3,254.507	0.014	45.563
14/12/2010	10	3,254.507	0.01	32.545
14/12/2010	19	3,254.507	0.019	61.836
14/12/2010	20	3,254.507	0.02	65.090
14/12/2010	12	3,254.507	0.012	39.054
14/12/2010	20	3,254.507	0.02	65.090
14/12/2010	29	3,254.507	0.029	94.381
13/12/2010	28	5,418.269	0.028	151.712
13/12/2010	27	5,418.269	0.027	146.293
13/12/2010	30	5,418.269	0.03	162.548
13/12/2010	30	5,418.269	0.03	162.548
13/12/2010	53	5,418.269	0.053	287.168
13/12/2010	41	5,418.269	0.041	222.149
12/12/2010	2	11,441.883	0.002	22.884
12/12/2010	2	11,441.883	0.002	22.884
12/12/2010	2	11,441.883	0.002	22.884
12/12/2010	2	11,441.883	0.002	22.884

Date	TSS (mg/L)	Flow (megaL/day)	TSS (tonnes/megaL)	TSS loading (tonnes/day)
12/12/2010	2	11,441.883	0.002	22.884
12/12/2010	1	11,441.883	0.001	11.442
11/12/2010	2	42,480.442	0.002	84.961
11/12/2010	4	42,480.442	0.004	169.922
11/12/2010	2	42,480.442	0.002	84.961
11/12/2010	2	42,480.442	0.002	84.961
11/12/2010	1	42,480.442	0.001	42.480
11/12/2010	3	42,480.442	0.003	127.441
9/12/2010	41	2,357.299	0.041	96.649
9/12/2010	10	2,357.299	0.01	23.573
9/12/2010	10	2,357.299	0.01	23.573
9/12/2010	10	2,357.299	0.01	23.573
9/12/2010	13	2,357.299	0.013	30.645
9/12/2010	13	2,357.299	0.013	30.645
9/12/2010	16	2,357.299	0.016	37.717
9/12/2010	6	2,357.299	0.006	14.144
8/12/2010	6	2,988.157	0.006	17.929
8/12/2010	6	2,988.157	0.006	17.929
8/12/2010	8	2,988.157	0.008	23.905
8/12/2010	2	2,988.157	0.002	5.976
8/12/2010	26	2,988.157	0.026	77.692
8/12/2010	23	2,988.157	0.023	68.728
8/12/2010	30	2,988.157	0.03	89.645
8/12/2010	27	2,988.157	0.027	80.680
8/12/2010	25	2,988.157	0.025	74.704
7/12/2010	30	4,447.365	0.03	133.421
7/12/2010	26	4,447.365	0.026	115.631
7/12/2010	15	4,447.365	0.015	66.710
7/12/2010	35	4,447.365	0.035	155.658
26/11/2010	10	113.597	0.01	1.136
25/11/2010	8	128.491	0.008	1.028

Date	TSS (mg/L)	Flow (megaL/day)	TSS (tonnes/megaL)	TSS loading (tonnes/day)
24/11/2010	18	151.498	0.018	2.727
22/11/2010	59	226.952	0.059	13.390
21/11/2010	4	286.43	0.004	1.148
20/11/2010	6	388.589	0.006	2.332
11/11/2010	17	694.485	0.017	11.806
7/11/2010	18	860.412	0.018	15.487
7/11/2010	20	860.412	0.02	17.208
5/11/2010	28	1,067.064	0.028	29.878
4/11/2010	0.5	1,375.082	0.0005	0.688
4/11/2010	3	1,375.082	0.003	4.125
3/11/2010	10	2,022.622	0.01	20.226
3/11/2010	2	2,022.622	0.002	4.045
3/11/2010	2	2,022.622	0.002	4.045
3/11/2010	1	2,022.622	0.001	2.023
3/11/2010	2	2,022.622	0.002	4.045
3/11/2010	2	2,022.622	0.002	4.045
3/11/2010	0.5	2,022.622	0.0005	1.011
3/11/2010	9	2,022.622	0.009	18.204
2/11/2010	14	415.067	0.014	5.811
13/10/2010	7	125.397	0.007	0.878
15/09/2010	8	362.081	0.008	2.897
19/08/2010	13	598.491	0.013	7.780
18/08/2010	13.5	733.873	0.0135	9.907
15/08/2010	12	754.346	0.012	9.052
14/08/2010	10	788.369	0.01	7.884
14/08/2010	17	788.369	0.017	13.402
11/08/2010	12	196.513	0.012	2.358
11/08/2010	12	196.513	0.012	2.358
9/08/2010	30	208.558	0.03	6.257
15/07/2010	4	56.504	0.004	0.226
7/06/2010	12	452.386	0.012	5.429

Date	TSS (mg/L)	Flow (megaL/day)	TSS (tonnes/megaL)	TSS loading (tonnes/day)
7/06/2010	7	452.386	0.007	3.167
7/06/2010	8	452.386	0.008	3.619
3/06/2010	16	561.772	0.016	8.989
3/06/2010	15	561.772	0.015	8.427
3/06/2010	14	561.772	0.014	7.864
3/06/2010	0.5	561.772	0.0005	0.281
3/06/2010	15	561.772	0.015	8.427
3/06/2010	16	561.772	0.016	8.988
3/06/2010	14	561.772	0.014	7.865
3/06/2010	14	561.772	0.014	7.865
3/06/2010	17	561.772	0.017	9.550
3/06/2010	13	561.772	0.013	7.303
3/06/2010	16	561.772	0.016	8.989
12/05/2010	5	10.949	0.005	0.054
14/04/2010	6	26.435	0.006	0.159
10/03/2010	6	78.38	0.006	0.470
19/02/2010	20	1,741.19	0.02	34.823
19/02/2010	29	1,741.19	0.029	50.495
16/02/2010	116	12,465.312	0.116	1445.976
16/02/2010	77	12,465.312	0.077	959.829
16/02/2010	53	12,465.312	0.053	660.662
15/02/2010	228	16,501.981	0.228	3762.452
15/02/2010	256	16,501.981	0.256	4224.507
15/02/2010	224	16,501.981	0.224	3696.444
15/02/2010	305	16,501.981	0.305	5033.104
15/02/2010	151	16,501.981	0.151	2491.799
15/02/2010	401	16,501.981	0.401	6617.294
15/02/2010	110	16,501.981	0.11	1815.218
15/02/2010	99	16,501.981	0.099	1633.696
14/02/2010	174	3,066.251	0.174	533.528
14/02/2010	29	3,066.251	0.029	88.921

Date	TSS (mg/L)	Flow (megaL/day)	TSS (tonnes/megaL)	TSS loading (tonnes/day)
14/02/2010	41	3,066.251	0.041	125.716
14/02/2010	42	3,066.251	0.042	128.783
14/02/2010	35	3,066.251	0.035	107.319
12/02/2010	46	1,478.331	0.046	68.003
12/02/2010	39	1,478.331	0.039	57.655
12/02/2010	35	1,478.331	0.035	51.742
11/02/2010	19	1,650.904	0.019	31.367
11/02/2010	30	1,650.904	0.03	49.527
11/02/2010	18	1,650.904	0.018	29.716
11/02/2010	12	1,650.904	0.012	19.811
9/02/2010	28	1,673.292	0.028	46.852
9/02/2010	35	1,673.292	0.035	58.565
8/02/2010	35	2,457.299	0.035	86.005
6/02/2010	102	1,438.228	0.102	146.699
6/02/2010	58	1,438.228	0.058	83.417
6/02/2010	79	1,438.228	0.079	113.620
13/01/2010	5.5	0	0.0055	0

Average TSS loading (tonnes/day)	Estimated TSS loading (tonnes/annum)
1,361.6	496,983

G

Appendix G – Rapid Geomorphology Walkover Assessment Templates

G.1 Upstream Zone

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	WDR EIS (Beca reference # 4512987)				**Date**	31/01/2019
Surveyor	DE	**Reach code:** US-01			**Time**	12:41 hrs
Drainage channel	**Creek**	**River**	**Estuary**	**Pond**	**Wetland**	**Lake**
		X (Wollondilly)				

Weather conditions	Sunny, hot, wind	**U-S elevation**	157m	**D-S elevation**	149m
Upstream grid reference	243026;6201566 (56H UTM)	**Downstream grid reference**	243020; 6201593		

Watercourse attributes

Dimensions	**Width**	30.4 m	**Max. depth**	U-S = 0.22 m D-S = 0.36 m	**Average velocity (ms^{-1})**	U-S = 0.06 ms^{-1} D-S = 0.18 ms^{-1}	
Shape description		Flat, open	**Max. Roughness Height**	0.3 m	**Bank erosion**	Attritional erosion to whole banks, no hotspots	

Instream vegetation (% cover [emergent, floating, submerged, algae, moss])	Benthic algae 60%	**Bank vegetation** None	**Bench vegetation** Grasses & herbs 30%; Casuarina and Mulga 70%	**Organic matter** Twigs / Leaves	

Flow type

Smooth surface flow [H1]	Broken standing waves [H2]	Unbroken standing waves [H3]	Chute [H4]	Rippled [H5]	Scarcely perceptible flow [H6]	Upwelling [H7]	Free fall [H8]	Standing water [H9]
			X					

Channel Planform

Sinuosity (straight, low, intermediate, high)	Low	***Form***	**Single** X	**Forked**	**Braided**	**Open**
Sand bars No	**Gravel bars** Yes	**Rock outcrops** No		**Riparian strip** No	**Floodplain connectivity**	Open
Floodplain land use	Site at end of Scabby Flat Trail (crossing indicated on map but out of use) National Park & Sydney Water Protected Catchment	**Bank Strength (kg/cm²)**	U-S 1.8, 1.2, 1.25 D-S 1.6, 2.4, 2.5		**Bank structure & angle**	15°, concave

Bed character

	Boulder		**Cobble**		**Gravel**		**Sand**		**Fine sand**		**Silt / clay**	
% composition	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**
	20	30	40	40	30	30	10	0	0	0	0	0

Bed stability	Packed and armoured	**Supply**	**Deposition**	**Erosion**	**Conveying**
					X

*DWF = Dry weather flow, BF = Bankfull flow, RHB = Right hand bank, LHB = Left hand bank, U-S = Upstream location of selected stretch, D-S = Downstream location of selected stretch

Created 04/08/2011 Dan Evans (after Thompson et al, 2011, *Aq Conserve*, **11**, 373 – 389)

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Historic Aerial US – 01 | October 2016

Not Available

Cross-section US - 01

Upstream US – 01

Downstream US - 01

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	WDR EIS (Beca reference # 4512987)		**Date**	31/01/2019
Surveyor	DE	**Reach code:** US-02	**Time**	14:30 hrs

Drainage channel	**Creek**	**River**	**Estuary**	**Pond**	**Wetland**	**Lake**
		X (Wollondilly)				

Weather conditions	Sunny, hot, wind	**U-S elevation**	156m	**D-S elevation**	152m
Upstream grid reference	244868 6206602 (56H UTM)	**Downstream grid reference**	244489; 6206888		

Watercourse attributes

Dimensions	**Width**	79.5 m	**Max. depth**	U-S = m D-S = m	**Average velocity (ms^{-1})**	U-S = 0.24 ms^{-1} D-S = 0.10 ms^{-1}
Shape description		Complex multi-terrace with mid-channel island	**Max. Roughness Height**	None	**Bank erosion**	No significant erosion observed

Instream vegetation (% cover [emergent, floating, submerged, algae, moss])	Submerged Elodea 50% Emergent Cumbungi 10%	**Bank vegetation** None	**Bench vegetation** Grasses & herbs 80%; Casuarina 20%	**Organic matter** Twigs / Leaves & detritus

Flow type

Smooth surface flow [H1]	**Broken standing waves** [H2]	**Unbroken standing waves** [H3]	**Chute** [H4]	**Rippled** [H5]	**Scarcely perceptible flow** [H6]	**Upwelling** [H7]	**Free fall** [H8]	**Standing water** [H9]
X			X	X	X			

Channel Planform

Sinuosity (straight, low, intermediate, high)	Intermediate	***Form***	**Single**	**Forked**	**Braided** X	**Open**

Sand bars	**Gravel bars**	**Rock outcrops**	**Riparian strip**	**Floodplain connectivity**	
No	Yes	No	No		Open

Floodplain land use	LHB Cleared area with small farm holding & activity centre (disused) at end of Burnt Flat W4A fire trail RHB National Park & Sydney Water Protected Catchment	**Bank Strength (kg/cm^2)**	U-S 0.8, 0.6, 1.5 D-S 0.5, 0.4, 0.2	**Bank structure & angle**	LHB 45°, concave RHB 20°, straight

Bed character

	Boulder		**Cobble**		**Gravel**		**Sand**		**Fine sand**		**Silt / clay**	
% composition	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**
	20	0	20	0	40	0	20	80	0	15	0	5

		Supply	**Deposition**	**Erosion**	**Conveying**
Bed stability	U-S Packed not armoured D-S No packing		X		X

*DWF = Dry weather flow, BF = Bankfull flow, RHB = Right hand bank, LHB = Left hand bank, U-S = Upstream location of selected stretch, D-S = Downstream location of selected stretch

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Not Available

Cross-section US – 02

Historic Aerial US – 02 |October 2016	Upstream US – 02	Downstream US - 02

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

<table>
<tr><td>Project</td><td colspan="6">WDR EIS (Beca reference # 4512987)</td><td>Date</td><td>31/01/2019</td></tr>
<tr><td>Surveyor</td><td>DE</td><td colspan="5">Reach code: US-04</td><td>Time</td><td>16:15 hrs</td></tr>
<tr><td colspan="2">Drainage channel</td><td>Creek</td><td>River</td><td>Estuary</td><td colspan="2">Pond</td><td>Wetland</td><td>Lake</td></tr>
<tr><td colspan="2"></td><td></td><td>X (Wollondilly)</td><td></td><td colspan="2"></td><td></td><td></td></tr>
<tr><td colspan="2">Weather conditions</td><td colspan="3">Overcast, hot, breeze</td><td>U-S elevation</td><td>125m</td><td>D-S elevation</td><td>120m</td></tr>
<tr><td colspan="2">Upstream grid reference</td><td colspan="3">251172 6013797 (56H UTM)</td><td>Downstream grid reference</td><td colspan="3">251159 6215797</td></tr>
</table>

<table>
<tr><th colspan="8">Watercourse attributes</th></tr>
<tr><td>Dimensions</td><td>Width</td><td>65.9 m</td><td>Max. depth</td><td>U-S = 0.31 m
D-S = 0.22 m</td><td>Average velocity (ms^{-1})</td><td colspan="2">U-S = 0.15 ms^{-1}
D-S = 0.69 ms^{-1}</td></tr>
<tr><td colspan="2">Shape description</td><td>Open u-shape</td><td>Max. Roughness Height</td><td>0.2 m</td><td>Bank erosion</td><td colspan="2">No erosion observed</td></tr>
<tr><td>Instream vegetation
(% cover [emergent, floating, submerged, algae, moss])</td><td colspan="2">U-S benthic algae 10%
D-S benthic algae 40%</td><td colspan="2">Bank vegetation
None</td><td colspan="2">Bench vegetation
Grasses & herbs 60%; Casuarina 20%</td><td>Organic matter
Logs</td></tr>
</table>

Flow type								
Smooth surface flow [H1]	**Broken standing waves** [H2]	**Unbroken standing waves** [H3]	**Chute** [H4]	**Rippled** [H5]	**Scarcely perceptible flow** [H6]	**Upwelling** [H7]	**Free fall** [H8]	**Standing water** [H9]
			X (U-S)	X (D-S)				

<table>
<tr><th colspan="8">Channel Planform</th></tr>
<tr><td>Sinuosity
(straight, low, intermediate, high)</td><td>Low</td><td>Form</td><td>Single
X</td><td>Forked</td><td colspan="2">Braided</td><td>Open</td></tr>
<tr><td>Sand bars
No</td><td colspan="2">Gravel bars
Yes</td><td colspan="2">Rock outcrops
No</td><td>Riparian strip
No</td><td>Floodplain connectivity</td><td>Open</td></tr>
<tr><td>Floodplain land use</td><td colspan="2">National Park & Sydney Water Protected Catchment
Ford crossing point across river on W4G fire trail</td><td colspan="2">Bank Strength (kg/cm²)</td><td>U-S 1.7, 2.5, 3.6
D-S 0.3, 0.7, 0.8</td><td>Bank structure & angle</td><td>10°, straight</td></tr>
</table>

<table>
<tr><th colspan="13">Bed character</th></tr>
<tr><td rowspan="3">% composition</td><td colspan="2">Boulder</td><td colspan="2">Cobble</td><td colspan="2">Gravel</td><td colspan="2">Sand</td><td colspan="2">Fine sand</td><td colspan="2">Silt / clay</td></tr>
<tr><td>U-S</td><td>D-S</td><td>U-S</td><td>D-S</td><td>U-S</td><td>D-S</td><td>U-S</td><td>D-S</td><td>U-S</td><td>D-S</td><td>U-S</td><td>D-S</td></tr>
<tr><td>0</td><td>0</td><td>100</td><td>100</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td rowspan="2">Bed stability</td><td colspan="4" rowspan="2">Packed & armoured</td><td colspan="2">Supply</td><td colspan="2">Deposition</td><td colspan="2">Erosion</td><td colspan="2">Conveying</td></tr>
<tr><td colspan="2"></td><td colspan="2">X</td><td colspan="2"></td><td colspan="2">X</td></tr>
</table>

*DWF = Dry weather flow, BF = Bankfull flow, RHB = Right hand bank, LHB = Left hand bank, U-S = Upstream location of selected stretch, D-S = Downstream location of selected stretch

Historic Aerial US – 04|December 2018

Not Available

Cross-section US – 04

Upstream US – 04

Downstream US - 04

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	WDR EIS (Beca reference # 4512987)					**Date**	04/02/2019
Surveyor	DE	**Reach code:** US-05				**Time**	10:00 hrs
Drainage channel	**Creek**	**River**	**Estuary**	**Pond**		**Wetland**	**Lake**
		X (Wollondilly)					
Weather conditions	Overcast, still			**U-S elevation**	111 m	**D-S elevation**	109 m
Upstream grid reference	2544193; 6218438 (56H UTM)			**Downstream grid reference**	2544205; 6218458		

Watercourse attributes						
Dimensions	**Width**	205 m	**Max. depth**	U-S = >5 m D-S = >5 m	**Average velocity (ms^{-1})**	U-S = 0.0 ms^{-1} D-S = 0.0 ms^{-1}
Shape description		Flat, u-shaped channel	**Max. Roughness Height**	n/a	**Bank erosion**	Rill erosion forming on unconsolidated banks due to runoff water from island
Instream vegetation (% cover [emergent, floating, submerged, algae, moss])	None	**Bank vegetation** None		**Bench vegetation** Grasses & herbs 100%		**Organic matter** Logs, Twigs / Leaves, Detritus

Flow type								
Smooth surface flow [H1]	**Broken standing waves** [H2]	**Unbroken standing waves** [H3]	**Chute** [H4]	**Rippled** [H5]	**Scarcely perceptible flow** [H6]	**Upwelling** [H7]	**Free fall** [H8]	**Standing water** [H9]
			X		X			

Channel Planform						
Sinuosity (straight, low, intermediate, high)	Low	***Form***	**Single** X	**Forked**	**Braided**	**Open**
Sand bars No	**Gravel bars** No	**Rock outcrops** No		**Riparian strip** No	**Floodplain connectivity**	Open
Floodplain land use	Delta Island at entrance to Lake Burragorang National Park & Sydney Water Protected Catchment	**Bank Strength (kg/cm²)**		U-S >4.5, 3.7, 2.5 D-S >4.5, >45, 2.7	**Bank structure & angle**	30°, straight

Bed character												
% composition	**Boulder**		**Cobble**		**Gravel**		**Sand**		**Fine sand**		**Silt / clay**	
	U-S	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**
					10		10		70	90	10	10
Bed stability	Moderate compaction				**Supply**		**Deposition**		**Erosion**		**Conveying**	
							X				X	

*DWF = Dry weather flow, BF = Bankfull flow, RHB = Right hand bank, LHB = Left hand bank, U-S = Upstream location of selected stretch, D-S = Downstream location of selected stretch

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Historic Aerial US – 05 | December 2018

Not Available

Cross-section US – 05

Upstream US – 05

Downstream US - 05

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	WDR EIS (Beca reference # 4512987)					**Date**	31/01/2019
Surveyor	DE	**Reach code:** US-06				**Time**	09:15 hrs
Drainage channel	**Creek**	**River**	**Estuary**	**Pond**	**Wetland**		**Lake**
		X (Nattai)					
Weather conditions	Sunny, hot		**U-S elevation**	117 m	**D-S elevation**	115 m	
Upstream grid reference	262542; 6218982 (56H UTM)		**Downstream grid reference**	262572; 6210017			

Watercourse attributes

Dimensions	**Width**	39.5 m	**Max. depth**	U-S = 0.31 m D-S = 0.38 m	**Average velocity (ms^{-1})**	U-S = 0.00 ms^{-1} D-S = 0.15 ms^{-1}	
Shape description		Flat u-shaped channel	**Max. Roughness Height**	U-S n/a D-S 0. 34m	**Bank erosion**	No signs of erosion observed	
Instream vegetation (% cover [emergent, floating, submerged, algae, moss])	None	**Bank vegetation** U-S Short grass 30% D-S None		**Bench vegetation** Casuarina, Juvenile Eucalypt & Water Gum 80%		**Organic matter** Logs & Twigs / Leaves	

Flow type

Smooth surface flow [H1]	Broken standing waves [H2]	Unbroken standing waves [H3]	Chute [H4]	Rippled [H5]	Scarcely perceptible flow [H6]	Upwelling [H7]	Free fall [H8]	Standing water [H9]
X (U-S)			X (D-S)	X (D-S)	X (U-S)			

Channel Planform

Sinuosity	Low	***Form***	**Single** X (U-S)	**Forked**	**Braided** X (D-S)	**Open**
Sand bars No	**Gravel bars** Yes	**Rock outcrops** Yes		**Riparian strip** No	**Floodplain connectivity**	Open
Floodplain land use	Smallwoods Crossing W4H fire trial access across reach Gauging station cableway 100 m upstream National Park & Sydney Water Protected Catchment	**Bank Strength (kg/cm^2)**		U-S >4.5, 1.2, 0.3 D-S 2.7, 2.0, 1.5	**Bank structure & angle**	U-S LHB 70°, straight RHB 25°, concave D-S 30°, concave both sides

Bed character

	Boulder		Cobble		Gravel		Sand		Fine sand		Silt / clay	
% composition	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**
	0	30	0	10	0	30	70	25	20	5	10	0

Bed stability	U-S Low compaction D-S Packed not armoured	**Supply**	**Deposition**	**Erosion**	**Conveying**
			X		X

*DWF = Dry weather flow, BF = Bankfull flow, RHB = Right hand bank, LHB = Left hand bank, U-S = Upstream location of selected stretch, D-S = Downstream location of selected stretch

Created 04/08/2011 Dan Evans (after Thompson et al, 2011, *Aq Conserve*, **11**, 373 – 389)

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Historic Aerial US – 06 | January 2019

Not Available

Cross-section US – 06

Upstream US – 06

Downstream US - 06

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	WDR EIS (Beca reference # 4512987)			**Date**	31/01/2019
Surveyor	DE	**Reach code:** US-07		**Time**	07:40 hrs

Drainage channel	**Creek**	**River**	**Estuary**	**Pond**	**Wetland**	**Lake**
		X (Nattai)				

Weather conditions	Cloud cover, warm	**U-S elevation**	132 m	**D-S elevation**	129 m
Upstream grid reference (m)	265063; 6220113	**Downstream grid reference (m)**	265086; 6220146		

Watercourse attributes

Dimensions	**Width**	9.8 m	**Max. depth**	U-S = 0.35 m D-S = 0.38 m	**Average velocity (ms^{-1})**	U-S = 0.47 ms^{-1} D-S = 0.58 ms^{-1}
Shape description		Flat alluvial pan	**Max. Roughness Height**	N/a	**Bank erosion**	Undercut banks into un-cohesive sediment deposits

Instream vegetation (% cover [emergent, floating, submerged, algae, moss])	No	**Bank vegetation**	None	**Bench vegetation**	LHB coppiced trees water edge – 10m (10% cover); RHB dense weeds (100% cover)	**Organic matter**	Logs

Flow type

Smooth surface flow [H1]	**Broken standing waves** [H2]	**Unbroken standing waves** [H3]	**Chute** [H4]	**Rippled** [H5]	**Scarcely perceptible flow** [H6]	**Upwelling** [H7]	**Free fall** [H8]	**Standing water** [H9]
			X (U-S)	X (D-S)				

Channel Planform

Sinuosity (straight, low, intermediate, high)	Low	***Form***	**Single** X	**Forked**	**Braided**	**Open**
Sand bars Yes	**Gravel bars** Yes	**Rock outcrops** No		**Riparian strip** No	**Floodplain connectivity**	Lower bench open, steep banks to 2nd bench
Floodplain land use	Metal bridge over Nattai River National Park & Sydney Water Protected Catchment	**Bank Strength (kg/cm^2)**		U-S 0.2, 0.55, 0.3 D-S 0.5, 0.3, 0.2	**Bank structure & angle**	LHB 40° stepped RHB 60° convex

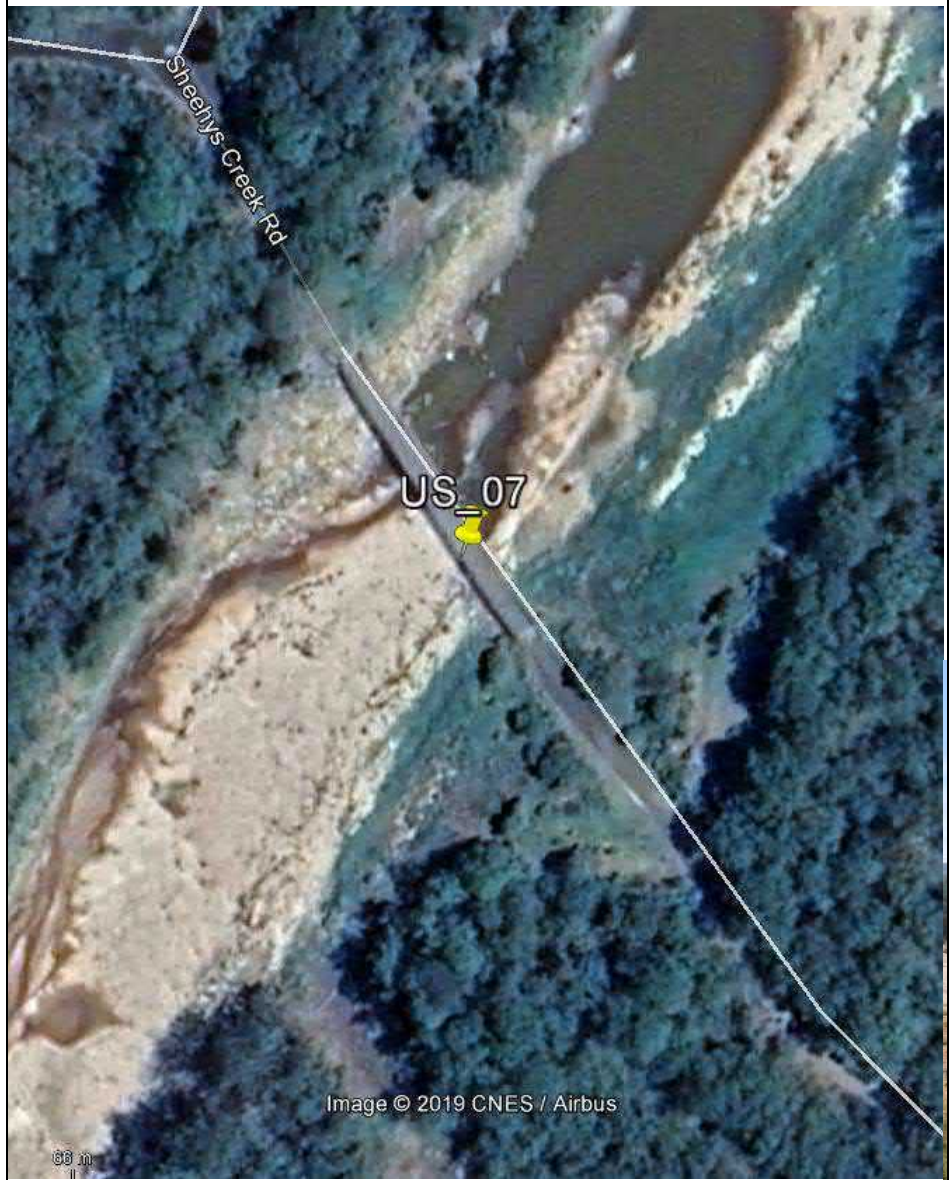
Bed character

	Boulder		**Cobble**		**Gravel**		**Sand**		**Fine sand**		**Silt / clay**	
% composition	U-S	D-S	U-S	D-S	U-S	D-S	U-S	D-S	U-S	D-S	U-S	D-S
	5	10	0	0	10	20	70	60	5	10		

Bed stability	Low compaction	**Supply**	**Deposition**	**Erosion**	**Conveying**
			X		X

*DWF = Dry weather flow, BF = Bankfull flow, RHB = Right hand bank, LHB = Left hand bank, U-S = Upstream location of selected stretch, D-S = Downstream location of selected stretch

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

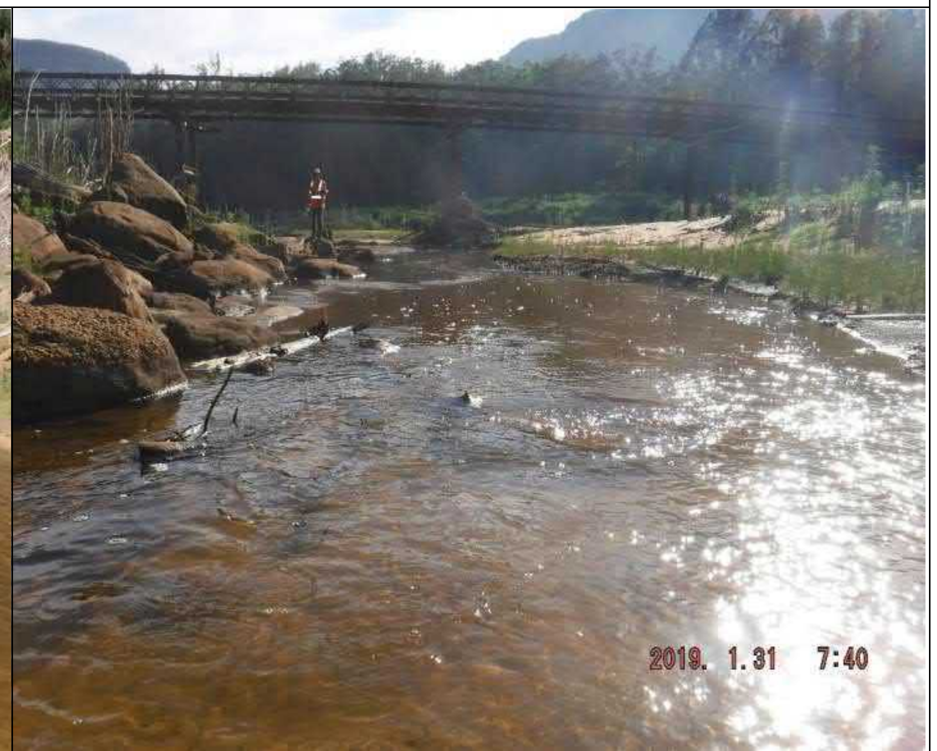


Historic Aerial US – 07 | October 2016

Not Available

Cross-section US – 07

Upstream US – 07



Downstream US - 07

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	WDR EIS (Beca reference # 4512987)							**Date**		04/02/2019
Surveyor	DE	**Reach code:** US-08						**Time**		11:30 hrs
Drainage channel		**Creek**	**River**	**Estuary**	**Pond**			**Wetland**		**Lake**
			X							
Weather conditions		Bright, hot			**U-S elevation**			113 m	**D-S elevation**	113 m
Upstream grid reference		265153; 6221602 (56H UTM)			**Downstream grid reference**			265153; 6221626		

Watercourse attributes							
Dimensions	**Width**	86.6 m	**Max. depth**	U-S = 0.15 m D-S = 0.20 m	**Average velocity (ms^{-1})**	U-S = 0.23 ms^{-1} D-S = 0.12 ms^{-1}	
Shape description		Rectangular, enclosed both sides by steep rockface	**Max. Roughness Height**	n/a	**Bank erosion**	Bankcliff cliff bank toe erosion & localised deposition on valley floor	
Instream vegetation (% cover [emergent, floating, submerged, algae, moss])	No	**Bank vegetation** None		**Bench vegetation** LHB Grasses & herbs 30% RHB None		**Organic matter** Logs & Twigs / Leaves	

Flow type								
Smooth surface flow [H1]	**Broken standing waves** [H2]	**Unbroken standing waves** [H3]	**Chute** [H4]	**Rippled** [H5]	**Scarcely perceptible flow** [H6]	**Upwelling** [H7]	**Free fall** [H8]	**Standing water** [H9]
X (D-S)			X (U-S)	X (U-S)				

Channel Planform						
Sinuosity (straight, low, intermediate, high)	Intermediate	***Form***	**Single**	**Forked** X	**Braided**	**Open**
Sand bars Yes	**Gravel bars** No	**Rock outcrops** No		**Riparian strip** No	**Floodplain connectivity**	Enclosed
Floodplain land use	Nattai inflow to Lake Burragorang National Park & Sydney Water Protected Catchment	**Bank Strength (kg/cm^2)**		U-S 0.2, 0.2, 0.15 D-S 0.2, 0.25, 0.25	**Bank structure & angle**	1st tier 70°, straight 2nd tier 90°, straight

Bed character												
% composition	**Boulder**		**Cobble**		**Gravel**		**Sand**		**Fine sand**		**Silt / clay**	
	U-S	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**
	0	0	0	0	10	0	70	80	20	20	0	0
Bed stability	Packed not armoured				**Supply**		**Deposition**		**Erosion**		**Conveying**	
							X				X	

*DWF = Dry weather flow, BF = Bankfull flow, RHB = Right hand bank, LHB = Left hand bank, U-S = Upstream location of selected stretch, D-S = Downstream location of selected stretch

Historic Aerial US – 08 | January 2019

Not Available

Cross-section US – 08

Upstream US – 08

Downstream US - 08

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

<table>
<tr><td>Project</td><td colspan="5">WDR EIS (Beca reference # 4512987)</td><td>Date</td><td>07/02/2019</td></tr>
<tr><td>Surveyor</td><td>DE</td><td colspan="4">Reach code: US-09</td><td>Time</td><td>13:00 hrs</td></tr>
<tr><td colspan="2">Drainage channel</td><td>Creek</td><td>River</td><td>Estuary</td><td>Pond</td><td>Wetland</td><td>Lake</td></tr>
<tr><td colspan="2"></td><td></td><td>X (Coxs)</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Weather conditions</td><td colspan="3">Warm, breeze</td><td>U-S elevation</td><td>53 m   D-S elevation</td><td>48 m</td></tr>
<tr><td colspan="2">Upstream grid reference</td><td colspan="3">246061; 6248709 (56H UTM)</td><td>Downstream grid reference</td><td colspan="2">246055; 6248710</td></tr>
</table>

Watercourse attributes

Dimensions	**Width**	17 m	**Max. depth**	U-S = 0.44 m D-S = 0.53 m	**Average velocity (ms^{-1})**	U-S = 0.19 ms^{-1} D-S = 0.36 ms^{-1}
Shape description		V-shaped, open	**Max. Roughness Height**	0.3 m	**Bank erosion**	Mostly vegetated stable channel sides

Instream vegetation (% cover [emergent, floating, submerged, algae, moss])	Submerged Milfoil 10% & Elodea 10%	**Bank vegetation** None	**Bench vegetation** Grasses & herbs 60%	**Organic matter** Twigs / Leaves & detritus 20%

Flow type

Smooth surface flow [H1]	Broken standing waves [H2]	Unbroken standing waves [H3]	Chute [H4]	Rippled [H5]	Scarcely perceptible flow [H6]	Upwelling [H7]	Free fall [H8]	Standing water [H9]
X (U-S)			X (D-S)	X (D-S)				

Channel Planform

Sinuosity (straight, low, intermediate, high)	Intermediate	***Form***	**Single** X	**Forked**	**Braided**	**Open**
Sand bars No	**Gravel bars** Yes	**Rock outcrops** Yes		**Riparian strip** No	**Floodplain connectivity**	Constrained by steep side bank
Floodplain land use	Flow gauging station transect 50m upstream from study reach National Park & Sydney Water Protected Catchment	**Bank Strength (kg/cm²)**		U-S 1.0. 0.6, 2.3 D-S 2.6, 4.0, >4.5	**Bank structure & angle**	60°, concave

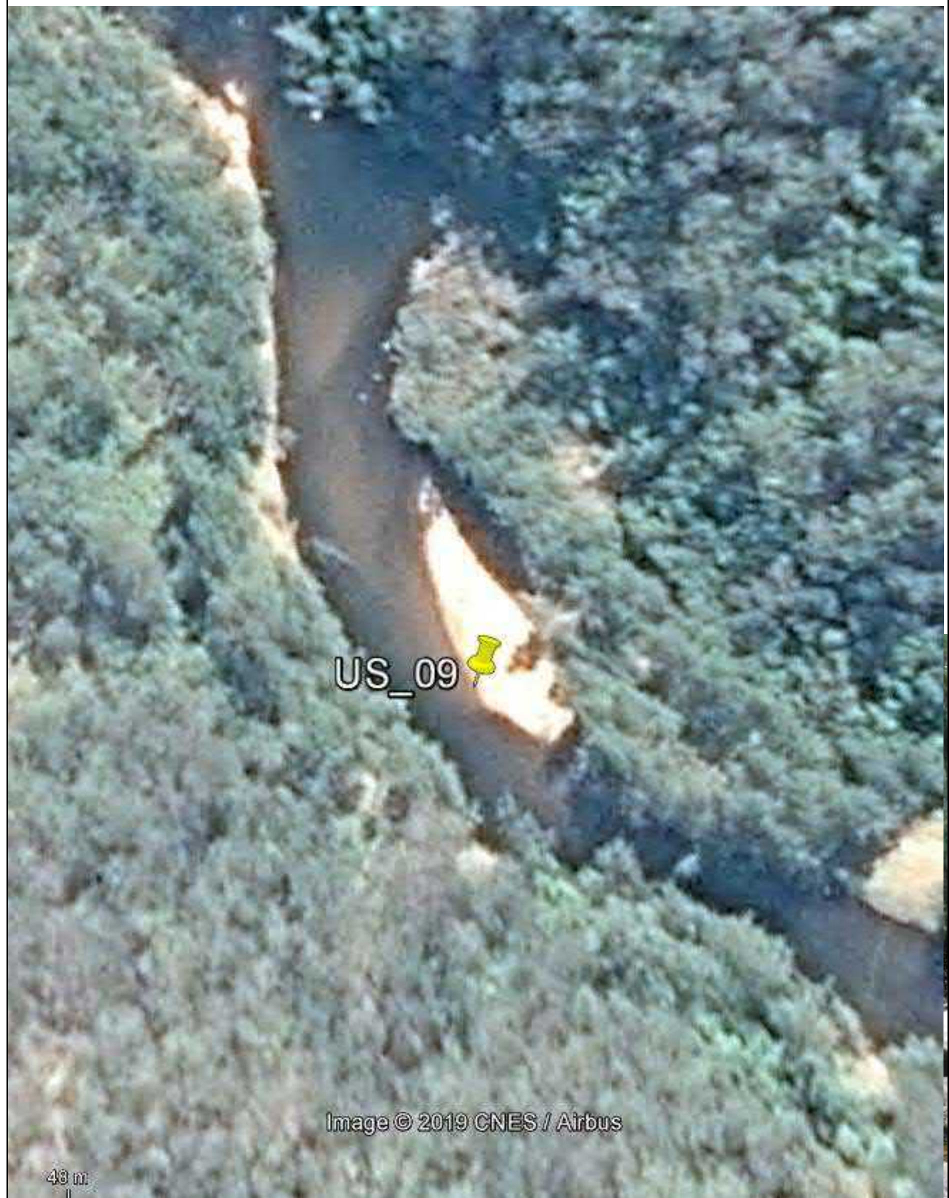
Bed character

	Boulder		Cobble		Gravel		Sand		Fine sand		Silt / clay	
% composition	U-S	D-S	U-S	D-S	U-S	D-S	U-S	D-S	U-S	D-S	U-S	D-S
	10	20	40	40	0	0	40	40	10	0	0	0

Bed stability	Packed & armoured	**Supply**	**Deposition**	**Erosion**	**Conveying**
		X	X	X	X

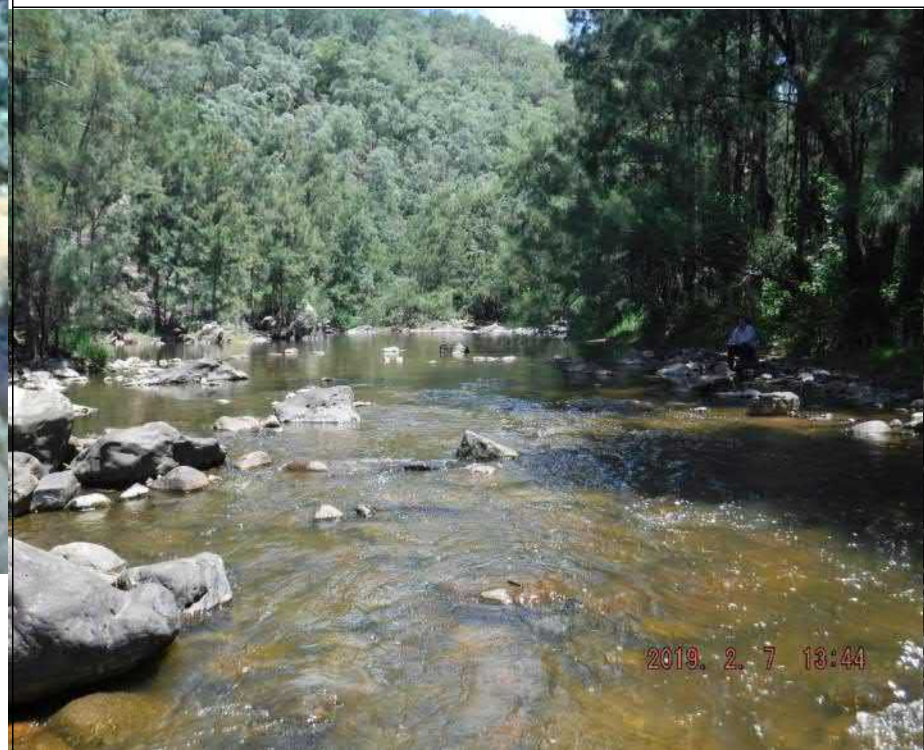
*DWF = Dry weather flow, BF = Bankfull flow, RHB = Right hand bank, LHB = Left hand bank, U-S = Upstream location of selected stretch, D-S = Downstream location of selected stretch

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE



Not Available

Cross-section US – 09



Historic Aerial US – 09 | October 2016	**Upstream US – 09**	**Downstream US - 09**

Created 04/08/2011 Dan Evans (after Thompson et al, 2011, *Aq Conserve*, **11**, 373 – 389)

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	WDR EIS (Beca reference # 4512987)	**Date**	07/02/2019
Surveyor	DE — **Reach code:** US - 10	**Time**	15:15 hrs

Drainage channel	**Creek**	**River**	**Estuary**	**Pond**	**Wetland**	**Lake**
		X (Cox's)				

Weather conditions	Sunny, hot, wind	**U-S elevation**	163 m	**D-S elevation**	142 m
Upstream grid reference	246764; 6249204 (56H UTM)	**Downstream grid reference**	246755; 6249236		

Watercourse attributes

Dimensions	**Width**	12 m	**Max. depth**	U-S = 0.89 m D-S = 0.47 m	**Average velocity (ms^{-1})**	U-S = 0.48 ms^{-1} D-S = 0.58 ms^{-1}
Shape description		Elongated rectangle with mid-channel berm	**Max. Roughness Height**	N/a	**Bank erosion**	Active erosion of mid-channel berm during high flow events and deposition during intermediate flows

Instream vegetation (% cover [emergent, floating, submerged, algae, moss])	Benthic algae 10% in low flow side channel	**Bank vegetation** None	**Bench vegetation** Grasses & herbs 20%	**Organic matter** Logs & Twigs / Leaves

Flow type

Smooth surface flow [H1]	**Broken standing waves** [H2]	**Unbroken standing waves** [H3]	**Chute** [H4]	**Rippled** [H5]	**Scarcely perceptible flow** [H6]	**Upwelling** [H7]	**Free fall** [H8]	**Standing water** [H9]
X (U-S)			X (D-S)	X (D-S)				

Channel Planform

Sinuosity (straight, low, intermediate, high)	High	***Form***	**Single**	**Forked** X	**Braided**	**Open**

Sand bars	**Gravel bars**	**Rock outcrops**	**Riparian strip**	**Floodplain connectivity**	
No	Yes	Yes	No		Constrained by steep side bank

Floodplain land use	National Park & Sydney Water Protected Catchment	**Bank Strength (kg/cm^2)**	1st tier 2.3, 2.5, 3.1 2nd tier 0.4, 0.4, 0.3	**Bank structure & angle**	LHB 20 ° concave RHB 40 ° straight

Bed character

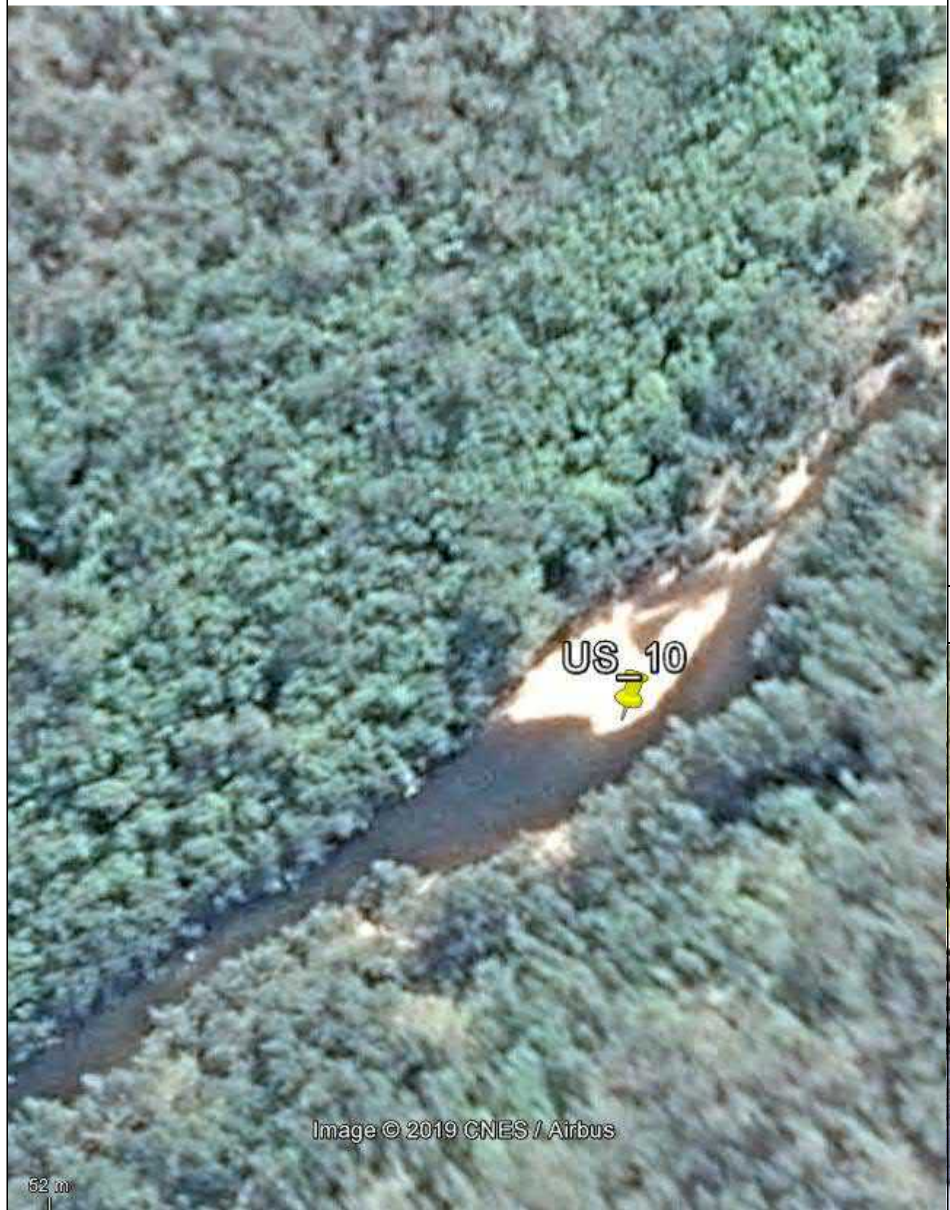
	Boulder		**Cobble**		**Gravel**		**Sand**		**Fine sand**		**Silt / clay**	
% composition	U-S	D-S	U-S	D-S	U-S	D-S	U-S	D-S	U-S	D-S	U-S	D-S
	0	0	30	80	40	20	30	0	0	0	0	0

		Supply	**Deposition**	**Erosion**	**Conveying**
Bed stability	Packed not armoured	X	X	X	X

*DWF = Dry weather flow, BF = Bankfull flow, RHB = Right hand bank, LHB = Left hand bank, U-S = Upstream location of selected stretch, D-S = Downstream location of selected stretch

Created 04/08/2011 Dan Evans (after Thompson et al, 2011, *Aq Conserve*, **11**, 373 – 389)

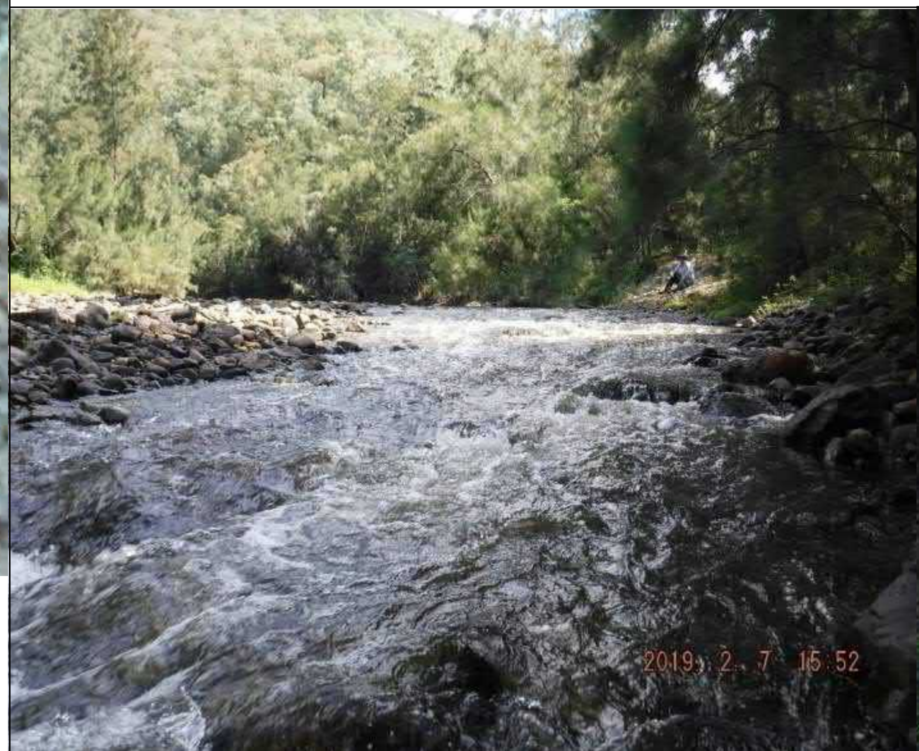
FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE



Historic Aerial US – 10 | October 2016

Not Available

Cross-section US – 10



Upstream US – 10

Downstream US - 10

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	WDR EIS (Beca reference # 4512987)						**Date**		08/02/2019
Surveyor	DE	**Reach code:** US-11					**Time**		10:30 hrs
Drainage channel		**Creek**	**River**	**Estuary**	**Pond**		**Wetland**		**Lake**
		X (Reddy)							
Weather conditions		Sunny, hot, windy			**U-S elevation**		155 m	**D-S elevation**	154 m
Upstream grid reference		256799;6253942 (56H UTM)			**Downstream grid reference**		256796; 6253945		

Watercourse attributes							
Dimensions	**Width**	3.8 m	**Max. depth**	U-S = 0.25 m D-S = 0.28 m	**Average velocity (ms^{-1})**	U-S = 0.07 ms^{-1} D-S = 0.07 ms^{-1}	
Shape description		Flat trapazoidal	**Max. Roughness Height**	0. m	**Bank erosion**	LHB - Erosion inlets on sandy bank	
Instream vegetation (% cover [emergent, floating, submerged, algae, moss])	No	**Bank vegetation** None		**Bench vegetation** Grasses & herbs 30%; Casuarina and Mulga 70%		**Organic matter** Twigs / Leaves	

Flow type								
Smooth surface flow [H1]	**Broken standing waves** [H2]	**Unbroken standing waves** [H3]	**Chute** [H4]	**Rippled** [H5]	**Scarcely perceptible flow** [H6]	**Upwelling** [H7]	**Free fall** [H8]	**Standing water** [H9]
			X					

