

Appendix L – Flood impact assessment

Newstan Mine Extension Project

Flood impact assessment

Prepared for Centennial Newstan Pty Ltd
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Newstan Mine Extension Project

Flood impact assessment

Report Number

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Client

Centennial Newstan Pty Ltd

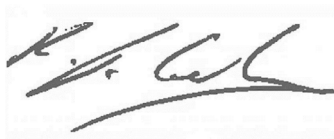
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Executive Summary

ES1 Overview

EMM Consulting Pty Ltd (EMM) was commissioned by Centennial Newstan Pty Ltd (Centennial Newstan) to prepare a flood impact assessment for the Newstan Mine Extension Project (the project). Newstan Colliery is located approximately 25 kilometres (km) south-west of Newcastle and approximately 140 km north of Sydney within the Lake Macquarie local government area. Centennial Newstan is currently seeking approval for the project, which includes the extension of underground mining operations both within and beyond existing approved mining areas.

A subsidence impact assessment was prepared for the project by Mine Subsidence Engineering Consultants (MSEC) (2019). The greatest subsidence was predicted to occur where the proposed workings occur beneath the existing Awaba workings in the overlying Great Northern seam. Intermediate subsidence effects were predicted where the proposed workings are outside the extent of the existing Awaba workings (MSEC 2019). Lower level subsidence effects were predicted outside of the existing Awaba workings or where there are first working areas within the proposed workings and/or the existing Awaba workings (MSEC 2019).

ES2 Assessment approach and purpose

Flood models were developed to assess existing flood conditions as well as the impact of predicted subsidence on flood behaviour within the study area and downstream areas. Flooding conditions and impacts were assessed for a range of flood frequencies up to and including an extreme event approximating the probable maximum flood.

Results of the flood modelling were also utilised to inform a watercourse geomorphology assessment undertaken by Soil Conservation Service (SCS), which forms Appendix A to this report. The primary objectives of the watercourse geomorphology assessment were to assess the impacts of potential subsidence on the geomorphology of watercourses within the Extension of Mining Area and to identify the level of risk to geomorphic integrity.

Results of the flood modelling were also utilised to inform an aquatic ecology assessment undertaken by GHD Pty Ltd.

ES3 Hydrology

A hydrology model was developed to assess design flows within the study area and adjacent catchments. The hydrology model was utilised to provide peak flow input into one-dimensional (1D) hydraulic models for select watercourse reaches within the predicted subsidence impact areas and to determine the critical storm events for assessment in a two-dimensional hydraulic model.

ES4 Hydraulics

A regional two-dimensional hydraulic model was developed to inform a watercourse geomorphic assessment, quantify changes in peak flows leaving the subsidence impact areas and identify flooding impacts within the Extension of Mining Area including changes to remnant ponding. Six watercourse reaches were selected for 1D hydraulic modelling to provide more detailed inputs to the watercourse geomorphology assessment.

ES5 Hydraulic assessment

ES5.1 Impacts within the study area

Predicted flooding impacts within the study area are described and presented in flood mapping for event frequencies ranging from 0.5 exceedances per year (EY) to an extreme event, with consideration of flood extents, depths and flow velocities.

In general, the impact of potential subsidence on flood behaviour was found to be localised around channel gradient changes within the subsidence impact areas. Flood impacts were contained predominantly on undeveloped Crown land and private land holdings relating to the Eraring Energy site. Localised flood impacts in these areas relate to potential maximum subsidence predictions which are unlikely to occur at the same time due to staged extraction.

Prior to extraction, subsidence management and extraction plans will be prepared. These plans will outline subsidence monitoring programs and management measures (such as filling) that may be undertaken to address areas of concern.

Other key findings include:

- Flow paths were generally confined due to the steep terrain. Some minor localised changes to flow paths are expected within the Extension of Mining Area.
- Majority of flooding predicted was relatively shallow.
- Velocities varied along the identified flow paths, indicative of changes in grade and/or remnant pools. Higher velocities generally occurred in locations of steep terrain (ie upper parts of the catchments).
- Flood levels are expected to decrease across the Extension of Mining Area, due to deformation of the final landform. Localised flood depths are expected to increase or decrease around longitudinal gradient changes.

Changes in remnant ponding within the study area were assessed for the 0.5 EY event, on the basis that changes to ponding following smaller, more frequent flood events would likely have greater potential ecological significance than larger, less frequent events. This showed that only a small additional area of remnant ponding may be experienced under subsided conditions for an event of this magnitude.

ES5.2 Downstream flood impacts

No change or minor reductions in peak flows were predicted in watercourses downstream of the Extension of Mining Area for all events assessed, which is attributed to the attenuation of flows associated with additional storage created within the subsided land profile.

ES5.3 Impacts to infrastructure

Potential impacts to infrastructure within the study area are summarised in Table 6.2. No material impacts to infrastructure, with respect to flooding, are expected to occur downstream of the study area.

ES5.4 Impacts to flood risk planning

Flood levels for the 1% annual exceedance probability event were predicted to decrease across the subsidence prediction extent due to the reduction in landform levels. As such, changes to flood planning levels within the study area have not been mapped as these are predicted to decrease.

Minor localised changes to floodway, flood fringe and flood storage categorisations are expected within the subsidence impact area in accordance with minor shifts of the watercourse alignments. Outside of the subsidence impact area, minor reductions in the area of more severe floodplain categories are expected due to the reductions in peak flows leaving the subsidence impact area.

Localised changes in flood hazard are expected around watercourses where longitudinal stream gradients are locally altered due to land deformations. Downstream of the subsidence impact areas, flood hazard is expected to decrease due to minor attenuation of peak flows within the Extension of Mining Area. Emergency management arrangements are not expected to change as a result of the project.

The study area is largely undeveloped, undulating natural bushland. As such, the localised changes in flood risk mentioned above are not expected to impact existing development or infrastructure.

ES5.5 Sensitivity analyses

The sensitivity of flood model results to changes in hydraulic roughness was investigated. Potential increases in rainfall intensities and tailwater levels as a result of future climate change on flooding were also considered. It was found that flooding impacts were generally insensitive to these influences.

ES6 Watercourse geomorphology assessment

Key findings of the watercourse geomorphology assessment were:

- The majority of watercourse reaches were assessed as having negligible or low risk of impact from subsidence.
- Several watercourse reaches of relatively short length were identified as being at moderate or high risk, including sections of:
 - Stockyard Creek (WC4a) and an unnamed tributary (WC4b);
 - unnamed watercourses (WC8, WC20a, WC20b and WC20-US); and
 - an unnamed watercourse north-west of the Eraring Energy site.

It was recommended that targeted monitoring and management plans are developed for these watercourses. Regular visual inspections will allow identification of problem areas and potential threats to nearby infrastructure, as well as development and implementation of appropriate stabilisation techniques as required.

Table of Contents

Executive Summary	ES.1
1 Introduction	1
1.1 Project overview	1
1.2 Extension of Mining Area	2
1.3 Predicted subsidence	6
1.4 Potential hydrologic impacts	6
1.5 Study area	7
1.6 Objectives	7
1.7 Report structure	9
2 Assessment requirements and guidelines	10
2.1 Overview	10
2.2 Assessment requirements	10
2.3 Relevant guidelines	10
2.4 Relevant studies	11
3 Assessment approach	12
3.1 Overview	12
3.2 Available data	12
3.3 Assessment methodology	12
4 Hydrology	15
4.1 Overview	15
4.2 Model schematisation and parameters	15
4.3 Design rainfall	17
4.4 Rainfall losses	17
4.5 Rainfall temporal patterns	18
4.6 Results	18
4.7 Validation of design flow estimates	18
5 Hydraulics	20
5.1 Overview	20
5.2 Two-dimensional model setup	20
5.3 One-dimensional model setup	24

6	Hydraulic assessment	28
6.1	Overview	28
6.2	Existing conditions	28
6.3	Subsided conditions	31
6.4	Impacts to infrastructure	39
6.5	Impacts to flood risk planning	39
6.6	Sensitivity assessment	40
7	Watercourse geomorphology assessment	42
7.1	Overview	42
7.2	Existing geomorphic condition	42
7.3	Watercourse response to catchment impacts	43
8	Summary and conclusions	45
8.1	Overview	45
8.2	Hydraulic assessment	45
8.3	Watercourse geomorphology assessment	46
	References	48
	Abbreviations	49
	Glossary	51

Appendices

Appendix A	Watercourse geomorphology assessment	A.1
Appendix B	Assessment requirements	B.1
Appendix C	Site inspection	C.1
Appendix D	HEC-RAS long sections	D.1
Appendix E	Flood maps	E.1

Tables

Table 3.1	Key storm events assessed	13
Table 4.1	Design rainfall depths	17
Table 4.2	Critical duration and peak flows – WC9 outlet	18
Table 4.3	Comparison of 1% AEP design flows – WC9 outlet	18
Table 5.1	Manning’s roughness values	22
Table 5.2	Whiteheads Lagoon constant water level boundary condition	23

Table 5.3	Adopted watercourse structure dimensions	23
Table 5.4	One-dimensional model peak flows	27
Table 6.1	Peak flows in Lords Creek	36
Table 6.2	Changes to remnant ponding	37
Table 6.3	Impacts to infrastructure	39
Table 6.4	Sensitivity assessment scenarios	40
Table 6.5	Climate change impacts to 1% AEP subsidence conditions flood characteristics	41
Table B.1	Assessment requirements	B.1

Figures

Figure 1.1	Project area	3
Figure 1.2	Extension of Mining Area	4
Figure 1.3	Watercourses	5
Figure 1.4	Study area and subsidence predictions	8
Figure 4.1	Hydrologic environment	16
Figure 5.1	Two-dimensional hydraulic modelling extent	21
Figure 5.2	One-dimensional hydraulic modelling extent	26
Figure 6.1	Existing conditions – flood depth (0.5 EY event)	29
Figure 6.2	Existing conditions – flood velocity (0.5 EY event)	30
Figure 6.3	Potential subsided conditions – change in depth (0.5 EY event)	32
Figure 6.4	Potential subsided conditions – change in velocity (0.5 EY event)	34
Figure 6.5	Comparison of discharge hydrographs – 0.5 EY event	35
Figure 6.6	Comparison of discharge hydrographs – 1% AEP event	36
Figure 6.7	Potential subsided conditions – change in remnant ponding (0.5 EY event)	38
Figure E.1	Existing conditions – flood depth (1% AEP event)	E.2
Figure E.2	Existing conditions – flood depth (0.5% AEP event)	E.2
Figure E.3	Existing conditions – flood depth (0.2% AEP event)	E.2
Figure E.4	Existing conditions – flood depth (extreme event)	E.2
Figure E.5	Existing conditions – flood velocity (1% AEP event)	E.2
Figure E.6	Existing conditions – flood velocity (0.5% AEP event)	E.2
Figure E.7	Existing conditions – flood velocity (0.2% AEP event)	E.2
Figure E.8	Existing conditions – flood velocity (extreme event)	E.2
Figure E.9	Potential subsided conditions – change in depth (1% AEP event)	E.2

Figure E.10	Potential subsided conditions – change in depth (0.5% AEP event)	E.2
Figure E.11	Potential subsided conditions – change in depth (0.2% AEP event)	E.2
Figure E.12	Potential subsided conditions – change in depth (extreme event)	E.2
Figure E.13	Potential subsided conditions – change in velocity (1% AEP event)	E.2
Figure E.14	Potential subsided conditions – change in velocity (0.5% AEP event)	E.2
Figure E.15	Potential subsided conditions – change in velocity (0.2% AEP event)	E.2
Figure E.16	Potential subsided conditions – change in velocity (extreme event)	E.2
Figure E.17	Climate change depth impacts (2050 subsided conditions event)	E.2
Figure E.18	Climate change velocity impacts (2050 subsided conditions event)	E.2
Figure E.19	Climate change depth impacts (2100 subsided conditions event)	E.2
Figure E.20	Climate change velocity impacts (2100 subsided conditions event)	E.2

1 Introduction

1.1 Project overview

Newstan Colliery is an existing underground coal mine in the Lake Macquarie local government area (LGA), approximately 25 kilometres (km) south-west of Newcastle and 140 km north of Sydney, NSW. It is owned and operated by Centennial Newstan Pty Ltd (Centennial Newstan), a wholly owned subsidiary of Centennial Coal Company Limited (Centennial Coal).

Mining operations at Newstan Colliery began in 1887 and upon the introduction of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act) operated pursuant to continuing use rights in accordance with Part 4, Division 10 of the EP&A Act (continuing use rights).

Newstan Colliery has at various times mined the upper coal seams (Great Northern and Fassifern seams) and lower coal seams (West Borehole, Borehole, Young Wallsend and Yard seams) and produced both semi-soft coking coal and thermal coal for the domestic and export markets. In the lower seams, workings to date have been concentrated to the west of the seam split, which is a defining geological feature of the mine. Mining has been undertaken using a combination of bord and pillar and longwall mining.

In August 2014, the underground operations at Newstan Colliery were placed onto care and maintenance due to poor market conditions. In recent years, Centennial Newstan has commenced feasibility investigations into the recommencement of mining at Newstan Colliery. The most recent modification to Newstan Colliery's Development Consent DA 73-11-98 (Mod 8) in January 2019, permits first workings mining within the West Borehole seam in the southern portion of the Newstan Colliery mining lease area. The first workings aim to improve Centennial Newstan's understanding of the geology within the West Borehole seam, including the presence, throw and strike of a major fault zone projected from the historical Newstan workings.

Centennial Newstan is now seeking approval for the continuation of mining within the West Borehole seam. The Newstan Mine Extension Project (the project) proposes to extract up to 25.9 million tonnes over a 15-year period at a maximum production rate of 4 million tonnes per annum of run of mine (ROM) coal. Bord and pillar mining is proposed using continuous miner methods that will include areas of first workings, partial extraction and total extraction. A mix of metallurgical and thermal coal is proposed to be extracted. ROM coal will be delivered to the Newstan Colliery Surface Site via a series of existing underground conveyors. Once the coal reaches the Newstan Colliery Surface Site it will be handled in accordance with the approved operations for the Northern Coal Logistics Project (SSD-5145), managed by Centennial Coal's Northern Coal Services business unit.

Other key features of the project include:

- Utilisation of the Newstan Colliery Surface Site to provide parking, bathhouse, administration and workshop facilities for the underground workforce. A small number of administrative, maintenance and monitoring personnel will also be located at Awaba Colliery Surface Site.
- Transportation of personnel and materials to and from the underground mining area via the existing men and materials drift at Newstan Colliery Surface Site.
- Continued operation of the two existing ventilation fans at Newstan Colliery Surface Site and the installation and operation of three new ventilation fans at the existing ventilation shaft at Awaba Colliery Surface Site.
- In-seam gas drainage, with gas transferred to a new gas flaring facility to be located within the existing disturbance footprint of Awaba Colliery Surface Site.

- Extraction of underground water via the existing Fassifern Pump Station at Newstan Colliery Surface Site and ongoing groundwater management in accordance with Centennial Coal's Northern Operations Regional Water Management Plan.

The project is aligned with the broader Centennial Coal business strategy in that it facilitates the development of a new semi-soft coking coal product stream and a thermal coal product for both the domestic and export markets. The project will enable supply of export coal products while meeting contractual coal supplies to the domestic markets. Over time, the project can potentially replace the coal product currently supplied to the domestic market by other Centennial Coal operations as these other resources become depleted. This will ensure ongoing security of supply for domestic electricity generation.

If approved, the project will allow for the optimisation of resource recovery from Newstan Colliery while providing ongoing direct and indirect employment opportunities. In addition, the project will provide a number of positive flow-on effects to the local, regional and state economies through additional wages and royalties.

1.2 Extension of Mining Area

The Project Application Area represents the entire area that is relevant to the project and encompasses the three distinct areas of Awaba Colliery, Newstan Colliery and the proposed Extension of Mining Area. The regional context of the project and Project Application Area are shown in Figure 1.1.

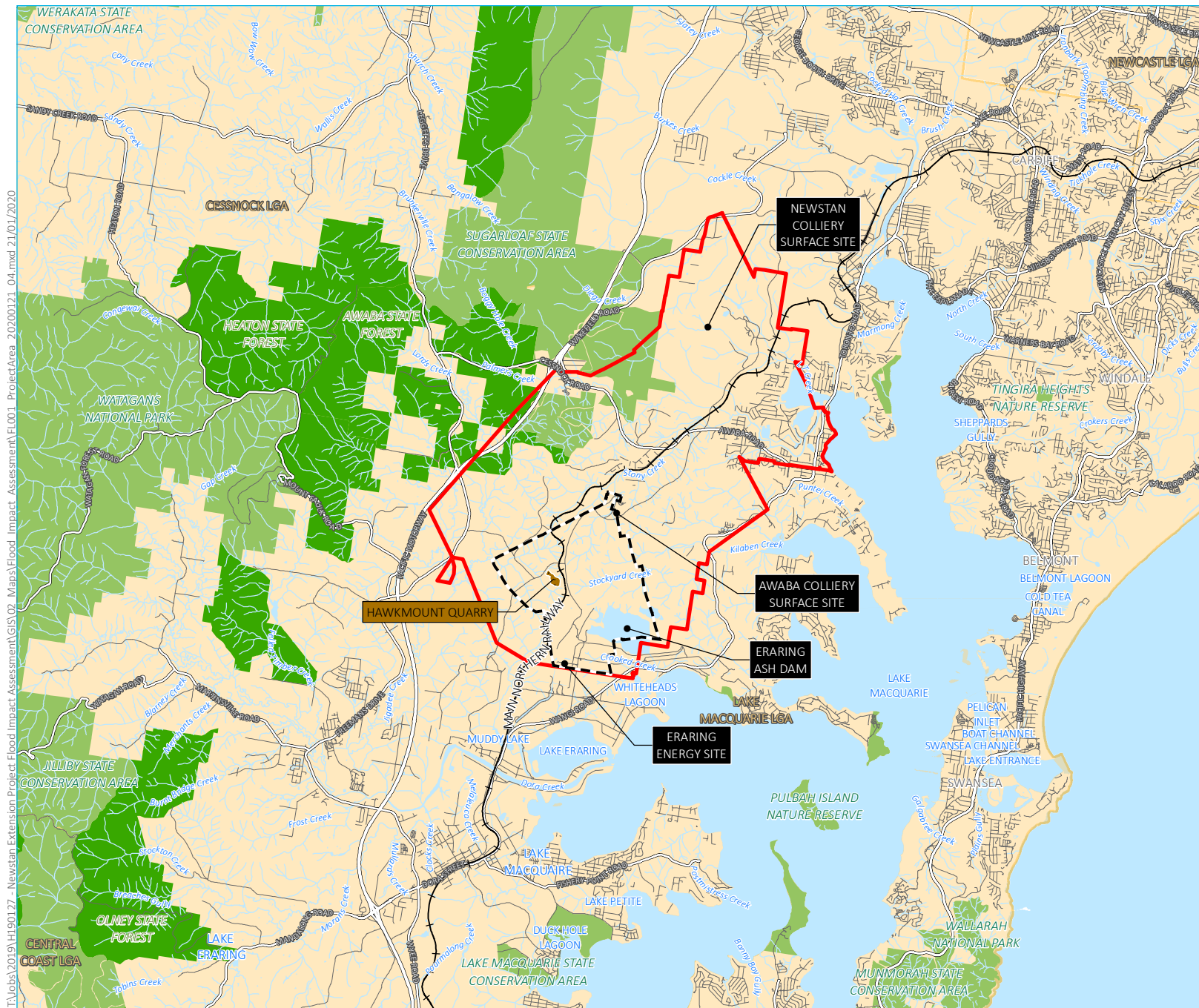
The Extension of Mining Area, as shown in Figure 1.2, is the area within which underground mining is proposed as part of the project. The majority of the Extension of Mining Area is beneath undulating natural bushland, with infrastructure associated with Eraring Energy site (including the Eraring Ash Dam) above the southern extent of the Extension of Mining Area. The Main Northern Railway traverses the Extension of Mining Area in a north-south direction. The Extension of Mining Area is bordered by previous Newstan Colliery mine workings to the north and north-west, while the western part of the proposed mining area is overlain with Awaba Colliery mine workings in the Great Northern seam.

Watercourses in the vicinity of the Extension of Mining Area are shown on Figure 1.3. The main watercourses relevant to this flood impact assessment include:

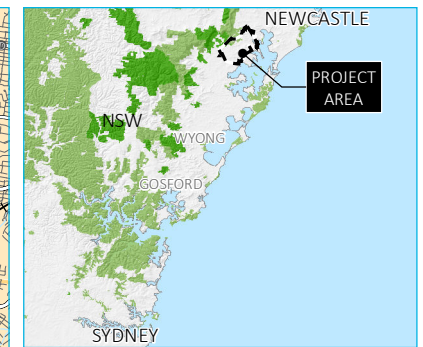
- Stony Creek (WC1), which flows in a north-easterly direction into Fennell Bay;
- Stockyard Creek (WC4), which flows in an easterly direction into Kilaben Creek (WC5) before draining to Kilaben Bay;
- Lords Creek (WC16) (including unnamed tributary WC9), which flows in a westerly direction into Jigadee Creek; and
- Crooked Creek (WC18), which flows in a south-easterly direction into Whiteheads Lagoon and then Myuna Bay.

The majority of watercourses within the Extension of Mining Area are ephemeral, with some sections of the lower reaches becoming perennial. Typically, the upper reaches of the watercourses are relatively steep and are confined to well-defined channels. The lower-lying reaches are comparatively flat with natural ponding evident in some sections.

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Source: EMM (2019); DFSI (2017); GA (2011); ASGC (2006)



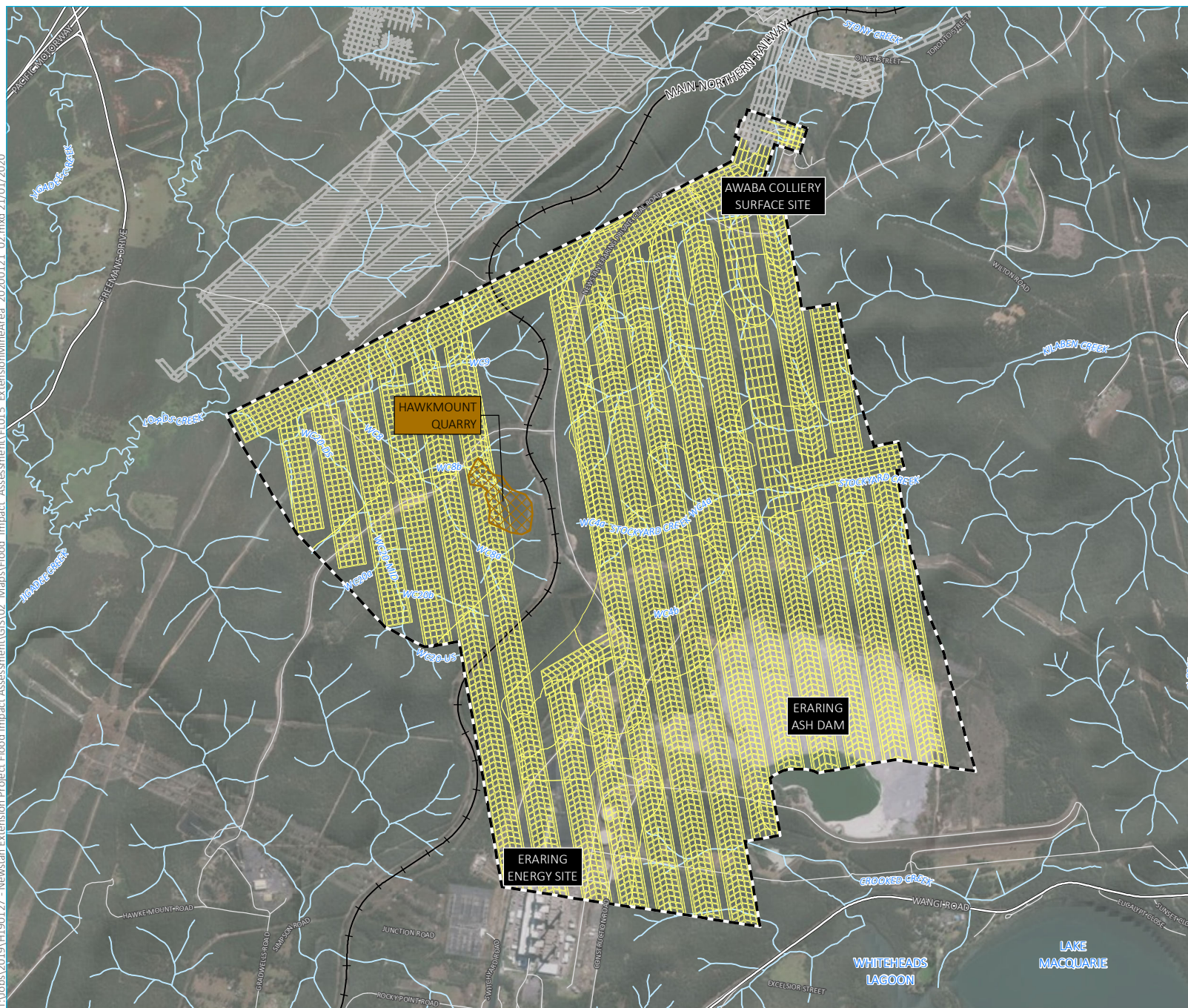
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- Project Application Area
- Extension of Mining Area
- Hawkmount Quarry
- Rail line
- Main road
- Local road
- Watercourse/drainage line
- Local government area
- NPWS reserve
- State forest

Project area

Newstan Mine Extension Project
Flood impact assessment
Figure 1.1





- KEY**
- Extension of Mining Area
 - Hawkmount Quarry
 - Existing West Borehole seam workings
 - Proposed extension mine plan
 - Watercourse/drainage line
 - Rail line
 - Main road
 - Local road

Extension of mining area

Newstan Mine Extension Project
Flood impact assessment
Figure 1.2

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KEY

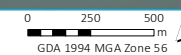
- Extension of Mining Area
- Hawkmount Quarry
- Rail line
- Main road
- Local road
- Watercourse/drainage line
- Strahler stream order
 - First order
 - Second order
 - Third order
 - Fourth order
 - Undefined

Watercourses

Newstan Mine Extension Project
Flood impact assessment
Figure 1.3



Source: EMM (2019); DFSI (2017); GA (2011); ASGC (2006)



1.3 Predicted subsidence

As part of the project, bord and pillar mining would be undertaken in the West Borehole seam using continuous miner methods including areas of first workings, partial extraction and total extraction. Historical mining undertaken by Awaba Colliery in the overlying Great Northern seam would result in some areas of multi-seam mining conditions. The development of first workings (ie no secondary extraction) is proposed to occur beneath sensitive surface features such as second and third order streams, the Main Northern Railway, a 132 kilovolt (kV) substation, the Eraring Energy site and the Eraring Ash Dam wall.

Subsidence occurs when the rock strata immediately above the coal seam is allowed to collapse into the void (referred to as the goaf) that is left after coal is extracted. Subsidence at the ground surface occurs as the underlying strata collapse to fill the void. The ground at the surface subsides vertically and, at the edges of the subsidence zone, it tilts and moves horizontally towards the centre of the zone. Most subsidence effects occur at approximately the same speed as the corresponding undermining. On-going residual settlements due to goaf reconsolidation may continue for a period of up to two years; however, these movements are likely to be small and are unlikely to result in significant impacts at the surface (MSEC 2007; IESC 2014).

A subsidence impact assessment has been prepared for the project by Mine Subsidence Engineering Consultants (MSEC) (2019). The predicted subsidence effects were determined using the incremental profile method, an empirical model developed by MSEC. The model was based on a large database of ground monitoring data from previous mining within the Newcastle, Hunter, Southern and Western coalfields of NSW and calibrated for the local conditions using available ground monitoring data. Comparisons of the predicted total subsidence profiles obtained using the empirical model with measured profiles indicate that this method provides reasonable, slightly conservative predictions. Subsidence predictions using the incremental profile method are conservatively skewed towards an over-estimate of maximum subsidence, with a 10% probability that the predicted maximum subsidence for mines in NSW will be exceeded (MSEC 2014). Numerical modelling was also undertaken to supplement the subsidence predictions obtained using the empirical model and assess the potential deformations within the overburden outside of the existing Awaba workings.

The maximum potential subsidence prediction contours provided by MSEC (2019) are shown in Figure 1.4. The maximum predicted values are after completion of all proposed panels and include multi-seam mining conditions due to the overlying Awaba workings, where present. The subsidence effects vary across the Extension of Mining Area as a result of factors including variations in the panel geometry, depth of cover, mining height, mining method, overburden geology and the existing Awaba workings in the overlying Great Northern seam.

The extraction of the proposed panels directly beneath or adjacent to the Awaba workings may result in the reactivation of these existing workings. As such, the greatest subsidence was predicted to occur where the proposed workings occur beneath the existing Awaba workings in the overlying Great Northern seam (ie multi-seam mining conditions). Intermediate subsidence effects were predicted where the proposed workings are outside the extent of the existing Awaba workings (ie single-seam mining conditions). Lower level subsidence effects were predicted outside of the existing Awaba workings or where there are first working areas within the proposed workings and/or the existing Awaba workings (MSEC 2019).

1.4 Potential hydrologic impacts

Subsidence may impact the form and extent of catchments and can alter or create new flow paths. Analysis of the subsidence predictions (MSEC 2019) indicates that some minor changes may occur in the alignment of minor drainage channels in the upper portions of catchments; however, these changes are unlikely to result in the diversion of headwaters to adjacent catchments or to result in any measurable changes in existing catchment boundaries.

Subsidence may also impact the timing, magnitude and total volume of flow within watercourses. Changes in catchment hydrology may result from the following mechanisms:

- flattening of the landform, leading to slower catchment response and attenuation of flow (ie reduced and delayed peak flow);
- steepening of the landform, leading to quicker catchment response and reduced attenuation of flow (ie increased and faster peak flow); and
- changes in surface storage within flow paths or undrained depressions in the catchment resulting in increased or decreased ponding of water.

These changes in catchment hydrology can result in hydraulic impacts on flood characteristics such as inundation extent, depth and velocity. The nature of the potential hydrologic impact mechanisms of subsidence has been used to inform the study approach, which is outlined in Chapter 3.

1.5 Study area

Subsidence predictions determined by MSEC (2019) have been used to define the study area for this assessment, which encompasses the surface area that could be affected by extraction within the Extension of Mining Area. The study area and maximum potential subsidence prediction contours are shown in Figure 1.4.

The study area encompasses the maximum potential subsidence prediction extent with the exclusion of Eraring Ash Dam. The exclusion boundary considered the catchment contributing to the dam. The assessment of how this catchment changed due to subsidence was considered in this study. However, flooding assessment within the dam was not considered due to the following reasons:

- Inflows to the ash dam are not predicted to materially change due to minor changes in upstream catchment boundaries as a result of subsidence predictions.
- No changes to landform are predicted at the downstream dam wall. Subsided conditions are predicted to slightly increase the ash dam capacity due to potential deformations at the upstream end of the dam. The elevation of the dam wall is not expected to change.
- The nature of how emplaced ash deforms under mining induced subsidence is further described by MSEC (2019) and is unlikely to be in a manner represented by the 2d model (that is a stable landform media typical of the remaining project area).

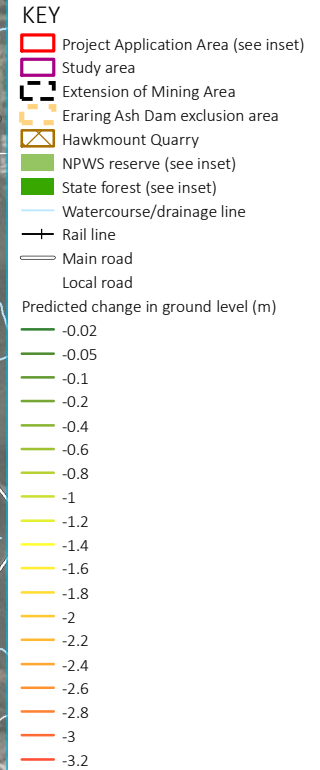
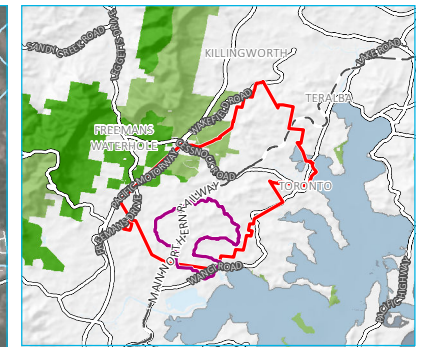
1.6 Objectives

1.6.1 Flood impact assessment

The primary objective of the flood impact assessment was to evaluate the potential impacts of the project on existing hydraulic behaviour. The assessment considers:

- impacts of the project on flood behaviour of other developments or land;
- impacts to infrastructure within the study area with reference to flood behaviour;
- potential changes to floodplain risk as a result of the project; and
- potential changes to watercourse hydraulic behaviour to assist in informing the aquatic ecology assessment (GHD 2019) and watercourse geomorphology assessment (SCS 2019) for the project.

Chapter 3 details the assessment approach undertaken to achieve the above objectives.



Study area and subsidence predictions

Newstan Mine Extension Project
Flood impact assessment
Figure 1.4

It is important to note that the results of the flood modelling are intended to be used for comparative purposes to assess the potential impacts of subsidence on flood behaviour within the Extension of Mining Area. The flood modelling results presented in this report are only considered to be appropriate for assessing changes in the hydraulic characteristics of the study area as a result of the project and not for defining absolute flood levels or flow velocities for planning purposes. The information has been prepared for Centennial Newstan and should not be relied upon by any third party.

1.6.2 Watercourse geomorphology assessment

The watercourse geomorphology assessment (SCS 2019) takes into consideration the results of hydraulic modelling discussed in Chapter 6. The primary objectives of this assessment were to assess the impacts of potential subsidence on the geomorphology of watercourses and to identify the level of risk to geomorphic integrity. The assessment includes:

- assessment and mapping of geomorphic type and condition of watercourses;
- assessment of watercourse response to potential gradient increases and decreases resulting from subsidence;
- identification of potential threats to infrastructure from watercourse impacts; and
- watercourse management recommendations.

The watercourse geomorphology assessment is provided in Appendix A.

1.7 Report structure

This report is structured as follows:

- Chapter 1 outlines the project background;
- Chapter 2 discusses the assessment requirements and relevant guidelines;
- Chapter 3 describes the available information and assessment methodology;
- Chapter 4 describes the hydrologic environment, hydrology model and hydrologic model results;
- Chapter 5 describes the development of hydraulic models used to assess potential flooding and geomorphic impacts; and
- Chapter 6 presents the hydraulic assessment and describes impacts due to potential subsided conditions.

2 Assessment requirements and guidelines

2.1 Overview

This section describes the assessment requirements and relevant guidelines and studies that have been used to inform the assessment.

2.2 Assessment requirements

The flood impact assessment forms part of an environmental impact statement (EIS) to support a State significant development (SSD) application (SSD-10333) under Part 4 of the EP&A Act. The flood impact assessment has been prepared to address the Planning Secretary's Environmental Assessment Requirements (SEARs) for the project and relevant requirements from the NSW Environment, Energy and Science (EES) (part of the Department of Planning, Industry and Environment (DPIE)). The SEARs and additional requirements are presented in Appendix B, along with where each requirement has been addressed in the report.

2.3 Relevant guidelines

2.3.1 IESC information guidelines

The Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) is a statutory body under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*. The key function of the IESC is to independently advise government regulators on the impacts that coal seam gas and large coal mining development may have on Australia's water resources.

The IESC has published information guidelines (IESC 2018) that outline the information considered necessary to enable the IESC to provide robust scientific advice to government regulators on the water-related impacts of coal seam gas and large coal mining development proposals. Appendix B presents the information requirements related to flooding impacts, as well as a reference to where each requirement has been addressed in the report.

2.3.2 Australian Rainfall and Runoff

Australian Rainfall and Runoff (ARR2019) (Ball et al. 2019) is a national guideline document, data and software suite that can be used for the estimation of flood characteristics in Australia. It is widely accepted as a design guideline for all flood and stormwater-related investigation and design in Australia.

2.3.3 NSW Floodplain Development Manual

The NSW *Floodplain Development Manual* (DIPNR 2005) describes flood prone land policy which has the primary objective of reducing the impact of flooding and flood liability on individual owners and occupiers of flood prone property and to reduce private and public losses resulting from floods. At the same time, the policy recognises the benefits from occupation and development of flood prone land.

2.3.4 NSW Floodplain Risk Management Guidelines

A number of guidelines have been developed to complement the *NSW Floodplain Development Manual* (DIPNR 2005). The following documents have also been considered as part of this assessment:

- *Floodplain Risk Management Guideline – Practical Considerations of Climate Change* (DECC 2007), which provides advice on considering climate change impacts in managing flood risk;
- *Floodplain Risk Management Guide – Modelling the interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways* (OEH 2015), which provides advice on approaches to derive oceanic boundary conditions and design flood levels for flooding assessments in coastal watercourses considering the interaction of catchment flooding and oceanic inundation; and
- *Floodplain Risk Management Guide – Incorporating 2016 Australian Rainfall and Runoff in Studies* (OEH 2019), which provides additional guidance for the application of ARR (2016 version) in NSW catchments.

2.4 Relevant studies

Flood studies for catchments adjacent to or within proximity of the study area have been completed for Lake Macquarie City Council. Relevant results from the following studies were used to inform the modelling methodology:

- *Stony Creek Flood Study* (Cardno 2005);
- *LT Creek Flood Study* (BMT WBM 2011);
- *Lake Macquarie Waterway Flood Study* (WMAwater 2012); and
- *Dora Creek Flood Study* (WMAwater 2015).

3 Assessment approach

3.1 Overview

This chapter describes the assessment approach including data utilised and the adopted assessment methodology.

3.2 Available data

A desktop assessment of existing information was undertaken at project commencement. Additional project-specific information was provided by Centennial Newstan. The following data has been used to inform the flood impact assessment:

- design rainfall intensity and temporal pattern information obtained from the Bureau of Meteorology (BoM);
- LiDAR digital elevation model (DEM) data at one metre (m) resolution (dated September 2014) obtained from NSW Government Department of Finance, Services and Innovation (DFSI) – Spatial Services department;
- project-specific data from Centennial Newstan:
 - *Newstan Mine Extension Project Scoping Report* (Centennial Coal 2019);
 - aerial imagery of the study area (dated 11 June 2019);
 - topography data including 2 m and 10 m contours and a 2 m grid (dated June 2018);
 - AutoCAD files of the infrastructure and site plans of Eraring Energy site and Eraring Ash Dam; and
 - proposed workings and mining methods (dated 23 March 2019);
- subsidence predictions from external modelling by MSEC, including subsidence contours, stream profiles and associated report (MSEC 2019); and
- site observations gathered during field survey (Section 3.3.1).

3.3 Assessment methodology

The key focus of this assessment is to evaluate the relative changes to hydraulic behaviour expected as a result of the project. The following sections describe the methodology adopted as part of this assessment.

