SARAJI EAST MINING LEASE PROJECT

Environmental Impact Statement

Appendix E-3

Hydrology, Hydraulics and GeomorphologyTechnical Report

BMA

BHP Mitsubishi Alliance

TECHNICAL REPORT: HYDROLOGY, HYDRAULICS AND GEOMORPHOLOGY

Saraji East Mining Lease Project

FINAL

January 2023

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Abbreviations and Glossary

ACARP	Australian Coal Association Research Program
AECOM	AECOM Australia Pty Ltd
AEP	Annual Exceedance Probability. The probability that a given rainfall total accumulated or peak flow rate for a given duration will be exceeded in any one year. See Table A-1-1 for conversion to ARI.
Alluvium	Alluvium Consulting Australia Pty Ltd
ARF	Areal Reduction Factor
ARI	Average Recurrence Interval. The average, or expected, value of the periods between exceedances of a given rainfall total accumulated or peak flow rate for a given duration. See Table A-1-1 below for conversion to AEP.
ARR	Australian Rainfall and Runoff
Avulsion	Rapid abandonment of stream channel and formation of a new channel
BMA	BHP Billiton Mitsubishi Alliance
BOM	Bureau of Meteorology
CHPP	Coal Handling and Preparation Plant
CL	Continuing Loss
CRC	Cooperative Research Centre
CRCCH	Cooperative Research Centre – Catchment Hydrology
CRCFORGE	Cooperative Research Centre – Focussed Rainfall Growth Estimation
DTM	Digital Terrain Model
EA	Environmental Authority
FY	Financial Year
GSDM	Generalised Short Duration Method
Head cut	A locally steep or abrupt section in channel bed, also known as a knickpoint; prone to erosion
HEC-RAS	A hydrodynamic model and analysis software package used for 1D and 2D hydraulic and sediment transport modelling
IFD	Intensity, Frequency, Duration
IL	Initial Loss
Incision	Deepening of channel resulting from erosion
IRC	Isaac Regional Council
LGA	Local Government Area
LiDAR	Light Detection And Ranging
Meander cut off	When flows scour a path across the neck of a meander to form a shorter channel (the abandoned channel is often known as an oxbow lake or billabong)
MIA	Mine Infrastructure Area
ML	Mining Lease
MLA	Mining Lease Application
MTPA	Million Tonnes Per Annum
PMP	Probable Maximum Precipitation
ROM	Run-of-mine
RORB	A rainfall runoff routing program used to calculate flood hydrographs from rainfall
SRTM	Shuttle Relay Topography Mission
Subsidence	Lowering or sinking of the ground surface resulting from extraction of material below the surface
TUFLOW	A hydrodynamic model and analysis software package, provides the 2D engine for XPSWMM
XPSWMM	A hydrodynamic model and analysis software package

A note on design flood probability terminology

The Bureau of Meteorology (BOM) outlines the probability terminology to be used in the upcoming Australian Rainfall and Runoff (ARR) update (http://www.bom.gov.au/water/designRainfalls/ifd/ifd-faq.shtml). The term Annual Exceedance Probability (AEP) should be used for design events (rainfalls and floods) including and rarer (less frequent) than those with a 10% AEP. However, the term Annual Recurrence Interval (ARI) is used throughout the Australian Coal Association Research Program (ACARP) criteria for assessing hydraulic parameters of channels and is commonly understood in this context, ARI has been used in this report for design events up to the 50-year ARI (i.e. 2% AEP).

As shown in Table A-1-1, ARIs of greater than 10 years are very closely aligned with the reciprocal of the AEP.

Table A-1-1. ARI to AEP conversion table

ARI (years)	AEP	AEP expressed as percentage (%)
2	0.393	39
5	0.181	18
10	0.095	10
20	0.049	5
50	0.020	2
100	0.010	1
200	0.005	0.5
500	0.002	0.2
1000	0.001	0.1
2000	0.0005	0.05

1 Introduction

Alluvium has been engaged to undertake an assessment of the potential impacts of the Saraji East Mining Lease Project (the Project) to inform the Environmental Impact Statement (EIS) being prepared under the *Environmental Protection Act 1994* (EP Act). The assessment has been undertaken in response to the Terms of Reference (ToR) dated May 2017, issued by the Department of Environment and Heritage Protection (DEHP), now known as the Department of Environment and Science (DES). This assessment specifically evaluates the potential impact of surface infrastructure and mine-related subsidence on waterways within and surrounding the Project Site.

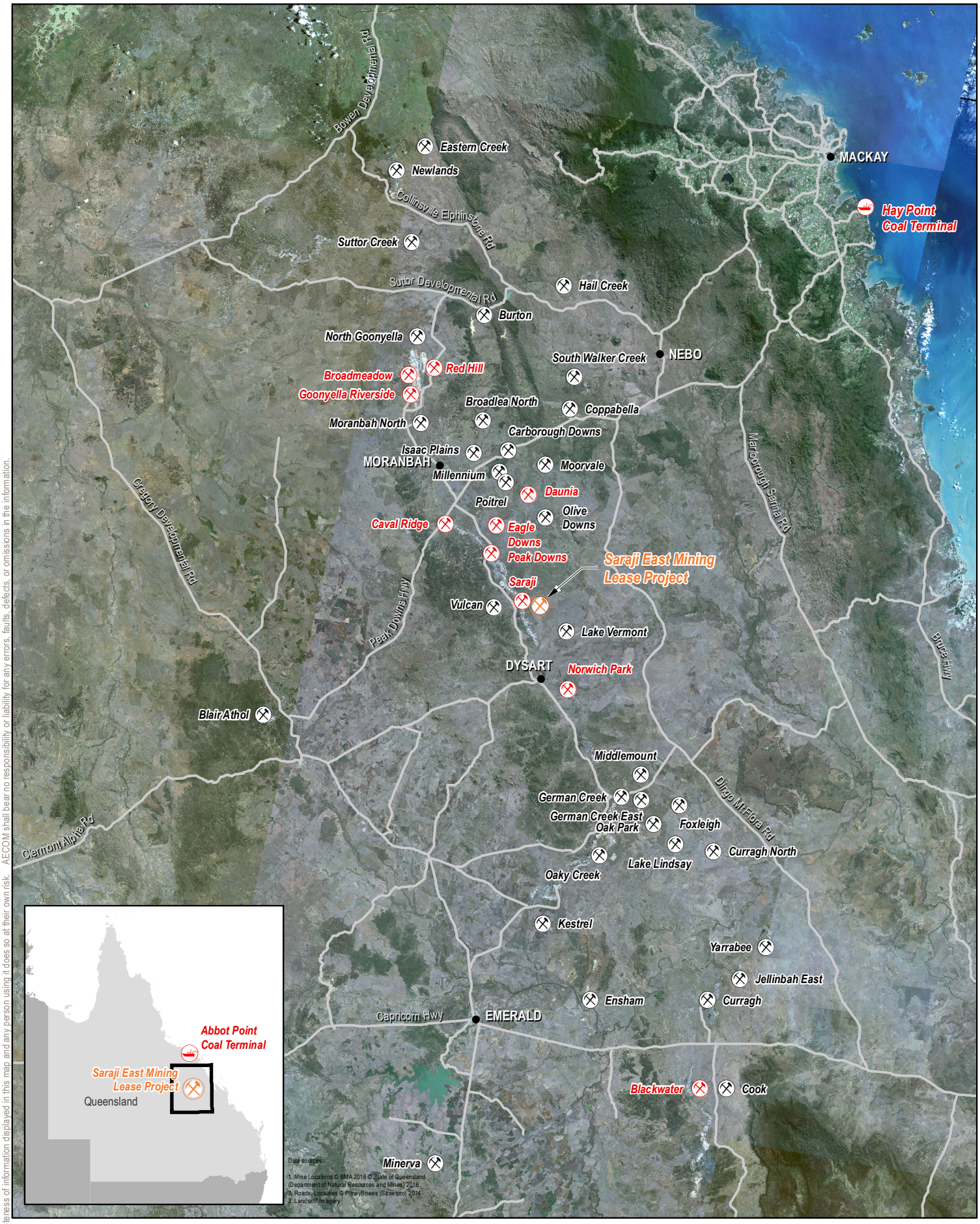
1.1 Project description

The Project is located within the Isaac Regional Council (IRC) Local Government Area (LGA) approximately 30 kilometres (km) north of Dysart and approximately 170 km south-west of Mackay in Queensland (Figure 1-1). The Project involves a greenfield single-seam underground mine and supporting infrastructure on Mining Lease Application (MLA) 70383 and MLA 70459 adjacent to, and accessed through, the existing open cut mine void within Mining Lease (ML) 1775. The Project Site (Figure 1-2), is immediately east of the existing Saraji Mine, between the Dysart-Moranbah Road and the Isaac River.

The Project involves the development of a series of underground longwall panels that will intersect three easterly flowing named watercourses, which combine to form a single tributary of the Isaac River. The mine plan consists of a northern block containing nine panels and a southern block containing eight panels, running approximately north-south (Figure 1-2). Panels range in length from approximately 1.4 kilometres (km) to 5.2 km with subsidence depths predicted to range from 0.75 metres (m) to 2.25 m in the northern panels and from 1.4 m to 3.4 m in the southern panels (Minserve 2022).

This assessment provides information about existing values, potential impacts and their significance, and proposed measures to mitigate impacts to an acceptable level. The assessment addresses comments on the Draft EIS and has been undertaken based on:

- A longwall panel footprint which relates to the limit of subsidence (herein referred to as the mine plan)
- A production schedule (from Year 1-20) which relates to the mine plan (Figure 1-3)
- Supplied predicted subsidence surfaces aligned with the production schedule.