Channel Planform						
Sinuosity (straight, low, intermediate, high)	Low	***Form***	**Single** X	**Forked**	**Braided**	**Open**
Sand bars No	**Gravel bars** **Yes**		**Rock outcrops** No	**Riparian strip** No	**Floodplain connectivity**	Open
Floodplain land use	National Park & Sydney Water Protected Catchment		**Bank Strength (kg/cm^2)**	U-S 0.5, 0.75, 0.8 D-S 1.2, 1.0, 0.75	**Bank structure & angle**	LHB 80°, straight RHB 15°, concave

Bed character												
% composition	**Boulder**		**Cobble**		**Gravel**		**Sand**		**Fine sand**		**Silt / clay**	
	U-S	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**
	0	0	80	70	10	20	10	10	0	0	0	0
Bed stability	Packed & armoured				**Supply**		**Deposition**		**Erosion**		**Conveying**	
					X				X		X	

***DWF = Dry weather flow, BF = Bankfull flow, RHB = Right hand bank, LHB = Left hand bank, U-S = Upstream location of selected stretch, D-S = Downstream location of selected stretch**

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

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<tr><td>Historic Aerial US – 11 | December 2015</td><td>Upstream US – 11</td><td>Downstream US - 11</td></tr>
</table>

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	WDR EIS (Beca reference # 4512987)	**Date**	04/02/2019
Surveyor	DE **Reach code:** US-12	**Time**	14:00 hrs

Drainage channel	**Creek**	**River**	**Estuary**	**Pond**	**Wetland**	**Lake**
		X (Coxs)				

Weather conditions	Overcast, warm	**U-S elevation**	157m	**D-S elevation**	149m
Upstream grid reference	252095; 6251374 (56H UTM)	**Downstream grid reference**	252120; 6251370		

Watercourse attributes

Dimensions	**Width**	120 m	**Max. depth**	U-S = 2.5 m D-S = 3.2 m	**Average velocity (ms^{-1})**	U-S = 0.08 ms^{-1} D-S = 0.08 ms^{-1}
Shape description		Trapazoidal, open	**Max. Roughness Height**	n/a	**Bank erosion**	LHB Stable sand bar RHB Rill erosion in parallel lines on soft bank material

Instream vegetation (% cover [emergent, floating, submerged, algae, moss])	No	**Bank vegetation**	None	**Bench vegetation**	Grasses & herbs 100%	**Organic matter**	Logs, Twigs / Leaves, Detritus

Flow type

Smooth surface flow [H1]	**Broken standing waves** [H2]	**Unbroken standing waves** [H3]	**Chute** [H4]	**Rippled** [H5]	**Scarcely perceptible flow** [H6]	**Upwelling** [H7]	**Free fall** [H8]	**Standing water** [H9]
			X		X			

Channel Planform

Sinuosity (straight, low, intermediate, high)	Intermediate	***Form***	**Single** X	**Forked**	**Braided**	**Open**

Sand bars	**Gravel bars**	**Rock outcrops**	**Riparian strip**	**Floodplain connectivity**	
Yes, LHB. No in-channel bars.	No	No	No		Open

Floodplain land use	National Park & Sydney Water Protected Catchment	**Bank Strength (kg/cm^2)**	U-S 2.0, 2.0, 2.1 D-S 0.7, 0.5, 0.75	**Bank structure & angle**	LHB 20° vegetated sand, concave RHB 40°, concave, bare soil

Bed character

	Boulder		**Cobble**		**Gravel**		**Sand**		**Fine sand**		**Silt / clay**	
% composition	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**
	0	0	0	0	0	0	5	5	25	35	70	60

		Supply	**Deposition**	**Erosion**	**Conveying**
Bed stability	No packing		X	X	

*DWF = Dry weather flow, BF = Bankfull flow, RHB = Right hand bank, LHB = Left hand bank, U-S = Upstream location of selected stretch, D-S = Downstream location of selected stretch

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Not Available

Cross-section US – 12

Historic Aerial US – 12 | July 2017	**Upstream US – 12**	**Downstream US - 12**

Created 04/08/2011 Dan Evans (after Thompson et al, 2011, *Aq Conserve*, **11**, 373 – 389)

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	WDR EIS (Beca reference # 4512987)	**Date**	08/02/2019
Surveyor	DE **Reach code:** US-13	**Time**	09:22 hrs

Drainage channel	**Creek**	**River**	**Estuary**	**Pond**	**Wetland**	**Lake**
		X (Kedumba)				

Weather conditions	Overcast, humid	**U-S elevation**	117 m	**D-S elevation**	109 m
Upstream grid reference	255672; 6254690 (56H UTM)	**Downstream grid reference**	255667; 6254678		

Watercourse attributes

Dimensions **Width**	11.6 m	**Max. depth**	U-S = 1.35 m D-S = 1.19 m	**Average velocity (ms^{-1})**	U-S = 0.27 ms^{-1} D-S = 0.25 ms^{-1}
Shape description	Trapazoidal, constrained in floodplain	**Max. Roughness Height**	n/a	**Bank erosion**	LHB exposed 20 m 90° bank RHB stable

Instream vegetation (% cover [emergent, floating, submerged, algae, moss])	**Bank vegetation**	**Bench vegetation**	**Organic matter**
No	Ferns and grasses 60%	Ferns and grasses 60%, casuarina 20%	Logs, Twigs / Leaves

Flow type

Smooth surface flow [H1]	**Broken standing waves** [H2]	**Unbroken standing waves** [H3]	**Chute** [H4]	**Rippled** [H5]	**Scarcely perceptible flow** [H6]	**Upwelling** [H7]	**Free fall** [H8]	**Standing water** [H9]
X								

Channel Planform

Sinuosity (straight, low, intermediate, high)		***Form***	**Single**	**Forked**	**Braided**	**Open**
	Low		X			

Sand bars	**Gravel bars**	**Rock outcrops**	**Riparian strip**	**Floodplain connectivity**	
No	No	No	No		Open to 2nd tier then constrained by high banks

Floodplain land use	National Park & Sydney Water Protected Catchment	**Bank Strength (kg/cm^2)**	U-S 0.2, 0.5, 0.5 D-S 0.5, 0.4, 0.25	**Bank structure & angle**	LHB 90°, straight RHB, 60°, concave

Bed character

	Boulder		**Cobble**		**Gravel**		**Sand**		**Fine sand**		**Silt / clay**	
% composition	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**
	0	0	0	0	0	0	0	10	80	70	20	20

Bed stability		**Supply**	**Deposition**	**Erosion**	**Conveying**
	Low compaction	X	X	X	X

*DWF = Dry weather flow, BF = Bankfull flow, RHB = Right hand bank, LHB = Left hand bank, U-S = Upstream location of selected stretch, D-S = Downstream location of selected stretch

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

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<tr><td>
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<tr><td>Historic Aerial US – 13 July 2017</td><td>Upstream US – 13</td><td>Downstream US - 13</td></tr>
</table>

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	WDR EIS (Beca reference # 4512987)	**Date**	08/02/2019
Surveyor	DE — **Reach code:** US-14	**Time**	12:00 hrs

Drainage channel	**Creek**	**River**	**Estuary**	**Pond**	**Wetland**	**Lake**
		X (Kedumba)				

Weather conditions	Sunny, warm	**U-S elevation**	90 m	**D-S elevation**	149m
Upstream grid reference	255645;6252815 (56H UTM)	**Downstream grid reference**	255643; 6252795		

Watercourse attributes

Dimensions **Width**	11.7 m	**Max. depth**	U-S = 1.15 m D-S = 0.79 m	**Average velocity (ms^{-1})**	U-S = 0.14 ms^{-1} D-S = 0.13 ms^{-1}
Shape description	Trapazoidal, closed	**Max. Roughness Height**	n/a	**Bank erosion**	Non-vegetated but stable banks (i.e. no signs of undercutting, slumping, cantilever failure)

Instream vegetation (% cover [emergent, floating, submerged, algae, moss])		**Bank vegetation**	**Bench vegetation**	**Organic matter**
	No	Isolated pockets of short grass (5%)	Casuarina, ferns and grasses 70%	Logs, Twigs / Leaves, Detritus

Flow type

Smooth surface flow [H1]	**Broken standing waves** [H2]	**Unbroken standing waves** [H3]	**Chute** [H4]	**Rippled** [H5]	**Scarcely perceptible flow** [H6]	**Upwelling** [H7]	**Free fall** [H8]	**Standing water** [H9]
X								

Channel Planform

Sinuosity (straight, low, intermediate, high)		***Form***	**Single**	**Forked**	**Braided**	**Open**
	Low		X			

Sand bars	**Gravel bars**	**Rock outcrops**	**Riparian strip**	**Floodplain connectivity**	
Yes	No	No	No		Open to 2^{nd} tier then constrained by high banks

Floodplain land use	National Park & Sydney Water Protected Catchment	**Bank Strength (kg/cm^2)**	U-S 0.2, 0.25, 0.4 D-S 0.2, 0.2, 0.1	**Bank structure & angle**	LHB 20°, concave RHB 90°, straight

Bed character

	Boulder		**Cobble**		**Gravel**		**Sand**		**Fine sand**		**Silt / clay**	
% composition	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**
	0	0	0	0	20	10	60	50	20	40	0	0

Bed stability		**Supply**	**Deposition**	**Erosion**	**Conveying**
	Low compaction				X

*DWF = Dry weather flow, BF = Bankfull flow, RHB = Right hand bank, LHB = Left hand bank, U-S = Upstream location of selected stretch, D-S = Downstream location of selected stretch

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Not Available

Cross-section US – 14

Historic Aerial US – 14 July 2017	**Upstream US – 14**	**Downstream US - 14**

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	WDR EIS (Beca reference # 4512987)	**Date**	07/02/2019
Surveyor	DE **Reach code:** US-16	**Time**	17: 20 hrs

Drainage channel	**Creek**	**River**	**Estuary**	**Pond**	**Wetland**	**Lake**
		X (Cedar Creek)				

Weather conditions	Overcast, warm	**U-S elevation**	220 m	**D-S elevation**	214 m
Upstream grid reference	255946; 6256582 (56H UTM)	**Downstream grid reference**	255942;6256562		

Watercourse attributes

Dimensions **Width**	10.8	**Max. depth**	U-S = 0.22 m D-S = 0.38 m	**Average velocity (ms^{-1})**	U-S = 0.27 ms^{-1} D-S = 0.24 ms^{-1}
Shape description	V-shaped	**Max. Roughness Height**	n/a	**Bank erosion**	Stable primary channel. Secondary tier has extensive erosion on RHB

Instream vegetation (% cover [emergent, floating, submerged, algae, moss])		**Bank vegetation**	**Bench vegetation**	**Organic matter**
	No	Small isolated pockets of ferns and aquatic emergent reeds (10%)	Grasses & herbs 30%	Logs & Twigs / Leaves

Flow type

Smooth surface flow [H1]	**Broken standing waves** [H2]	**Unbroken standing waves** [H3]	**Chute** [H4]	**Rippled** [H5]	**Scarcely perceptible flow** [H6]	**Upwelling** [H7]	**Free fall** [H8]	**Standing water** [H9]
			X	X				

Channel Planform

Sinuosity (straight, low, intermediate, high)		***Form***	**Single**	**Forked**	**Braided**	**Open**
	Low		X			

Sand bars	**Gravel bars**	**Rock outcrops**	**Riparian strip**	**Floodplain connectivity**	
No	No	No	No		Constrained to secondary floodplain

Floodplain land use	National Park & Sydney Water Protected Catchment	**Bank Strength (kg/cm²)**	U-S 2.6, 3.8, 2.8 D-S 2.6, 3.6, 3.85	**Bank structure & angle**	° Concave

Bed character

	Boulder		**Cobble**		**Gravel**		**Sand**		**Fine sand**		**Silt / clay**	
% composition	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**
	0	0	80	70	20	20	0	10	0	0	0	0

Bed stability		**Supply**	**Deposition**	**Erosion**	**Conveying**
	Packed & armoured	X	X	X	

*DWF = Dry weather flow, BF = Bankfull flow, RHB = Right hand bank, LHB = Left hand bank, U-S = Upstream location of selected stretch, D-S = Downstream location of selected stretch

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Historic Aerial US – 16 | July 2017

Not Available

Cross-section US – 16

Upstream US – 16

Downstream US - 16

G.2 Lake Zone

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	WDR EIS (Beca reference # 4512987)	**Date**	04/02/2019
Surveyor	DE — **Reach code:** R-01	**Time**	10:50 hrs

Drainage channel	Creek	River	Estuary	Pond	Wetland	Lake
						X

Weather conditions	Overcast, warm	**Land use**	National Park & Sydney Water Protected Catchment
Grid reference	259395; 6223463 (56H UTM)	**Elevation**	112 m

Bank attributes

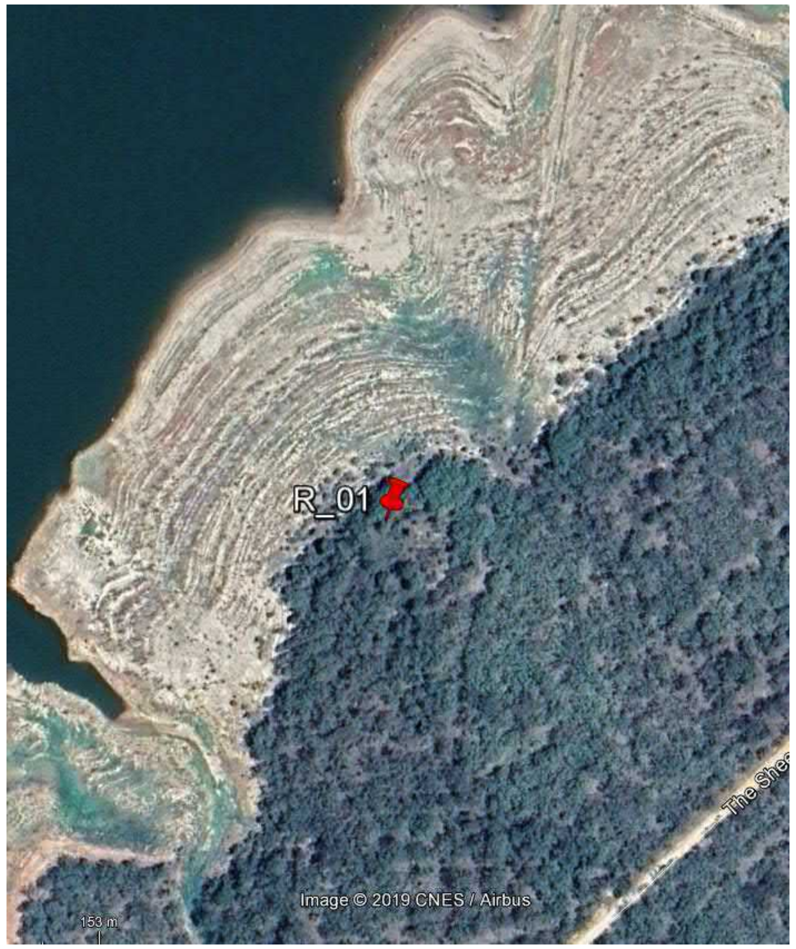
Wave height	10 cm	**Bank structure and angle**	30° straight over hardened sand/clay with pockets of unconsolidated sand
Bank strength (kg/cm²)	SL 0.2, 0.2, 0.1 FSL 2.8, 3.0, 2.7	**Bank erosion**	Rill erosion parallel to the bank and approx. 1 m spacing

Aquatic vegetation	None	**Bank vegetation** None	**Bench vegetation** Partial grass revegetation 20%	**Organic matter** None

Bed character

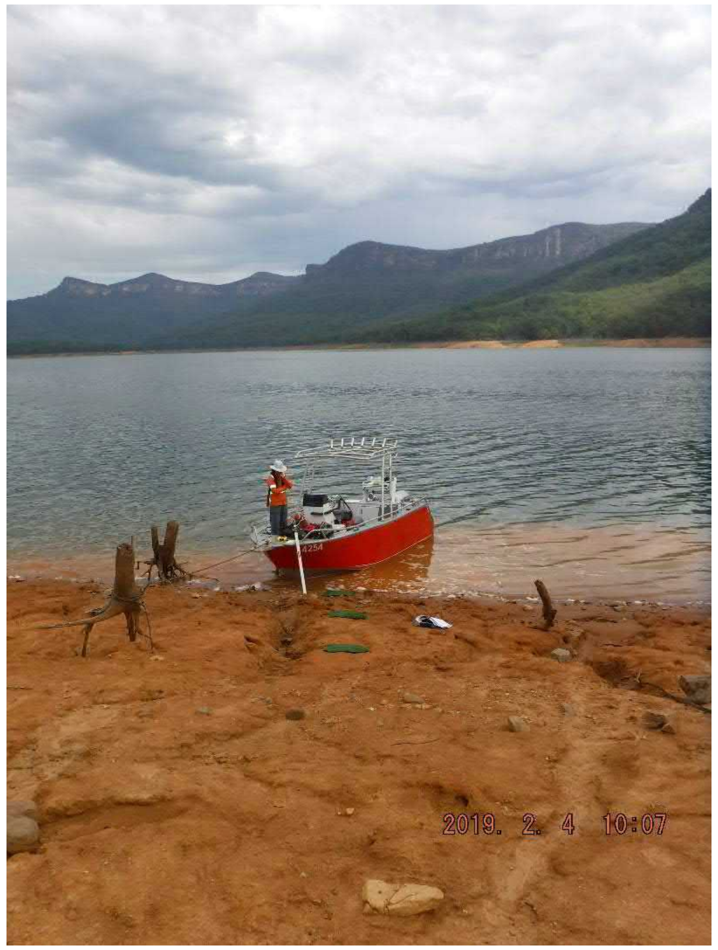
	Boulder	Cobble	Gravel	Sand	Fine sand	Silt / clay
% composition	0	0	20	70	10	0

***SL = Shoreline, FSL = Full Storage Level**



Aerial view of R01 site | January 2019

Exposed Bank Erosion R01



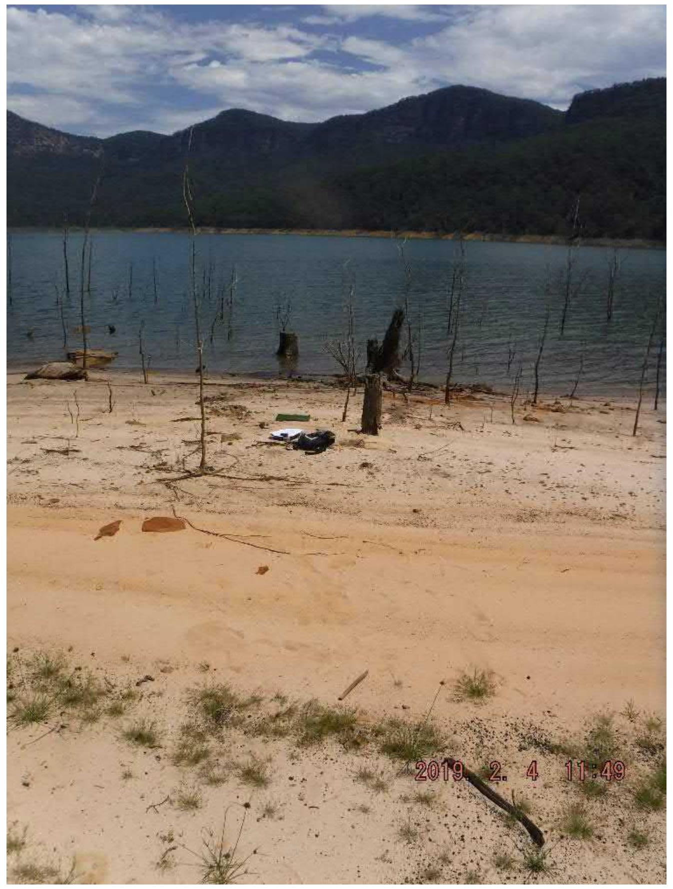
Foreshore with rill initiation R01

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	WDR EIS (Beca reference # 4512987)				**Date**	04/02/2019
Surveyor	DE	**Reach code:** R-02			**Time**	11:30 hrs
Drainage channel	**Creek**	**River**	**Estuary**	**Pond**	**Wetland**	**Lake**
						X
Weather conditions	Bright, hot			**Land use**	National Park & Sydney Water Protected Catchment	
Grid reference	261129; 6229158 (56H UTM)			**Elevation**	96 m	
Bank attributes						
Wave height	15 cm		**Bank structure and angle**	10° straight		
Bank strength (kg/cm^2)	SL 0.4, 0.6, 0.75, FSL 0.3, 0.2, 0.6		**Bank erosion**	Rill erosion parallel to the bank and approx. 1 m spacing		
Aquatic vegetation	None	**Bank vegetation** None		**Bench vegetation** Dead trees waters edge - 40 m, Grasses & herbs +40 m 75% cover	**Organic matter** Twigs & leaves, Detritus	
Bed character						
% composition	**Boulder**	**Cobble**	**Gravel**	**Sand**	**Fine sand**	**Silt / clay**
	0	0	0	40	40	20

*SL = Shoreline, FSL = Full Storage Level

Aerial view of R02 site | March 2019



Foreshore North View R02

Foreshore East View R02

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	WDR EIS (Beca reference # 4512987)	**Date**	04/02/2019
Surveyor	DE **Reach code:** R-03	**Time**	14:00 hrs

Drainage channel	Creek	River	Estuary	Pond	Wetland	Lake
						X

Weather conditions	Overcast, warm	**Land use**	National Park & Sydney Water Protected Catchment
Grid reference	258021; 6243589 (56H UTM)	**Elevation**	112 m

Bank attributes

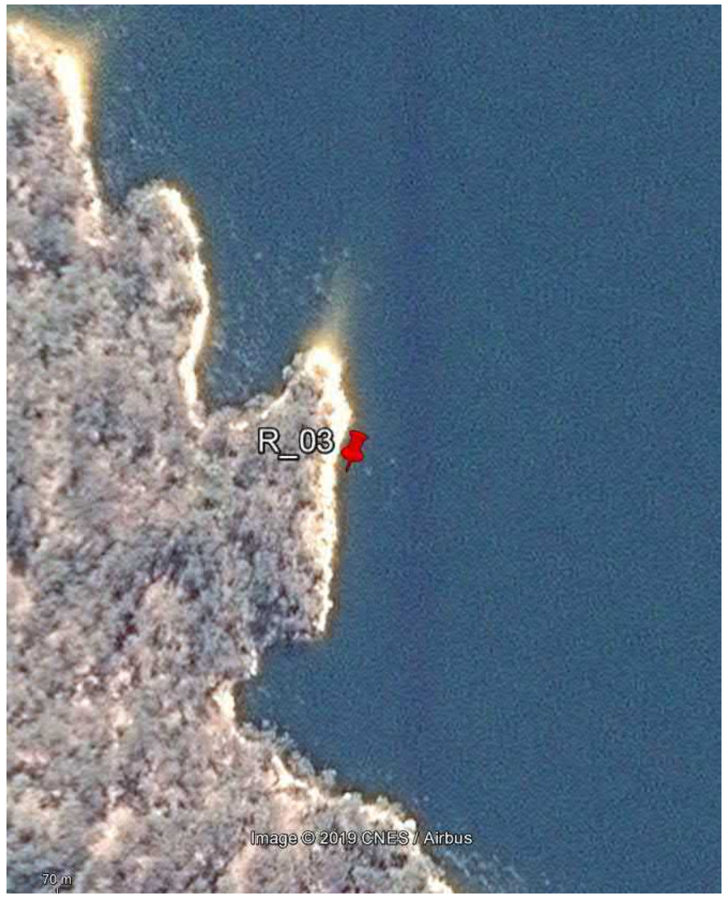
Wave height	5 cm	**Bank structure and angle**	30° straight
Bank strength (kg/cm^2)	SL 0.5, 0.5, 0.4 FSL 0.6, 0.3, 0.4	**Bank erosion**	None visible

Aquatic vegetation	None	**Bank vegetation** None	**Bench vegetation** Dead trees from 2m above water edge – 30m	**Organic matter** Logs, Twigs / Leaves

Bed character

% composition	Boulder	Cobble	Gravel	Sand	Fine sand	Silt / clay
	0	20	20	20	40	0

*SL = Shoreline, FSL = Full Storage Level



Aerial view of R03 site | October 2016

Foreshore North View R03

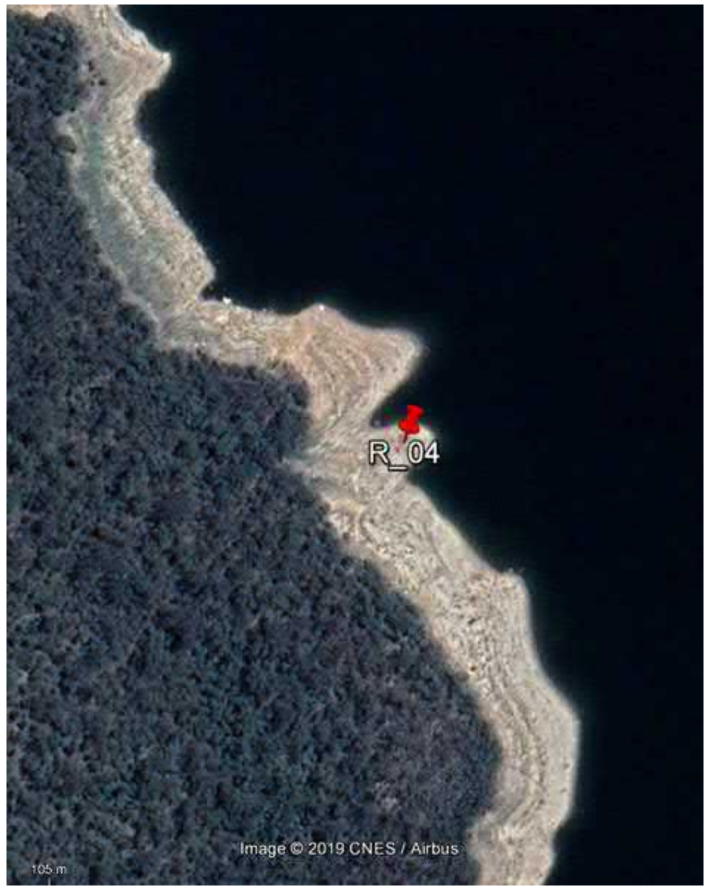
Foreshore South View R03

Created 04/08/2011 Dan Evans (after Thompson et al, 2011, *Aq Conserve*, **11**, 373 – 389)

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	WDR EIS (Beca reference # 4512987)					**Date**	04/02/2019
Surveyor	DE	**Reach code:** R-04				**Time**	14:40 hrs
Drainage channel		**Creek**	**River**	**Estuary**	**Pond**	**Wetland**	**Lake**
							X
Weather conditions	Overcast, warm				**Land use**	National Park & Sydney Water Protected Catchment	
Grid reference	265441; 6239719 (56H UTM)				**Elevation**	121 m	
Bank attributes							
Wave height	2 cm			**Bank structure and angle**	20° straight		
Bank strength (kg/cm^2)	SL 0.2, 0.2, 0.3 FSL 1.2, 1.1, 0.9			**Bank erosion**	None visible Sand deposition at creek inlet to immediate north of site		
Aquatic vegetation	None	**Bank vegetation** None			**Bench vegetation** Dead trees and scattered grass (20% cover) 2m from waters edge – 20m	**Organic matter** None	
Bed character							
% composition	**Boulder**	**Cobble**	**Gravel**	**Sand**	**Fine sand**	**Silt / clay**	
	0	0	20	40	40	0	

*SL = Shoreline, FSL = Full Storage Level



Aerial view of R04 site

Foreshore north view R04

East view with sandy deposit R04

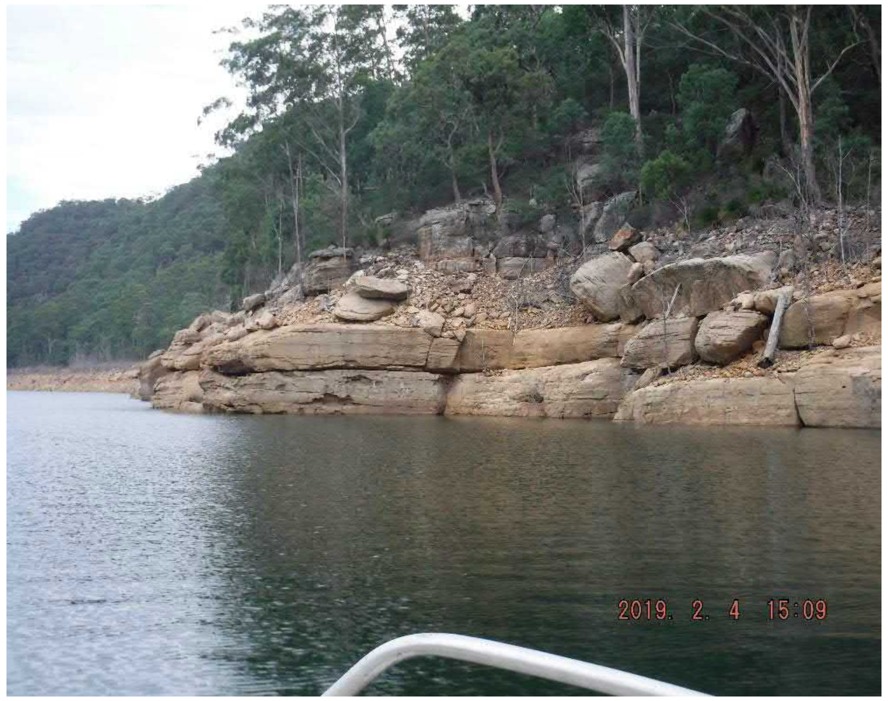
FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	WDR EIS (Beca reference # 4512987)				**Date**	04/02/2019
Surveyor	DE	**Reach code:** R-05			**Time**	16:00 hrs
Drainage channel	**Creek**	**River**	**Estuary**	**Pond**	**Wetland**	**Lake**
						X
Weather conditions	Overcast, warm			**Land use**	National Park & Sydney Water Protected Catchment	
Grid reference	269976; 6242220 (56H UTM)			**Elevation**	109 m	
Bank attributes						
Wave height	5 cm		**Bank structure and angle**	70° straight boulders		
Bank strength (kg/cm²)	SL All >4.5 FSL All >4.5		**Bank erosion**	Cantilever failure caused by undercutting and subsequent slumping of sandstone blocks		
Aquatic vegetation	None	**Bank vegetation** None		**Bench vegetation** Dead trees (<5% cover)	**Organic matter** None	
Bed character						
% composition	**Boulder**	**Cobble**	**Gravel**	**Sand**	**Fine sand**	**Silt / clay**
	80	20	0	0	0	0

***SL = Shoreline, FSL = Full Storage Level**

Aerial view of R05 site | October 2018

Sandstone bedrock banks south west view R05



Sandstone bedrock banks north east view R05

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	WDR EIS (Beca reference # 4512987)	**Date**	04/02/2019
Surveyor	DE **Reach code:** R-06	**Time**	16:20 hrs

Drainage channel	**Creek**	**River**	**Estuary**	**Pond**	**Wetland**	**Lake**
						X

Weather conditions	Overcast, warm	**Land use**	National Park & Sydney Water Protected Catchment
Grid reference	276354; 6247113 (56H UTM)	**Elevation**	116 m

Bank attributes

Wave height	5 cm	**Bank structure and angle**	90° sandstone bedrock cliff face
Bank strength (kg/cm²)	SL All >4.5 FSL All >4.5	**Bank erosion**	Cantilever failure caused by undercutting and subsequent slumping of sandstone blocks

Aquatic vegetation	**Bank vegetation**	**Bench vegetation**	**Organic matter**
None	None	None	None

Bed character

	Boulder	**Cobble**	**Gravel**	**Sand**	**Fine sand**	**Silt / clay**
% composition	0	100	0	0	0	0

***SL = Shoreline, FSL = Full Storage Level**

Aerial view of R06 site | October 2018

Steep sandstone gorge east view R06

Steep sandstone gorge north east view R06

G.3 Downstream Zone

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	WDR EIS (Beca reference # 4512987)					**Date**	01/02/2019
Surveyor	DE	**Reach code:** DS-01 (Weir Road @ Warragamba)				**Time**	08:15 hrs
Drainage channel		**Creek**	**River**	**Estuary**	**Pond**	**Wetland**	**Lake**
			X (Warragamba)				

Weather conditions	Overcast, humid	**U-S elevation**	26 m	**D-S elevation**	24 m
Upstream grid reference	278025; 6248522 (56H UTM)	**Downstream grid reference**	278048; 6248540		

Watercourse attributes

Dimensions	**Width**	10.8 m	**Max. depth**	U-S = 0.22 m D-S = 0.18 m	**Average velocity (ms^{-1})**	U-S = 0 ms^{-1} D-S = 0 ms^{-1}	
Shape description		u-shaped constrained valley	**Max. Roughness Height**	n/a	**Bank erosion**	None observed	
Instream vegetation	No		**Bank vegetation** LHB Emergent reeds 80% RHB bare		**Bench vegetation** LHB Casuarina 30% RHB Bare	**Organic matter** None	

Flow type

Smooth surface flow [H1]	Broken standing waves [H2]	Unbroken standing waves [H3]	Chute [H4]	Rippled [H5]	Scarcely perceptible flow [H6]	Upwelling [H7]	Free fall [H8]	Standing water [H9]
			X		X			

Channel Planform

Sinuosity (straight, low, intermediate, high)	Low	***Form***	**Single** X	**Forked**	**Braided**	**Open**
Sand bars No	**Gravel bars** No	**Rock outcrops** No		**Riparian strip** No	**Floodplain connectivity**	Constrained by gorge
Floodplain land use	Dam infrastructure directly upstream	**Bank Strength (kg/cm^2)**		U-S 1.25, 1.4, >4.5 D-S 2.2, 25, >4.5	**Bank structure & angle**	LHB 30°, concave RHB 90°, straight

Bed character

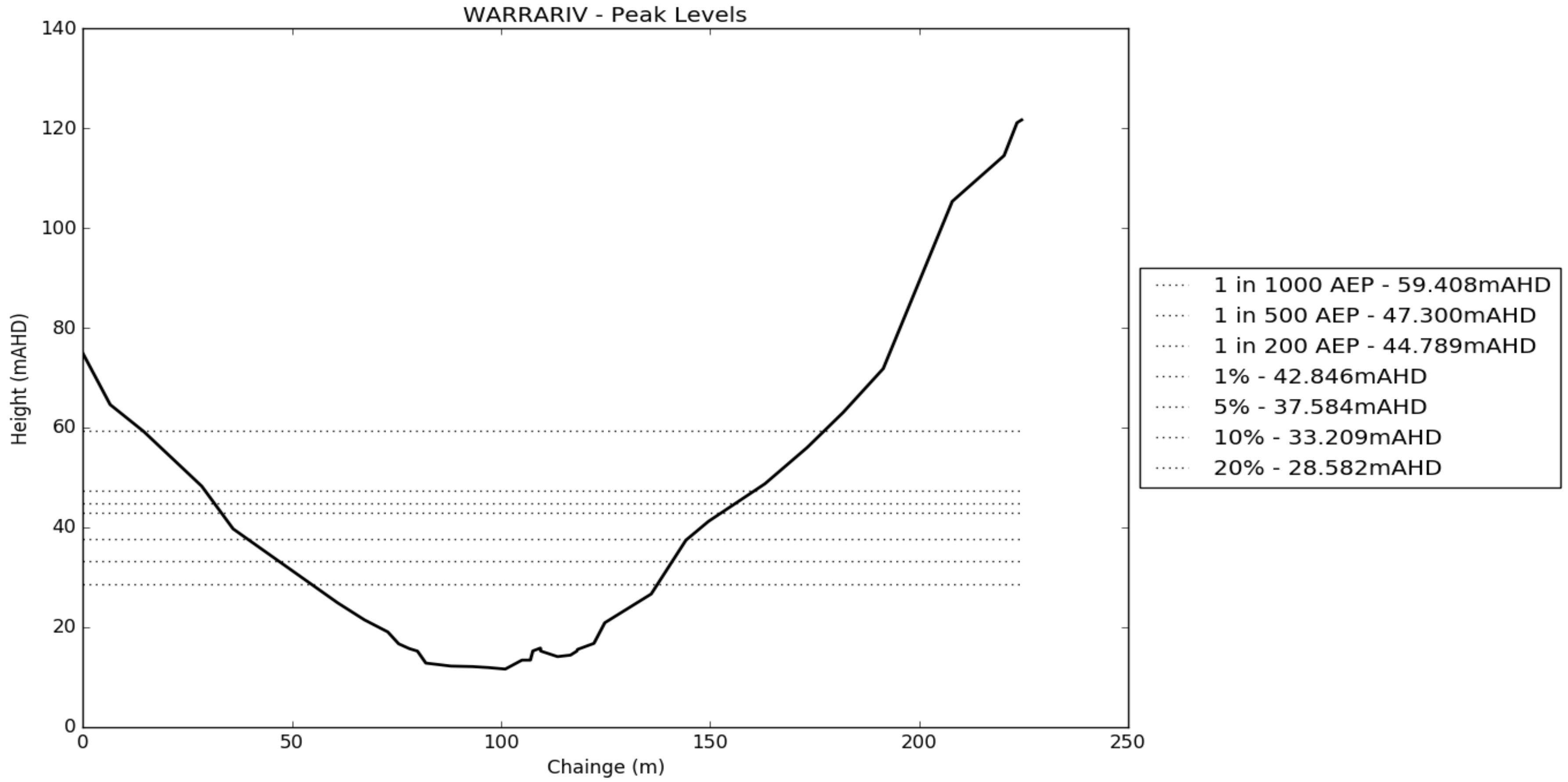
	Boulder		**Cobble**		**Gravel**		**Sand**		**Fine sand**		**Silt / clay**	
% composition	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**
	60	50	0	10	30	30	20	10	0	0	0	0

Bed stability	Packed and armoured	**Supply**	**Deposition**	**Erosion**	**Conveying**
		X		X	

*DWF = Dry weather flow, BF = Bankfull flow, RHB = Right hand bank, LHB = Left hand bank, U-S = Upstream location of selected stretch, D-S = Downstream location of selected stretch

Created 04/08/2011 Dan Evans (after Thompson et al, 2011, *Aq Conserve*, **11**, 373 – 389)

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE



Cross-section DS - 01

Historic Aerial DS – 01 | October 2018

Upstream DS – 01

Downstream DS - 01

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	WDR EIS (Beca reference # 4512987)	**Date**	01/02/2019
Surveyor	DE **Reach code:** DS-02 (Nortons Basin Road @ Warragamba)	**Time**	09:20 hrs

Drainage channel	**Creek**	**River**	**Estuary**	**Pond**	**Wetland**	**Lake**
		X (Wollondilly-Nepean Confluence)				

Weather conditions	Overcast, humid	**U-S elevation**	12 m	**D-S elevation**	12 m
Upstream grid reference	279017; 6250858 (56H UTM)	**Downstream grid reference**	279002; 6250882		

Watercourse attributes

Dimensions	**Width**	33.2 m	**Max. depth**	Unknown – not wadeable	**Average velocity (ms^{-1})**	0	
Shape description		v-shaped constrained valley	**Max. Roughness Height**	None	**Bank erosion**	No significant erosion observed	
Instream vegetation	Peruvian Primrose (Emergents) 10%	**Bank vegetation** None		**Bench vegetation** Grasses & herbs 5%; Casuarina 5%		**Organic matter** None	

Flow type

Smooth surface flow [H1]	**Broken standing waves** [H2]	**Unbroken standing waves** [H3]	**Chute** [H4]	**Rippled** [H5]	**Scarcely perceptible flow** [H6]	**Upwelling** [H7]	**Free fall** [H8]	**Standing water** [H9]
					X			

Channel Planform

Sinuosity (straight, low, intermediate, high)	Straight	***Form***	**Single** X	**Forked**	**Braided** X	**Open**
Sand bars No	**Gravel bars** No	**Rock outcrops** No		**Riparian strip** No	**Floodplain connectivity**	Low, constrained by cliff escarpments
Floodplain land use	LHB Warragamba Park RHB National Park	**Bank Strength (kg/cm^2)**		U-S 1.2, >4.5, >4.5 D-S >4.5, >4.5, >4.5	**Bank structure & angle**	LHB 5°, bedrock ledge RHB 30° concave

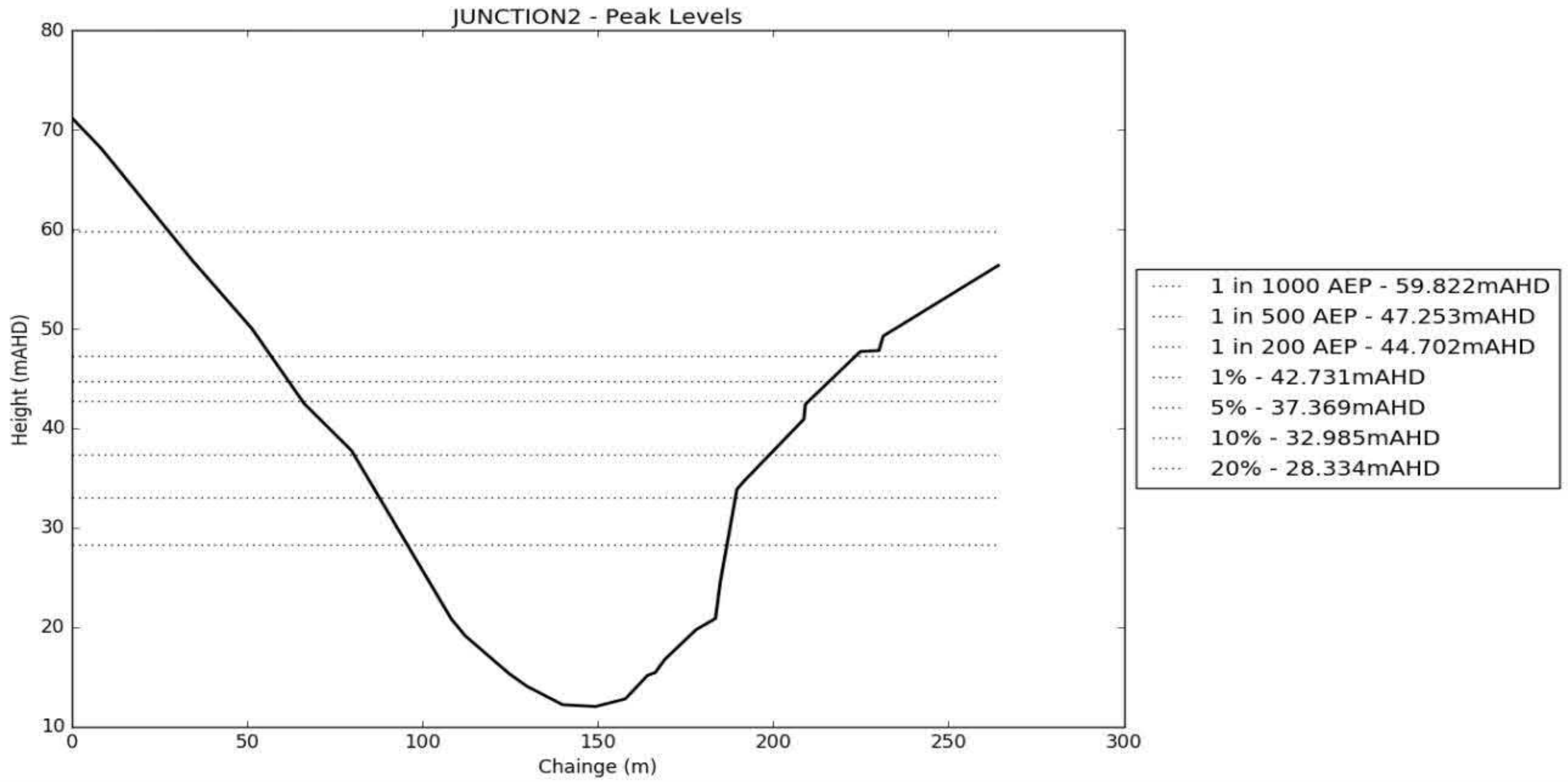
Bed character

% composition	**Boulder**		**Cobble**		**Gravel**		**Sand**		**Fine sand**		**Silt / clay**	
Bedrock channel 100% (no surficial sediments observed)	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**
	0	0	0	0	0	0	0	0	0	0	0	0

Bed stability	n/a	**Supply**	**Deposition**	**Erosion**	**Conveying**
					X

*DWF = Dry weather flow, BF = Bankfull flow, RHB = Right hand bank, LHB = Left hand bank, U-S = Upstream location of selected stretch, D-S = Downstream location of selected stretch

Historic Aerial DS – 02 | October 2018



Cross-section DS - 02

Upstream DS – 02

Downstream DS - 02

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	WDR EIS (Beca reference # 4512987)			**Date**	01/02/2019
Surveyor	DE	**Reach code:** DS-03 (Bruce Neale Drive @ Penrith)		**Time**	10:30 hrs

Drainage channel	**Creek**	**River**	**Estuary**	**Pond**	**Wetland**	**Lake**
		X (Nepean)				

Weather conditions	Overcast, breeze	**U-S elevation**	23 m	**D-S elevation**	20 m
Upstream grid reference	285409; 6263656 (56H UTM)	**Downstream grid reference**	285414; 6263686		

Watercourse attributes

Dimensions	**Width**	157 m	**Max. depth**	Unknown – not wadeable	**Average velocity (ms^{-1})**	U-S = 0.02 ms^{-1} D-S = 0.02 ms^{-1}	
Shape description		Elongated flat-bottomed u-shape	**Max. Roughness Height**	n/a	**Bank erosion**	No erosion observed	

Instream vegetation	U-S Ribbonweed (submerged) 75 %; D-S None	**Bank vegetation** None	**Bench vegetation** Grasses & weeds 60%	**Organic matter** Logs

Flow type

Smooth surface flow [H1]	**Broken standing waves** [H2]	**Unbroken standing waves** [H3]	**Chute** [H4]	**Rippled** [H5]	**Scarcely perceptible flow** [H6]	**Upwelling** [H7]	**Free fall** [H8]	**Standing water** [H9]
					X			

Channel Planform

Sinuosity (straight, low, intermediate, high)	Low	***Form***	**Single** X	**Forked**	**Braided**	**Open**

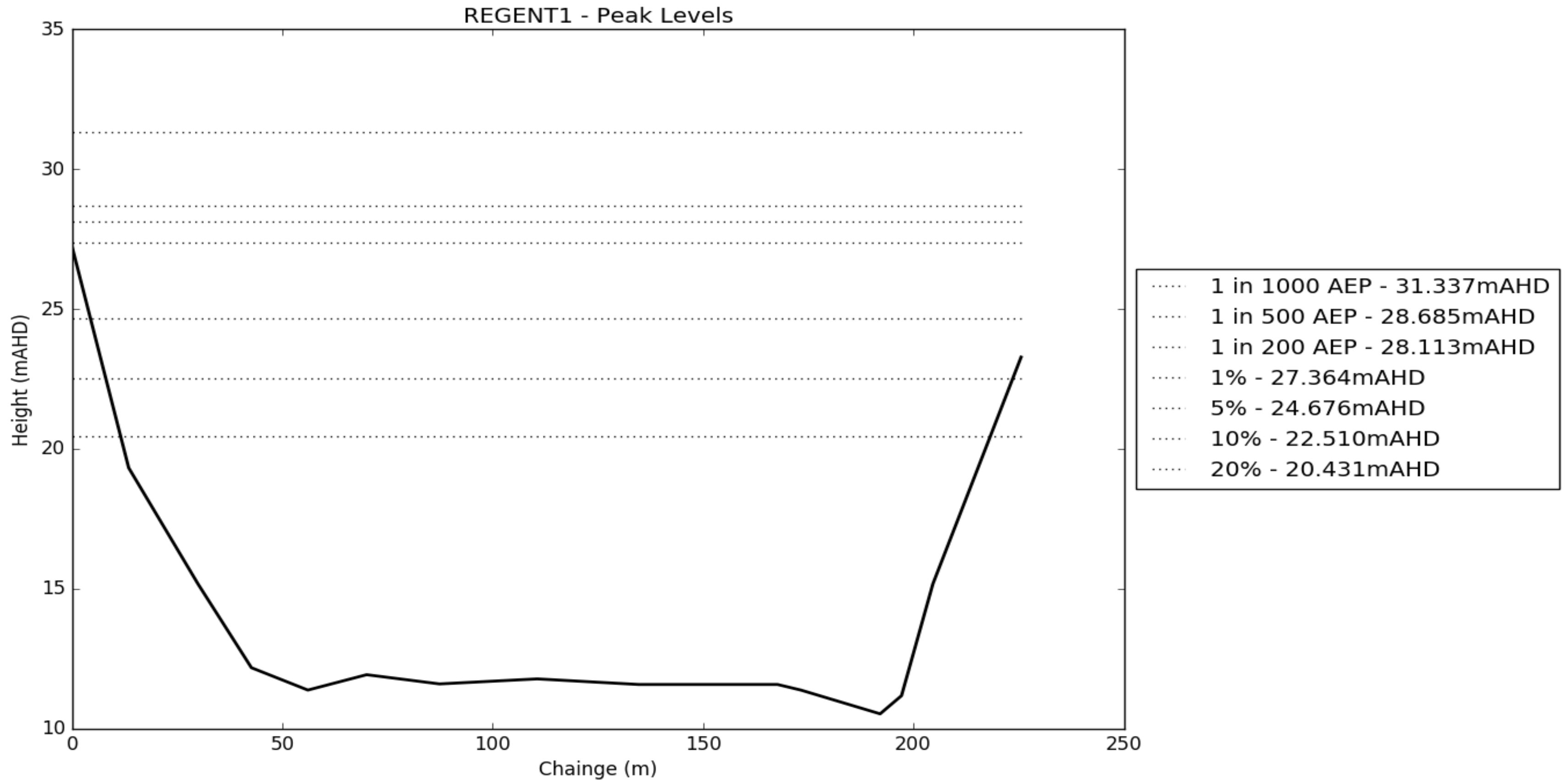
Sand bars No	**Gravel bars** No	**Rock outcrops** No	**Riparian strip** Yes, 40 m	**Floodplain connectivity**	Open
Floodplain land use	LHB car park, Nepean Rowing Club, sports oval & Weir Reserve RHB McCarthy College, residential / light industrial & Boral quarry	**Bank Strength (kg/cm^2)**	U-S >4.5 all D-S 1.8, 2.3, 0.5	**Bank structure & angle**	LHB 90°, straight, engineered for boat access RHB 30°, concave

Bed character

	Boulder		**Cobble**		**Gravel**		**Sand**		**Fine sand**		**Silt / clay**	
% composition	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**
	0	0	30	0	30	60	30	30	10	10	0	0

Bed stability	Low compaction	**Supply**	**Deposition**	**Erosion**	**Conveying**
					X

*DWF = Dry weather flow, BF = Bankfull flow, RHB = Right hand bank, LHB = Left hand bank, U-S = Upstream location of selected stretch, D-S = Downstream location of selected stretch



Cross-section DS - 03

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Historic Aerial DS – 03 | October 2018	Upstream DS – 03	Downstream DS – 03

Project	WDR EIS (Beca reference # 4512987)					**Date**	01/02/2019
Surveyor	DE	**Reach code:** US-04 (Cassola Place @ Penrith)				**Time**	11:15 hrs
Drainage channel		**Creek**	**River**	**Estuary**	**Pond**	**Wetland**	**Lake**
			X (Nepean)				
Weather conditions		Overcast, still		**U-S elevation**		20 m	**D-S elevation** 20 m
Upstream grid reference		2544193; 6218438 (56H UTM)		**Downstream grid reference**		2544205; 6218458	

Watercourse attributes							
Dimensions	**Width (m)**	108 m	**Max. depth**	Unknown – not wadeable	**Average velocity (ms^{-1})**	U-S = 0.03 ms^{-1} D-S = 0.03 ms^{-1}	
Shape description		Rectangular	**Max. Roughness Height**	n/a	**Bank erosion**	Inter-layer river terrace cobble / gravel	
Instream vegetation	Water Milfoil (submerged) 30%	**Bank vegetation** 80% grass & herbs;		**Bench vegetation** Grasses & herbs 60%; Casurina 30%		**Organic matter** Twigs / Leaves, Detritus	

Flow type								
Smooth surface flow [H1]	**Broken standing waves** [H2]	**Unbroken standing waves** [H3]	**Chute** [H4]	**Rippled** [H5]	**Scarcely perceptible flow** [H6]	**Upwelling** [H7]	**Free fall** [H8]	**Standing water** [H9]
			X		X			