3.3.1 Field survey

A field survey of the study area was undertaken by SCS and EMM in August 2019. The field survey focused on watercourses and watercourse structures with the greatest potential to be impacted as a result of predicted subsidence. Photographs and observations made during the site inspection are included in Appendix C.

3.3.2 Digital elevation model

A DEM has been developed for both existing and potential subsided conditions. A comparison between the 1 m elevation data obtained from DFSI Spatial Services (dated 2014) and the 2 m elevation data provided by Centennial Newstan (dated 2018) identified no material differences in modelled ground level.

The 1 m elevation data obtained from DFSI – Spatial Services has been used to inform the existing conditions DEM due to the improved terrain representation along watercourses as a result of the finer grid resolution. The subsidence conditions DEM has been developed by subtracting the maximum potential subsidence prediction contours (MSEC 2019) from the existing conditions DEM.

The existing and predicted subsided conditions DEMs have been used to identify changes to the hydrologic environment (refer Section 4.2) and inform the one-dimensional (1D) hydraulic model terrain (refer Section 5.3.2). The existing conditions DEM has been further modified to inform both the existing and subsided conditions two-dimensional (2D) hydraulic model terrain (refer Section 5.2.3).

3.3.3 Hydrology and hydraulic modelling

A hydrology model was developed as a tool to determine the critical duration storm event and applicable rainfall temporal pattern for input to the hydraulic modelling. Excess rainfall from the hydrology model was applied to a 2D hydraulic model. Peak flows from the hydrology model were applied to a 1D hydraulic model. The 2D model was developed to assess hydraulic impacts due to predicted subsidence across the study area, whereas the 1D model was developed to provide greater resolution of hydraulic behaviour within key watercourse reaches to inform the geomorphic assessment.

Further details on the hydrology and hydraulic models are provided in Chapter 4 and Chapter 5, respectively.

3.3.4 Key storm events

Storm events considered for the hydraulic assessment are listed in Table 3.1.

As noted in Table 3.1, an extreme event was assessed as a proxy for the probable maximum flood (PMF) by factoring up the 1% annual exceedance probability (AEP) design rainfall depths by a multiple of four. This multiplication factor was determined from review of the *Dora Creek Flood Study* (WMAwater 2015) and comparison of results for the 1% AEP and PMF events for nearby Jigadee Creek presented as part of this study.

Table 3.1 Key storm events assessed

Storm event	Model approach	Assessment objective
2 exceedances per year (EY) event	1D modelling	- Utilised to assess impacts to watercourse velocity for frequent events. - Informs the geomorphic assessment.
	1D modelling	- Utilised to assess impacts to watercourse velocity for frequent events. - Informs the geomorphic assessment.
0.5 EY event	2D modelling	- Utilised to assess potential changes to watercourse alignment. - Utilised to assess potential changes to remnant ponding. - Informs aquatic ecology assessment.

Table 3.1 **Key storm events assessed**

Storm event	Model approach	Assessment objective
1% AEP event	2D modelling	• Utilised to assess: – impacts to flood behaviour of other developments or land; – impacts to infrastructure within the study area; and – impacts to floodplain risk as a result of the project.
0.5% AEP event	2D modelling	• Utilised to assess flood impacts for larger storm events. • Utilised as a proxy for assessing a 10% increase in rainfall as a result of climate change.
0.2% AEP event	2D modelling	• Utilised to assess flood impacts for larger storm events. • Utilised as a proxy for assessing a 30% increase in rainfall as a result of climate change.
Extreme event	2D modelling	• Utilised as a proxy for the PMF event to estimate the upper limit of flooding within the study area.

The 10% AEP event was identified in the SEARs (Appendix B); however, was not assessed as:

- the 10% AEP event is generally utilised for assessing minor drainage infrastructure that is not relevant to this assessment; and
- the 0.5 EY and 1% AEP events are assessed, and interpolation of these results provides context for the 10% AEP event.

4 Hydrology

4.1 Overview

An XPRAFTS (version 2018.1.1) hydrology model was developed to assess design flows within the study area and adjacent catchments. The key purpose of the hydrology model was to determine the critical duration storm event and applicable rainfall temporal pattern for input to the 1D and 2D hydraulic models. Hydrological modelling has been undertaken to:

- develop runoff hydrographs to inform the 1D HEC-RAS model;
- obtain excess rainfall estimates to be applied to the 2D TUFLOW model domain; and
- determine peak flows within the Lords Creek catchment resulting from the study area critical storm duration event.

This chapter describes the XPRAFTS hydrology model and hydrologic results for the study area.

4.2 Model schematisation and parameters

XPRAFTS model parameters were determined via inspection of available data including photographs, aerial imagery and the DEMs described in Section 3.3.3. The study area catchment was found to be predominantly moderate to densely vegetated bushland with pockets of cleared/impervious land associated with access roads and Eraring Energy site infrastructure.

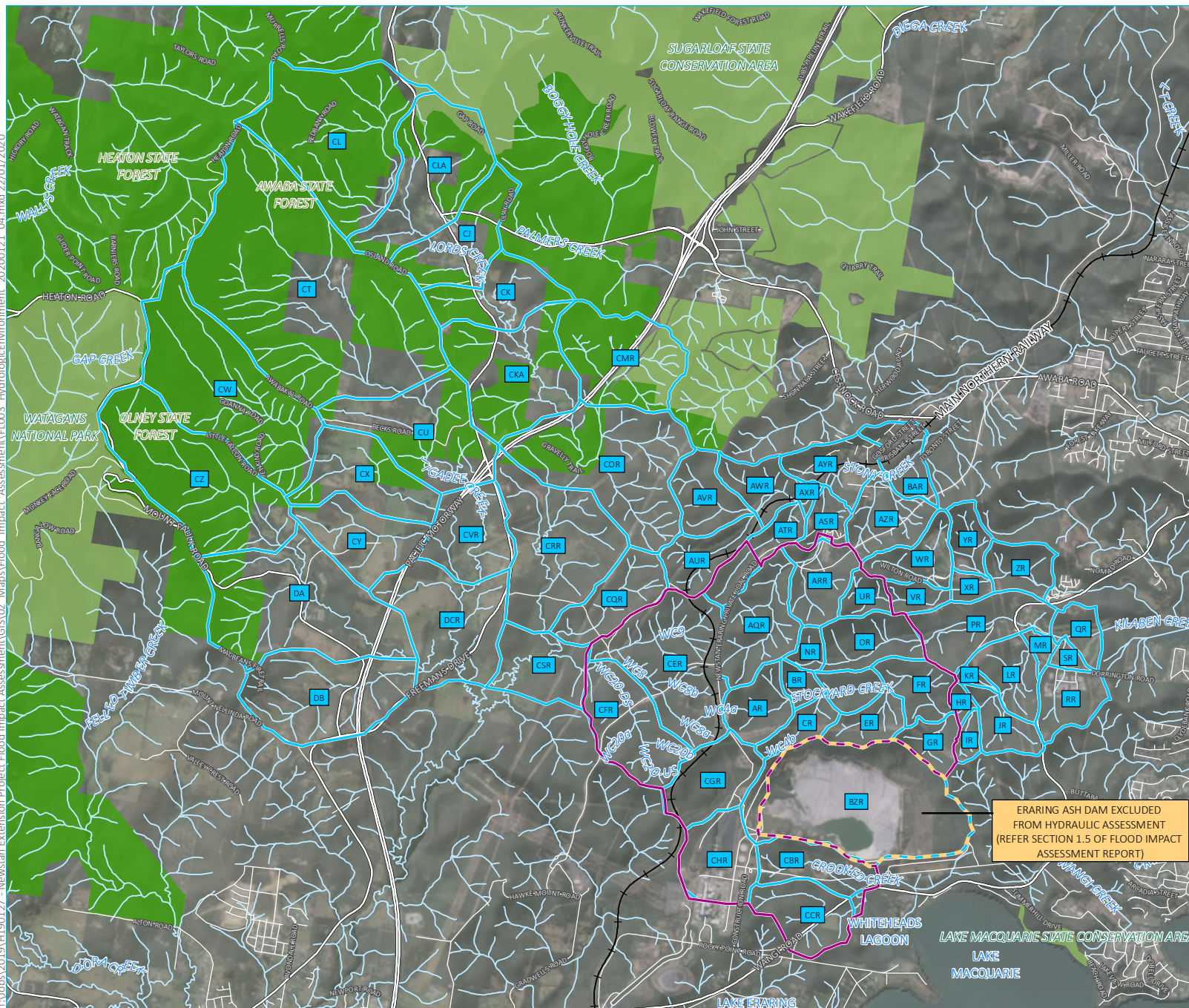
As the purpose of the hydrology model was to determine the critical duration design storm to be applied to the hydraulic models, design flows were validated by comparing XPRAFTS flows to the TUFLOW model flows at the WC9 catchment outlet (refer to Section 4.7). This validation process identified that Manning's roughness values in the order of 0.04 resulted in a similar runoff response between the XPRAFTS and TUFLOW models. Hence, a Manning's value of 0.04 was adopted for pervious catchments within the study area.

Catchment slope and stream length were calculated for each sub-catchment via interrogation of the DEMs (refer Section 3.3.3). Lag times for inter-catchment routing were determined using the slope and length of the major flow path through each sub-catchment. Lag time was calculated based on the following assumptions:

- slope $\geq 2\%$ – assumed velocity of 1.5 metres per second (m/s);
- slope 1% to 2% – assumed velocity of 1.0 m/s; and
- slope $< 1\%$ – assumed velocity of 0.5 m/s.

Sub-catchment delineation was undertaken for both the existing and predicted subsidence conditions DEMs described in Section 3.3. A comparison of the delineated catchments identified minor changes to sub-catchment areas and boundaries within the study area as a result of the maximum potential subsidence predictions. However, these changes were considered to have no appreciable impact on stream flows and hence, the same sub-catchment schematisation and parameters have been adopted for both existing and subsided conditions. Regardless of this, the hydraulic modelling approach (discussed in Section 5), accounts for the minor changes in catchment boundary by utilising a direct rainfall approach.

The hydrologic environment, including sub-catchment delineation, is presented in Figure 4.1.



- KEY
- Study area
 - Eraring Ash Dam exclusion area
 - Hydrology catchment
 - NPWS reserve
 - State forest
 - Rail line
 - Main road
 - Local road
 - Watercourse/ drainage line

Hydrologic environment

Newstan Mine Extension Project
Flood impact assessment
Figure 4.1

4.3 Design rainfall

Design rainfall depths were obtained from the BoM. An analysis of design rainfall depths across the study area was undertaken to identify potential design rainfall gradients. The analysis indicated that there is no significant design rainfall gradient across the study area. Hence, a single, uniformly applied rainfall depth has been adopted for each design storm event and duration. Design rainfall depths are provided in Table 4.1.

Table 4.1 Design rainfall depths

Duration (minutes)	2 EY event (mm)	0.5 EY event (mm)	1% AEP event (mm)	0.5% AEP event (mm)	0.2% AEP event (mm)
60	20.1	43.7	88.7	101	119
90	23.2	50.2	101	115	136
120	25.6	55.4	111	126	149
180	29.7	63.9	128	145	171
270	34.5	74.1	149	168	199
360	38.5	82.8	167	189	223
540	45.1	97.4	199	224	265
720	50.5	110	226	254	300

4.4 Rainfall losses

ARR2019 (Ball et al. 2019) recommends initial and continuing losses for the study area of 34 millimetres (mm) and 2.8 millimetres per hour (mm/hour) respectively, sourced from the ARR Data Hub. The recommended ARR2019 initial loss value is considered relatively high based on experience and also when compared to nearby catchments with similar land uses and topographic characteristics. The recommended ARR2019 continuing loss is similar to what would be expected based on experience and also with respect to previous studies undertake for nearby catchments.

The *Floodplain Risk Management Guideline* (OEH 2019) recognises that loss values for NSW from the ARR Data Hub have resulted in “a significant bias toward underestimation of flows”. The guideline provides a hierarchical approach to estimating loss and pre-burst values in NSW. This approach recommends using the average calibration losses from other studies in similar adjacent catchments if suitable calibration of losses within the study catchment is not possible. Based on this approach an initial loss of 20 mm and continuing loss of 2.5 mm/hour, which were derived from flood studies in nearby catchments (Cardno 2005; BMT WBM 2011; WMAwater 2015), have been adopted for this assessment. The adopted losses are conservative for the purposes of this assessment as they are below the recommended ARR2019 values and do not consider the additional initial loss that would be associated with historical subsidence in the Awaba areas of the project.

The adopted initial loss of 20 mm has been adjusted for pre-burst in accordance with the methodology outlined in the *Floodplain Risk Management Guideline* (OEH 2019). Pre-burst rainfall depths were assumed to be 0 mm for the more frequent 2 EY and 0.5 EY events. Losses for the rarer 0.5% AEP and 0.2% AEP events were assumed to be the same as the 1% AEP event.

4.5 Rainfall temporal patterns

Rainfall temporal patterns are used to describe how rainfall is distributed as a function of time. The recommended ARR2019 ensemble approach to applying temporal patterns has been utilised. The ensemble approach to flood modelling applies a suite of 10 temporal patterns for each duration. Point temporal patterns have been implemented as the study area catchment size is less than 75 square kilometres (km²). The temporal patterns were obtained from ARR Data Hub for the 'East Coast South' region.

4.6 Results

Hydrology model design flows have been determined using the ARR2019 ensemble approach, which identifies the critical duration as the duration with the highest mean flow and the temporal pattern, which is closest to, but above, the mean flow.

The critical storm duration for the WC9 catchment was adopted for the hydraulic models, as this catchment is expected to experience the greatest impacts due to predicted subsidence conditions. An investigation of the other catchments within the study area identified minor differences in the critical storm duration. However, the difference in peak flows across the varying critical duration storms were found to be minor. Accordingly, the critical duration for the WC9 catchment was adopted across the entire study area. The critical duration and peak flow at the WC9 outlet for each design storm event are provided in Table 4.2.

Table 4.2 Critical duration and peak flows – WC9 outlet

Storm event	Critical duration (minutes)	Peak flow (m ³ /s)
2 EY	360	5.9
0.5 EY	360	17.1
1% AEP	60	77.6
0.5% AEP	45	97.8
0.2% AEP	45	123
Extreme event	60	291

4.7 Validation of design flow estimates

To improve confidence in the XPRAFTS design flow estimates, a validation process was undertaken using the 2D TUFLOW hydraulic model with direct rainfall applied, as well as the Regional Flood Frequency Estimation (RFFE) Model. Peak flow estimates for the WC9 catchment and 1% AEP design event are provided in Table 4.3.

Table 4.3 Comparison of 1% AEP design flows – WC9 outlet

Location	XPRAFTS hydrology model (m ³ /s)	TUFLOW hydraulic model (m ³ /s)	RFFE Model design estimates (m ³ /s)		
			1% AEP estimate	Upper confidence limit	Lower confidence limit
WC9 outlet	77.6	75.2	136	318	58.3

The results presented in Table 4.3 show peak flows from the XPRAFTS and TUFLOW model are similar. The XPRAFTS and TUFLOW peak flows are approximately 45% less than the 1% AEP RFFE Model flows but are still within the upper and lower RFFE Model confidence limits.

When considering RFFE Model flow estimates, it is important to note ARR2019 states “that the relative accuracy of regional flood estimates using the RFFE Model is likely to be within $\pm 50\%$ of the true value” and as such, RFFE Model design flows estimates should be carefully considered. This is particularly the case for smaller catchments as ARR2019 (Ball et al. 2019) states that “there are only a few gauged catchments smaller than 10 km² included in the data base to develop the RFFE Model” and as such “it is likely that there will be a greater degree of error in the quantile estimates for these smaller catchments”. The WC9 catchment is approximately 3.2 km² and accordingly, the RFFE Model estimates are likely to have a higher degree of error.

Given that the purpose of the XPRAFTS hydrology model was to identify the critical duration storm to be used in the hydraulic modelling and was not intended to assess the rainfall-runoff response from the study area, the close match between the XPRAFTS and TUFLOW model peak flows provides confidence in the identified critical duration storm. The difference between the 1% AEP modelled design flows and the 1% AEP RFFE Model design flows is considered acceptable given that peak flow estimates are still within the confidence range.

5 Hydraulics

5.1 Overview

A 2D TUFLOW model (version 2018-03-AE) was developed to assess hydraulic impacts due to predicted subsided conditions across the study area. A 1D HEC-RAS model was also developed to provide greater resolution of hydraulic processes within key watercourse reaches to inform the geomorphic assessment. The 2D model aims to assess impacts across the broader study area and further validate the reaches selected for 1D modelling.

This chapter describes the development of the 2D TUFLOW and 1D HEC-RAS models, with results presented in Chapter 6.

5.2 Two-dimensional model setup

5.2.1 Model version

TUFLOW is a hydrodynamic model used for simulating 1D and 2D flows where the 2D solution occurs over a regular grid of square elements. TUFLOW has been used in Australia by major consultancies and government departments to simulate flooding for a wide variety of rural and urban locations and is well known by the Australian hydrological profession as an appropriate tool for runoff simulation when appropriate site-specific parameters are used.

The high-performance computing (HPC) version of TUFLOW partitions 2D grid solutions into compartments for parallel solving, using either multiple computer processing units (CPU) or graphic processing units (GPU). Parallel computations can reduce model runtimes, with GPU typically resulting in a faster solution than CPU. Hence, TUFLOW HPC (GPU) has been used as the software platform for modelling runoff within the study area.

5.2.2 Model domain and grid size

The hydraulic model domain covers the entire predicted subsidence extent except for within the Eraring Ash Dam footprint (refer Section 1.5). The model domain covers an area of 13.1 km² and is shown in Figure 5.1.

Site observations identified that many of the key watercourses had channel widths of 10 m or greater. A model grid size of 2 m x 2 m has been implemented to adequately model the key hydraulic features of the study area and predicted changes to ground levels in suitable resolution.

5.2.3 Model terrain

The existing conditions DEM described in Section 5.2.2 has been used to inform the 2D hydraulic model terrain. The existing conditions DEM was cross-referenced against available aerial imagery, topography data, site infrastructure plans and field survey observations. Where required, the existing conditions DEM was modified to more accurately represent key floodplain features and provide continuous flow paths through obstructed drainage lines (refer to Section 5.2.6).

The modified existing conditions DEM was also used to form the base terrain for the subsided conditions hydraulic model. The maximum potential subsidence prediction contours (MSEC 2019) were then subtracted from the 2D hydraulic model terrain to represent subsided conditions.

5.2.4 Manning's roughness

Manning's roughness values were selected based on inspection of aerial imagery and from site observations. Catchments were observed to be vegetated with significant leaf litter, dense grasses and trees. Shallow water flows would experience greater hydraulic roughness, flowing between grass and over leaf litter, while deeper flows may flow over these obstructions and experience lower roughness. To simulate this effect, depth varying roughness was applied, as described in Table 5.1. Depth varying roughness was also applied to simulate the effect of rainfall falling directly on building rooftops (lower roughness) versus overland flow through buildings (greater roughness).

In some densely vegetated areas, a higher roughness value may be appropriate. If so, then the values provided in Table 5.1 would result in slightly faster runoff and slightly lower depths in these locations. It is not expected that these effects will influence the outcomes of this assessment.

Table 5.1 Manning's roughness values

Land use ¹	Lower Manning's value ²	Upper Manning's value ²
Minimal vegetation (grassed)	0.10	0.04
Moderate vegetation (shrubs)	0.10	0.06
Thick vegetation (trees)	0.10	0.08
Waterbodies	0.03	0.03
Roads	0.02	0.02
Hardstand areas (some obstructions)	0.03	0.03
Railway corridor	0.10	0.04
Power sub-station (gravel pad)	0.10	0.04
Coal stockpiles	0.10	0.10
Industrial block with high building density	0.02	1.00

Notes: 1. Spatial variation of land use categories shown in Figure 5.1.
2. Lower and upper Manning's depth triggers of 0.03 m and 0.10 m, respectively. Manning's value interpolated when depth of flow is between lower and upper triggers.

5.2.5 Boundary conditions

Excess rainfall hyetographs from the XPRAFTS hydrology model were applied to the TUFLOW model domain. The excess rainfall hyetograph for each sub-catchment varied depending on the percentage of pervious and impervious areas.

A constant water level (HT) boundary condition was applied at the downstream model boundary that adjoins Whiteheads Lagoon. The downstream tailwater levels for Lake Macquarie were determined in accordance with *Modelling the interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways* (OEH 2015). The adopted water level at the Whiteheads Lagoon boundary for each scenario is provided in Table 5.2.

Stage-discharge (HQ) boundary conditions were applied at all other downstream model boundaries. The water surface slope at the downstream boundary was defined so that the stage-discharge relationship at each boundary was automatically generated by TUFLOW.

Table 5.2 Whiteheads Lagoon constant water level boundary condition

Design storm event	Lake water level ¹ (m)	Comments
0.5 EY	0.65	Corresponds to a 0.5 EY lake level.
1% AEP	1.23	Corresponds to a 5% AEP lake level.
0.5% AEP ²	1.61	Corresponds to a 5% AEP lake level + 2050 sea level rise.
0.2% AEP ²	2.1	Corresponds to a 5% AEP lake level + 2100 sea level rise.
Extreme event	2.45	Corresponds to a PMF lake level.

Notes: 1. Lake levels taken from WMAwater (2012).

2. Lake water levels for the 0.5% and 0.2% AEP events taken as the corresponding 2050 and 2100 1% AEP storm event lake levels to allow for climate change to be assessed with the 0.5% and 0.2% AEP events as proxies.

5.2.6 Initial water levels

Initial water levels were defined for several existing waterbodies within the 2D model domain, including Hawkmount Quarry, sediment dams along the Newstan-Eraring Private Coal Haul Road the detention basins associated with the Eraring Energy site. The existing and subsided DEMs (refer to Section 3.3.2) were interrogated to determine the lowest embankment level for each waterbody. Initial water levels were assigned a value 0.5 m below the lowest embankment level to allow for some storage capability in more frequent design storm events.

Where subsided conditions result in a lowering of the waterbody embankment, the initial water level was also lowered to maintain the 0.5 m freeboard. This assumes that the standing water level within the waterbodies will be maintained below the embankment level regardless of whether the maximum potential subsidence is realised or not. Furthermore, the loss in storage due to a lowering of the embankment is expected to be somewhat offset by the increase in storage due to subsidence beneath the waterbody footprint. Impacts to infrastructure are further described in Section 6.4.

5.2.7 Hydraulic features

Watercourse structures have been identified within three key watercourses, as shown in Figure 5.1. The arrangement and approximate dimensions of the watercourse structures were obtained during the field survey (refer to Section 3.3.1). An additional two watercourse structures were identified to convey flows beneath the Eraring Energy site. The dimensions of these two structures have been estimated from aerial imagery and advice from Centennial Newstan.

All five watercourse structures have been modelled as 1D elements embedded within the 2D domain. The outlet of watercourse structure C5 is not located within the 2D domain. Subsequently, flows through watercourse structure C5 have been directed outside the model domain via a 1D boundary condition. Adopted watercourse structure dimensions are provided in Table 5.3.

Table 5.3 Adopted watercourse structure dimensions

ID	Type	Number of culverts	Width (m)	Height (m)
C1	Rectangular culvert	1	2.1	1.2
C2	Rectangular culvert	2	2.1	1.2
C3	Rectangular culvert	3	2.1	1.2

Table 5.3 **Adopted watercourse structure dimensions**

ID	Type	Number of culverts	Width (m)	Height (m)
C4	Rectangular culvert	1	3.0	3.0
C5	Rectangular culvert	1	5.0	3.0

Where watercourse structure information was unavailable and visual inspection of the underlying terrain identified a potential drainage line obstruction (typically a road or access track), it was assumed that watercourse structures exist to allow overland flow to traverse the obstruction. These watercourse crossings were modelled as a two-cell (4 m) wide opening in the 2D terrain. This method allows for flows to pass the obstruction; however, may underestimate or overestimate the actual watercourse area of the structure. Without any other watercourse structure details, this approach was considered an appropriate way of representing a continuous flow path through the catchment. Furthermore, the approach was considered appropriate for the intended use of the hydraulic model for impact assessment purposes.

5.3 One-dimensional model setup

Key watercourse reaches within the predicted subsidence area were selected for detailed 1D hydraulic modelling to provide greater resolution of hydraulic processes and inform the geomorphic assessment. This included selected first order, second order and all third order watercourses that traverse predicted elevation changes greater than 200 mm. No fourth or fifth order watercourses required assessment as these watercourses were clear of the predicted subsidence area. The watercourse reaches selected for detailed 1D hydraulic assessment are shown on Figure 5.2.

5.3.1 Model version

The 1D hydraulic assessment was completed using HEC-RAS (version 5.0.6), a 1D hydraulic model developed by the US Army Corp of Engineers.

5.3.2 Model terrain

Cross sections were extracted from the existing and subsided conditions DEMs (refer to Section 3.3.2), at a maximum spacing of 50 m depending on topography and creek conditions. The estimated subsidence contours were overlaid when digitising the cross sections to ensure that the resolution of cross sections captured for the model schematisation was adequate to capture predicted watercourse gradient changes.

5.3.3 Manning's roughness

Manning's roughness values were selected for the 1D model to be consistent with the 2D model (described in Section 5.2.4) and site observations. Key reaches assessed in the 1D model are characterised by first order, second order or third order watercourses with poorly defined or undefined channels and dense vegetation covering. Photograph 5.1 and Photograph 5.2 show typical vegetation covering of key watercourse reaches.

Appropriate Manning's roughness values were determined as 0.1 for the channel and overbank areas of watercourses. A sensitivity assessment was carried out on the Manning's roughness value assumptions by reducing the channel roughness to 0.04. This was found to have a negligible difference on the impacts described in Section 6.3.

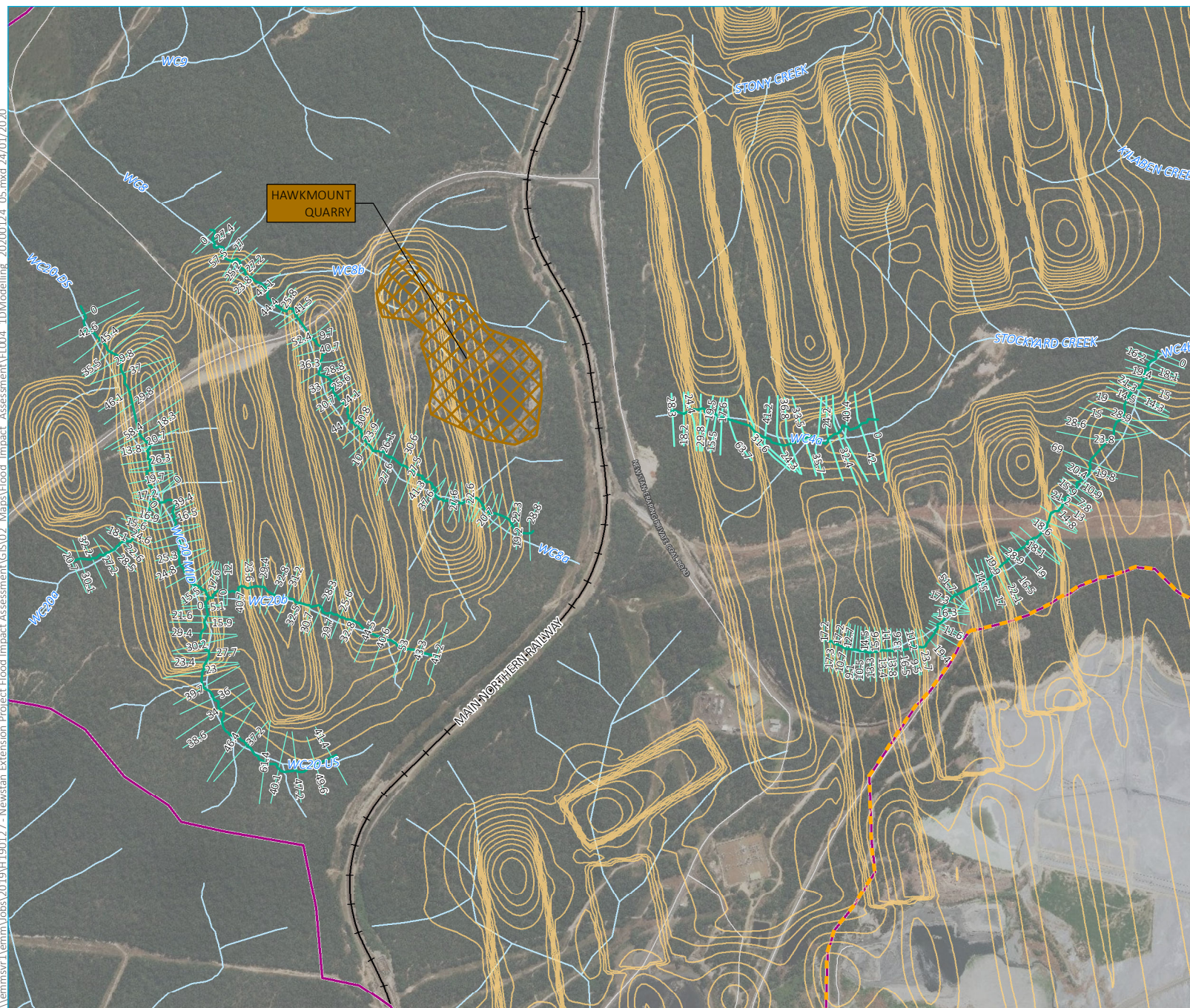


Photograph 5.1 Typical channel vegetation of a key watercourse reach



Photograph 5.2 Typical floodplain vegetation of a key watercourse reach

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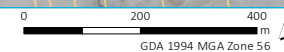
- KEY
- Study area
 - - - Eraring Ash Dam exclusion area
 - ▨ Hawkmount Quarry
 - + + + Rail line
 - Main road
 - Local road
 - Watercourse/drainage line
 - Predicted subsidence contours (varied interval)
 - 1D model reach
 - 1D model cross-section

One-dimensional hydraulic
modelling extent

Newstan Mine Extension Project
Flood impact assessment
Figure 5.2



Source: EMM (2019); DFSI (2017); GA (2011); ASGC (2006)



5.3.4 Hydraulic features

Watercourse structures on key watercourses were modelled to be consistent with the 2D structures presented in Section 5.2.6. Where watercourse structure information was unavailable it was assumed that a 4 m-wide opening was present in rail or road embankment structures to allow overland flow to traverse the obstruction.

Contraction and expansion coefficients of 0.3 and 0.5 respectively were implemented in the model for all hydraulic structure cross sections. Artificial levees and obstructions were required at some model sections to conservatively ensure the flow through each section was 1D and direct flow appropriately through the model.

5.3.5 Boundary conditions

HEC-RAS models for key watercourses were simulated as steady state, with constant peak flow at relevant cross sections and normal depth downstream boundary conditions measured from the DEM. Peak flows and boundary condition slopes utilised for each modelled reach are presented in Table 5.4.

Table 5.4 One-dimensional model peak flows

Watercourse	Cross section chainage (m)	2 EY event peak flow (m ³ /s)	0.5 EY event peak flow (m ³ /s)
WC4a	565	0.4	1.2
WC4b	1247	0.4	0.9
	777	1.2	2.7
WC8a	1268	0.9	2.3
	196	2.0	4.7
WC20-US	671	0.9	2.0
WC20-MID	310	1.7	3.8
WC20-DS	532	2.4	5.5
	257	3.1	7.0
WC20b	619	0.5	1.2
WC20a	278	0.5	1.0

6 Hydraulic assessment

6.1 Overview

The hydraulic models described in Chapter 5 were used to establish existing flood characteristics (flood extent, depth and velocity) within the study area. The hydraulic models were also used to assess the impact of the maximum potential subsided conditions on flood characteristics, including flood extent, depth, velocity, discharge and remnant ponding.

This chapter describes the hydraulic assessment results for both existing and subsided conditions. Hydraulic assessment results have also been used to inform the watercourse geomorphology assessment provided in Appendix A.

6.2 Existing conditions

6.2.1 Flood depth

Predicted existing conditions flood extent and depth mapping for the 0.5 EY event is shown in Figure 6.1. Flood extent and depth mapping for the 1% AEP, 0.5% AEP, 0.2% AEP and extreme events are provided in Appendix E. The flood extent and depth results indicate the following key hydraulic properties:

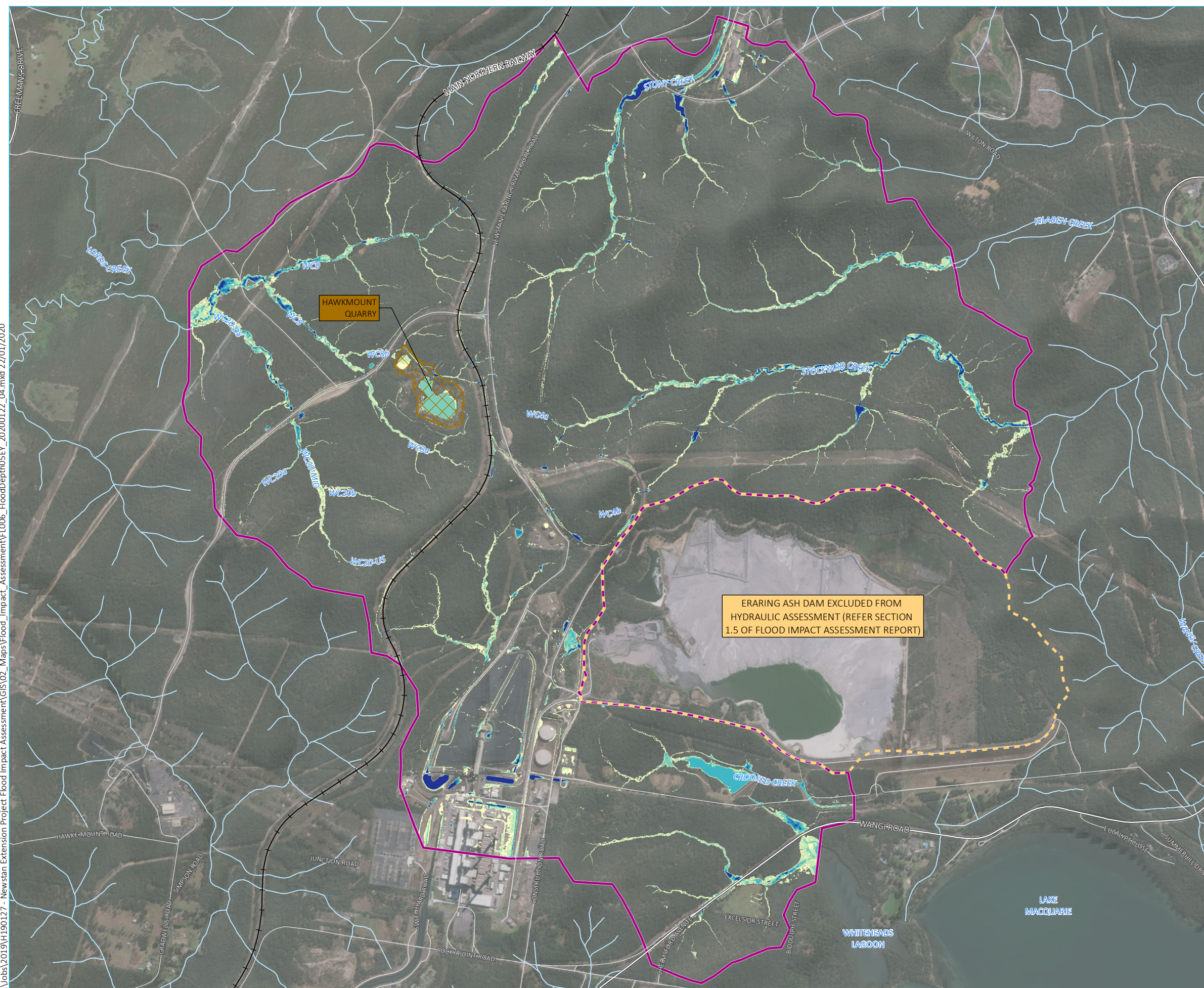
- A total flood inundation area (where peak flood depths are greater than 100 mm) of 84 hectares (ha) and 131 ha is experienced in the 0.5 EY and 1% AEP events respectively. The 1% AEP event results in a 56% increase in the flood inundation area compared to the 0.5 EY event.
- Flood depths of greater than 100 mm are typically confined to defined watercourses, with most of the study area experiencing flood depths of less than 100 mm.
- Flood depths of greater than 1 m are generally only experienced within:
 - the thalweg of larger watercourses such as WC8, WC9, Stony Creek and Stockyard Creek;
 - upstream of assumed watercourse crossing areas where ponding occurs due to flow constrictions; and
 - within existing waterbodies such as the detention basins and dams associated with the Eraring Energy site.

6.2.2 Flood velocity

The flood velocity results shown in Figure 6.2 and Appendix E indicate the following key hydraulic properties:

- the majority of inundated areas within the study area are flowing at peak velocities less than 1.5 m/s; and
- peak velocities greater than 1.5 m/s generally occur in areas of steeper terrain, or in channel reaches that experience constrictions and/or sharp changes in longitudinal grade.