LEGEND

- Saraji East Mining Lease Project
- Locality
- Major Road
- BMA Coal Terminal
- BMA Mine
- Other Mine

N

Figure 1-1
Regional Context

Environmental Impact Statement
Saraji East Mining Lease Project

0 5 10 20
Kilometres

Scale: 1:1,500,000 (when printed at A4)
Projection: Map Grid of Australia - Zone 55 (GDA94)

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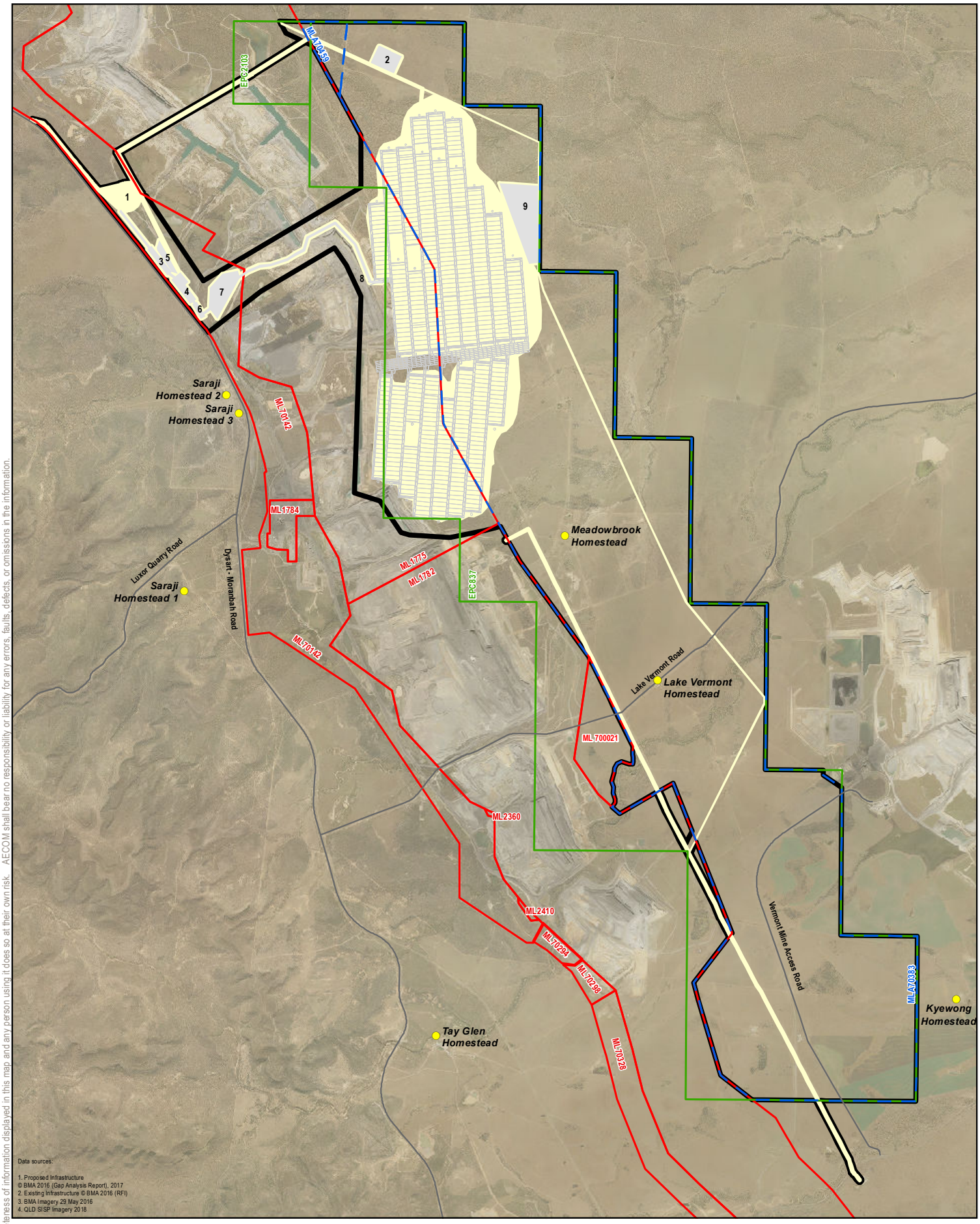
Filename: L:\Secure\Projects\605X\60507031\4. Tech Work Area\4.98 GIS 2021\02_MXDs\01 Environmental Impact Statement\03 Project Description\60507031_G073_v5_A4P_RegionalContext.mxd



Data sources:

1. Proposed Infrastructure
© BMA 2016 (Gap Analysis Report), 2017
2. Existing Infrastructure © BMA 2016 (RFI)
3. BMA Imagery 29 May 2016
4. QLD SISP Imagery 2018

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LEGEND

- Project Site
- Project Footprint
- Exploration Permit Coal (EPC)
- Mining Lease (ML)
- Mining Lease Application (MLA)
- Underground layout (optimised)
- Surface Infrastructure
- Homestead

Surface Infrastructure

1 Rail Loading Balloon Loop
2 Process Water Dam
3 Product Stockpiles
4 CHPP
5 Raw Water Dam
6 ROM Pad
7 Future MIA
8 Conveyor
9 Construction Accommodation Village

N

Figure 1-2
Project Layout

Rehabilitation Management Plan
Saraji East Mining Lease Project

0 0.5 1 2
Kilometres

Scale: 1:110,000 (when printed at A4)

Projection: Map Grid of Australia - Zone 55 (GDA94)

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1.2 Objectives

The objectives of this technical report are to meet the ToR by identifying the likely impacts from the Project on surface water hydrology, flooding and geomorphic behaviour of waterways in the Project Site and to identify appropriate mitigation options. Subsidence resulting from the underground mining activities will be the primary cause of impacts on waterways and their floodplains. For this assessment the Study Area is defined as the extent of the watercourses and their catchments directly influenced by the Project. This is approximately the area of predicted subsidence around the longwall panels, extending to a short distance downstream of the Boomerang Creek and Hughes Creek confluence.

The ToR identifies four items considered to be critical matters requiring detailed treatment in the EIS. This assessment addresses, in part, three of those matters (Table 1-1). Items of the ToR not covered by this assessment but covered by others include surface water quality assessment (AECOM, 2022a), groundwater dependent ecosystems assessment (3D Environmental, 2022), aquatic ecology assessment (Hydrobiology, 2022), and terrestrial ecology assessment (AECOM, 2022b).

Table 1-1. Critical matters, as defined by the ToR, addressed by this assessment

Critical matter	Objectives and requirements of the ToR	Focus of this assessment	Report section
Water quantity and quality	Demonstrate that the Project operates in a way that protects the environmental values of waters, wetlands, groundwater, groundwater-dependent ecosystems and any associated surface ecological systems. The assessment is to identify the environmental values of groundwater and surface waters within the Project Area and immediately downstream that may be affected by the Project.	Impacts to surface water quantity of catchment-generated runoff only.	Section 2.2 and Section 3.2 of this report.
Water resources	Demonstrate that construction and operation of the Project will maintain the condition and natural functions of water bodies including bed and bank stability of watercourses. Water resources should be used sustainably to maintain environmental flows, in-stream habitat diversity, interaction with riparian zones and the ecological health of water bodies.	Impacts to the natural functions of watercourses including riparian zones and in-stream habitat.	Section 3.2 of this report.
Flooding/regulated dams	Demonstrate that the Project will avoid, minimise or be able to mitigate the risk and potential adverse impacts from flooding to protect people, property and the environment. Flood modelling should be used to identify potential changes to current flood characteristics for a range of AEPs up to the probable maximum flood (PMF) including vulnerabilities to climate change.	Impacts to current (baseline) flood characteristics only; regulated structures did not form part of this assessment.	Section 3.3 of this report.

1.3 Scope

This report details and evaluates the risks associated with predicted changes to the land surface, surface water and geomorphic characteristics of the watercourses directly affected by the Project. Boomerang Creek, Plumtree Creek and Hughes Creek are the only watercourses that intersect with the mine plan. The southern panels will modify the contributing catchment of One Mile Creek but will not directly impact the waterway.

Evaluating predicted changes involved a comparison of existing conditions with post-subsidence conditions based on the predicted post-subsidence landform. Three scenarios were assessed for the 20-year mine schedule:

- Year 0, existing conditions
- Year 10, intermediate post-subsidence landform
- Year 20, final post-subsidence landform.

The existing conditions and predicted post-subsidence terrain models were provided to facilitate the assessment. The assessment determined the likely impacts of predicted changes through the Project Site and the implications for adjoining upstream and downstream reaches of the major streams.

The impact assessment for waterways and surface water is generally undertaken using the structure developed during the Isaac River Cumulative Impact Assessment of Mine Developments (Alluvium 2008), a project jointly funded by AAMC and BMA (hereafter referred to as the IRCIA). The findings of the IRCIA assisted the development of the draft Watercourse Subsidence – Central Queensland Mining Industry guideline (DERM 2011). The framework for assessing impacts on watercourses by subsidence was developed into the following hierarchy:

- 1st order – direct physical effects of subsidence
- 2nd order – geomorphic response to subsidence
- 3rd order – changes to water quantity and quality
- 4th order – biological response
- 5th order – impacts of human response to other impacts

This report assesses 1st to 3rd order impacts, excluding water quality, which is addressed by AECOM (2022a). Assessments into 4th order responses are addressed by Hydrobiology (2022) and AECOM (2022b) and 5th order responses are addressed by Elliott-Whiteing (2023). A subsidence management plan, being developed by others, details the management of the impacts discussed in these assessments.

The assessments in this report quantify physical changes in surface water and sediment transport budgeting, which relates to bedload and does not quantify suspended loads that would inform water quality assessments.