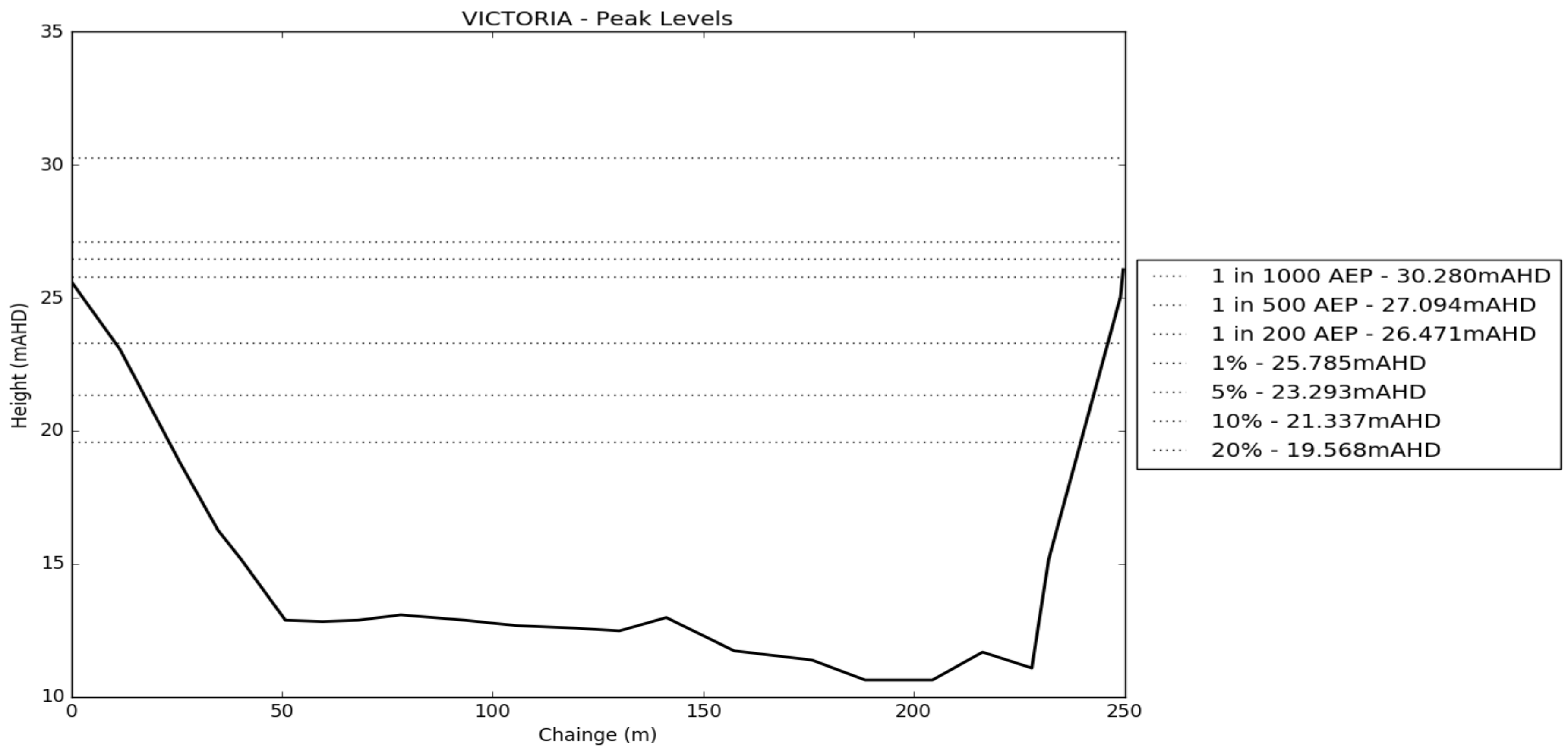
Channel Planform						
Sinuosity (straight, low, intermediate, high)	Low	***Form***	**Single**	**Forked** **X**	**Braided**	**Open**
Sand bars No	**Gravel bars** No	**Rock outcrops** No		**Riparian strip** No	**Floodplain connectivity**	Open after overtopping 1st terrace
Floodplain land use	LHB Cycleway / pedestrian path, light industrial warehouses RHB Boral quarry	**Bank Strength (kg/cm^2)**		U-S 1.7, 1.6, 0.9 D-S 0.8, 1.2, 1.9	**Bank structure & angle**	50°, straight both sides

Bed character												
	Boulder		**Cobble**		**Gravel**		**Sand**		**Fine sand**		**Silt / clay**	
% composition	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**
	0	0	20	0	40	50	10	30	0	20	0	0

Bed stability	Unknown – unable to access the channel	**Supply**	**Deposition**	**Erosion**	**Conveying**
			X		X

*DWF = Dry weather flow, BF = Bankfull flow, RHB = Right hand bank, LHB = Left hand bank, U-S = Upstream location of selected stretch, D-S = Downstream location of selected stretch

Historic Aerial DS – 04 | January 2019



Cross-section DS - 04

Upstream DS – 04

Downstream DS - 04

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	WDR EIS (Beca reference # 4512987)	**Date**	01/02/2019
Surveyor	DE **Reach code:** DS-06 (Devlin Road @ Castlereagh)	**Time**	13:15 hrs

Drainage channel	**Creek**	**River**	**Estuary**	**Pond**	**Wetland**	**Lake**
		X (Nepean)				

Weather conditions	Cloudy, still	**U-S elevation**	5 m	**D-S elevation**	4 m
Upstream grid reference	283774; 6273783 (56H UTM)	**Downstream grid reference**	283827; 6273807		

Watercourse attributes

Dimensions	**Width (m)**	126 m	**Max. depth**	Unknown – not wadeable	**Average velocity (ms^{-1})**	U-S = 0.03 ms^{-1} D-S = 0.02 ms^{-1}
Shape description		Flat u-shaped channel	**Max. Roughness Height**	n/a	**Bank erosion**	Vegetation cover removal and foot induced erosion

Instream vegetation	Azola (floating) 20% Peruvian Primrose (Emergents) 10%	**Bank vegetation** U-S Short grass, reeds 30% D-S None	**Bench vegetation** U-S Casuarina 40% D-S None	**Organic matter** Detritus

Flow type

Smooth surface flow [H1]	**Broken standing waves** [H2]	**Unbroken standing waves** [H3]	**Chute** [H4]	**Rippled** [H5]	**Scarcely perceptible flow** [H6]	**Upwelling** [H7]	**Free fall** [H8]	**Standing water** [H9]
X (U-S)								X (D-S)

Channel Planform

Sinuosity	Low	***Form***	**Single** X	**Forked**	**Braided**	**Open**
Sand bars No	**Gravel bars** No	**Rock outcrops** No		**Riparian strip** No	**Floodplain connectivity**	Open
Floodplain land use	LHB Heavily used bank for fishing / kayak access / picnic area RHB Lynch Creek Reserveb	**Bank Strength (kg/cm²)**		U-S 0.3, 0.2, 0.2 D-S 0.4, 1.2, 2.5	**Bank structure & angle**	LHB 20°, straight RHB 30°, concave

Bed character

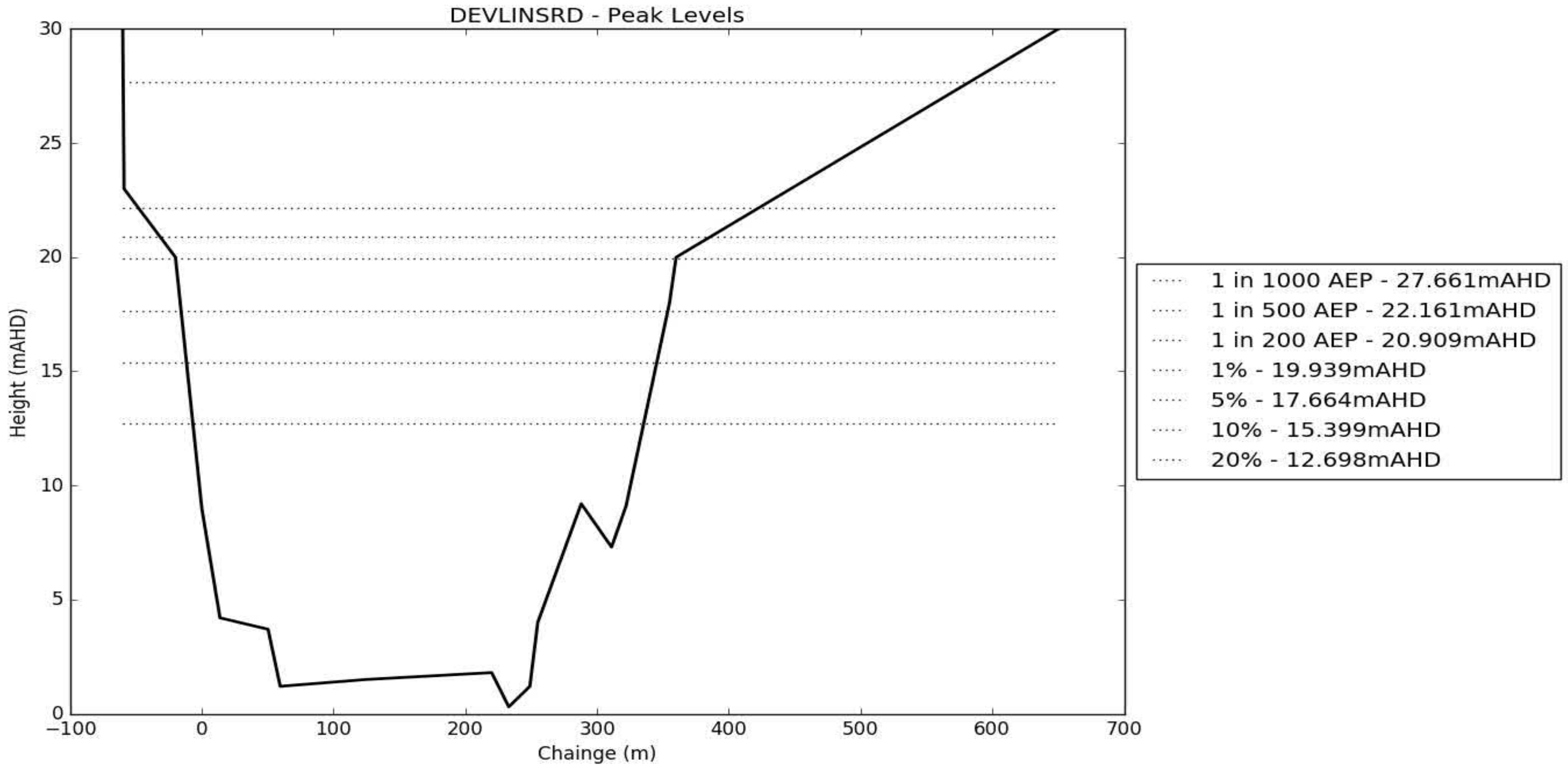
	Boulder		**Cobble**		**Gravel**		**Sand**		**Fine sand**		**Silt / clay**	
% composition	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**
	0	3	10	0	80	30	10	50	0	20	0	0

Bed stability	Low compaction	**Supply**	**Deposition**	**Erosion**	**Conveying**
					X

*DWF = Dry weather flow, BF = Bankfull flow, RHB = Right hand bank, LHB = Left hand bank, U-S = Upstream location of selected stretch, D-S = Downstream location of selected stretch

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Historic Aerial DS – 06 | January 2019



Cross-section DS - 06

Upstream DS – 06

Downstream DS - 06

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	WDR EIS (Beca reference # 4512987)	**Date**	01/02/2019
Surveyor	DE **Reach code:** US-07 (off Springwood Road @ Yarramundi)	**Time**	13:45 hrs

Drainage channel	**Creek**	**River**	**Estuary**	**Pond**	**Wetland**	**Lake**
		X (Nepean)				

Weather conditions	Cloud cover, warm	**U-S elevation**	0 m	**D-S elevation**	0 m
Upstream grid reference	286444; 6278169 (UTM 56H)	**Downstream grid reference**	286428; 6278144		

Watercourse attributes

Dimensions	**Width (m)**	88 m left hand channel 234 m right hand channel	**Max. depth**	0.8	**Average velocity (ms^{-1})**	U-S = 0.18 ms^{-1} D-S = 0.19 ms^{-1}
Shape description		Flat alluvial pan	**Max. Roughness Height**	n/a	**Bank erosion**	Banks worn by foot impact from recreational use

Instream vegetation	Water Milfoil 30%	**Bank vegetation** Grass 60%	**Bench vegetation** Casuarina 40%	**Organic matter** Twigs and leaves

Flow type

Smooth surface flow [H1]	**Broken standing waves** [H2]	**Unbroken standing waves** [H3]	**Chute** [H4]	**Rippled** [H5]	**Scarcely perceptible flow** [H6]	**Upwelling** [H7]	**Free fall** [H8]	**Standing water** [H9]
X (D-S)			X (U-S)					

Channel Planform

Sinuosity (straight, low, intermediate, high)	Straight	***Form***	**Single**	**Forked** X (divided by walking path)	**Braided**	**Open**

Sand bars	**Gravel bars**	**Rock outcrops**	**Riparian strip**	**Floodplain connectivity**	
No	No	No	50m grassed / trees before floodplain		Open

Floodplain land use	LHB Farming RHB Yarramundi Reserve	**Bank Strength (kg/cm^2)**	U-S 0.2, 0.8, 0.6 D-S 0.5, 0.3, 0.7	**Bank structure & angle**	LHB 40 ° stepped RHB 30 °convex

Bed character

	Boulder		**Cobble**		**Gravel**		**Sand**		**Fine sand**		**Silt / clay**	
% composition	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**
	0	0	70	70	20	20	10	10	0	0	0	0

Bed stability	Packed not armoured	**Supply**	**Deposition**	**Erosion**	**Conveying**
					X

***DWF = Dry weather flow, BF = Bankfull flow, RHB = Right hand bank, LHB = Left hand bank, U-S = Upstream location of selected stretch, D-S = Downstream location of selected stretch**

Created 04/08/2011 Dan Evans (after Thompson et al, 2011, *Aq Conserve*, **11**, 373 – 389)

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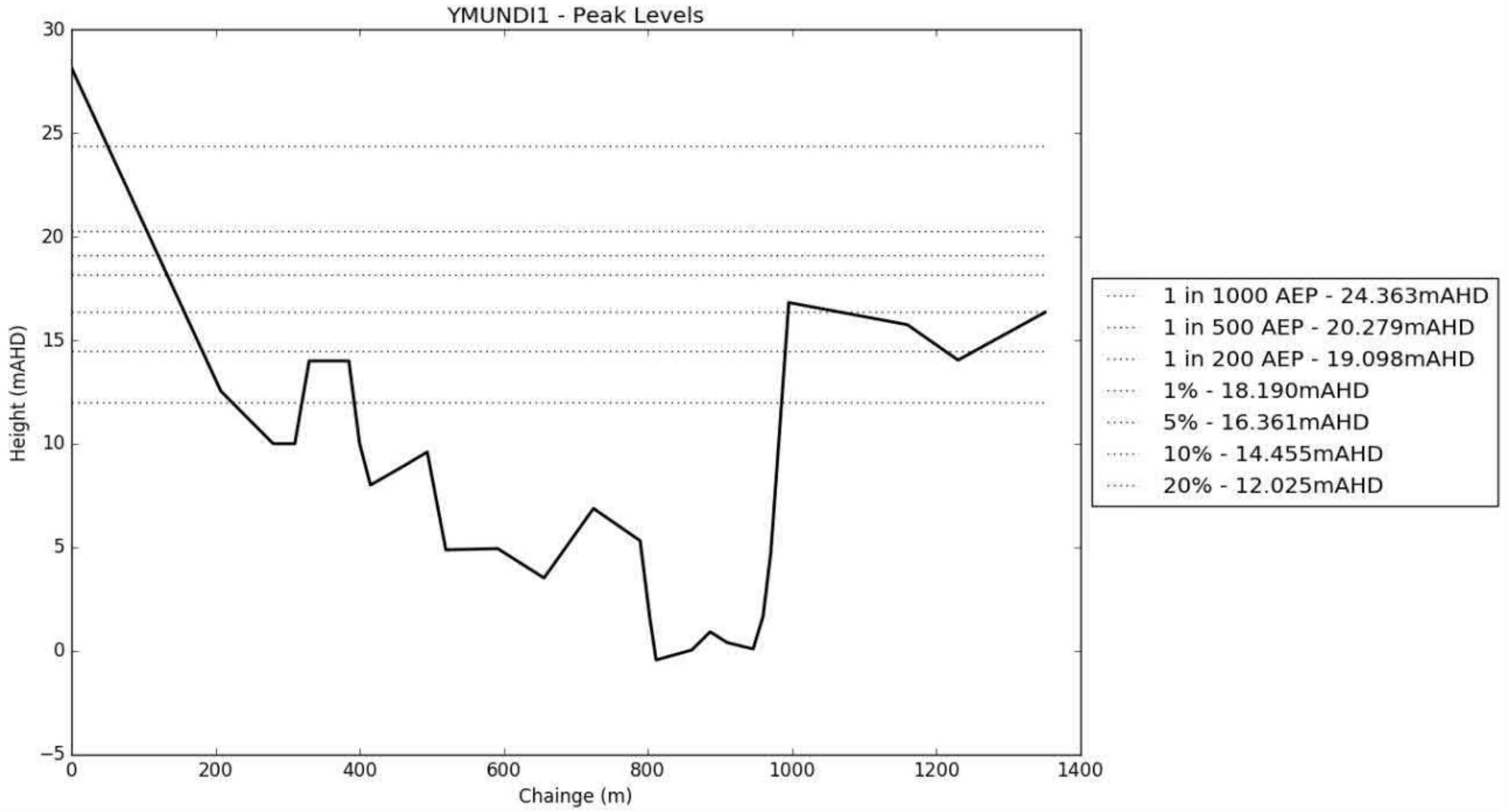
</td><td colspan="2">
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<tr><td>Historic Aerial DS – 07 |January 2019</td><td>Upstream DS – 07</td><td>Downstream DS - 07</td></tr>
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FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	WDR EIS (Beca reference # 4512987)						**Date**	01/02/2019
Surveyor	DE	**Reach code:** DS-08 (off Springwood Road @ Yarramundi)					**Time**	14:30 hrs
Drainage channel	**Creek**	**River**	**Estuary**	**Pond**		**Wetland**		**Lake**
		X (Grose)						
Weather conditions	Overcast, breeze			**U-S elevation**	41 m		**D-S elevation**	33 m
Upstream grid reference	286290; 6278764 (56H UTM)			**Downstream grid reference**	286364; 6278801			

Watercourse attributes

Dimensions	**Width (m)**	55 m	**Max. depth**	0.9	**Average velocity (ms^{-1})**	U-S = 0.12 ms^{-1} D-S = 0.10 ms^{-1}
Shape description		v-shaped channel	**Max. Roughness Height**	n/a	**Bank erosion**	LHB uniform attritional erosion RHB stable
Instream vegetation	No		**Bank vegetation** Grasses 60%	**Bench vegetation** Casuarina 80% both sides		**Organic matter** Logs & Twigs / Leaves

Flow type

Smooth surface flow [H1]	Broken standing waves [H2]	Unbroken standing waves [H3]	Chute [H4]	Rippled [H5]	Scarcely perceptible flow [H6]	Upwelling [H7]	Free fall [H8]	Standing water [H9]
X								

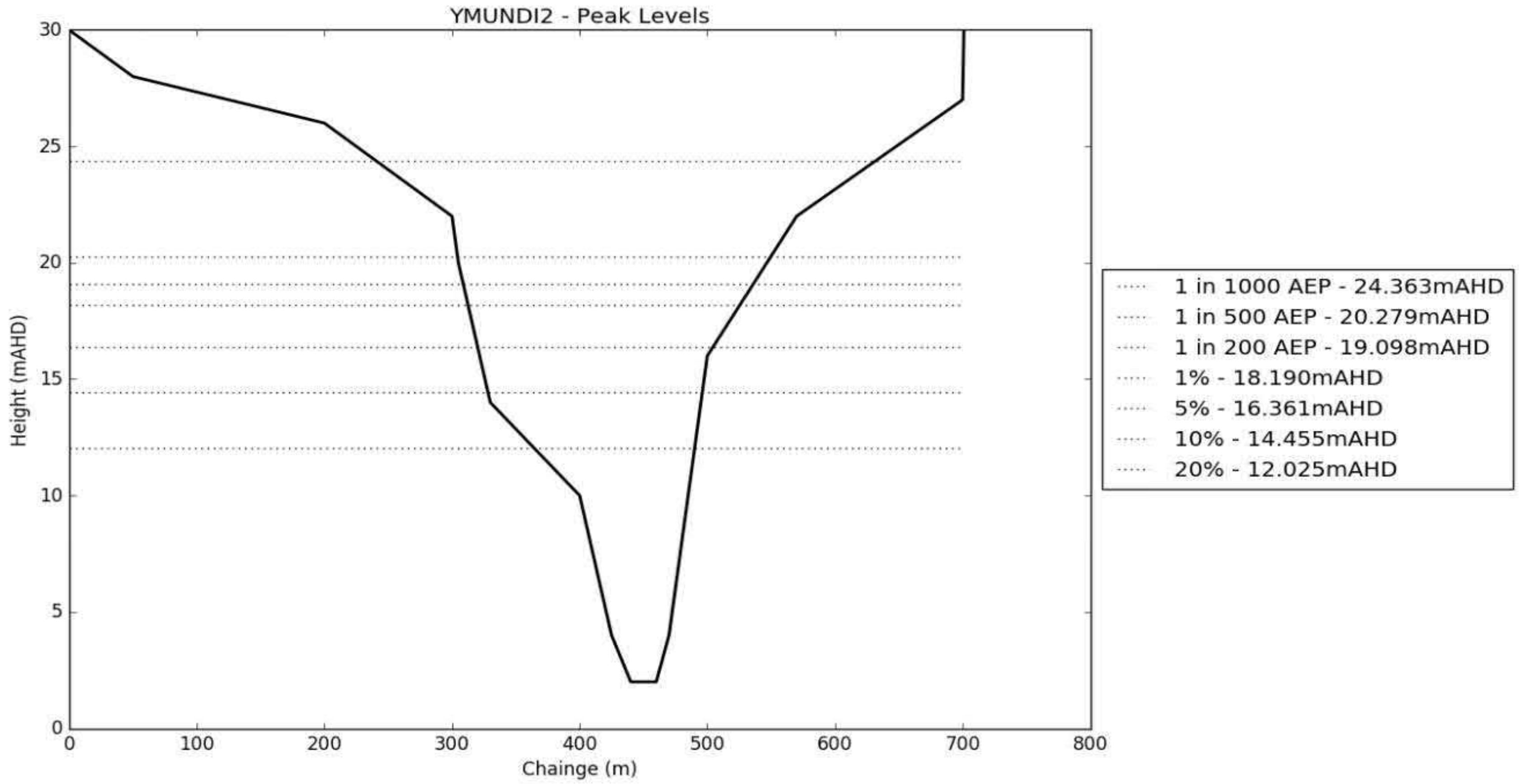
Channel Planform

Sinuosity (straight, low, intermediate, high)	Straight	***Form***	**Single** X	**Forked**	**Braided**	**Open**
Sand bars Yes	**Gravel bars** No	**Rock outcrops** No		**Riparian strip** LHB >5 m trees RHB 20 m trees	**Floodplain connectivity**	Open
Floodplain land use	LHB Yarramundi Reserve RHB Navua Reserve / cleared grassland	**Bank Strength (kg/cm²)**		U-S 0.7, 1.2, 1.4 D-S 0.5, 0.3, 0.7	**Bank structure & angle**	LHB 45°, straight RHB 70°, concave

Bed character

	Boulder		Cobble		Gravel		Sand		Fine sand		Silt / clay	
% composition	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**
	0	0	0	0	20	20	70	70	10	10	0	0
Bed stability	Low compaction				**Supply**		**Deposition**		**Erosion**		**Conveying**	
					X		X				X	

*DWF = Dry weather flow, BF = Bankfull flow, RHB = Right hand bank, LHB = Left hand bank, U-S = Upstream location of selected stretch, D-S = Downstream location of selected stretch



Cross-section DS - 08

Historic Aerial DS – 08 | October 2018

Upstream DS – 08

Downstream DS - 08

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	WDR EIS (Beca reference # 4512987)				**Date**	01/02/2019
Surveyor	DE	**Reach code:** DS-09 (Nr Beaumont Ave, North Richmond)			**Time**	14:30 hrs
Drainage channel	**Creek**	**River**	**Estuary**	**Pond**	**Wetland**	**Lake**
		X (Hawkesbury)				
Weather conditions	Overcast, still			**U-S elevation**	0 m	**D-S elevation** 0 m
Upstream grid reference	288850; 6281650 (56H UTM)			**Downstream grid reference**	288969; 6281746	

Watercourse attributes

Dimensions	**Width (m)**	135 m	**Max. depth**	Unknown – not wadeable	**Average velocity (ms^{-1})**	0 (zero)	
Shape description		U-shape	**Max. Roughness Height**	n/a	**Bank erosion**	Toe protection for 1st tier bank & no signs erosion RHB significant slump failure (approximately 5m wide each) 2nd tier at numerous locations	
Instream vegetation	Hornwort & Ribbonweed (submerged) 40%	**Bank vegetation** Emergent Cumbungi 20%		**Bench vegetation** LHB Eucalyptus 40% RHB Grasses 100%		**Organic matter** Detritus 20%	

Flow type

Smooth surface flow [H1]	Broken standing waves [H2]	Unbroken standing waves [H3]	Chute [H4]	Rippled [H5]	Scarcely perceptible flow [H6]	Upwelling [H7]	Free fall [H8]	Standing water [H9]
X								

Channel Planform

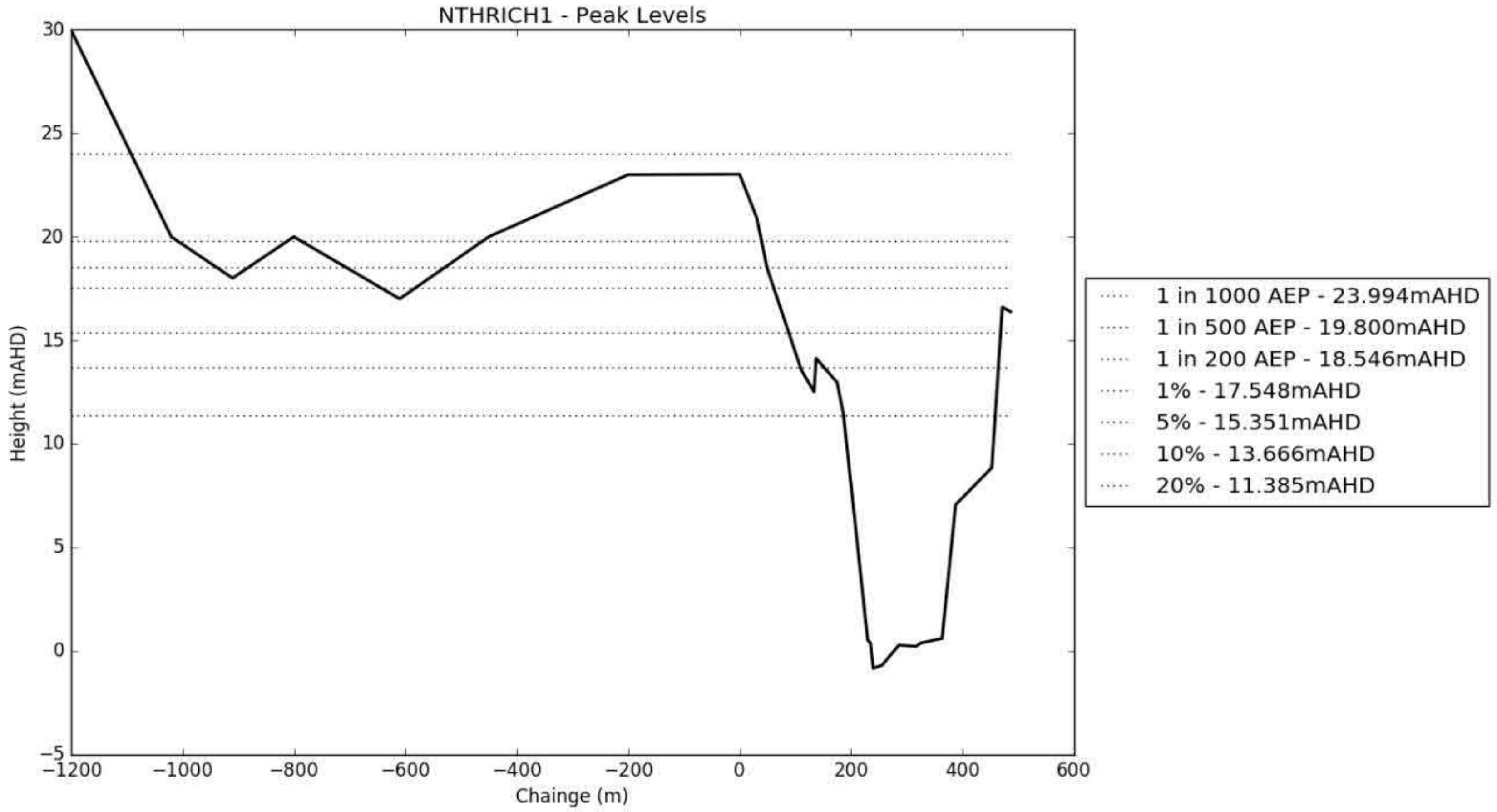
Sinuosity (straight, low, intermediate, high)	Straight	***Form***	**Single** X	**Forked**	**Braided**	**Open**
Sand bars No		**Gravel bars** No	**Rock outcrops** No	**Riparian strip** RHB yes	**Floodplain connectivity**	Constrained by steep side banks
Floodplain land use	LHB Farmland RHB Hanna Park		**Bank Strength (kg/cm^2)**	U-S 0.5, 0.9, 1.5 D-S 0.75, 0.8, 1.1	**Bank structure & angle**	LHB 60°, concave RHB 50

Bed character

	Boulder		Cobble		Gravel		Sand		Fine sand		Silt / clay	
% composition	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**
	10	20	40	40	0	0	40	40	10	0	0	0
Bed stability	Packed & armoured				**Supply**		**Deposition**		**Erosion**		**Conveying**	
					X		X		X		X	

*DWF = Dry weather flow, BF = Bankfull flow, RHB = Right hand bank, LHB = Left hand bank, U-S = Upstream location of selected stretch, D-S = Downstream location of selected stretch

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

		
	Cross-section DS - 09	
		
Historic Aerial DS – 09 | October 2018	**Upstream DS – 09**	**Downstream DS - 09**

Created 04/08/2011 Dan Evans (after Thompson et al, 2011, *Aq Conserve*, **11**, 373 – 389)

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	WDR EIS (Beca reference # 4512987)					**Date**	01/02/2019	
Surveyor	DE	**Reach code:** DS-11 (Wilberforce Road, Windsor)				**Time**	15:15 hrs	
Drainage channel	**Creek**	**River**	**Estuary**	**Pond**		**Wetland**	**Lake**	
		X (Hawkesbury)						
Weather conditions	Dark, humid			**U-S elevation**		0 m	**D-S elevation**	0 m
Upstream grid reference	297419; 6279568 (56H UTM)			**Downstream grid reference**		297508; 6279573		

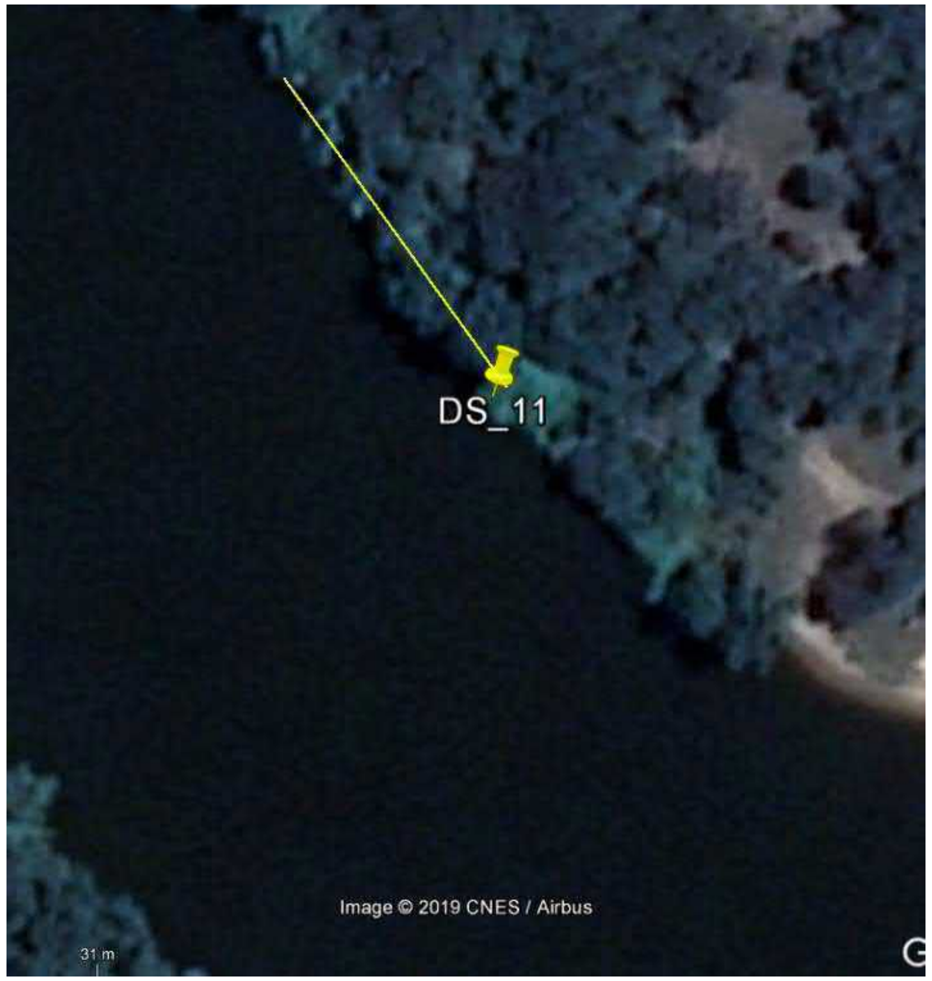
Watercourse attributes							
Dimensions	**Width (m)**	92 m	**Max. depth**	Unknown – not wadeable	**Average velocity (ms^{-1})**	U-S = 0.14 ms^{-1} D-S = 0.14 ms^{-1}	
Shape description		Flat trapazoidal	**Max. Roughness Height**	n/a	**Bank erosion**	LHB - Erosion inlets on sandy bank	
Instream vegetation	No	**Bank vegetation** Isolated patch of vegetation		**Bench vegetation** LHB Grasses 40%; Trees 30% RHB None (sand beach)		**Organic matter** None	

Flow type								
Smooth surface flow [H1]	**Broken standing waves** [H2]	**Unbroken standing waves** [H3]	**Chute** [H4]	**Rippled** [H5]	**Scarcely perceptible flow** [H6]	**Upwelling** [H7]	**Free fall** [H8]	**Standing water** [H9]
X			X					

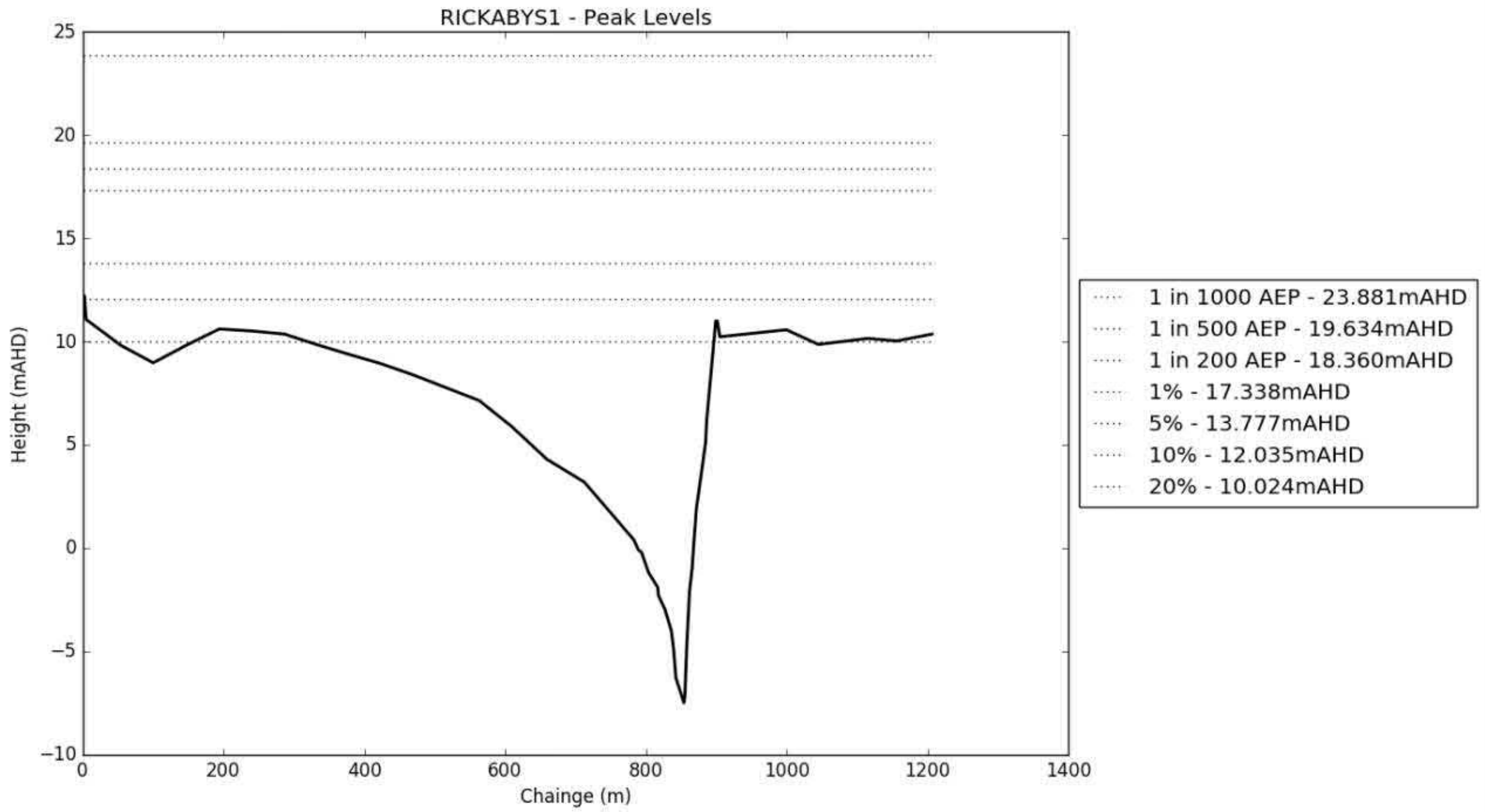
Channel Planform							
Sinuosity (straight, low, intermediate, high)	Intermediate	***Form***	**Single** X	**Forked**	**Braided**		**Open**
Sand bars Yes	**Gravel bars** No		**Rock outcrops** No		**Riparian strip** No	**Floodplain connectivity**	Open
Floodplain land use	LHB Deerubbun Park RHB Macquarie Park		**Bank Strength (kg/cm^2)**		U-S 0.2, 0.2, 0.4 D-S 0.2, 0.5, 0.4	**Bank structure & angle**	LHB 40°, straight RHB 30°, concave

Bed character												
% composition	**Boulder**		**Cobble**		**Gravel**		**Sand**		**Fine sand**		**Silt / clay**	
	U-S	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**
	0	0	0	0	0	0	90	90	10	10	0	0
Bed stability	No packing				**Supply**		**Deposition**		**Erosion**		**Conveying**	
					X		X				X	

*DWF = Dry weather flow, BF = Bankfull flow, RHB = Right hand bank, LHB = Left hand bank, U-S = Upstream location of selected stretch, D-S = Downstream location of selected stretch



Historic Aerial DS – 11 | October 2018



Cross-section DS - 11

Upstream DS – 11

Downstream DS - 11

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	WDR EIS (Beca reference # 4512987)					**Date**		01/02/2019
Surveyor	DE	**Reach code:** DS-12 (Arndells Trail at Cattai National Park)				**Time**		16:30 hrs
Drainage channel	**Creek**	**River**	**Estuary**	**Pond**		**Wetland**		**Lake**
		X (Hawkesbury)						
Weather conditions	Dark, humid			**U-S elevation**		0 m	**D-S elevation**	0 m
Upstream grid reference	304063; 6284790 (56H UTM)			**Downstream grid reference**		304065; 6284824		

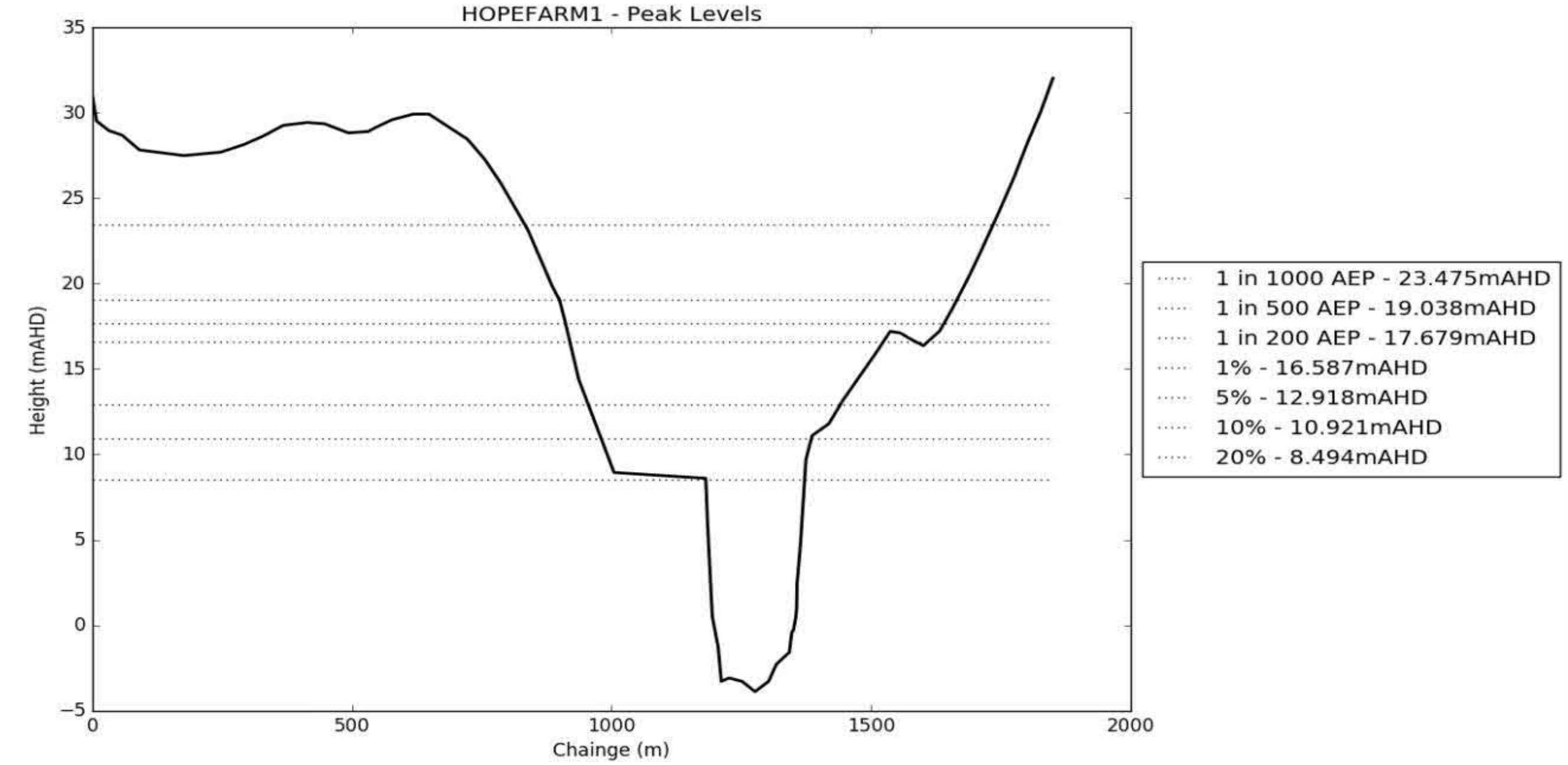
Watercourse attributes							
Dimensions	**Width (m)**	133 m	**Max. depth**	Unknown – not wadeable	**Average velocity (ms^{-1})**	U-S = 0.10 ms^{-1} D-S = 0.09 ms^{-1}	
Shape description		Tight u-shape with confined banks	**Max. Roughness Height**	n/a	**Bank erosion**	Boat swash causing undermining of banks, root mat protects surface material	
Instream vegetation	No	**Bank vegetation** Sedge		**Bench vegetation** Trees 100%		**Organic matter** Detritus	

Flow type								
Smooth surface flow [H1]	**Broken standing waves** [H2]	**Unbroken standing waves** [H3]	**Chute** [H4]	**Rippled** [H5]	**Scarcely perceptible flow** [H6]	**Upwelling** [H7]	**Free fall** [H8]	**Standing water** [H9]
X								

Channel Planform						
Sinuosity (straight, low, intermediate, high)	Straight	***Form***	**Single** X	**Forked**	**Braided**	**Open**
Sand bars No	**Gravel bars** No	**Rock outcrops** No		**Riparian strip** No	**Floodplain connectivity**	Constrained by steep side banks
Floodplain land use	LHB Cattai National Park RHB Cleared land for horse riding / farming	**Bank Strength (kg/cm^2)**		1st tier 2.3, 2.5, 2.0 2nd tier 0.5, 0.5, 0.6	**Bank structure & angle**	LHB 80 ° straight RHB 90 ° straight

Bed character												
% composition	**Boulder**		**Cobble**		**Gravel**		**Sand**		**Fine sand**		**Silt / clay**	
	U-S	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**	**U-S**	**D-S**
	0	0	0	0	0	0	80	80	20	20	0	0
Bed stability	Low compaction				**Supply**		**Deposition**		**Erosion**		**Conveying**	
							X		X		X	

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE



Cross-section DS - 12

Historic Aerial DS – 12 | October 2017

Upstream DS – 12

Downstream DS - 12

H

Appendix H – Bank Strength Data

Table 24 Bank strengths dataset

Site Code	Bank Strength Readings (kg m^{-2})																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Min	Max	Average
DS-01	1.25	1.4	5	2.2	2.5	5	1.35	1.5	5	2.1	2.4	5	1.15	1.3	5	2.3	2.6	5	1.2	5.0	2.9
DS-02	1.2	5	5	5	5	5	1.1	5	5	5	5	1.2	5	5	5	5	5	5	1.1	5.0	4.4
DS-03	5	5	5	1.8	2.3	0.5	5	5	5	1.9	2.4	0.6	5	5	5	1.7	2.1	0.4	0.4	5.0	3.3
DS-04	0.8	1.2	1.9	1	1	1.9	0.9	1.3	2	0.9	0.9	1.7	0.8	1.1	1.8	1.1	1.1	2	0.8	2.0	1.3
DS-06	0.3	0.2	0.2	0.4	1.2	2.5	0.4	0.3	0.3	0.5	1.3	2.6	0.2	0.1	0.1	0.5	1.3	2.6	0.1	2.6	0.8
DS-07	0.2	0.8	0.6	0.3	0.5	0.7	0.3	0.9	0.7	0.2	0.4	0.6	0.25	0.9	0.4	0.5	0.6	0.55	0.2	0.9	0.5
DS-08	0.7	1.2	1.4	0.5	0.3	0.7	0.6	1.4	1.6	0.3	0.1	0.5	0.5	1.1	1.3	0.6	0.5	0.8	0.1	1.6	0.8
DS-09	0.5	0.9	1.5	0.7	0.95	1.3	0.25	0.8	1.4	0.9	0.6	1.1	0.6	0.8	1.3	0.8	1.1	1.4	0.3	1.5	0.9
DS-11	0.2	0.2	0.4	0.3	0.25	0.5	0.1	0.1	0.25	0.4	0.45	0.5	0.1	0.1	0.5	0.45	0.2	0.4	0.1	0.5	0.3
DS-12	2.5	2	2.3	0.5	0.6	0.5	2.25	2.25	2.4	0.4	0.5	0.5	2.6	2.1	2.4	0.4	0.4	0.3	0.3	2.6	1.4
R-01	0.2	0.2	0.1	2.8	3	2.7	0.25	0.1	0.2	2.9	3.1	2.6	0.1	0.15	0.2	3	2.8	2.6	0.1	3.1	1.5
R-02	0.4	0.6	0.75	0.3	0.2	0.6	0.5	0.7	0.8	0.25	0.1	0.5	0.3	0.5	0.7	0.4	0.3	0.7	0.1	0.8	0.5
R-03	0.5	0.5	0.4	0.6	0.3	0.5	0.6	0.6	0.55	0.5	0.2	0.4	0.3	0.3	0.4	0.5	0.4	0.65	0.2	0.7	0.5
R-04	0.2	0.3	0.3	1.2	1.1	0.9	0.3	0.5	0.4	1.1	1	1	0.25	0.4	0.5	1.1	1	0.8	0.2	1.2	0.7
R-05	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5.0	5.0	5.0
R-06	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5.0	5.0	5.0
US 01	1.8	1.2	1.25	1.6	2.4	2.5	1.9	1.3	1.35	1.5	2.3	2.4	1.9	1.3	1.35	1.5	2.3	2.4	1.2	2.5	1.8
US-02	0.8	0.6	1.5	0.5	0.4	0.2	0.9	0.7	1.6	0.4	0.3	0.1	0.7	0.5	1.4	0.6	0.5	0.3	0.1	1.6	0.7
US-04	1.7	2.5	3.6	0.3	0.7	0.9	1.8	2.6	3.7	0.2	0.6	0.8	1.6	2.4	3.5	0.4	0.8	1.0	0.2	3.7	1.6
US-05	5	3.7	2.5	5	5	2.7	5	3.8	2.6	5	5	2.6	5	3.6	2.4	5	5	2.8	2.4	5.0	4.0
US-06	4.5	1.2	0.3	2.7	2	1.5	4.6	1.3	0.4	2.6	1.9	1.4	4.4	1.1	0.2	2.8	2.1	1.6	0.2	4.6	2.0
US-07	0.5	0.3	0.2	0.2	0.55	0.3	0.6	0.4	0.3	0.1	0.45	0.2	0.4	0.2	0.1	0.3	0.65	0.4	0.1	0.7	0.3
US-08	0.2	0.25	0.25	0.3	0.25	0.25	0.2	0.4	0.25	0.25	0.15	0.25	0.25	0.2	0.2	0.3	0.25	0.25	0.2	0.4	0.2
US-09	1	0.6	2.3	1.2	0.4	2.5	0.9	0.8	2.25	2.6	4	5	2.4	4.3	4.75	2.55	3	4.1	0.4	5.0	2.5
US-10	2.3	2.5	3.1	2	2.7	3	2.5	2.3	3	0.4	0.4	0.3	0.6	0.4	0.15	0.5	0.55	0.25	0.2	3.1	1.5
US-11	0.5	0.75	0.8	0.6	0.7	0.9	0.4	0.8	0.9	1.2	1	0.75	1	1.2	0.8	1.3	0.9	0.95	0.4	1.3	0.9
US-12	2	2	2.1	0.7	0.7	0.5	1.8	1.9	1.7	0.7	0.5	0.75	2.1	2.2	2	0.8	0.6	0.6	0.5	2.2	1.3
US-13	0.2	0.5	0.5	0.4	0.4	0.5	0.5	0.25	0.5	0.4	0.25	0.4	0.4	0.3	0.3	0.3	0.25	0.25	0.2	0.5	0.4
US-14	0.2	0.25	0.4	0.4	0.4	0.2	0.2	0.4	0.1	0.2	0.2	0.1	0.2	0.2	0.25	0.2	0.25	0.1	0.1	0.4	0.2
US-16	2.6	3.8	2.8	3	2.9	2.9	2.75	3.4	3.1	2.6	3.6	3.85	2.8	3.4	3.5	2.9	3.1	3.9	2.6	3.9	3.2

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I

Appendix I – Sediment Particle Size Data

Table 25 Bed sediment composition data

Site Code	Bed Sediment particle size (mm)												Site D_{50}
	Upstream						Downstream						
	Boulder (>256)	Cobble (64-256)	Gravel (2-64)	Sand (0.250-64)	Fine sand (0.063-0.250)	Silt / clay (<0.063)	Boulder (>256)	Cobble (64-256)	Gravel (2-64)	Sand (0.250-64)	Fine sand (0.063-0.250)	Silt / clay (<0.063)	
DS-01	50	-	30	20	-	-	50	10	30	10	-	-	167
DS-02	100	-	-	-	-	-	100	-	-	-	-	-	256
DS-03	-	30	30	30	10	-	-	-	60	30	10	-	72
DS-04	-	-	40	40	20	-	-	-	40	50	10	-	56
DS-06	-	-	10	80	10	-	-	-	-	80	20	-	49
DS-07	-	70	20	10	-	-	-	50	40	10		-	117
DS-08	-	-	20	70	10	-	-	-	-	90	10	-	54
DS-09	-	-	-	80	20	-	-	-	-	80	20	-	50
DS-11	-	-	-	90	10	-	-	-	-	90	10	-	52
DS-12	-	-	-	80	20	-	-	-	-	80	20	-	50
R-01	-	-	20	70	10	-	-	-	20	70	10	-	56
R-02	-	-	-	40	40	20	-	-	-	40	40	-	38
R-03	-	20	20	20	40	-	-	20	20	20	40	-	60
R-04	-	-	20	40	40	-	-		20	40	40	-	49
R-05	80	20	-	-	-	-	-	80	20	-	-	-	216
R-06	100	-	-	-	-	-	-	100	-	-	-	-	256
US-01	20	40	30	10			30	50	15	5	-	-	159
US-02	20	20	40	20	-	-	-	-	-	80	15	5	71
US-04	-	100	-	-	-	-	-	100	-	-	-	-	135
US-05	-	-	10	10	70	10	-	-	-	-	90	10	38
US-06	-	-		70	20	10	30	10	30	25	5		68
US-07	5	0	10	70	5	10	10	0	20	60	10	0	59
US-08	-	-	10	80	10					80	20		52
US-09	10	40	0	40	10	0	20	40	0	40	0	0	105
US-10	0	30	40	30	0	0	0	80	20	0	0	0	112
US 11	0	80	10	10	0	0	0	70	20	10	0	0	125
US-12	0	0	0	5	25	70	0	0	0	5	35	60	29
US-13	0	0	0	0	80	20	0	0	0	10	70	20	36
US-14	0	0	20	60	20	0	0	0	10	50	40	0	50
US-16	0	80	20	0	0	0	0	70	20	10	0	0	52