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KEY

- Study area
- Eraring Ash Dam exclusion area
- Hawkmount Quarry
- Rail line
- Main road
- Local road
- Watercourse/ drainage line

Peak flood depth (m)

- < 0.2
- 0.2 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1
- > 1

Existing conditions - flood depth
(0.5 EY event)

Newstan Mine Extension Project
Flood impact assessment
Figure 6.1

Source: EMM (2019); DFSI (2017); Nearmap (2018); GA (2011)

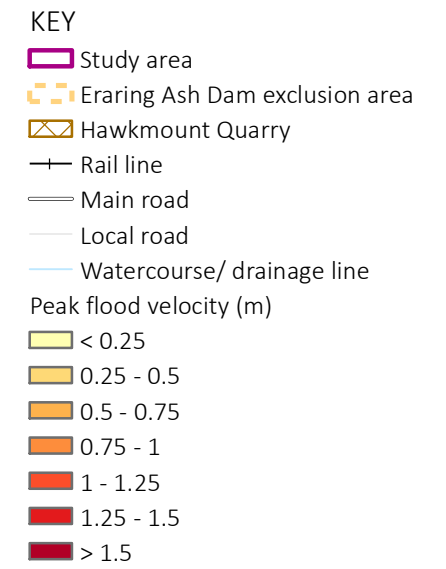
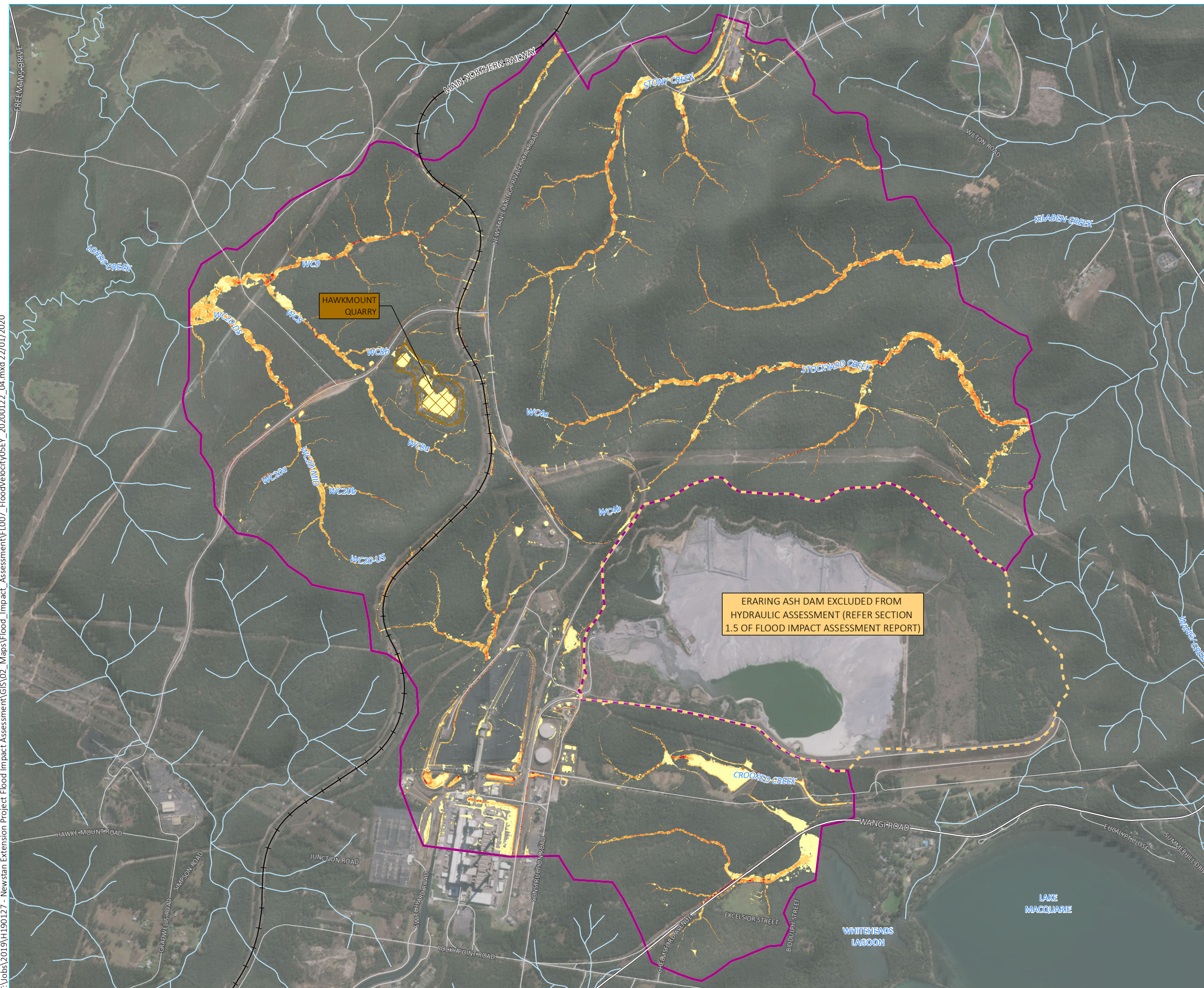
0 0.5 1 km

GDA 1994 MGA Zone 56

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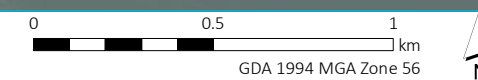
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Existing conditions - flood velocity
(0.5 EY flood event)

Newstan Mine Extension Project
Flood impact assessment
Figure 6.2

Source: EMM (2019); DFSI (2017); GA (2011)



6.3 Subsided conditions

6.3.1 Flood depth

The change in flood extent and depth resulting from subsided conditions for the 0.5 EY event are shown in Figure 6.3. Changes to flood extent and depth for the 1% AEP, 0.5% AEP, 0.2% AEP and extreme events are provided in Appendix E. Key changes to flood extent and depth when compared to existing conditions are:

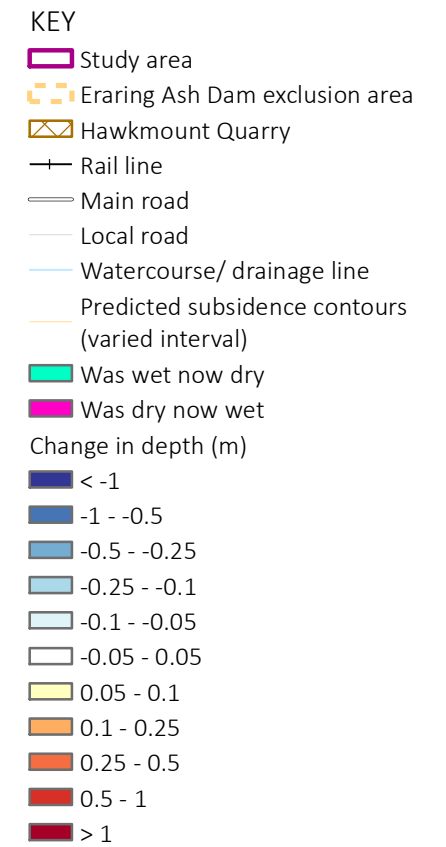
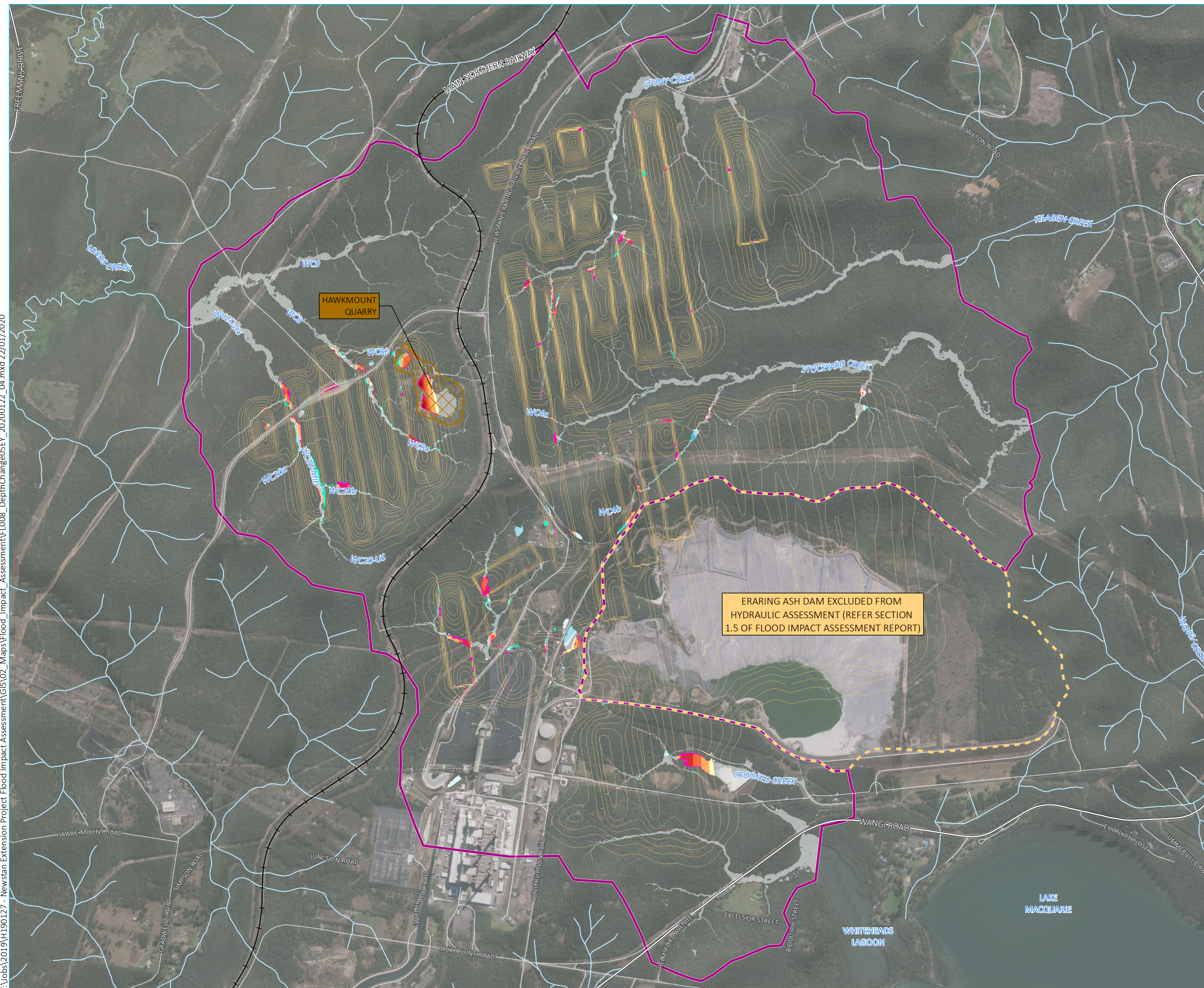
- The extent of flood inundation is similar to existing conditions with new areas of flooding ('was dry now wet') and areas that no longer experience flooding ('was wet now dry') generally being evenly distributed.
- Depth changes greater than 50 mm typically occur in isolated areas or in reaches where the predicted subsidence contours are adjacent to the watercourse. Depth changes are primarily experienced in the following locations:
 - WC8a and WC20 both upstream and downstream of the Newstan-Eraring Private Coal Haul Road;
 - watercourses upstream of the Eraring Energy site;
 - Stony Creek downstream of the predicted subsidence area and upstream of the Awaba Colliery Surface Site; and
 - within existing waterbodies such as the detention basins and dams associated with the Eraring Energy site (primarily due to the change in bathymetry and initial water level assumptions described in Section 5.2).
- Depth increases generally occur where drainage lines have been changed to have flatter or adverse longitudinal grades as a result of subsidence. This typically occurs in areas where subsidence predictions reduce between adjacent excavation on the downstream side of the potential subsidence area.
- Depth decreases generally occur where drainage lines are steepened as a result of subsidence. This typically occurs as a drainage line first enters an area of subsidence. Decreases in depth are also experienced along watercourses downstream of the predicted subsidence area, where flows have been reduced or delayed due to increased storage (eg Stony Creek upstream of the Awaba Colliery Surface Site).

In some areas, subsidence predictions result in a change to watercourse alignments. This typically occurs where a watercourse alignment is parallel to the subsidence contours, essentially redirecting flow from one side of the watercourse to the other.

Watercourse realignment is particularly evident in the upstream reach of WC20 during the 0.5 EY event (refer to Figure 6.3). Greater potential subsidence occurs on the left bank of WC20 in this area, resulting in flows that previously occurred along the right bank of WC20 being redirected toward the left bank. The redirection of flows results in the right side of the watercourse drying up ('was wet now dry'). Further downstream, greater potential subsidence occurs of the right bank of WC20 resulting in the opposite wetting/drying pattern.

The risk of realignment drying up a section of a watercourse decreases as the storm event increases in intensity, as there are greater flows available to fill the entire watercourse cross-sectional profile.

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Potential subsided conditions -
change in depth (0.5 EY event)

Newstan Mine Extension Project
Flood impact assessment
Figure 6.3

6.3.2 Flood velocity

The changes in flood velocity resulting from subsided conditions for the 0.5 EY event are shown in Figure 6.4. Changes to flood velocity for the 1% AEP, 0.5% AEP, 0.2% AEP and extreme events are provided in Appendix E. Subsided conditions hydraulic model results show the following key changes to flood velocity compared to existing conditions:

- Subsided conditions generally reduce velocities within the study area with a greater area of negative velocity change (comparatively slower water) experienced compared to positive velocity change (comparatively faster water).
- Velocity changes greater than 0.05 m/s typically occur in isolated areas or in reaches where the predicted subsidence contours result in a change to the grade of a watercourse. Velocity changes are primarily experienced in the following locations:
 - WC8a and WC20 both upstream and downstream of the Newstan-Eraring Private Coal Haul Road;
 - watercourses upstream of the Eraring Energy site;
 - the upper reaches of the Stony Creek and Stockyard Creek catchments; and
 - within existing waterbodies such as the detention basins and dams associated with the Eraring Energy site.
- Velocity increases are generally below 0.5 m/s and typically occur along drainage lines where the terrain has been steepened due to predicted subsidence. Velocity increases are also experienced in areas where watercourse realignment has resulted in greater flows occurring in one portion of a channel cross section compared to another.
- A decrease in velocity generally occurs along drainage lines where subsided conditions have resulted in flatter or adverse longitudinal grades. This mainly occurs as flow paths exit the area of predicted subsidence (or at the point where potential subsidence decreases slightly between adjacent excavations).

6.3.3 Discharge

Discharge hydrographs for the 0.5 EY and 1% AEP events are provided in Figure 6.5 and Figure 6.6, respectively. The discharge hydrographs compare existing and subsidence conditions at key model outlets (WC9, Stockyard Creek and Stony Creek). The following changes to discharge are observed:

- Subsided conditions are shown to reduce peak flows discharging from the study area. The largest change in peak flow occurs at the WC9 outlet with a reduction of 0.4 cubic metres per second (m^3/s) (-2.4%) and 2.9 m^3/s (-3.8%) in the 0.5 EY and 1% AEP events, respectively. It should be noted that although peak flows at the outlet of the study area are reduced under subsided conditions, local discharge hydrographs within the study area may experience increased peak flow at some locations.
- The timing of the discharge hydrograph is delayed at some locations for subsided conditions. The magnitude of the delay is a function of the extent and degree of potential subsidence within each sub-catchment and how the predicted subsidence aligns with existing watercourses (ie whether the watercourse alignment is parallel or perpendicular to the subsidence contours).
- Although peak flows are reduced for subsided conditions, the delay in timing may increase flows on the falling limb of the discharge hydrograph compared to existing conditions. The maximum increase in discharge resulting from subsidence conditions occurs at the WC9 outlet with an increase of 0.2 m^3/s (+2.1%) and 1.3 m^3/s (+3.8%) in the 0.5 EY and 1% AEP events, respectively.

The reduction in peak flow and delayed hydrograph timing for subsided conditions is interpreted to be a result of increased attenuation due to a slower catchment response and additional catchment storage due to potential subsidence forming areas of ponding within drainage lines or undrained depressions within the catchment.

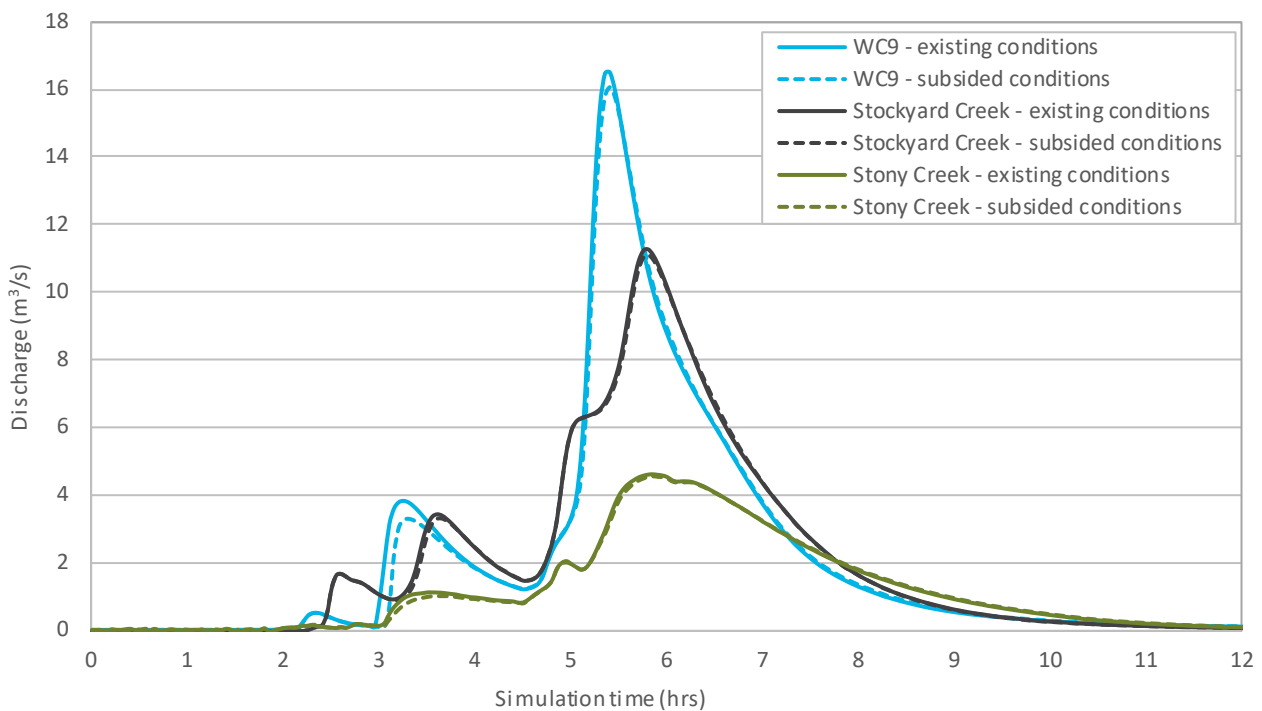


Figure 6.5 Comparison of discharge hydrographs – 0.5 EY event

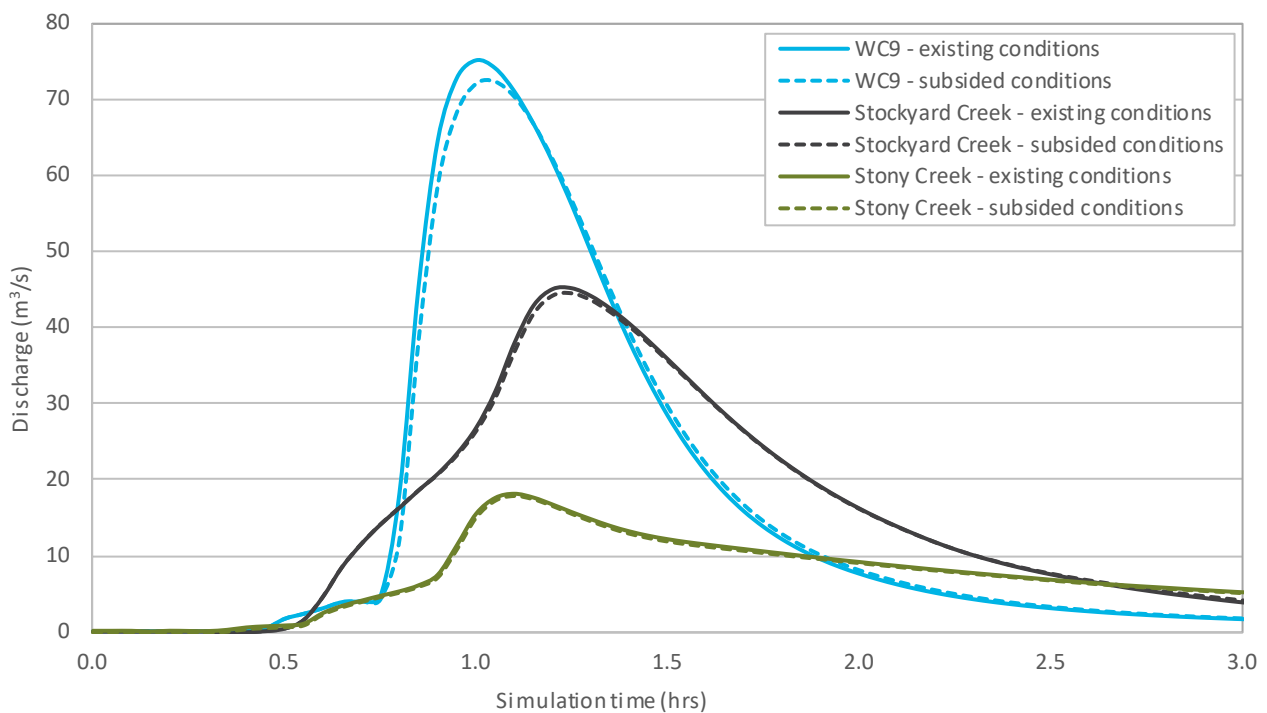


Figure 6.6 Comparison of discharge hydrographs – 1% AEP event

The greatest discharge hydrograph impacts are experienced for WC9, which is a tributary of Lords Creek. The peak flows in Lords Creek for existing and subsidence conditions are shown in Table 6.1. The Lords Creek 1% AEP event peak flow is reduced by 3.2 m³/s for subsided conditions, which is similar to the 2.9 m³/s reduction experienced at the outlet of the WC9 catchment. There is no change to peak flow for the 0.5 EY event as peak flow from the WC9 catchment does not coincide with the Lords Creek catchment peak for this storm event.

Table 6.1 Peak flows in Lords Creek

Storm event	Peak flow – existing conditions (m ³ /s)	Peak flow – subsided conditions (m ³ /s)	Difference (m ³ /s)
0.5 EY	49.1	49.1	0.0
1% AEP	143.2	140.0	3.2

6.3.4 Remnant ponding

It is expected that changes to remnant ponding during more frequent rainfall events will have a greater potential to impact ecological communities. Therefore, the change in remnant ponding has only been assessed for the 0.5 EY event. Remnant ponding was assessed by running the hydraulic model for an extended period of time so that all unimpeded runoff was drained from the model. Water that remained within the model domain was assumed to be associated with remnant ponding. By calculating the difference in depth grids between the existing and subsided conditions it was possible to determine new areas of remnant ponding ('was dry now wet') and areas where remnant ponding no longer occurs ('was wet now dry'). Table 6.2 presents the results of the remnant ponding assessment for the watercourses within the study area.

Table 6.2 **Changes to remnant ponding**

Watercourse / catchment area	Existing conditions predicted remnant ponding (m ²)	Subsided conditions predicted remnant ponding (m ²)	Net change to remnant ponding (m ²)
WC1	2190	610	1580
WC4a	790	80	710
WC4b	1370	1000	370
WC4 (downstream of 4a and 4b)	330	70	260
WC8	2510	380	2130
WC18	3560	1030	2530
WC20a	20	40	-20
WC20b	1430	10	1420
WC20	1790	250	1540
Unnamed watercourse (upstream of Eraring Energy site)	5270	950	4320
Other catchment areas (including Hawkmount Quarry and Eraring Energy site)	3730	2130	1600
Total study area	22990	6550	16440

The hydraulic model results show that an additional 1.6 ha of remnant ponding may be experienced under subsided conditions. The change in remnant ponding associated with subsided conditions is shown in Figure 6.7.

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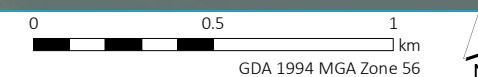


- KEY
- Study area
 - Eraring Ash Dam exclusion area
 - Hawkmount Quarry
 - Rail line
 - Main road
 - Local road
 - Watercourse/ drainage line
 - Predicted subsidence contours (varied interval)
 - Change in remnant ponding
 - Was wet now dry
 - Was dry now wet

Potential subsided conditions- change in remnant ponding (0.5 EY event)

Newstan Mine Extension Project
Flood impact assessment
Figure 6.7

Source: EMM (2019); DFSI (2017); Nearmap (2018); GA (2011)



6.4 Impacts to infrastructure

The hydraulic results for the predicted subsided conditions described in Section 6.3 and shown in Appendix E identify the changes in flood characteristics have the potential to impact infrastructure within the study area. No material impacts to infrastructure are expected to occur downstream of the study area as subsided conditions have been shown to reduce peak flows discharging from the study area in all modelled watercourses and design storm events.

Potential impacts to infrastructure within the study area are described in Table 6.3. Impacts to the Eraring Ash Dam have not been assessed as part of this flood assessment (refer Section 1.5).

Table 6.3 **Impacts to infrastructure**

Issue/description	Potential impact	Relevant locations
Lowering of waterway structure upstream and/or downstream inverts	• Waterway structure may become structurally unstable. • Modifications to the hydraulic regime which may increase/decrease flows received downstream. • Modifications to the hydraulic regime which may result in additional ponding upstream of the waterway structure. • Modifications to the hydraulic regime which may increase outlet velocities and the risk of scour.	• Observed culverts beneath Newstan-Eraring Private Coal Haul Road (C1, C2 and C3). • Upstream end of culvert that drains beneath the Eraring Energy site(C4)¹. • Other minor waterway crossings assumed to exist within the predicted subsidence area.
Lowering of existing waterbody embankments	• Embankment may become structurally unstable increasing risk of failure/overtopping. • More frequent overtopping due to lower spillway level and storage volume.	• Sediment dams along Newstan-Eraring Private Coal Haul Road. • Sediment dam downstream (but offline) of Hawkmount Quarry.
Changes to waterbody bathymetry	• Redistribution of stored water resulting in altered waterbody footprint. • Increased depth of stored water.	• Hawkmount Quarry and downstream sediment dam. • Sediment dams along Newstan-Eraring Private Coal Haul Road. • Eraring Energy site dam.
Nuisance ponding due to newly created localised low areas	• Reduced access during and after material storm events. • Increased driving hazard where ponding occurs on roads and access tracks.	• Sections of Newstan-Eraring Private Coal Haul Road. • Several access tracks north of Eraring Power Station. • Clean water diversions around Eraring Ash Dam.

Notes: 1. Hydraulic model results indicate a reduced peak flow through culvert C4 for subsided conditions.

6.5 Impacts to flood risk planning

Flood impacts described in Section 6.3.1 and Section 6.3.2 are contained predominantly on undeveloped Crown land and private land holdings relating to the Eraring Energy site. Localised flood impacts in these areas relate to potential maximum subsidence predictions which are unlikely to occur at the same time due to staged extraction. Prior to extraction, subsidence management and extraction plans will outline subsidence monitoring. Measures such as filling, may be undertaken to address any areas of concern. As such, mapping of flood risk planning instruments within the subsidence prediction extent is considered of little benefit.

Peak flows of watercourses downstream of the study area are expected to decrease, as demonstrated in Section 6.3.3, causing a minor reduction in peak flood levels outside of the subsidence prediction extent. Comments on the impacts of flood risk planning are provided in the following sections.

6.5.1 Flood planning levels

Flood levels for the 1% AEP event are predicted to decrease across the subsidence impact area due to the reduction in landform levels. As such, flood planning levels within the study area have not been mapped as these are predicted to decrease. In addition to this, areas across the subsidence impact area are largely undeveloped, undulating natural bushland. As described in Section 6.3.3, peak flows of watercourses downstream of the study area are expected to decrease, causing a reduction in flood planning levels for any downstream properties. Flood affectation of properties is not expected to change as a result of the project.

6.5.2 Floodplain categorisation

Minor localised changes to the floodway, flood fringe and flood storage categories are expected within the subsidence impact area in accordance with minor shifts of the watercourse alignment. Localised changes to floodplain categorisation are not expected to impact existing development or infrastructure, as the subsidence impact area is largely undeveloped, undulating bushland. Outside of the subsidence impact area, minor reductions in the area of more severe floodplain categories is expected due to the reduction of peak flows leaving the subsidence impact area.

6.5.3 Flood hazard and emergency management

Localised changes in flood hazard are expected around watercourses where longitudinal stream gradients are locally altered due to land deformations. Localised changes to flood hazard are not expected to impact existing development or infrastructure, as the subsidence impact area is largely undeveloped, undulating bushland. Downstream of the subsidence impact areas, flood hazard is expected to decrease due to minor attenuation of peak flows within the Extension of Mining Area. Emergency management arrangements are not expected to change as a result of the project.

6.6 Sensitivity assessment

A sensitivity assessment was completed for the scenarios presented in Table 6.4.

Table 6.4 Sensitivity assessment scenarios

Sensitivity scenario	Description	Purpose
Manning's roughness	Increase Manning's roughness globally by 20% and rerun the 1% AEP design event.	Investigate whether increasing the Manning's roughness value results in material changes to the hydraulic properties of the study area.
	Decrease Manning's roughness globally by 20% and rerun the 1% AEP design event.	Investigate whether decreasing the Manning's roughness value results in material changes to the hydraulic properties of the study area.
Climate change	0.2% AEP rainfall with 0.4 m increase to Lake Macquarie 5% AEP tailwater level.	Utilised as a proxy for assessing a 10% increase in rainfall as a result of climate change.
	0.5% AEP rainfall with 0.9 m increase to Lake Macquarie 5% AEP tailwater level.	Utilised as a proxy for assessing a 30% increase in rainfall as a result of climate change.

6.6.1 Manning's roughness

Increasing the existing conditions TUFLOW model Manning's roughness values by 20% resulted in the following changes to hydraulic properties:

- minor increases to flood extent were generally experienced at the fringe of most watercourses;
- depth increases of generally less than 100 mm; and
- velocity decreases of up to 0.2 m/s in most areas and up to 0.5 m/s in some areas.

Decreasing the existing conditions TUFLOW model Manning's roughness values by 20% resulted in the following changes to hydraulic properties:

- minor decreases to flood extent were generally experienced at the fringe of most watercourses;
- depth decreases of generally less than 100 mm; and
- velocity increases of up to 0.2 m/s in most areas and up to 0.5 m/s in some areas.

Modifying the Manning's roughness values results in minor changes to the hydraulic properties of the study area. Modification of the Manning's roughness values is not expected to influence the predicted changes in hydraulic properties as a result of project-related subsidence.

6.6.2 Climate change

Climate change impacts have been assessed by comparing the 1% AEP hydraulic model results to the 0.5% and 0.2% AEP hydraulic model results for the predicted subsidence conditions. Increasing rainfall generally results in an increase to flood extent, depth, velocity and discharge. The magnitude of the impact increases with rainfall intensity. The impacts of the modelled climate change scenarios on key flood characteristics are quantified in Table 6.5 and shown in flood maps provided in Appendix E.

Table 6.5 Climate change impacts to 1% AEP subsidence conditions flood characteristics

Scenario	Flood level/depth	Flood velocity	Peak discharge at WC9 outlet
0.5% AEP (10% rainfall increase)	Increase by up to 0.6 m	Increase by up to 0.7 m/s	Increase by 24 m ³ /s
0.2% AEP (30% rainfall increase)	Increase by up to 1.3 m	Increase by up to 1.0 m/s	Increase by 45 m ³ /s

7 Watercourse geomorphology assessment

7.1 Overview

Results of the 1D hydraulic modelling for the 2 EY and 0.5 EY events were used to inform the watercourse geomorphology assessment (SCS 2019), which is provided in Appendix A. This chapter describes the approach and findings of the watercourse geomorphic assessment.

7.2 Existing geomorphic condition

7.2.1 Stream types

Watercourses were characterised according to the principles of the River Styles framework (Brierley and Fryirs 2005). The River Styles framework integrates attributes of watercourses into defined classifications which describe landscape setting, geomorphic processes and range of behaviour.

The assessed watercourses were categorised into the following River Styles classifications:

- **headwater systems** characterised by confined, bedrock dominated channels with limited alluvial deposits and no floodplains, typically high gradient and found in upper catchment, low stream order watercourses;
- **valley fill systems** characterised by a flat-bottomed valley floor dominated by fine alluvial sediments, typically densely vegetated with poorly defined channels;
- **channelised fill systems** characterised by laterally stable, steep-walled channels that are typically low sinuosity and result from processes such as headcut retreat and channel incision in alluvial systems;
- **chain of ponds systems** characterised by a discontinuous channel divided by a series of typically symmetrical ponds at irregular intervals;
- **planform controlled, low sinuosity, fine grained systems** characterised by a defined, inset low sinuosity channel in a partly confined valley setting;
- **swamp systems** are similar to valley fill systems, typically with a flat-bottomed, alluvial-filled valley floor and are typically wetter than valley fill systems with long periods of water retention;
- **low sinuosity, fine grained systems** characterised by a wider valley setting allowing for continuous floodplains and a low gradient and energy hydraulic behaviour; and
- **modified systems** characterised by channel structures that are unnatural in shape and behaviour for the setting and have been altered substantially from the natural state.

Figure 2 of the watercourse geomorphology assessment (SCS 2019), provided in Appendix A, shows the watercourse types within the Extension of Mining Area.

7.2.2 Bed gradients

Bed gradients can be associated with watercourse type according to catchment position and valley confinement. Bed gradients within the Extension of Mining Area ranged from 0.002 metres per metre (m/m) to 0.15 m/m, with the lowest gradients being associated with swamp and low sinuosity, fine grained systems and higher gradients being associated with headwater reaches.

7.2.3 Geomorphic condition

Watercourses were also assessed for geomorphic condition and categorised as good, moderate or poor condition. Geomorphic condition accounts for degradation from original condition, signs or potential for recovery, likelihood of ongoing degradation and river behaviour.

Good condition reaches (84% of assessed watercourse length) were the most common type due to the relatively undisturbed nature of the Extension of Mining Area. Moderate condition reaches (11% of assessed watercourse length) displayed signs of disturbance such as channel incision, bank erosion, degraded vegetation or increased sedimentation. Many moderate condition reaches displayed evidence of channel stabilisation and recovery from past disturbances.

Poor condition reaches (5% of assessed watercourse length) were uncommon within the Extension of Mining Area and were largely restricted to areas impacted by infrastructure such as road crossings, disused railway lines or drainage cuttings. Poor condition reaches frequently contained large headcuts (greater than 0.5 m) and presented signs of active erosion and continuing gully headcut retreat and gully wall expansion. These reaches have undergone shifts in geomorphic behaviour and type due to channel incision and expansion reducing overland flows and reducing surrounding water dependent ecosystems.

Reaches classified as 'modified' watercourses (4% of assessed watercourse length) were considered in poor condition due to the extreme reduction in geomorphic complexity and low ecosystem value. These reaches included those in recently rehabilitated sinkhole areas due to the uniform, canal-like channel design and evidence of instabilities.

The geomorphic condition of watercourses within the Extension of Mining Area are mapped on Figure 3 of the watercourse geomorphology assessment (SCS 2019), presented in Appendix A.

7.2.4 Geomorphic stability

The majority of assessed watercourses were geomorphically stable due to low levels of disturbance and the types of watercourses present. In disturbed areas, many of the streams displayed geomorphic instability in the form of headcut retreat and bank erosion. Many reaches of poor or moderate condition showed signs of increasing stability through recovery processes such as bank stabilisation and revegetation, in-channel deposition and pond reformation.

7.3 Watercourse response to catchment impacts

Watercourses were assessed to determine the potential risks to geomorphic integrity from the predicted subsidence effects. Risk from disturbance due to subsidence is dependent on watercourse characteristics including valley confinement, gradient, flow resistance and condition. Existing instabilities, including headcut erosion and stream channelisation, are more susceptible to change if subsidence occurs. Potential impacts include:

- increased headcut erosion rates resulting in increased stream channelisation and flow concentration; and
- increased sediment conveyance resulting in lower erosion recovery rates and less in-channel vegetation establishment.

7.3.1 Watercourse responses to increased gradient and flow velocities

The potential risk of geomorphic change occurring due to increases in gradient and flow velocities is dependent on the watercourse type and the ability for a watercourse to undergo geomorphic change as well as the severity of change in gradient or flow velocity.

The majority of watercourses were assessed to have a low risk of impact specifically as a result of subsidence increasing grade. This was due to the low severity of change in gradient or flow velocity. Several watercourse reaches of relatively short length were identified as being at moderate or high risk, including sections of:

- Stockyard Creek (WC4a) and an unnamed tributary (WC4b);
- unnamed watercourses (WC8, WC20a, WC20b and WC20-US); and
- an unnamed watercourse north-west of the Eraring Energy site.

Geomorphic risk of the watercourses within the Extension of Mining Area are presented in Figure 5 of the watercourse geomorphology assessment (SCS 2019), presented in Appendix A.

7.3.2 Watercourse responses to decreased gradient and flow velocities

Watercourse types within the Extension of Mining Area are less susceptible to the effects of decreased gradient and flow velocities due to being predominantly fine grained, low energy systems. Localised predicted minimum flow velocities of 0.03 m/s could result in reduced sediment transport leading to increased rates of sediment deposition. However, the velocity of the majority of subsided areas is predicted to remain above 0.2 m/s and should be able to maintain suspended sediment transport and are unlikely to result in significant sediment deposition.

Increased remnant ponding predicted, including for WC8 and WC20 (refer Section 6.3.4), has the potential to affect the transport of water and sediment, particularly during periods of low flow. Increased sediment accumulation and water retention in these areas of ponding could result in impacts to in-channel vegetation due to longer periods of inundation.

7.3.3 Impacts on infrastructure

Key infrastructure within the study with the potential to be directly impacted by subsidence predictions is outlined in the subsidence impact assessment (MSEC 2019). Geomorphic impacts from subsidence may threaten key infrastructure if headcut retreat is initiated in reaches immediately below infrastructure. There is potential risk to the Northern Railway loop from subsidence of the tributaries of Stockyard Creek that intersect or flow below the railway embankment. These reaches are currently swamp systems on the uppermost gradient for the watercourse type and therefore have low tolerance to increased gradients. There is a moderate to high risk that subsidence could initiate headcut erosion and retreat in these systems, resulting in undercutting or bank failure.

7.3.4 Recommendations

The watercourse geomorphology assessment recommended that targeted monitoring and management plans are developed for watercourses with a moderate or high geomorphic risk rating. Regular visual inspections will allow identification of problem areas and potential threats to nearby infrastructure, as well as development and implementation of appropriate stabilisation techniques as required. These recommendations would be captured as works associated with mine extraction plans.

8 Summary and conclusions

8.1 Overview

Hydrologic and hydraulic models were developed to assess existing flooding conditions as well as the impact of predicted subsidence on flood behaviour within the study area and downstream areas. Flooding conditions and impacts were assessed for a range of flood frequencies up to and including an extreme event approximating the PMF. Hydraulic modelling utilised two separate modelling approaches:

- a 2D hydraulic model was developed to quantify changes in peak flows leaving the subsidence impact areas and identify flooding impacts within the Extension of Mining Area, including changes to remnant ponding; and
- several 1D hydraulic models were developed for selected watercourse reaches to provide a more detailed understanding of hydraulic behaviour.

Results of the flood modelling were also utilised to inform a watercourse geomorphology assessment (refer Appendix A). The primary objectives of the geomorphology assessment were to assess the impacts of potential subsidence on the geomorphology of watercourses within the Extension of Mining Area and to identify the level of risk to geomorphic integrity.

8.2 Hydraulic assessment

8.2.1 Overview

Existing flood conditions and predicted flooding impacts within the study area are described and presented in flood mapping for event frequencies ranging from 0.5 EY to an extreme event, with consideration to extents, depths and flow velocities.

8.2.2 Impacts within the study area

In general, the impact of potential subsidence on flood behaviour was found to be localised around channel gradient changes within the subsidence impact areas. Flood impacts were contained predominantly on undeveloped Crown land and private land holdings relating to the Eraring Energy site. Localised flood impacts in these areas relate to potential maximum subsidence predictions which are unlikely to occur at the same time due to staged extraction.

Prior to extraction, subsidence management and extraction plans will be prepared. These plans will outline subsidence monitoring programs and management measures (such as filling) that may be undertaken to address areas of concern.

Other key findings include:

- Flow paths were generally confined due to the steep terrain. Some minor localised changes to flow paths are expected within the Extension of Mining Area.
- Majority of flooding was relatively shallow.
- Velocities varied along the identified flow paths, indicative of changes in grade and or remnant pools. Higher velocities generally occurred in locations of steep terrain (ie upper parts of the catchments).

- Flood levels are expected to decrease across the Extension of Mining Area, due to deformation of the final landform. Localised flood depths are expected to increase or decrease around longitudinal gradient changes.