1.4 Methodology

The assessment required the establishment of baseline environmental values (existing conditions) against which changes caused by predicted subsidence could be compared. Hydraulic models were created for pre-subsidence (Year 0) and post-subsidence scenarios (Year 10 and Year 20) using two software packages:

- HEC-RAS (Hydrologic Engineering Centre River Analysis System), one-dimensional (1D) modelling
- TUFLOW, simulation software for waterway and flooding analysis, two-dimensional (2D) modelling

Modelling was first undertaken for the Year 0 scenario using a range of flow events to establish baseline conditions. The same flow events were then used in the Year 10 and Year 20 scenarios to inform the likely hydrologic, hydraulic, and geomorphic responses and appropriate mitigation options for each scenario. HEC-RAS was used to assess instream hydraulics and sediment transport budgeting while TUFLOW was used to evaluate changes in flooding behaviour, flood storage and overland flow paths.

Predicted subsidence will have no impact on the flows entering the Project Site from upstream, therefore the same flow estimates were used for both the pre- and post-subsidence modelling. Details on the hydrological analysis are provided in Section 2.2.

1.4.1 Environmental values

Data was collected through on-ground inspections, sediment sampling, previous relevant studies, aerial imagery and hydrological records. A hydrologic model was developed to estimate hydrographs and peak flows through the streams of the Project Site. Flow estimates were used in 1D and 2D modelling to establish instream hydraulic and sediment transport characteristics and characterise flooding behaviour.

The following tasks were undertaken to identify environmental values:

- Field investigation of the morphological characteristics of each watercourse affected by the Project to determine stream forms, dominant geomorphic processes and stream trajectory
- Collection of sediment samples in 2016 for analysis to inform sediment transport modelling
- Determination of the extent of the hydrologic model to capture the catchment areas of streams affected by the Project
- Determination and analysis of available rainfall, evaporation and stream flow data for input and calibration of the hydrologic model
- Determination of existing rainfall frequency and intensity
- Calibration of the hydrologic model to historical events
- Generation of hydrographs and peak discharge estimates for a range of design events from two-year average recurrence interval (ARI) to the 1:1000-year ARI for input into hydraulic models
- Development of 1D hydraulic models using existing terrain for instream hydraulic and sediment transport analysis
- Determine key hydraulic characteristics for stream power, shear stress and velocity for a range of flow events through the Project Site and adjoining reaches
- Determine key sediment transport characteristics for a range of flow events through the Project Site and adjoining reaches
- Development of 2D hydraulic model using existing terrain for sediment transport analysis
- Determine key sediment transport characteristics for a range of flow events through the Project Site and adjoining reaches
- Development of 2D hydraulic model using existing terrain for assessment of flood behaviour
- Determine key flood characteristics for depth, velocity and extents.

1.4.2 First order impacts - direct physical effects of subsidence

The potential physical effects of subsidence through the Project Site were identified in the predicted subsidence report (Minserve 2022). Surface depressions caused by subsidence will form in each of the panels with maximum depths of subsidence up to 2.25 m in the northern panels, which intersect the waterways, with minimal subsidence occurring over pillar zones between panels. Subsidence is estimated to be greater in the southern panels, though they don't intersect with any waterways. Due to the depth of the mine, geology and angle of inflection from the Goaf, there is not a differential subsidence profile across the northern section of the mine; instead, a uniform land depression is expected.

The predicted subsidence was superimposed on the relatively low relief terrain of the Boomerang and Hughes Creek floodplains to form a post-mine surface. This surface was used to inform second and third order impact assessment. Interpretation of the impacts resulting from these physical effects was informed by on-ground inspections, the results of hydraulic modelling and a knowledge and understanding of subsidence impacts of the assessment team gained through experience in assessment of other longwall mines.

Subsidence cracking in relation to hydraulic connectivity to surface strata is discussed in Appendix 1 of the Minserve (2022) report.

1.4.3 Second order impacts - geomorphic response to subsidence

The likely geomorphic response to subsidence was informed through 1D and 2D hydraulic modelling of the post-subsidence conditions. Modelling was used to determine hydraulic and sediment transport characteristics and compared with the results from modelling of existing conditions. The resulting changes were used to identify risks and develop mitigation measures. The following tasks were undertaken:

- Development of 1D and 2D hydraulic models for the post-subsidence conditions (the Project)
- Determine key hydraulic characteristics for stream power, shear stress and velocity for a range of flow events through the Project Site and adjoining reaches
- Quantify changes in hydraulic characteristics from pre-subsidence conditions
- Determine key sediment transport characteristics for a range of flow events through the Project Site and adjoining reaches
- Quantify changes in sediment transport characteristics from pre-subsidence conditions

- Provide qualitative assessment for potential erosion of subsidence cracks

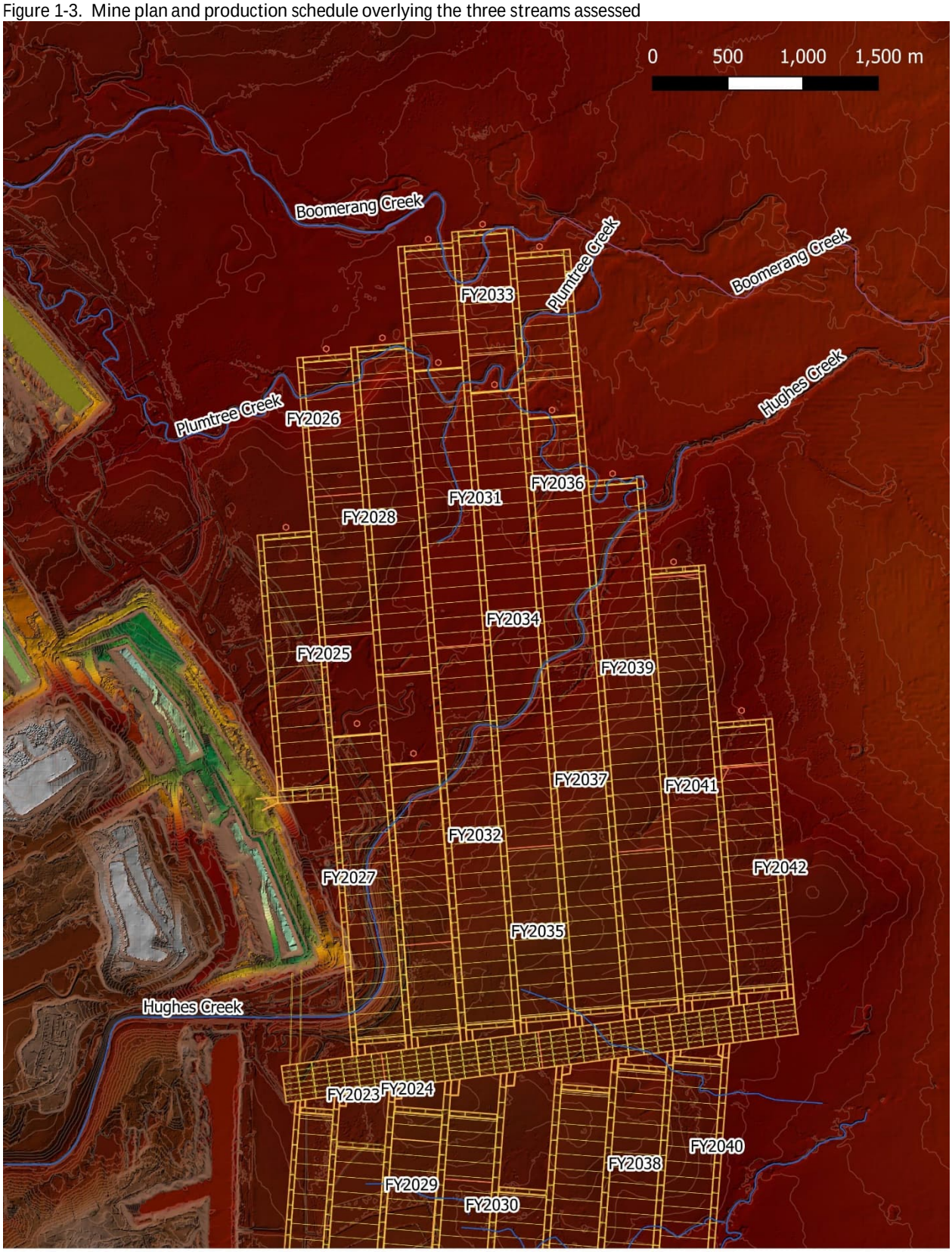
1.4.4 Third order impacts - changes to flooding behaviour in response to subsidence

The potential changes to flooding behaviour were determined through 2D hydraulic modelling of the post-subsidence conditions. Modelling was used to determine flooding behaviour and compared with the results from modelling of existing conditions. The following tasks were undertaken:

- Development of 2D hydraulic models for each post-subsidence scenario (the Project)
- Determine key flood characteristics for depth, velocity and extents
- Quantify changes in flooding characteristics from pre-subsidence conditions

The potential changes in channel hydraulics, sediment transport and flooding behaviour were used to identify risks to environmental values and develop mitigation measures to minimise impacts to the Project and the environment.

Figure 1-3. Mine plan and production schedule overlying the three streams assessed



Mine plan overlying the three larger streams assessed
Saraji East Mining Lease Project

alluvium

Project Number 221028
Date 01 July 2022
Projection GDA94 Zone 55
Prepared by Vanessa Warrington

1.5 Data and limitations

Digital Elevation Model (DEM) data provided for assessment of existing conditions and post-subsidence conditions consisted of:

- 2016 DEM surface for existing conditions (Year 0)
- Predicted subsidence surfaces at Year 3, Year 4, Year 6, Year 10 and Year 20

Each dataset had a horizontal accuracy of five metres over the extent of both northern and southern longwall panels and the waterways intersecting them. Publicly available data with a lower resolution has been merged with the DEM provided to extend coverage downstream of the mine footprint and ensure adequate coverage of the watercourses for modelling.