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J

Appendix J – Erosion Hotspot Model Maps

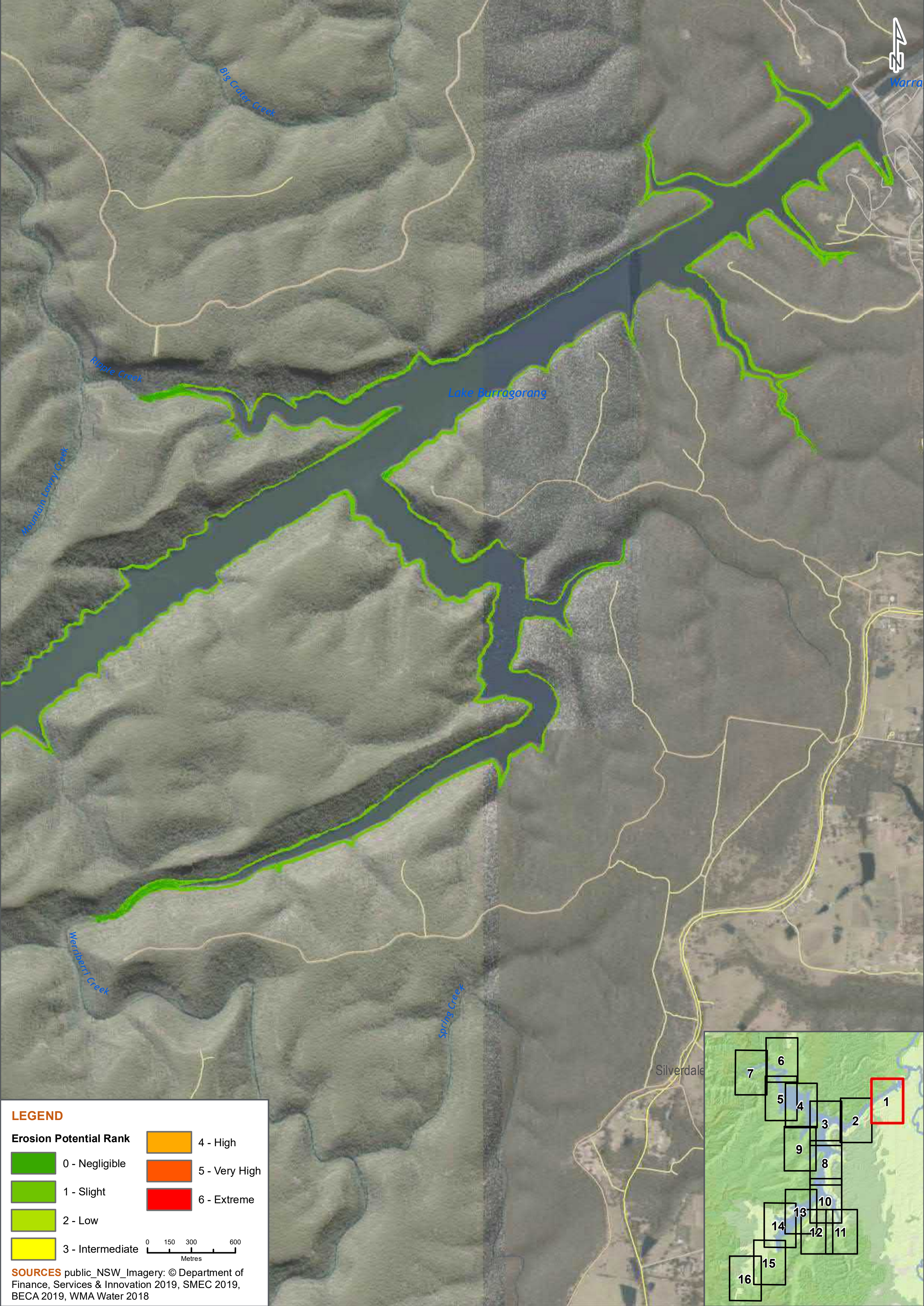
J.1 Erosion Hotspot Model – Existing Scenario

Table 26 Erosion Hotspot Tool Classifications for the Existing' Scenario in upstream creeks / rivers

Erosion Potential Risk	20% AEP Existing		10% AEP Existing		5% AEP Existing		1% AEP Existing		PMF Existing	
	Area (m^2)	Percentage	Area (m^2)	Percentage	Area (m^2)	Percentage	Area (m^2)	Percentage	Area (m^2)	Percentage
0 – Negligible	719	0.0%	1,015	0.2%	1,025	0.2%	4,744	0.3%	1,634	0.0%
1 – Slight	1,195,572	71.5%	412,148	64.7%	238,456	42.2%	515,772	36.6%	2,166,572	41.0%
2 – Low	447,963	26.8%	202,353	31.8%	299,012	52.9%	798,127	56.6%	2,504,601	47.4%
3 – Intermediate	27,660	1.7%	21,083	3.3%	26,356	4.7%	92,402	6.5%	593,177	11.2%
4 – High	-	0.0%	-	0.0%	-	0.0%	14	0.0%	21,048	0.4%
5 – Very High	-	0.0%	-	0.0%	-	0.0%	-	0.0%	-	0.0%
6 - Extreme	-	0.0%	-	0.0%	-	0.0%	-	0.0%	-	0.0%
Total Area (m^2)	**1,671,914**		**636,599**		**564,849**		**1,411,059**		**5,287,032**	

Table 27 Erosion Hotspot Tool Classifications for the Existing Scenario around Lake Burragorang

Erosion Potential Risk	20% AEP Existing		10% AEP Existing		5% AEP Existing		1% AEP Existing		PMF Existing	
	Area (m^2)	Percentage	Area (m^2)	Percentage	Area (m^2)	Percentage	Area (m^2)	Percentage	Area (m^2)	Percentage
0 – Negligible	5,389	0.7%	6,974	0.9%	7,881	1.1%	40,877	1.1%	153,096	1.1%
1 – Slight	520,700	66.9%	504,590	67.3%	471,553	67.1%	1,966,970	52.4%	7,328,282	52.6%
2 – Low	248,936	32.0%	236,243	31.5%	221,565	31.5%	1,710,266	45.6%	6,315,239	45.4%
3 – Intermediate	2,953	0.4%	1,897	0.3%	1,666	0.2%	36,557	1.0%	123,580	0.9%
4 – High	-	0.0%	-	0.0%	-	0.0%	20	0.0%	27	0.0%
5 – Very High	-	0.0%	-	0.0%	-	0.0%	-	0.0%	-	0.0%
6 - Extreme	-	0.0%	-	0.0%	-	0.0%	-	0.0%	-	0.0%
Total Area (m^2)	**777,978**		**749,704**		**702,665**		**3,754,690**		**13,920,224**	



Big Crater Creek
Warra
Ripple Creek
Lake Burragorang
Mountain Lowry Creek
Werriberri Creek
Spring Creek
Silverdale
LEGEND
Erosion Potential Rank
0 - Negligible
1 - Slight
2 - Low
3 - Intermediate
4 - High
5 - Very High
6 - Extreme
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

Mountain Lowry Creek
Gogongolly Creek
Lake Burragorang
N
LEGEND
Erosion Potential Rank
0 - Negligible
1 - Slight
2 - Low
3 - Intermediate
4 - High
5 - Very High
6 - Extreme
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018

N
Pearces Mountain Gully
Pearces Creek
Lake Burragorang
Popes Creek
LEGEND
Erosion Potential Rank
0 - Negligible
1 - Slight
2 - Low
3 - Intermediate
4 - High
5 - Very High
6 - Extreme
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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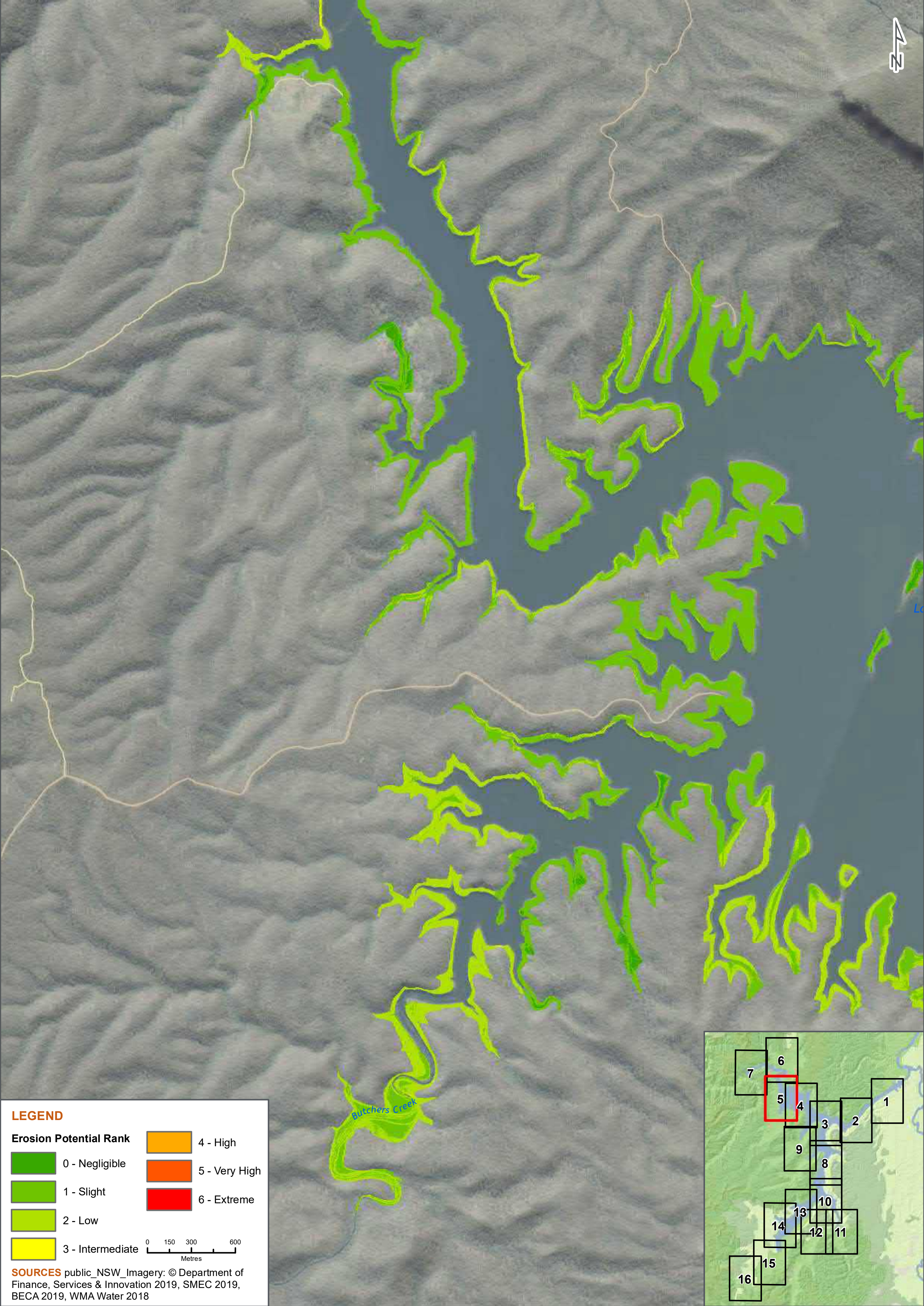

Butchers Creek
LEGEND
Erosion Potential Rank
0 - Negligible
1 - Slight
2 - Low
3 - Intermediate
4 - High
5 - Very High
6 - Extreme
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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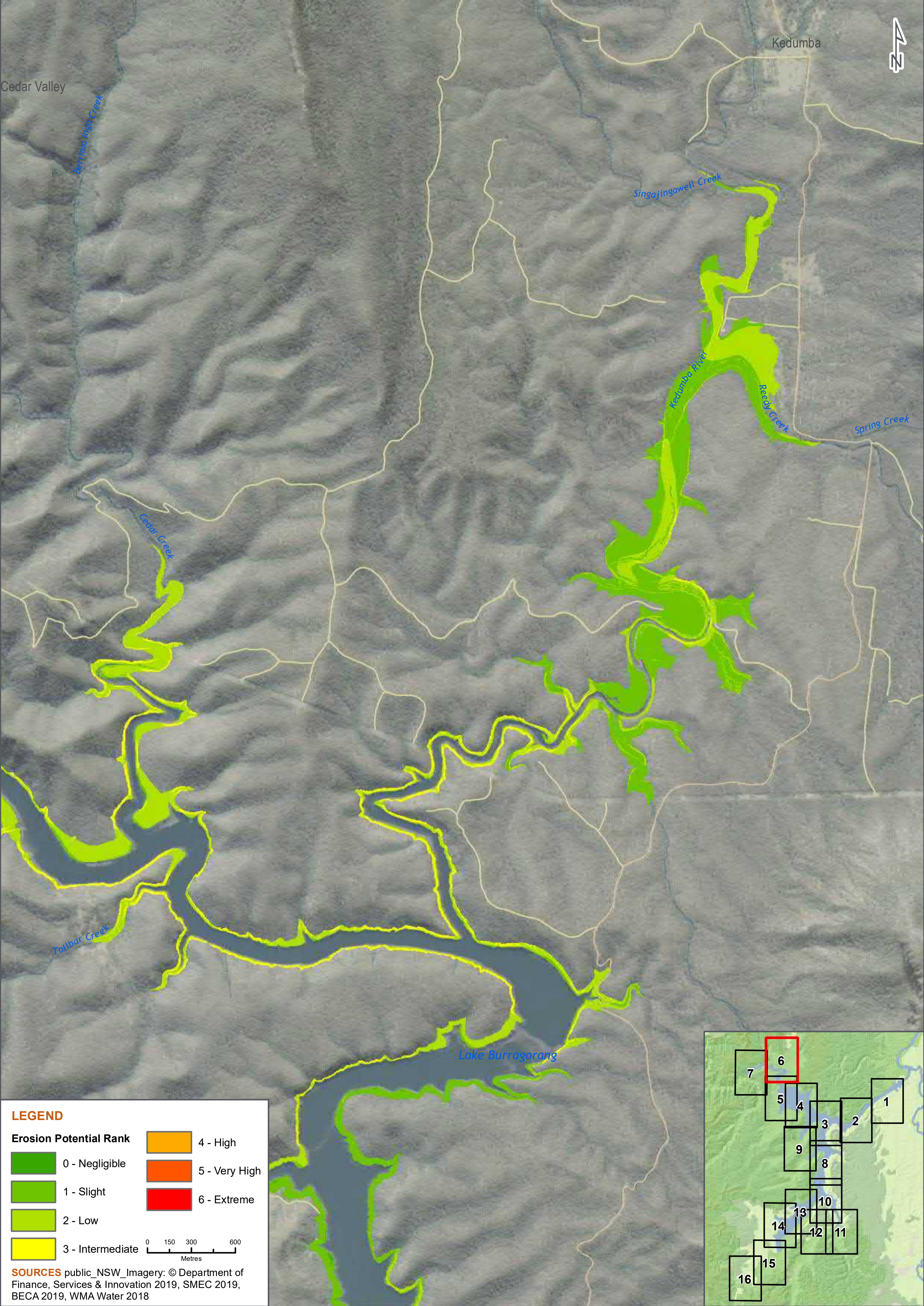

Kedumba
Cedar Valley
Bermanangee Creek
Singajingawell Creek
Kedumba River
Reedy Creek
Spring Creek
Cedar Creek
Tollbar Creek
Lake Burragorang
LEGEND
Erosion Potential Rank
0 - Negligible
1 - Slight
2 - Low
3 - Intermediate
4 - High
5 - Very High
6 - Extreme
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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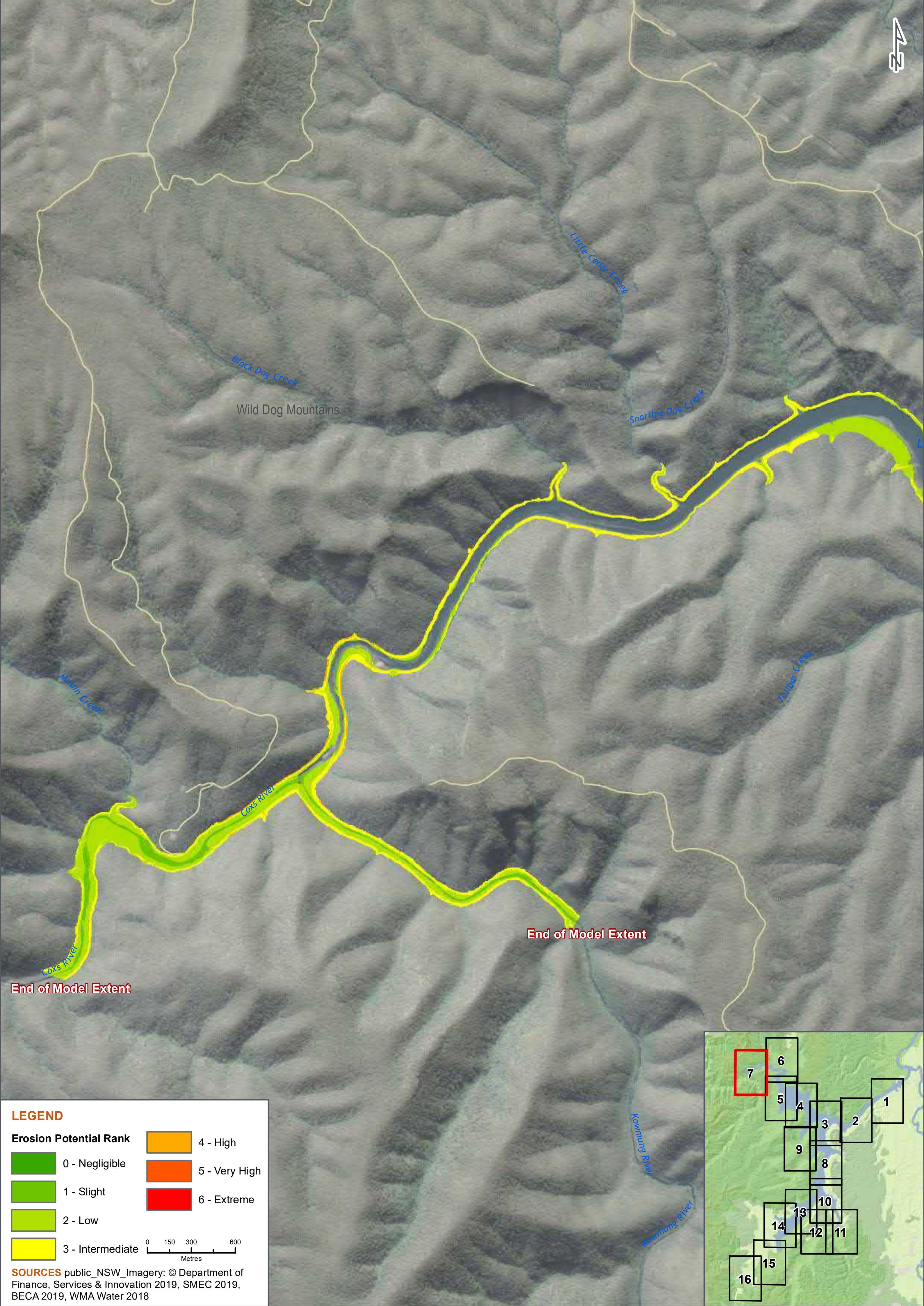

Little Cedar Creek
Black Dog Creek
Wild Dog Mountains
Snarling Dog Creek
Moorin Creek
Tallbar Creek
Coxs River
Coxs River
End of Model Extent
End of Model Extent
Kowmung River
Kowmung River
N
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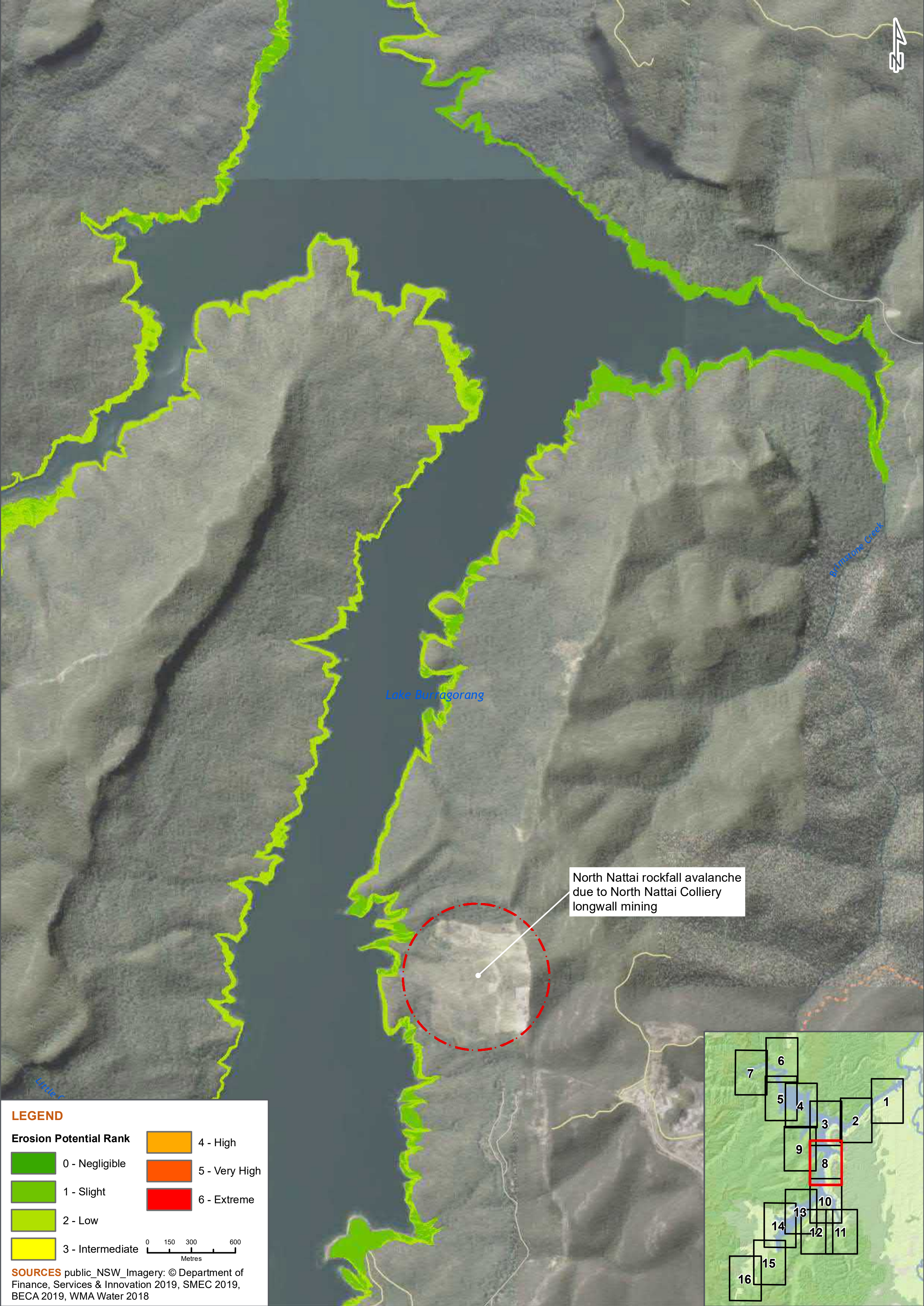
LEGEND
Erosion Potential Rank
0 - Negligible
1 - Slight
2 - Low
3 - Intermediate
4 - High
5 - Very High
6 - Extreme
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018



Lake Burragorang
Brimstone Creek
North Nattai rockfall avalanche due to North Nattai Colliery longwall mining
LEGEND
Erosion Potential Rank
0 - Negligible
1 - Slight
2 - Low
3 - Intermediate
4 - High
5 - Very High
6 - Extreme
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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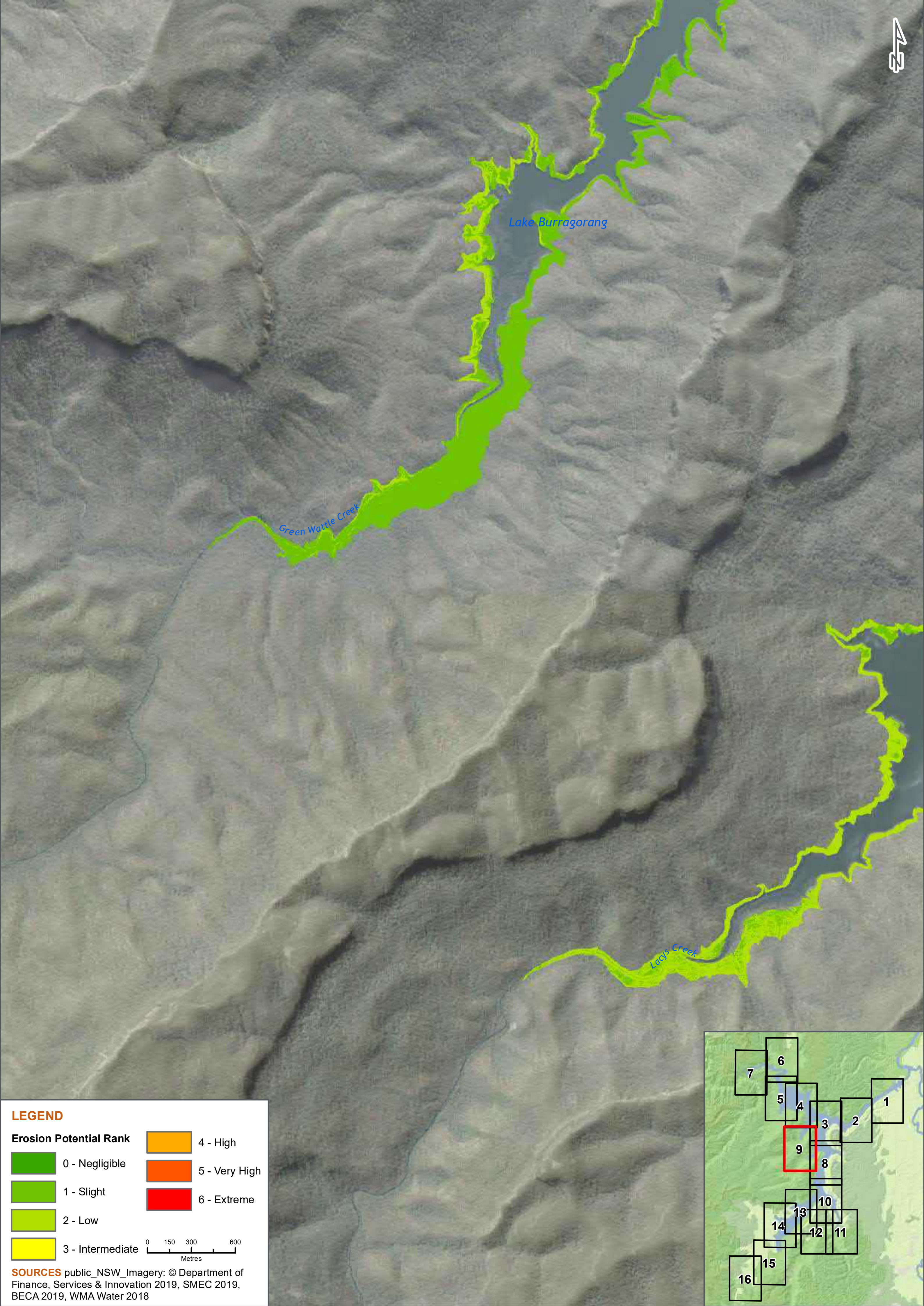
Lake Burragorang
Green Wattle Creek
Lacys Creek
LEGEND
Erosion Potential Rank
0 - Negligible
1 - Slight
2 - Low
3 - Intermediate
4 - High
5 - Very High
6 - Extreme
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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N
Nattai
Burragorang Road
Lake Burragorang
Davis Creek
Rangers Creek
Blossom Lodge Gully
LEGEND
Erosion Potential Rank
0 - Negligible
1 - Slight
2 - Low
3 - Intermediate
4 - High
5 - Very High
6 - Extreme
0
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Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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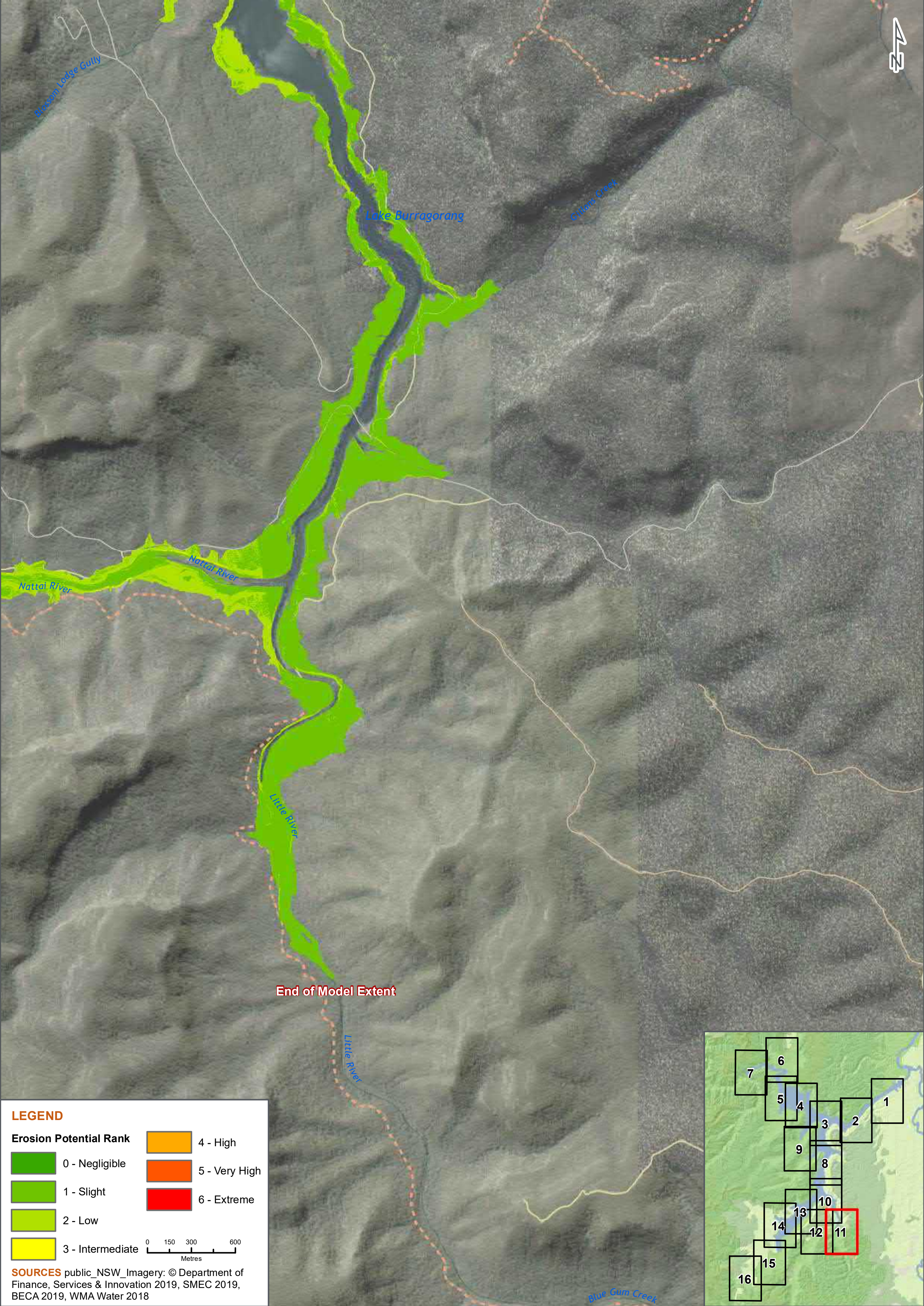
Blossom Lodge Gully
Lake Burragorang
Nattai River
Nattai River
Little River
End of Model Extent
Little River
Blue Gum Creek
LEGEND
Erosion Potential Rank
0 - Negligible
1 - Slight
2 - Low
3 - Intermediate
4 - High
5 - Very High
6 - Extreme
0
150
300
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Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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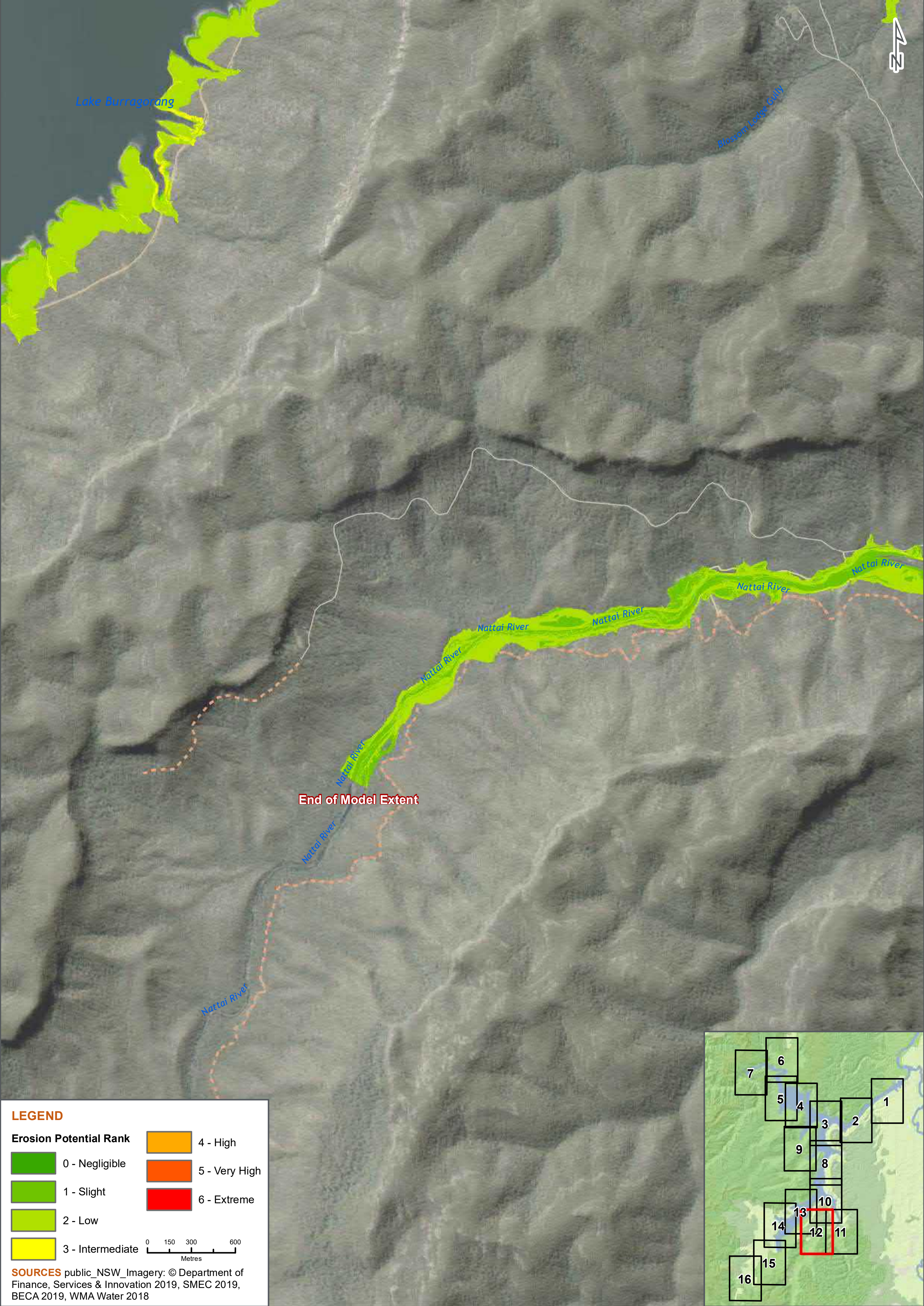

Lake Burragorang
Blossom Lodge Gully
Nattai River
Nattai River
Nattai River
Nattai River
Nattai River
Nattai River
Nattai River
End of Model Extent
Nattai River
Nattai River
LEGEND
Erosion Potential Rank
0 - Negligible
1 - Slight
2 - Low
3 - Intermediate
4 - High
5 - Very High
6 - Extreme
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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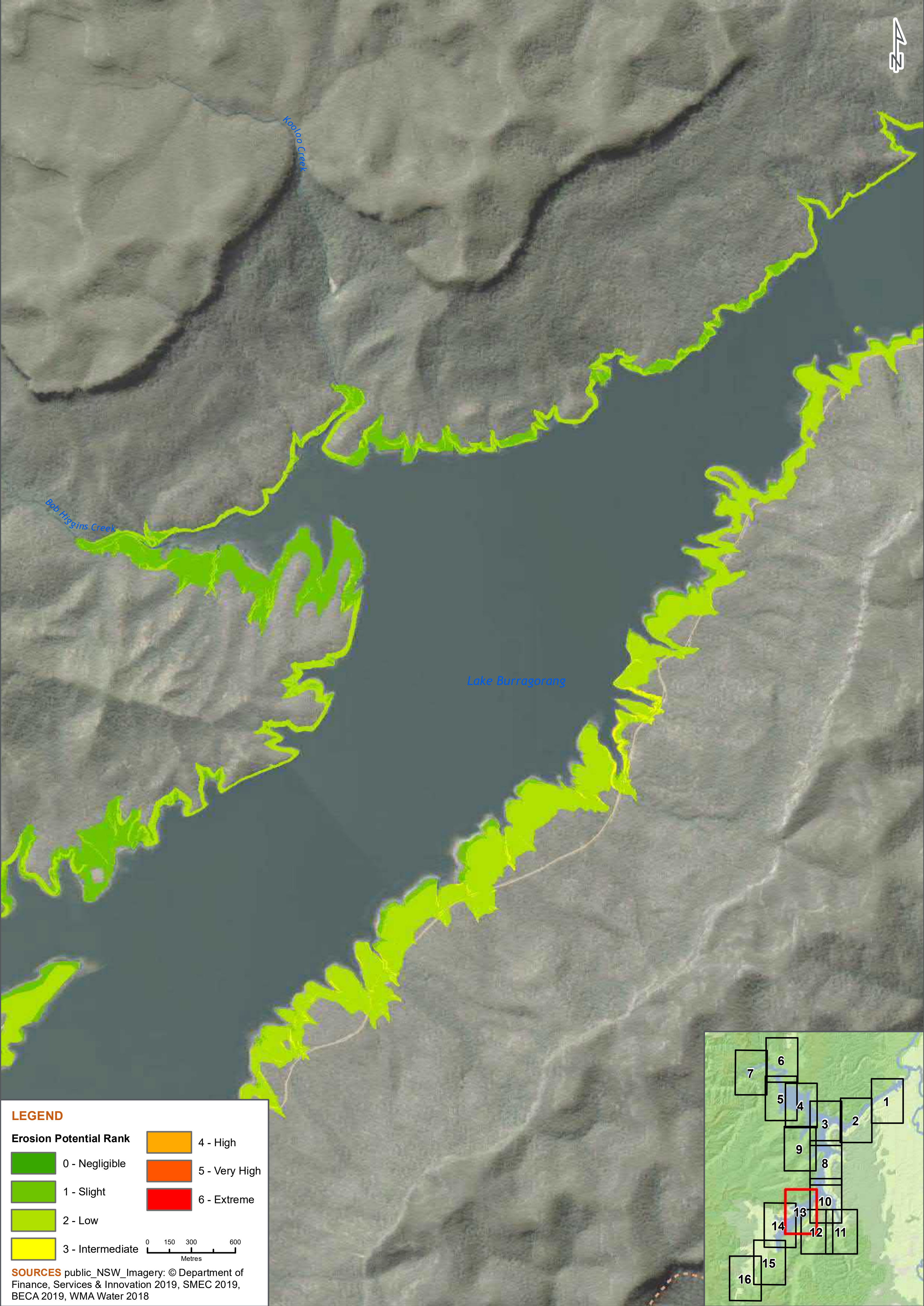

Kooloo Creek
Bob Higgins Creek
Lake Burragorang
LEGEND
Erosion Potential Rank
0 - Negligible
1 - Slight
2 - Low
3 - Intermediate
4 - High
5 - Very High
6 - Extreme
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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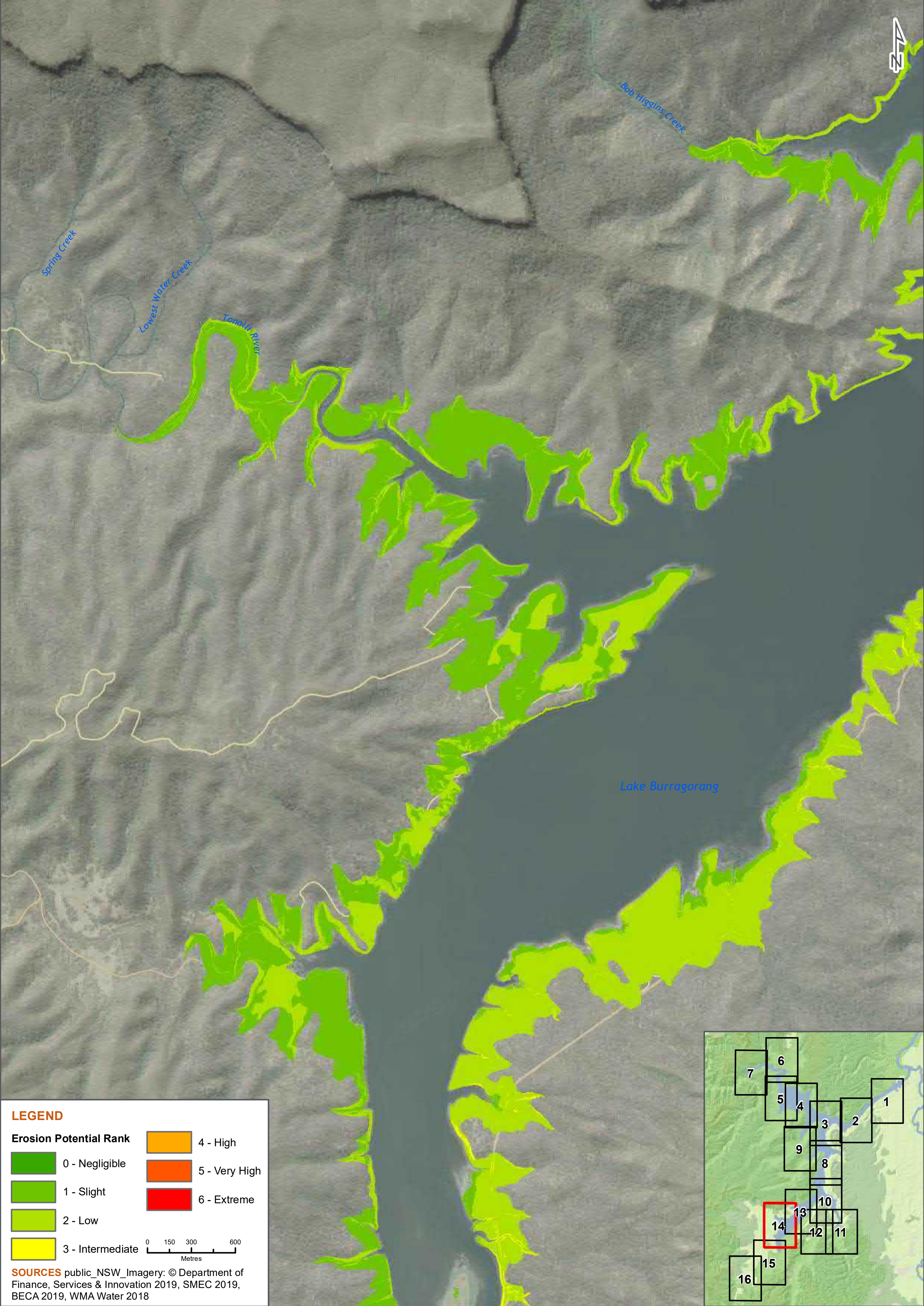
Bob Higgins Creek
Spring Creek
Lowest Water Creek
Tonalli River
Lake Burragorang
LEGEND
Erosion Potential Rank
0 - Negligible
1 - Slight
2 - Low
3 - Intermediate
4 - High
5 - Very High
6 - Extreme
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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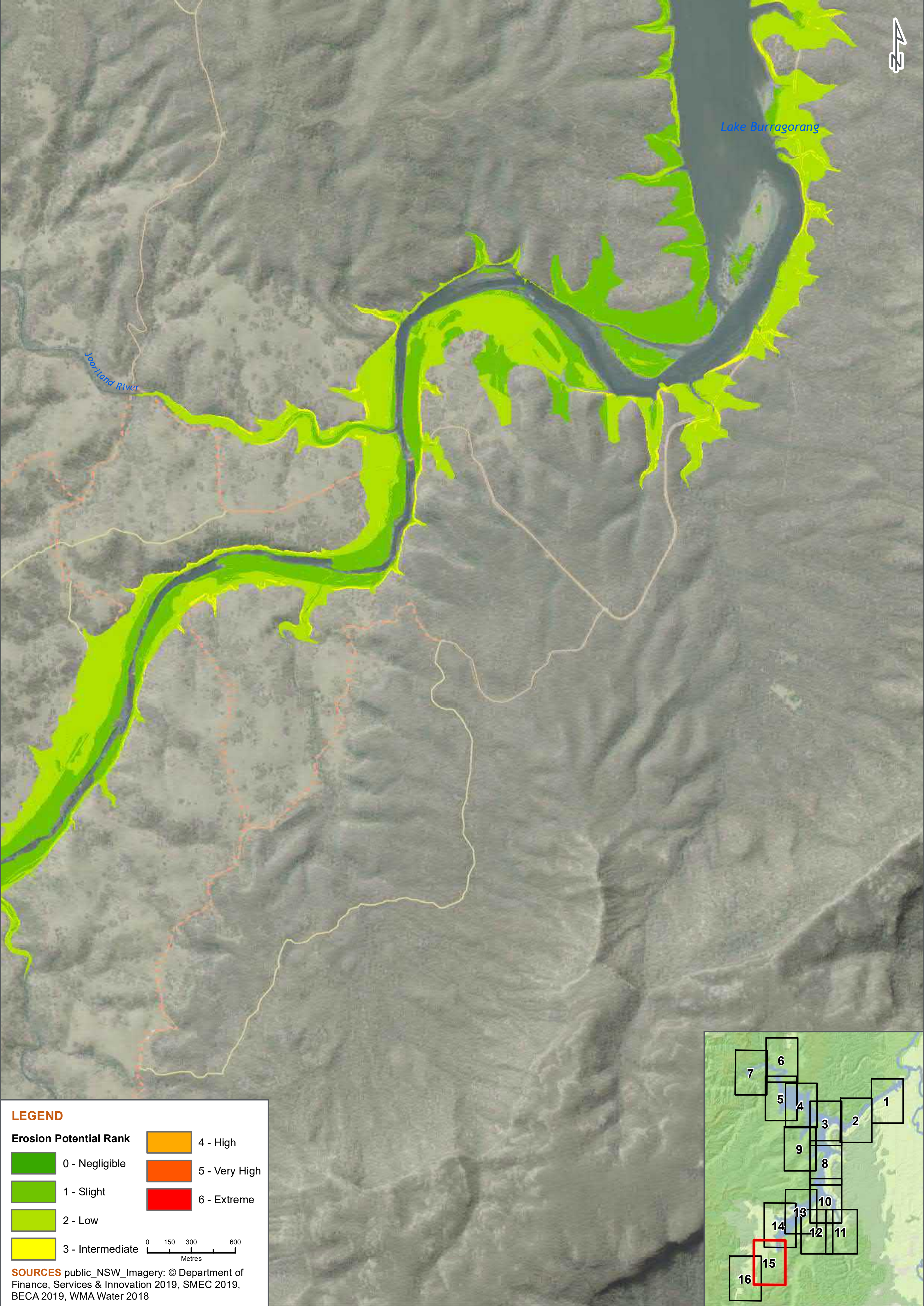

Lake Burragorang
Jooriland River
LEGEND
Erosion Potential Rank
0 - Negligible
1 - Slight
2 - Low
3 - Intermediate
4 - High
5 - Very High
6 - Extreme
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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End of Model Extent
Bonnum Pic Creek
LEGEND
Erosion Potential Rank
0 - Negligible
1 - Slight
2 - Low
3 - Intermediate
4 - High
5 - Very High
6 - Extreme
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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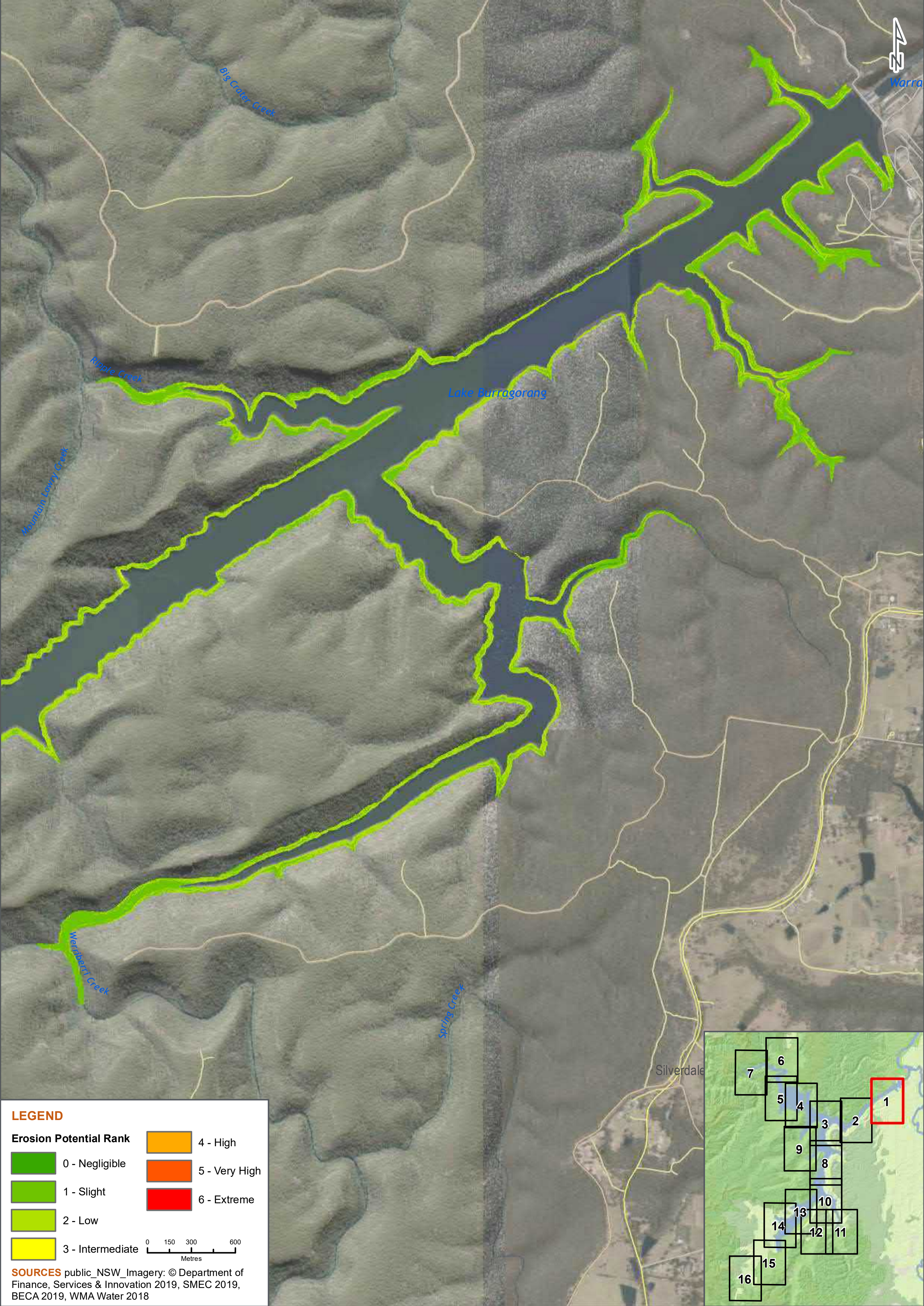
J.2 Erosion Hotspot Model – With Project Scenario

Table 28 Erosion Hotspot Tool Classifications for the With Project Scenario in upstream creeks / rivers

Erosion Potential Risk	20% AEP With Project		10% AEP With Project		5% AEP With Project		1% AEP With Project		PMF With Project	
	Area (m^2)	Percentage	Area (m^2)	Percentage	Area (m^2)	Percentage	Area (m^2)	Percentage	Area (m^2)	Percentage
0 – Negligible	1,016	0.0%	1,113	0.1%	757	0.0%	571	0.0%	426	0.0%
1 – Slight	25,859	1.0%	26,237	1.9%	406,124	22.9%	527,278	17.4%	2,118,040	26.8%
2 – Low	1,892,763	75.3%	1,022,644	74.4%	1,149,957	64.9%	2,019,997	66.7%	4,516,787	57.1%
3 – Intermediate	542,021	21.6%	281,318	20.5%	201,273	11.4%	448,140	14.8%	1,194,981	15.1%
4 – High	50,483	2.0%	43,211	3.1%	15,045	0.8%	34,317	1.1%	74,404	0.9%
5 – Very High	-	0.0%	-	0.0%	-	0.0%	-	0.0%	-	0.0%
6 - Extreme	-	0.0%	-	0.0%	-	0.0%	-	0.0%	-	0.0%
Total Area (m^2)	2,512,142		1,374,523		1,773,156		3,030,303		7,904,638	