Changes in remnant ponding within the study area were assessed for the 0.5 EY event, on the basis that changes to ponding following smaller, more frequent flood events would likely have greater potential ecological significance than larger, less frequent events. This showed that only a small additional area of remnant ponding may be experienced under subsided conditions for an event of this magnitude.

8.2.3 Downstream flood impacts

No change or minor reductions in peak flows were predicted in watercourses downstream of the Extension of Mining Area for all events assessed, which is attributed to the attenuation of flows associated with additional storage created within the subsided land profile.

8.2.4 Impacts to infrastructure

Potential impacts to infrastructure within the study area are summarised in Table 6.2. No material impacts to infrastructure are expected to occur downstream of the study area.

8.2.5 Impacts to flood risk planning

Flood levels for the 1% AEP event were predicted to decrease across the subsidence prediction extent due to the reduction in landform levels. As such, changes to flood planning levels within the study area have not been mapped as these are predicted to decrease.

Minor localised changes to floodway, flood fringe and flood storage categorisations are expected within the subsidence impact area in accordance with minor shifts of the watercourse alignments. Outside of the subsidence impact area, minor reductions in the area of more severe floodplain categories are expected due to the reductions in peak flows leaving the subsidence impact area.

Localised changes in flood hazard are expected around watercourses where longitudinal stream gradients are locally altered due to land deformations. Downstream of the subsidence impact areas, flood hazard is expected to decrease due to minor attenuation of peak flows within the Extension of Mining Area. Emergency management arrangements are not expected to change as a result of the project.

8.2.6 Sensitivity analyses

The sensitivity of flood model results to changes in hydraulic roughness was investigated. Potential increases in rainfall intensities and tailwater levels as a result of future climate change on flooding were also considered. It was found that flooding impacts were generally insensitive to these influences.

8.3 Watercourse geomorphology assessment

Key findings of the watercourse geomorphology assessment were:

- The majority of watercourse reaches were assessed as having negligible or low risk of impact from subsidence.
- Several watercourse reaches of relatively short length were identified as being at moderate or high risk, including sections of:
 - Stockyard Creek (WC04a) and an unnamed tributary (WC04b);

- unnamed watercourses (WC08, WC020a, WC020b and WC20-US); and
- an unnamed watercourse north-west of the Eraring Energy site.

It is recommended that targeted monitoring and management plans are developed for these watercourses. Regular visual inspections will allow identification of problem areas and potential threats to nearby infrastructure, as well as development and implementation of appropriate stabilisation techniques as required.

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Abbreviations

Acronym/abbreviation	Definition
AEP	Annual exceedance probability
ARR2019	<i>Australian Rainfall and Runoff</i> (Ball et al. 2019)
BoM	Bureau of Meteorology
Centennial Coal	Centennial Coal Company Limited
Centennial Newstan	Centennial Newstan Pty Ltd
CPU	Computer processing units
DEM	Digital elevation model
DFSI	Department of Finance, Services and Innovation
DPIE	Department of Planning, Infrastructure and Environment
EES	Environment, Energy and Science (formerly Office of Environment and Heritage)
EIS	Environmental impact statement
EP&A Act	<i>Environmental Planning and Assessment Act 1979</i>
EY	Exceedances per year
GIS	Geographic information system
GPU	Graphic processing unit
ha	Hectare
HPC	High performance computing
IESC	Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development
km	Kilometre
km ²	Square kilometre
LGA	Local Government Area
m	Metre
m/m	Metres per metre
m/s	Metre per second
m ³ /s	Cubic metre per second
mm	Millimetre
mm/hour	Millimetre per hour
MSEC	Mine Subsidence Engineering Consultants
OEH	Office of Environment and Heritage
PMF	Probable maximum flood
RFEE	Regional Flood Frequency Estimation
ROM	Run of mine
SCS	Soil Conservation Service
SEARs	Secretary's Environmental Assessment Requirements

Acronym/abbreviation	Definition
SSD	State significant development
1D	One-dimensional
2D	Two-dimensional

Glossary

Term	Definition
Alluvial	Deposition of sediment over a long period of time by flowing water.
Annual exceedance probability (AEP)	The probability of an event being equalled or exceeded in any one year.
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average recurrence interval (ARI)	The average time period between occurrences equalling or exceeding a given value.
Attenuation	A weakening or reduction in amount, magnitude or value.
Bathymetry	The topography or shape of the land below the water surface.
Bord and pillar	A mining method whereby coal is extracted leaving pillars of coal to support the overlying strata.
Boundary conditions	The upstream and/or downstream conditions defined at the start of a model simulation.
Calibration	Process of adjusting the values of model parameters within physically defensible ranges until the model performance adequately matches observed historical data from one or more locations represented by the model (ie a match is obtained that is robust and fit for purpose).
Catchment	The land area draining through the main stream and tributary streams to a particular location.
Continuing loss	The average rate of rainfall loss that occurs throughout a rainfall event, after the initial rainfall loss is accounted for.
Critical duration	The duration of a specific design storm event that creates the largest volume or peak flow.
Digital elevation model (DEM)	Digital representation of ground surface topography or terrain.
Depth of cover	The depth from the ground surface to the top of the coal seam.
Discharge	The rate of flow of water measured in terms of volume over time.
Ephemeral watercourse	Watercourse that is usually dry, but may contain water for rare and irregular periods, usually after significant rainfall.
Erosion	Process of detachment and transport of sediment by the action of water, wind, gravity or ice.
Excess rainfall	Amount of rainfall that results in surface runoff.
Extension of Mining Area	The area within which underground mining is proposed as part of the project.
First workings	Development of mining roadways within the coal seam that forms pillars of coal between each roadway.
Flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or overland runoff before entering a watercourse and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences.
Flood hazard	The potential loss of life, injury and economic loss caused by flood events.
Floodplain	Flat or nearly flat land adjacent to a watercourse that experiences occasional or periodic flooding.
Geomorphology	The scientific study of landforms, their processes, form and sediments at the surface of the Earth.
Goaf	The void created by the extraction of coal.
Gradient	The rate of elevation change between two specified sites of horizontal distance measured along the thalweg of a channel.

Term	Definition
Gully	A small hollow or channel incised into sediments or unconsolidated material by flowing water.
Headcut	Erosional feature where an abrupt vertical drop in the bed of a channel occurs that interrupts the channel gradient and, through processes of channel erosion, progressively moves up-channel.
Headward erosion	Erosion of a watercourse at its head in an upstream direction, lengthening the watercourse in the direction of its source.
Headwaters	The source of a watercourse.
Hydraulic	The study of water flow in watercourses, particularly the evaluation of parameters such as water level and velocity.
Hydrograph	A graph showing the level, discharge, velocity or some other feature of water, with respect to time.
Hydrology	The study of rainfall and surface water runoff processes.
Hyetograph	A graphical representation of the distribution of rainfall over the total duration of a storm event.
Initial loss	The amount of rainfall loss before surface runoff occurs.
LiDAR	Aircraft based acquisition of terrain data, using laser scanners to collect and process digital information that defines landscape and topography.
Manning's roughness value	A measure of channel roughness that is used in the calculation of flow velocity and discharge.
One-dimensional hydraulic model	Model that simulates flow in the longitudinal direction only, with watercourse terrain represented by a sequence of cross sections, whereby average velocity and depth are estimated at each cross section.
Overland flow	Water flowing over the land surface.
Partial extraction	Bord and pillar mining where three of four rows of pillars are extracted, leaving a spine pillar (ie one row of pillars) within each panel.
Peak flow	The maximum flow or discharge occurring during a flood event.
Perennial watercourse	Watercourse that always flows in some parts all year round.
Ponding	The accumulation of runoff within depression storage that does not drain to a watercourse.
Pre-burst rainfall	Rainfall that occurs before the main part of the storm.
Probable maximum flood (PMF)	The largest flood that could conceivably be expected to occur, which is used to define the maximum extent of flood prone land or floodplain.
Rainfall loss	The amount of rainfall that does not appear as direct runoff due to interception by vegetation, depression storage and infiltration before the soil surface is saturated. Also see continuing loss and initial loss.
Reach	Defined section of a watercourse with a uniform character and behaviour.
Risk	The chance of something happening that will have an impact. It is measured in terms of consequences and likelihood.
River Styles framework	A framework to describe river character, behaviour, condition and recovery potential that is used to support river management.
Runoff	The amount of rainfall that becomes streamflow.
Sedimentation	Process by which sediment is deposited by the action of water, wind, gravity or ice.
Sinkhole	A depression or hole in the ground caused by the collapse of the surface layer which conducts surface water underground.
Sinuosity	Extent of curvature or meandering of a watercourse. High sinuosity watercourses meander over a low gradient and short distance. Low sinuosity watercourses are straighter and have a steeper gradient.
Steady state flow	Flow properties at any single point in a system that do not change over time.

Term	Definition
Strata	Layers of rock or soil with internally consistent characteristics that distinguish it from other layers.
Stream order	Stream classification system that assigns a numeric order to all reaches in a stream network. All reaches without any tributaries are assigned an order of 1 and are referred to as first order. The stream order increases when streams of the same order intersect eg the intersection of first order streams will create a second order stream.
Subsidence	Vertical lower, sinking or collapse of the ground surface.
Tailwater	Water level that forms the downstream boundary for hydraulic modelling.
Thalweg	The line extending down a channel that follows the lowest elevation of the bed.
Topography	Representation of the features and configuration of land surfaces.
Total extraction	Bord and pillar mining where all pillars in a panel are removed.
Two-dimensional hydraulic model	Model that simulates flow in both the longitudinal and lateral directions with watercourse terrain represented as a continuous surface, which allows for the interaction of flow between the main channel and the floodplain.
Validation	The comparison of the predictions of a calibrated model to a set of measurements that were not used to calibrate the model, in order to confirm that the model is suitable for use as a predictive tool.
Valley confinement	The degree to which bounding topographic features limit the lateral extent of the valley floor and floodplain along a river.
Velocity	The rate or speed of flow of water measured in terms of length over time.

Appendix A

Watercourse geomorphology assessment



Watercourse Geomorphology Assessment

Newstan Mine Extension Project,
Centennial Coal

December 2019



Title

Watercourse Geomorphology Assessment, Newstan Mine Extension Project, Centennial Coal

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Disclaimer

The information contained in this publication is based on knowledge and understanding at the time of writing, January 2020. However, because of advances in knowledge, users are reminded of the need to ensure that information upon which they rely is up to date and to check currency of the information with the appropriate officer of Soil Conservation Service or the user's independent adviser.

Contents

Contents	iii
Figures	iv
Tables	iv
Acronyms & Abbreviations	iv
1. Introduction	1
1.1. Background	1
1.2. Purpose of this study	2
1.3. Location and extent of watercourse assessment	2
2. Methodology	4
2.1. Field assessment and watercourse types	4
2.2. Geomorphic condition	4
3. Existing geomorphic conditions	4
3.1. Stream types	4
3.2. Bed Gradients	10
3.3. Geomorphic Condition	10
3.4. Geomorphic Stability	12
3.4.1. Headcut erosion	12
4. Watercourse response to catchment impacts	14
4.1. Introduction	14
4.2. Watercourse Responses to Increased Gradient and Flow Velocities	16
4.3. Watercourse Responses to Decreased Gradient and Flow Velocities	17
4.4. Impacts on Infrastructure	24
5. Recommendations	24
6. References	24

Figures

Figure 1 Study area – Strahler stream order	3
Figure 2 Watercourse types – River Styles	9
Figure 3 Geomorphic condition.....	11
Figure 4 Observed watercourse instabilities and controls.....	13
Figure 5 Geomorphic risk	23

Tables

Table 1 Description of watercourse types according to the River Styles framework.	5
Table 2 Bed gradient associations according to valley confinement and watercourse type	10
Table 3 Geomorphic risk matrix used to assess the likelihood and consequence of substantial geomorphic change resulting from changes in gradient and velocity.	15
Table 4 Maximum predicted total vertical subsidence and tilt within third order or above watercourses (MSEC 2019).	15
Table 5 Potential geomorphic consequence of stream types expected from increased gradients and flow velocities.	16
Table 6 Likelihood of geomorphic risk from increases in gradient and velocity.	17
Table 7 Geomorphic risk associated with predicted changes in stream gradient and flow velocity.	18

Acronyms & Abbreviations

Acronym / abbreviation	Definition
ARI	Average reoccurrence interval
Centennial Coal	Centennial Coal Company Limited
Centennial Newstan	Centennial Newstan Pty Ltd
CF	Channelised fill
COP	Chain of ponds
EP&A Act	Environmental Planning and Assessment Act 1979
EY	Exceedances per year
LGA	Local Government Area
LSFG	Low sinuosity fine grained
m	Metre
m/m	Metres per metre
m/s	Metres per second
mm	Millimetres
mm/m	Millimetres per metre
NSW	New South Wales
PCLSFG	Partly confined low sinuosity fine grained
ROM	Run of mine
VF	Valley fill

1. Introduction

1.1. Background

Newstan Colliery is an existing underground coal mine located in the Lake Macquarie Local Government Area (LGA), approximately 25 kilometres south west of Newcastle and 140 kilometres north of Sydney, New South Wales (NSW). It is owned and operated by Centennial Newstan Pty Ltd (Centennial Newstan).

Mining operations at Newstan Colliery began in 1887 and upon the introduction of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act) operated pursuant to continuing use rights in accordance with Part 4, Division 10 of the EP&A Act (continuing use rights).

Newstan Colliery has at various times mined the upper coal seams (Great Northern and Fassifern seams) and lower coal seams (West Borehole, Borehole, Young Wallsend and Yard seams) and produced both semi-soft coking coal and thermal coal for the domestic and export markets. In the lower seams, workings to date have been concentrated to the west of the seam split, which is a defining geological feature of the mine. Mining has been undertaken using a combination of bord and pillar and longwall mining.

In August 2014, the underground operations at Newstan Colliery were placed onto care and maintenance due to poor market conditions. In recent years, Centennial Newstan has commenced feasibility investigations into the recommencement of mining at Newstan Colliery. The most recent modification to DA 73-11-98 in January 2019, permits first workings mining within the West Borehole seam in the southern portion of the Newstan Colliery mining lease area. The first workings aim to improve Centennial Newstan's understanding of the geology within the West Borehole seam, including the presence, throw and strike of a major fault zone projected from the historical Newstan workings.

Centennial Newstan is now seeking approval for the continuation of mining within the West Borehole seam. The Newstan Mine Extension Project proposes to extract up to 25.9 million tonnes over a fifteen year period at a maximum production rate of 4 million tonnes per annum of run of mine (ROM) coal. Bord and pillar mining is proposed using continuous miner methods that will include areas of first workings, partial extraction and total extraction. A mix of metallurgical and thermal coal is proposed to be extracted. ROM coal will be delivered to the Newstan Colliery Surface Site via a series of existing underground conveyors. Once the coal reaches the Newstan Colliery Surface Site it will be handled in accordance with the approved operations for the Northern Coal Logistics Project (SSD-5145), managed by Centennial Coal Company Limited's (Centennial Coal) Northern Coal Services business unit.

Other key features of the project include:

- Utilisation of the Newstan Colliery Surface Site to provide parking, bathhouse, administration and workshop facilities for the underground workforce. A small number of administrative, maintenance and monitoring personnel will also be located at Awaba Colliery Surface Site.
- Transportation of personnel and materials to and from the underground mining area via the existing men and materials drift at Newstan Colliery Surface Site.
- Continued operation of the two existing ventilation fans at Newstan Colliery Surface Site and the installation and operation of three new ventilation fans at the existing ventilation shaft at Awaba Colliery Surface Site.
- In-seam gas drainage, with gas transferred to a new gas flaring facility to be located within the existing disturbance footprint of Awaba Colliery Surface Site.

- Extraction of underground water via the existing Fassifern Pump Station at Newstan Colliery Surface Site and ongoing groundwater management in accordance with Centennial Coal's Northern Operations Regional Water Management Plan.

The project is aligned with the broader Centennial Coal business strategy in that it facilitates the development of a new semi-soft coking coal product stream and a thermal coal product for both the domestic and export markets. The project will enable supply of export coal products while meeting contractual coal supplies to the domestic markets. Over time, the project can potentially replace the coal product currently supplied to the domestic market by other Centennial operations as these other resources become depleted. This will ensure ongoing security of supply for domestic electricity generation.

If approved, the project will allow for the optimisation of resource recovery from Newstan Colliery while providing ongoing direct and indirect employment opportunities. In addition, the project will provide a number of positive flow-on effects to the local, regional and state economies through additional wages and royalties.

1.2. Purpose of this study

The primary objective of this watercourse geomorphic assessment to assess the impacts of potential mining subsidence on watercourses in the study area and identify the level of risk to geomorphic integrity. This study will guide Newstan Colliery in the subsidence tolerance of watercourses in the study area to inform the nature and location of mining operations.

This watercourse geomorphic assessment includes the following:

- Assessment and mapping of geomorphic type and condition of watercourses within the study area.
- Assessment of watercourse response to potential gradient increases and decreases resulting from subsidence.
- Identification of potential threats to infrastructure from watercourse impacts.
- Watercourse management recommendations.

1.3. Location and extent of watercourse assessment

The study area covers the aboveground extent of proposed underground mine works based on a 600 metres (m) boundary surrounding the works area. All watercourses with potential subsidence impacts were included in the assessment, including 1st, 2nd and 3rd order streams. The named watercourses targeted for geomorphic assessment are listed below and shown in Figure 1.

- Stony Creek (WC01)
- Kilaben Creek (WC05)
- Stockyard Creek (WC04)
- Crooked Creek (WC18)
- Lords Creek (WC16)

The remaining watercourses are unnamed.

2. Methodology

2.1. Field assessment and watercourse types

The targeted watercourses are set within predominantly unpopulated bushland with small areas of mine related surface infrastructure. Most watercourses are ephemeral in nature and were observed during a period of low rainfall, with little to no surface water observed.

Targeted watercourses were not restricted by stream order and ranged from 1st to 4th order streams. Watercourses were targeted according to predicted subsidence and reaches with the highest predicted changes in gradient due to subsidence were prioritised. Low stream order watercourses adjacent to targeted reaches were assessed opportunistically.

Watercourses were characterised during the field assessment according to the principles of the River Styles™ framework (Brierley and Fryirs, 2005). The River Styles™ framework integrates attributes of watercourses into defined classifications which describe their landscape setting, geomorphic processes and range of behaviour. Watercourse classification was largely determined by:

- Degree of valley confinement and bedrock influences
- Presence and continuity of channel
- Channel planform (number of channels, sinuosity)
- Channel and floodplain geomorphic features
- Character of channel and floodplain sediments

2.2. Geomorphic condition

Watercourses were assessed for geomorphic condition and categorised as good, moderate or poor. Geomorphic condition accounts for degradation from original condition, signs or potential for recovery, likelihood of ongoing degradation and river behaviour. Characteristics used to assess geomorphic condition include:

- Bed and bank stability (extent and severity of erosion)
- Riparian vegetation associations
- Geomorphic features such as bars, pools, riffles and benches
- Evidence of channel lateral migration, expansion, incision and/or straightening
- Evidence of excessive sediment deposition
- Evidence of geomorphic recovery from past disturbances

3. Existing geomorphic conditions

3.1. Stream types

The assessed watercourses were categorised into a total of seven different River Styles™ classifications in addition to a highly modified classification, according to observations from remote and field assessment. The distribution of watercourse types within the study area is displayed in Figure 2 and the characteristics of each River Style™ is described in Table 1.

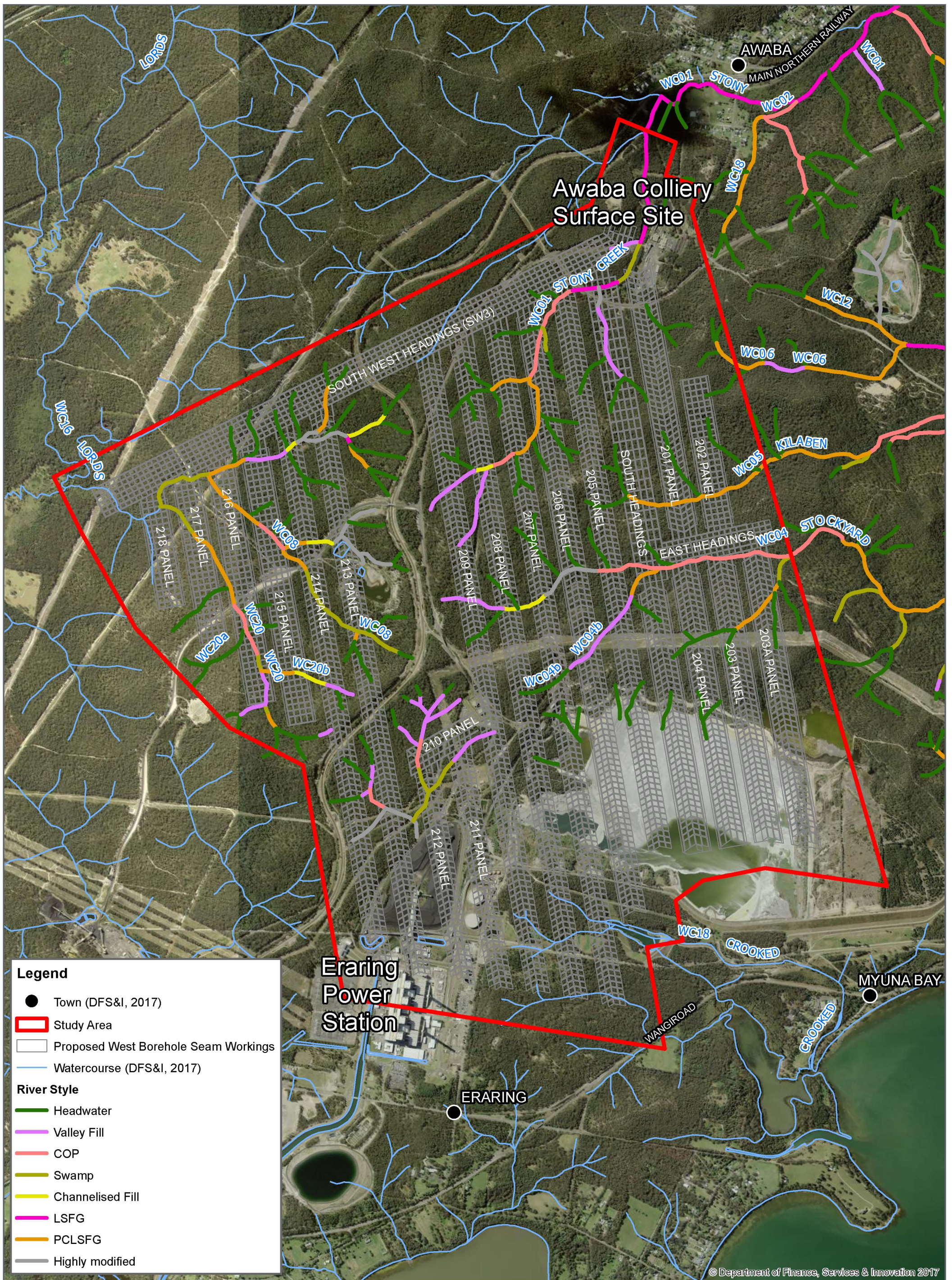
Table 1 Description of watercourse types according to the River Styles framework.

River Style™	Characteristics
Headwater 	Headwater systems consist of confined, bedrock dominated channels with limited alluvial deposits and no floodplains. Headwater channels are typically high gradient and found in upper catchment low stream order watercourses. Within the study area: • Headwater systems are typically located in the upper catchment on 1st or 2nd order streams. • All headwater reaches occur on unnamed systems • The majority of headwater systems are in good condition, with many in moderate or poor condition showing signs of recovery. • Vegetation associated with headwaters is open and less water-dependent than other systems in the study area.
Valley Fill (VF) 	Valley Fill systems are comprised of a flat-bottomed valley floor dominated by fine alluvial sediments. Channels are typically poorly defined or discontinuous and transport limited, resulting in deposition and storage of sediments from the catchment. VF systems are typically densely vegetated and dominated by water-dependent or -tolerant species. They remain water-logged for long periods of time. Degradation of VF systems usually occurs through the incision of a defined, continuous channel within the valley floor sediments. Recovery from channel incision is limited and systems change characteristics to a channelised fill system. Within the study area: • VF systems are found in 1st, 2nd and 3rd order streams. • Stockyard Creek has reaches of VF, with most occurring on unnamed watercourses. • The majority of VF systems are in good condition, with isolated areas in moderate condition due to incisional processes.

River Style™	Characteristics
Channelised Fill (CF) 	Channelised fill systems result from processes such as head cut retreat and channel incision in alluvial systems such as VF, Chain of Ponds (COP) or swamp. CF are characterised by laterally stable, steep walled channels that are typically low sinuosity. Sediment conveyance can increase in CF systems due to higher flow velocities. Flows become concentrated within the channel resulting in less support for surrounding water-dependent species. Recovery to previous conditions is limited but stabilisation to a new state is possible. Within the study area: • Reaches are located in upper and middle catchment positions on 2nd and 3rd order streams. • CF are typically associated with watercourse disturbance such as road crossings or sinkholes. • CF occurs on Stockyard Creek, Stony Creek and mostly unnamed watercourses. • Most CF reaches are in moderate to poor condition, with some showing signs of increased stability and recovery.
Chain of Ponds 	Chain of Ponds systems consist of a discontinuous channel divided by a series of typically symmetrical ponds at irregular intervals. The valley is usually unconfined, low gradient and features fine sediments high in organic matter. These systems support water-dependent species due to the ponds retaining water in otherwise ephemeral systems. Degradation generally occurs from incision joining each of the ponds, forming a continuous channel. This results in an increase in channel velocities and a reduction in sediment deposition. Recovery back to a chain of ponds system is limited once fully incised and systems typically transition to a CF or Low Sinuosity Fine Grained (LSFG) system. Within the study area: • COP systems occur mid-catchment on mostly 3rd order streams. • Stockyard and Stony Creek feature COP systems, with many reaches on unnamed watercourses. • COP systems range from good to moderate condition. Some systems are showing signs of recovery.

River Style™	Characteristics
Planform Controlled, Low Sinuosity, Fine Grained (PCLSFG) 	This stream type features a defined, inset low sinuosity channel in a partly confined valley setting. Discontinuous floodplain pockets allow lateral movement of the channel through erosional and depositional processes such as concave bank erosion. Fine-grain sediments dominate the floodplains and channel. Within the study area: • PCLSFG systems are typically mid-catchment on 2nd order or higher streams • Stony, Stockyard and Kilaben Creek feature PCLSFG as well as many of their branches. • PCLSFG reaches are mostly in good condition.
Swamp 	Swamp systems are similar in character to VF systems and typically have a flat-bottomed, alluvial-filled valley floor comprised of fine silts and muds. Swamps are typically wetter than VF systems and support water-dependent species due to long periods of water retention. Sediment from the catchment is stored in swamps due to the transport limited nature of these low energy systems. Within the study area: • Swamps typically occur in upper to middle catchment positions on 2nd and 3rd order streams. • Stony Creek has reaches of swamp, with the majority on unnamed watercourses. • The majority of swamps are in good condition.
Low Sinuosity, Fine Grained 	This stream type is characterised by a wider valley setting allowing for continuous floodplains and a low gradient and energy hydraulic behaviour. Sediment is predominantly fine-grained on the floodplains and banks with coarser material within the channel. Within the study area: • LSFG systems are found in mid- to lower-catchment settings on 3rd order or higher streams. • Stony, Kilaben and Stockyard Creek as well as many unnamed watercourses feature LSFG. • LSFG reaches are typically in moderate condition.

River Style™	Characteristics
Modified 	Modified streams are characterised by channel structures that are unnatural in shape and behaviour for the setting and have been altered substantial from their natural state. Modified streams are often simplified channel or canals with low geomorphic or habitat value and are design primarily for water conveyance. Within the study area: • Modified systems are typically associated with infrastructure and rehabilitation sites • Stockyard Creek and the upper reaches of several unnamed watercourses feature modified streams • Modified streams in the study area were typically in poor condition due to poor design and construction



3.2. Bed Gradients

Bed gradients found in the study area can be associated with watercourse types according to catchment position and valley confinement. Table 2 outline bed gradients for each valley confinement setting and the gradient range for each watercourse type within the study area. Bed gradients range from 0.002 metres per metre (m/m) to 0.15 m/m, with the lowest gradients being associated with swamp and LSFG reaches and higher gradients being associated with headwater reaches.

Table 2 Bed gradient associations according to valley confinement and watercourse type

River Style™	Gradient Range (m/m)
CF	0.009 – 0.036
COP	0.008 – 0.033
Headwater	0.02 - 0.150
LSFG	0.003 – 0.011
PCLSFG	0.008 – 0.035
Swamp	0.002 – 0.05
VF	0.005 – 0.091

3.3. Geomorphic Condition

Geomorphic condition was assessed according to the extent of watercourse disturbance, change in geomorphic behaviour, ecosystem implications and ongoing trajectory of degradation or recovery (Figure 3).

Good condition reaches (84% of assessed watercourse length) were the most common due to the relatively undisturbed nature of the study area. Good condition watercourses remain largely intact and exhibit the expected physical characteristics of the watercourse type.

Moderate condition reaches (11% of assessed watercourse length) displayed signs of disturbance such as channel incision, bank erosion, degraded vegetation or increased sedimentation. Many reaches displayed evidence of channel stabilisation and recovery from past disturbances. Geomorphic behaviour remained largely in line with that expected from the watercourse type.

Poor condition reaches (5% of assessed watercourse length) were uncommon within the study area and were largely restricted to areas impacted by infrastructure such as road crossings, disused railway lines or drainage cuttings. Poor condition reaches frequently contained large headcuts (>0.5 m) and presented signs of active erosion and continuing gully headcut retreat and gully wall expansion. These reaches have undergone shifts in geomorphic behaviour and type due to channel incision and expansion reducing overland flows and reducing surrounding water dependent ecosystems.

Reaches classified as 'modified' watercourses (4% of assessed watercourse length) were considered in poor condition due to the extreme reduction in geomorphic complexity and low ecosystem value. These reaches included those in recently rehabilitated sinkhole areas due to the uniform, canal-like channel design and evidence of instabilities.

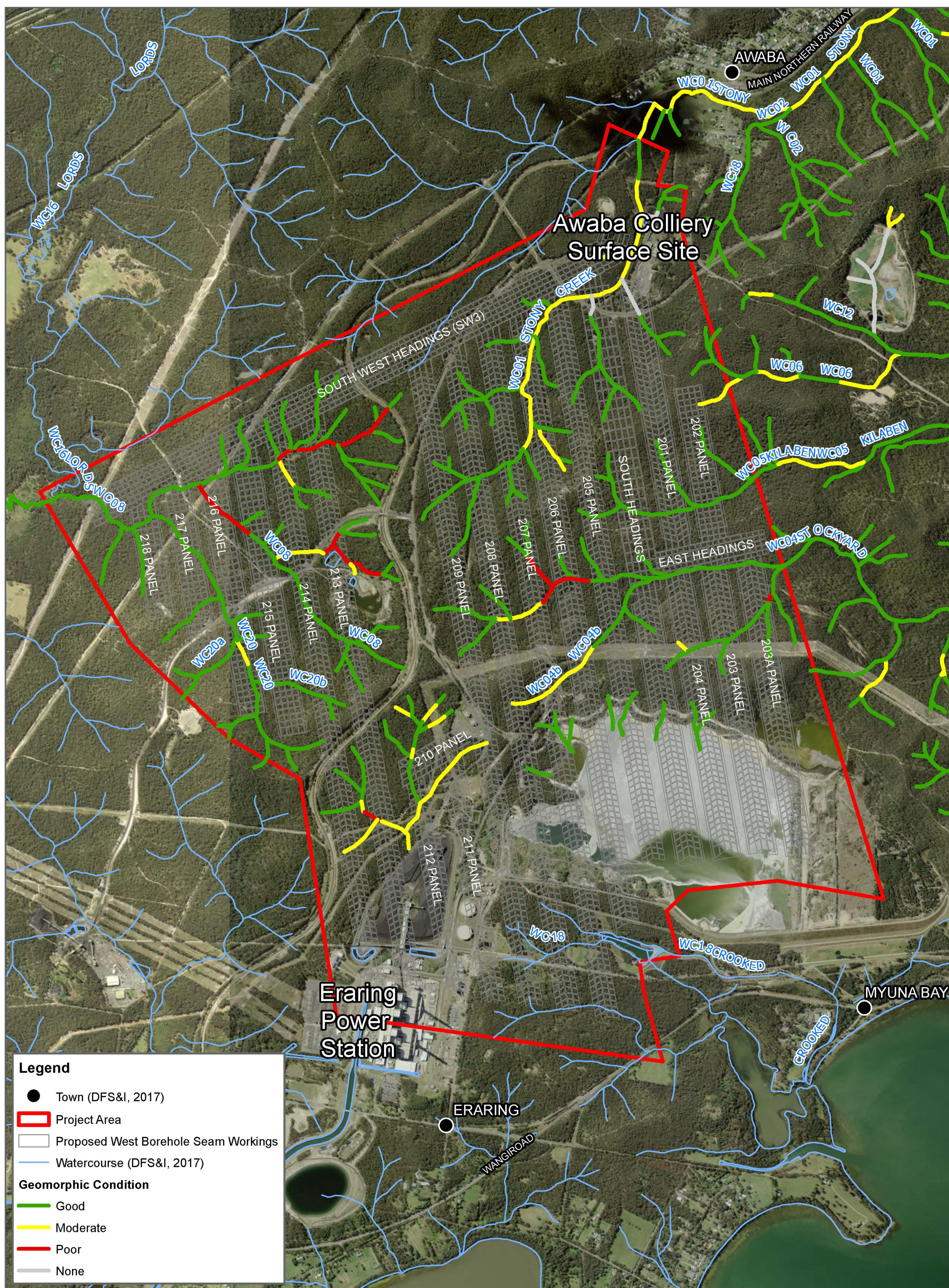
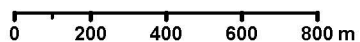


FIGURE 3

1:20,000 Scale at A3



Geomorphic Condition

GEOMORPHOLOGY ASSESSMENT NEWSTAN MINE EXTENSION PROJECT



Centennial Coal



Soil Conservation Service

Map Produced by SCS Parramatta
Date: 2019-11-21

Coordinate System: GDA 1994 MGA Zone 56

Map: SCS-08105-1-GS-005-WaterwayCondition.mxd 02
Aerial Imagery supplied by DFS&I (2017)

3.4. Geomorphic Stability

The majority of watercourses within the study area are considered geomorphically stable due to low levels of disturbance and the types of watercourses present. Watercourses within the study area are particularly stable due to:

- Low energy flows that dissipate across flat-bottomed valley floors in systems such as VF, COP, swamps and LSFG. These systems are well vegetated, composed of fine-grained cohesive sediments and are found on relatively low gradients.
- Confined or partly confined valley settings, which prevent substantial lateral or vertical channel movement. These systems include headwaters and PCLSFG.

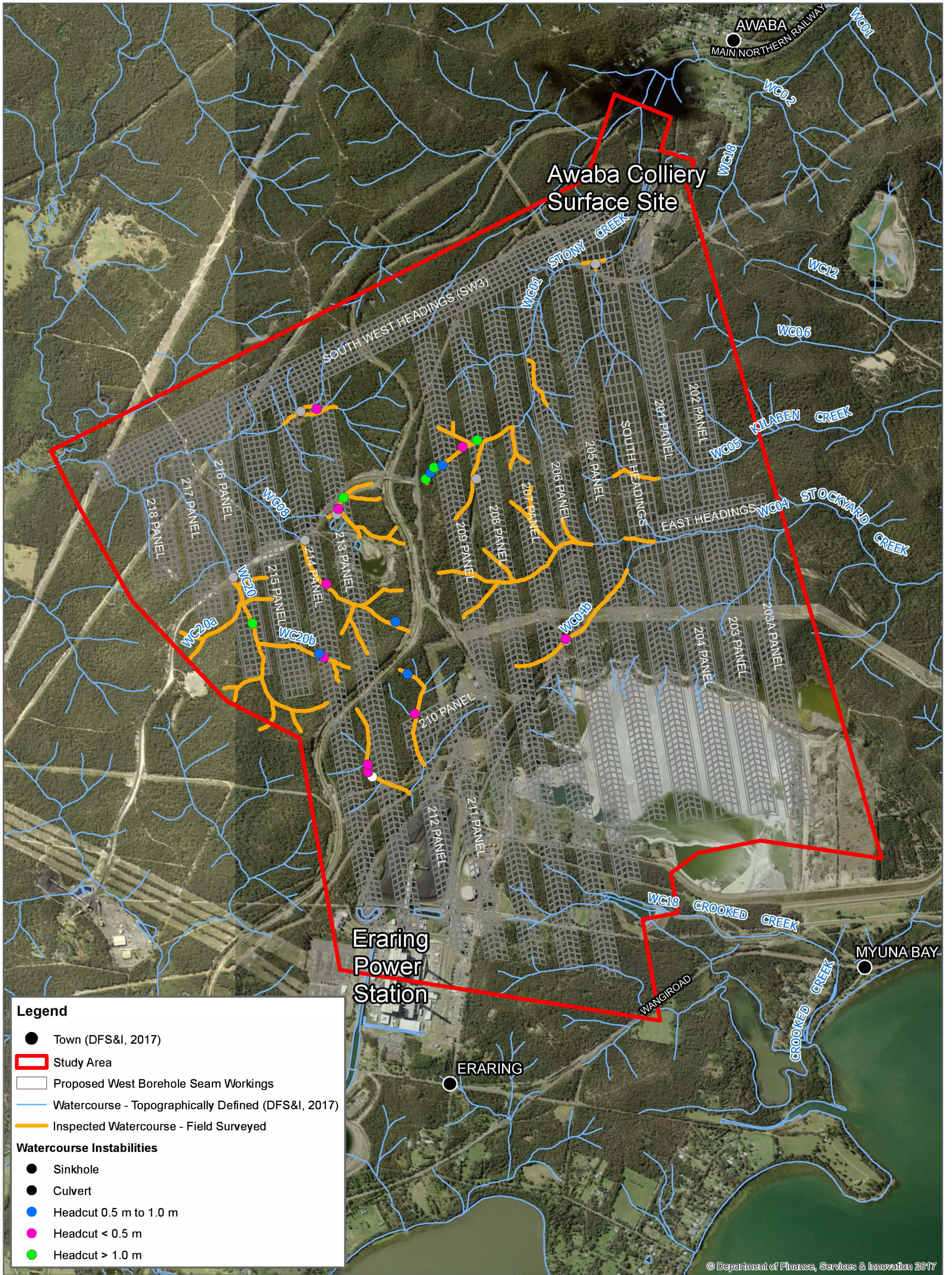
In disturbed areas many streams display geomorphic instability in the form of headcut retreat and bank erosion (Figure 4). Many reaches of poor or moderate condition showed signs of increasing stability through recovery processes such as bank stabilisation and revegetation, in-channel deposition and pond reformation.