Channel definition is poor in some areas downstream of the mine footprint where tree canopy has been captured in the LiDAR. This reduces reliability in the results for those areas with poor definition. It will likely have some influence on in-channel flows immediately upstream but since channel capacity is low and the floodplain is frequently engaged the extent of influence will be minor and reduce with increased flows. It is not considered to impact the validity of the assessment.

Stream flow data for Boomerang Creek and Hughes Creek was provided for the period 2017 to 2021, however without associated rainfall data it is not able to be used for calibration of hydrologic models. It is also unclear from the data provided whether the gauges are appropriately configured to accurately measure the high flow events typically used in a hydraulic model calibration.

Interim Climate Change Factors provided in ARR2019 provide some estimates of increases in rainfall depth under three Representative Concentration Pathways (RCPs). In 2050 the interim factors suggest allowances of 6.4%, 6.2% and 9.0% increase in rainfall depth for RCP4.5, RCP6 and RCP8.5 respectively. Rainfall depth increases of these magnitudes do not typically have a significant impact on estimates of flood depth and hydraulic parameters of stream power, shear stress and velocity, hence these have not been modelled

2 Environmental values

This section describes the existing condition of the landscape and surface water environments interacting with the Project. It provides a baseline to inform the impact assessment and any mitigation strategies that may be required. The assessment involves a hydrological assessment to estimate the magnitude and frequency of stream flows. One-dimensional (1D) and two-dimensional (2D) hydraulic modelling has been used to determine channel hydraulics and sediment transport characteristics. Two-dimensional (2D) hydrodynamic modelling has been used to assess the behaviour of overbank flows.

This section starts with an overview of the contributing catchment and streams passing through the Project Site before detailing the hydrological analysis undertaken. Stream morphology is then described in terms of the findings from the hydraulic and sediment transport modelling. Finally, an assessment of flooding characteristics is presented.

2.1 Catchment, watercourses and drainage features

The Project Site sits within the Isaac River catchment, a sub-catchment of the broader Fitzroy Basin (Figure 2-1). The Fitzroy Basin covers an area of approximately 142,660 km^2 (DES 2018a), comprising numerous rivers, streams, waterholes and impoundments. It is the largest river catchment flowing to the eastern coast of Australia (Fitzroy Basin Association 2018). The Fitzroy River discharges to the ocean in Keppel Bay, near Rockhampton, approximately 260 km from the Project Site. Its major tributaries are the Nogoa, Comet, Mackenzie, Isaac, Connors and Dawson Rivers and Callide Creek.

There are three streams that pass through the Project Site. Combined, they form approximately 2% of the Isaac River catchment (DES 2018b), or 0.3% of the Fitzroy River catchment (Table 2-1). The Study Area for the hydrological component of this study is shown within the Fitzroy River Basin for context (Figure 2-1).

Table 2-1. Comparison of catchment areas

	Fitzroy River	Isaac River	Streams of the Project Site*
Catchment area (km^2)	142,660	22,360	448

* Including northern and central catchments shown on Figure 2-1.

Boomerang Creek and Hughes Creek commence in the Harrow Range west of Peak Downs Mine and Saraji Mine where the upper reaches are relatively confined in narrow valleys. These upper catchments are steep, containing occasional escarpments. As streams emerge from the range the valley widens, and longitudinal slope decreases as they enter a broad, gently undulating floodplain. Plumtree Creek is a much smaller stream, commencing inside the Saraji mine lease, with much of its catchment modified by mining.

Vegetation in the upper catchment is mostly continuous and remnant while many of the flatter areas in the floodplain have been cleared for grazing, agriculture and mining. Through the Project Site the three streams flow within a wedge of remnant open woodland in a shallow valley contained by the last of the hillslope of the Range. Much of Hughes Creek through this area runs along the southern boundary of the woodland resulting in a relatively narrow strip of riparian vegetation along its southern bank.

Open cut mining operations immediately west of the Project Site have modified the catchment and landscape of the streams. Boomerang Creek and Hughes Creek have been diverted within the open cut mining area, converging approximately 1 km downstream (east) of the Project Site. The upper reaches of Plumtree Creek have been modified such that it only becomes a continuous channel downstream (east) of current mining operations. Plumtree Creek joins Boomerang Creek approximately 2.6 km upstream of the Hughes Creek confluence.

2.2 Catchment hydrology

Hydrological analysis of the Project Site was derived from a hydrologic model previously developed for a project adjacent to the Project Site, which involved the determination of flows for multiple streams including Boomerang Creek, Plumtree Creek and Hughes Creek (Alluvium 2016). The existing model was used to extract flow hydrographs and determine peak flow estimates, at desired locations, for design flood events from 2-year ARI (39% AEP) up to 0.1% AEP for the three creeks passing through the Project Site (Figure 2-2). The events simulated in the hydrologic model describe relatively rare floods and do not describe the long-term hydrologic regimes in the catchments.

2.2.1 Hydrologic model description

The hydrologic modelling software used in this study is RORB. The software represents the rainfall runoff process occurring in a catchment by:

- Conceptualising the catchment as a linked series of sub-catchments represented in the model by catchment storages and river reach storages
- Applying rainfall excess (rainfall minus losses) to each sub-catchment (rainfall is assumed to enter the sub-catchment at its centroid)
- Calculating the resulting runoff from each sub-catchment storage
- Routing the runoff through the catchment system, combining flows at channel junctions
- Outputting flow hydrographs at points of interest in the catchment

The model represents only the rapid flow or surface runoff component of stream flow. The slow response, or base flow, component has not been included in the model. This is considered an appropriate assumption given Boomerang Creek, Plumtree Creek and Hughes Creek are ephemeral watercourses. This is confirmed by the on-site gauging provided which suggests negligible baseflow before recorded higher flow events.

Configuring the model comprised of:

- Determining the catchment boundary and dividing the catchment into sub-catchments
- Calculating the area of each sub-catchment

- Placing model nodes at sub-catchment inflows and junctions
- Placing reach storages between nodes
- Measuring the length of reach between adjacent nodes.

The RORB model uses four parameters to define how the catchment responds to rainfall. These include k_c, m, initial loss (IL) and continuing loss (CL). The k_c and m parameters are factors in the storage discharge relationship.

The storage discharge relationship for the reach storages in the model has the general form:

$$S = 3600k\,Q^m$$

Where:

S is the volume of water in storage (m^3)
k is related to travel time of a particular reach and the characteristics of the whole catchment
Q is outflow rate from the reach storage
M is a dimensionless exponent representing the non-linearity of catchment response; m varies in the range 0.6 to 1.0 with a value of one representing a linear response. This study has adopted a value of 0.8 in line with guidance provided in ARR2019 (Babister et al 2016).

The relationship between k and k_c is given by the equation:

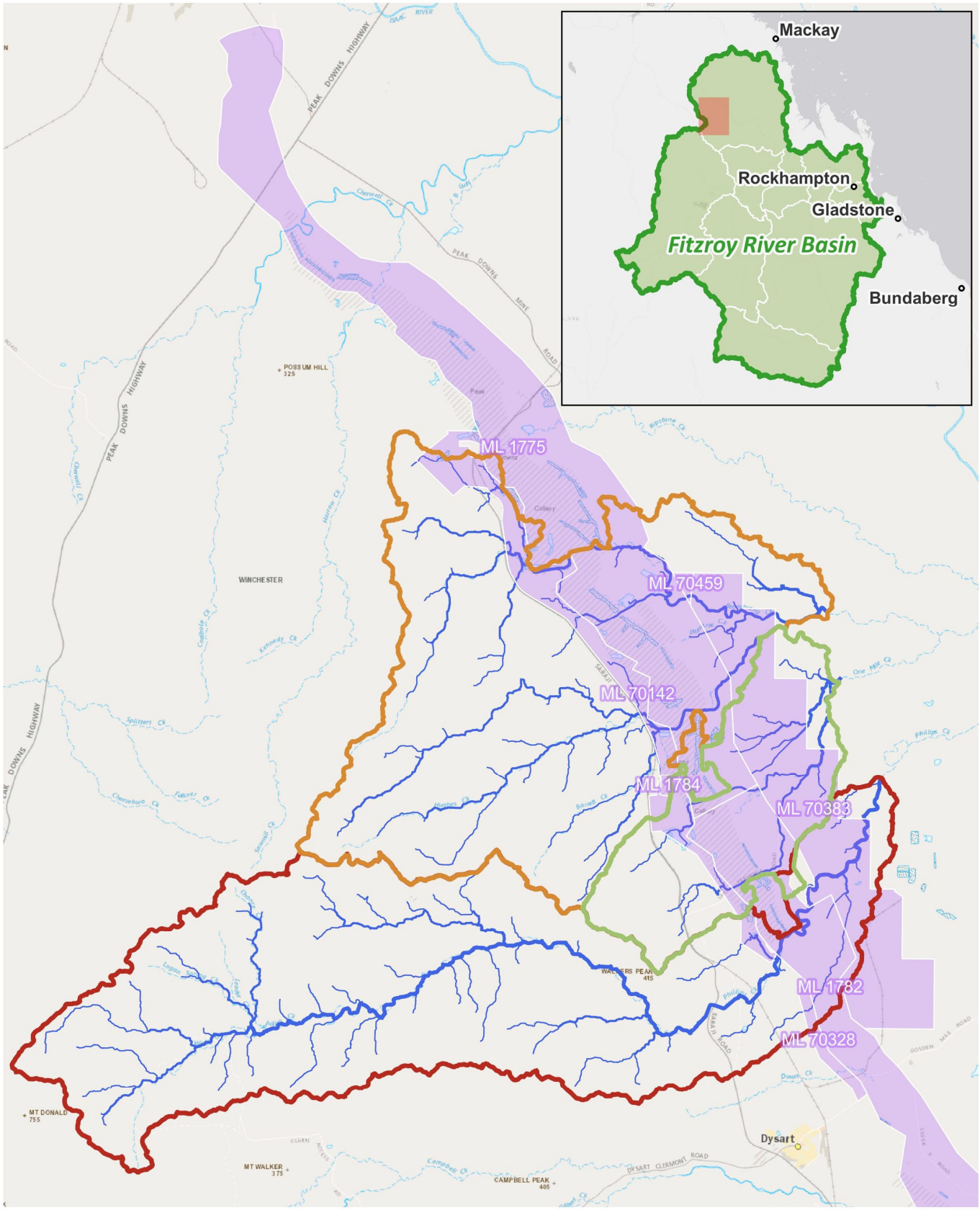
$$k = k_{ri}\,k_c$$

Where:

k_{ri} is the relative delay time of reach i
k_c is an empirical coefficient applicable to the catchment and is a constant for the whole catchment.