Table 29 Erosion Hotspot Tool Classifications for the With Project Scenario in Lake Burragorang

Erosion Potential Risk	20% AEP With Project		10% AEP With Project		5% AEP With Project		1% AEP With Project		PMF Existing	
	Area (m^2)	Percentage	Area (m^2)	Percentage	Area (m^2)	Percentage	Area (m^2)	Percentage	Area (m^2)	Percentage
0 – Negligible	1,218	0.0%	2,570	0.1%	6,634	0.1%	7,634	0.1%	7,514	0.0%
1 – Slight	65,106	1.5%	80,510	2.2%	613,007	12.2%	818,907	11.5%	1,972,721	11.9%
2 – Low	2,321,971	52.1%	1,906,660	51.7%	3,220,566	64.2%	4,641,429	65.3%	10,568,117	64.0%
3 – Intermediate	2,005,274	45.0%	1,652,415	44.8%	1,174,420	23.4%	1,633,624	23.0%	3,954,430	24.0%
4 – High	64,156	1.4%	42,423	1.2%	2,789	0.1%	3,013	0.0%	7,907	0.0%
5 – Very High	-	0.0%	-	0.0%	-	0.0%	-	0.0%	-	0.0%
6 - Extreme	-	0.0%	-	0.0%	-	0.0%	-	0.0%	-	0.0%
Total Area (m^2)	4,457,725		3,684,578		5,017,416		7,104,607		16,510,689	



Warra
Big Crater Creek
Ripple Creek
Lake Burragorang
Mountain Lowry Creek
Werriberri Creek
Spring Creek
Silverdale
LEGEND
Erosion Potential Rank
0 - Negligible
1 - Slight
2 - Low
3 - Intermediate
4 - High
5 - Very High
6 - Extreme
0
150
300
600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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Mountain Lowry Creek
Gogongolly Creek
Lake Burragorang
LEGEND
Erosion Potential Rank
0 - Negligible
1 - Slight
2 - Low
3 - Intermediate
4 - High
5 - Very High
6 - Extreme
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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Pocket Creek
Gogongolly Creek
Lake B
LEGEND
Erosion Potential Rank
0 - Negligible
1 - Slight
2 - Low
3 - Intermediate
4 - High
5 - Very High
6 - Extreme
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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Pearces Mountain Gully
Pearces Creek
Lake Burragorang
Popes Creek
N
LEGEND
Erosion Potential Rank
0 - Negligible
1 - Slight
2 - Low
3 - Intermediate
4 - High
5 - Very High
6 - Extreme
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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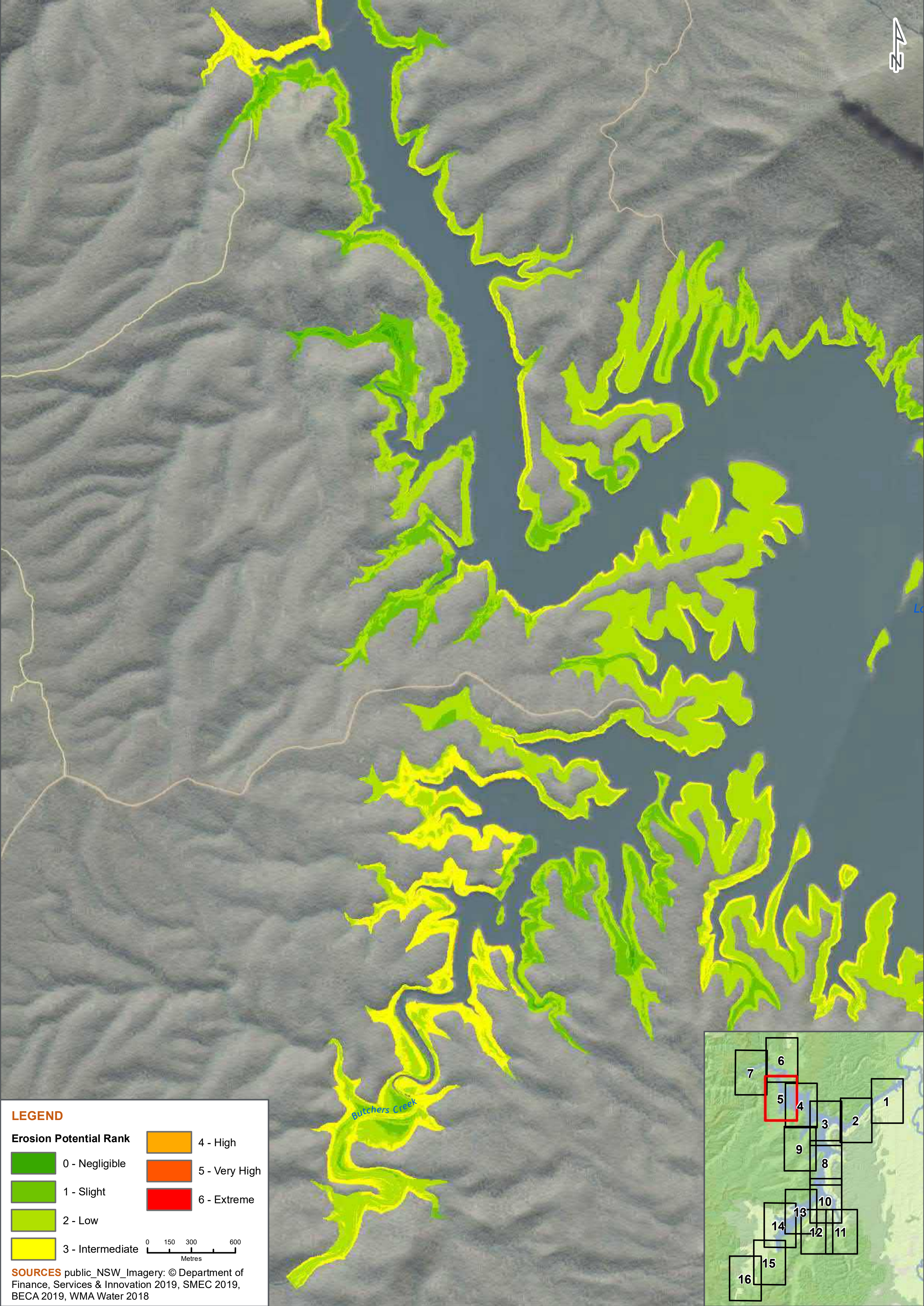
Butchers Creek
LEGEND
Erosion Potential Rank
0 - Negligible
1 - Slight
2 - Low
3 - Intermediate
4 - High
5 - Very High
6 - Extreme
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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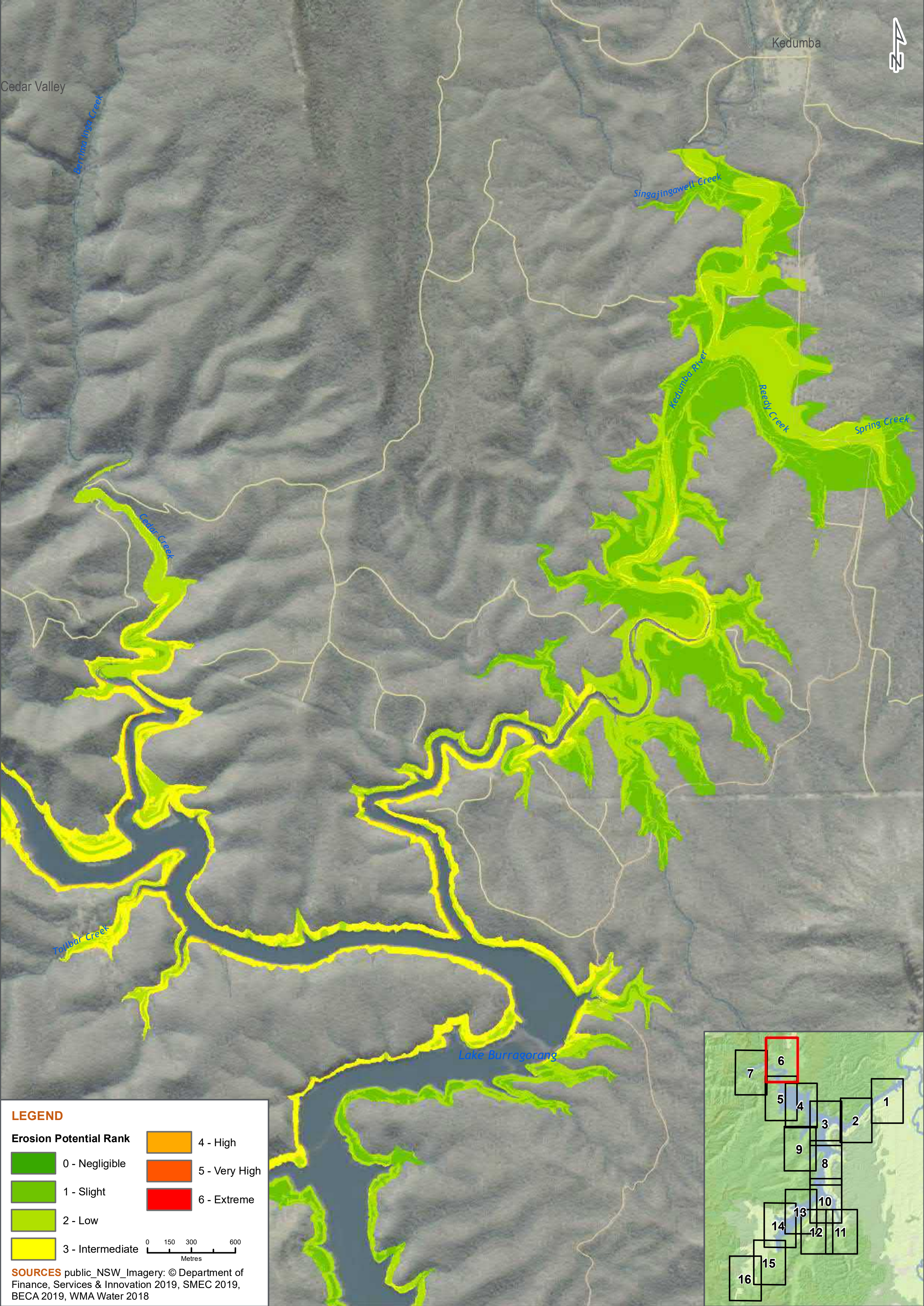
Kedumba
Cedar Valley
Bermalonga Creek
Singajingawell Creek
Kedumba River
Reedy Creek
Spring Creek
Cedar Creek
Tollbar Creek
Lake Burragorang
LEGEND
Erosion Potential Rank
0 - Negligible
1 - Slight
2 - Low
3 - Intermediate
4 - High
5 - Very High
6 - Extreme
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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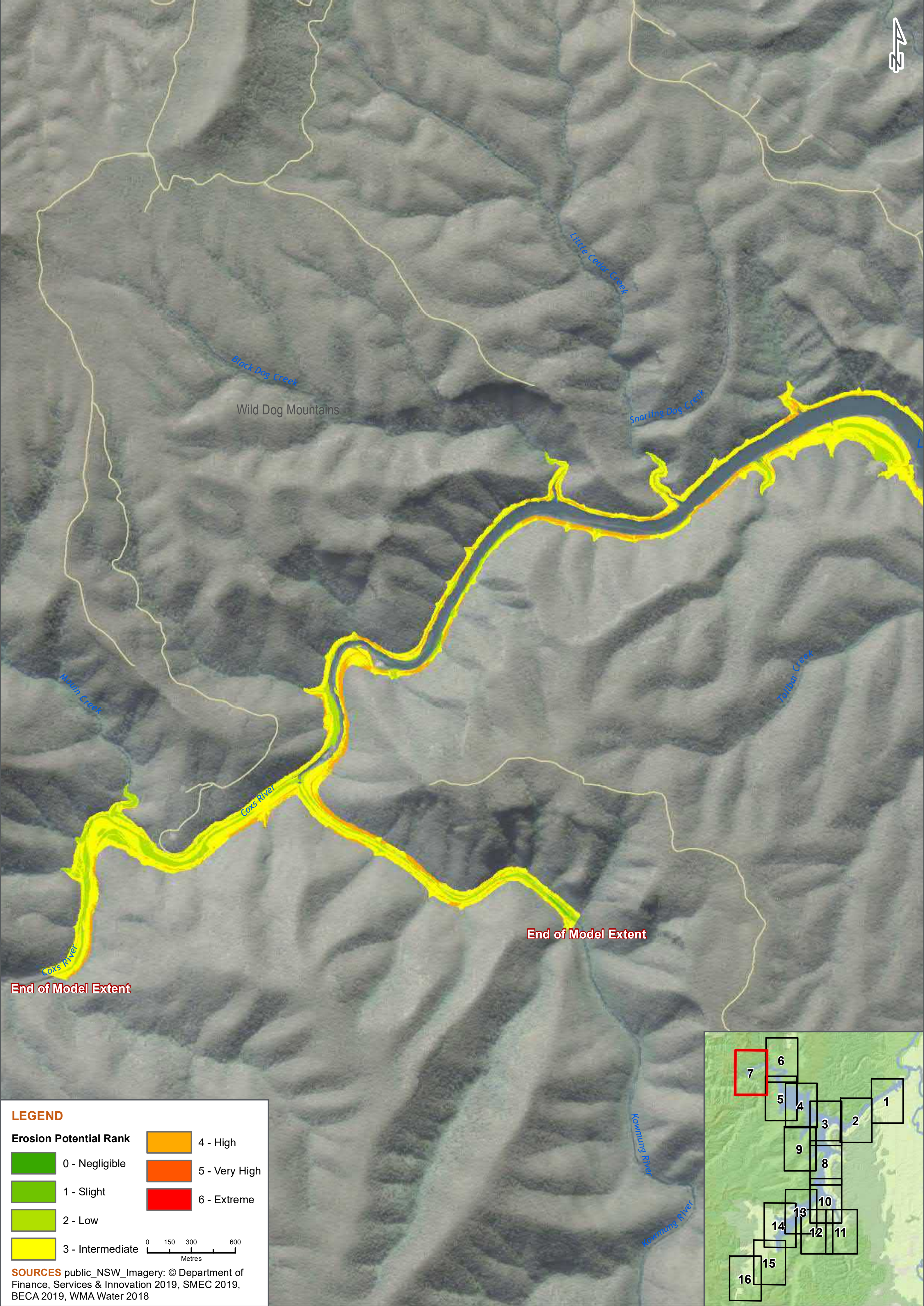

Little Cedar Creek
Black Dog Creek
Wild Dog Mountains
Snarling Dog Creek
Tollbar Creek
Moun Creek
Coxs River
Coxs River
End of Model Extent
End of Model Extent
Kowmung River
Kowmung River
7
6
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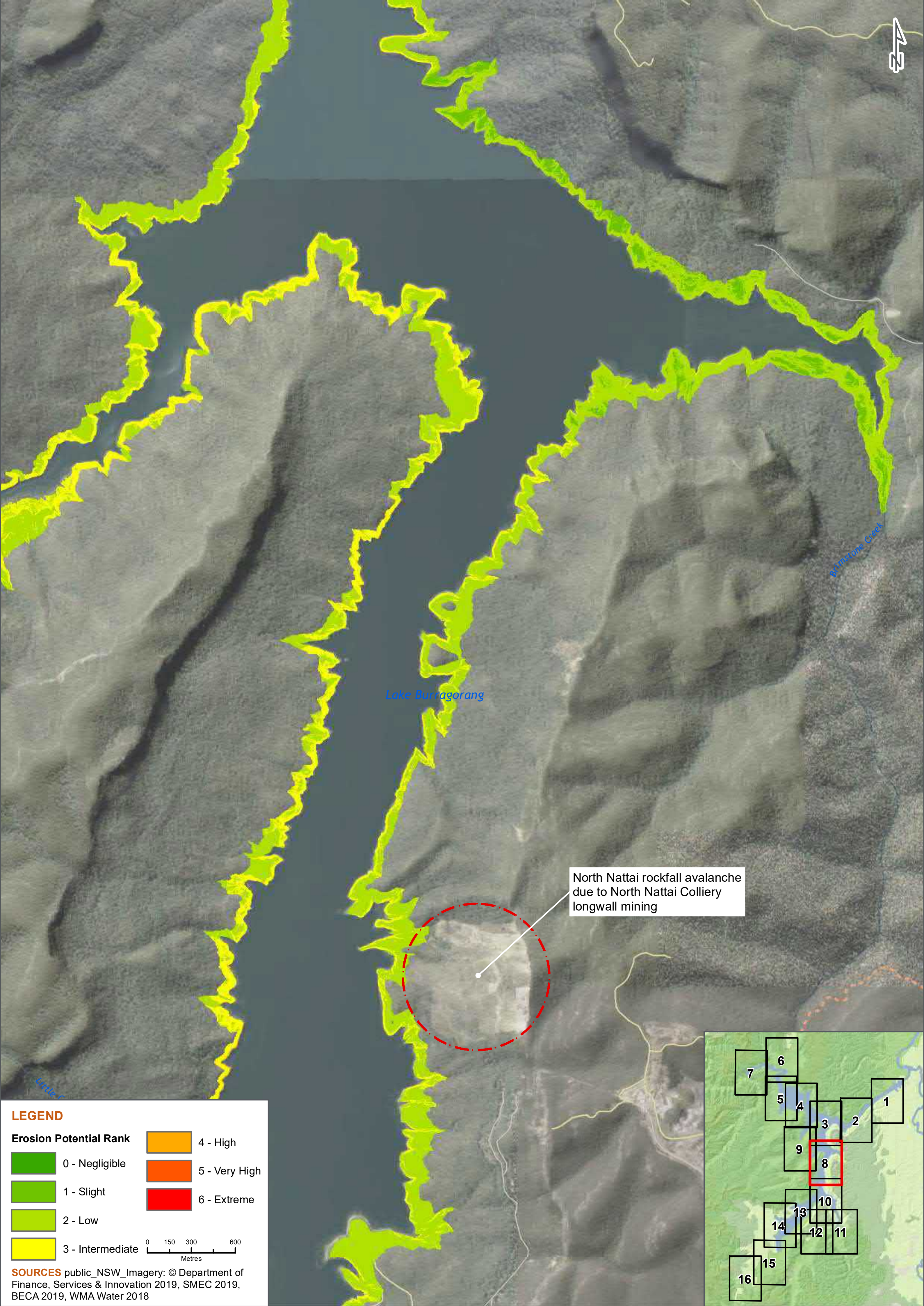
LEGEND
Erosion Potential Rank
0 - Negligible
1 - Slight
2 - Low
3 - Intermediate
4 - High
5 - Very High
6 - Extreme
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018



North Nattai rockfall avalanche due to North Nattai Colliery longwall mining
Lake Burragorang
LEGEND
Erosion Potential Rank
0 - Negligible
1 - Slight
2 - Low
3 - Intermediate
4 - High
5 - Very High
6 - Extreme
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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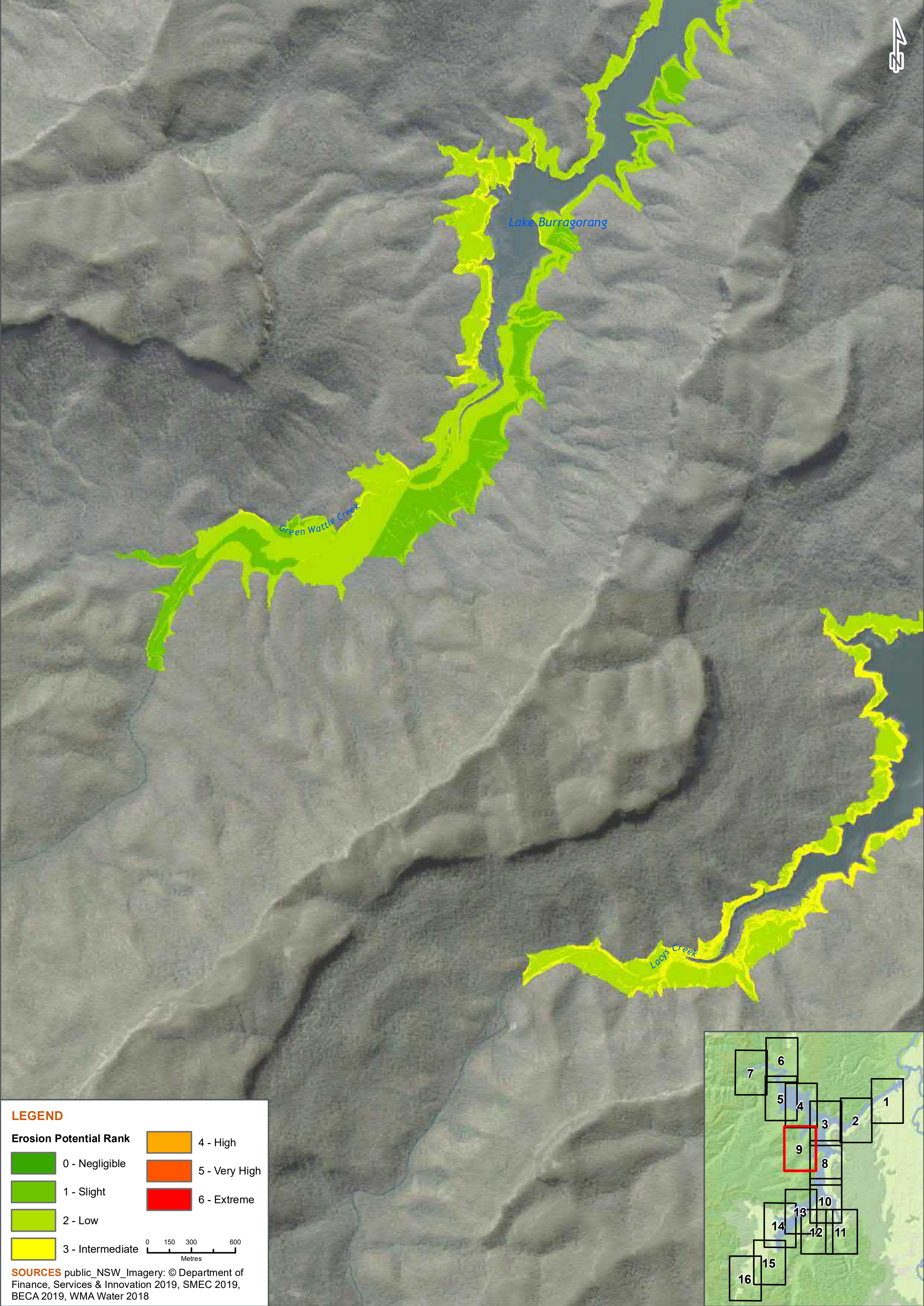
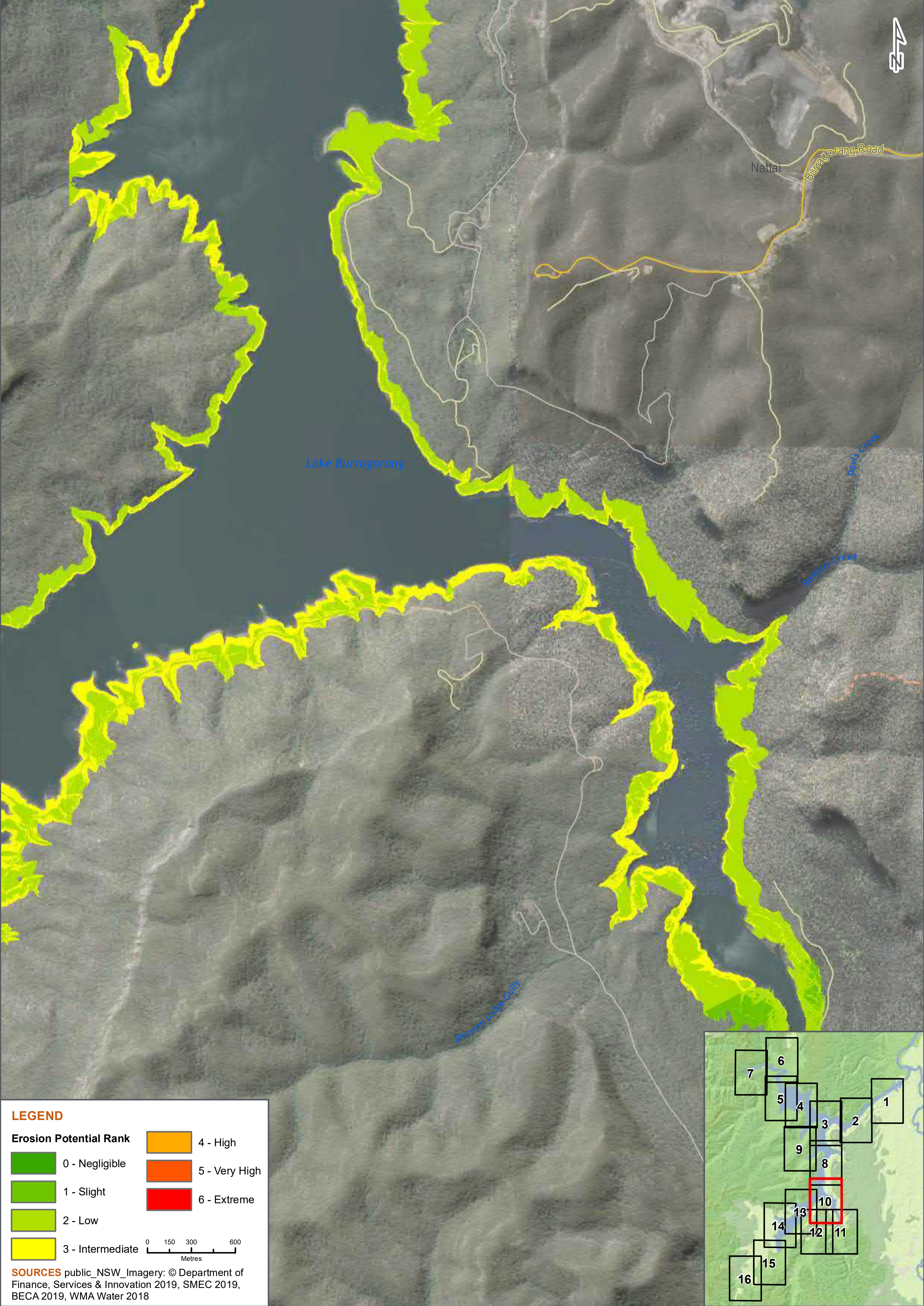

Lake Burragorang
Green Wattle Creek
Lacys Creek
LEGEND
Erosion Potential Rank
0 - Negligible
1 - Slight
2 - Low
3 - Intermediate
4 - High
5 - Very High
6 - Extreme
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16



Nattai
Burragorang Road
Lake Burragorang
Davis Creek
Rangers Creek
Blossom Lodge Gully
LEGEND
Erosion Potential Rank
0 - Negligible
1 - Slight
2 - Low
3 - Intermediate
4 - High
5 - Very High
6 - Extreme
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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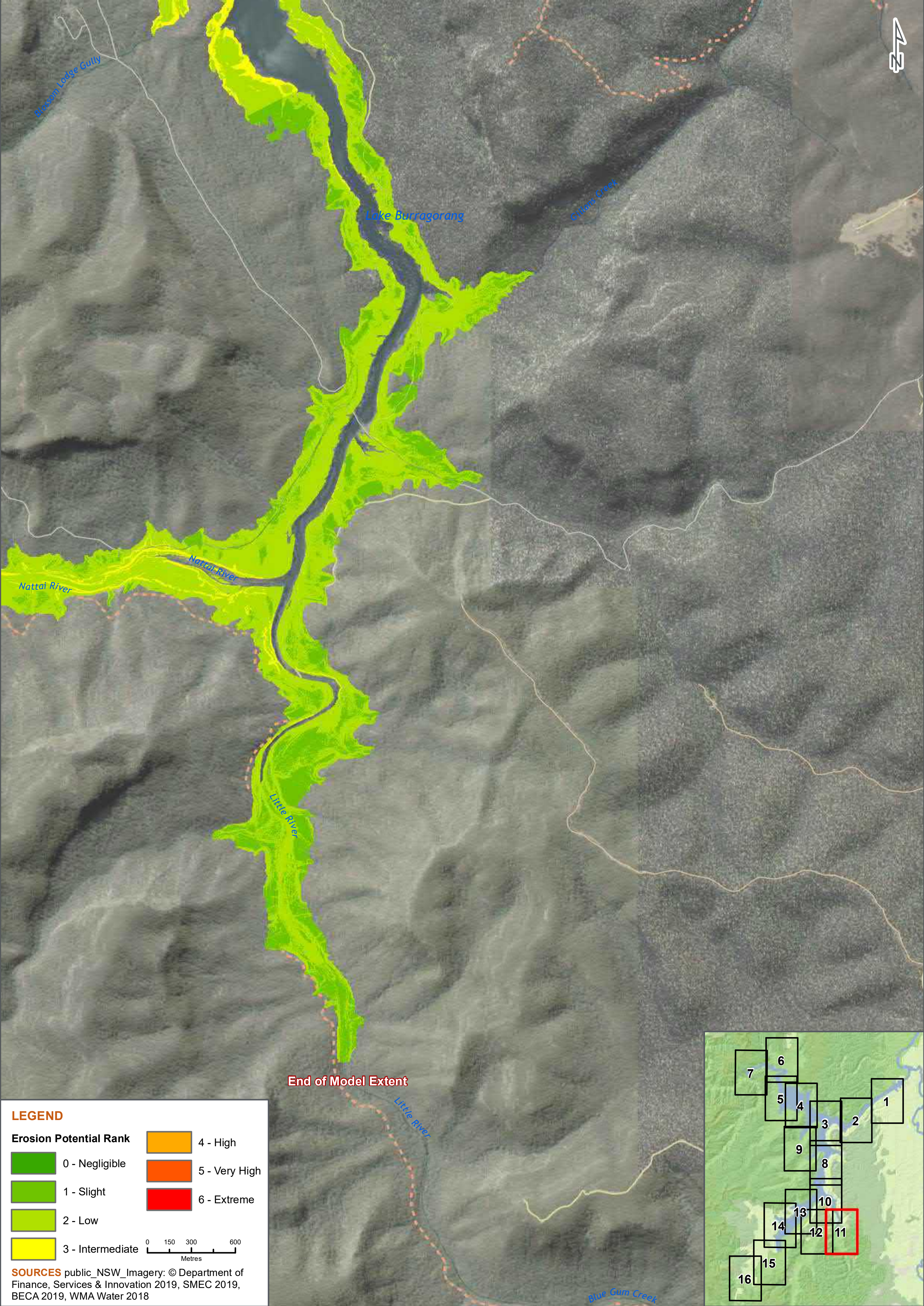
Blossom Lodge Gully
Lake Burragorang
Gillans Creek
Nattai River
Nattai River
Little River
End of Model Extent
Little River
Blue Gum Creek
LEGEND
Erosion Potential Rank
0 - Negligible
1 - Slight
2 - Low
3 - Intermediate
4 - High
5 - Very High
6 - Extreme
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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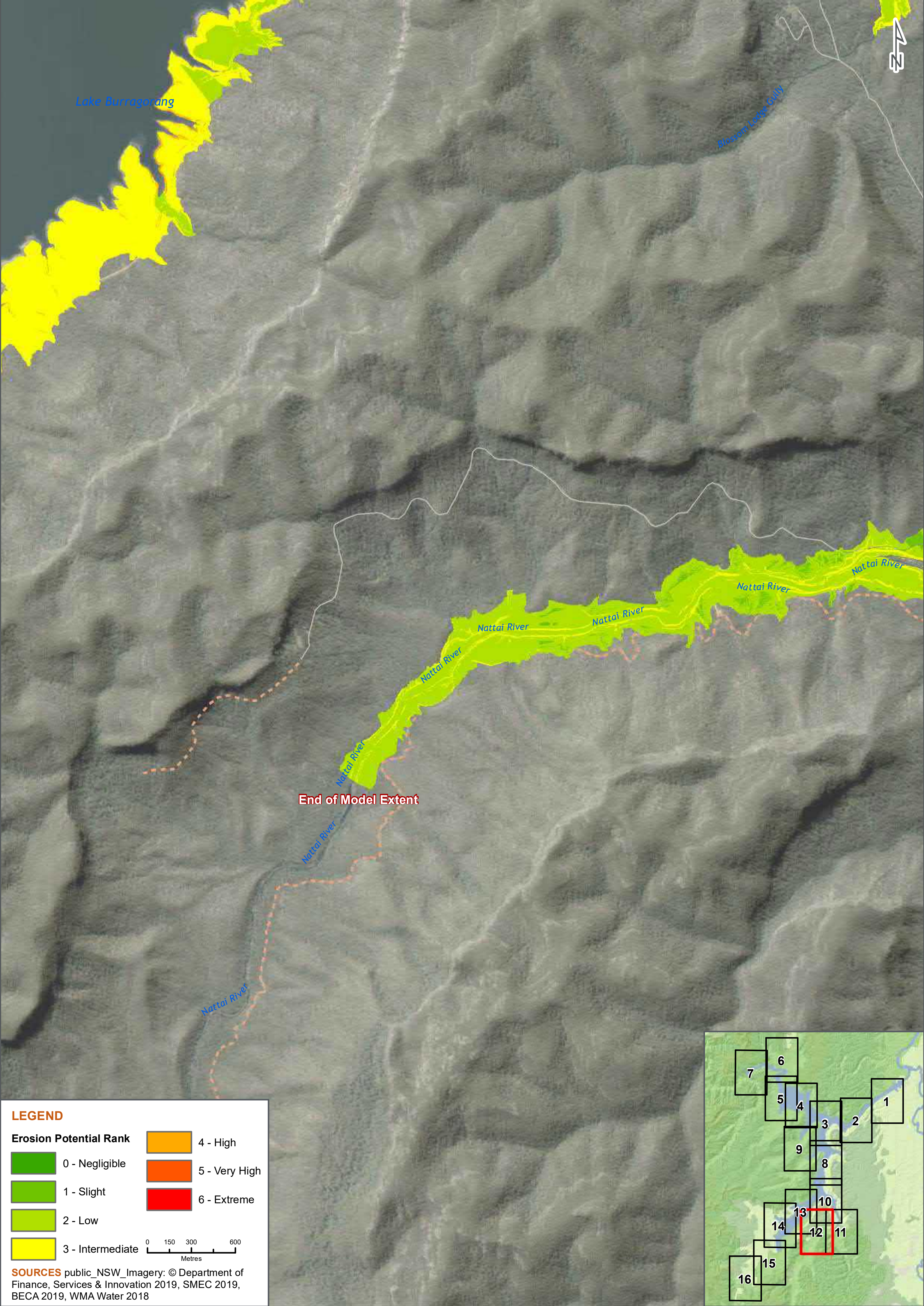

Lake Burragorang
Blossom Lodge Gully
Nattai River
End of Model Extent
LEGEND
Erosion Potential Rank
0 - Negligible
1 - Slight
2 - Low
3 - Intermediate
4 - High
5 - Very High
6 - Extreme
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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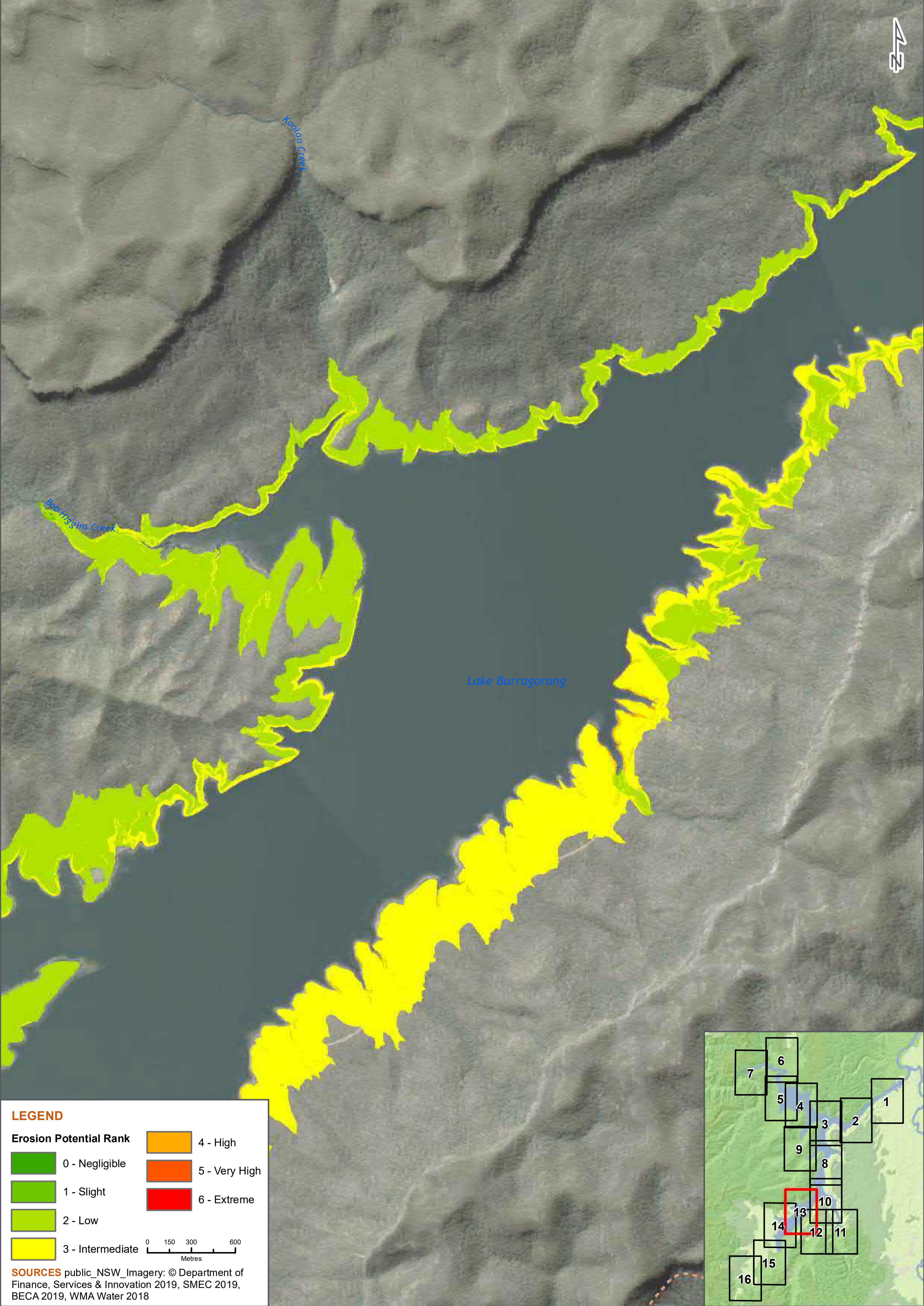

Kooloo Creek
Bob Higgins Creek
Lake Burragorang
LEGEND
Erosion Potential Rank
0 - Negligible
1 - Slight
2 - Low
3 - Intermediate
4 - High
5 - Very High
6 - Extreme
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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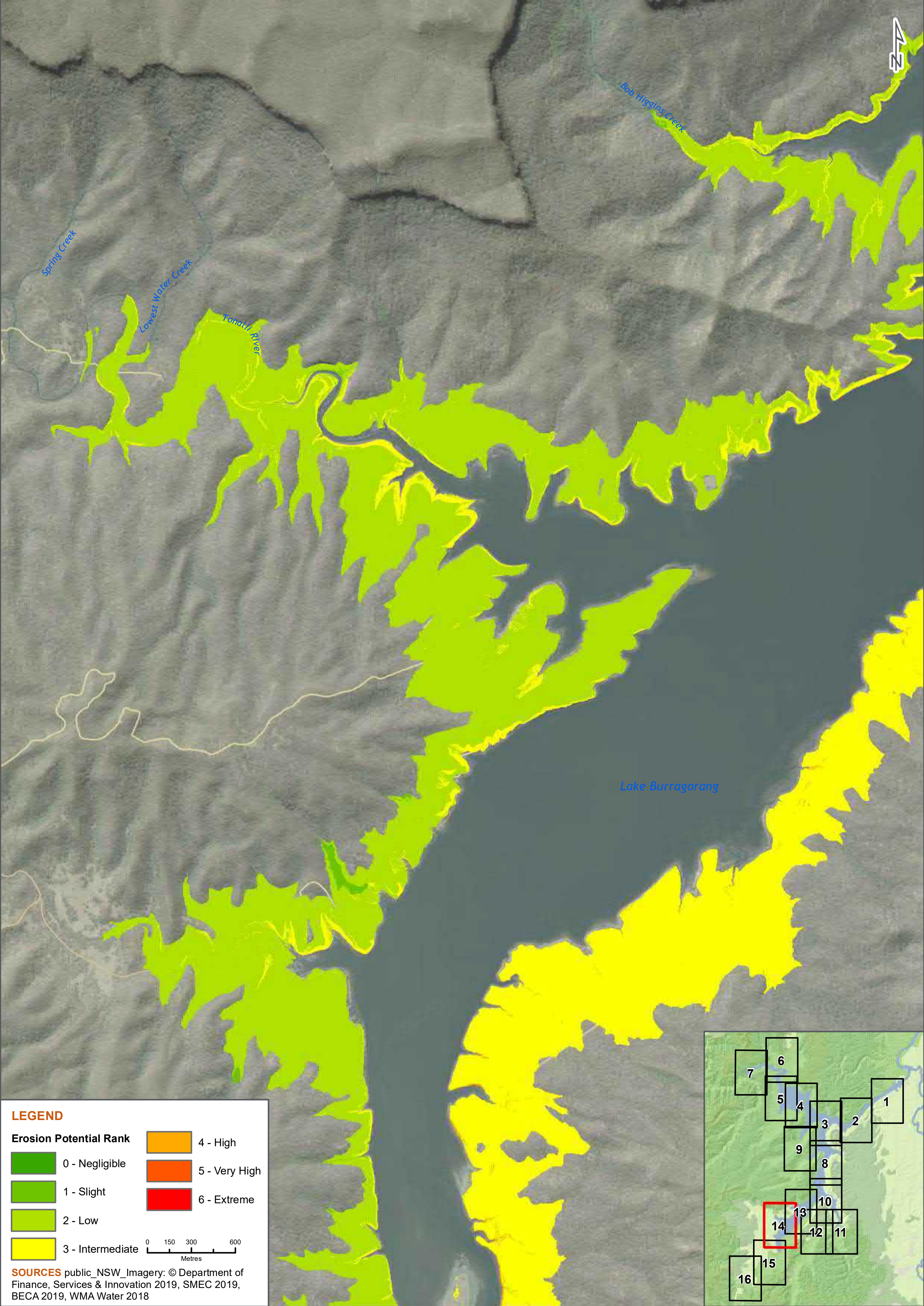
Bob Higgins Creek
Spring Creek
Lowest Water Creek
Tonalli River
Lake Burragorang
LEGEND
Erosion Potential Rank
0 - Negligible
1 - Slight
2 - Low
3 - Intermediate
4 - High
5 - Very High
6 - Extreme
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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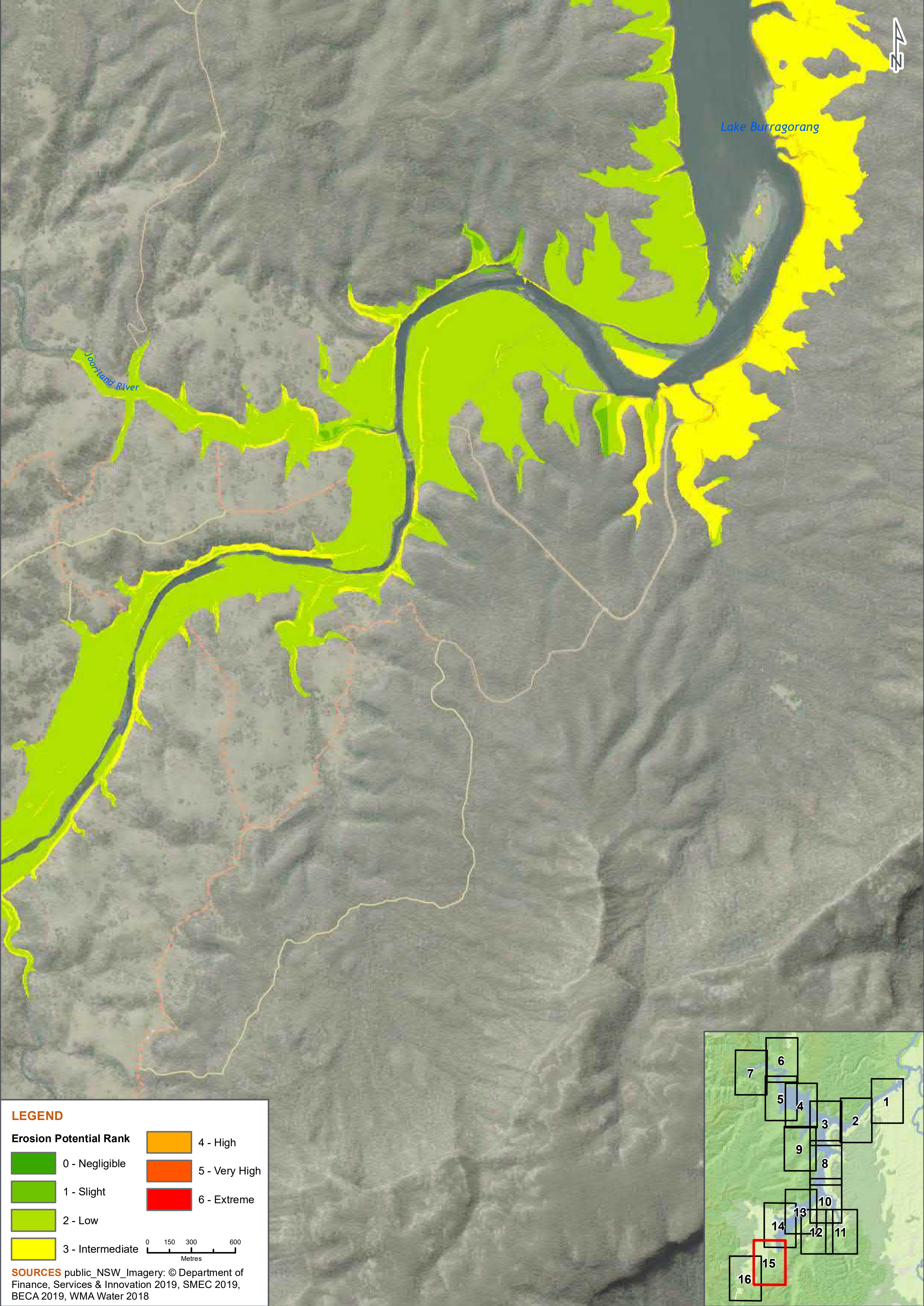

Lake Burragorang
Joorland River
LEGEND
Erosion Potential Rank
0 - Negligible
1 - Slight
2 - Low
3 - Intermediate
4 - High
5 - Very High
6 - Extreme
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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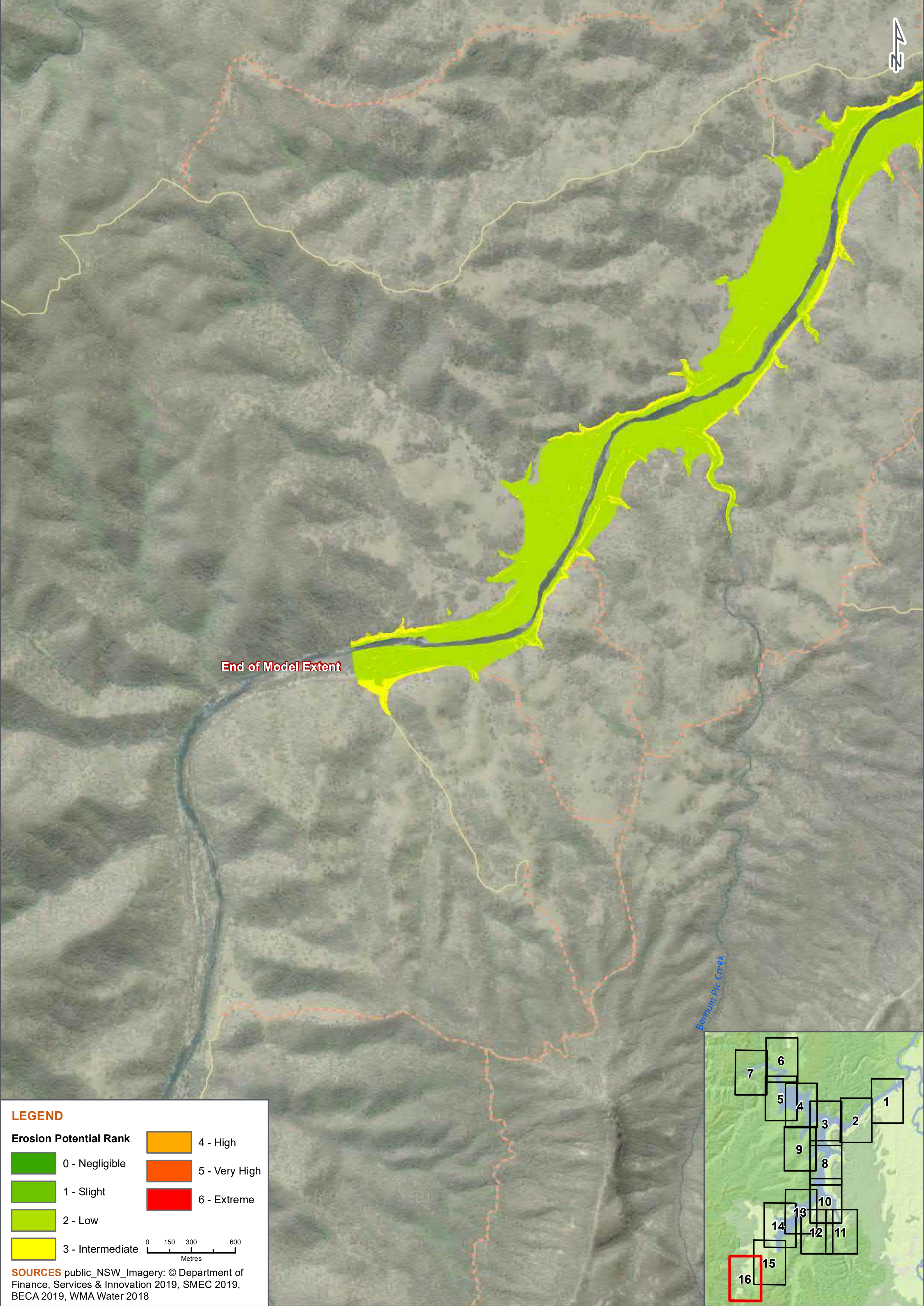