3.4.1. Headcut erosion

Headcut erosion, also referred to as knickpoint retreat, is an erosion process that occurs due to an oversteepened section of channel migrating upstream through bank and streambed erosion. Headcut erosion appears as a steep, vertical drop in the channel longitudinal profile and results in plunge pool formation, bank erosion and bank steepening from channel incision. Channel incision that results from headcut erosion can inhibit overbank flows resulting in increased energy concentration within the channel and exacerbated erosion rates.

Headcut erosion was present throughout the study area and more frequent in the steeper upper catchment reaches. Many headcuts were associated with obvious disturbances such as road or track crossings, tree fall or channel excavation that are likely to have initiated headcut erosion. Headcuts ranged from minor (less than 0.5 m high) to major (greater than 1 m high) disturbances. The most severe headcut observed was associated with a sinkhole that has developed on an unnamed watercourse in the south-western section of the study area.

Reaches of COP and VF showed the greatest disturbance from headcut erosion due to the formation of a defined channel. In most cases, densely vegetated channels display low rates of headcut retreat and exhibit signs of high rates of recovery through stabilisation by vegetation growth.



4. Watercourse response to catchment impacts

4.1. Introduction

Watercourses were assessed to determine the levels of mining subsidence that can be tolerated without threatening geomorphic integrity. Geomorphic integrity was considered as the following:

- No significant alteration to the form of the watercourse (i.e. change in stream type).
- No significant acceleration or expansion of instability processes along the watercourse, such as headcut erosion, channel incision or bank erosion.
- No hindrance to potential watercourse recovery processes that are occurring, such as pool reformation and in-channel vegetation establishment.

Subsidence can impact watercourse integrity by changing channel morphology and behaviour due to changes in valley floor tilt and bed cracking. Channel bed cracking is not considered a significant issue in the study area due to the alluvial nature of the watercourses. However, changes to valley floor tilt are likely to result in the steepening of longitudinal gradients and potential shifts in valley floor cross-fall. Potential watercourse impacts that can result from subsidence include:

- Increases or decreases to flow velocities
- Changed channel bed and/or bank erosion rates
- Increased watercourse or floodplain channelisation or sedimentation
- Altered sediment transport and storage
- Changed flow path position
- Shifts in overall geomorphic behaviour and character, including changes to geomorphic type

Risk from disturbance due to subsidence is dependent on watercourse characteristics including valley confinement, gradient, flow resistance and condition. Geomorphic risk is the product of geomorphic consequence and the likelihood of a response occurring. The matrix in Table 3 provides an outcome of the geomorphic risk assessment as a combination of likelihood and consequence.

Existing instabilities within the study area, including headcut erosion and stream channelisation, are more susceptible to change if subsidence occurs. Potential impacts may include:

- Increased headcut erosion rates resulting in increased stream channelisation and flow concentration.
- Increased sediment conveyance resulting in lower erosion recovery rates and less in-channel vegetation establishment

Table 3 Geomorphic risk matrix used to assess the likelihood and consequence of substantial geomorphic change resulting from changes in gradient and velocity.

Likelihood	Geomorphic Risk Rating (combination of likelihood and consequence)			
	Consequence			
	High	Moderate	Low	Negligible
High	High	High	Moderate	Low
Moderate	High	Moderate	Low	Low
Low	Moderate	Low	Low	Negligible
Negligible	Low	Low	Negligible	Negligible

Watercourses within the study area are predicted to be affected by varying amounts of total vertical subsidence (millimetres (mm)) and total tilt (millimetres per m (mm/m)) (Table 4). Hydraulic modelling was focused to reaches predicted to have high likelihood or consequence of geomorphic risk due to predicted subsidence and from desktop/field assessment. These reaches are shown in Figure 5 and included:

- WC04a, WC04b
- WC08
- WC20, WC20a, WC20b

Table 4 Maximum predicted total vertical subsidence and tilt within third order or above watercourses (MSEC 2019).

Watercourse	Maximum predicted total vertical subsidence (mm)	Maximum predicted total tilt (mm/m)
Stony Creek (WC01)	200	2.0
Stockyard Creek (WC04)	< 20	< 0.5
Crooked Creek (WC18)	1000	7.5
Lords Creek (WC16)	< 20	< 0.5
Unnamed (WC08)	2100	45
Unnamed (WC09)	< 20	< 0.5
Unnamed (WC20)	1850	35

4.2. Watercourse Responses to Increased Gradient and Flow Velocities

The potential risk of geomorphic change occurring due to increases in gradient and flow velocities is a product of consequence (geomorphic response) and likelihood. Geomorphic response is largely dependent on watercourse type and the ability for a watercourse to undergo geomorphic change. Certain watercourse types are likely to have higher geomorphic consequences from increased gradients and flow velocities due to their ability to undergo wholesale shifts in behaviour and structure as described in Table 5.

Table 5 Potential geomorphic consequence of stream types expected from increased gradients and flow velocities.

Potential Consequence	Stream Type	Rationale
High	Valley Fill	These systems have an undefined or discontinuous channel that dissipates flows evenly across a flat valley bottom, when in an intact state. As a result, when undisturbed these systems are relatively stable due to low flow velocities and fine grained sediments not initiating bed scour or bank erosion. However, minor disturbances can result in incision and channelisation that results in a wholesale shift in geomorphic behaviour and character due to the concentration of flows and reduction of valley inundation. Channelisation of these systems can result in significant releases of sediment into downstream environments and impacts surrounding water-dependent vegetation communities.
	Swamp	
	Chain of Ponds	
Moderate	LSFG	These systems are characterised by having a continuous inset channel within alluvial deposits and continuous or discontinuous floodplains. Well-vegetated systems are resilient and more likely to recover from disturbances. Disturbances can occur from gradient and velocity increases that initiate bed and bank erosion or accelerate existing erosion. Channel erosion in these systems can result in changes in geomorphic behaviour due to channel expansion and disconnection between in-channel flows and the floodplain. Channel expansion can result in reduced geomorphic complexity and reduced ecological value.
	PCLSFG	
	Channelised Fill	
Low	Headwater	These systems are typically stable due to being bedrock confined and in upper catchment positions. Bed scour or bank erosion is not common in these systems and disturbances such as increased gradients or velocities are unlikely to result in significant changes in geomorphic character or behaviour.

The likelihood of geomorphic change is largely dependent on the severity of change in gradient or flow velocity. Metrics outlined in Table 6 were used to assess the likelihood of geomorphic change occurring if predicted increases in gradient and velocity were to occur. Existing instabilities such as headcut erosion also increase the likelihood of geomorphic change occurring due to reducing watercourse resilience and ability to recover from disturbance.

Table 6 Likelihood of geomorphic risk from increases in gradient and velocity.

Likelihood	Rationale
Low	Post subsidence gradient < 1.5 times existing gradient
	Post subsidence gradient well below maximum gradient for stream type
	Localised velocity increases < 0.2 metres per second (m/s)
Moderate	Post subsidence gradient 1.5 to 2 times existing gradient
	Post subsidence gradient well below maximum gradient for stream type
	Localised velocity increases 0.2 to 0.5 m/s
High	Post subsidence gradient > 2 times existing gradient
	Post subsidence gradient approaches or exceeds maximum gradient for stream type
	Localised velocity increases > 0.5 m/s

The assigned geomorphic consequence (Table 5) and likelihood (Table 6) have been applied to the risk rating matrix (Table 3) to determine the overall risk of impacts from increased gradients and flow velocities from subsidence. The majority of watercourse reaches are assessed as having negligible or low risk of impact from subsidence, however, several reaches are identified as being at moderate or high risk (Figure 5). Moderate or high risk ratings will require management and the implementation of mitigation measures. Reaches identified as being at moderate or high risk are discussed below (Table 7).

4.3. Watercourse Responses to Decreased Gradient and Flow Velocities

Decreased watercourse gradients and flow velocities can occur where a watercourse passes across a subsided area (depression) to an unaffected elevated area. This process can result in reduced stream grade or grade reversal, which has the potential to cause surface water ponding and increased sedimentation.

Watercourse types within the study area are less susceptible to the effects of decreased gradient and flow velocities due to being predominantly fine grained, low energy systems. Localised predicted minimum flow velocities of 0.03 m/s for the watercourses within the study area could result in reduced sediment transport leading to increased rates of sediment deposition. However, the velocity of the majority of subsided areas will remain above 0.2 m/s and should be able to maintain suspended sediment transport and are unlikely to result in significant sediment deposition.

Increased ponding is predicted within the study area, including WC08, WC20a and WC20c. The predicted ponding has the potential to affect the transport of water and sediment, particularly during periods of low flow. Increased sediment accumulation and water retention in these areas of ponding could result in impacts to in-channel vegetation due to longer periods of inundation. These processes could result in a shift in vegetation community over time to favour more water-tolerant species.

Table 7 Geomorphic risk associated with predicted changes in stream gradient and flow velocity.

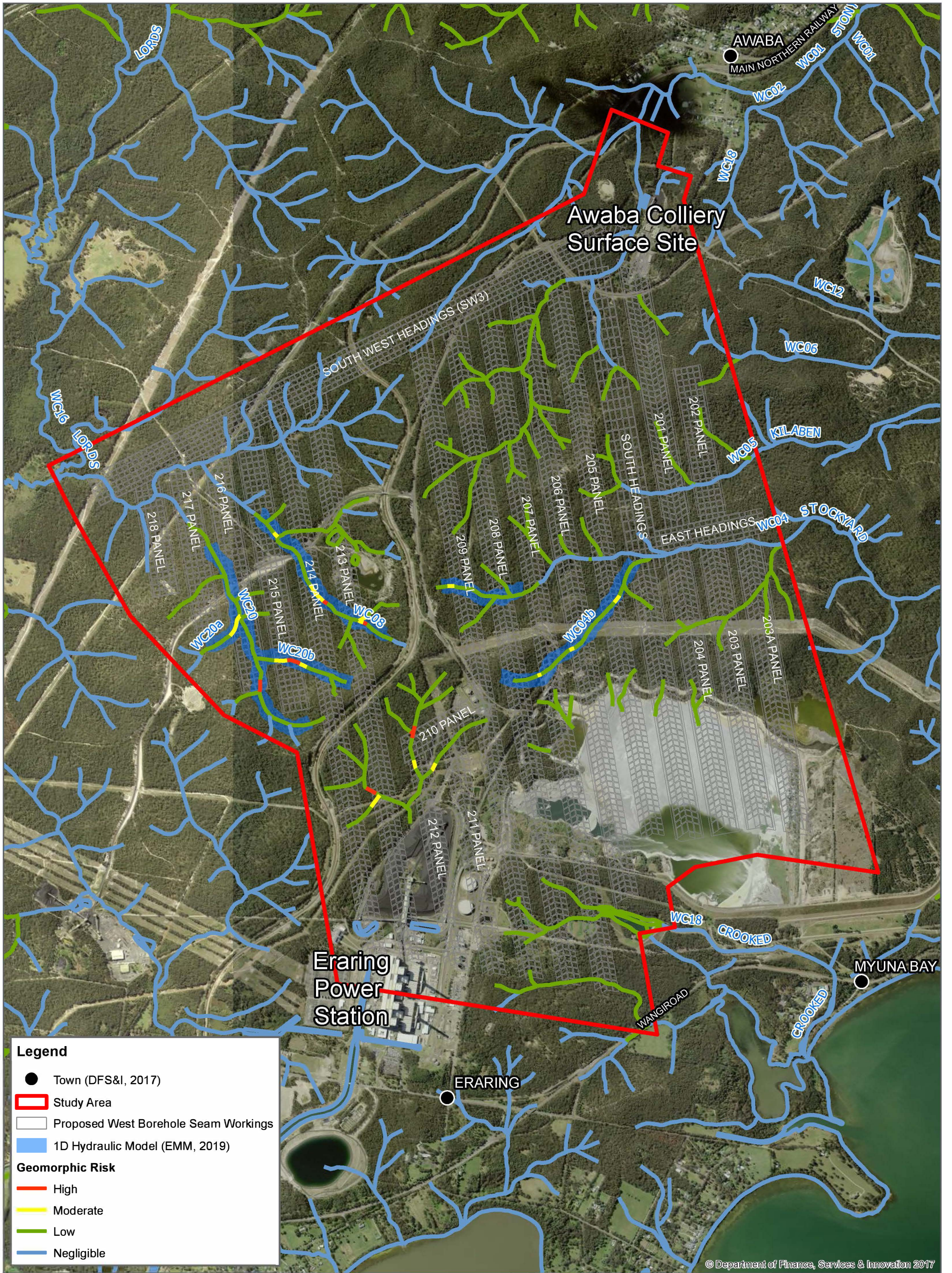
Watercourse	Workings	Grade change due to predicted subsidence	Modelled Hydraulic Impact		Potential Geomorphic Risk
			2 exceedances per year (EY) event (6 month average reoccurrence interval (ARI))	0.5 EY event (2 year ARI)	
Stony Creek (WC01)	Panels 205 to 209	Up to a 1.4 times increase in grade when entering Panel 206. Grade increase between 1 and 1.2 times when entering Panels 205, 207, 208 and 209. No areas of substantial pooling are predicted.	Not targeted in hydraulic model due to low risk factors.		Low geomorphic risk due to no predicted gradient increase greater than 1.5 times the existing gradient. The maximum predicted increase in gradient, entering Panel 206, will not exceed the maximum PCLSFG gradient in the study area.
Kilaben Creek (WC05)	Panels 201 to 202	No substantial gradient increase or pooling predicted.	Not targeted in hydraulic model due to low risk factors.		Low geomorphic risk due to negligible gradient increases predicted. The majority of Kilaben Creek does not overly proposed panels.
Stockyard Creek (WC04a)	Panels 205 to 209	Maximum grade increase of 1.4 times when entering Panel 209. No areas of substantial pooling are predicted.	Maximum localised flow velocity increases of 0.33 m/s from 0.75 m/s to 1.08 m/s.	Maximum localised flow velocity increases of 0.3 m/s from 0.98 m/s to 1.28 m/s.	Moderate geomorphic risk entering Panel 209 due to an almost 1.5 times gradient increase that would exceed the maximum VF gradient of 0.091 m/m for the study area. No reaches presented different geomorphic risk under 2 EY and 0.5 EY hydraulic impact modelling.

Watercourse	Workings	Grade change due to predicted subsidence	Modelled Hydraulic Impact		Potential Geomorphic Risk
			2 exceedances per year (EY) event (6 month average reoccurrence interval (ARI))	0.5 EY event (2 year ARI)	
Unnamed watercourse (WC04b) Tributary of Stockyard Creek	Panels 205 to 208	Greater than 2 times grade increase entering Panels 206 and across Panel 207. Greater than 1.5 times grade increase when entering Panels 205 and 207.	Maximum localised flow velocity increase of up to 0.61 m/s from 0.59 m/s to 1.2 m/s are predicted.	Maximum localised flow velocity of up to 0.93 m/s from 0.55 m/s to 1.48 m/s.	Moderate geomorphic risk entering Panel 207 due to a greater than 1.5 times gradient increase that approaches the maximum gradient of 0.15 m/m for headwater and accounts for a 0.38 m/s velocity increase. Moderate geomorphic risk entering Panel 206 due to a greater than 2 times gradient increase that approaches the maximum VF gradient of 0.091 m/m and accounts for a 0.52 m/s velocity increase. No reaches presented different geomorphic risk under 2 EY and 0.5 EY hydraulic impact modelling.
Crooked Creek (WC18)	Panels 207 to 209	Up to a 1.4 times increase in grade when entering Panel 207 and 208. No areas of predicted mining induced ponding.	Not targeted in hydraulic model due to low risk factors.		Low geomorphic risk due to no predicted gradient increase greater than 1.5 times the existing gradient. The maximum predicted increase in gradient, entering Panel 207 will not exceed the maximum headwater gradient of 0.15 m/m for the study area.
Unnamed watercourse (WC08)	Panels 218 to 213	Up to a 3 times grade increase entering Panels 214 and 2 times	Maximum localised flow velocity increase of up to 0.34 m/s	Maximum localised flow velocity increase of up to 0.51 m/s	High geomorphic risk entering Panel 213 due to a greater than 2 times grade increase, which exceeds the maximum swamp gradient of 0.05 m/m for the study area.

Watercourse	Workings	Grade change due to predicted subsidence	Modelled Hydraulic Impact		Potential Geomorphic Risk
			2 exceedances per year (EY) event (6 month average reoccurrence interval (ARI))	0.5 EY event (2 year ARI)	
		increase entering Panels 213 and 215.	from 0.66 m/s to 1.0 m/s.	from 0.76 m/s to 1.27 m/s.	High geomorphic risk entering Panel 214 due to a greater than 3 times grade increase and greater than 0.2 m/s velocity increase coinciding with a section of stream with existing headcut instabilities. Moderate geomorphic risk across Panels 213, 214 and 215 due to a greater than 1.5 times increase in gradient that does not exceed the maximum swamp gradient for the study area. Potential for minor pooling exiting Panel 214, however it is not considered to threaten the geomorphic condition of the site. No reaches presented different geomorphic risk under 2 EY and 0.5 EY hydraulic impact modelling.
Unnamed watercourse (WC20a) Tributary of WC08	Panel 216	Over a 3 times grade increase entering Panel 216 and between 2 and 3 times grade increase across Panel 216.	Maximum localised flow velocity increase of up to 0.3 m/s from 0.35 m/s to 0.65 m/s entering Panel 216.	Maximum localised flow increase of up to 0.35 m/s from 0.41 m/s to 0.76 m/s.	High geomorphic risk entering Panel 216 due to a greater than 3 times grade increase and a 0.3 m/s velocity increase. Moderate geomorphic risk across Panel 216 due to a predicted greater than 2 times grade increase.

Watercourse	Workings	Grade change due to predicted subsidence	Modelled Hydraulic Impact		Potential Geomorphic Risk
			2 exceedances per year (EY) event (6 month average reoccurrence interval (ARI))	0.5 EY event (2 year ARI)	
					Potential for pooling exiting Panel 216, however it is not considered a threat to geomorphic condition due to the existing COP system. Likely shift in channel position due to change in valley cross-fall tilting towards the left-hand bank. Change in channel position is unlikely to pose high geomorphic risk due to the discontinuous or undefined nature of flow paths in swamp and COP systems. No reaches presented different geomorphic risk under 2 EY and 0.5 EY hydraulic impact modelling.
Unnamed watercourse (WC20b) Tributary of WC08	Panel 216	Grade increase between 1.5 and 2 times entering Panel 216.	Maximum localised velocity increase of up to 0.21 m/s from 0.44 m/s to 0.65 m/s.	Maximum localised flow velocity increase of up to 0.49 m/s from 0.84 m/s to 1.33 m/s.	Moderate geomorphic risk entering Panel 216 due to a grade increase between 1.5 and 2 times and velocity increase of over 0.2 m/s. No reaches presented different geomorphic risk under 2 EY and 0.5 EY hydraulic impact modelling.
Unnamed watercourse (WC20c)	Panels 214 to 216.	Grade increase up to 2 times entering Panel 215.	Maximum localised velocity increase of up to 0.4 m/s from 0.53 m/s to 0.93 m/s.	Maximum localised flow velocity increase of up to 0.45 m/s from 0.67 m/s to 1.12 m/s.	High geomorphic risk entering Panel 215 due to a grade increase of up to 2 times and a velocity increase of 0.4 m/s. This exceeds the maximum gradient of 0.036 m/m for CF in the area.

Watercourse	Workings	Grade change due to predicted subsidence	Modelled Hydraulic Impact		Potential Geomorphic Risk
			2 exceedances per year (EY) event (6 month average reoccurrence interval (ARI))	0.5 EY event (2 year ARI)	
Tributary of WC08					Moderate pooling of 0.6 m is predicted exiting Panel 215. This is considered to pose moderate risk to the geomorphic condition due to changes in flow conveyance. No reaches presented different geomorphic risk under 2 EY and 0.5 EY hydraulic impact modelling.
Unnamed watercourse – Northwest Eraring Power Station	Panels 210 to 213		Not targeted in hydraulic model due to waterways not being included in topographic mapping data.		High geomorphic risk entering Panels 210 and 213 due to substantial grade and velocity increases coinciding with existing headcut instabilities. Moderate geomorphic risk entering Panel 212 and 213 due to substantial grade and velocity increases. Change in channel position is likely to occur along the western boundary of Panel 213. The flow path is likely to shift towards the left-bank. There is potential for increased instability in the form of bank erosion due to the confined nature of VF systems and the potential for flows to be concentrated against the valley margin.



4.4. Impacts on Infrastructure

Geomorphic impacts from subsidence could threaten key infrastructure if headcut retreat is initiated in reaches immediately below infrastructure. There is potential risk to the Northern Railway loop from subsidence of the tributaries of Stockyard Creek that intersect or flow below the railway embankment. These reaches are currently swamp systems on the uppermost gradient for the watercourse type and therefore have low tolerance to increased gradients. There is a moderate to high risk that subsidence could initiate headcut erosion and retreat in these systems, which left unchecked may result in undercutting or bank failure occurring.

It is recommended that monitoring and management plans are put in place to mitigate potential threats to infrastructure that may result from subsidence. There is potential for adverse effects in areas that have not been predicted and these areas should be approached according to the management plan recommendations described in Section 5.

5. Recommendations

Management plans should be developed for watercourses listed in Section 4.2 and Section 4.3 that have been identified as having moderate or high geomorphic risk.

Targeted watercourse management plans should include:

- Visual inspection of moderate and high risk reaches annually or more frequently if a known threat such as localised subsidence is reported. Inspections should monitor for active erosion (bank, bed and headcut erosion), increased sedimentation, altered flow path position and potential threats to infrastructure. All observations should be recorded and photographed.

If stabilisation works are required, it is recommended that:

- Stabilisation works are appropriate to the pre-disturbance watercourse type and minimise disturbance to the surrounding environment during construction. Stabilisation works should mimic pre-disturbance watercourse condition and behaviour as far as possible, including geomorphic complexity and habitat value.
- Watercourse condition is recorded before and after stabilisation works are undertaken and that any stabilisation works are monitored regularly for signs of erosion or failure. If continued erosion is observed following stabilisation, further investigation and management should be undertaken to resolve the disturbance.
- All management efforts should be recorded and photographed for documentation purposes.

Monitoring of watercourse condition throughout the entire study area should be undertaken prior to, during and after mining activities to ensure that any unpredicted impacts are captured. If impacts to watercourse are observed, targeted watercourse management plans should be developed and appropriate management practices should be applied.

6. References

Brierley G and Fryirs K, (2005) *Geomorphology and River Management: Applications of the River Styles Framework*. Blackwell Publishing, Oxford, UK, 398pp.

EMM Consulting (2019) *Newstan Mine Extension Project Flood Impact Assessment*. EMM Newcastle.

MSEC (2019) *Newstan Colliery: Mine Extension Project Environmental Impact Statement (Report Number: MSEC1042)*. Mine Subsidence Engineering Consultants (MSEC). Chatswood, Australia.



Appendix B

Assessment requirements

Table B.1 Assessment requirements

Source	Assessment requirements	Where addressed
SEARs	An assessment of any likely flooding impacts of the development	Chapter 6
	An assessment of the likely impacts of the development on aquifers, watercourses, riparian land, water-related infrastructure, and other water users	Appendix A
Office of Environment and Heritage (now DPIE – Biodiversity and Conservation Division)	The EIS must map the following features relevant to flooding as described in the Floodplain Development Manual 2005 (NSW Government 2005) including: a. Flood prone land. b. Flood planning area, the area below the flood planning level. c. Hydraulic categorisation (floodways and flood storage areas).	Section 6.5
	The EIS must describe flood assessment and modelling undertaken in determining the design flood levels for events, including a minimum of the 1 in 10 year, 1 in 100 year flood levels and the probable maximum flood, or an equivalent extreme event.	Section 3.3 Chapters 4 and 5
	The EIS must model the effect of the proposed development (including fill) on the flood behaviour under the following scenarios: a. Current flood behaviour for a range of design events as identified above. This includes the 1 in 200 year and 1 in 500 year flood events as proxies for assessing sensitivity to an increase in rainfall intensity of flood producing rainfall events due to climate change.	Section 6.6.2
	Modelling in the EIS must consider and document: a. The impact on existing flood behaviour for a full range of flood events including up to the probable maximum flood. b. Impacts of the development on flood behaviour resulting in detrimental changes in potential flood affectation of other developments or land. This may include redirection of flow, flow velocities, flood levels, hazards and hydraulic categories. c. Relevant provisions of the NSW Floodplain Development Manual 2005.	Section 3.3.4 Sections 6.3, 6.4 and 6.5
	The EIS must assess the impacts on the proposed development on flood behaviour including: a. Whether there will be detrimental increases in the potential flood affectation of other properties, assets and infrastructure. b. Consistency with Council floodplain risk management plans. c. Compatibility with the flood hazard of the land. d. Compatibility with the hydraulic functions of flow conveyance in floodways and storage in flood storage areas of the land. e. Whether there will be adverse effect to beneficial inundation of the floodplain environment, on, adjacent to or downstream of the site. f. Whether there will be direct or indirect increase in erosion, siltation, destruction of riparian vegetation or a reduction in the stability of river banks or watercourses. g. Any impacts the development may have upon existing community emergency management arrangements for flooding. These matters are to be discussed with the SES and Council. h. Emergency management, evacuation and access, and contingency measures for the development considering the full range of flood risk (based upon the probable maximum flood or an equivalent extreme flood event). These matters are to be discussed with and have the support of Council and the SES. i. Any impacts the development may have on the social and economic costs to the community as consequence of flooding.	Section 6.3 Chapter 4 Section 6.5 Section 6.5 Section 6.3.4 Appendix A Section 6.5 Section 6.5 Section 6.5

Table B.1 **Assessment requirements**

Source	Assessment requirements	Where addressed
IESC information guidelines	Describe the existing flood regime, including flood volume, depth, duration, extent and velocity for a range of annual exceedance probabilities. Provide flood hydrographs and maps identifying peak flood extent, depth and velocity. This assessment should be informed by topographic data that has been acquired using lidar or other reliable survey methods with accuracy stated.	Sections 6.2 and 6.3
	Use methods in accordance with the most recent publication of <i>Australian Rainfall and Runoff</i> .	Chapter 4
	Provide an assessment of the risks of flooding (including channel form and stability, water level, depth, extent, velocity, shear stress and stream power), and impacts to ecosystems, project infrastructure and the final project landform.	Chapter 6 Appendix A

Appendix C

Site inspection

Photograph

Description



WC8a headwater drainage line looking downstream.
Drainage line approximately 10 m to 20 m wide with poorly defined channel.
Dense vegetation present corresponding to high Manning's roughness values within drainage lines.



WC8a mid-catchment (upstream of Newstan-Eraring Private Coal Haul Road) drainage line looking downstream.
Drainage line approximately 10 m wide with poorly defined channel.
Dense vegetation and swampy in areas.



Typical non-drainage line groundcover within the WC8 catchment.
High Manning's roughness values associated with typical catchment groundcover.

Photograph

Description



Modified drainage line within WC8b upper catchment.
Several additional modified drainage lines were observed within the WC8b catchment.
Drainage lines observed to be moderate to densely vegetated with dense vegetation on overbank.



Overview of Hawkmount Quarry located within WC8b catchment.
Quarry spillway and outlet channel located to the left of image.
The quarry is expected to provide significant storage of rainfall and runoff from contributing catchment.



Hawkmount Quarry outlet channel looking upstream toward quarry.
The quarry outlet channel forms part of the WC8b drainage line.

Photograph

Description



Typical drainage line vegetation for the upper reaches of WC9 catchment.

Drainage lines generally have a poorly defined channel and dense vegetation corresponding to high Manning's roughness values.



Midway along WC20b.

Intermittent sections of incised channels are present within some sections of the WC20 watercourses.

Dense vegetation present on overbank corresponding to high Manning's roughness values.



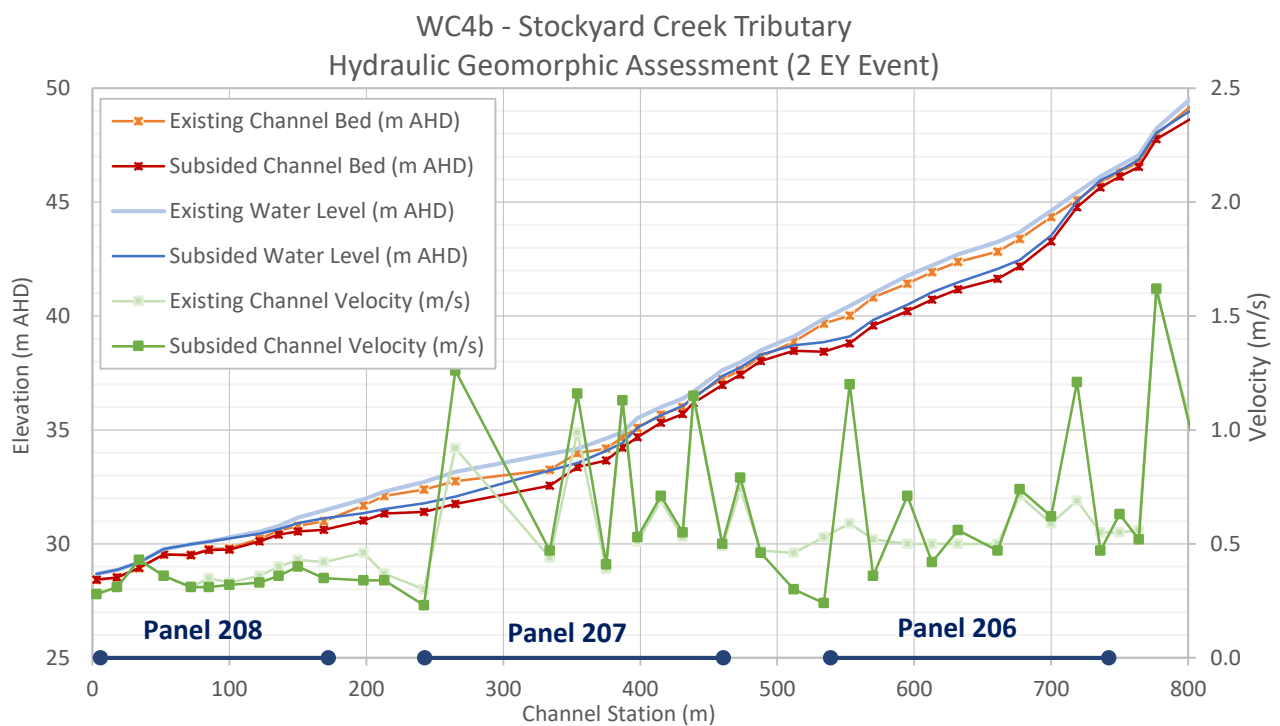
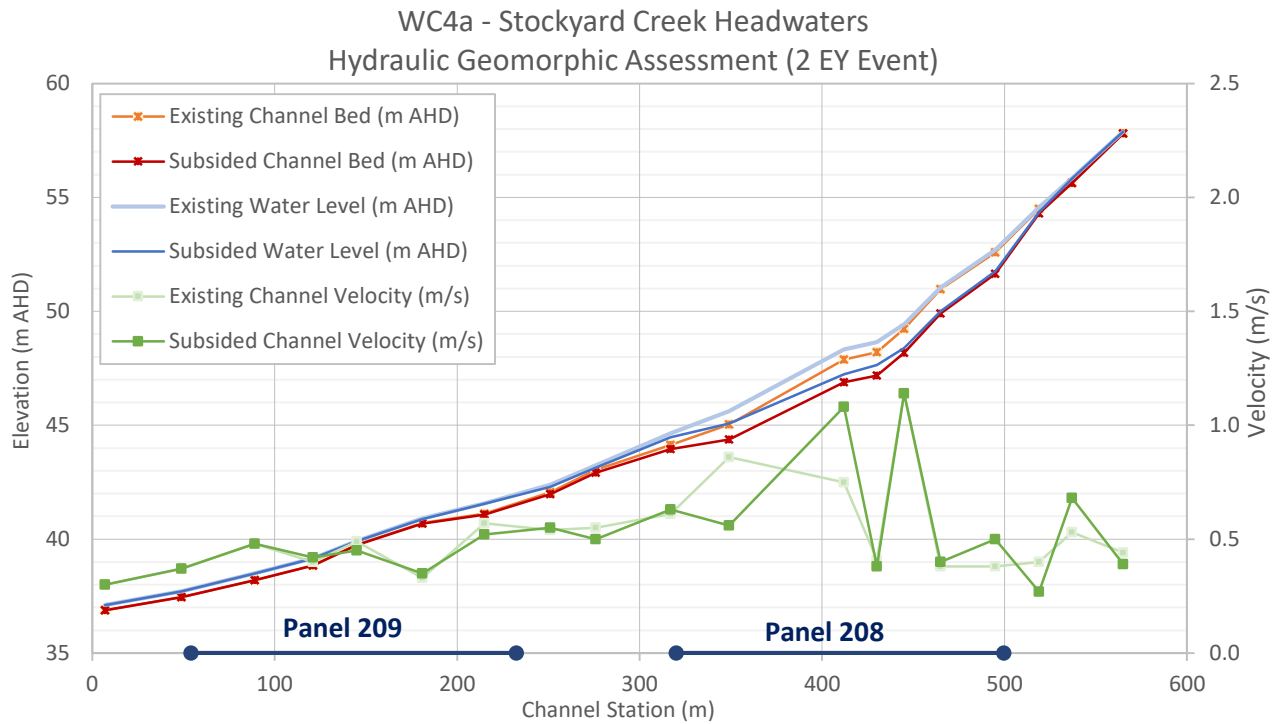
WC20-mid (upstream of Newstan-Eraring Private Coal Haul Road) drainage line looking upstream.

Dense vegetation and swampy in areas.