The two rainfall loss parameters (IL and CL) are used in the generation of the rainfall excess hyetograph for the model. Initial Loss (IL) is the rainfall at the start of a storm event which fills soil and groundwater storage, is intercepted by vegetation, or is lost by another process and does not contribute to runoff. Continuing Loss (CL) is the ongoing portion of rainfall that falls after the IL that does not produce surface runoff. This could be due to deep soil storage, vegetation interception or evaporation. The loss parameters used in the model can be event and catchment specific.

Figure 2-1. Catchment context



LEGEND

Stream Order (Horton)
- 2
- 3
- 4
- 5

Mining Leases
Fitzroy River Basin
Fitzroy River Subcatchments

Northern Catchment
Central Catchment
Southern Catchment

0 5 10 km

SARAJI EAST EIS:
HYDROLOGIC MODELLING
CATCHMENT CONTEXT

Coordinates: GDA94 MGA Zone 55
Created: 9/8/2022
Scale:1:250,000 (A4)

Originator: CB
Checked: GE
Approved: RL

Sources: QLD Basemap, Esri, DeLorme, HERE, MapmyIndia

2.2.2 Catchment delineation

Catchment delineation and subdivision was undertaken in the previous study (Alluvium 2016). *Hydrology and Flood Modelling Report: Saraji Open Cut Mine Extension*) using the CatchmentSIM software program. CatchmentSIM delineates sub-catchments from a Digital Terrain Model (DTM), calculates relevant subcatchment properties and creates output files for a range of hydrologic models including RORB.

The catchment delineation and subdivision accounted for all known diversions and watercourses within the Project Site and made allowances for catchment areas which report directly to mine affected water management systems.

2.2.3 Model parameter derivation

Due to insufficient rainfall records for the catchment, it was not possible to directly calibrate the model. To complete a calibration, rainfall data from within or close to the catchments is required to support the stream flow data. The closest rainfall gauge is the Dysart Road TM Gauge (BOM #534035) on Hughes Creek which does not have rainfall data available online at this time.

2.2.4 Weeks regional relationship method

Chapter 6 of Book 7 of ARR 2019 outlines the regional relationships developed to calculate k_c for ungauged catchments. For Queensland, the relevant method was derived by Weeks and takes the form:

$$k_c = 0.88 * Area^{0.53}$$

The Weeks k_c values derived for existing conditions are presented in Table 2-2, modified from Alluvium (2016).

Table 2-2. Calculated Weeks value based on existing conditions scenario

Scenario	Catchment Area (km^2)	Weeks k_c Value
Northern catchment*	343.66	19.43

Note that the Weeks Method has been developed using a default m value of 0.8 and this value has been adopted for this study. *The Northern catchment refers to the catchment area defined in the existing model (Figure 2-2).

The existing RORB modelling (Alluvium 2016) contains three separate models; the northern sub-catchment area formed the combined catchment of Boomerang Creek, Plumtree Creek and Hughes Creek. The streams used in the existing RORB model are shown along with the Northern area catchment boundary in Figure 2-2. The total catchment boundary and area (Table 2-2) are slightly larger than required for this assessment, however flow estimates were able to be generated for the Project Site without including contributions from the downstream catchment.

2.2.5 Other modelling parameters

Typical Queensland design values were used for IL and CL for all events up to the 1% AEP design flood event. For larger events, the loss values recommended by the Bureau of Meteorology (BOM) for the Probable Maximum Precipitation (PMP) were adopted (BOM 2003). These are presented in Table 2-3.

The modelling undertaken here has assumed consistent continuing loss values across all pervious land uses. In areas storing spoil or areas which have been rehabilitated the continuing loss values may initially be higher, however this assessment has conservatively assumed that they adopt the continuing loss rate of the natural catchment.

Table 2-3. Adopted model parameters for initial loss and continuing loss

Parameter	Two-year ARI to 1% AEP	Larger events
Initial Loss (mm)	25	0
Continuing Loss (mm/hr)	2.5	1

Figure 2-2. Streams and catchments of the study area

LEGEND

Stream Order (Horton)
- 1
- 2
- 3
- 4
- 5

- Northern Catchment
- Northern Subcatchments
- Central Catchment
- Central Subcatchment
- Subsidence Extent (Year 20)
- Subsidence Contours (Year 20)

0 2.5 5 km

n

SARAJI EAST EIS:
HYDROLOGIC MODELLING
SUB-CATCHMENT OVERVIEW

Coordinates: GDA94 MGA Zone 55
Created: 9/8/2022
Scale:1:150,000 (A4)

Originator: CB
Checked: GE
Approved: RL

Sources: QLD Basemap, Esri, DeLorme, HERE, MapmyIndia

2.2.6 Design rainfall

Design rainfall was estimated using the methods and data included in Australian Rainfall and Runoff 2019 (ARR2019). Catchment specific parameters were sourced from the ARR DataHub.

Design rainfall hyetographs were developed using the StormInjector software package for the 39%, 10%, 5%, 2%, 1% and 0.1% AEP events. The hyetographs used the losses provided from the ARR datahub which include an Initial Loss (IL) of 47 mm and a Continuing Loss of 1.9 mm/hr. Intensity, Frequency, Duration (IFD) for the northern catchment area is presented in Table 2-4.

Table 2-4. Design rainfall depths - northern catchment area

Event Duration (hours)	Depth (mm)			
	39% AEP (2 year ARI)	2% AEP (50 year ARI)	1% AEP	0.1 % AEP
0.25	10.9	20.2	21.6	31.7
0.5	18.8	35.1	37.7	55.6
1	27.6	52.2	56.1	82.3
3	41.7	81.2	87.7	124.6
6	51.2	109.7	122.1	183.1
12	62.1	143	162.1	248.7
18	69.2	166.5	190.1	295.3
24	75.1	186.3	214.9	337.4
48	91.5	235.5	273.9	428.6
72	102.2	266.8	311.2	486

2.2.7 Temporal patterns

The study adopted the 10 temporal pattern ensembles as outlined in the ARR2019 methodology. Within the northern catchment, the overall catchment area being 330 km^2 it is therefore required to use the areal temporal patterns with the 200-500 km^2 patterns being adopted.

As per the ARR2019 approach, the median peak flow from the ensemble was adopted for each AEP.

2.2.8 RORB model output flow

The RORB model outputs for the three streams of interest are presented in Table 2-5.

Table 2-5. Design discharges generated from hydrologic modelling (m^3/s)

Creek	Catchment Area (km^2)	39% AEP	2% AEP	1% AEP	0.1% AEP
Plumtree Creek	8.5	19.5	45.4	51.5	74.8
Boomerang Creek (including Plumtree Creek)	146.3	214	552.6	636.1	910
Hughes Creek (Upstream of confluence)	174.8	271.1	694.7	799.4	1126

2.3 Geomorphology

The assessment of the geomorphic character, behaviour and condition of the waterways through the Project Site has been undertaken through qualitative (expert observation) and quantitative (terrain, hydraulic and sediment transport modelling) means. This section includes an overview of the hydraulic and sediment

transport modelling undertaken to assess in-channel energy conditions for each of the waterways and relates that to on ground observations.

The waterways passing through the Project Site originate in the Harrow Range where they are in narrow valleys and partly confined by hillslope and bedrock. As they emerge from the range, they pass through open cut mine leases where they are confined by deeply cut diversions in narrow corridors between open cut pits, conveying very large flows in-channel, with no floodplain to spread across and dissipate energy. Downstream of the open cut mine, longitudinal gradients of the channels decrease, and the valley broadens substantially. Here the waterways are largely unconfined and able to migrate within the floodplain. Evidence of channel change in the form of meander cut-offs that form billabong habitat is present adjacent and between Boomerang and Hughes Creeks. In the floodplain the capacity of the continuous channel decreases considerably, and much lower flow events will more regularly engage the floodplain than in upstream reaches. Disturbances from agriculture, infrastructure and mining elevate erosion rates in the catchment. In this setting, the high sediment loads supplied to these reaches tend to infill (aggrade) the channel bed and obliquely accrete the channel banks. These characteristics are illustrated in figures and on-ground photos for each of the waterways below.

Boomerang Creek and Hughes Creek floodplains merge in the Project Site. These waterways border a section of largely uncleared (or extensively regrown) floodplain woodland.