End of Model Extent
Bonnum Pic Creek
LEGEND
Erosion Potential Rank
0 - Negligible
1 - Slight
2 - Low
3 - Intermediate
4 - High
5 - Very High
6 - Extreme
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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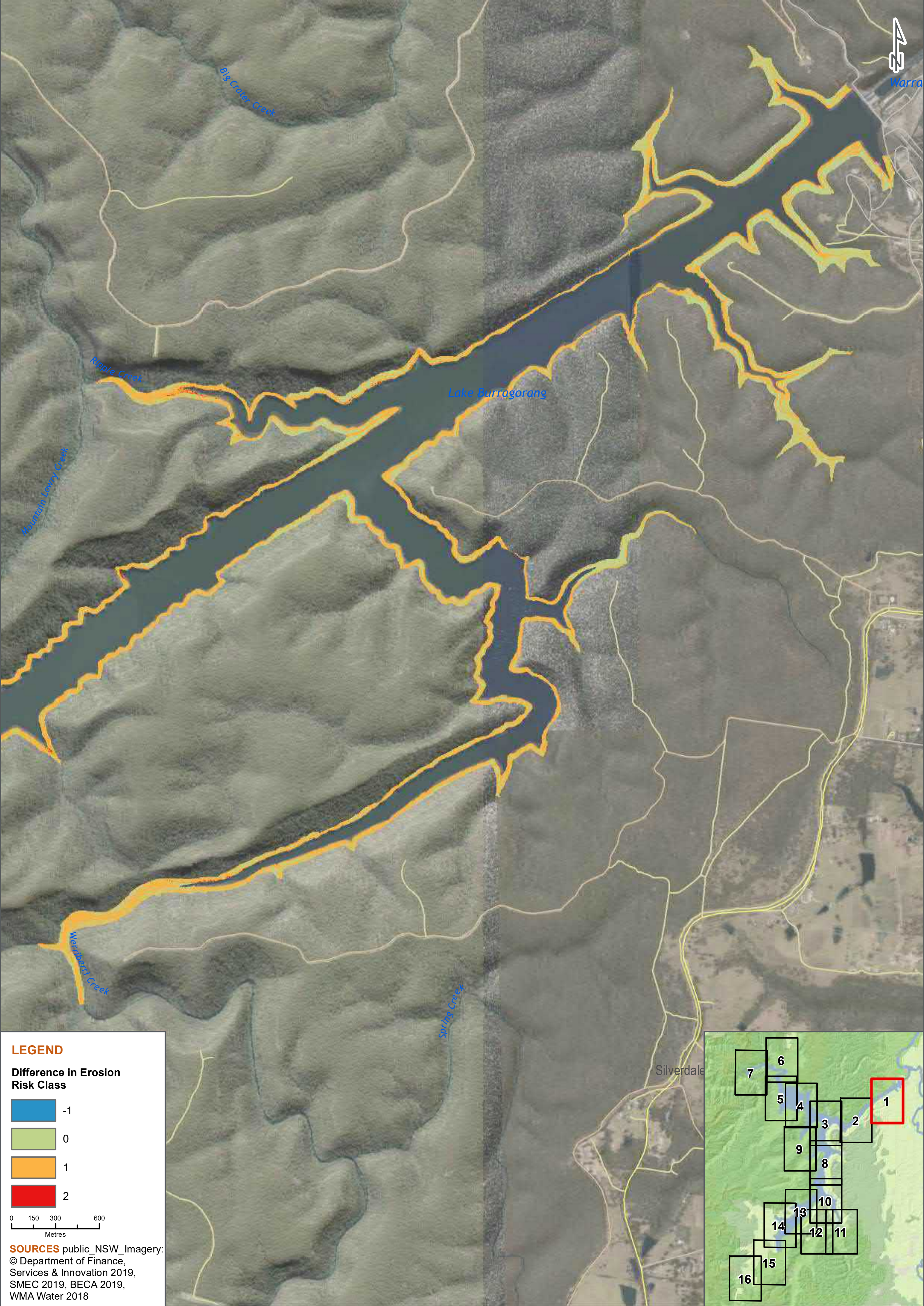
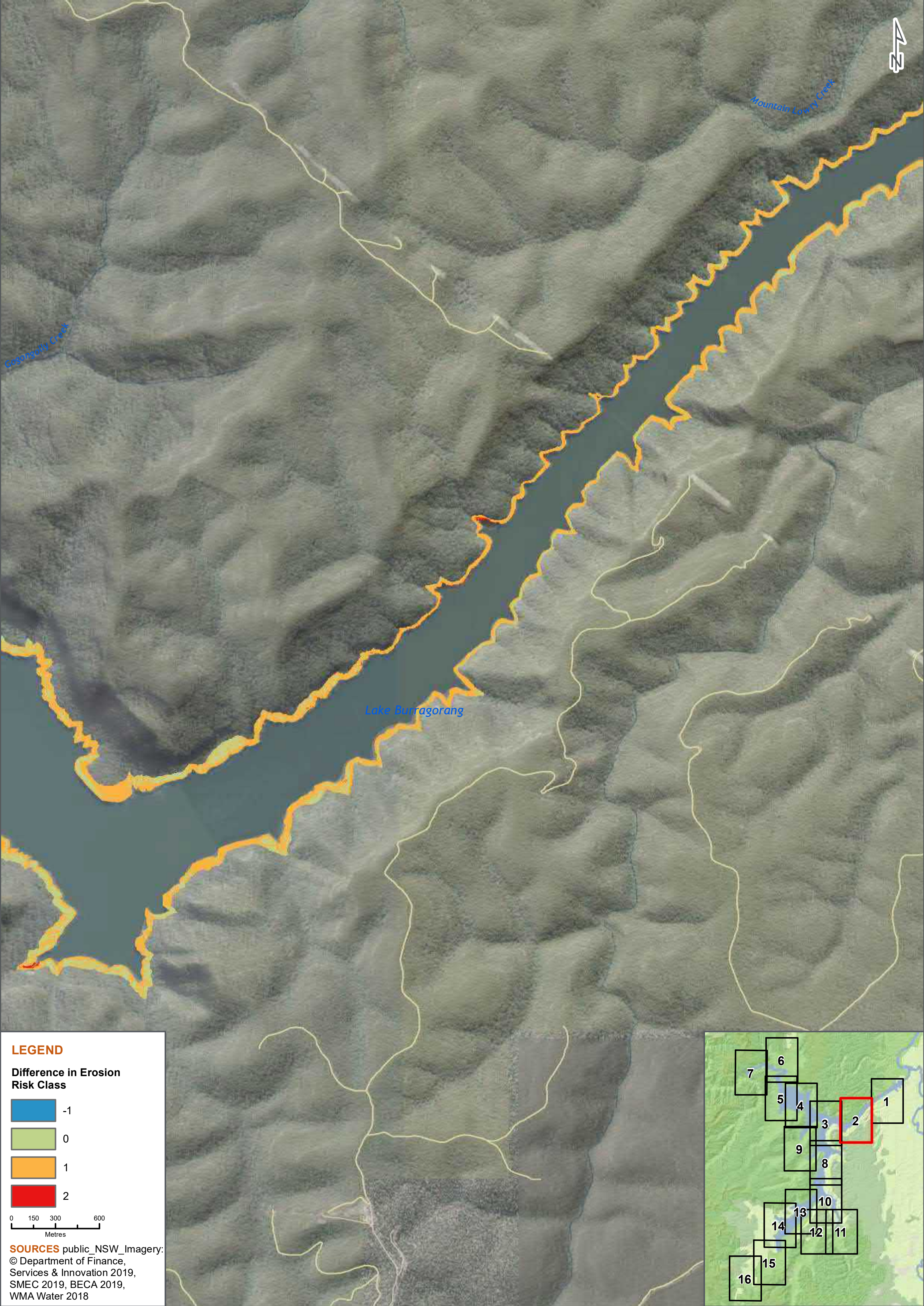
J3 Erosion Hotspot Model – Comparison between Existing and With Project Scenario



SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018


N
Mountain Lowry Creek
Gogongolly Creek
Lake Burragorang
LEGEND
Difference in Erosion Risk Class
-1
0
1
2
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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Pocket Creek
Gossingully Creek
Lake B
LEGEND
Difference in Erosion Risk Class
-1
0
1
2
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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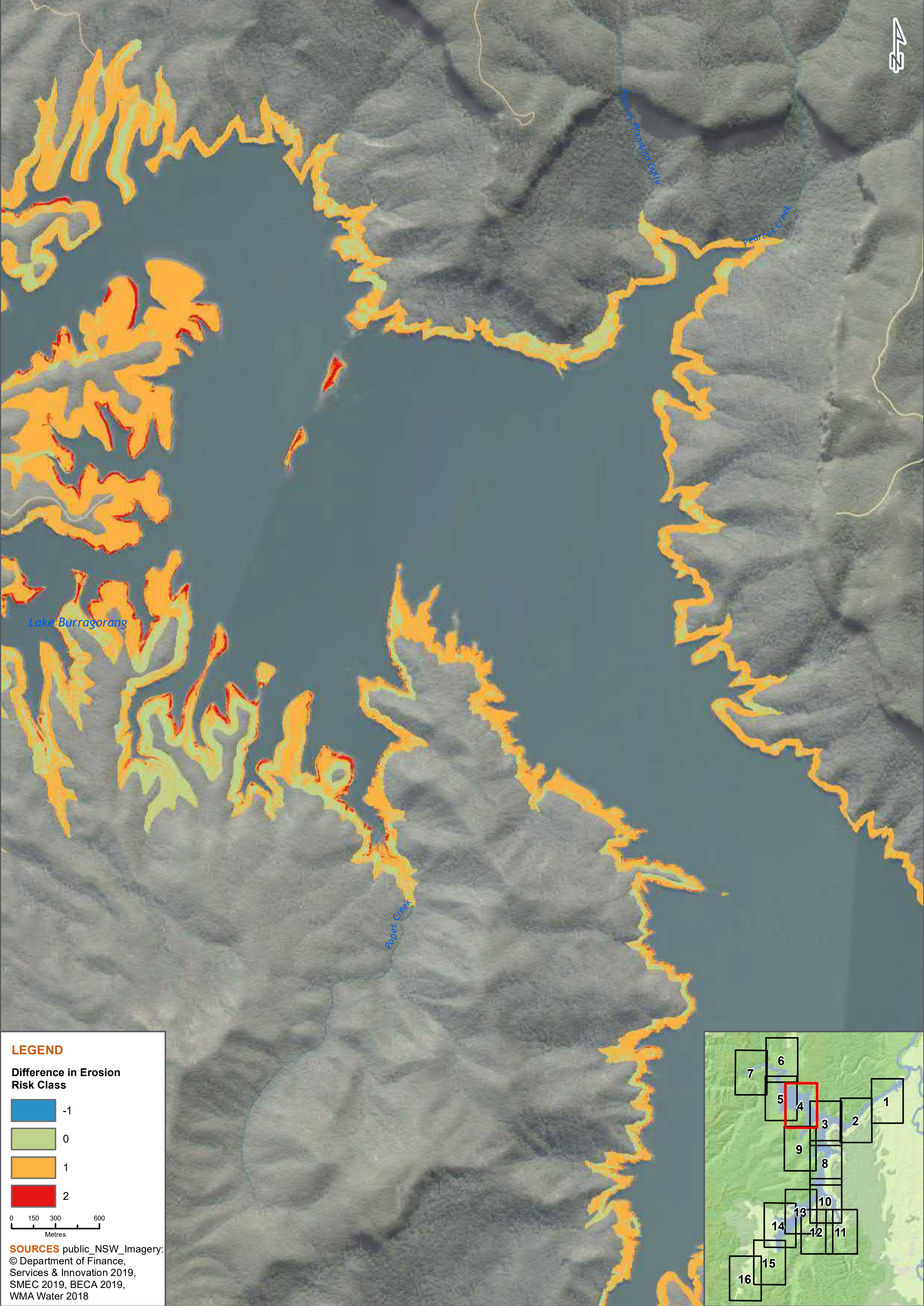
Pearces Mountain Gully
Pearces Creek
Lake Burragorang
Popes Creek
LEGEND
Difference in Erosion Risk Class
-1
0
1
2
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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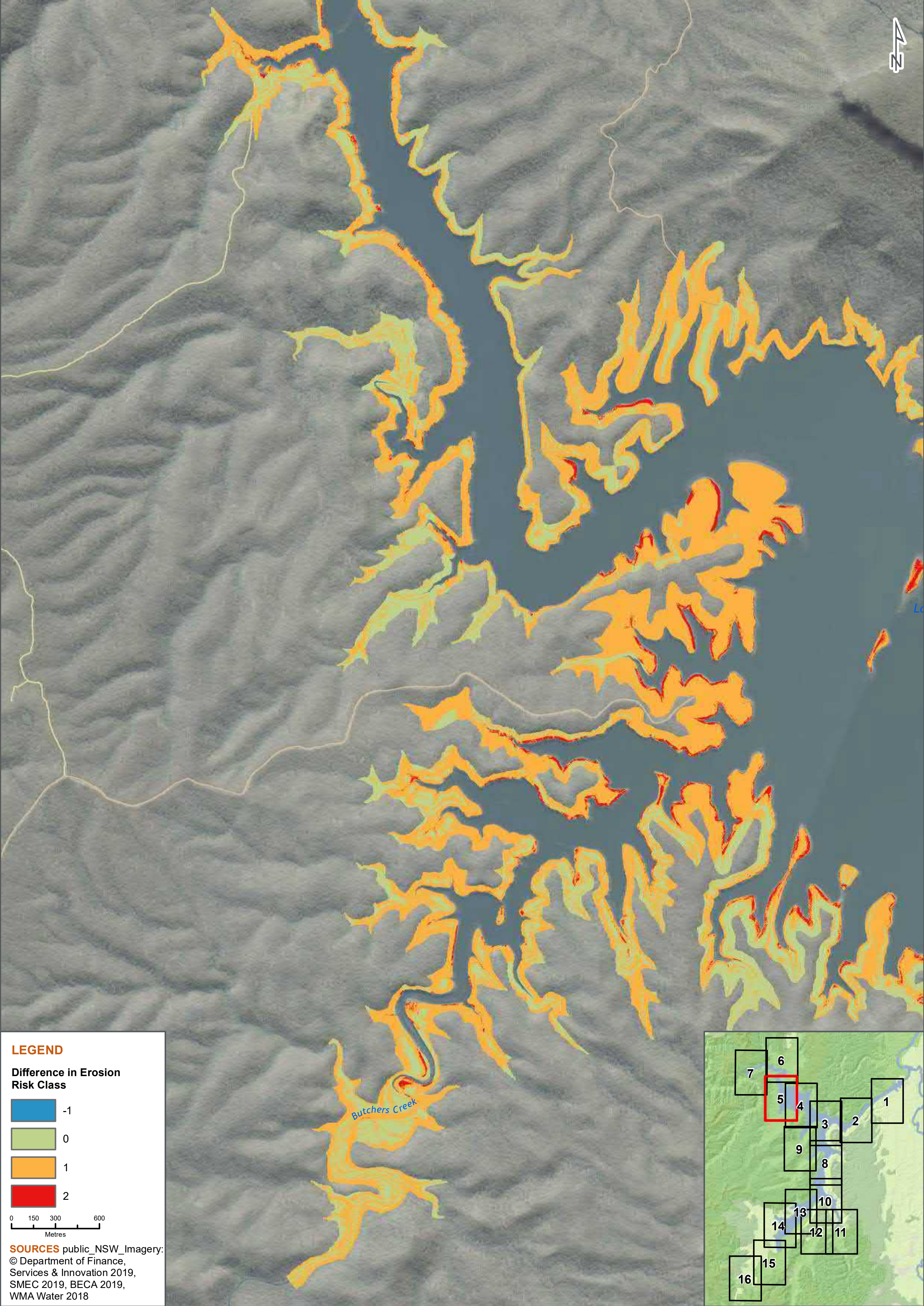

N
Butchers Creek
LEGEND
Difference in Erosion Risk Class
-1
0
1
2
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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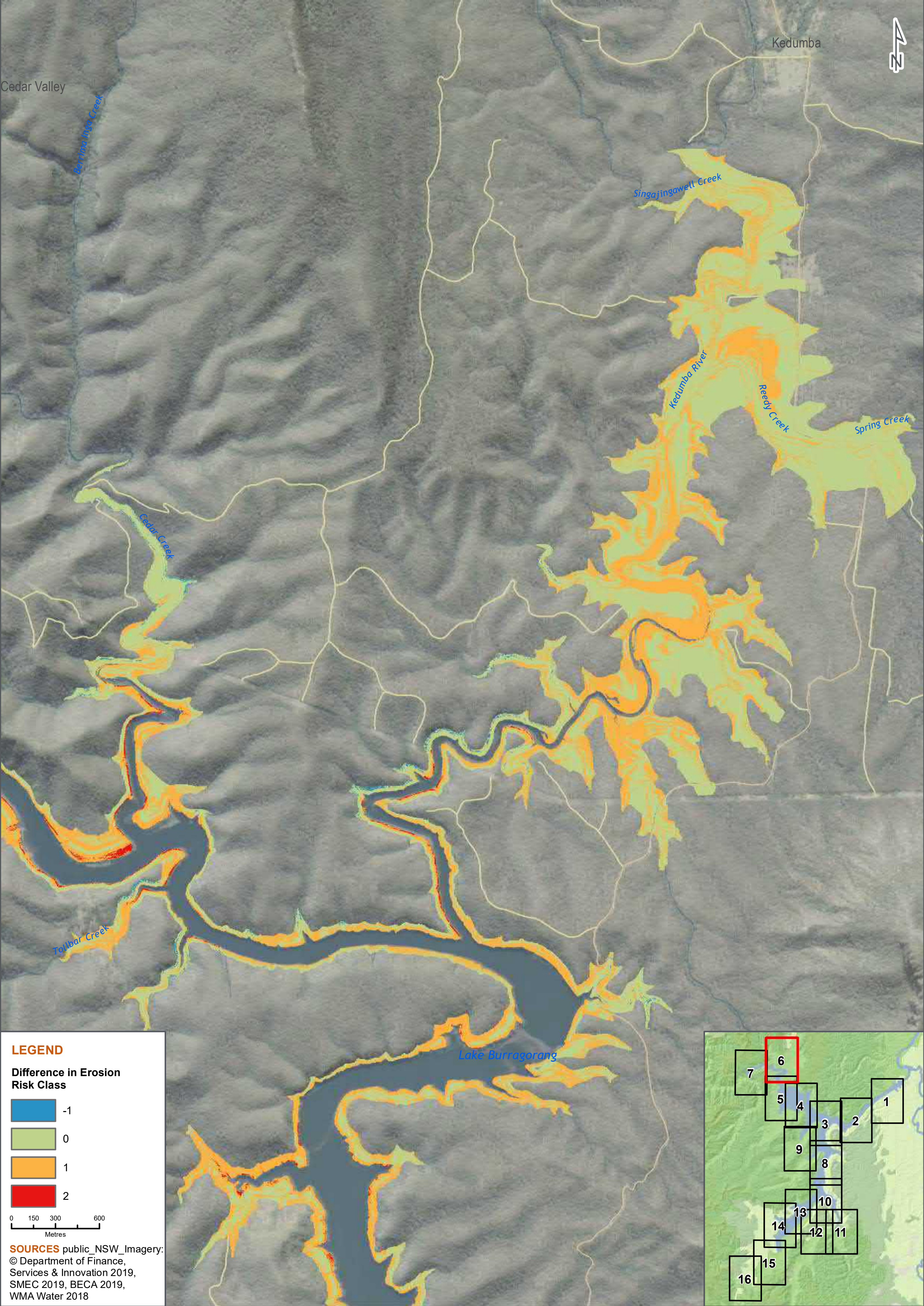
Kedumba
Cedar Valley
Singajingawell Creek
Kedumba River
Reedy Creek
Spring Creek
Cedar Creek
Tollbar Creek
Lake Burragorang
LEGEND
Difference in Erosion Risk Class
-1
0
1
2
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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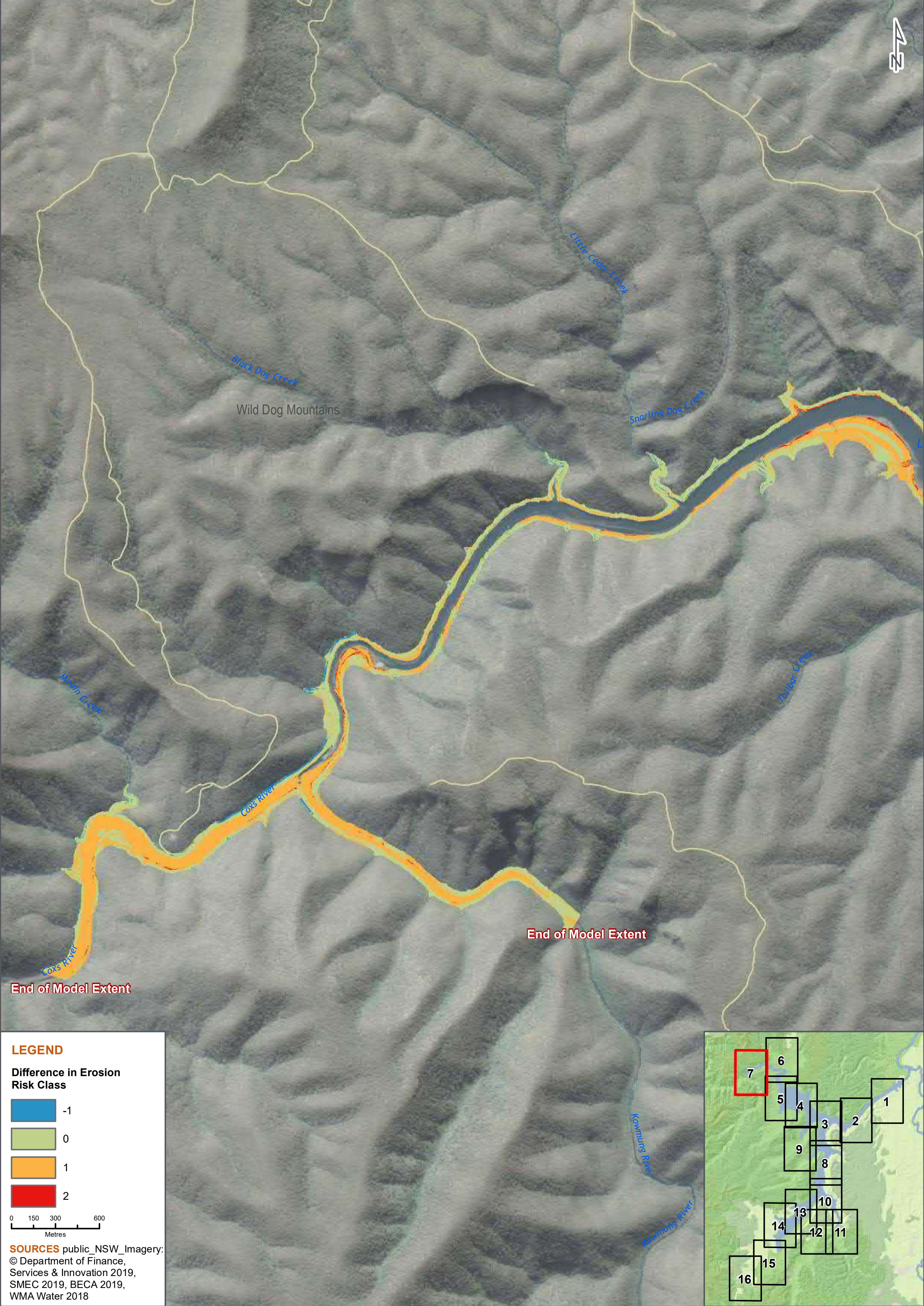

Little Cedar Creek
Black Dog Creek
Wild Dog Mountains
Snarling Dog Creek
Moun Creek
Tallbar Creek
Coxs River
End of Model Extent
Coxs River
End of Model Extent
Kowmung River
Kowmung River
LEGEND
Difference in Erosion Risk Class
-1
0
1
2
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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15
16


N
Lake Burragorang
Brimstone Creek
North Nattai rockfall avalanche due to North Nattai Colliery longwall mining
LEGEND
Difference in Erosion Risk Class
-1
0
1
2
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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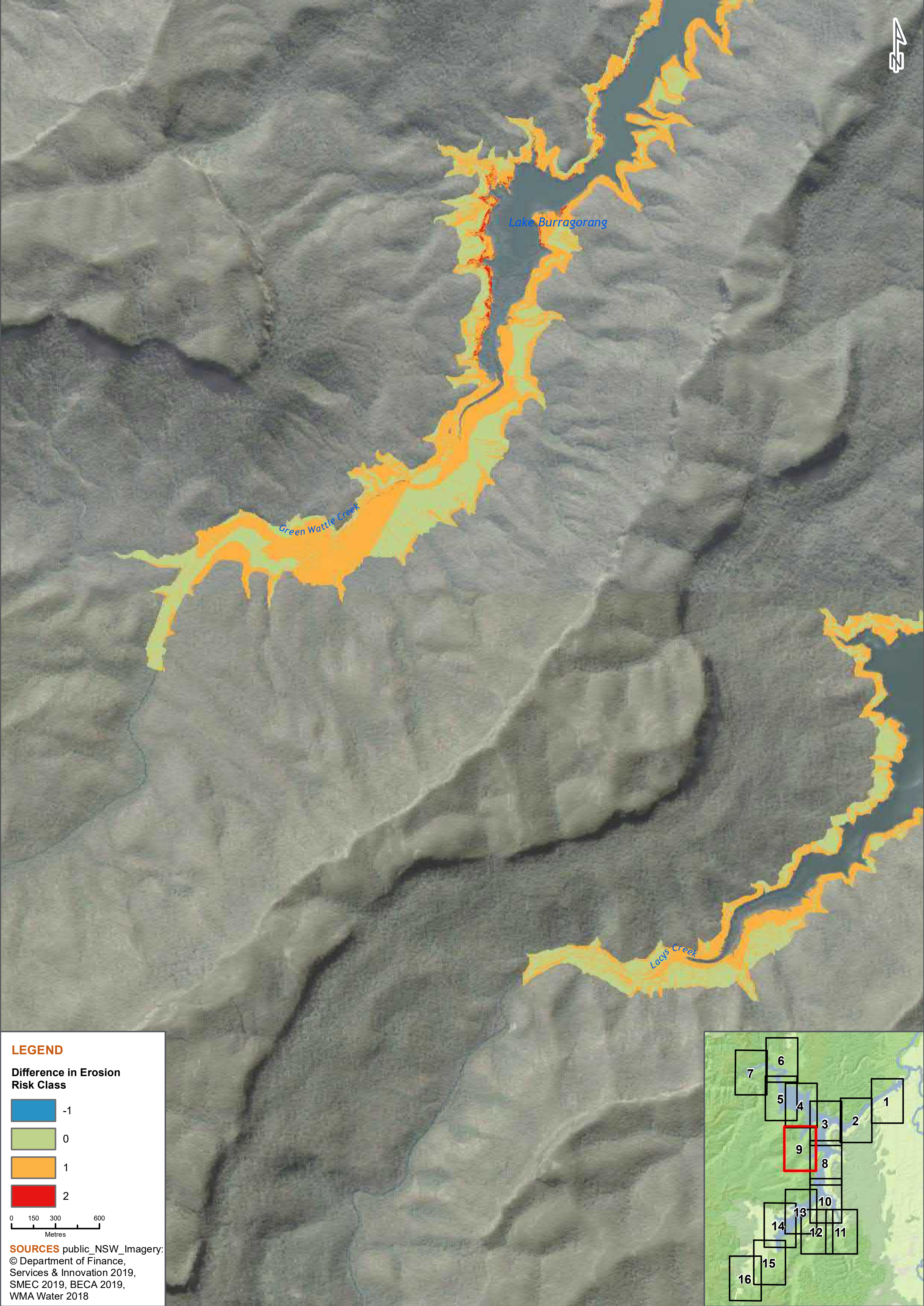

Lake Burragorang
Green Wattle Creek
Lacys Creek
LEGEND
Difference in Erosion Risk Class
-1
0
1
2
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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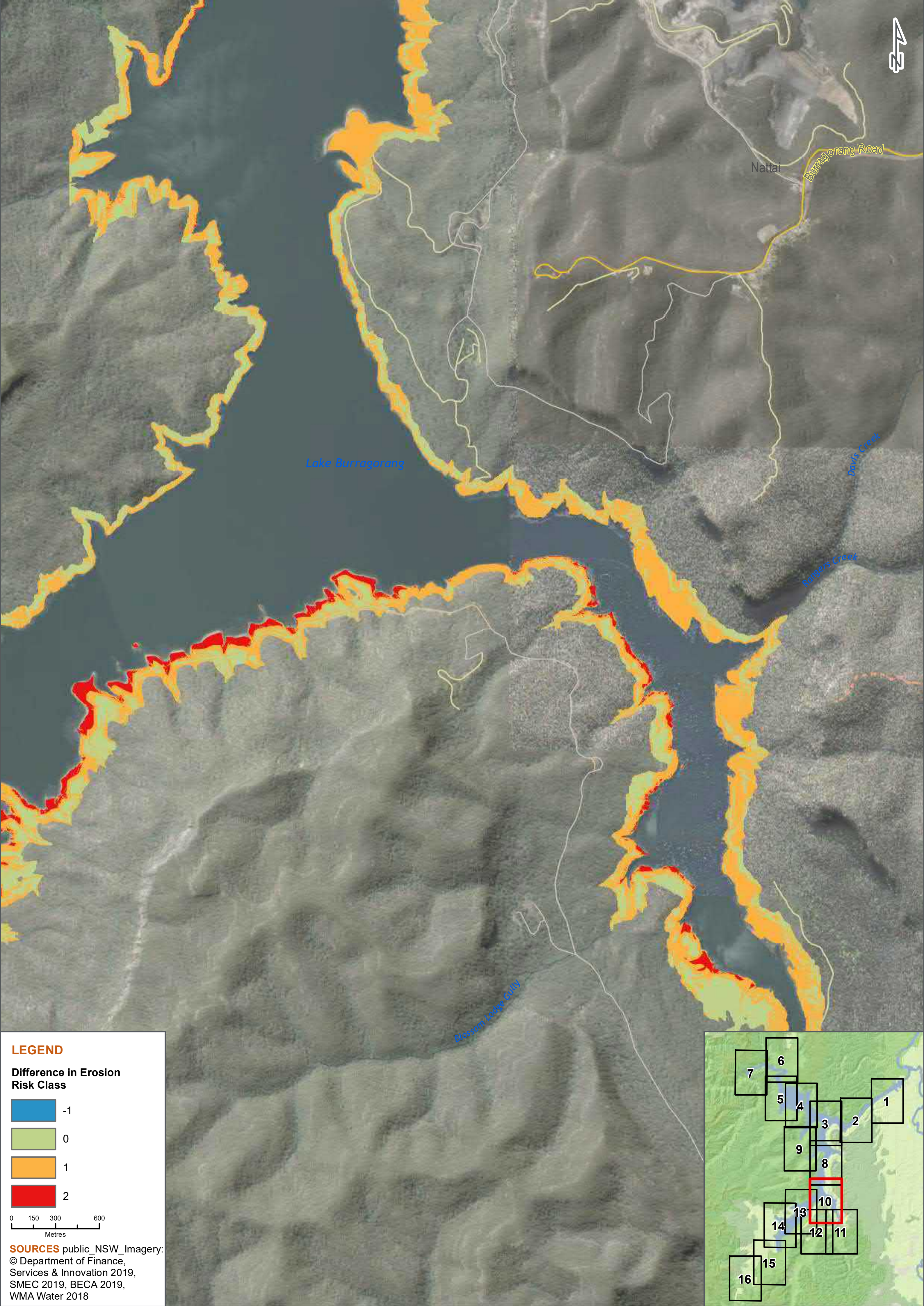

Nattai
Burragorang Road
Lake Burragorang
Davis Creek
Rangers Creek
Blossom Lodge Gully
LEGEND
Difference in Erosion Risk Class
-1
0
1
2
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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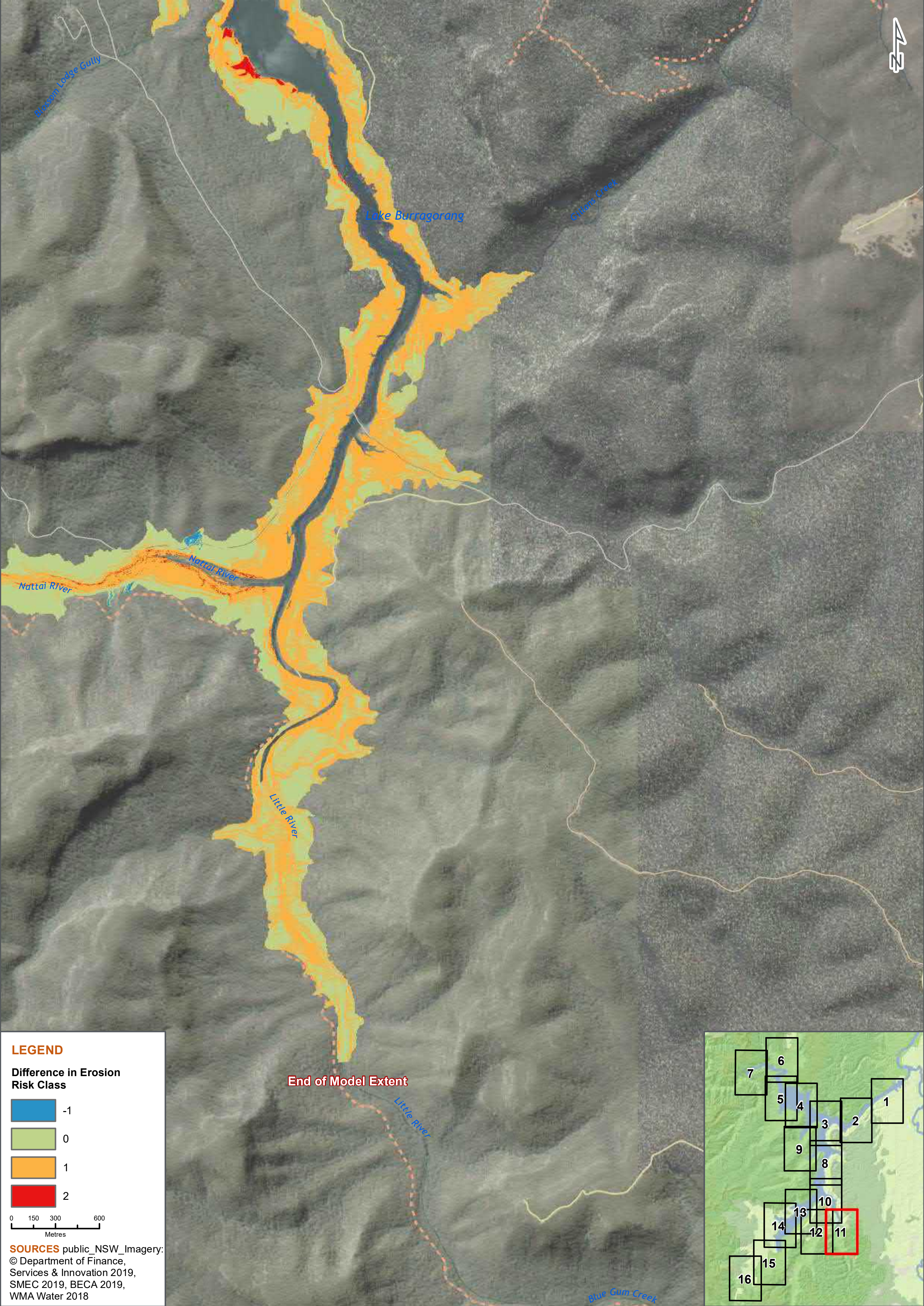
Blossom Lodge Gully
Lake Burragorang
Nattai River
Nattai River
Little River
End of Model Extent
Little River
Blue Gum Creek
LEGEND
Difference in Erosion Risk Class
-1
0
1
2
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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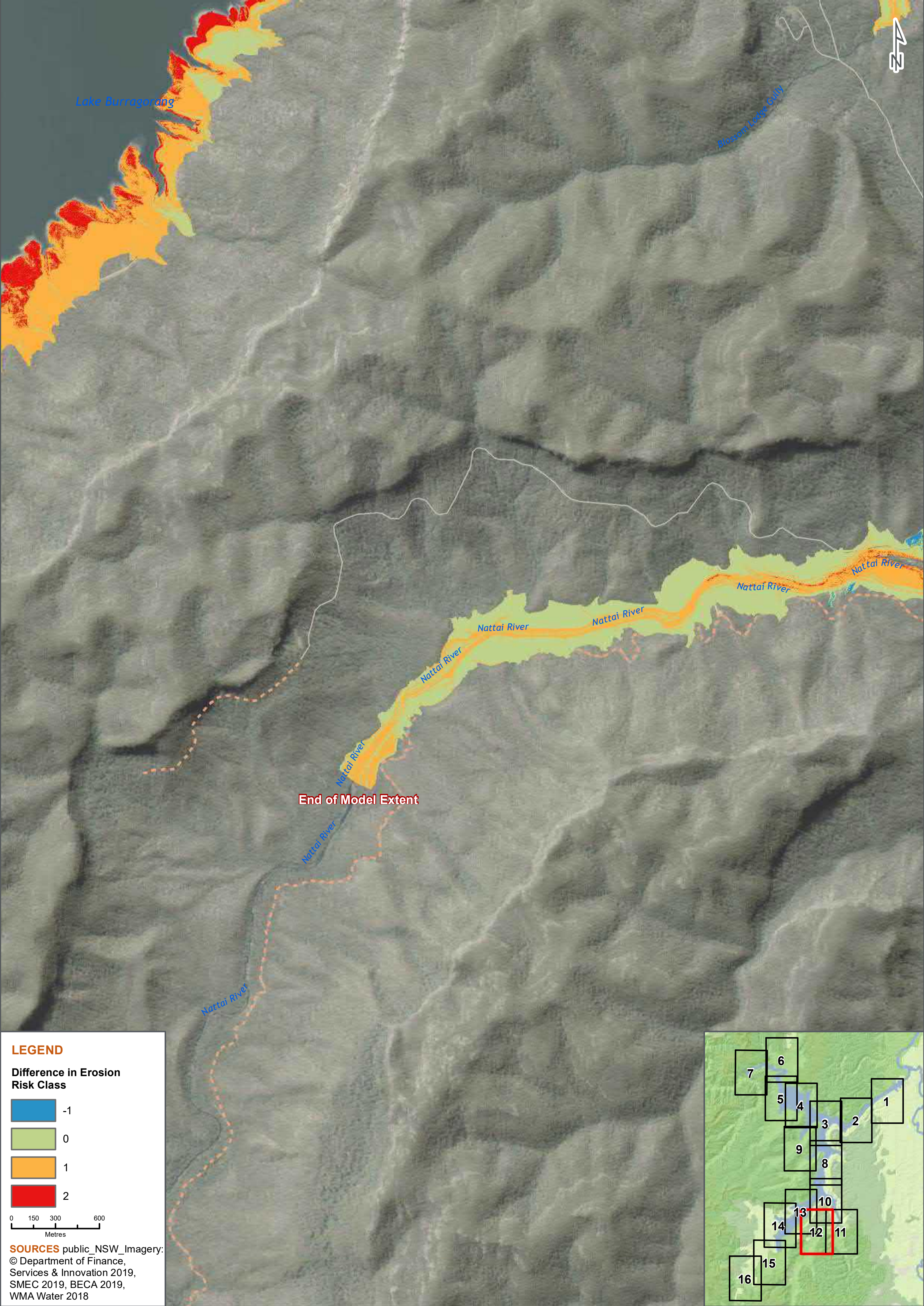
Lake Burragorang
Blossom Lodge Gully
Nattai River
Nattai River
Nattai River
Nattai River
Nattai River
Nattai River
End of Model Extent
Nattai River
Nattai River
LEGEND
Difference in Erosion Risk Class
-1
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1
2
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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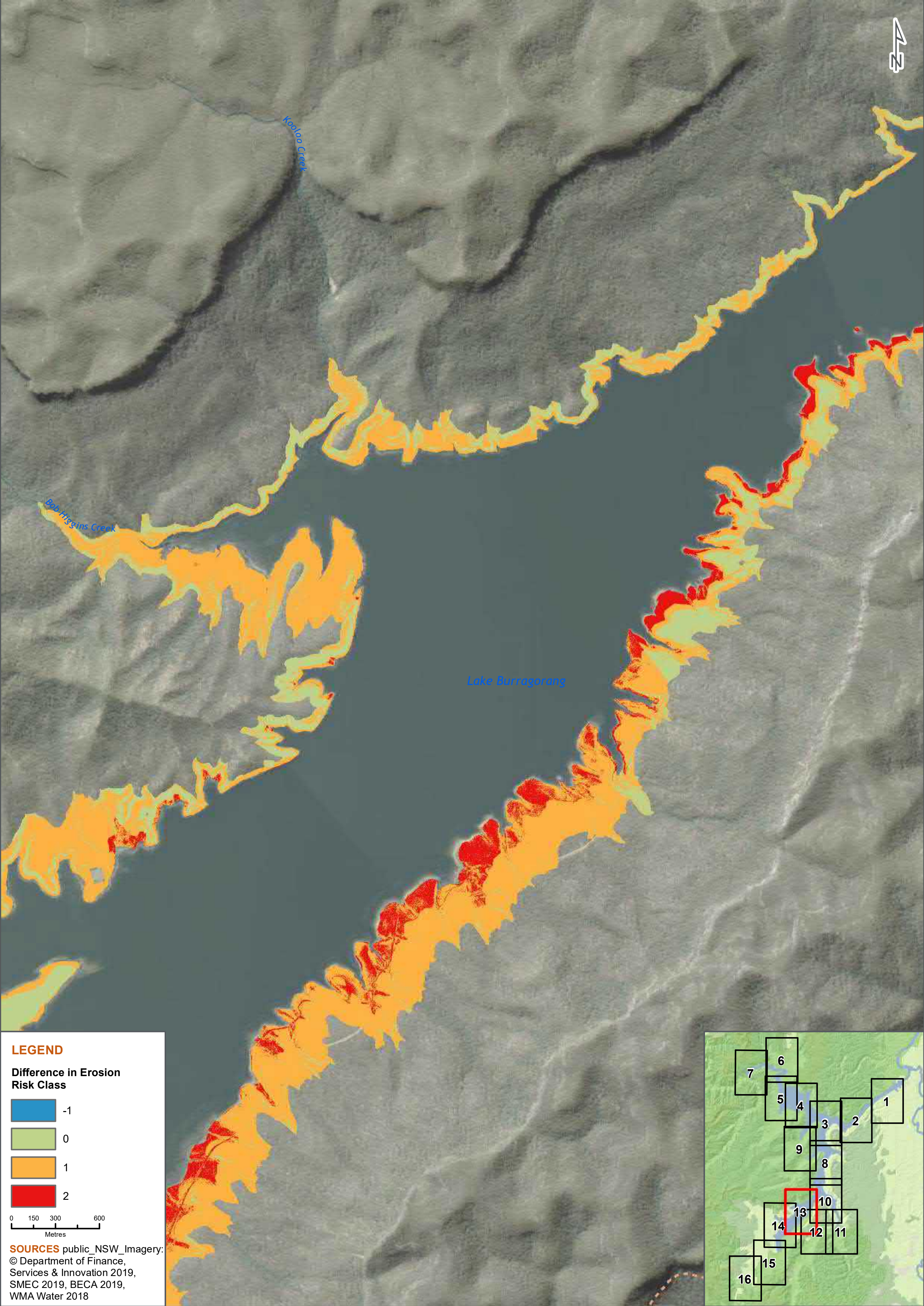

Kooloo Creek
Bob Higgins Creek
Lake Burragorang
LEGEND
Difference in Erosion Risk Class
-1
0
1
2
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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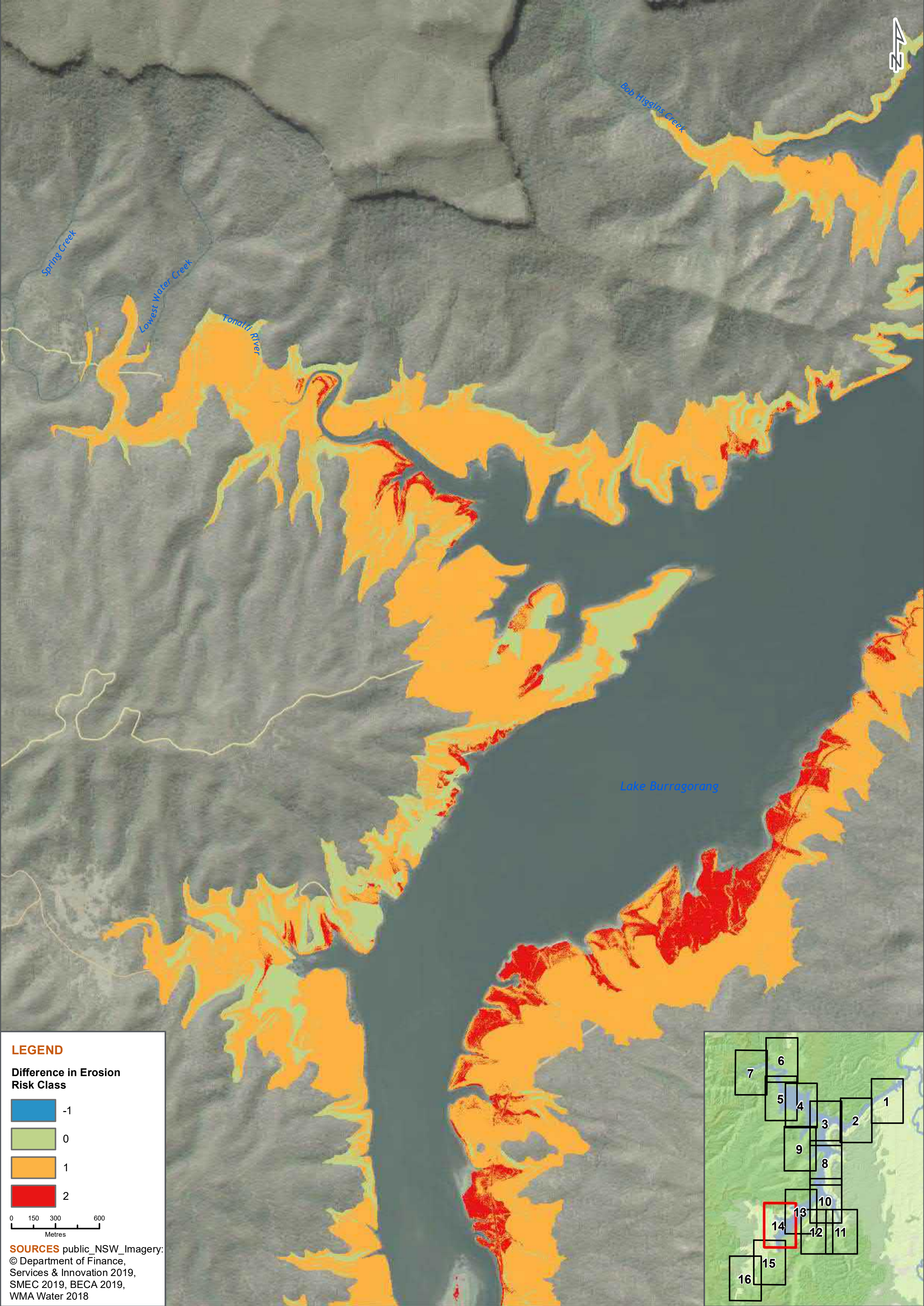

Bob Higgins Creek
Spring Creek
Lowest Water Creek
Tonalli River
Lake Burragorang
LEGEND
Difference in Erosion Risk Class
-1
0
1
2
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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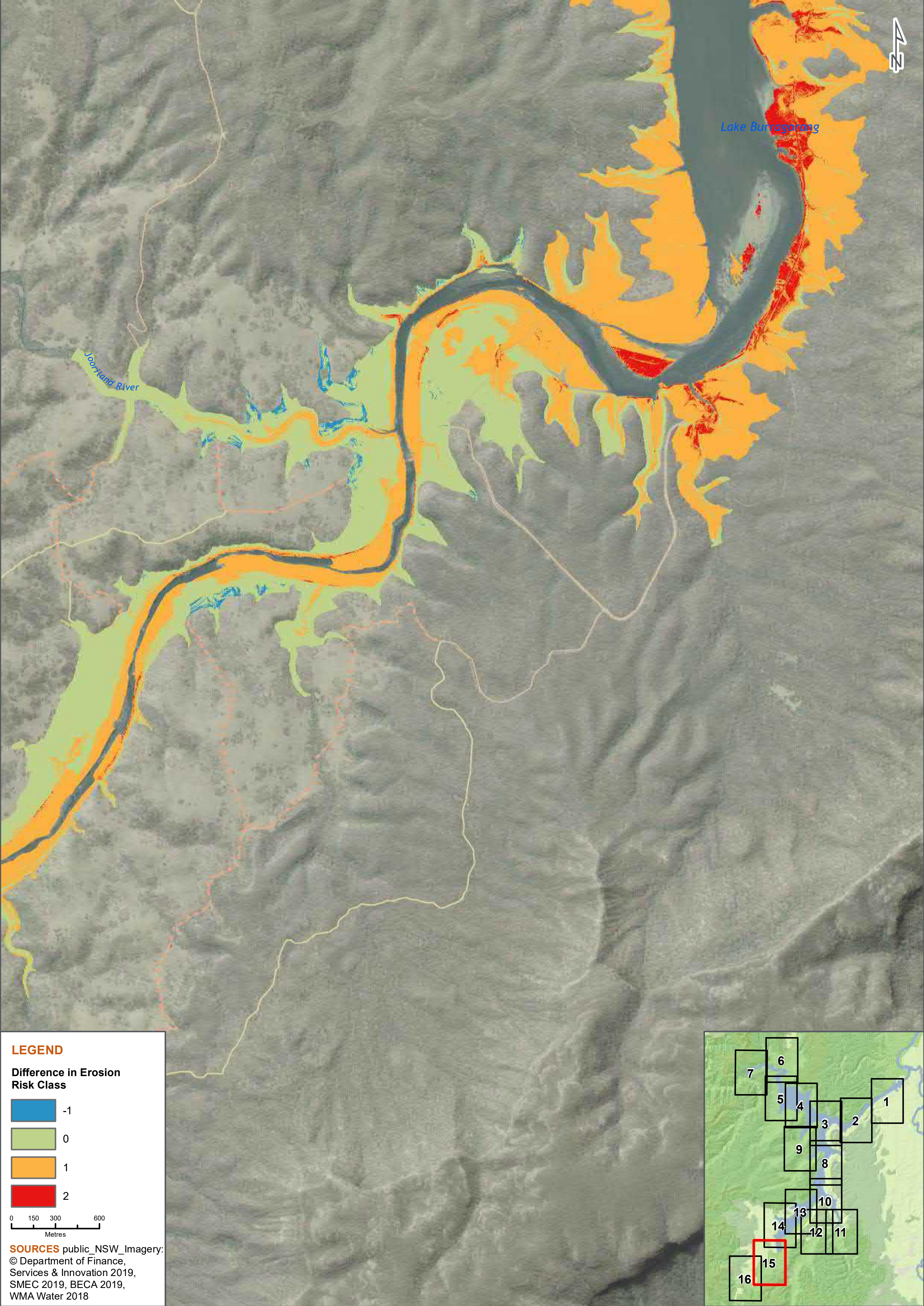

Lake Burragorang
Joorland River
LEGEND
Difference in Erosion Risk Class
-1
0
1
2
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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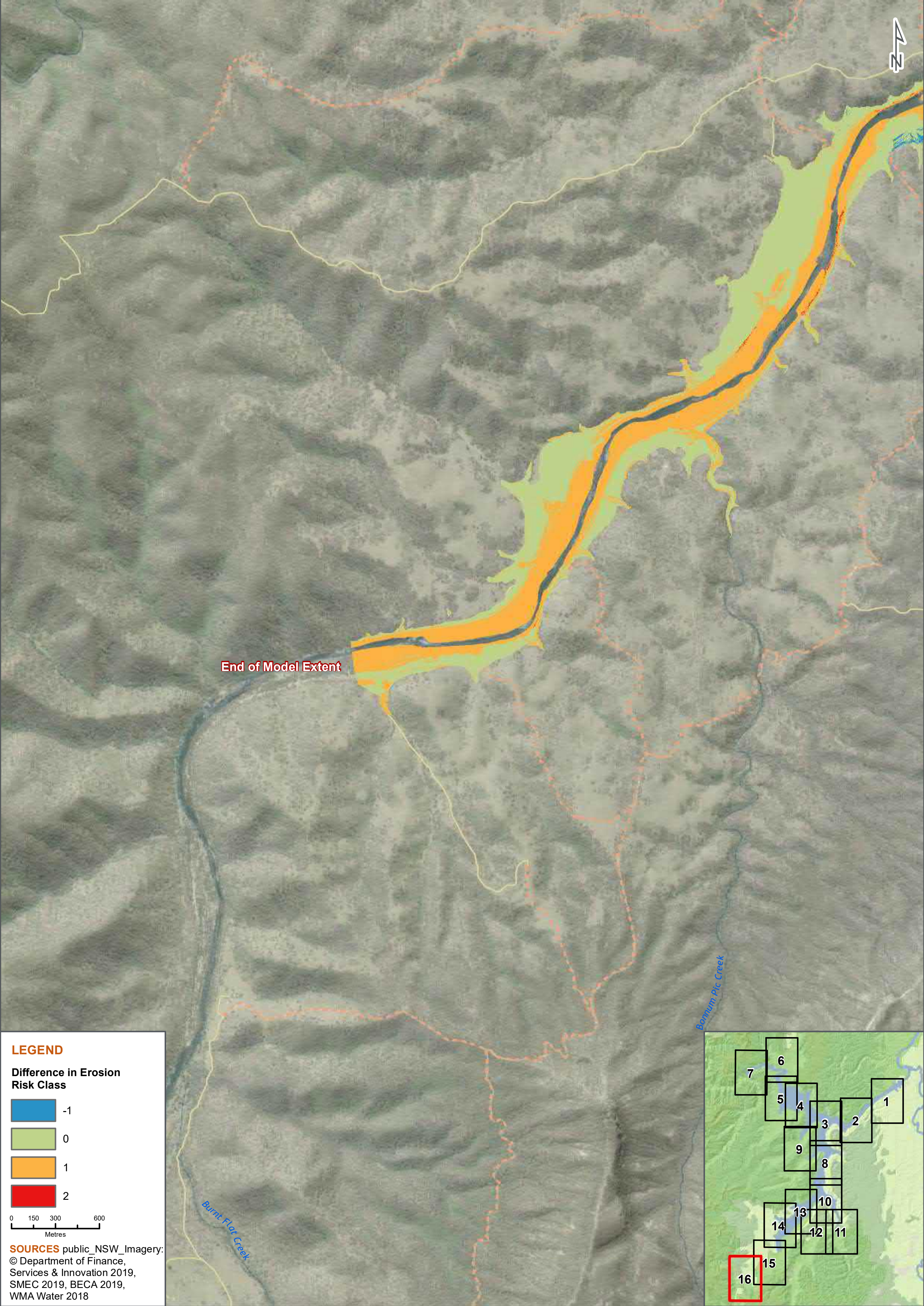

End of Model Extent
Bonnum Pic Creek
Burnt Flat Creek
LEGEND
Difference in Erosion Risk Class
-1
0
1
2
0 150 300 600
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, SMEC 2019, BECA 2019, WMA Water 2018
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K

Appendix K – Floodplain Land Use and Sedimentation

K.1 Land use and turbidity records

Location	Type	Sheet	Turbidity (mean) (NTU)	Turbidity (max) (NTU)
Lower Mangrove	Grazing	1	7	8
	Tree & shrub cover	1	7	8
	Urban area	1	7	8
Wendoree Park	Conservation Area	2	7	8
	Grazing	2	7	8
	Tree & shrub cover	2	7	8
	Urban area	2	7	8
	Wetland	2	7	8
Spencer	Conservation area	2	7	8
	Grazing	2	7	8
	Tree & shrub cover	2	7	8
	Urban area	2	7	8
	Wetland	2	7	8
Marlow	Conservation area	2	7	12
	Grazing	2	7	12
	Tree & shrub cover	2	7	12
	Urban area	2	7	12
	Wetland	2	7	12
Gunderman	Conservation area	3	6	8
	Grazing	3	6	8
	Horticulture	3	6	8
	Intensive animal production	3	6	8
	Special category	3	6	8
	Tree & shrub cover	3	6	8
	Urban area	3	6	8
	Wetland	3	6	8
Laughtondale	Conservation area	4	7	nr
	Grazing	4	7	nr
	Special category	4	7	nr
	Transport & other corridors	4	7	nr
	Tree & shrub cover	4	7	nr