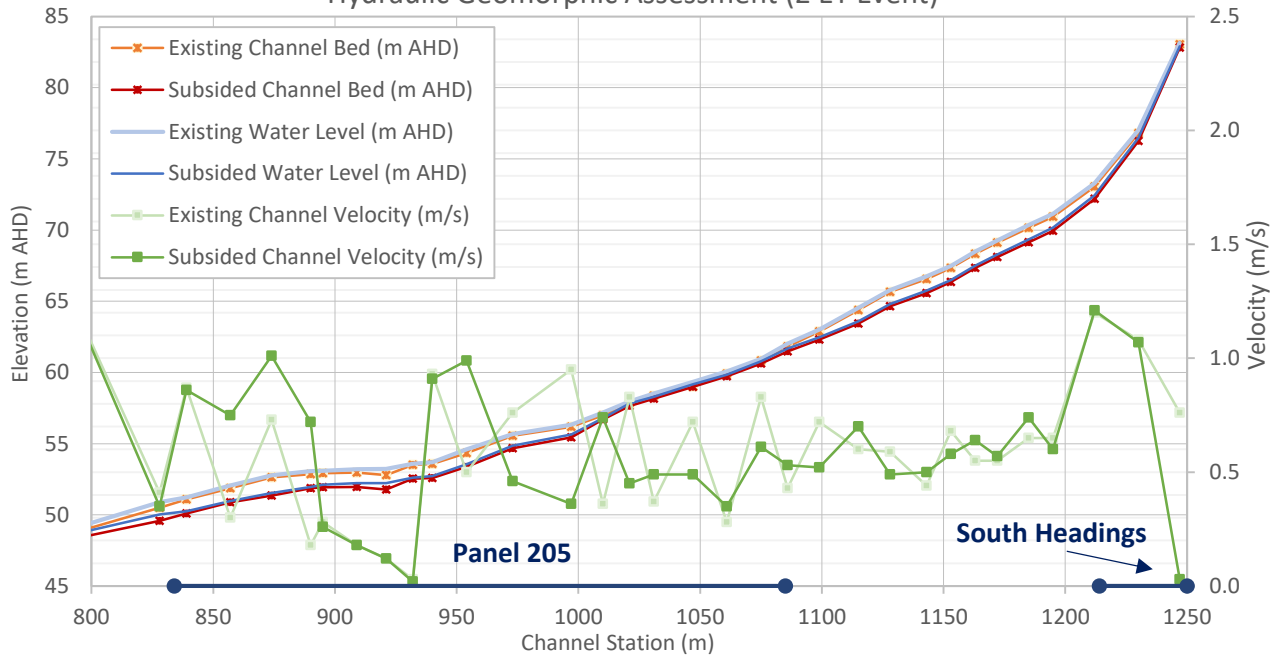
Appendix D

HEC-RAS long sections

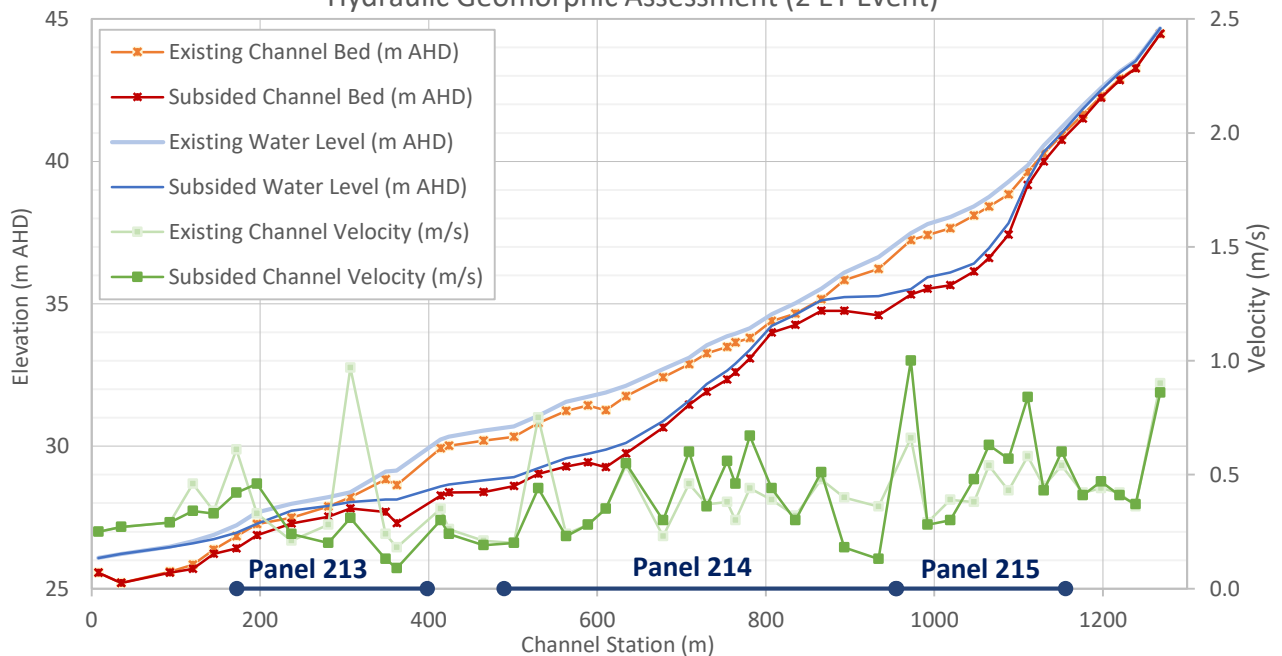
D.1 1D hydraulic model results – 2 EY event



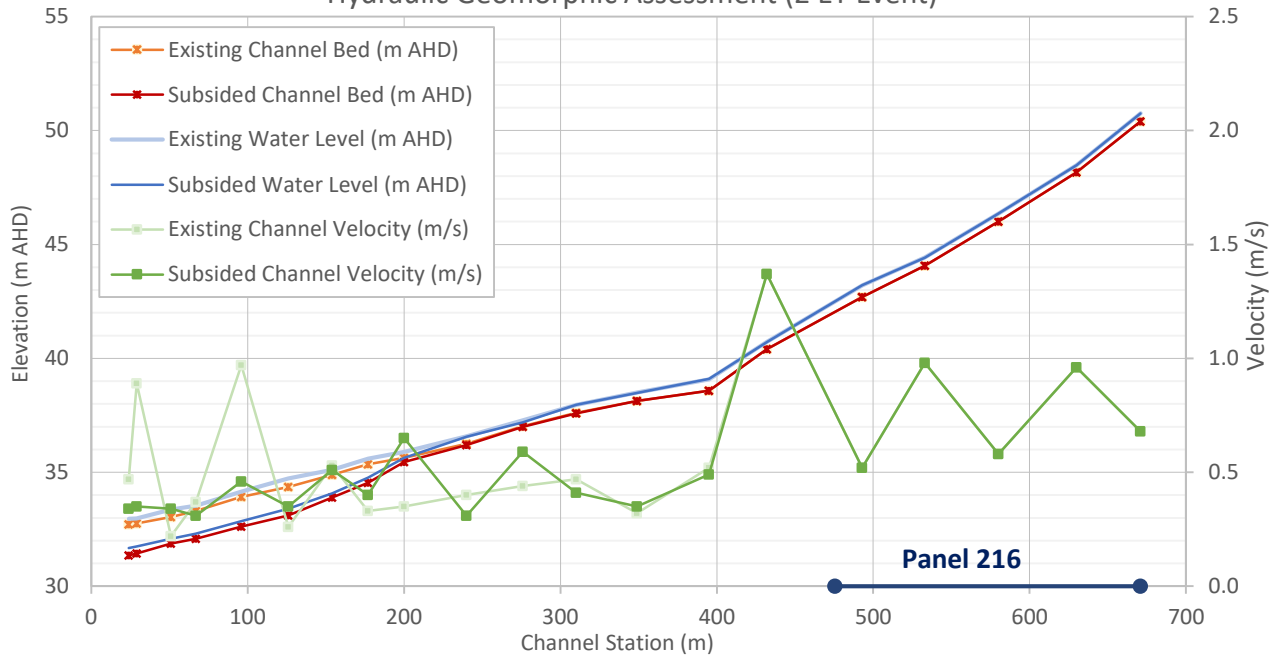
WC4b - Stockyard Creek Tributary Hydraulic Geomorphic Assessment (2 EY Event)



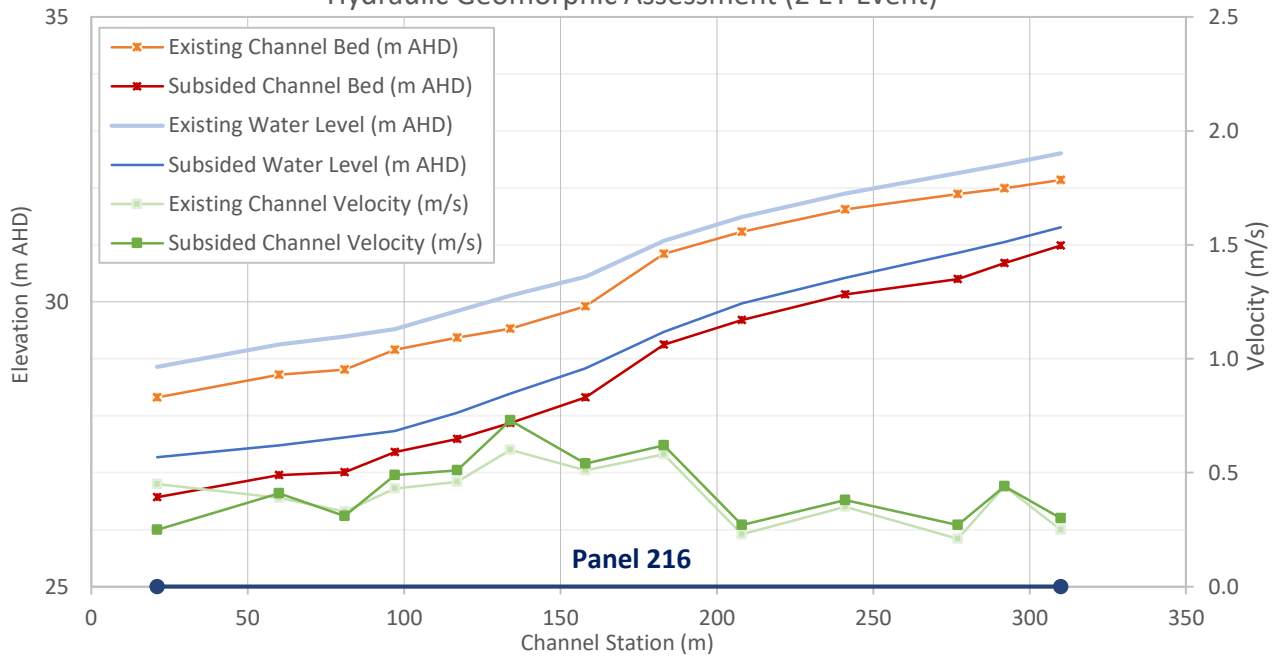
WC8 - Lords Creek Tributary Hydraulic Geomorphic Assessment (2 EY Event)



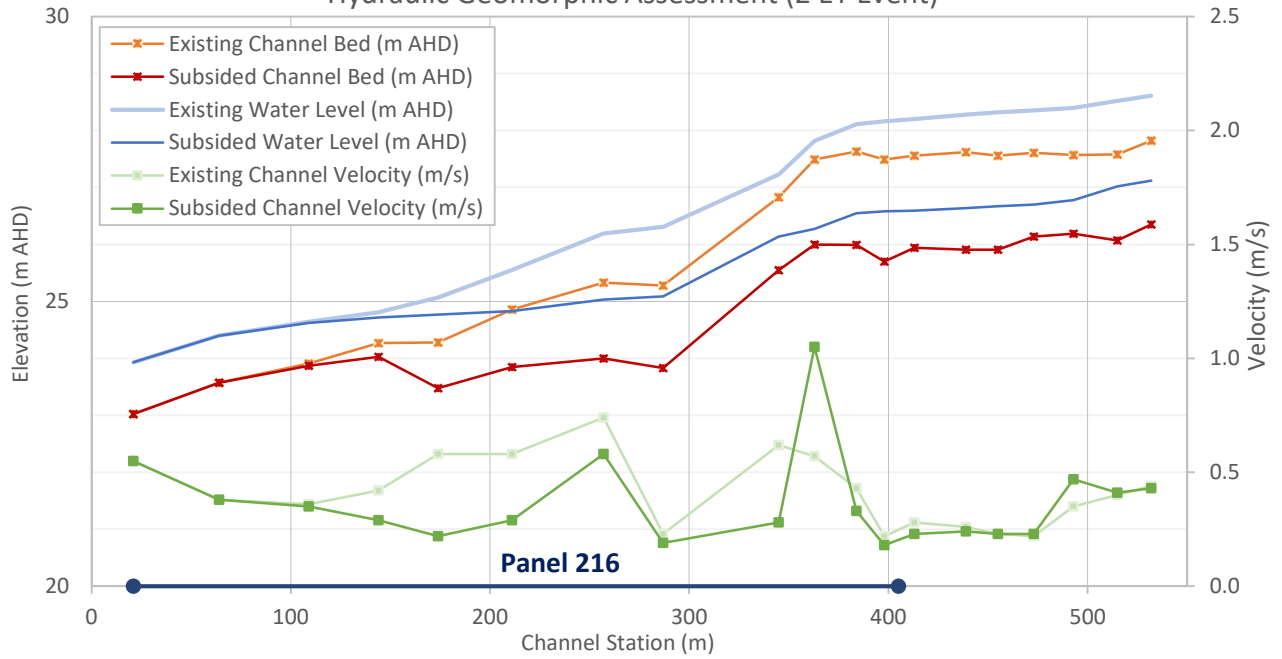
WC20-US - Lords Creek Tributary
Hydraulic Geomorphic Assessment (2 EY Event)



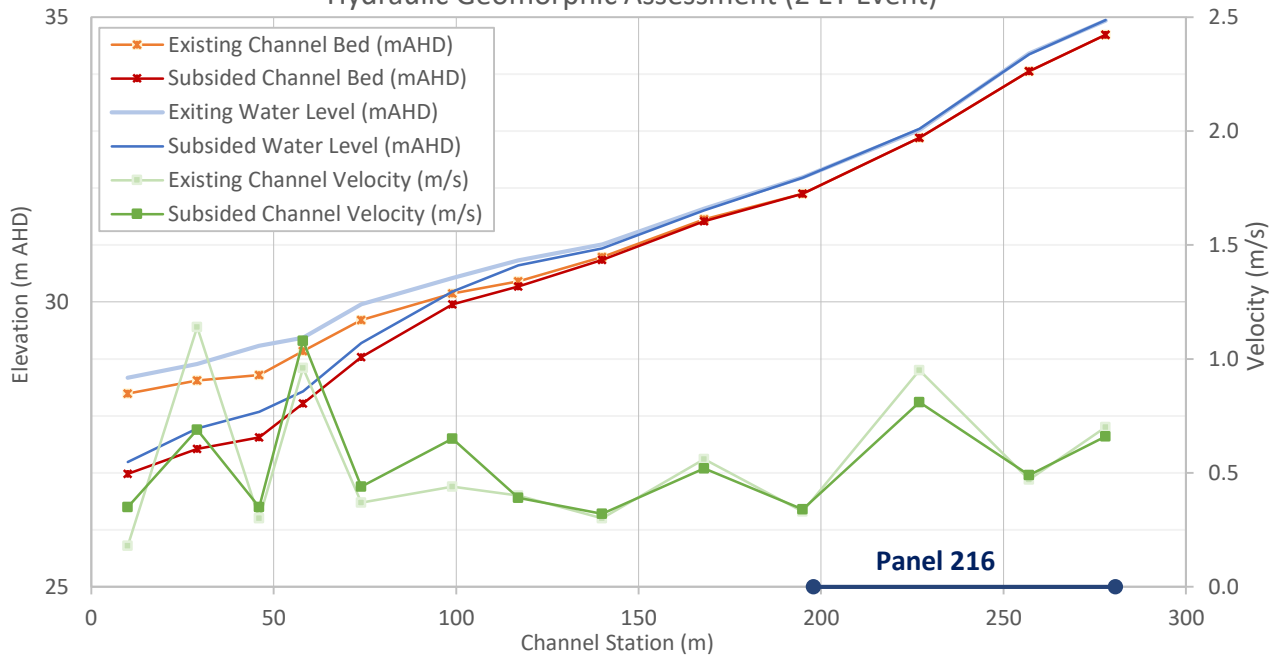
WC20-MID - Lords Creek Tributary
Hydraulic Geomorphic Assessment (2 EY Event)

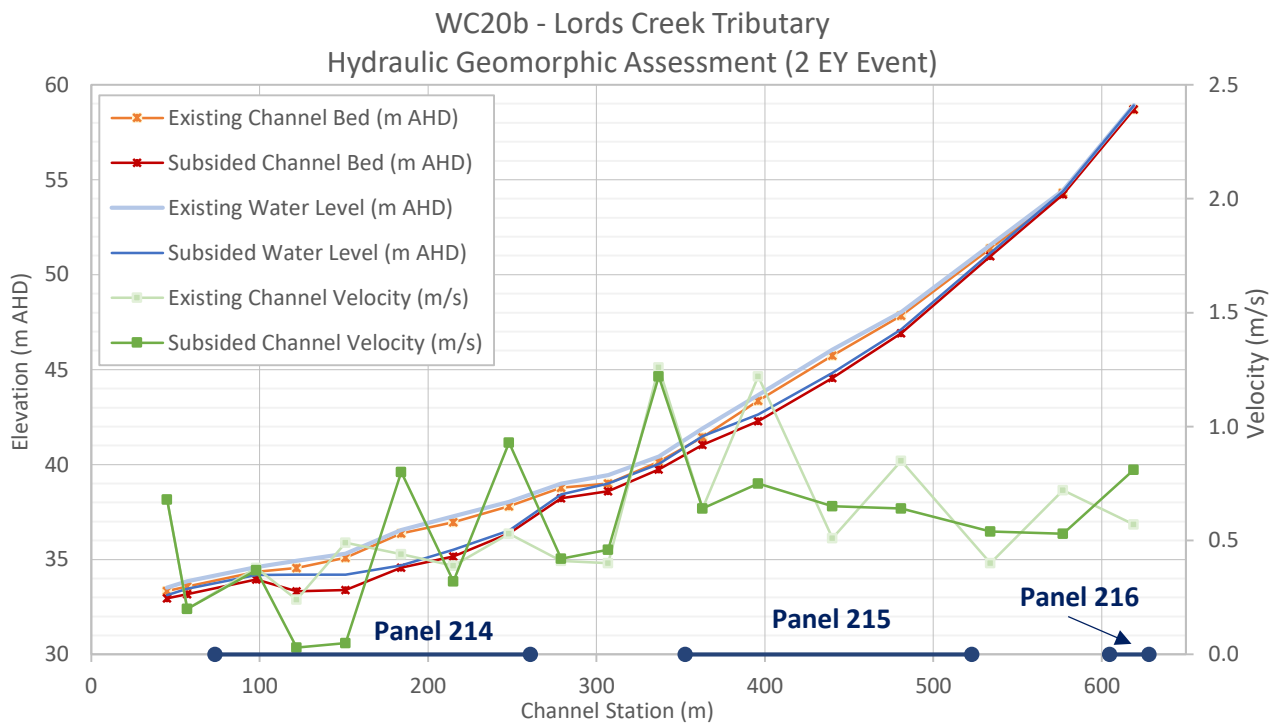


WC20-DS - Lords Creek Tributary
Hydraulic Geomorphic Assessment (2 EY Event)

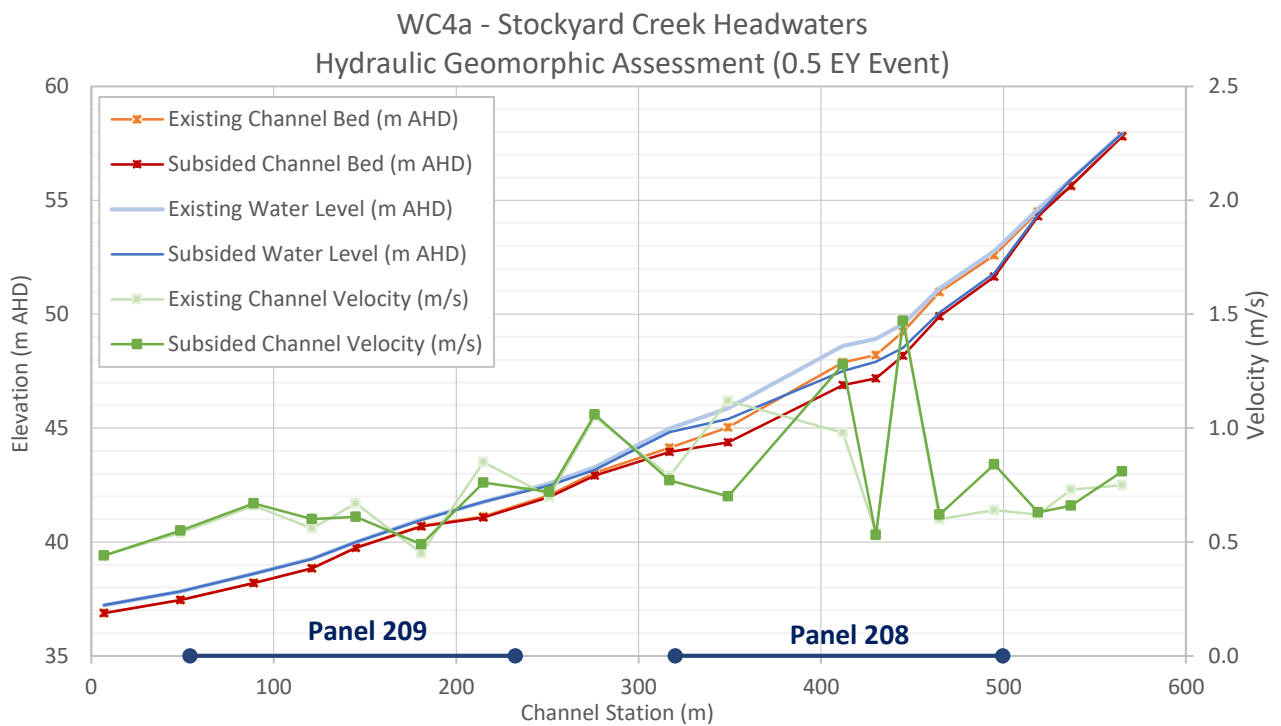


WC20a - Lords Creek Tributary
Hydraulic Geomorphic Assessment (2 EY Event)

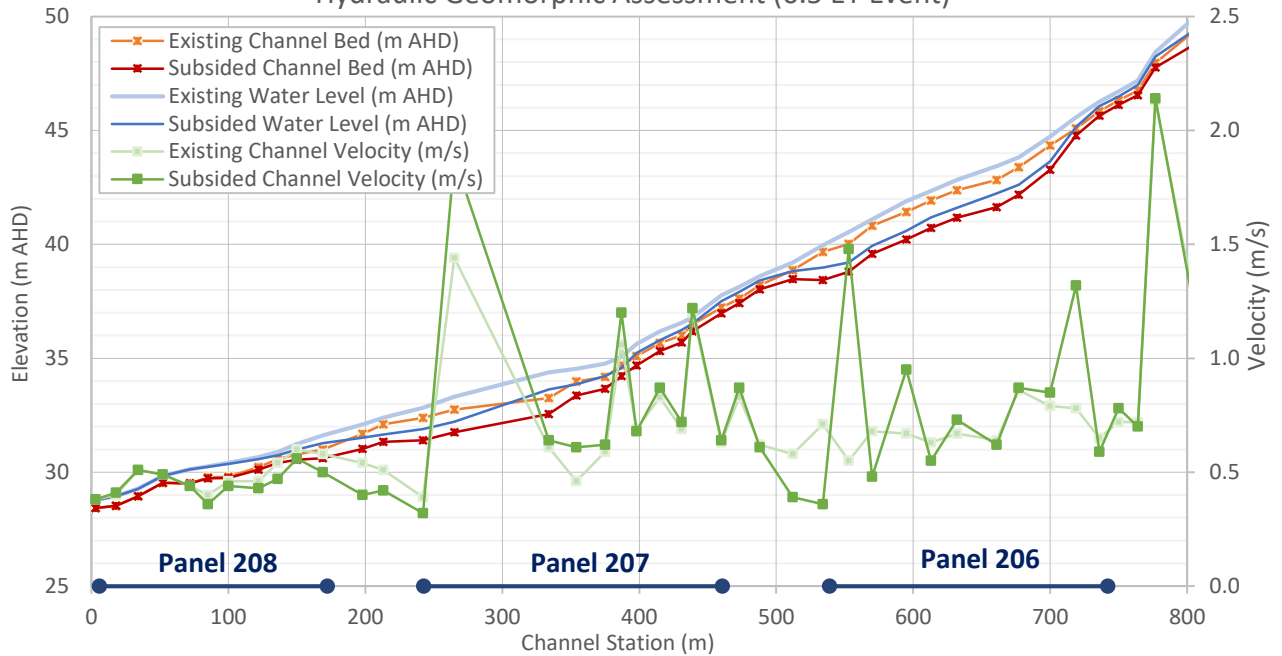




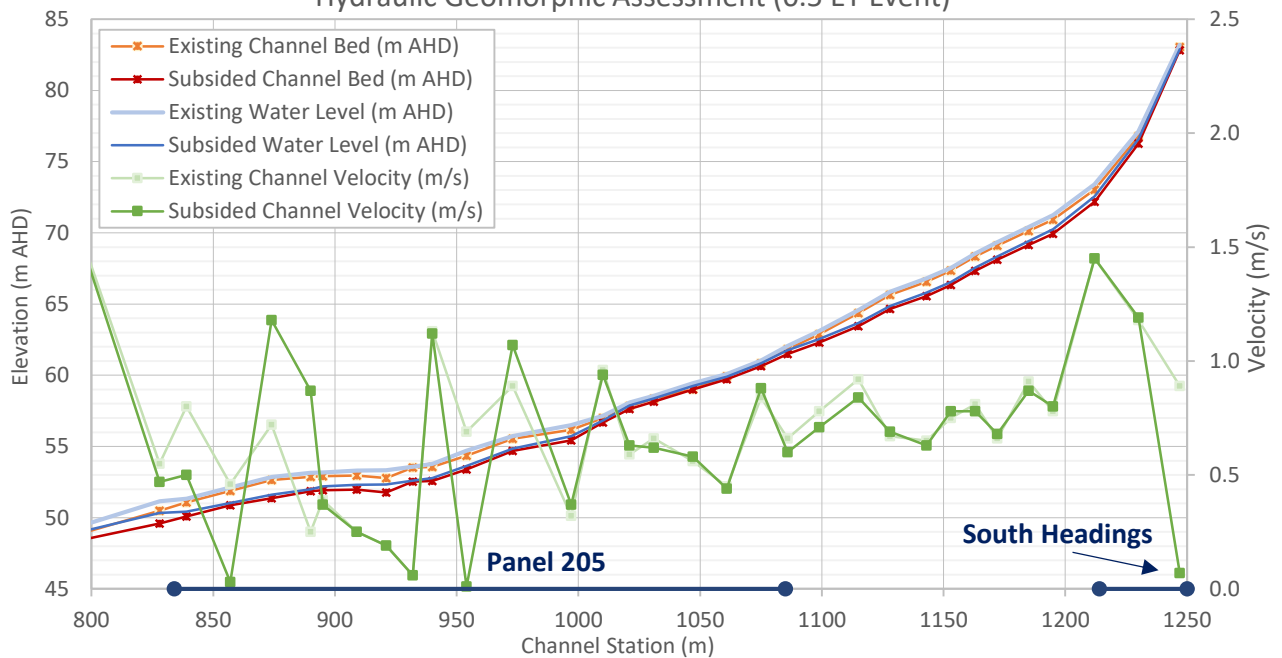
D.2 1D hydraulic model results – 0.5 EY event



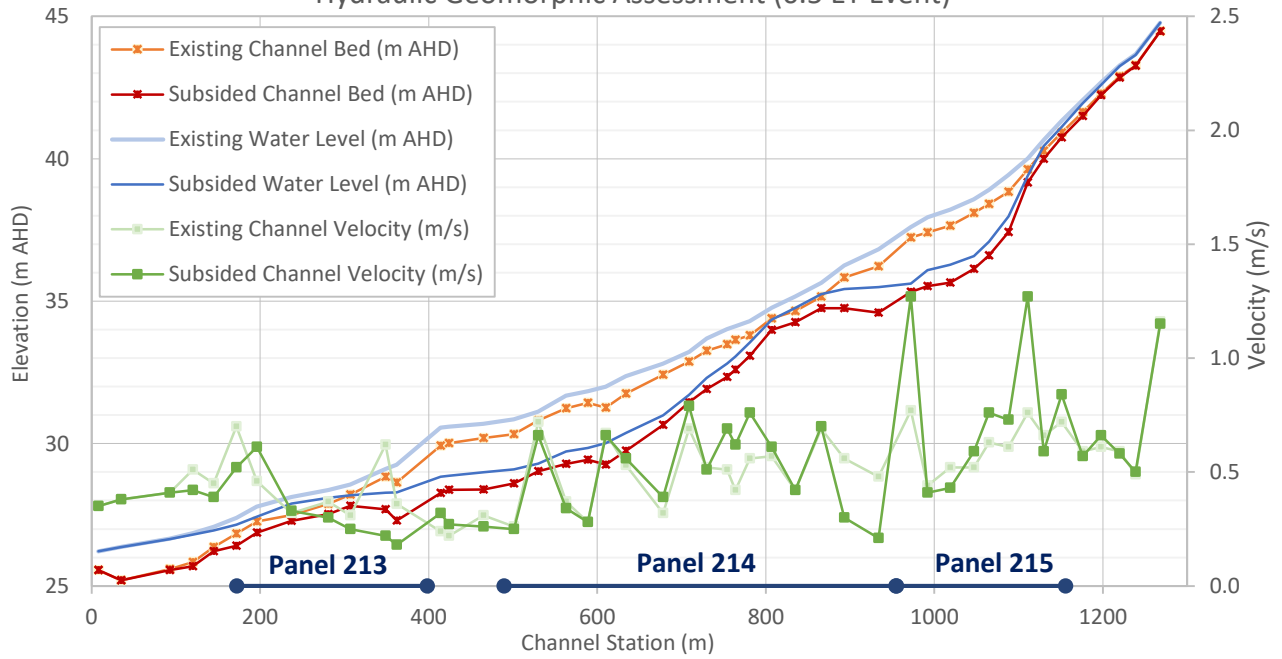
WC4b - Stockyard Creek Tributary
Hydraulic Geomorphic Assessment (0.5 EY Event)



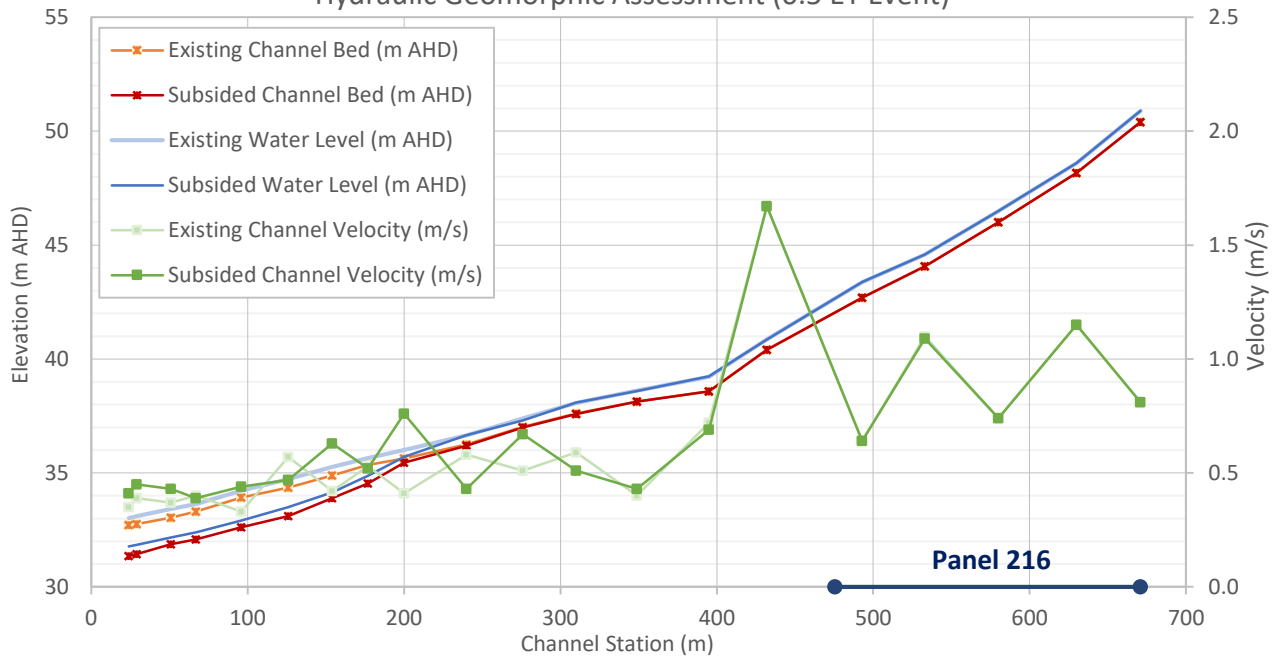
WC4b - Stockyard Creek Tributary
Hydraulic Geomorphic Assessment (0.5 EY Event)



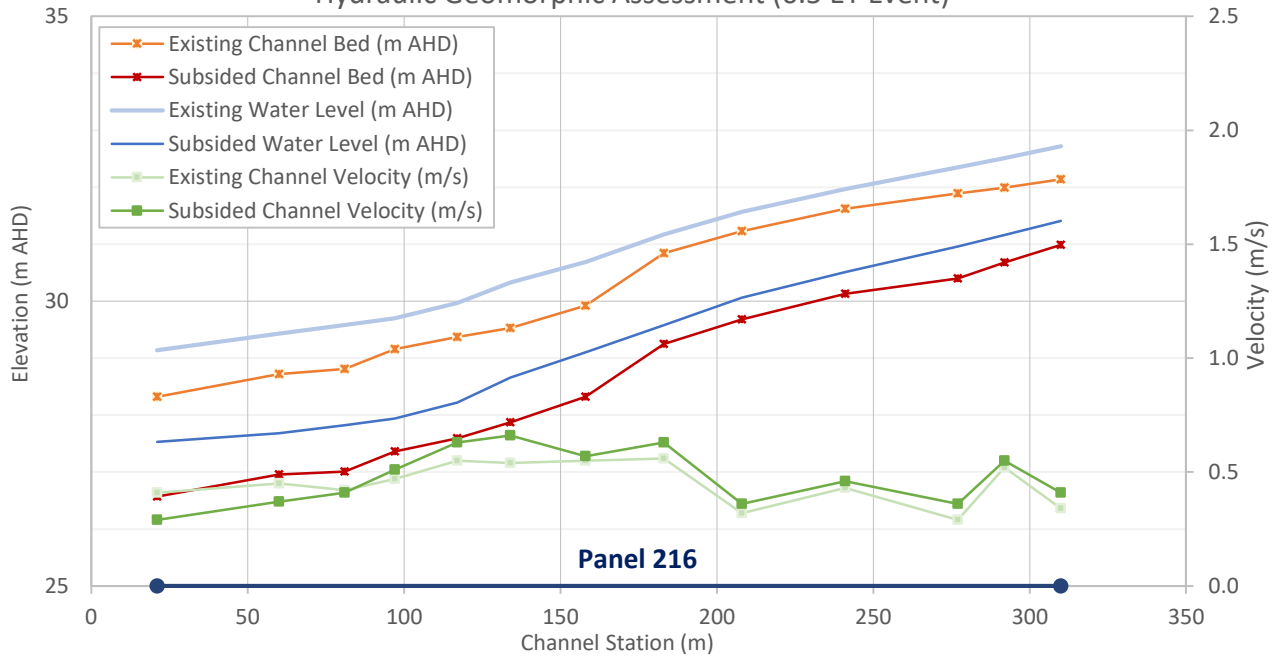
WC8 - Lords Creek Tributary Hydraulic Geomorphic Assessment (0.5 EY Event)



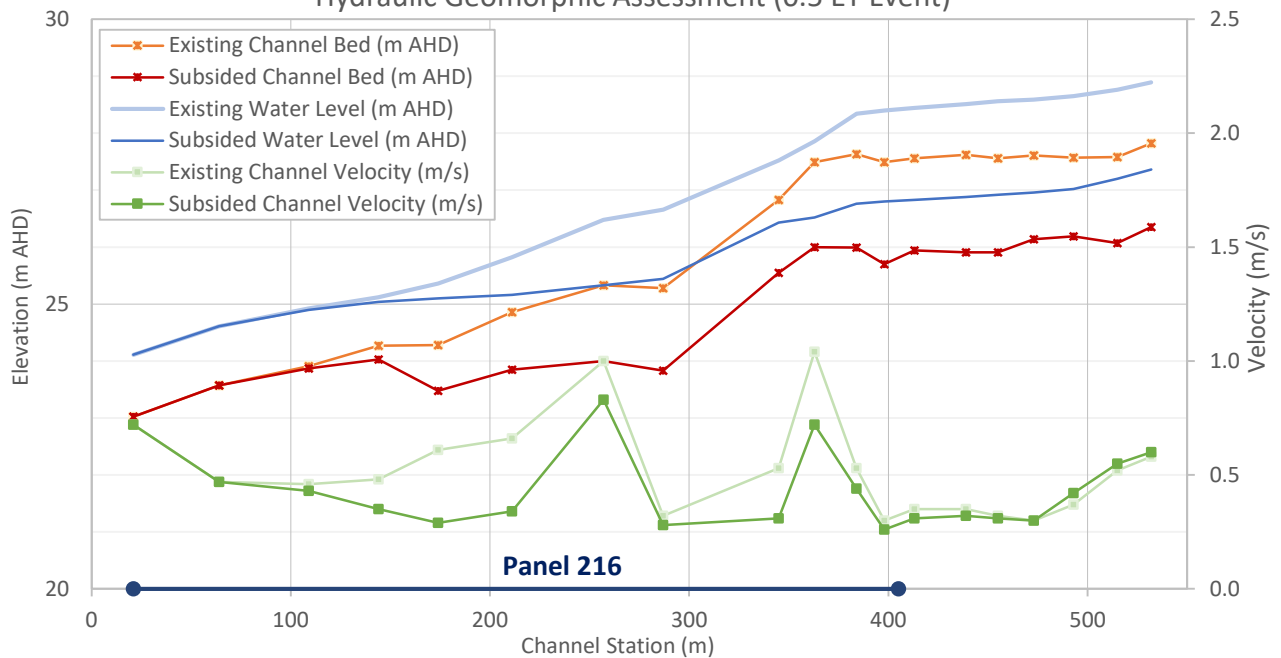
WC20-US - Lords Creek Tributary Hydraulic Geomorphic Assessment (0.5 EY Event)



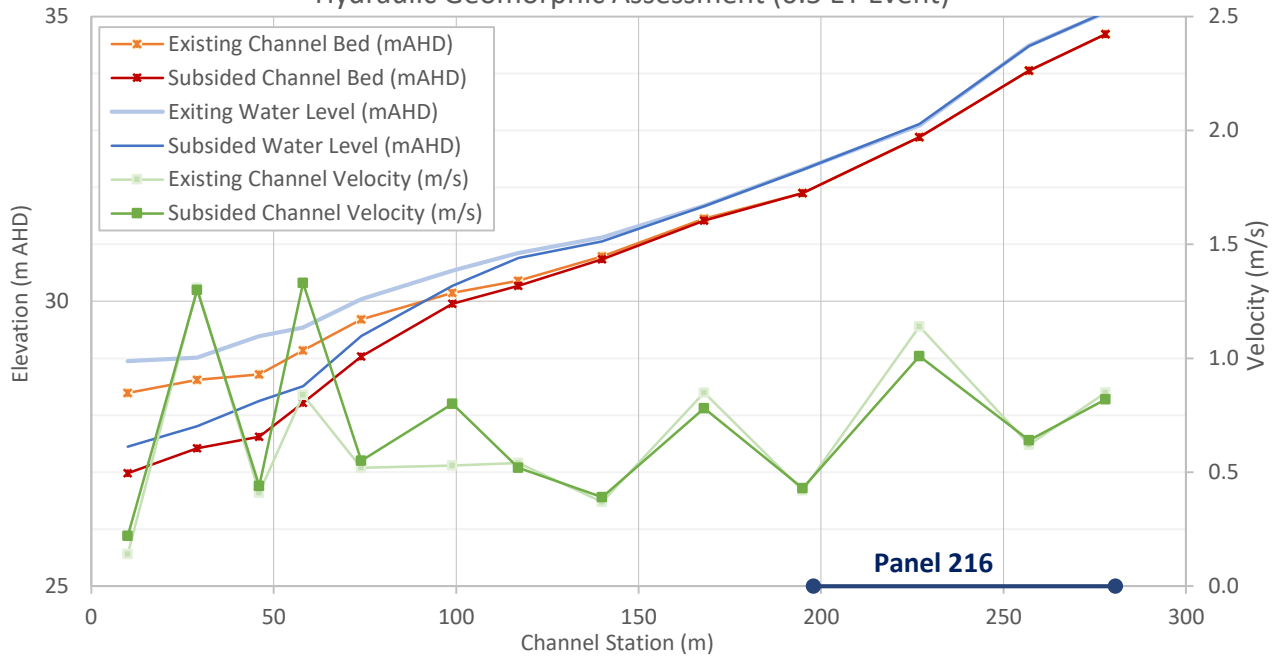
WC20-MID - Lords Creek Tributary
Hydraulic Geomorphic Assessment (0.5 EY Event)



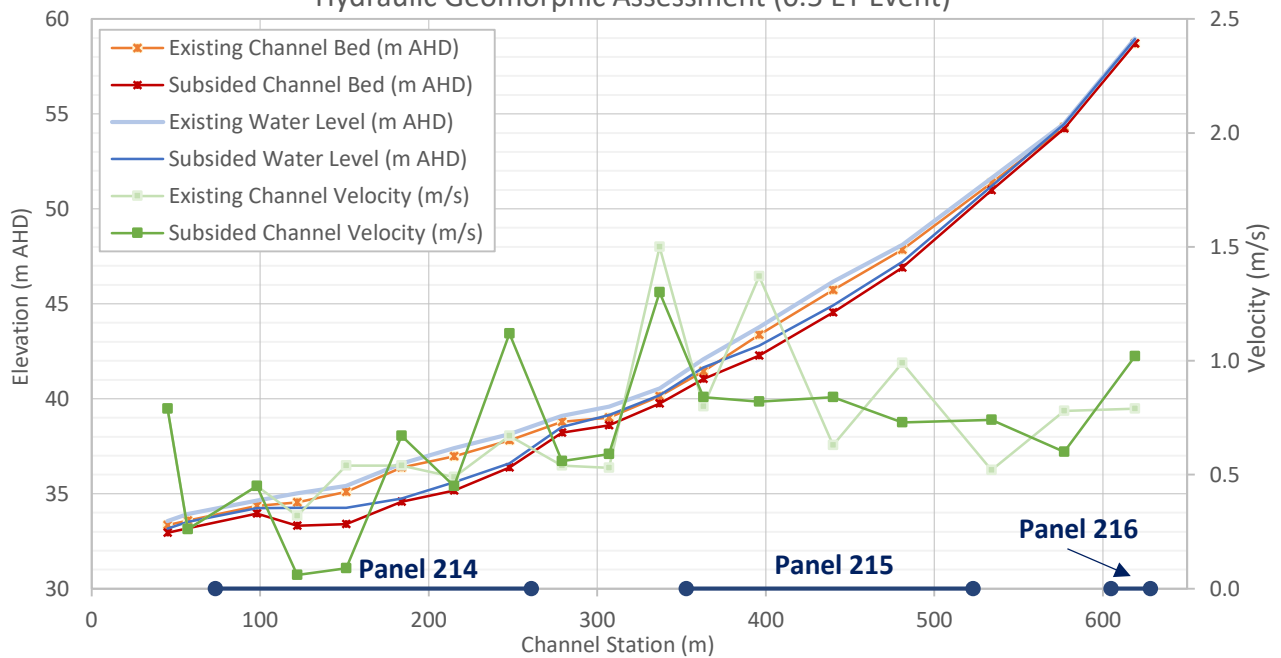
WC20-DS - Lords Creek Tributary
Hydraulic Geomorphic Assessment (0.5 EY Event)