2.3.1 In-channel hydraulic conditions

In-channel hydraulics of Boomerang Creek, Plumtree Creek and Hughes Creek have been assessed using the 1D Hydrologic Engineering Centre's River Analysis System (HEC-RAS) for steady state flow conditions. The HEC-RAS models were formed by creating a series of cross-sections extracted from the digital terrain models (DTM) provided. Each HEC-RAS model extends upstream and downstream of the proposed subsidence reach so that those reaches may serve as control reaches in the subsequent assessment of subsidence impacts. Three HEC-RAS models were created:

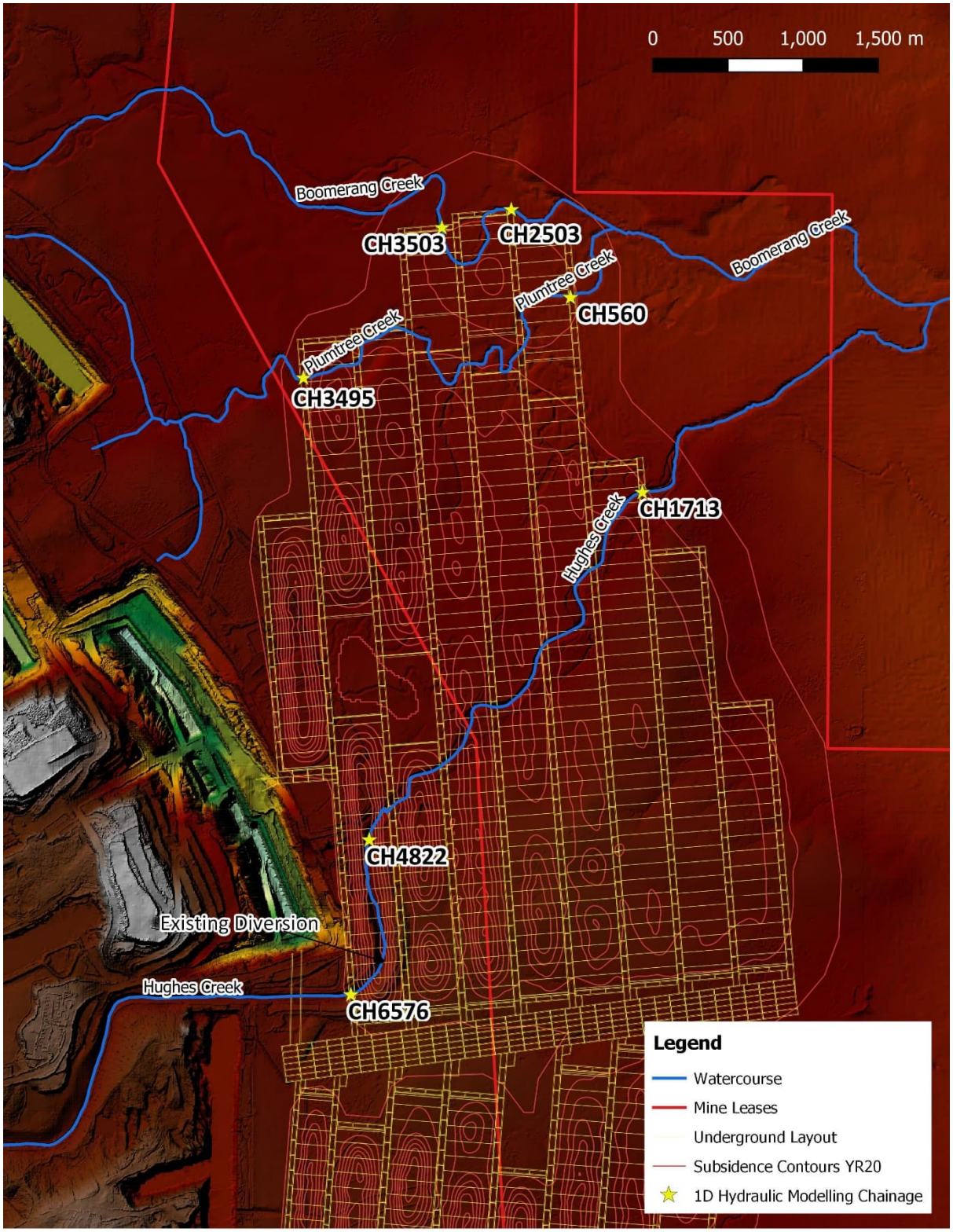
- Boomerang Creek
- Plumtree Creek
- Hughes Creek

The Hughes Creek and Boomerang Creek models extend a short distance downstream of their confluence. The Plumtree Creek model terminates at the confluence of Boomerang Creek. Model watercourse chainages in relation to the underground layout indicate the approximate extent of the models (Figure 2-3).

Frictional resistance to flow is defined by Manning's roughness coefficient, which has been determined by site inspection and review of site photos. The roughness coefficient is divided into channel and floodplain components. The same roughness coefficients have been used for each waterway due to their similar physical character, land use and vegetation cover. The main channel is characterised as clean, no rifts or deep pools, with some stones and weeds. The floodplain is characterised as medium density vegetation (Plate 1) and medium to dense brush in summer.

The part of Hughes Creek being assessed contains a diversion which has developed a similar main channel characterisation to its upstream and downstream reaches. The batters of the constructed diversion have been lined with aggregate to achieve a similar roughness to ensure stabilisation of the channel (Plate 5).

Figure 2-3. Overview of streams assessed with 1D hydraulic models overlying the underground layout



Mine plan assessed
Saraji East Mining Lease Project

alluvium

Project Number 221028
Date 08 December 2022
Projection GDA94 Zone 55
Prepared by Vanessa Warrington

Model inputs include topographical data, Manning's roughness coefficient (n) and model boundary conditions (Table 2-6).

Table 2-6. HEC-RAS model inputs

Inputs	2022 HEC-RAS model		
Cross-sections	Created from 2016 topographical data		
Manning's roughness coefficient	0.035 in-channel, 0.07 floodplain		
Temperature (°C)	25		
Specific Gravity (g/m^3)	2.65		
Boundary conditions	Boomerang Creek	Plumtree Creek	Hughes Creek
Upstream – adopted normal depth (taken from DTM) (m/m)	0.00196	0.00047	0.0008
Downstream – adopted normal depth (taken from DTM) (m/m)	0.0001	0.00077	0.0036
Model length (m)	7,397	4,665	9,131
Length directly impacted by subsidence in 20-year design (m)	1,000	2,935	4,853 (1,754 is an existing diversion)

Modelling utilised Queensland government guidelines for watercourse diversions (DNRM 2014) for the basis of evaluating changes in hydraulic conditions resulting from predicted subsidence. The diversion guidelines provide upper and lower thresholds of hydraulic parameters for velocity, shear stress and stream power. The thresholds have been developed for the 2-year and 50-year ARI flow events, typical channel forming events for streams in the Bowen Basin, and represent reach-average values.

For this assessment, streams have been split into upstream, downstream and subsidence reaches to enable evaluation of direct and indirect impacts, pre- and post-subsidence. For Hughes Creek, the subsidence reach has been further split into natural and diversion reaches to evaluate whether predicted impacts differ within those sub-reaches. Reach average hydraulic values were determined from hydraulic modelling for each stream.

Modelling indicates hydraulic values are higher in the larger streams and decrease from upstream to downstream for each creek, except for the diversion reach of Hughes Creek which causes a local increase (Table 2-7). Hydraulic values in Boomerang Creek and Plumtree Creek are generally well below threshold values, though velocity is near the threshold value for both flow events modelled. In the downstream reach of Boomerang Creek and Plumtree Creek, hydraulic values are much lower than threshold values, which is indicative of low gradient, small capacity channels.

In Hughes Creek, hydraulic conditions are more variable. Values in the downstream reach are below threshold for each parameter in both flow events. The upstream and natural subsidence reaches are below threshold for shear stress and 50-year stream power but exceed thresholds for 2-year stream power and velocity. The diversion reach in Hughes Creek exceeds threshold values for all but the 50-year shear stress.

The high hydraulic values in the upstream and diversion reaches of Hughes Creek reflect erosion observed. The downstream reach has a bed grade of 0.11%, approximately half that of the upstream and diversion reaches, which has contributed to the lower hydraulic values.

Table 2-7. Reach average values for key hydraulic parameters, existing conditions

	Shear stress (N/m²)		Stream power (N/m.s)		Velocity (m/s)	
	2yr	50yr	2yr	50yr	2yr	50yr
Bowen Basin diversion criteria	<40	<80	35-60	80-150	<1.0 (no veg)	<2.5
					<1.5 (with veg)	
Boomerang Creek						
Upstream reach	28.0	39.9	52.9	91.7	1.6	2.0
Subsidence reach (1,000 m)	24.0	30.2	41.1	57.4	1.5	1.8
Downstream reach	8.1	10.7	9.5	15.6	0.7	0.9
Plumtree Creek						
Upstream reach	18.5	20.2	25.8	30.1	1.3	1.4
Subsidence reach (2,935 m)	15.4	17.0	19.8	23.1	1.2	1.3
Downstream reach	8.9	9.1	8.1	8.2	0.8	0.8
Hughes Creek						
Upstream reach	39.2	51.1	85.3	137.2	2.0	2.6
Subsidence reach – diversion (1,754 m)	43.9	73.3	101.1	234.6	2.2	3.0
Subsidence reach – natural (3,099 m)	34.9	47.9	72.4	124.5	1.9	2.4
Downstream reach	28.3	44.9	56.9	125.4	1.5	2.0

Values above threshold shown in bold.