Location	Type	Sheet	Turbidity (mean) (NTU)	Turbidity (max) (NTU)
	Urban area	4	7	nr
	Wetland	4	7	nr
Wisemans Ferry	Conservation area	5	8	11
	Grazing	5	8	11
	Tree & shrub cover	5	8	11
	Urban area	4	8	11
Webbs Creek	Conservation area	4	8	30
	Grazing	4	8	30
	Tree & shrub cover	4	8	30
	Urban area	4	8	30
Letts Vale	Conservation area	4	9	12
	Grazing	4	9	12
	Tree & shrub cover	6	9	12
	Urban area	6	9	12
	Wetland	6	9	12
Lower Portland	Conservation area	6	10	16
	Grazing	6	10	16
	Horticulture	6	10	16
	Tree & shrub cover	6	10	16
	Urban area	6	10	16
	Wetland	6	10	16
Cumberland Reach	Cropping	6	10	nr
	Grazing	6	10	nr
	Horticulture	6	10	nr
	Tree & shrub cover	6	10	nr
	Urban area	6	10	nr
Sackville	Grazing	7	10	nr
	Horticulture	7	10	nr
	Special category	7	10	nr
	Transport & other corridors	7	10	nr
	Urban area	7	10	nr

Location	Type	Sheet	Turbidity (mean) (NTU)	Turbidity (max) (NTU)
	Wetland	7	10	nr
South Maroota	Special category	7	11	14
	Tree & shrub cover	7	11	14
	Urban area	7	11	14
	Wetland	7	11	14
Cattai Creek Junction	Conservation Area	8	12	14
	Grazing	8	12	14
	Mining & quarrying	8	12	14
	Special category	8	12	14
	Tree & shrub cover	8	12	14
	Urban area	8	12	14
	Wetland	8	12	14
Cattai	Conservation Area	8	18	24
	Grazing	8	18	24
	Special category	8	18	24
	Transport & other corridors	8	18	24
	Tree & shrub cover	8	18	24
	Urban area	8	18	24
	Wetland	8	18	24
Pitt Town	Conservation Area	8	20	24
	Grazing	8	20	24
	Intensive animal production	8	20	24
	Special category	8	20	24
	Tree & shrub cover	8	20	24
	Urban area	9	20	24
	Wetland	9	20	24
Windsor	Special category	9	17	46
	Transport & other corridors	9	17	46
	Tree & shrub cover	9	17	46
	Urban area	9	17	46
Clarendon	Grazing	9	14	38

Location	Type	Sheet	Turbidity (mean) (NTU)	Turbidity (max) (NTU)
	Horticulture	9	14	38
	Intensive animal production	9	14	38
	Mining & quarrying	9	14	38
	Special category	9	14	38
	Transport & other corridors	9	14	38
	Urban area	9	14	38
Bligh Park	Grazing	10	14	38
	Horticulture	10	14	38
	Intensive animal production	10	14	38
	Power generation	10	14	38
	Special category	10	14	38
	Transport & other corridors	10	14	38
	Urban area	10	14	38
North Richmond	Grazing	11	7	8
	Horticulture	11	7	8
	Intensive animal production	11	7	8
	Special category	11	7	8
	Transport & other corridors	11	7	8
	Urban area	11	7	8
Yarramundi	Grazing	12	3	4
	Horticulture	12	3	4
	Intensive animal production	12	3	4
	Special category	12	3	4
	Transport & other corridors	12	3	4
	Tree & shrub cover	12	3	4
	Urban area	12	3	4
	Wetland	12	3	4
Castlereagh	Conservation area	12	4	4
	Grazing	12	4	4
	Intensive animal production	12	4	4
	Mining & quarrying	12	4	4

Location	Type	Sheet	Turbidity (mean) (NTU)	Turbidity (max) (NTU)
	Power generation	12	4	4
	Special category	12	4	4
	Tree & shrub cover	12	4	4
	Urban area	12	4	4
Penrith	Conservation area	13	4	4
	Mining & quarrying	13	4	4
	Tree & shrub cover	13	4	4
	Urban area	13	4	4

Data sources – SMEC 2019 EIS mapping for land use / DECC 2009 for turbidity data

nr = No record

K.2 Critical infrastructure and turbidity records

Location	Type	Sheet	Turbidity (mean) (NTU)	Turbidity (max) (NTU)
Lower Mangrove	Tourist Park	1	7	8
	Community Facility	1	7	8
Wendoree Park	Place of worship	2	7	8
	Tourist Park	2	7	8
	Firestation - Bush	2	7	8
Spencer	Tourist Park	2	7	8
	Firestation - Bush	2	7	8
Marlow	Tourist Park	2	7	12
Gunderman	Tourist Park	3	6	8
Laughtondale	Tourist Park	4	7	nr
Wisemans Ferry	Tourist Park	4	8	11
	Firestation - Bush	5	8	11
	Firestation - Bush	5	8	11
	Primary School	5	8	11
	Police Station	5	8	11
	Place of worship	5	8	11
	Medical Centre	5	8	11
	Shopping Centre	5	8	11
	Community Facility	5	8	11
	Firestation - Bush	5	8	11
	Tourist Park	4	8	11
	Tourist Park	4	8	11
	Tourist Park	4	8	11
	Tourist Park	4	8	11
Webbs Creek	Tourist Park	4	8	30
	Tourist Park	4	8	30
	Tourist Park	4	8	30
Letts Vale	Tourist Park	4	9	12
	Tourist Park	4	9	12
	Tourist Park	6	9	12
	Tourist Park	6	9	12

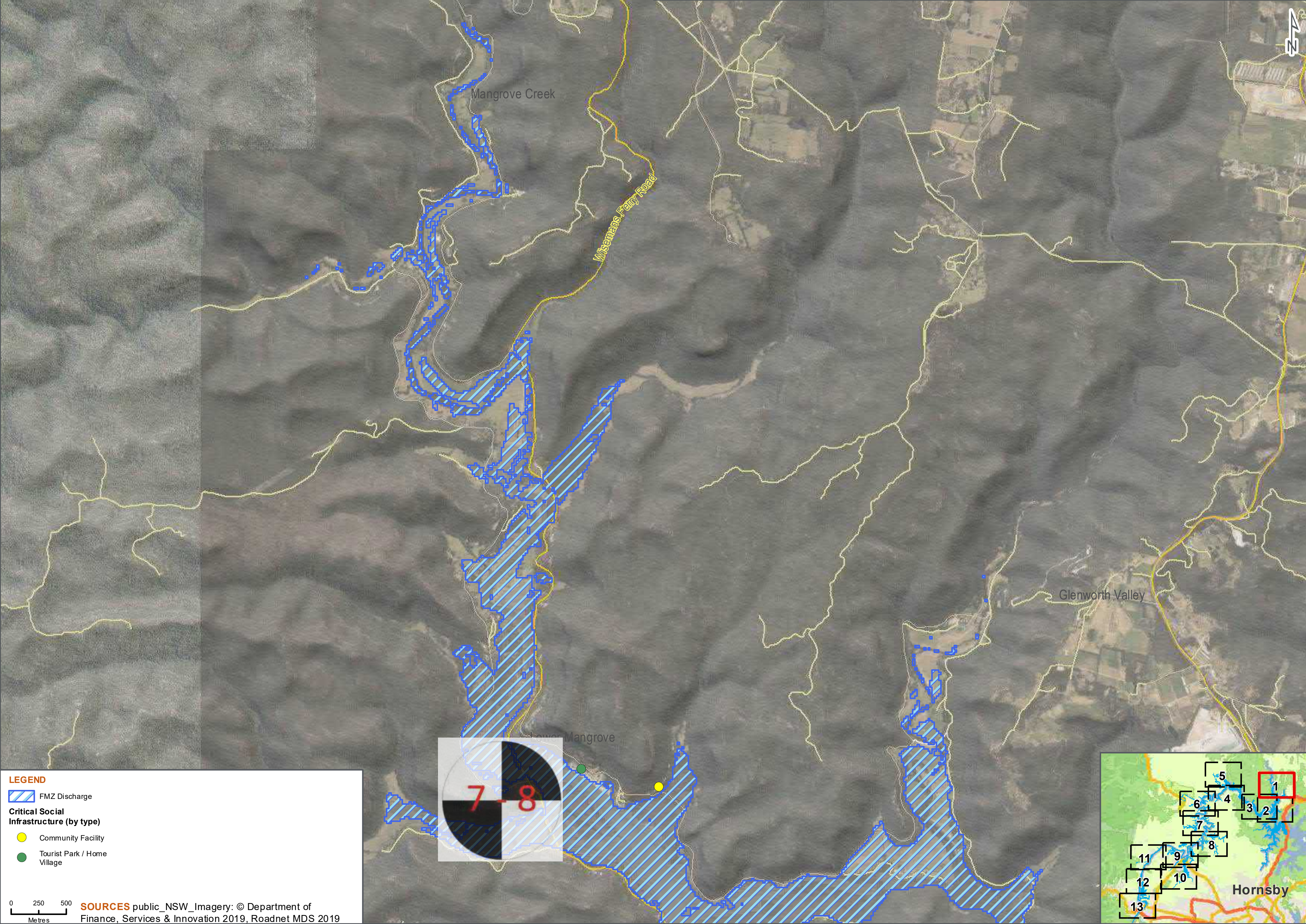
Location	Type	Sheet	Turbidity (mean) (NTU)	Turbidity (max) (NTU)
	Tourist Park	6	9	12
Lower Portland	Tourist Park	6	10	16
	Tourist Park	6	10	16
	Firestation - Bush	6	10	16
	Tourist Park	6	10	16
	Tourist Park	6	10	16
	Firestation - Bush	6	10	16
Cumberland Reach	Tourist Park	6	10	nr
	Tourist Park	6	10	nr
Sackville	Tourist Park	7	10	nr
	Tourist Park	7	10	nr
	Community Facility	7	10	nr
South Maroota	Tourist Park	7	11	14
	Tourist Park	7	11	14
	Community Facility	7	11	14
Cattai Creek Junction	Tourist Park	7	12	14
	Place of worship	7	12	14
Cattai	Tourist Park	8	18	24
	Tourist Park	8	18	24
	Primary School	8	18	24
	Community Facility	8	18	24
Pitt Town	Place of worship	8	20	24
	Place of worship	8	20	24
	Primary School	8	20	24
	Shopping Centre	8	20	24
	Tourist Park	9	20	24
	Tourist Park	9	20	24
Windsor	Primary School	9	17	46
	Place of worship	9	17	46
	Community Facility	9	17	46
	Firestation	9	17	46

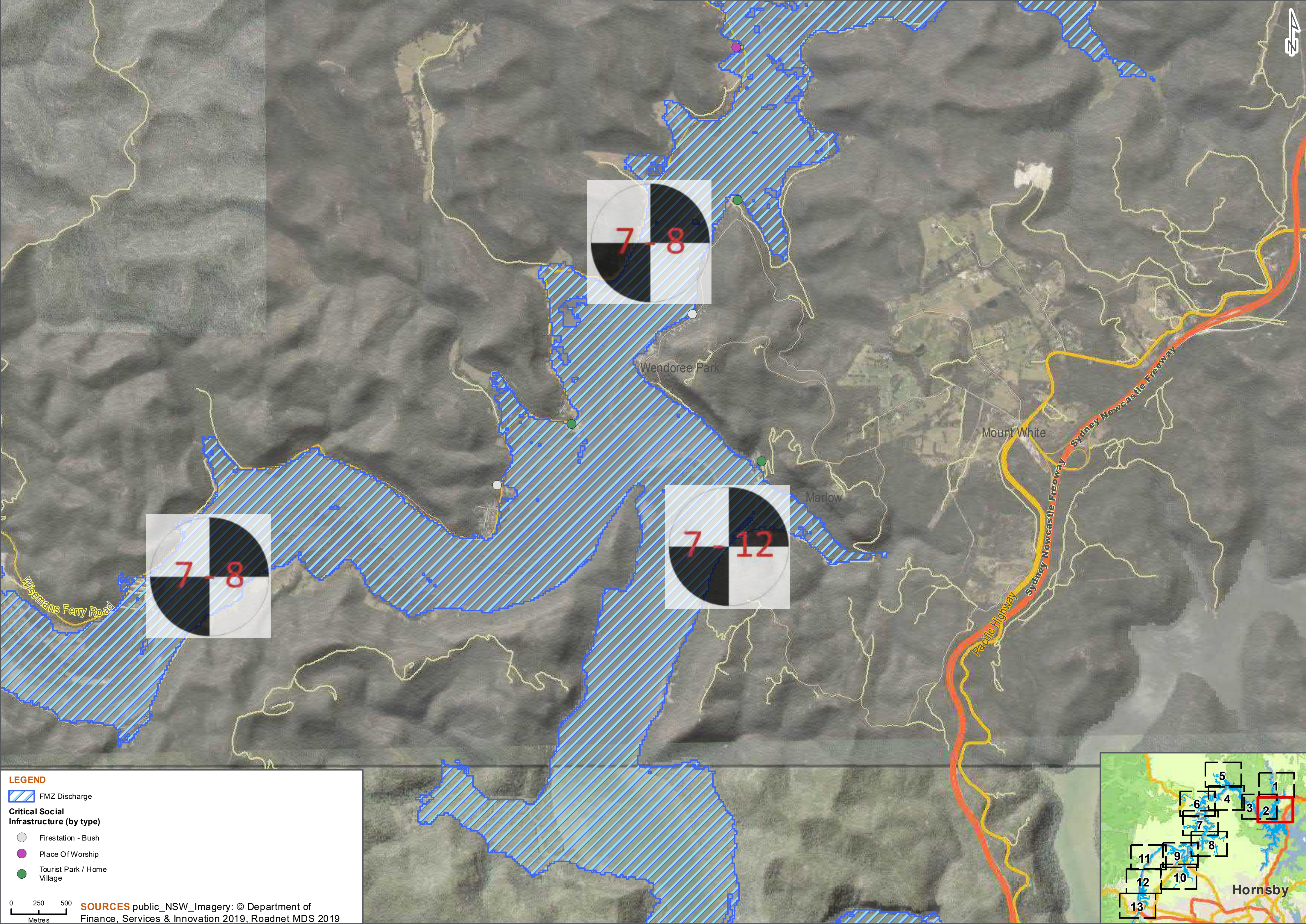
Location	Type	Sheet	Turbidity (mean) (NTU)	Turbidity (max) (NTU)
Clarendon	Hospital	9	14	38
	Railway Station	9	14	38
North Richmond	Sewage Works	11	7	8
	Hospital	11	7	8
Yarramundi	Community Facility	12	3	4

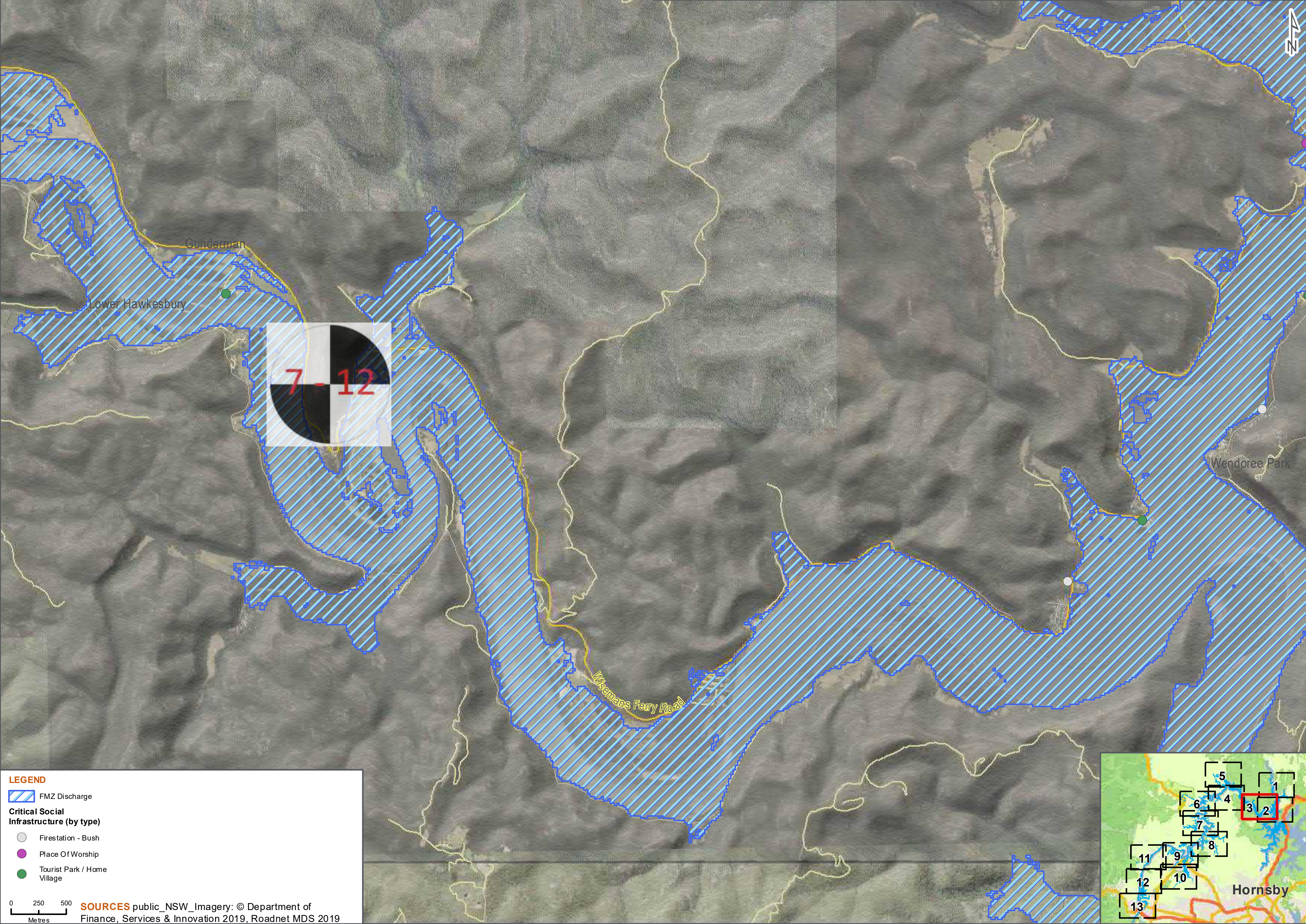
Data sources – SMEC 2019 EIS mapping for critical infrastructure / DECC 2009 for turbidity data

nr = No record

K.3 Critical infrastructure and turbidity mapping


Mangrove Creek
Wisemans Ferry Road
Glenworth Valley
Lower Mangrove
7 - 8
LEGEND
FMZ Discharge
Critical Social Infrastructure (by type)
Community Facility
Tourist Park / Home Village
0 250 500
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019
1
2
3
4
5
6
7
8
9
10
11
12
13
Hornsby


7 - 8
7 - 12
7 - 8
Wendoree Park
Marlow
Mount White
Wisemans Ferry Road
Pacific Highway
Sydney Newcastle Freeway
5
1
4
6
3
2
7
8
11
9
10
12
Hornsby
13
LEGEND
FMZ Discharge
Critical Social Infrastructure (by type)
Firestation - Bush
Place Of Worship
Tourist Park / Home Village
0 250 500
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019



LEGEND

FMZ Discharge

Critical Social Infrastructure (by type)

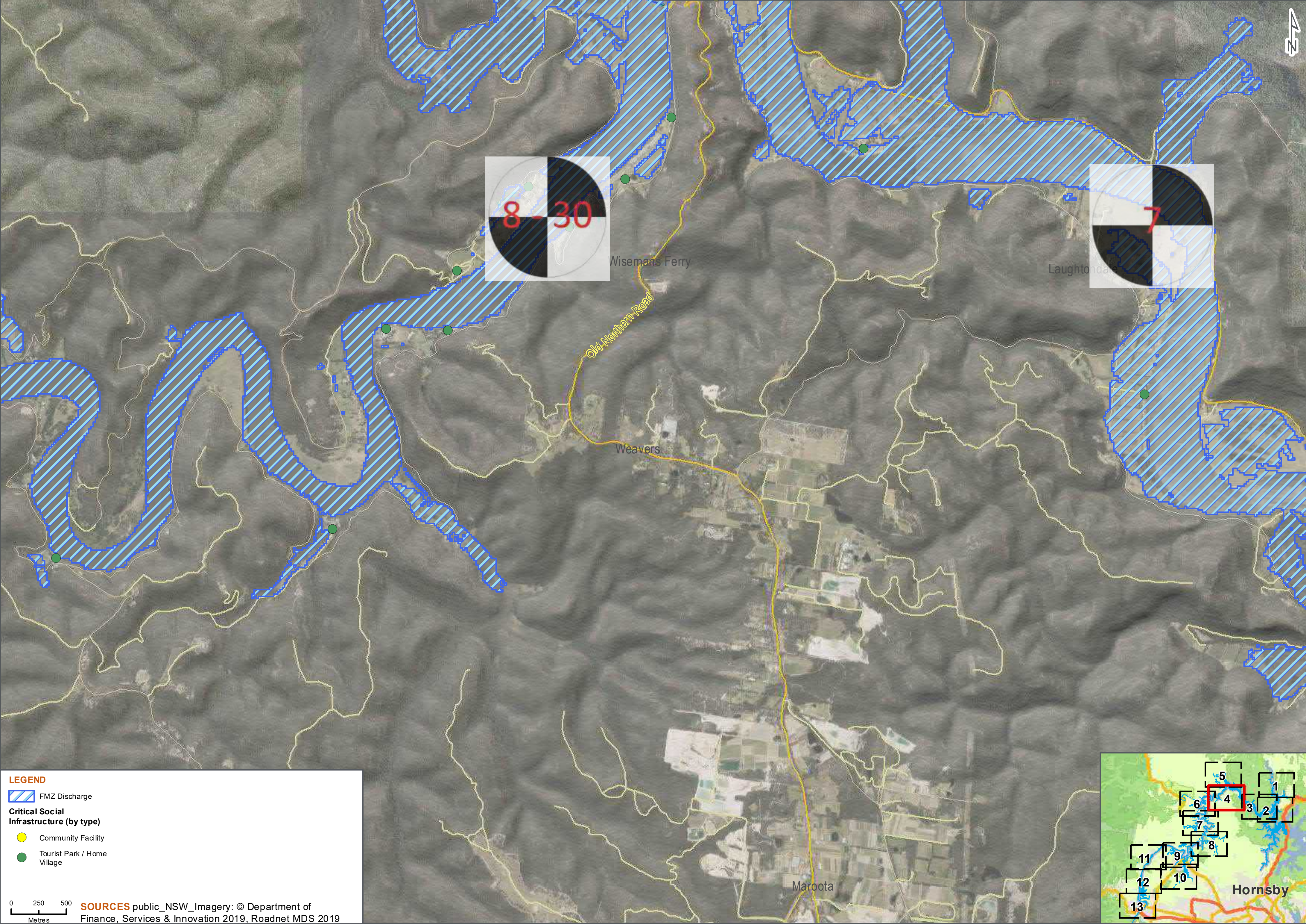
Firestation - Bush

Place Of Worship

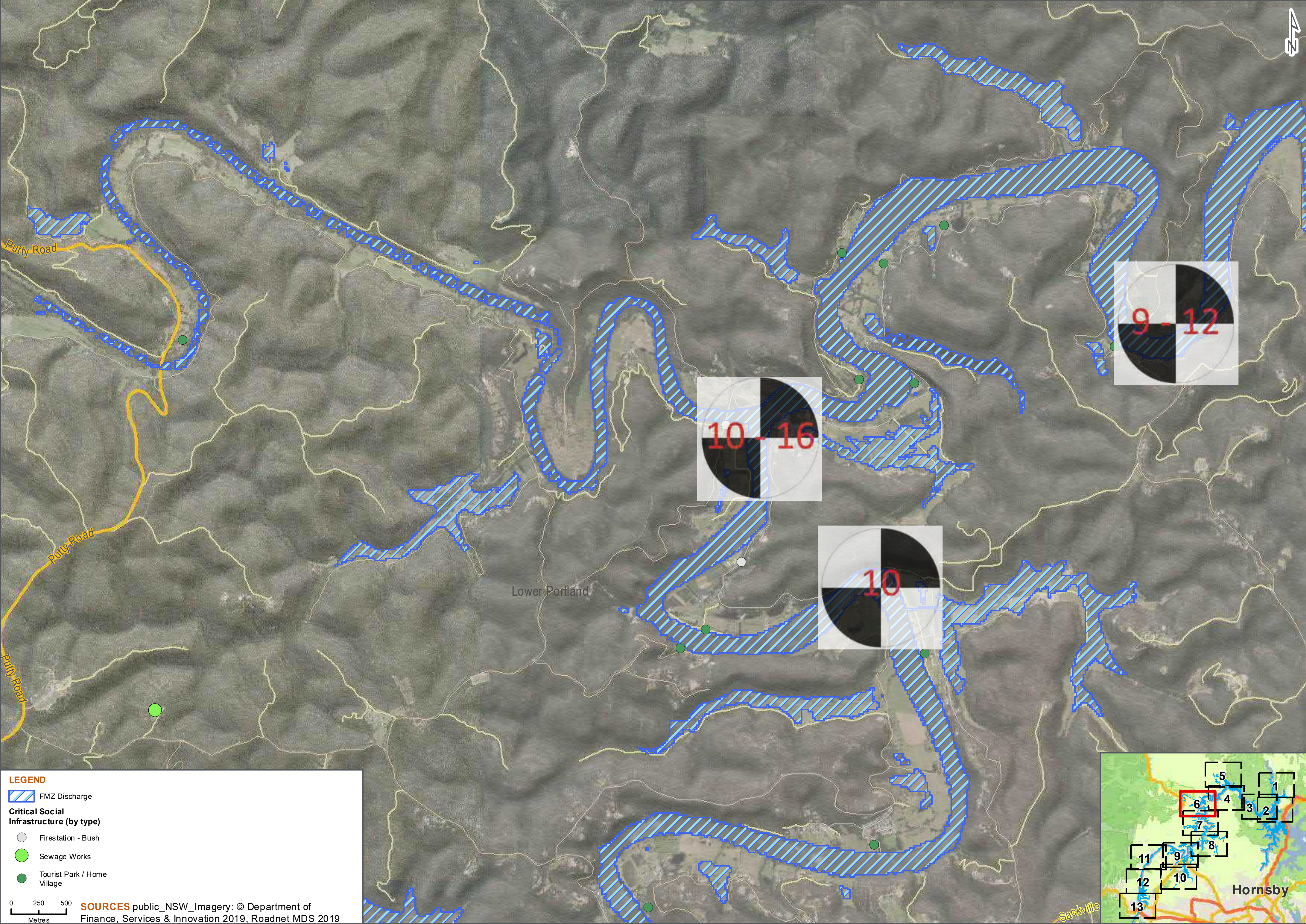
Tourist Park / Home Village

0 250 500
Metres

SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019


8 - 30
7
Wisemans Ferry
Old Northern Road
Weavers
Maroota
Hornsby
1
2
3
4
5
6
7
8
9
10
11
12
13
LEGEND
FMZ Discharge
Critical Social Infrastructure (by type)
Community Facility
Tourist Park / Home Village
0 250 500
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019

Central Macdonald
St Albans Road
8 - 11
Hornsby
1
2
3
4
5
6
7
8
9
10
11
12
13
LEGEND
FMZ Discharge
Critical Social Infrastructure (by type)
Community Facility
Firestation - Bush
Medical Centre
Place Of Worship
Police Station
Primary School
Shopping Centre
0 250 500
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019



LEGEND

FMZ Discharge

Critical Social Infrastructure (by type)

Firestation - Bush

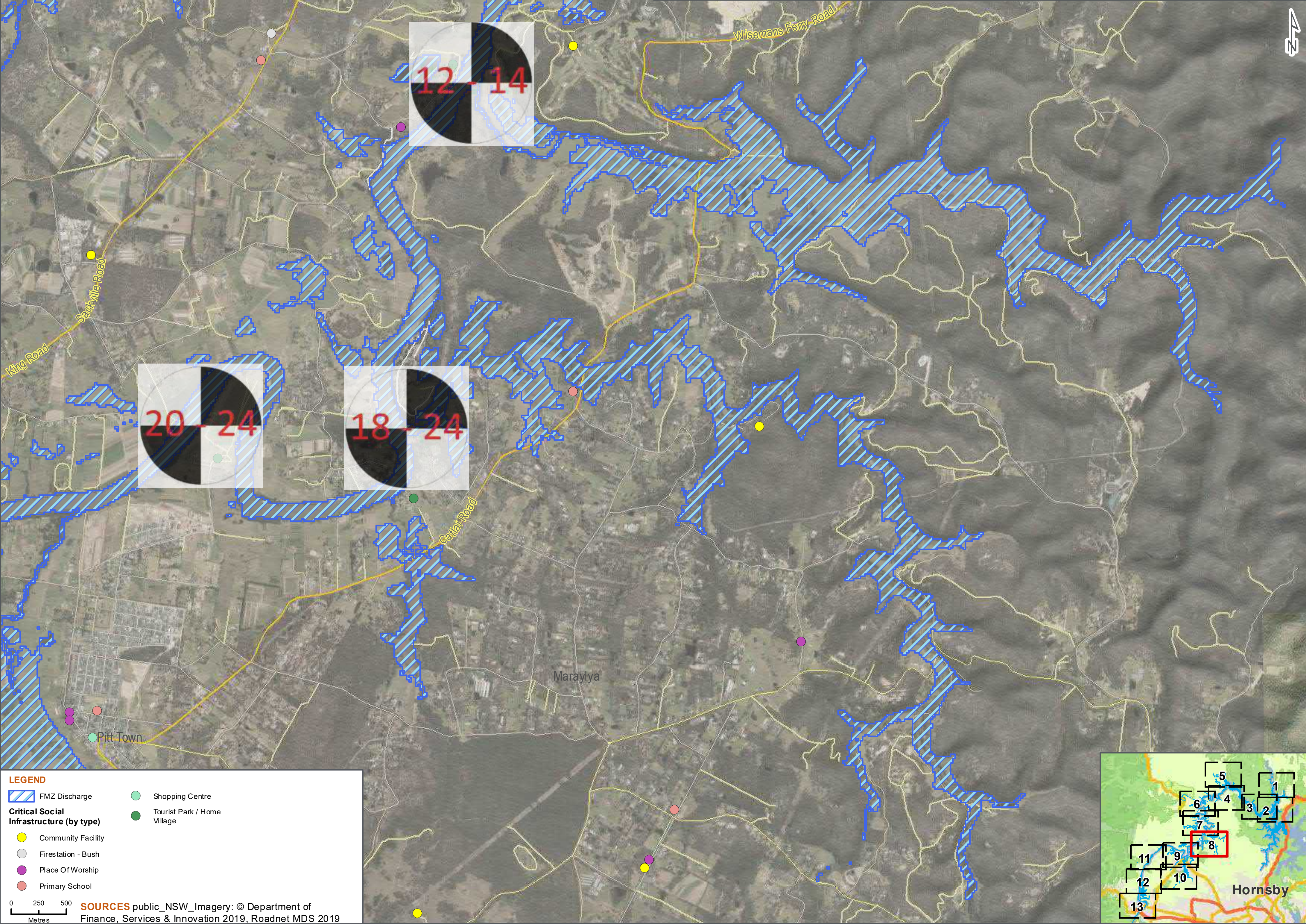
Sewage Works

Tourist Park / Home Village

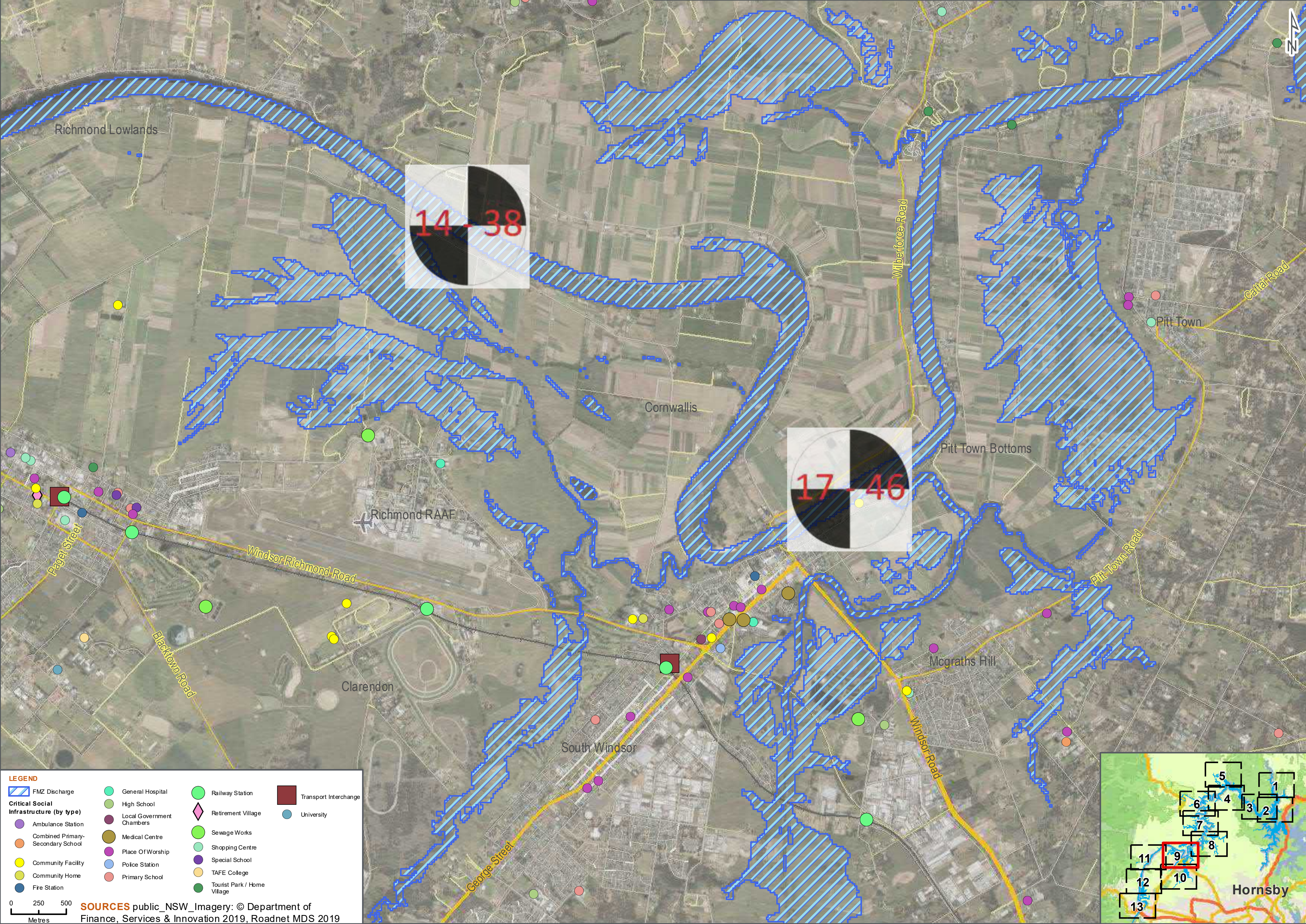
0 250 500
Metres

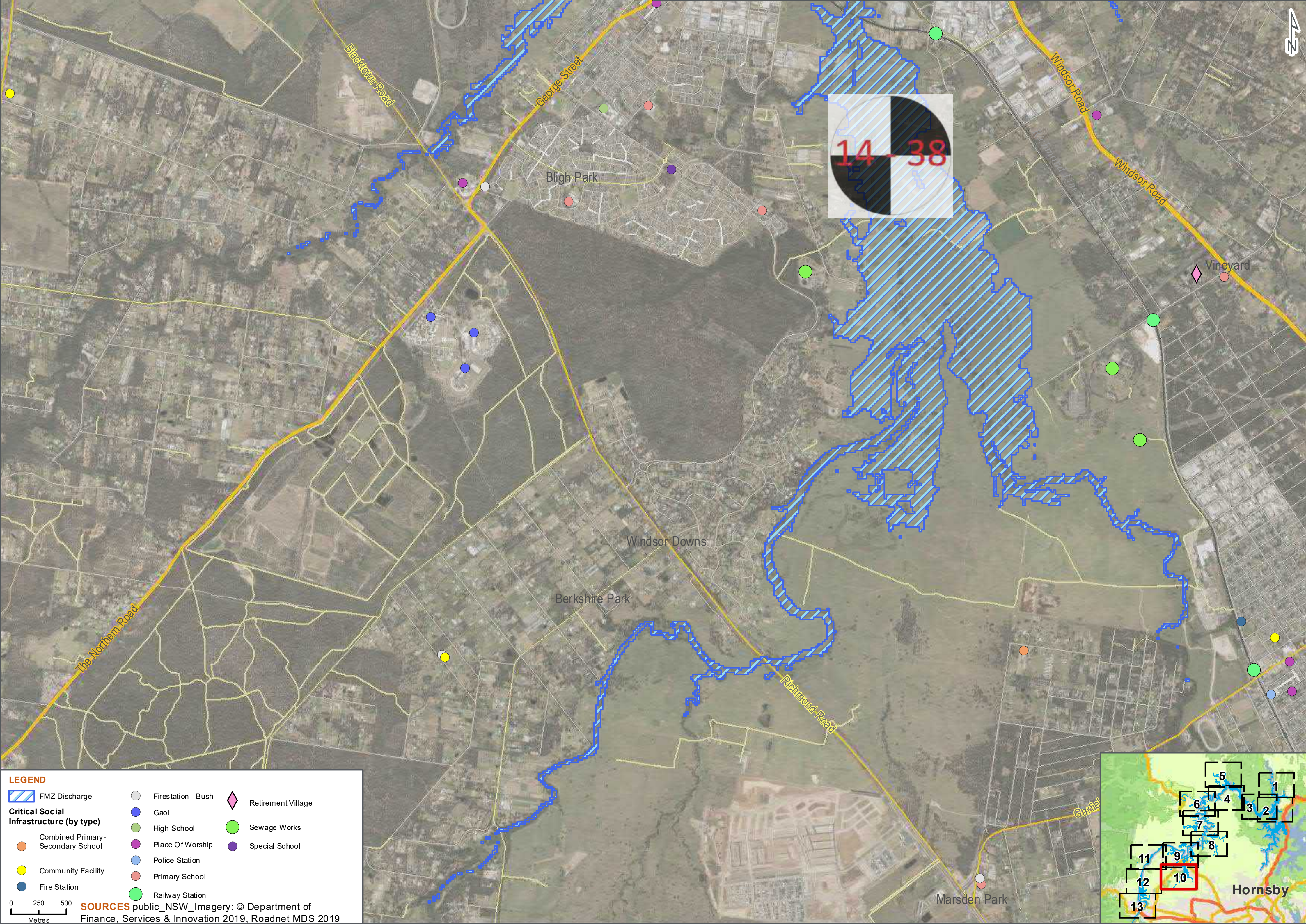
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019


Sackville Ferry Road
Sackville North
10
11 - 14
Sackville
Sackville Road
South Maroota
Ebenezer
Hornsby
5
1
6
4
3
2
7
8
11
9
10
12
13
LEGEND
FMZ Discharge
Critical Social Infrastructure (by type)
Community Facility
Firestation - Bush
Place Of Worship
Primary School
Tourist Park / Home Village
0 250 500
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019

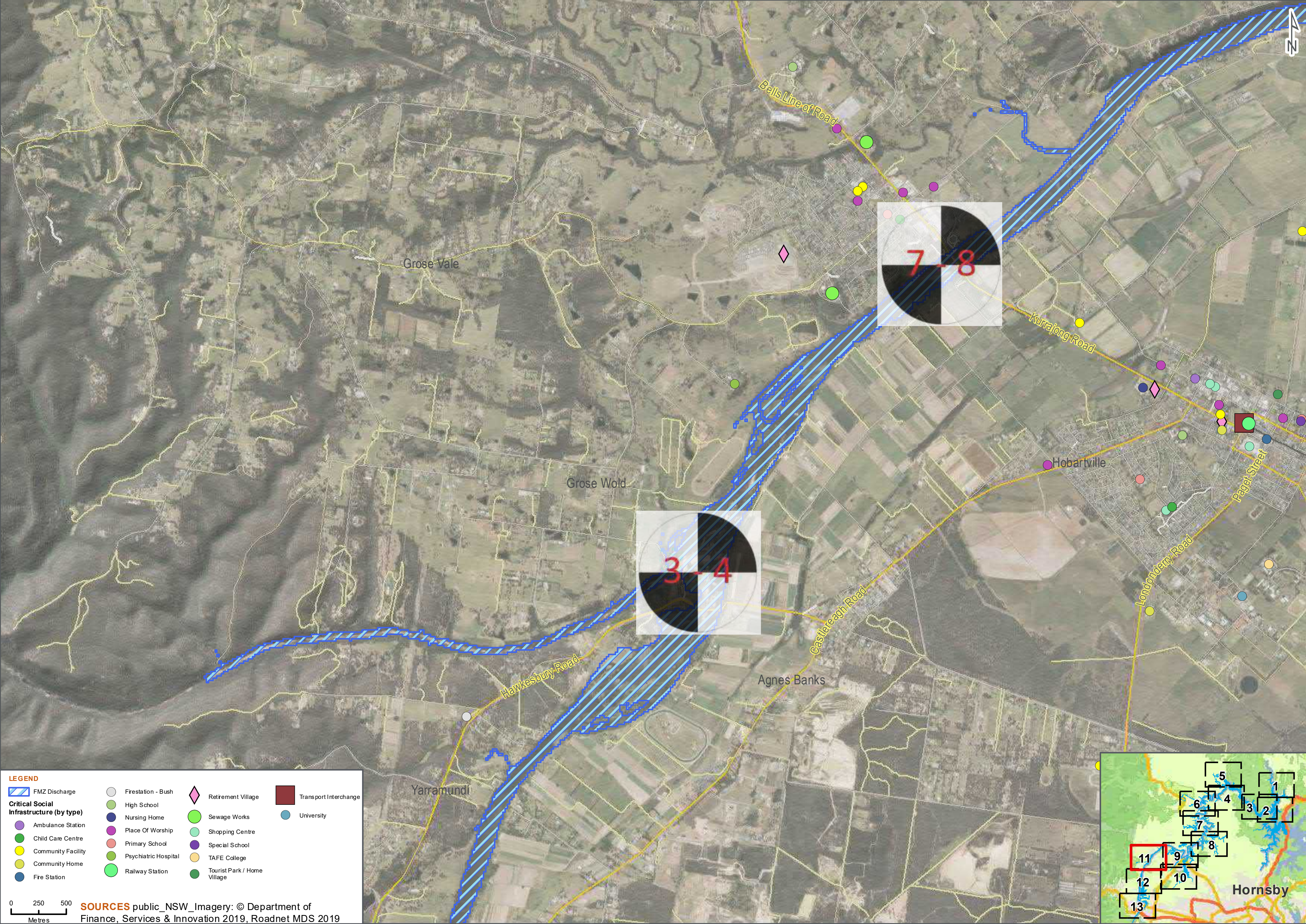


Wisemans Ferry Road
Sackville Road
King Road
Cattai Road
Maraylya
Pitt Town
12 - 14
20 - 24
18 - 24
LEGEND
FMZ Discharge
Critical Social Infrastructure (by type)
Community Facility
Firestation - Bush
Place Of Worship
Primary School
Shopping Centre
Tourist Park / Home Village
0 250 500
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019
Hornsby
1
2
3
4
5
6
7
8
9
10
11
12
13

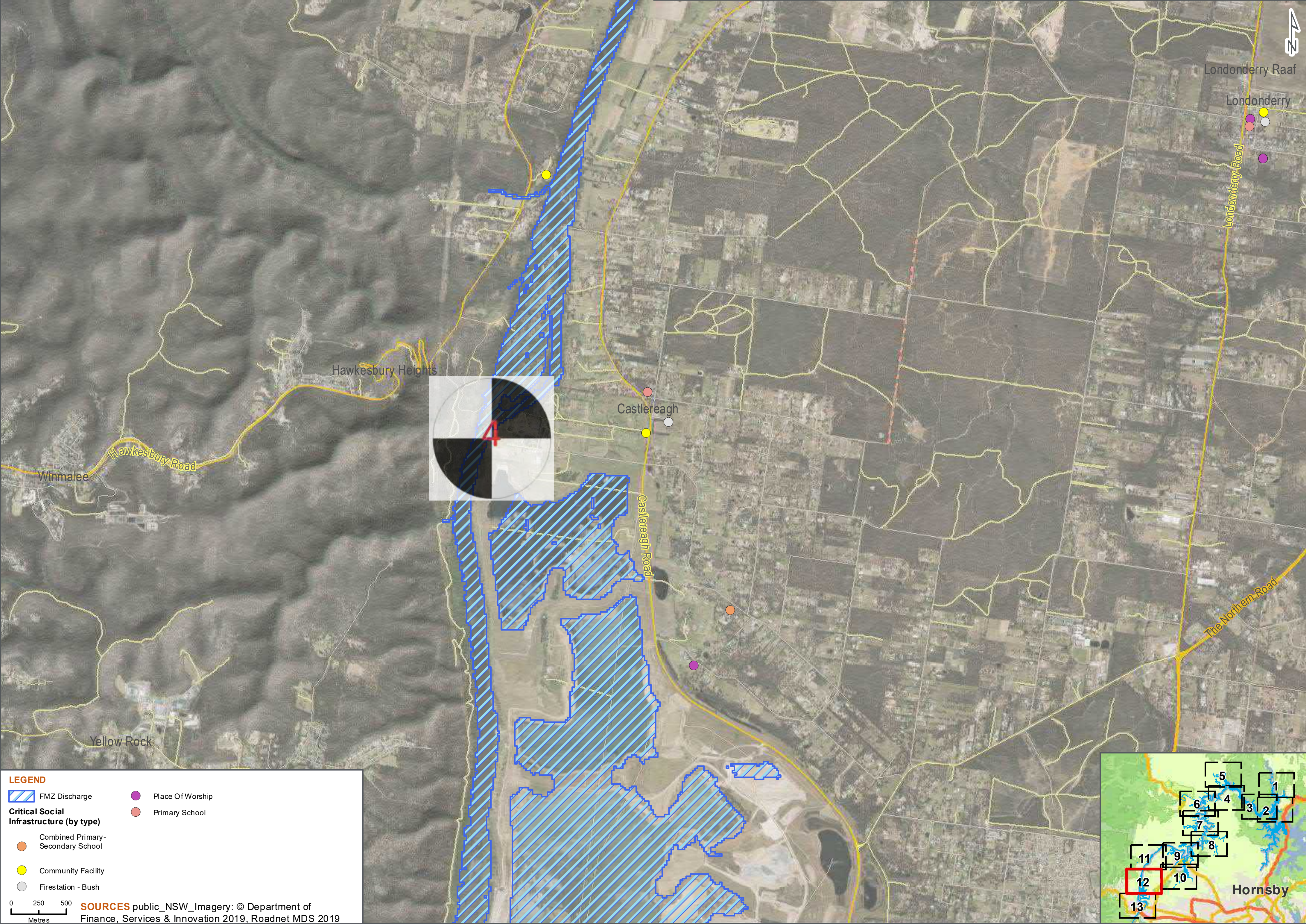

Richmond Lowlands
14 - 38
17 - 46
Wilberforce Road
Cattai Road
Pitt Town
Cornwallis
Pitt Town Bottoms
Richmond RAAF
Windsor Richmond Road
Paget Street
Blacktown Road
Pitt Town Road
Mcgraths Hill
Clarendon
South Windsor
Windsor Road
George Street
Hornsby
1
2
3
4
5
6
7
8
9
10
11
12
13
LEGEND
FMZ Discharge
Critical Social Infrastructure (by type)
Ambulance Station
Combined Primary-Secondary School
Community Facility
Community Home
Fire Station
General Hospital
High School
Local Government Chambers
Medical Centre
Place Of Worship
Police Station
Primary School
Railway Station
Retirement Village
Sewage Works
Shopping Centre
Special School
TAFE College
Tourist Park / Home Village
Transport Interchange
University
0 250 500
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019



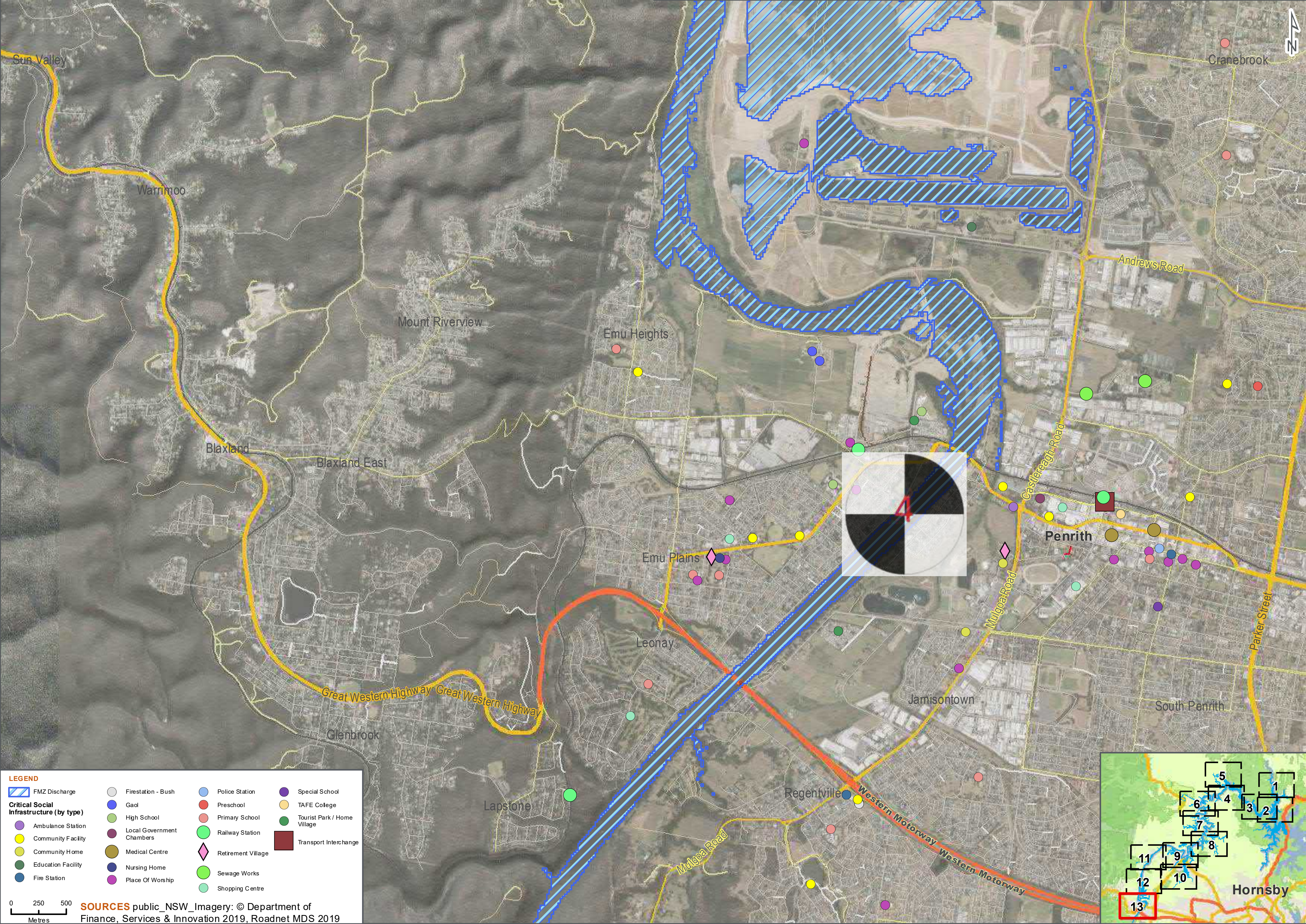
14 - 38
Blacktown Road
George Street
Windsor Road
Windsor Road
Bligh Park
Vineyard
Windsor Downs
Berkshire Park
The Northern Road
Richmond Road
Marsden Park
Hornsby
1
2
3
4
5
6
7
8
9
10
11
12
13
LEGEND
FMZ Discharge
Critical Social Infrastructure (by type)
Combined Primary-Secondary School
Community Facility
Fire Station
Firestation - Bush
Gaol
High School
Place Of Worship
Police Station
Primary School
Railway Station
Retirement Village
Sewage Works
Special School
0 250 500
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019