WC20a - Lords Creek Tributary
Hydraulic Geomorphic Assessment (0.5 EY Event)



WC20b - Lords Creek Tributary
Hydraulic Geomorphic Assessment (0.5 EY Event)



Appendix E

Flood maps

E.1 Existing conditions

Figure E.1 Existing conditions – flood depth (1% AEP event)

Figure E.2 Existing conditions – flood depth (0.5% AEP event)

Figure E.3 Existing conditions – flood depth (0.2% AEP event)

Figure E.4 Existing conditions – flood depth (extreme event)

Figure E.5 Existing conditions – flood velocity (1% AEP event)

Figure E.6 Existing conditions – flood velocity (0.5% AEP event)

Figure E.7 Existing conditions – flood velocity (0.2% AEP event)

Figure E.8 Existing conditions – flood velocity (extreme event)

E.2 Subsided conditions

Figure E.9 Potential subsided conditions – change in depth (1% AEP event)

Figure E.10 Potential subsided conditions – change in depth (0.5% AEP event)

Figure E.11 Potential subsided conditions – change in depth (0.2% AEP event)

Figure E.12 Potential subsided conditions – change in depth (extreme event)

Figure E.13 Potential subsided conditions – change in velocity (1% AEP event)

Figure E.14 Potential subsided conditions – change in velocity (0.5% AEP event)

Figure E.15 Potential subsided conditions – change in velocity (0.2% AEP event)

Figure E.16 Potential subsided conditions – change in velocity (extreme event)

E.3 Climate change conditions

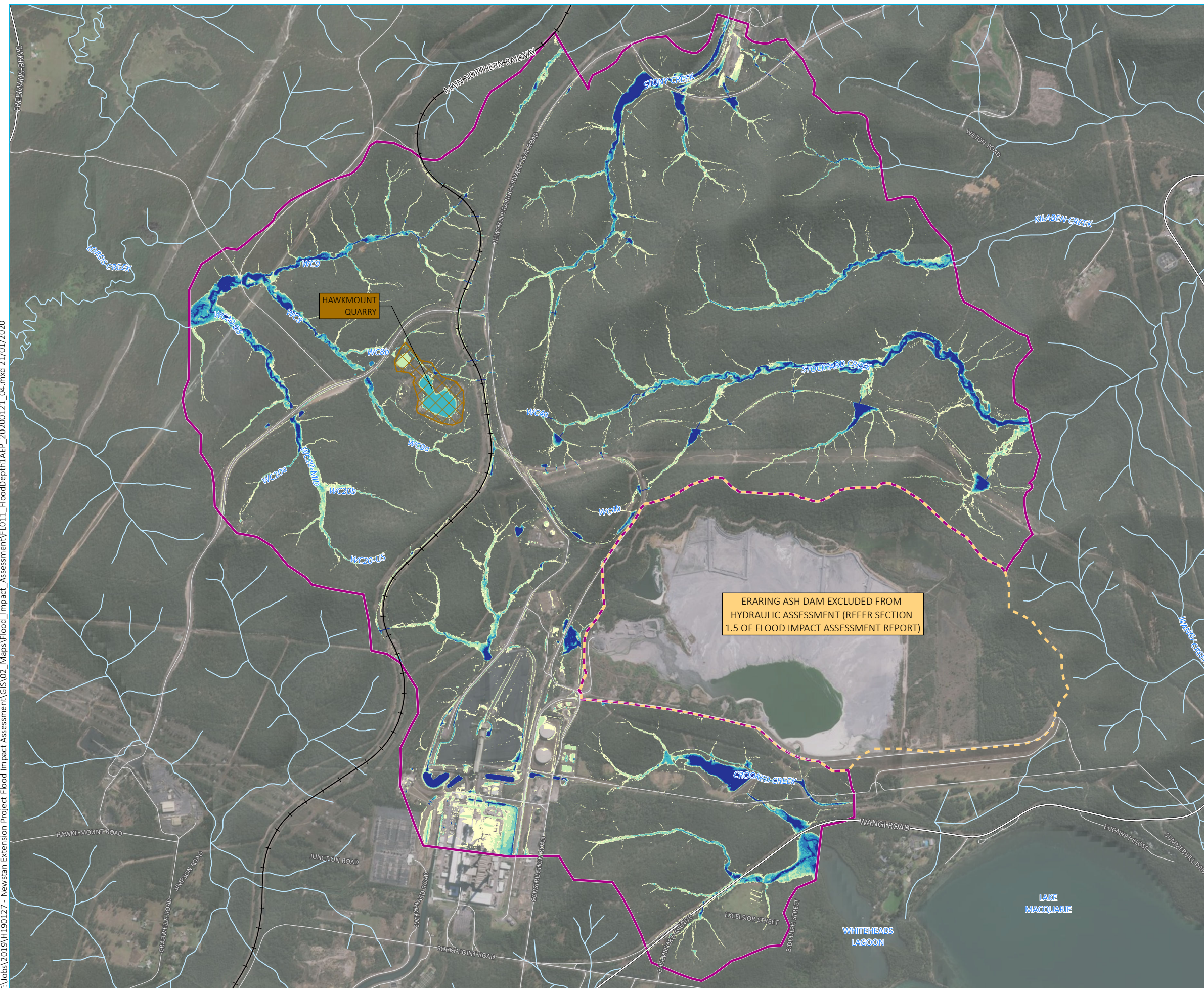
Figure E.17 Climate change depth impacts (2050 subsided conditions event)

Figure E.18 Climate change velocity impacts (2050 subsided conditions event)

Figure E.19 Climate change depth impacts (2100 subsided conditions event)

Figure E.20 Climate change velocity impacts (2100 subsided conditions event)

T:\Jobs\2019\1190127 - Newstan Extension Project Flood Impact Assessment\GIS\02_Maps\Flood_Impact_Assessment\FI011_FloodDepth1AEP_20200121_04.mxd 21/01/2020

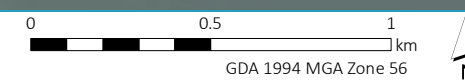


- KEY
- Study area
 - Rail line
 - Eraring Ash Dam exclusion area
 - Hawkmount Quarry
 - Main road
 - Local road
 - Watercourse/ drainage line
- Peak flood depth (m)
- < 0.2
 - 0.2 - 0.4
 - 0.4 - 0.6
 - 0.6 - 0.8
 - 0.8 - 1
 - > 1

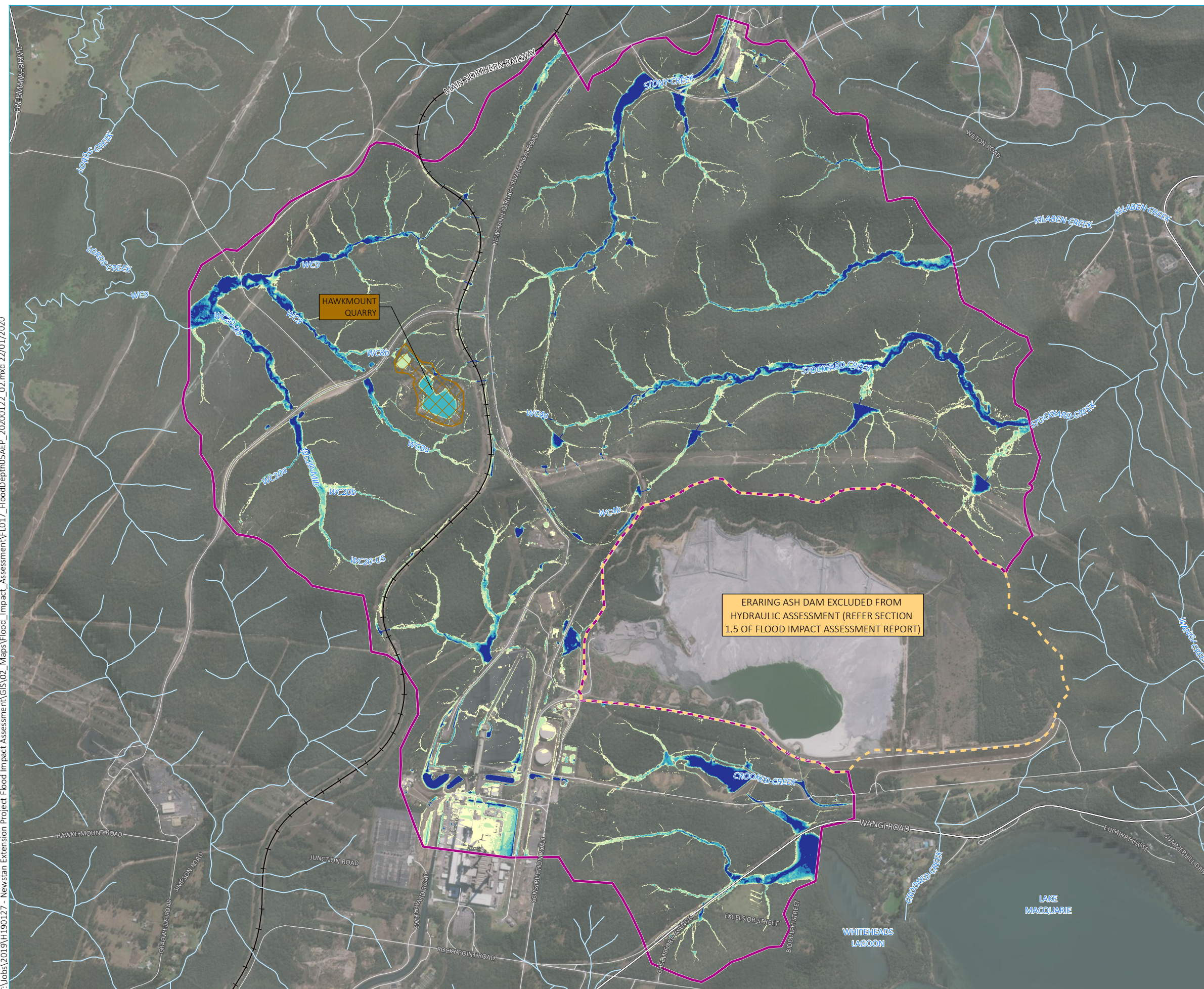
Existing conditions - flood depth
(1% AEP event)

Newstan Mine Extension Project
Flood impact assessment
Figure E.1

Source: EMM (2019); DFSI (2017); Nearmap (2018); GA (2011)



T:\Jobs\2019\1190127 - Newstan Extension Project Flood Impact Assessment\GIS\02_Maps\Flood_Impact_Assessment\FI017_FloodDepth05AEP_20200122_02.mxd 22/01/2020

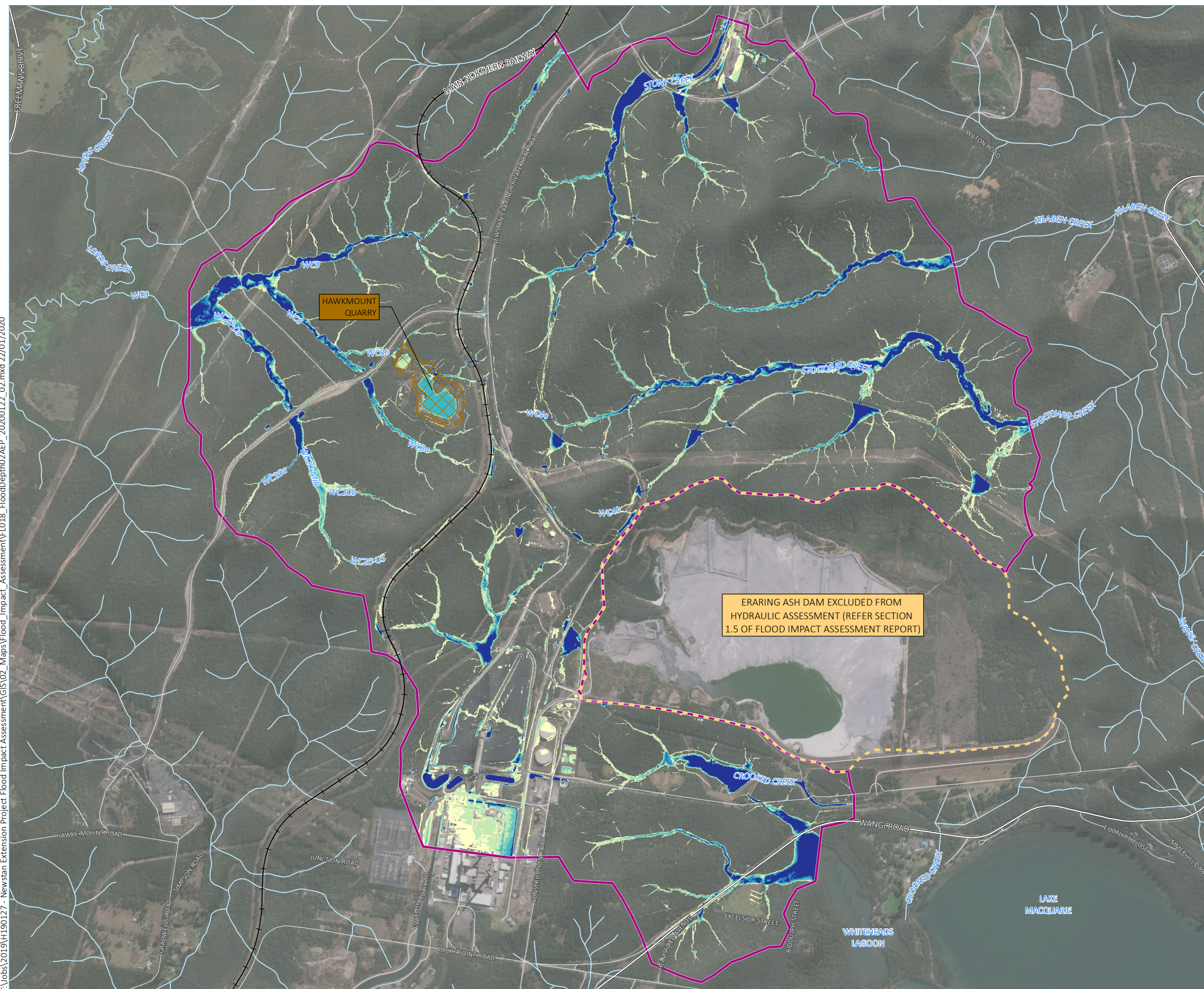


- KEY
- Study area
 - Eraring Ash Dam exclusion area
 - Hawkmount Quarry
 - Rail line
 - Main road
 - Local road
 - Watercourse/ drainage line
- Peak flood depth (m)
- < 0.2
 - 0.2 - 0.4
 - 0.4 - 0.6
 - 0.6 - 0.8
 - 0.8 - 1
 - > 1

Existing conditions - flood depth
(0.5% AEP event)

Newstan Mine Extension Project
Flood impact assessment
Figure E.2

T:\Jobs\2019\1190127 - Newstan Extension Project Flood Impact Assessment\GIS\02_Maps\Flood_Impact_Assessment\FI018_FloodDepth02AEP_20200122_02.mxd 22/01/2020

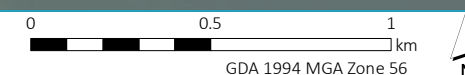


- KEY
- Study area
 - Eraring Ash Dam exclusion area
 - Hawkmount Quarry
 - Rail line
 - Main road
 - Local road
 - Watercourse/ drainage line
- Peak flood depth (m)
- < 0.2
 - 0.2 - 0.4
 - 0.4 - 0.6
 - 0.6 - 0.8
 - 0.8 - 1
 - > 1

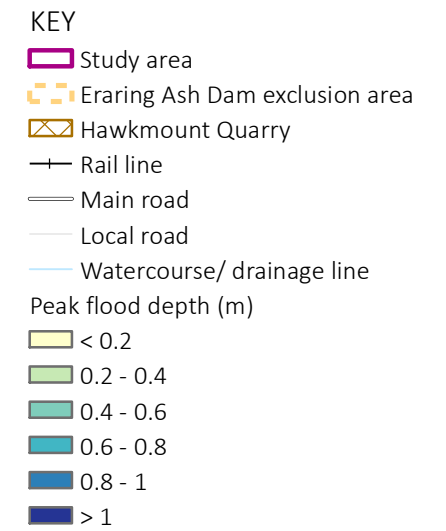
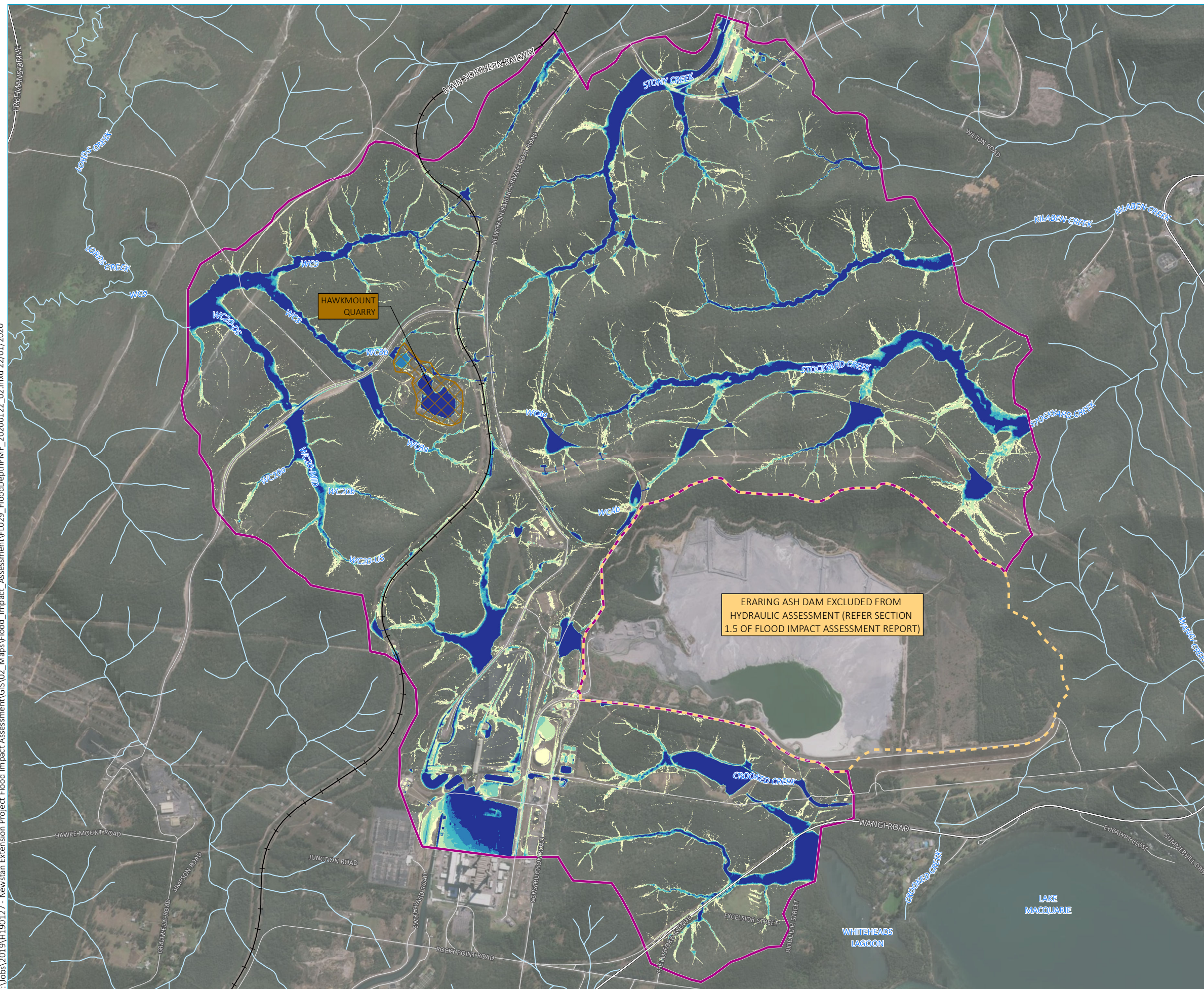
Existing conditions - flood depth
(0.2% AEP event)

Newstan Mine Extension Project
Flood impact assessment
Figure E.3

Source: EMM (2019); DFSI (2017); Nearmap (2018); GA (2011)



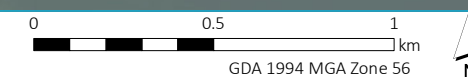
T:\Jobs\2019\1190127 - Newstan Extension Project Flood Impact Assessment\GIS\02_Maps\Flood_Impact_Assessment\FI029_FloodDepthPMF_20200122_02.mxd 22/01/2020



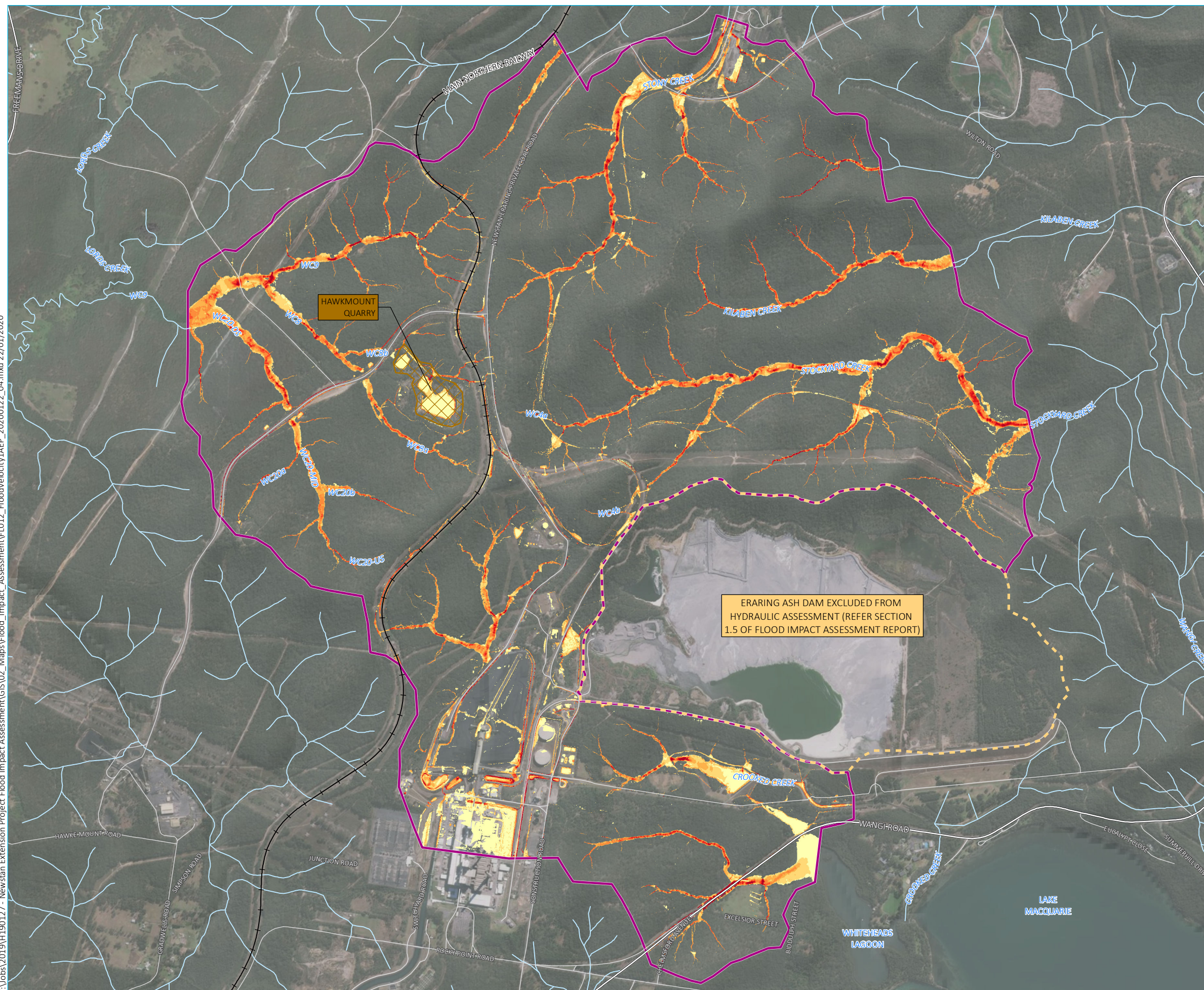
Existing conditions - flood depth
(extreme event)

Newstan Mine Extension Project
Flood impact assessment
Figure E.4

Source: EMM (2019); DFSI (2017); Nearmap (2018); GA (2011)



T:\Jobs\2019\1190127 - Newstan Extension Project Flood Impact Assessment\GIS\02_Maps\Flood_Impact_Assessment\FI012_FloodVelocityIAEP_20200122_04.mxd 22/01/2020

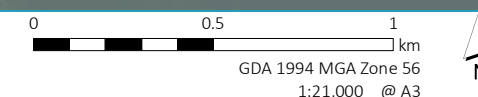


- KEY**
- Study area
 - Eraring Ash Dam exclusion area
 - Hawkmount Quarry
 - Rail line
 - Main road
 - Local road
 - Watercourse/ drainage line
- Peak flood velocity (m)**
- < 0.25
 - 0.25 - 0.5
 - 0.5 - 0.75
 - 0.75 - 1
 - 1 - 1.25
 - 1.25 - 1.5
 - > 1.5

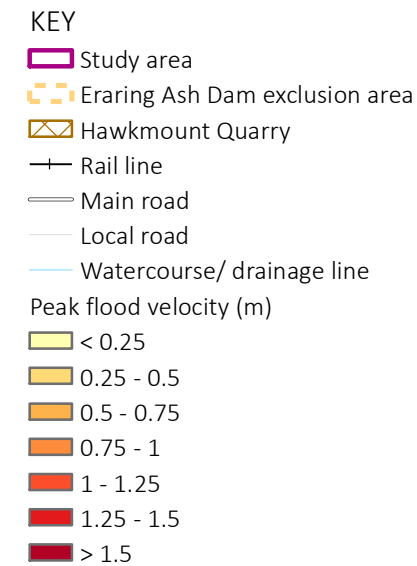
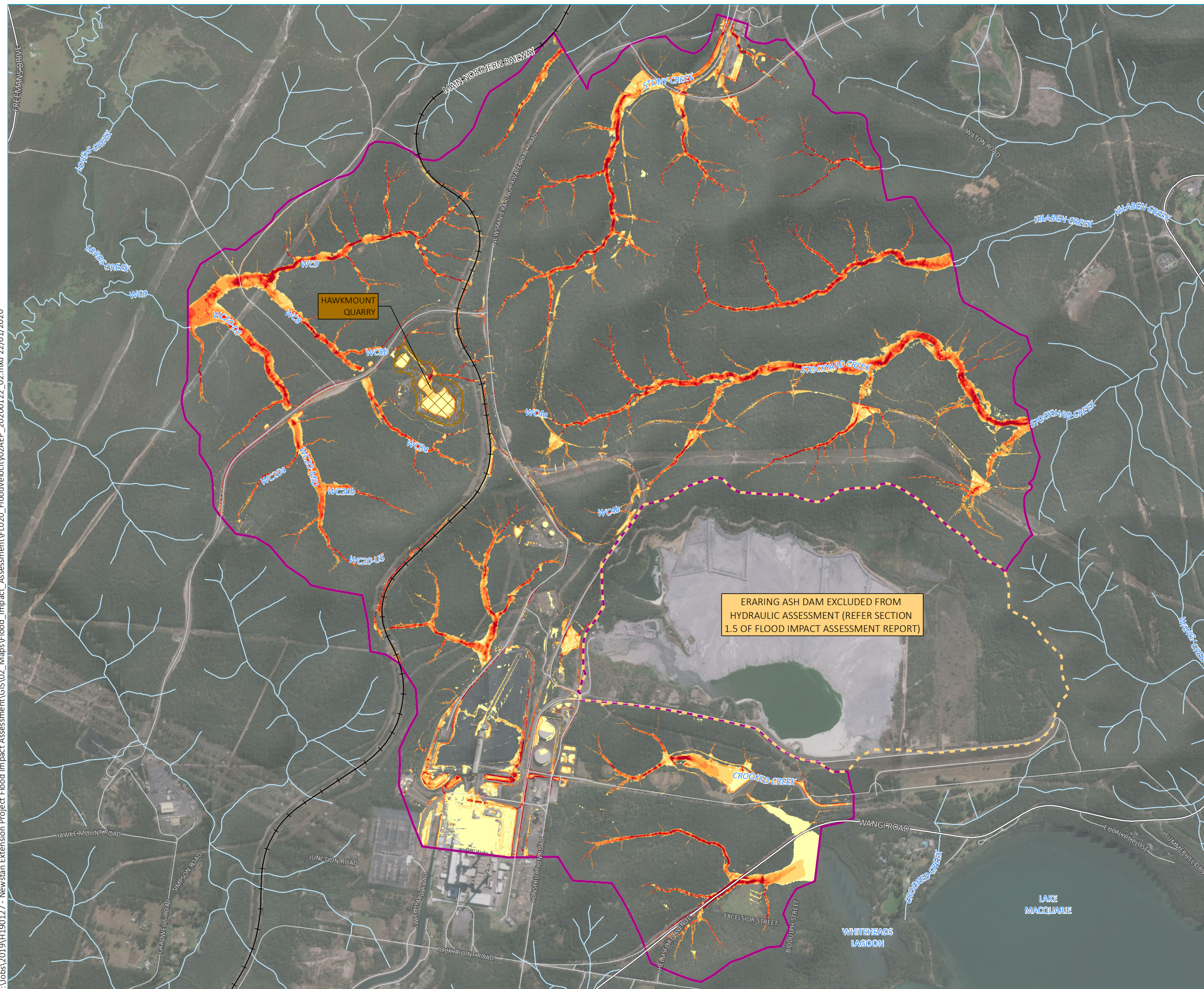
Existing conditions - flood velocity
(1% AEP event)

Newstan Mine Extension Project
Flood impact assessment
Figure E.5

Source: EMM (2019); DFSI (2017); Nearmap (2018); GA (2011)



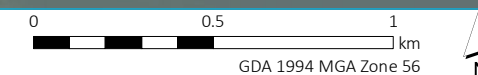
T:\Jobs\2019\1190127 - Newstan Extension Project Flood Impact Assessment\GIS\02_Maps\Flood_Impact_Assessment\FI020_FloodVelocity02AEP_20200122_02.mxd 22/01/2020



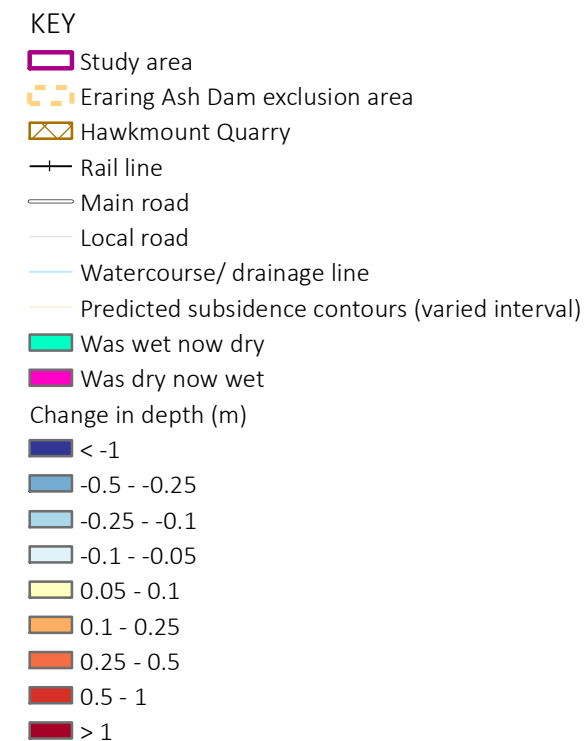
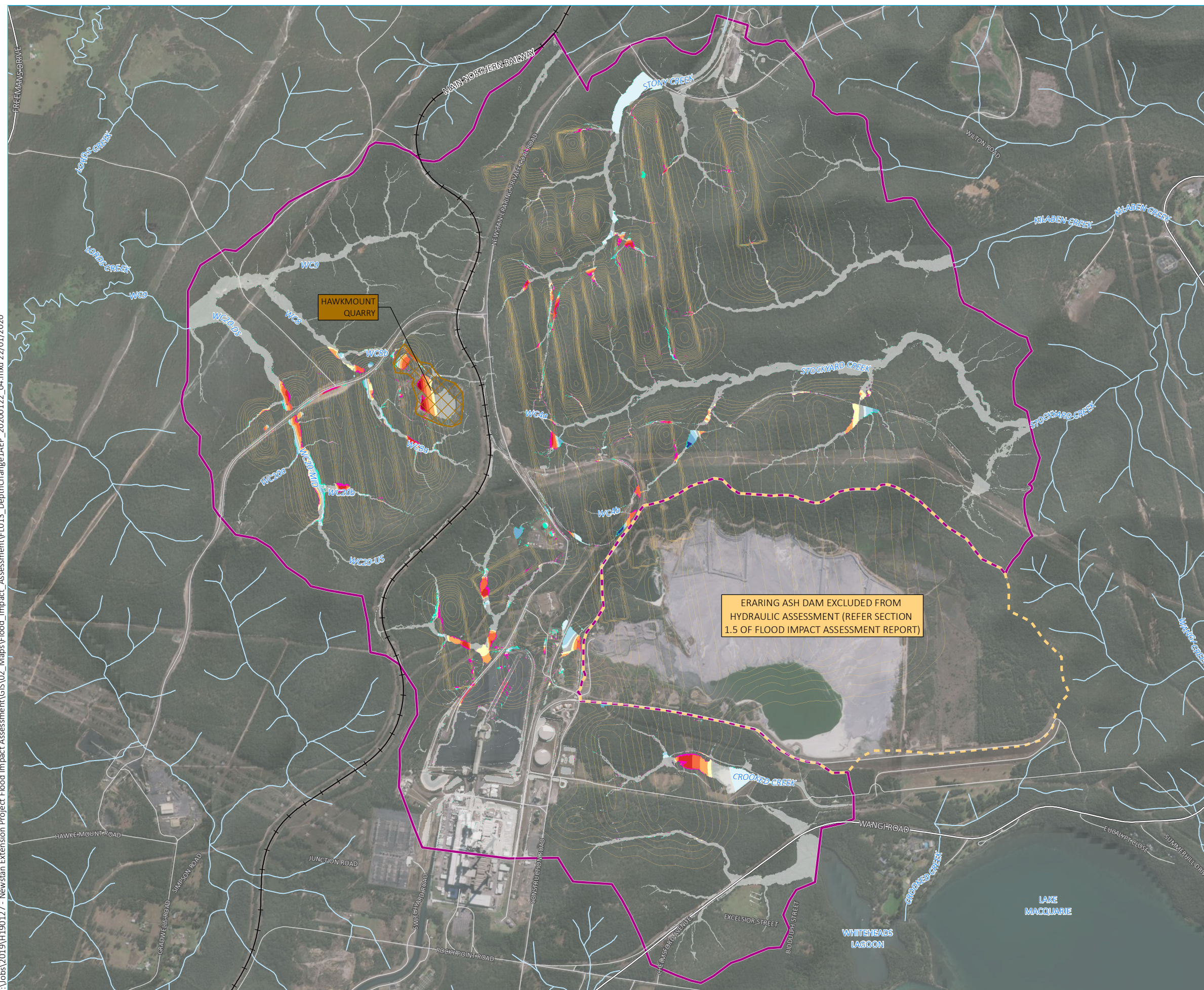
Existing conditions - flood velocity
(0.2% AEP event)

Newstan Mine Extension Project
Flood impact assessment
Figure E.7

Source: EMM (2019); DFSI (2017); Nearmap (2018); GA (2011)



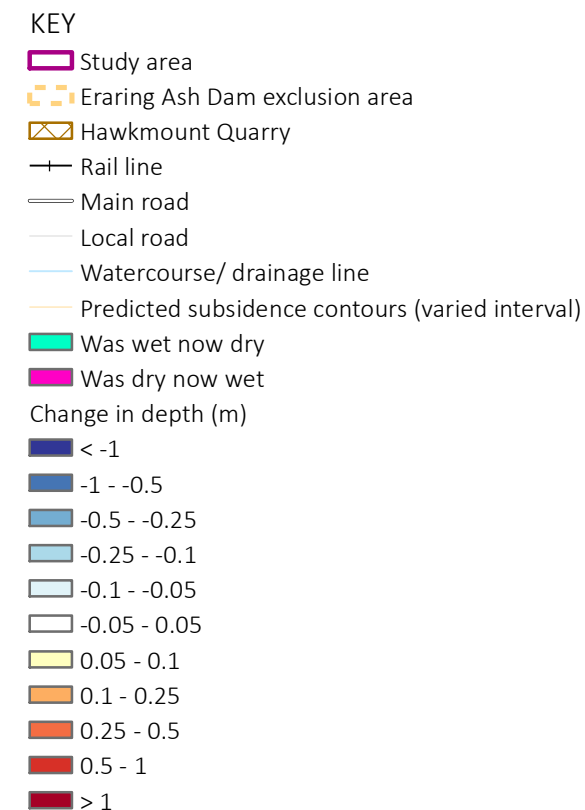
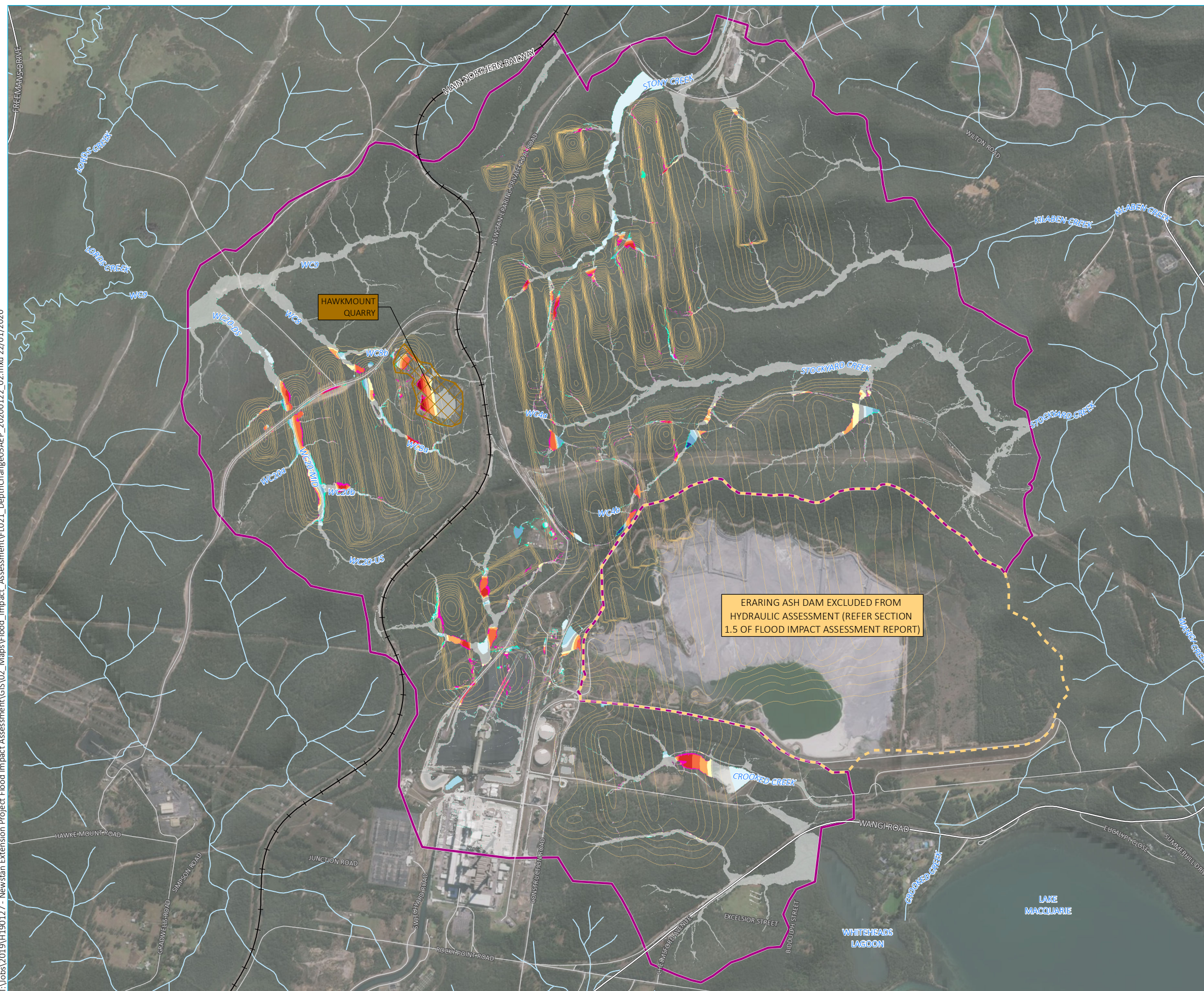
T:\Jobs\2019\1190127 - Newstan Extension Project Flood Impact Assessment\GIS\02_Maps\Flood_Impact_Assessment\FI013_DepthChangeIAEP_20200122_04.mxd 22/01/2020