2.3.2 Boomerang Creek

Downstream of Peak Downs Mine, Boomerang Creek meanders gently south then east before joining Hughes Creek, which eventually makes its way to the Isaac River. It forms a continuous channel with a relatively uniform, symmetrical cross-section in straights and asymmetrical on bends. The channel bed is severely aggraded with sand several metres thick smothering all bed forms and limiting habitat diversity. The system is generally accreting as it is in a transport limited state (it receives more sediment than it can transport). The transport limited state often limits the potential for bank erosion, consistent with observations through the Project extents. A thick mud drape on the channel banks, generally colonised by fine roots allows for steep banks to be stable.

Under existing conditions, the two-year stream power profile fluctuates above and below diversion criteria thresholds in the upstream and subsidence reaches, remaining below threshold in the downstream reach (Figure 2-4), reflecting the low energy, depositional environment. The reach of Boomerang Creek modelled has a constant bed grade for the upper two-thirds, but it flattens out in the lower third where channel capacity reduces. Longwall panels will pass under the creek at this transition. Shear stress and velocity produce similar profiles.

Cattle grazing disturbs the channel bed and banks, limiting potential for regeneration of riparian vegetation. This has led to a relatively dense line of *Melaleuca leucadendra* and occasional *Eucalyptus tereticornis* overstorey lining the banks (Plate 1, Plate 2, Plate 3), with an exotic grass ground cover, the density of which is a direct result of grazing regime. Mid story (shrub) vegetation is largely absent.

Figure 2-4. Longitudinal profile of Boomerang Creek reach assessed (includes water surface and stream power)

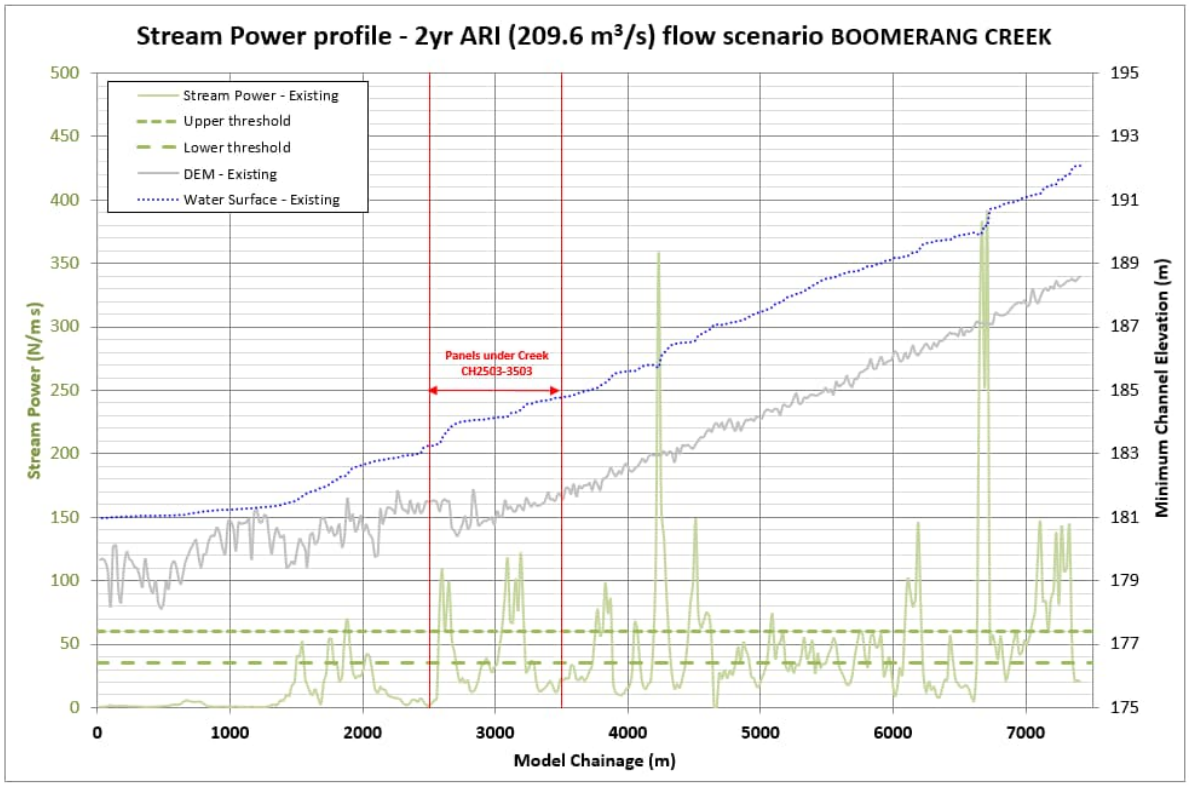


Plate 1. Typical conditions of Boomerang Creek across northern extents of proposed panels, Sept 2016

Plate 2. Boomerang Creek at confluence of Plumtree Creek (in predicted subsidence zone), Sept 2016

Plate 3. Boomerang Creek 2.8 km downstream of proposed underground workings, Sept 2016

2.3.3 Plumtree Creek

This tributary of Boomerang Creek is relatively short, commencing on the eastern edge of Saraji Mine. The upstream catchment has been mined and no longer contributes flows. The open cut operations have modified its catchment and diverted the channel upstream of the reaches modelled. Plumtree Creek flows east then north-east before its confluence with Boomerang Creek on the northern edge of the mine plan. The

watercourse is a continuous, single-thread, meandering channel with a gentle bed grade that is similar in profile to the modelled reach of Boomerang Creek (Figure 2-5).

The flat bed grade and low-capacity channel result in stream power that is well below threshold level (Figure 2-5), reflecting a low energy system through the Project Site. Longitudinal bed grade is controlled by Boomerang Creek downstream which has led to aggradation of the channel. The consequent reduced flows are reflected in a channel that is inactive and being colonised by terrestrial vegetation in part and blanketed in clay in others, leading to ephemeral wetland development in channel (Plate 4). There are no signs of instability on Plumtree Creek within the Project Site.

Figure 2-5. Longitudinal profile of Plumtree Creek reach assessed (includes water surface and stream power)

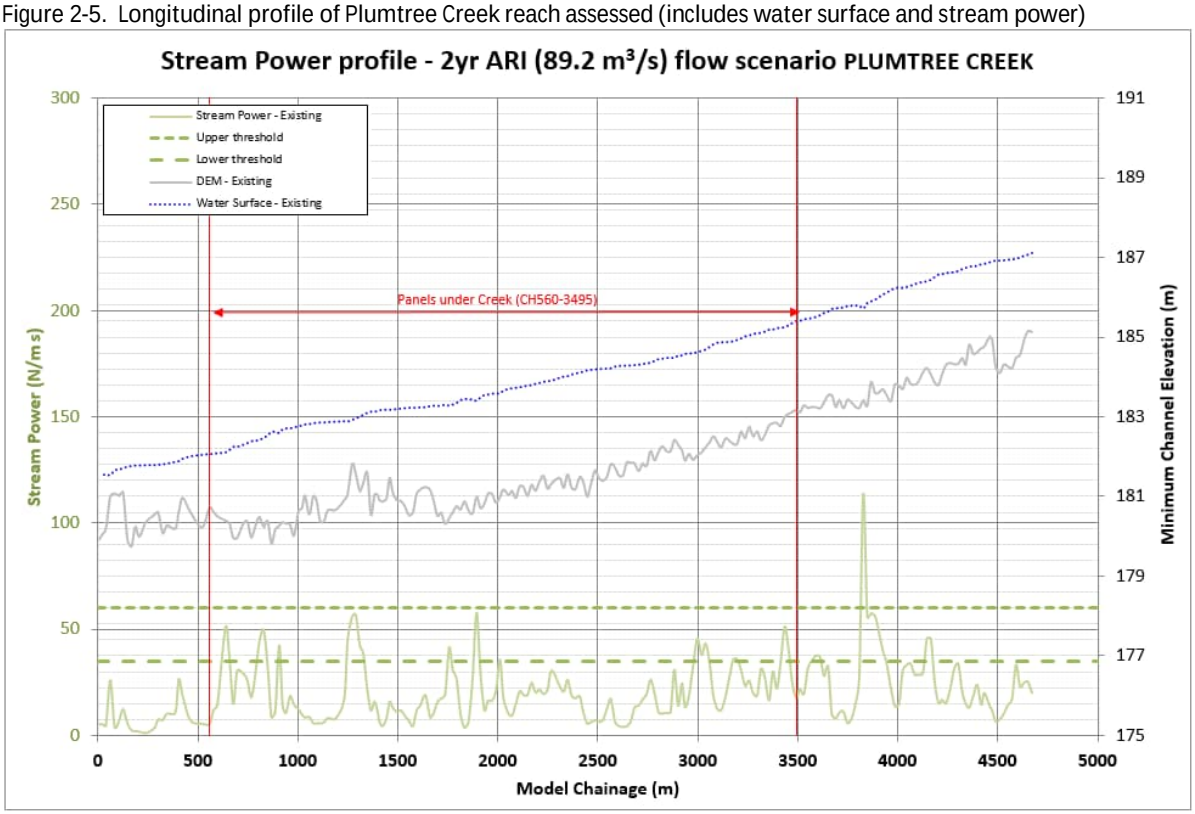


Plate 4. Plumtree Creek with ephemeral in-channel wetland, Sept 2016

2.3.4 Hughes Creek

Hughes Creek is a single alluvial continuous channel that has been diverted between pits in Saraji Mine. The diversion has a high angle bend into the western side of the northern panels in the Project Site. The proposed panels will subside approximately 1,750 m of the diversion, at its downstream end. The diversion reach is a deeply cut, large capacity channel with no floodplain connectivity. It is cut through dispersive subsoils and has been subject to considerable erosion and rehabilitation effort. These rehabilitation works comprise covering the long and relatively steep diversion batter slopes with pit-sourced sandstone. This type of sandstone typically completely weathers to constituent parts in 2-5 years. Vegetation has been slow to establish on the batters. Some vegetation has been left in the low flow channel.