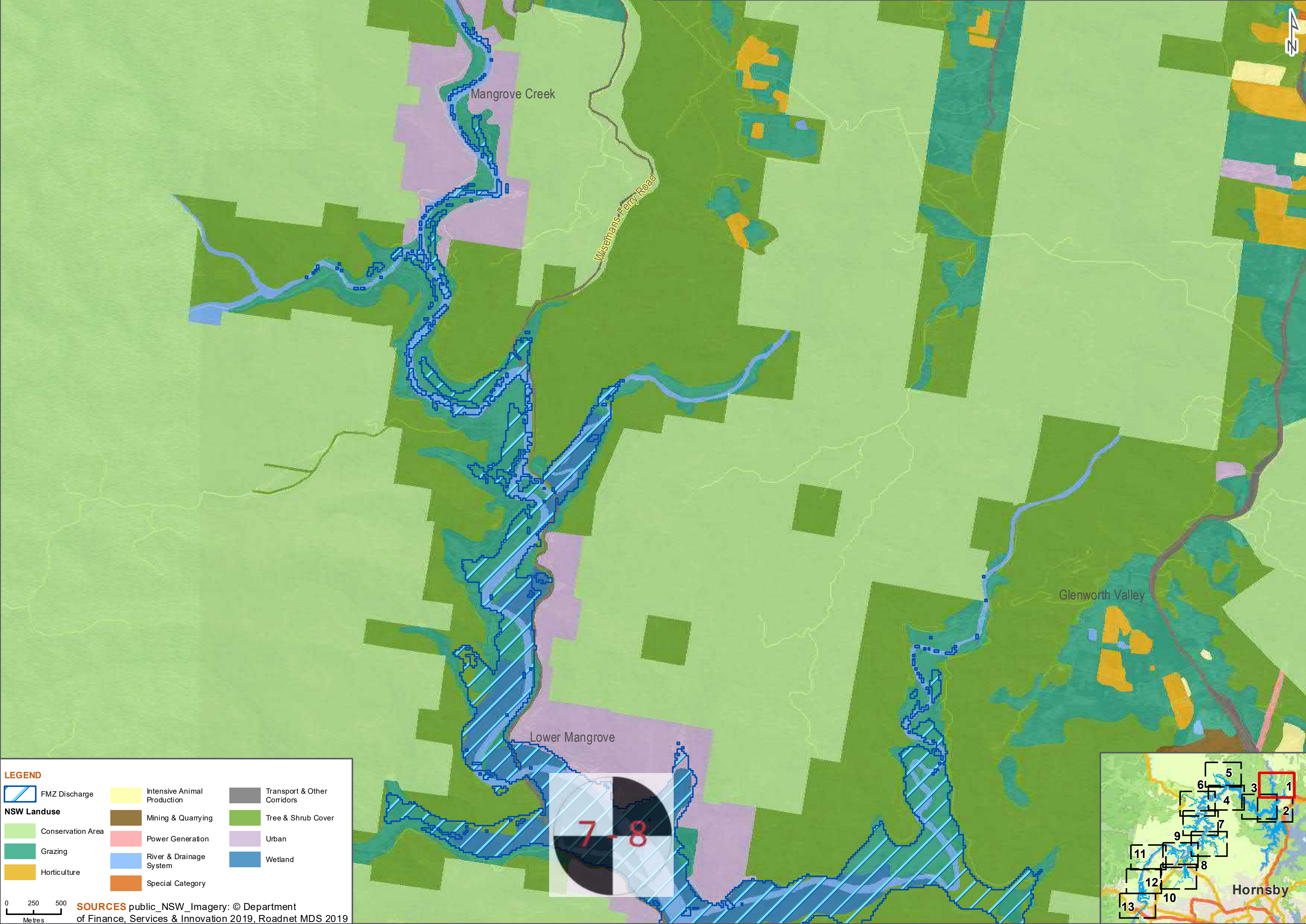
N
Bells Line of Road
Grose Vale
7 - 8
Kurrajong Road
Hobartville
Grose Wold
Paget Street
3 - 4
Londonderry Road
Castlereagh Road
Hawkesbury Road
Agnes Banks
Yarramundi
LEGEND
FMZ Discharge
Critical Social Infrastructure (by type)
Ambulance Station
Child Care Centre
Community Facility
Community Home
Fire Station
Firestation - Bush
High School
Nursing Home
Place Of Worship
Primary School
Psychiatric Hospital
Railway Station
Retirement Village
Sewage Works
Shopping Centre
Special School
TAFE College
Tourist Park / Home Village
Transport Interchange
University
0 250 500
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019
5
1
6
4
3
2
7
8
11
9
10
12
13
Hornsby



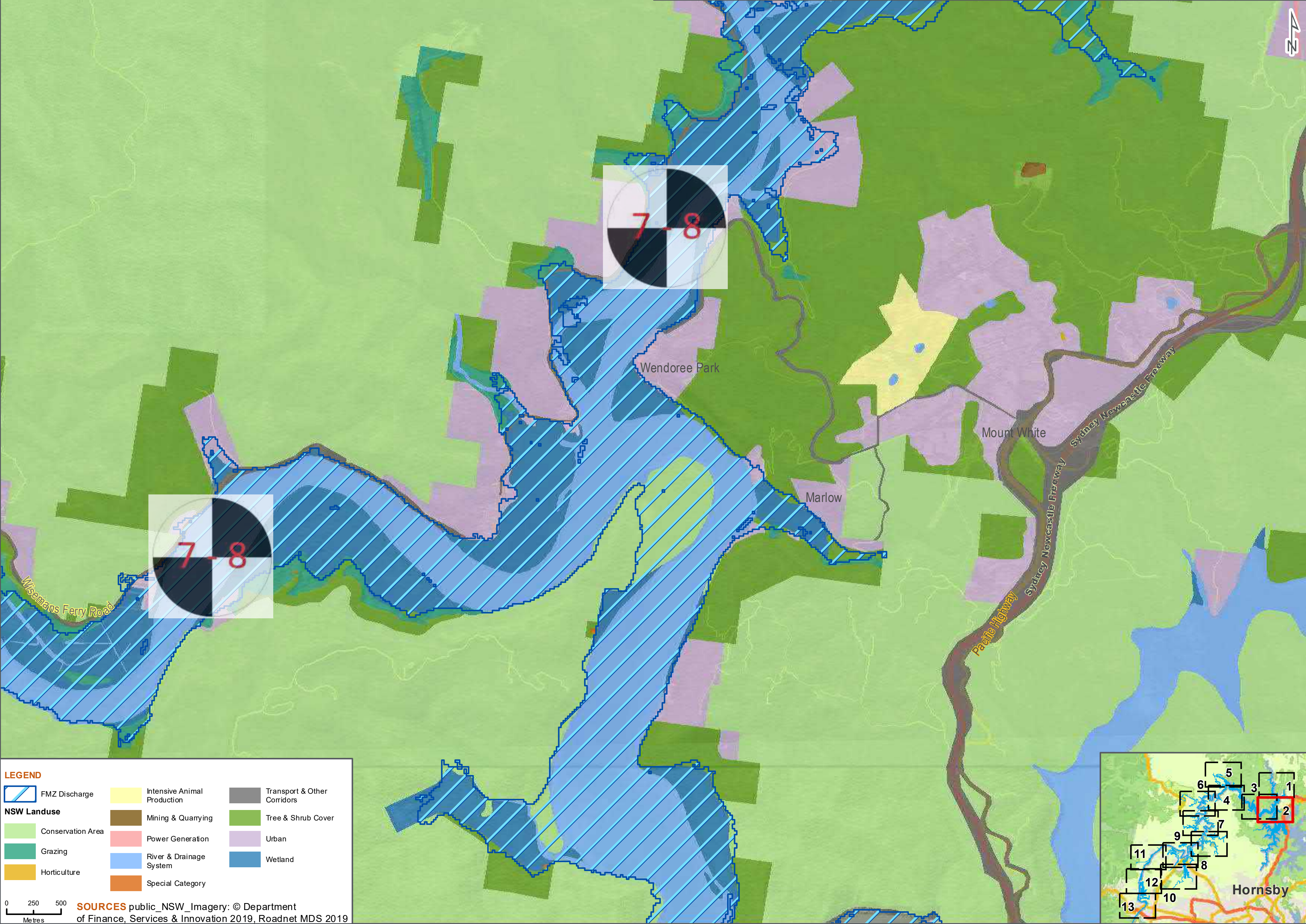
Londonderry Raaf
Londonderry
Londonderry Road
Hawkesbury Heights
Castlereagh
4
Winmalee
Hawkesbury Road
Castlereagh Road
The Northern Road
Yellow Rock
LEGEND
FMZ Discharge
Critical Social Infrastructure (by type)
Combined Primary-Secondary School
Community Facility
Firestation - Bush
Place Of Worship
Primary School
0 250 500
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019
5 1 6 4 3 2 7 8 11 9 12 10 13
Hornsby


Sun Valley
Warrimoo
Mount Riverview
Blaxland
Blaxland East
Emu Heights
Emu Plains
Leonay
Glenbrook
Lapstone
Regentville
Jamisontown
Penrith
South Penrith
Cranebrook
Andrews Road
Castlereagh Road
Mulgoa Road
Parker Street
Great Western Highway
Western Motorway
4
Hornsby
1
2
3
4
5
6
7
8
9
10
11
12
13
LEGEND
FMZ Discharge
Critical Social Infrastructure (by type)
Ambulance Station
Community Facility
Community Home
Education Facility
Fire Station
Firestation - Bush
Gaol
High School
Local Government Chambers
Medical Centre
Nursing Home
Place Of Worship
Police Station
Preschool
Primary School
Railway Station
Retirement Village
Sewage Works
Shopping Centre
Special School
TAFE College
Tourist Park / Home Village
Transport Interchange
0 250 500
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019

K.4 Land use and turbidity mapping



Mangrove Creek
Wisemans Ferry Road
Glenworth Valley
Lower Mangrove
7 - 8
N
LEGEND
FMZ Discharge
NSW Landuse
Conservation Area
Grazing
Horticulture
Intensive Animal Production
Mining & Quarrying
Power Generation
River & Drainage System
Special Category
Transport & Other Corridors
Tree & Shrub Cover
Urban
Wetland
0 250 500
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019
1
2
3
4
5
6
7
8
9
10
11
12
13
Hornsby



7
8
7
8
Wendoree Park
Mount White
Marlow
Wisemans Ferry Road
Sydney Newcastle Freeway
Pacific Highway
LEGEND
FMZ Discharge
NSW Landuse
Conservation Area
Grazing
Horticulture
Intensive Animal Production
Mining & Quarrying
Power Generation
River & Drainage System
Special Category
Transport & Other Corridors
Tree & Shrub Cover
Urban
Wetland
0 250 500
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019
1
2
3
4
5
6
7
8
9
10
11
12
13
Hornsby


6 - 8
7 - 12
Gunderman
Lower Hawkesbury
Wisemans Ferry Road
Wendoree Park
LEGEND
FMZ Discharge
NSW Landuse
Conservation Area
Grazing
Horticulture
Intensive Animal Production
River & Drainage System
Special Category
Transport & Other Corridors
Tree & Shrub Cover
Urban
Wetland
0 250 500
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019
1
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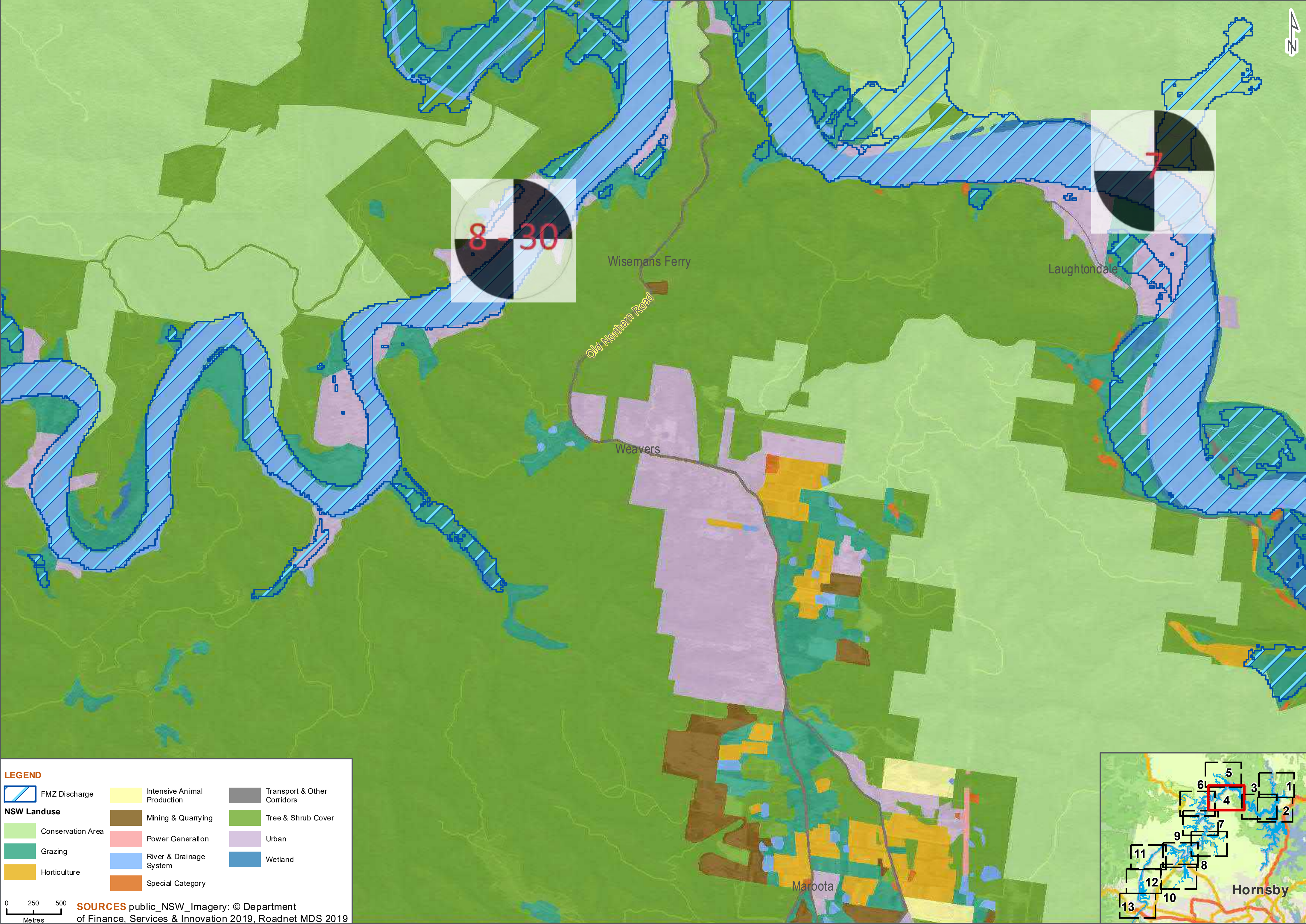
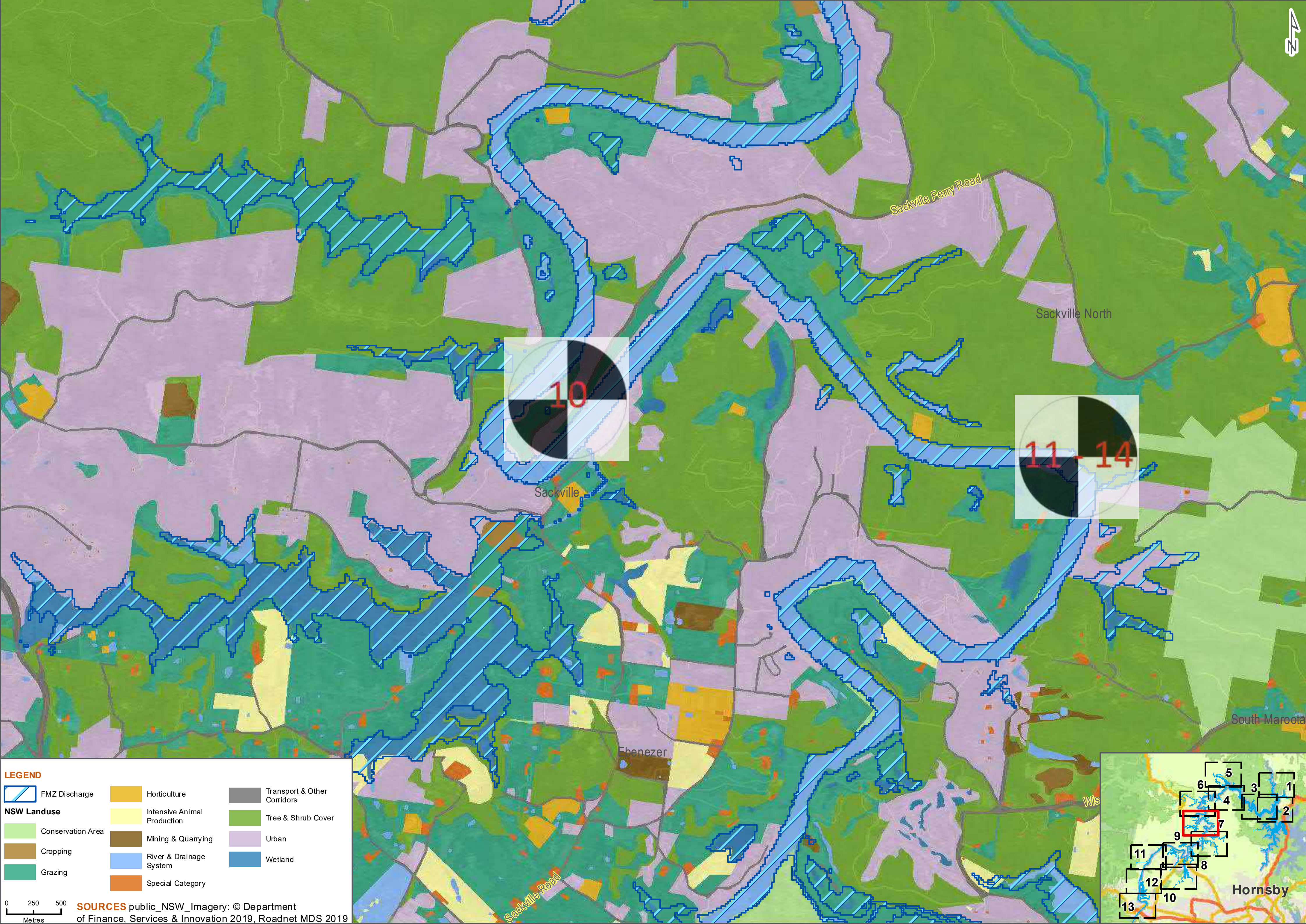
3
4
5
6
7
8
9
10
11
12
13
Hornsby



8 - 30
7
Wisemans Ferry
Laughtondale
Old Northern Road
Weavers
Maroota
Hornsby
LEGEND
FMZ Discharge
NSW Landuse
Conservation Area
Grazing
Horticulture
Intensive Animal Production
Mining & Quarrying
Power Generation
River & Drainage System
Special Category
Transport & Other Corridors
Tree & Shrub Cover
Urban
Wetland
0 250 500
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019

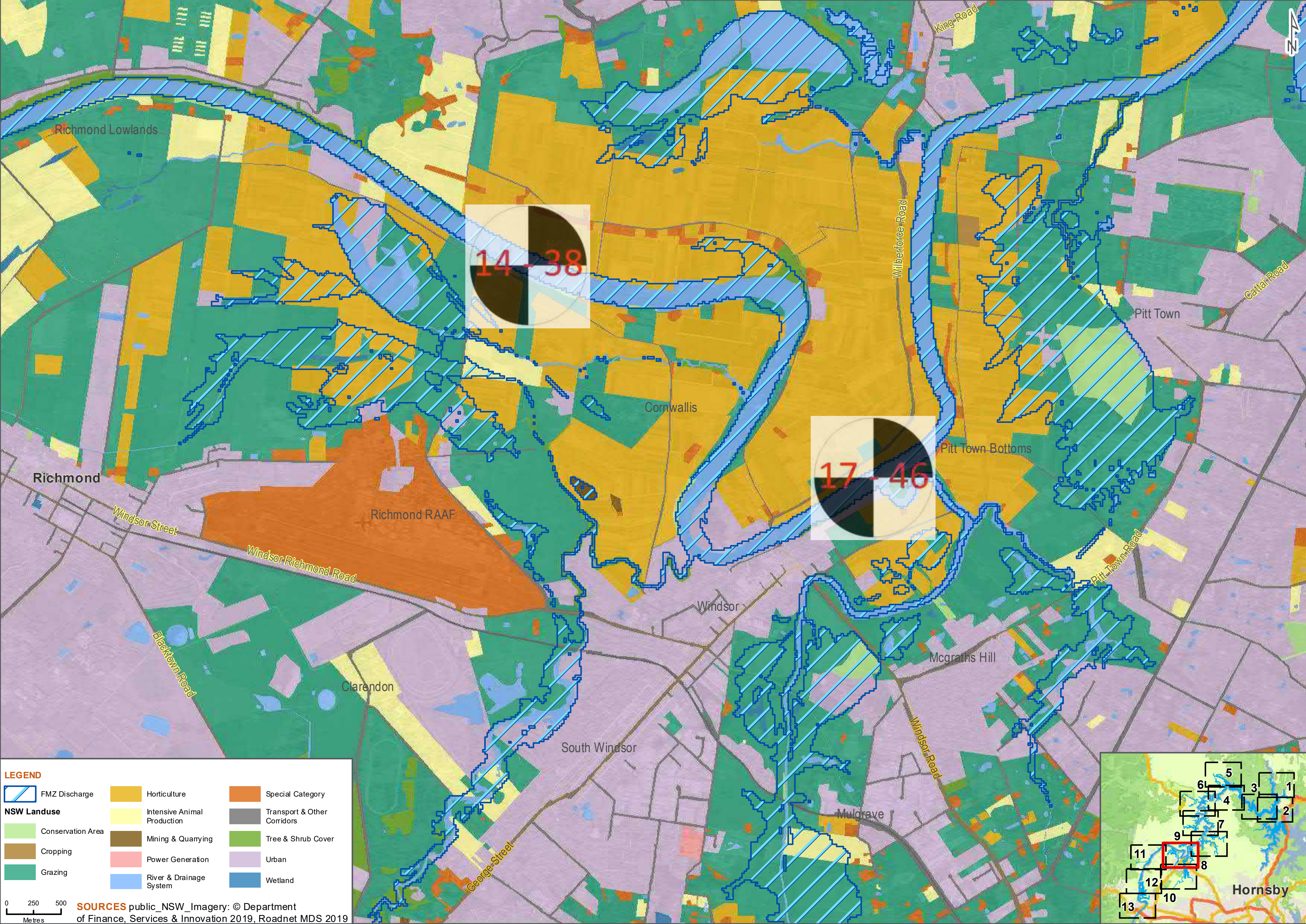

Central Macdonald
St Albans Road
8 - 11
LEGEND
FMZ Discharge
NSW Landuse
Conservation Area
Grazing
River & Drainage System
Transport & Other Corridors
Tree & Shrub Cover
Urban
Wetland
0 250 500
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019
1
2
3
4
5
6
7
8
9
10
11
12
13
Hornsby

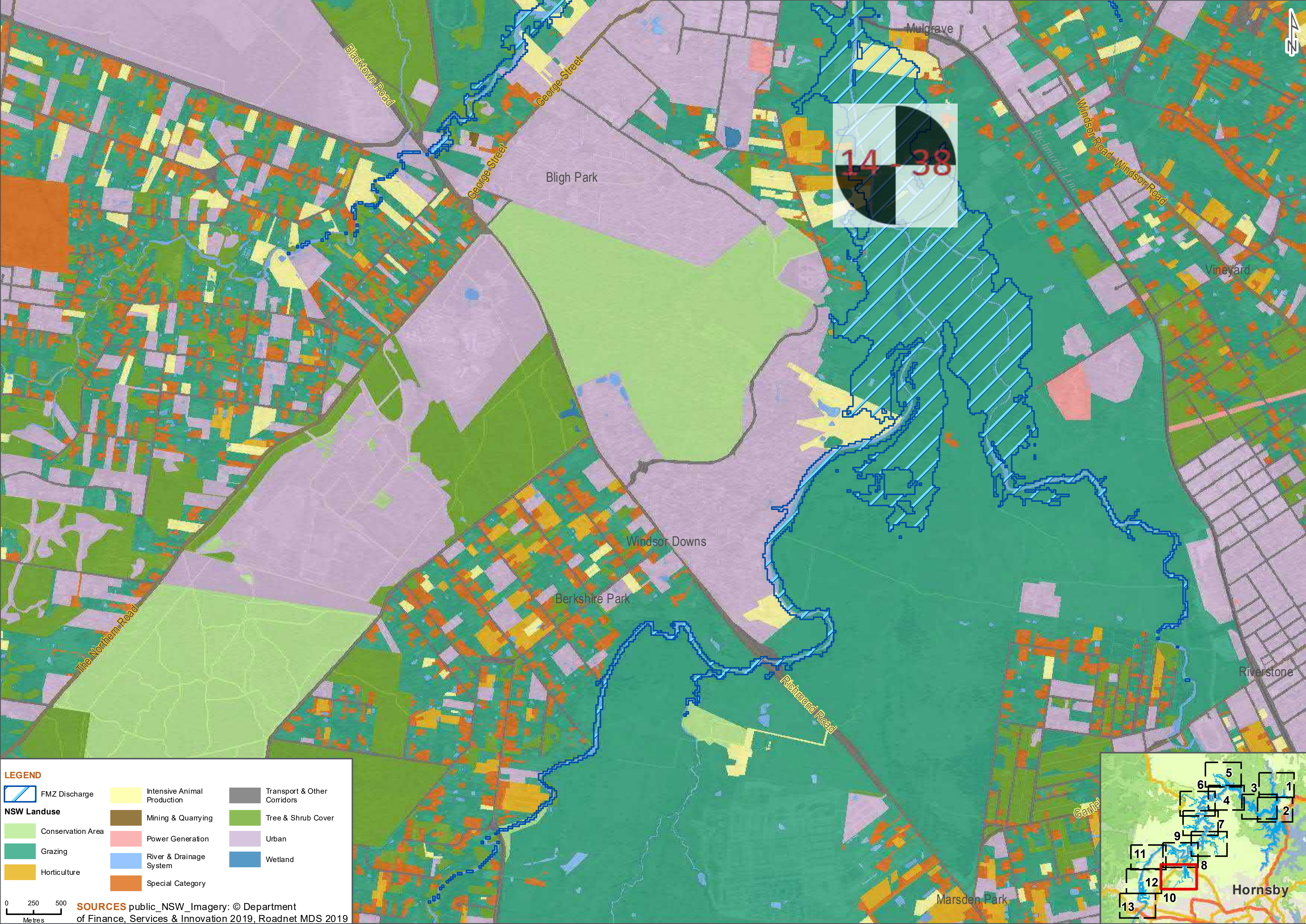
Putty Road
Putty Road
Putty Road
Lower Portland
Sackville
10 - 16
9 - 12
10
N
LEGEND
FMZ Discharge
NSW Landuse
Conservation Area
Cropping
Grazing
Horticulture
River & Drainage System
Transport & Other Corridors
Tree & Shrub Cover
Urban
Wetland
0 250 500
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019
1
2
3
4
5
6
7
8
9
10
11
12
13
Hornsby



Sackville Ferry Road
Sackville North
10
11 - 14
Sackville
Ebenezer
South Maroota
Sackville Road
LEGEND
FMZ Discharge
NSW Landuse
Conservation Area
Cropping
Grazing
Horticulture
Intensive Animal Production
Mining & Quarrying
River & Drainage System
Special Category
Transport & Other Corridors
Tree & Shrub Cover
Urban
Wetland
0 250 500
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019
1
2
3
4
5
6
7
8
9
10
11
12
13
Hornsby

Wisemans Ferry Road
Sackville Road
King Road
Cattai Road
12 14
20 24
18 24
Maraylya
Pitt Town
LEGEND
FMZ Discharge
NSW Landuse
Conservation Area
Grazing
Horticulture
Intensive Animal Production
Mining & Quarrying
Power Generation
River & Drainage System
Special Category
Transport & Other Corridors
Tree & Shrub Cover
Urban
Wetland
0 250 500
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019
1
2
3
4
5
6
7
8
9
10
11
12
13
Hornsby


14 - 38
17 - 46
Richmond Lowlands
King Road
Wilberforce Road
Cattai Road
Pitt Town
Cornwallis
Pitt Town Bottoms
Richmond
Richmond RAAF
Windsor Street
Windsor Richmond Road
Windsor
Pitt Town Road
Mcgraths Hill
Blacktown Road
Clarendon
South Windsor
Windsor Road
Mulgrave
George Street
LEGEND
FMZ Discharge
NSW Landuse
Conservation Area
Cropping
Grazing
Horticulture
Intensive Animal Production
Mining & Quarrying
Power Generation
River & Drainage System
Special Category
Transport & Other Corridors
Tree & Shrub Cover
Urban
Wetland
0 250 500
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019
1
2
3
4
5
6
7
8
9
10
11
12
13
Hornsby


Mulgrave
Blacktown Road
George Street
George Street
Bligh Park
14 - 38
Richmond Line
Windsor Road
Windsor Road
Vineyard
Windsor Downs
Berkshire Park
The Northern Road
Richmond Road
Riverstone
Marsden Park
LEGEND
FMZ Discharge
NSW Landuse
Conservation Area
Grazing
Horticulture
Intensive Animal Production
Mining & Quarrying
Power Generation
River & Drainage System
Special Category
Transport & Other Corridors
Tree & Shrub Cover
Urban
Wetland
0 250 500
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019
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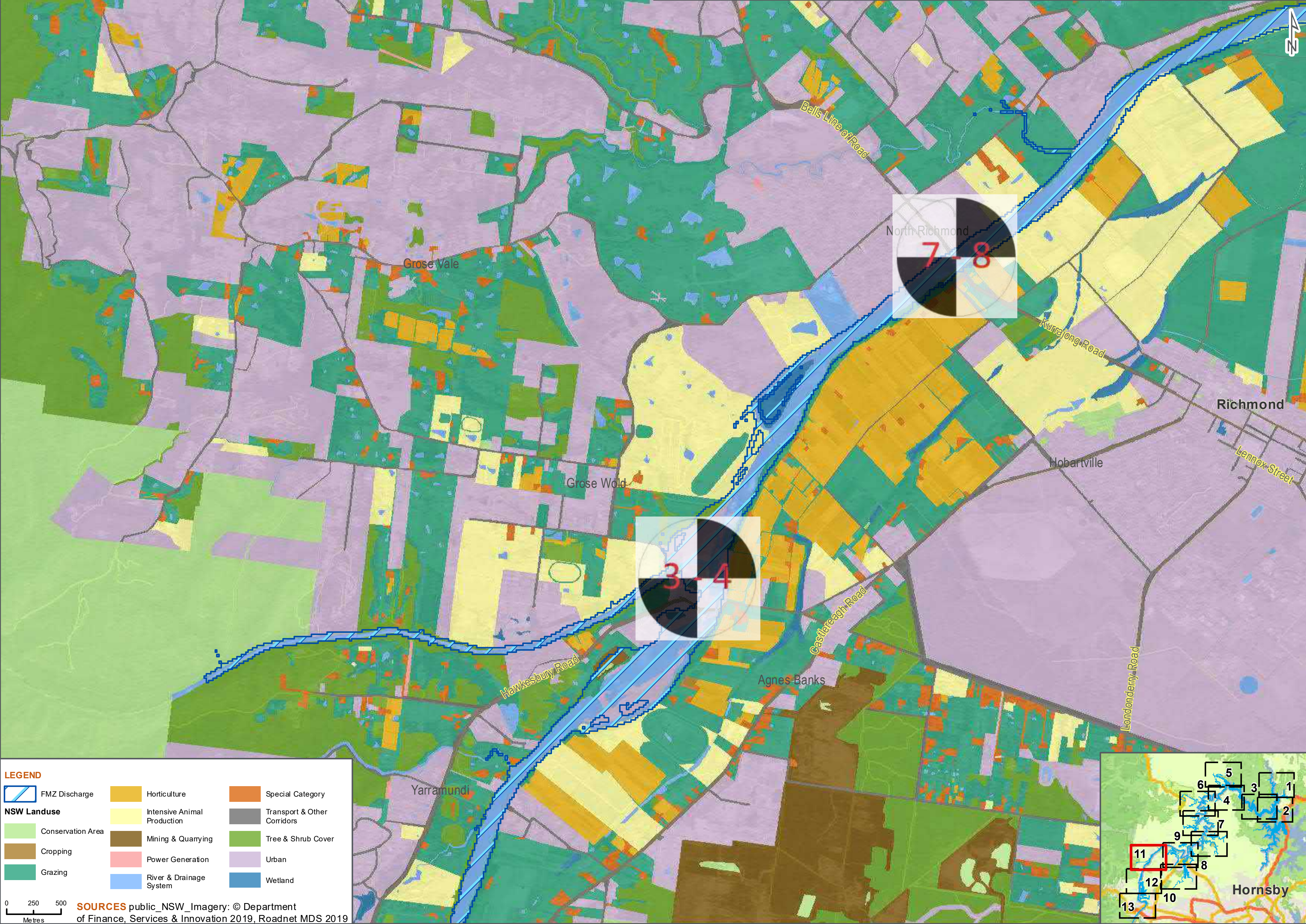
Hornsby



Bells Line of Road
North Richmond
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Grose Vale
Kurrajong Road
Richmond
Hobartville
Lennox Street
Grose Wold
3
4
Castlereagh Road
Londonderry Road
Hawkesbury Road
Agnes Banks
Yarramundi
LEGEND
FMZ Discharge
NSW Landuse
Conservation Area
Cropping
Grazing
Horticulture
Intensive Animal Production
Mining & Quarrying
Power Generation
River & Drainage System
Special Category
Transport & Other Corridors
Tree & Shrub Cover
Urban
Wetland
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SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019
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Hornsby

Londonderry Raaf
Londonderry
Londonderry Road
Hawkesbury Heights
Castlereagh
Hawkesbury Road
Winmalee
Castlereagh Road
The Northern Road
Yellow Rock
4
LEGEND
FMZ Discharge
NSW Landuse
Conservation Area
Cropping
Grazing
Horticulture
Intensive Animal Production
Mining & Quarrying
Power Generation
River & Drainage System
Special Category
Transport & Other Corridors
Tree & Shrub Cover
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0 250 500
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SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019
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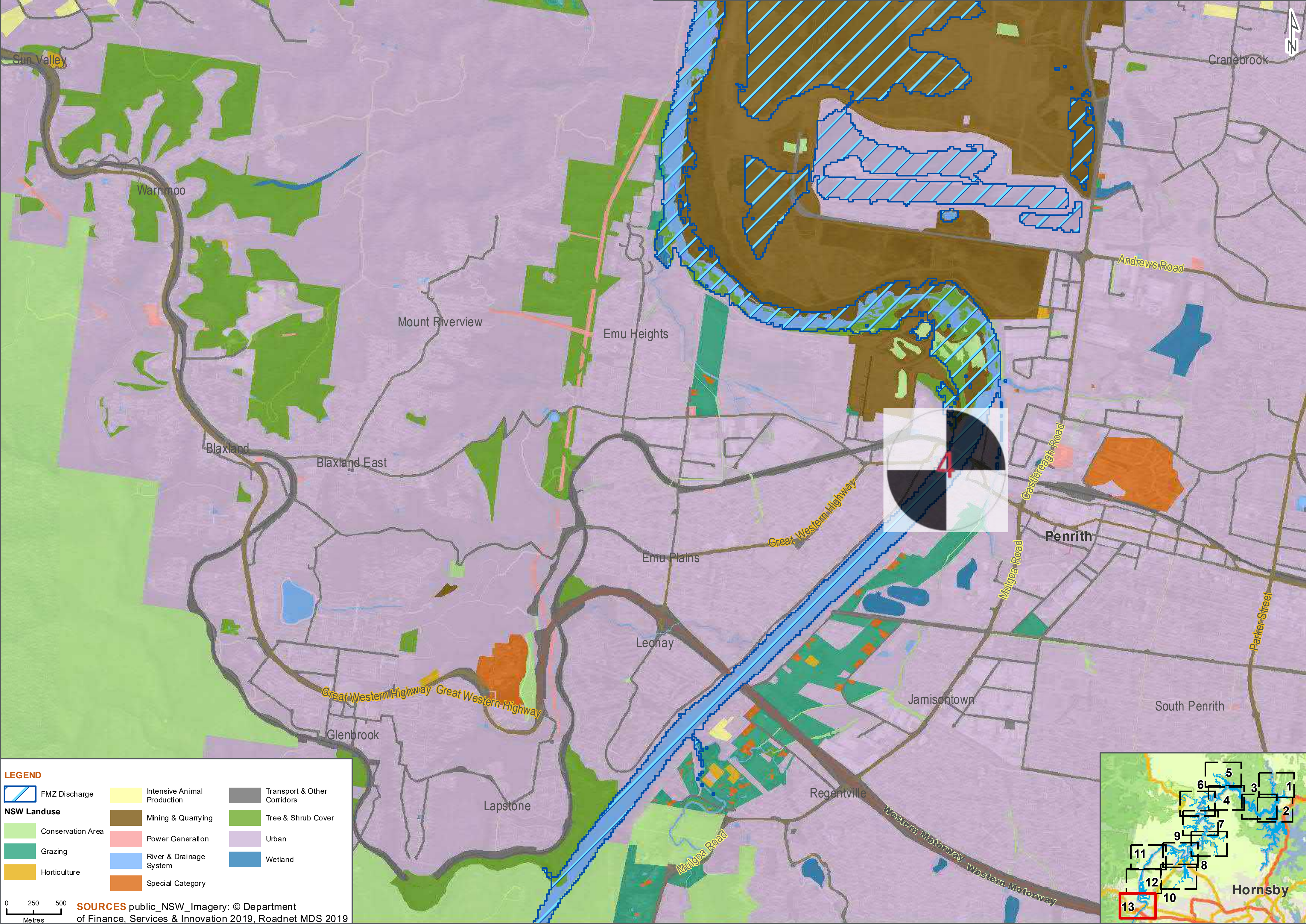
Hornsby



Sun Valley
Warrimoo
Mount Riverview
Emu Heights
Cranebrook
Andrews Road
Blaxland
Blaxland East
Castlereagh Road
Great Western Highway
Penrith
Emu Plains
Mulgoa Road
Parker Street
Leonay
Jamisontown
South Penrith
Great Western Highway
Great Western Highway
Glenbrook
Regentville
Lapstone
Mulgoa Road
Western Motorway
Western Motorway
Hornsby
LEGEND
FMZ Discharge
NSW Landuse
Conservation Area
Grazing
Horticulture
Intensive Animal Production
Mining & Quarrying
Power Generation
River & Drainage System
Special Category
Transport & Other Corridors
Tree & Shrub Cover
Urban
Wetland
0 250 500
Metres
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019
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Appendix L – Mitigation Measures

Operation mitigation measures

Mitigation measure code	Mitigation Measure Description	Broad mitigation measure category
Impact: Out of bank erosion - **Brimstone Creek, Green Wattle Creek, Nattai River, Tonalli Creek, Wollondilly River** - **Butchers Creek, Coxs River, Kedumba River, Kowmung River (lower), Laceys Creek**		
MM01	A Catchment Erosion Management Plan would be developed in consultation with NPWS as part of National Parks EMP. The plan will: - Develop and implement a monitoring program to identify the current catchment condition and any changes due to the Project - Identify locations where existing erosion is occurring or landscape stability is poor and target appropriate control measures - Identify locations where vegetation cover is poor or impacted by grazing and target appropriate control measures - Detail monitoring and implementation of appropriate erosion and rehabilitation measures after operation of the Flood Mitigation Zone	National Parks EMP
MM02	Adaptive management if erosion impacts observed - bank engineering works	
MM03	Bank erosion control at impacted sites on the Cox's Kedumba, Nattai and Wollondily Rivers. The type of control will depend on the magnitude and spatial scale as well as the bank structure but could include tree spiling, mattress / geotextile / plant roll revetments, coir matting or sheet piling.	
MM04	Bank stabilisation work in vulnerable areas where existing vegetation cover protection is poor. This includes the Coxs and Wollondilly catchment where land has been grazed adjacent to the river channel and the Nattai River where Rockfall Avalanches are close to the river channel. Careful selection of native species, documented in a vegetation management plan, that have deep roots and can withstand inundation where possible.	
MM05	Geomorphology walkover survey to monitor changes in channel geometry and excessive erosion as part of WaterNSW data quality and monitoring improvement program. Recommended frequency would be following construction and then on an annual routine basis. Field surveys or air photo analysis (in remote areas) to provide robust perspective of bank erosion within the catchment and target mitigation measures.	
MM06	Construction of porous flow retardation structures upon gully floors in upper catchments of the Coxs and Wollondilly as part of the WaterNSW Grazing and Erosion Program. These will reduce flow velocity, encourage sediment deposition (to provide a substrate for vegetation regrowth where this may be lacking) and retain moisture higher in the landscape.	Existing mitigation measures

Mitigation measure code	Mitigation Measure Description	Broad mitigation measure category
MM07	Gully networks in the Coxs and Wollondilly sub-catchments are relatively stable in their planform extent. Emphasis should be placed on retaining sediments eroded principally from sidewall erosion within the gully system and attempting to convert established gullies from efficient conveyors of sediment (due to their channelisation) to efficient retainers of sediment.	Existing mitigation measures (continued)
MM08	Improving management practices on agricultural land, as part of the WaterNSW Grazing and Erosion Program, to minimise hillslope-derived sediment delivery to the stream network. This action also falls under the SASPoM Four Year Land Management Priorities 2016-19.	
MM09	Management practices that preserve the vegetation cover upon upstream sediment deposits as part of the WaterNSW Grazing and Erosion Program and WaterNSW Catchment Protection Work Program should be encouraged to inhibit scour and floodplain stripping by flood waters. This action also falls under the SASPoM Four Year Land Management Priorities 2016-19.	
MM10	Preventing wildfire within the Warragamba Special Area in accordance with the WaterNSW Remote Areas Fire Management Program. If wildfire or hazard reduction burns occur, reducing sediment yield impacts by installing sediment curtains in the affected area of burnt sub-catchments until revegetation occurs.	
MM11	Riverine improvements works on the Coxs, Nattai and Wollondilly as part of the WaterNSW Grazing and Erosion Program including reinstatement of sinuosity whilst maintaining flow capacity, installation of waterway riffles, re-profiling to decrease bank height and vegetation management to reduce channel shade. Opportunities to implement these measures may be limited as the original works were probably completed for flood protection purposes.	
MM12	Stock exclusion from gully networks in the Coxs and Wollondilly catchments as part of the WaterNSW Grazing and Erosion Program to enhance vegetation growth, which in turn should increase sediment trapping potential, and reduce poaching to decrease sediment available for transport / reduce mass failure. This will also reduce trampling / soil compaction which reduces vegetation cover. Provision of off-stream watering systems. This action also falls under the SASPoM Four Year Land Management Priorities 2016-19.	
MM13	Suppression or removal of weeds and pest species as part of the WaterNSW Catchment Protection Work Program	
MM14	The presence or emplacement of large woody debris in channels as part of aquatic habitat management 'seeding' improvements in the Coxs, Kedumba, Kowmung, Nattai and Wollondilly should be considered carefully to not exacerbate existing bank erosion issues.	Outside scope mitigation measures
Impact: Translocation of sediment features upstream – Coxs and Wollondilly Rivers		

Mitigation measure code	Mitigation Measure Description	Broad mitigation measure category
MM15	Adaptive management if upstream deposition impacts observed - removal of sediments (i.e. dredging)	National Parks EMP
Impact: Floodplain sediment deposition – Kedumba and Wollondilly Rivers		
MM16	Preventing wildfire within the Warragamba Special Area in accordance with the WaterNSW Remote Areas Fire Management Program. If wildfire or hazard reduction burns occur, reducing sediment yield impacts by installing sediment curtains in the affected area of burnt sub-catchments until revegetation occurs.	Existing mitigation measures
MM17	Reduce sediment generation from road and track surfaces in the Warragamba Special Areas as part of the WaterNSW Unsealed Roads Program	
MM18	Use of the Erosion Hotspot Tool provided as part of this assessment (or the existing WaterNSW Pollution Assessment Tool) to target management effort to minimise diffuse sources of sediments in the upstream catchment under the SASPoM Four Year Land Management Priorities 2016-19.	
MM19	Riparian vegetation buffer projects including minimum 10 metre widths upslope and 5 m grass filter strip to trap sediment-laden runoff before it enters channels. Note requirements of Core Riparian Zone Widths as part of Guidelines for Controlled Activities near Watercourses (only relevant for Downstream Zone).	Outside scope mitigation measures
MM20	Forestry clearfell practices in state forests to reduce sediment incursion into watercourses	
MM21	Increase the potential for sediment storage on Coxs River below Lyell Dam and lower Wollondilly River floodplains which have efficient pathways to the reservoir due to the steep topography. This could include the identification and maintenance of existing in-stream wetlands particularly in the tributaries of the major rivers. The possibility of strategic re-establishment of equivalent features should also be investigated, in consultation with local landholders and catchment management groups.	
MM22	Influence the planning decisions and holding mining companies to account for remediation actions associated with the Yerranderie abandoned silver mining	
Impact: Out of shoreline erosion – Lake Burragorang North, South and West Arms		
MM23	Shoreline stabilisation works including reprofiling, vegetation planting and edging (e.g. coir rolls) to reduce wave energy in exposed areas where cultural / ecological assets need to be protected. Careful selection of native species that have deep roots and can withstand inundation, where possible.	National Parks EMP
MM24	In severe erosion cases, terracing or wave deflectors could be deployed.	

Mitigation measure code	Mitigation Measure Description	Broad mitigation measure category
MM25	Influence the planning decisions and hold mining companies to account for remediation actions associated with the North Nattai Rockfall Avalanche	Existing mitigation measures
MM26	Preventing wildfire within the Warragamba Special Area in accordance with the WaterNSW Remote Areas Fire Management Program. If wildfire or hazard reduction burns occur, reducing sediment yield impacts by installing sediment curtains in the affected area of burnt sub-catchments until revegetation occurs.	
Impact: Elevated erosion of shoreline banks – Lake Burragorang North, South and West Arms		
MM27	Bank erosion control at impacted sites in the central, north-west and southern arms of the lake foreshore where cultural / ecological assets need to be protected. The type of control will depend on the magnitude and spatial scale as well as the bank structure but could include tree spiling, mattress / geotextile / plant roll revetments, coir matting or sheet piling.	National Parks EMP
MM28	Bank stabilisation work in vulnerable areas where existing protection is poor and wave undercutting is observed. This should focus on exposed banks in the central and southern areas of the lake where cultural / ecological assets need to be protected. Careful selection of native species, documented in a vegetation management plan, that have deep roots and can withstand inundation where possible.	
MM29	Shoreline stabilisation works including reprofiling, vegetation planting and edging (e.g. coir rolls) to reduce wave energy in exposed areas where cultural / ecological assets need to be protected. Careful selection of native species that have deep roots and can withstand inundation, where possible.	
MM30	Stock exclusion from gully networks in the Coxs and Wollondilly catchments as part of the WaterNSW Grazing and Erosion Program to enhance vegetation growth, which in turn should increase sediment trapping potential, and reduce poaching to decrease sediment available for transport / reduce mass failure. This will also reduce trampling / soil compaction which reduces vegetation cover. Provision of off-stream watering systems. This action also falls under the SASPoM Four Year Land Management Priorities 2016-19.	Existing mitigation measures
MM31	Adaptive management if impacts erosion observed - lake foreshore engineering works	National Parks EMP
MM32	Construction of porous flow retardation structures upon gully floors on the lake foreshore that are more than 0.3 m depth. These will reduce flow velocity, encourage sediment deposition (to provide a substrate for vegetation regrowth where this may be lacking) and retain moisture higher in the landscape.	
MM33	Geomorphology boat survey to monitor changes in channel geometry and excessive erosion as part of WaterNSW data quality and monitoring improvement program. Recommended frequency would be following	

Mitigation measure code	Mitigation Measure Description	Broad mitigation measure category
	construction and then on an annual routine basis. Field surveys or air photo analysis to provide robust perspective of bank erosion within the catchment and target mitigation measures. Fixed point photography of any rockfall avalanches to monitor change.	
MM34	Geosynthetic fabric to stabilise banks initially and help to re-establish vegetation	
MM35	In severe erosion cases, terracing or wave deflectors could be deployed.	
Impact: Deposition of sediments on sensitive ecological / heritage receptors during lake inundation events - North, South and West Arms		
MM43	Preventing wildfire within the Warragamba Special Area in accordance with the WaterNSW Remote Areas Fire Management Program. If wildfire or hazard reduction burns occur, reducing sediment yield impacts by installing sediment curtains in the affected area of burnt sub-catchments until revegetation occurs.	Existing mitigation measures
MM44	Reduce sediment generation from road and track surfaces in the Warragamba Special Areas as part of the WaterNSW Unsealed Roads Program	
MM45	Increase the potential for sediment storage on floodplains, especially the Coxs River below Lyell Dam and lower Wollondilly River sub-catchments which have efficient pathways to the reservoir due to the steep topography. This could include the identification and maintenance of existing in-stream wetlands particularly in the tributaries of the major rivers. The possibility of strategic re-establishment of equivalent features should also be investigated, in consultation with local landholders and catchment management groups.	Outside scope mitigation measures
MM46	Riparian vegetation buffer projects including minimum 10 metre widths upslope and 5 m grass filter strip to trap sediment-laden runoff before it enters channels. Note requirements of Core Riparian Zone Widths as part of Guidelines for Controlled Activities near Watercourses (only relevant for Downstream Zone).	
Impact: Change in lake circulation patterns causing sediment redistribution		
MM47	Monitoring including review of depth integrated turbidimeters. Adaptive management if stratification causes sediment impacts – bubblers, changing offtake level or switching supply source	Mitigation Measures – Water Quality
Impact: Cumulative bank erosion impact in downstream reaches caused by prolonged FMZ flows		
MM48	Audit and investigation of riverbanks (e.g. materials, riparian vegetation, existing patterns of erosion and the vulnerability to future erosion caused by the project) to determine specific capital works requirements to mitigate the projects effects Focus on the two high risk reaches, but also investigate potential localised risk sites in medium risk reaches.	Geomorphic stability program

Mitigation measure code	Mitigation Measure Description	Broad mitigation measure category
MM49	Survey of bank erosion protection structures (eg weirs, gabion walls, rock protection/rip-rap and retaining walls) to determine specific capital works required to mitigate the projects effects.	
MM50	This mitigation number is intentionally blank	
MM51	Based on the findings of MM48/MM49 - Bank erosion control at identified locations within 'High' rated reaches. The type of control will depend on the magnitude and spatial scale as well as the bank structure but could include tree spiling, mattress / geotextile / plant roll revetments, coir matting or sheet piling, or other site-specific engineering structures.	
MM52	Based on the findings of MM48/MM49 - Bank stabilisation work in vulnerable areas in reaches ranked as at Medium risk. Control measures expected to be less intensive in nature than in MM51.	
MM53	This mitigation number is intentionally blank	
MM54	This mitigation number is intentionally blank	
MM55	This mitigation number is intentionally blank	
MM56	Follow FMZ Drawdown Framework for releasing water from the FMZ. This includes guiding principles to assist in mitigating downstream impacts from FMZ releases.	Mitigation Measures – Hydrology
MM57	Controlled ramping up and ramping down of FMZ release rates to minimise bank erosion issues. Variation in dam release depending on the antecedent moisture condition of the downstream river banks. If the flood occurs when the river banks are already wet, but not yet totally saturated, the ideal strategy would be to control the release so that there is a fast drawdown to avoid bank saturation being reached. If the flood occurs when the river banks are relatively dry, there is less likelihood of banks suffering wet failures and a longer and flatter drawdown to allow controlled drainage/ exfiltration of the river banks could reduce bank erosion.	
MM58	The presence or emplacement of large woody debris in the Nepean River between Penrith Weir and the Grose River Junction and the Hawkesbury River between North Richmond and Colo River Junction as part of aquatic habitat management improvements should be considered carefully to not exacerbate existing bank erosion issues.	Outside scope mitigation measures
Impact: Increased fine sediment content in Hawkesbury-Nepean river channel		
MM59	Adaptive management if downstream sedimentation impacts observed - removal of sediments (i.e. dredging)	Mitigation Measures – Water Quality
MM60	Changing discharge points through the dam wall if new, sediment-laden inflows are stratified within the reservoir.	

Mitigation measure code	Mitigation Measure Description	Broad mitigation measure category
MM61	Control water discharge release immediately after high rainfall events, with the aim of avoiding the most turbid water being transferred downstream into the Warragamba-Nepean-Hawkesbury River Systems.	
MM62	Consider timing of FMZ release to avoid both neap tide (avoid migration of turbidity maximum) and spring tides (minimise estuarine turbidity)	
MM63	Follow FMZ Drawdown Framework for releasing water from the FMZ. This includes guiding principles to assist in mitigating downstream impacts from FMZ releases.	Mitigation Measures – Hydrology
MM64	Riparian vegetation buffer projects including minimum 10 metre widths upslope and 5 m grass filter strip to trap sediment-laden runoff before it enters channels. Note requirements of Core Riparian Zone Widths as part of Guidelines for Controlled Activities near Watercourses (only relevant for Downstream Zone).	Outside scope mitigation measures
Impact: Floodplain sedimentation from out of bank flows		
MM65	Downstream Notification System of Sunny Day Releases developed and implemented. This would include providing sufficient notice to land users (e.g. farmers to move livestock to higher ground that might suffer from high sedimentation, irrigators to move pumps that may be covered in sediments, recreational sites to reorganise activity).	Mitigation Measures – Hydrology
MM66	Follow FMZ Drawdown Framework for releasing water from the FMZ. This includes guiding principles to assist in mitigating downstream impacts from FMZ releases.	
MM67	Monitoring of sensitive receptors during operational inundation - impacts observed	Mitigation Measures – Ecology Mitigation Measures – Heritage
MM68	Check floodgates and drainage systems Richmond-Windsor floodplain are operating as designed to reduce the backwater effect and therefore risk of constraints to land use from excessive sedimentation on the floodplain.	Outside scope mitigation measures
MM69	Levee construction to protect sensitive areas	

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