Potential subsided conditions
- change in depth (1% AEP event)

Newstan Mine Extension Project
Flood impact assessment
Figure E.9

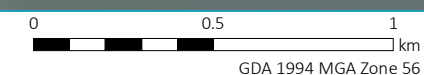
T:\jobs\2019\1190127 - Newstan Extension Project Flood Impact Assessment\GIS\02_Maps\Flood_Impact_Assessment\FI021_DepthChange05AEP_20200122_02.mxd 22/01/2020



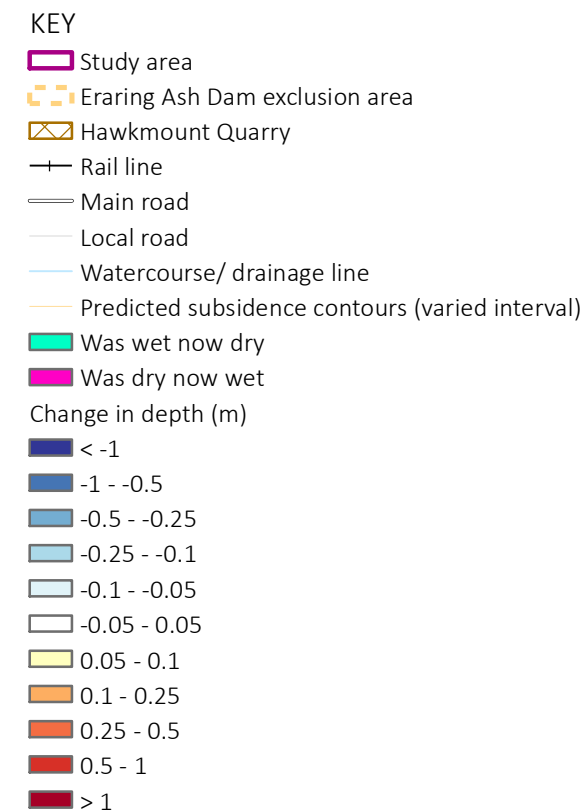
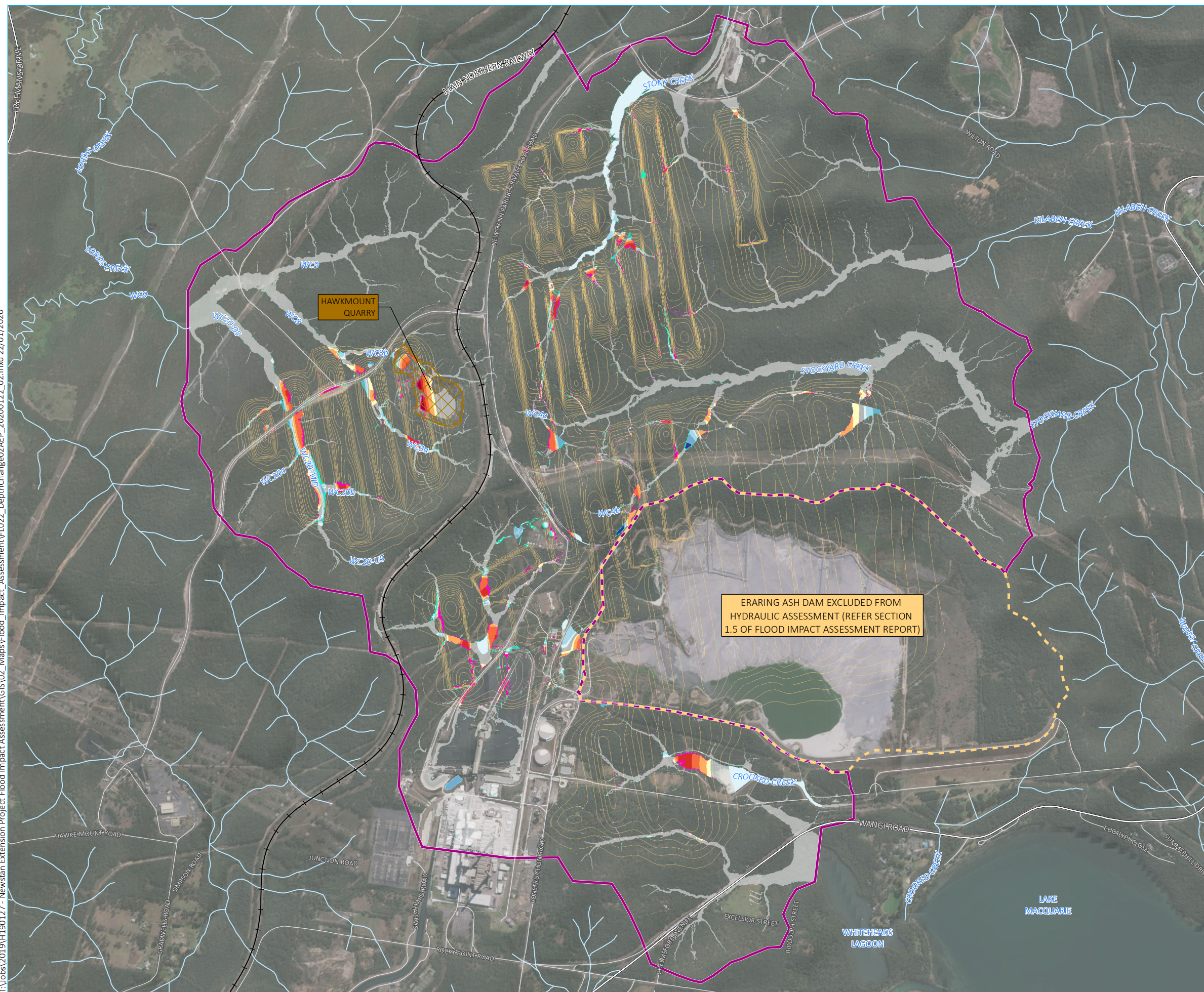
Potential subsided conditions -
change in depth (0.5% AEP event)

Newstan Mine Extension Project
Flood impact assessment
Figure E.10

Source: EMM (2019); DFSI (2017); Nearmap (2018); GA (2011)



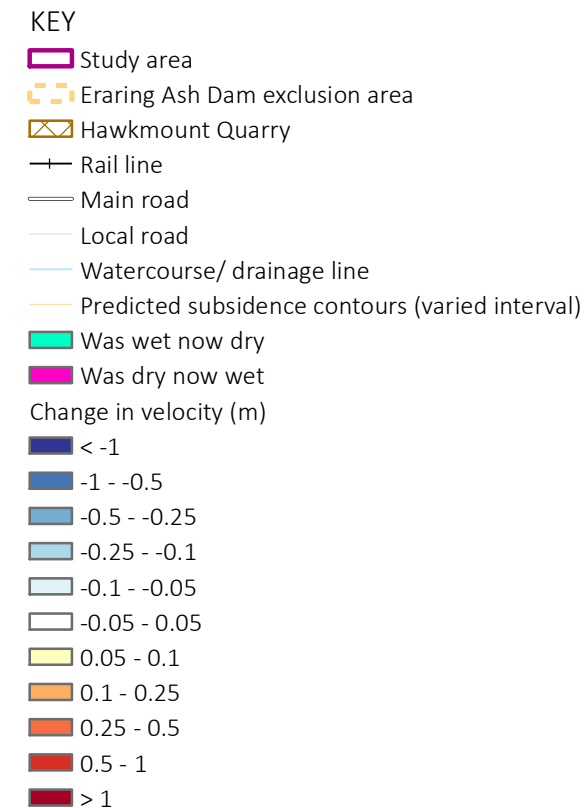
T:\Jobs\2019\1190127 - Newstan Extension Project Flood Impact Assessment\GIS\02_Maps\Flood_Impact_Assessment\FI022_DepthChange02AEP_20200122_02.mxd 22/01/2020



Potential subsided conditions -
change in depth (0.2% AEP event)

Newstan Mine Extension Project
Flood impact assessment
Figure E.11

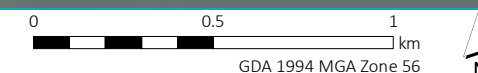
T:\Jobs\2019\1190127 - Newstan Extension Project Flood Impact Assessment\GIS\02_Maps\Flood_Impact_Assessment\FI014_VelocityChange\AEP_20200122_04.mxd 22/01/2020



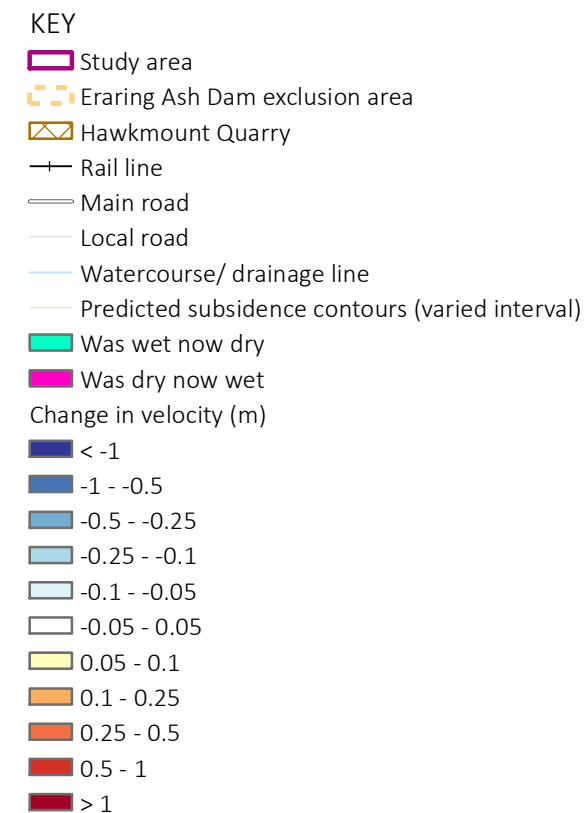
Potential subsided conditions -
change in velocity (1% AEP event)

Newstan Mine Extension Project
Flood impact assessment
Figure E.13

Source: EMM (2019); DFSI (2017); Nearmap (2018); GA (2011)



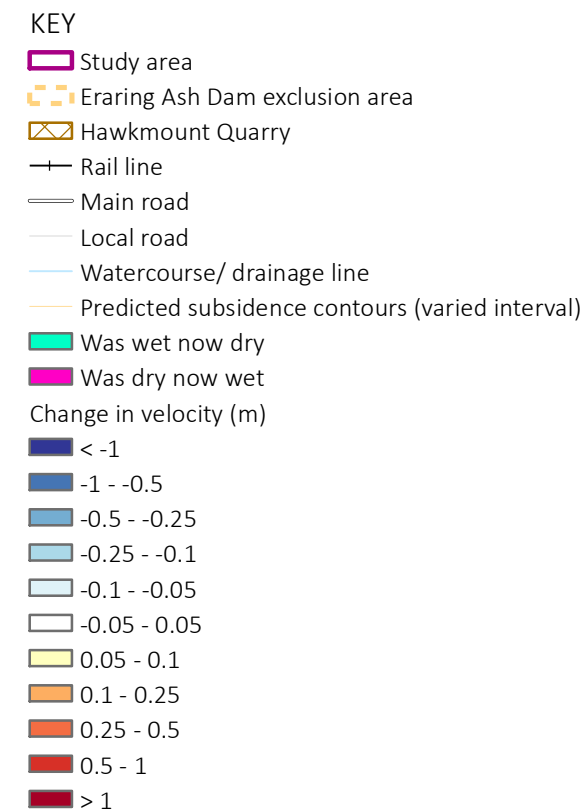
T:\Jobs\2019\1190127 - Newstan Extension Project Flood Impact Assessment\GIS\02_Maps\Flood_Impact_Assessment\FI023_VelocityChange05AEP_20200122_02.mxd 22/01/2020



Potential subsided conditions -
change in velocity (0.5% AEP event)

Newstan Mine Extension Project
Flood impact assessment
Figure E.14

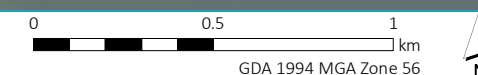
T:\Jobs\2019\1190127 - Newstan Extension Project Flood Impact Assessment\GIS\02_Maps\Flood_Impact_Assessment\FI024_VelocityChange02AEP_20200122_02.mxd 22/01/2020



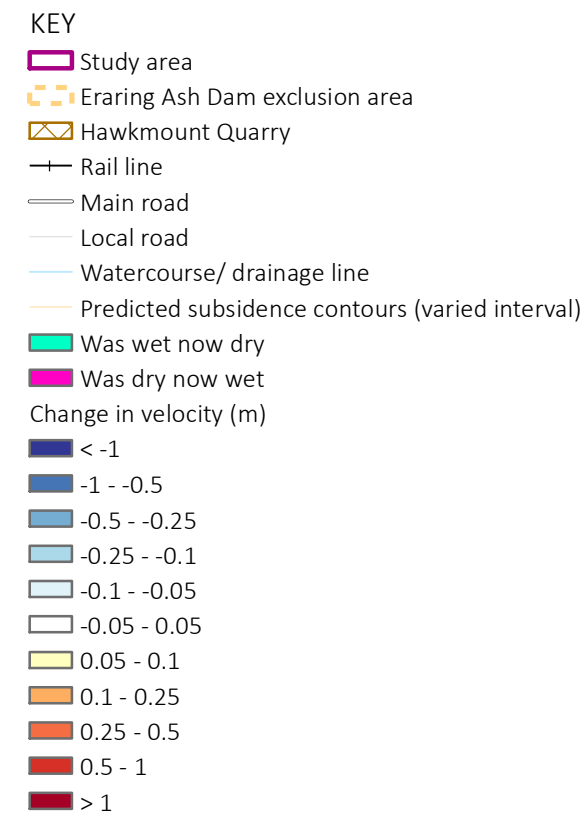
Potential subsided conditions -
change in velocity (0.2% AEP event)

Newstan Mine Extension Project
Flood impact assessment
Figure E.15

Source: EMM (2019); DFSI (2017); Nearmap (2018); GA (2011)



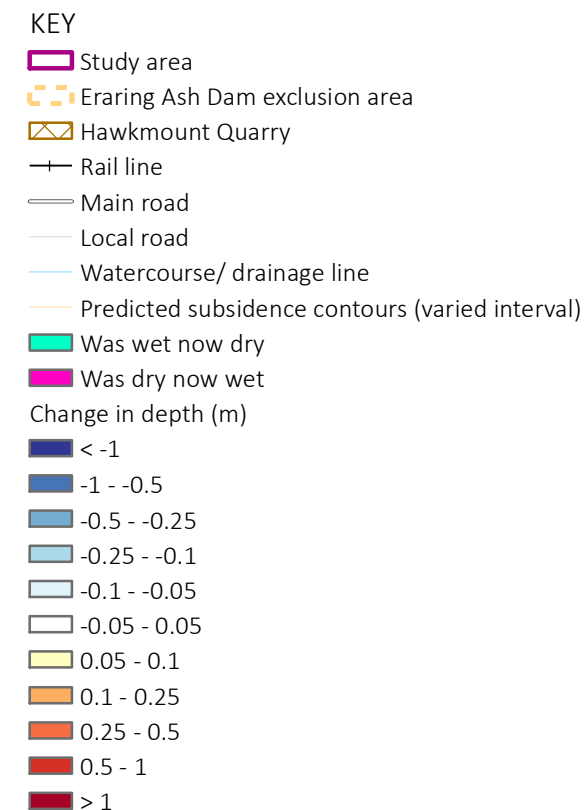
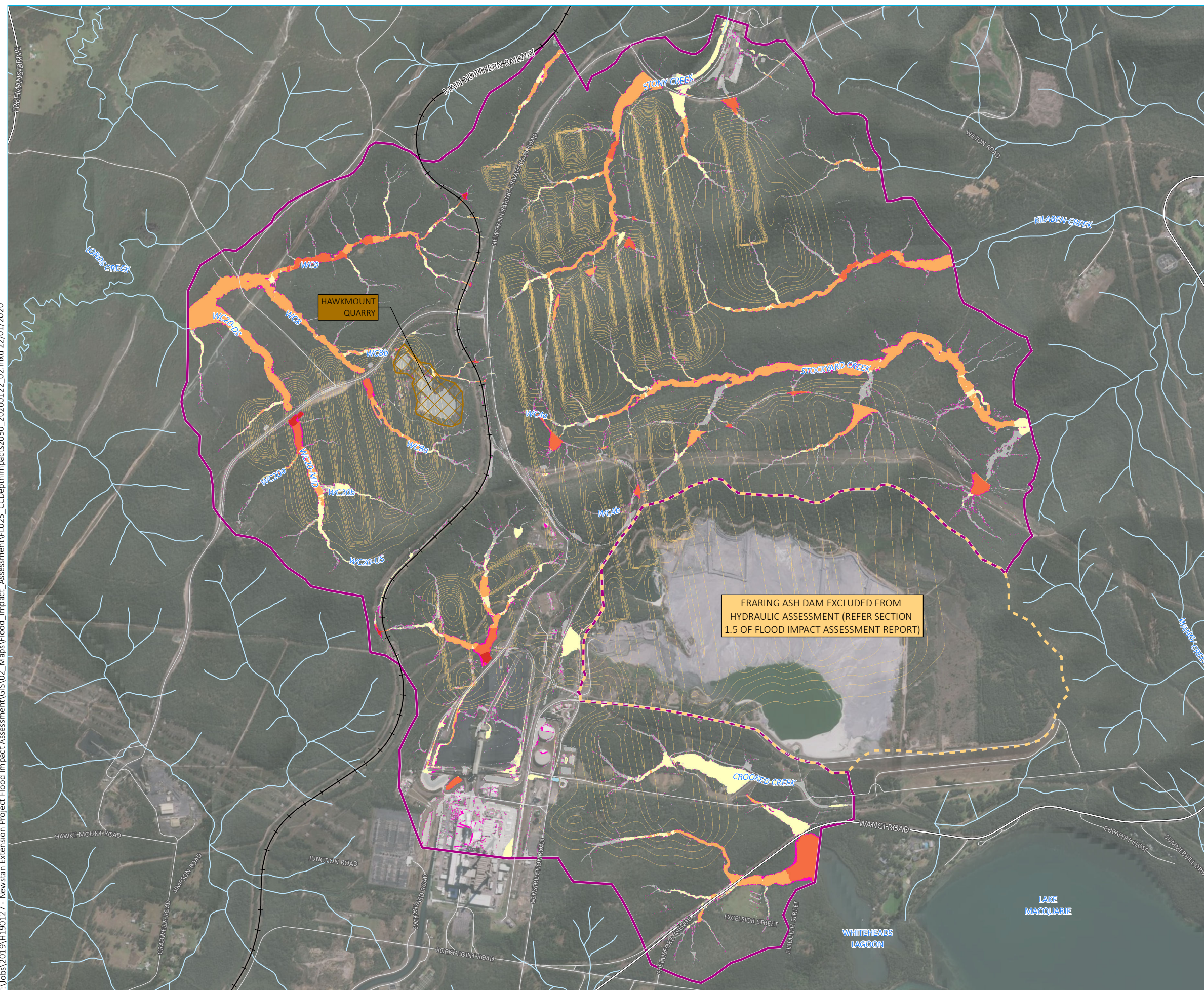
T:\Jobs\2019\1190127 - Newstan Extension Project Flood Impact Assessment\GIS\02_Maps\Flood_Impact_Assessment\FI032_VelocityChangePMF_20200122_02.mxd 22/01/2020



Potential subsided conditions - change in velocity (extreme event)

Newstan Mine Extension Project
Flood impact assessment
Figure E.16

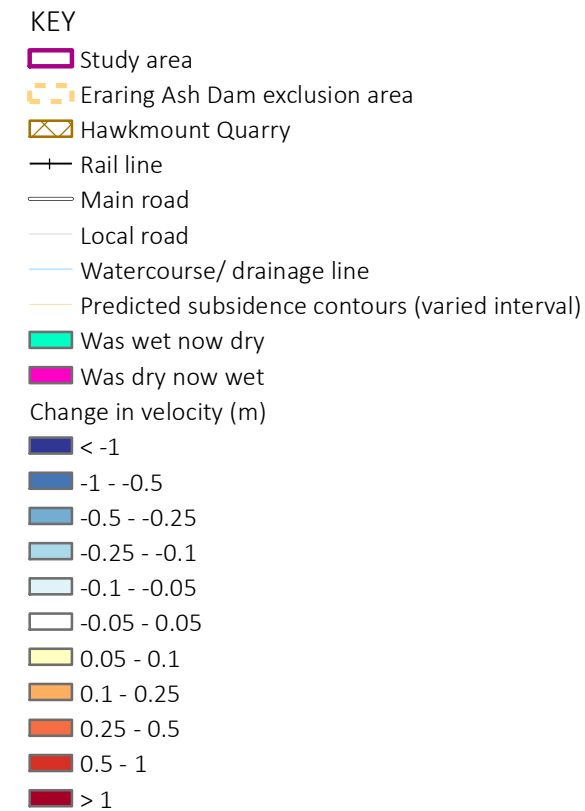
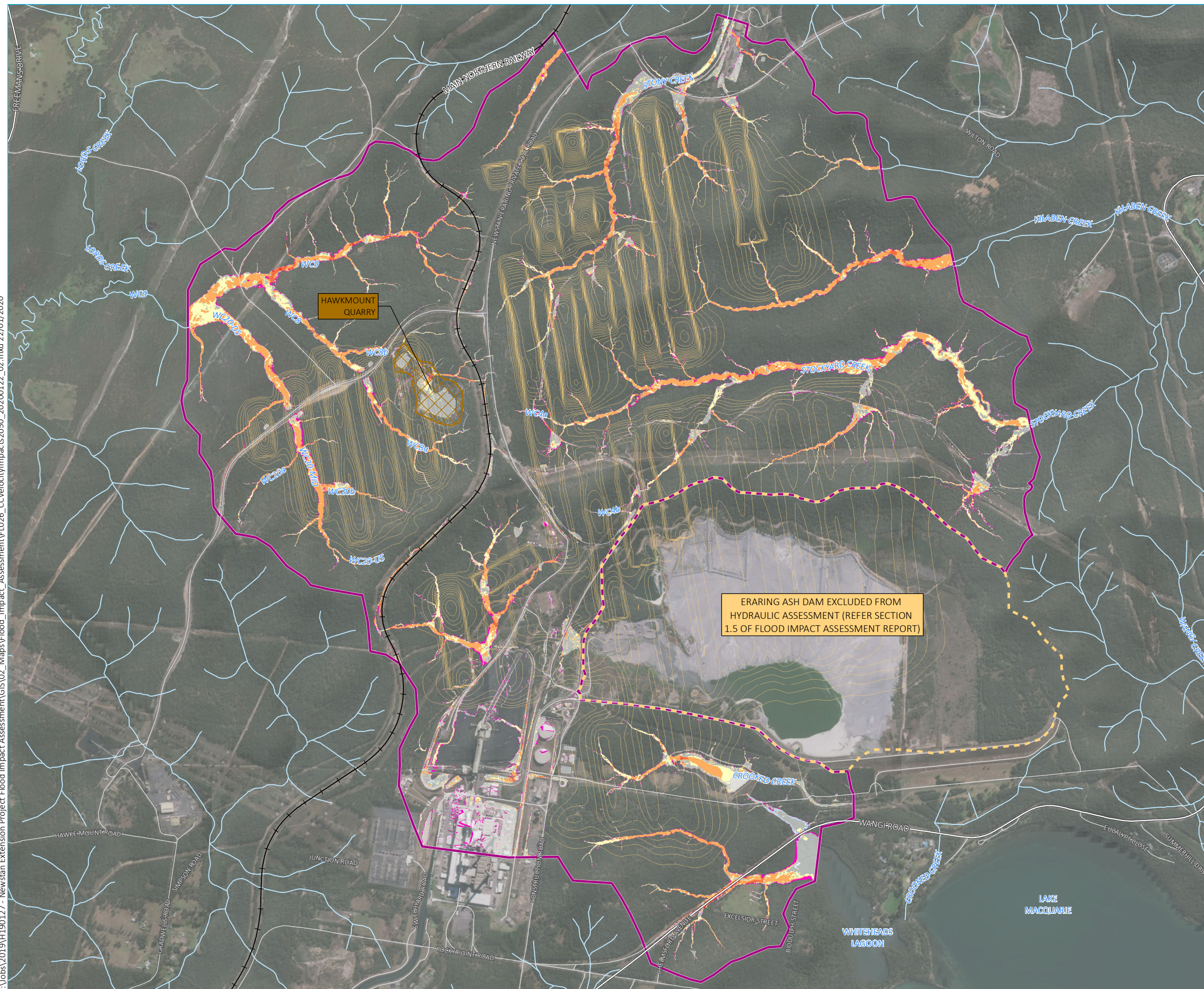
T:\Jobs\2019\1190127 - Newstan Extension Project Flood Impact Assessment\GIS\02_Maps\Flood_Impact_Assessment\FI025_CCDepthImpacts2050_02.mxd 22/01/2020



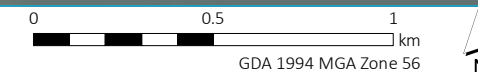
Climate change depth impacts
(2050 subsided conditions event)

Newstan Mine Extension Project
Flood impact assessment
Figure E.17

T:\jobs\2019\1190127 - Newstan Extension Project Flood Impact Assessment\GIS\02_Maps\Flood_Impact_Assessment\FI026_COVelocityImpacts2050_20200122_02.mxd 22/01/2020



Source: EMM (2019); DFSI (2017); Nearmap (2018); GA (2011)

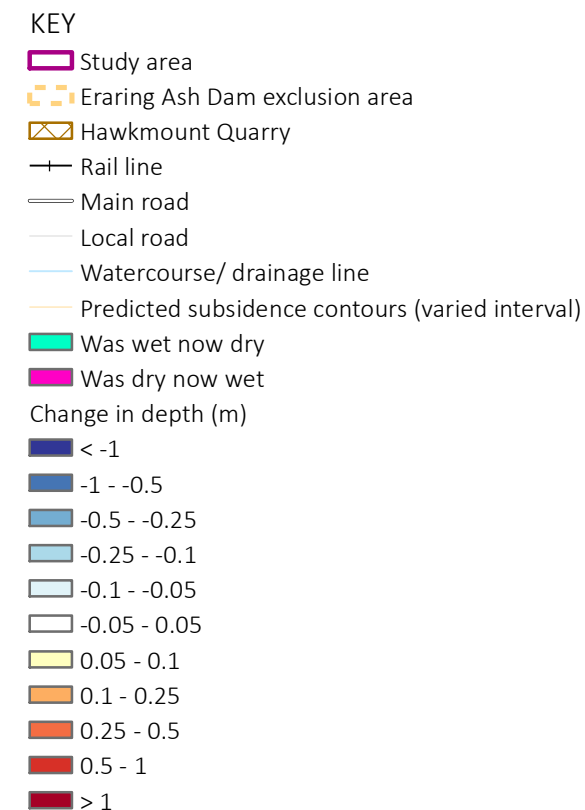
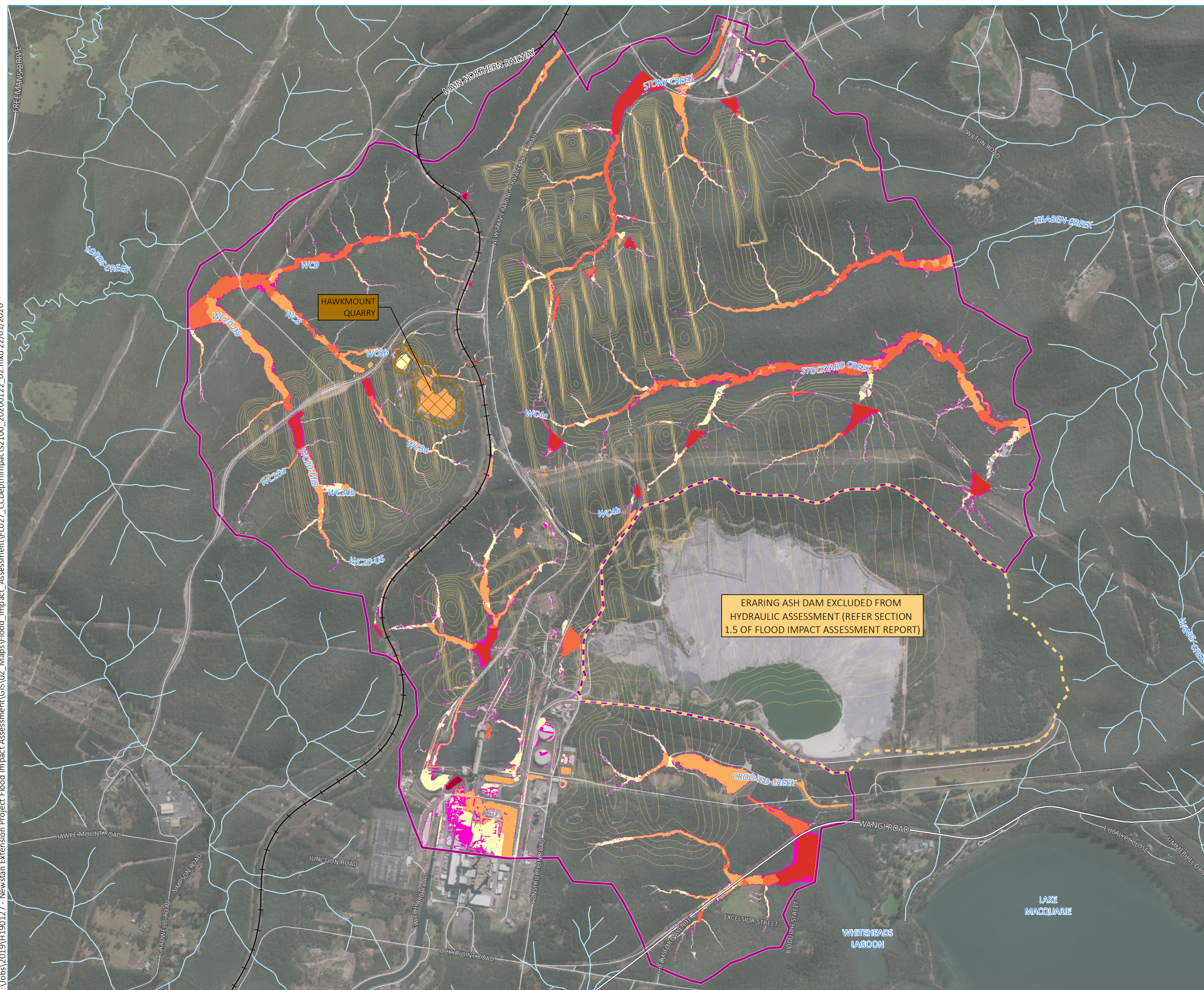


Climate change velocity impacts
(2050 subsided conditions event)

Newstan Mine Extension Project
Flood impact assessment
Figure E.18



T:\Jobs\2019\1190127 - Newstan Extension Project Flood Impact Assessment\GIS\02_Maps\Flood_Impact_Assessment\FI027_CCDepthImpacts2100_20200122_02.mxd 22/01/2020



Climate change depth impacts
(2100 subsided conditions event)

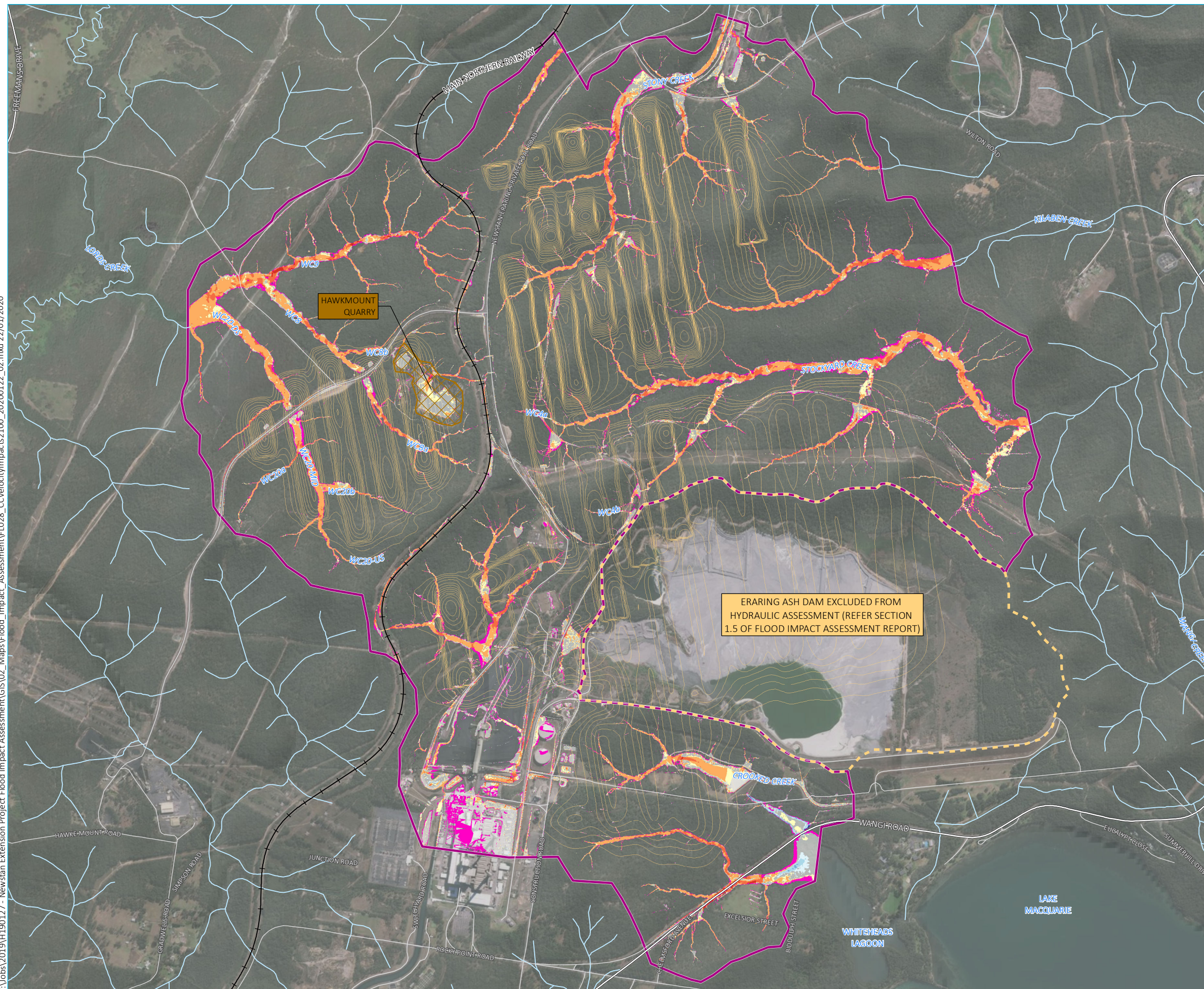
Newstan Mine Extension Project
Flood impact assessment
Figure E.19

Source: EMM (2019); DFSI (2017); Nearmap (2018); GA (2011)

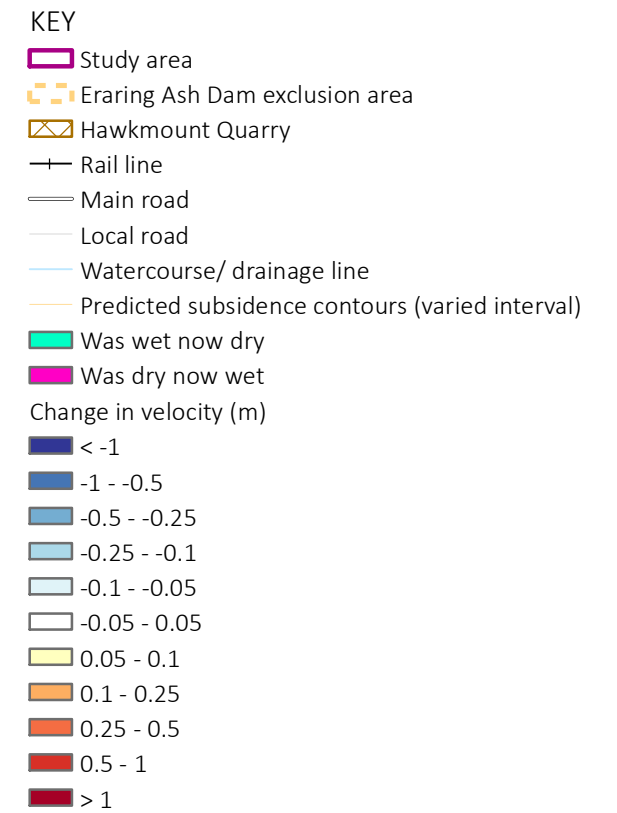
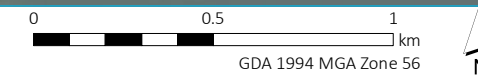
0 0.5 1
km
GDA 1994 MGA Zone 56



T:\Jobs\2019\1190127 - Newstan Extension Project Flood Impact Assessment\GIS\02_Maps\Flood_Impact_Assessment\FI028_COVelocityImpacts2100_20200122_02.mxd 22/01/2020



Source: EMM (2019); DFSI (2017); Nearmap (2018); GA (2011)



Climate change velocity impacts
(2100 subsided conditions event)

Newstan Mine Extension Project
Flood impact assessment
Figure E.20