A series of photos from the upstream extents of the Project Site to downstream are provided in Plate 5, Plate 6, Plate 7, Plate 8, Plate 9 and Plate 10, below. These highlight bank erosion where the channel capacity remains relatively large close to the diversion, with decreasing erosion and increasing deposition moving downstream. Channel capacity decreases in a downstream direction. Where this occurs, flood connection with Boomerang Creek occurs (Figure 2-15).

The two-year ARI stream power fluctuates above and below threshold values in each reach, though it is generally above threshold (Figure 2-6). Where it exceeds thresholds, it reflects potential for erosion in parts across the Project Site. The bed profile is uniform along most of the reach modelled but flattens out as it approaches Boomerang Creek, with a consequent reduction in channel capacity.

Figure 2-6. Longitudinal profile of Hughes Creek reach assessed (includes water surface and stream power)

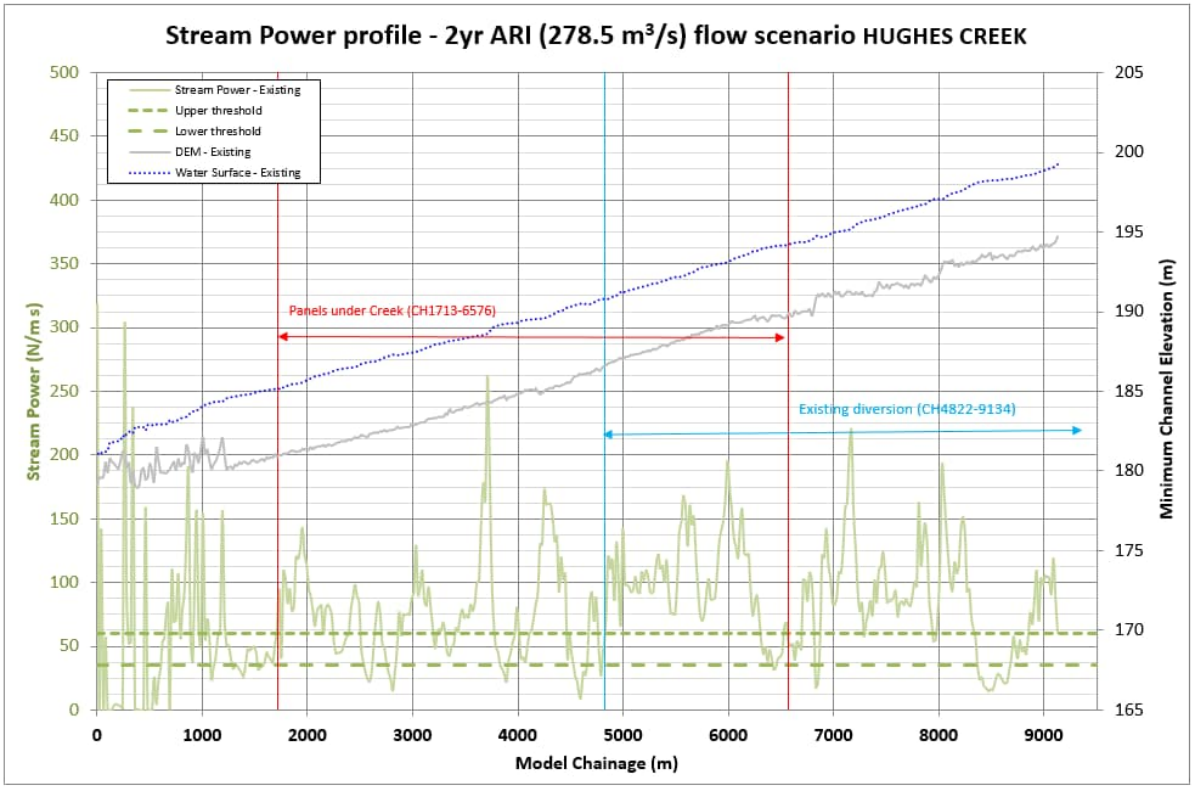


Plate 5. Hughes Creek Diversion, above proposed underground layout, Sept 2016

Plate 6. Hughes Creek downstream of diversion, above proposed underground layout, Sept 2016

Plate 7. Substantial bank erosion on Hughes Creek downstream of diversion, above proposed underground layout, Sept 2016

Plate 8. Gully erosion outside the floodplain woodland near mid-section of Hughes Creek over the Project Site, Sept 2016

Plate 9. Typical section of Hughes Creek mid-way across the Project Site, Sept 2016

Plate 10. Typical section of Hughes Creek at downstream extent of the Project Site, Sept 2016

2.3.5 Sediment transport

Sediment transport describes the transfer of sediment along a stream by fluvial processes. A stream's sediment transport capacity (STC) is the maximum rate at which sediment could be transferred through the system if there is sufficient sediment supply. Changes in runoff, sediment supply, sediment size and stream slope can result in either erosion or deposition within the channel. These processes can then propagate upstream and downstream impacting adjacent reaches.

Geomorphic response to the changes in the landscape brought about by subsidence such as a local slope increase (around pillars) and decrease (in panels) will be linked to the scale of the system (such as catchment area and flow), soil types and vegetation coverage.

Subsidence of the stream bed creates a depression that captures sediment. The geomorphic response to subsidence in alluvial sand bed streams, such as Boomerang Creek, Plumtree Creek and Hughes Creek, is similar to that for sediment extraction (Figure 2-7). Note the depression caused by subsidence is referred to as a pit in the figure. In brief:

a) Large sediment load relative to the subsidence – the depression migrates downstream, but overall bed lowering is small
b) Small sediment load relative to the subsidence – the bed fills in slowly and the bed lowers considerably.

To predict the geomorphic response of Boomerang Creek, Plumtree Creek and Hughes Creek to subsidence, it is necessary to quantify the volume of bed sediments transported in comparison to the volume of subsidence depressions created in channel, both spatially and temporally. If the volume of the depressions created by the subsidence is found to be insignificant when compared to the volume of sediment transported by the creek, then we would expect ongoing sediment transport in the creek to overwhelm the depressions. Under this scenario, the subsidence would be expected to have limited to no impact on geomorphic processes in Boomerang Creek, Plumtree Creek and Hughes Creek at a reach scale. Impacts would be limited to short terms and a local level.

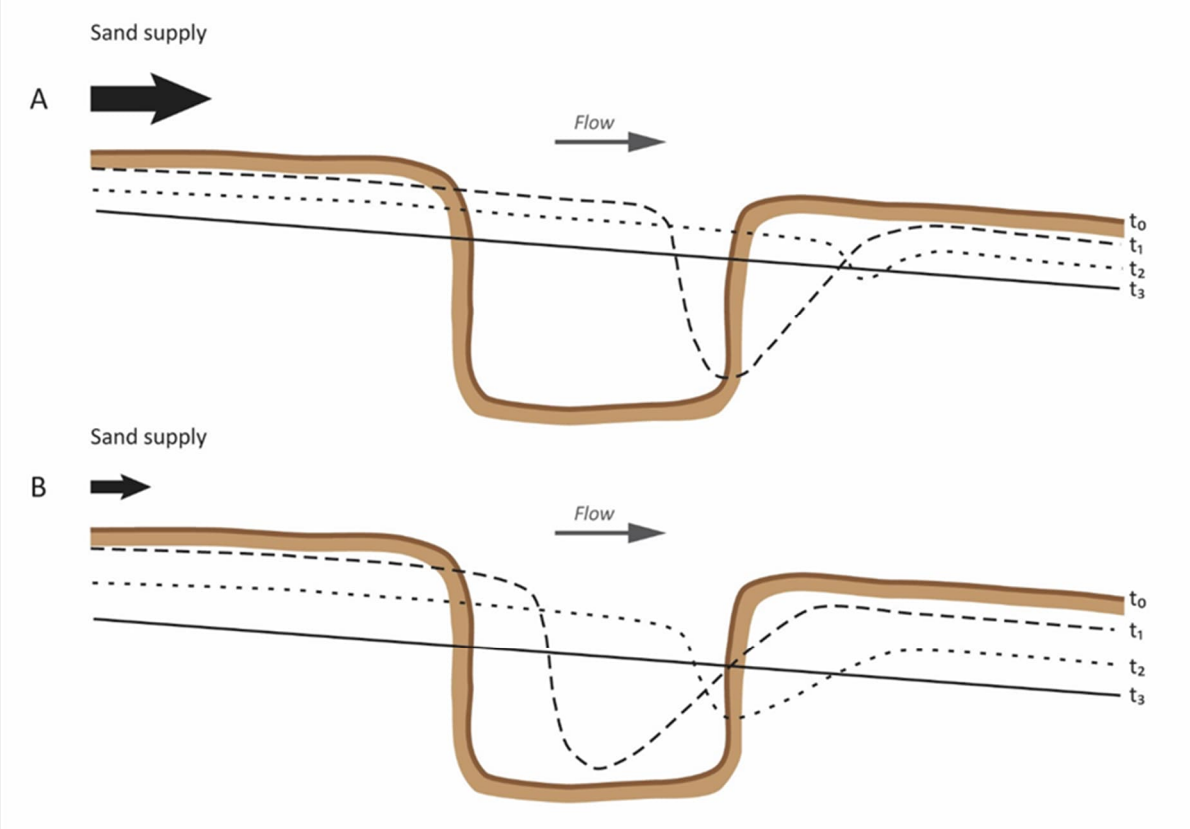
Alternatively, if the volume of depressions created by subsidence is of a similar scale or larger than the event sediment transport then we could expect some geomorphic impacts. The capture of sediment in the depressions creates a deficit between the STC and the sediment available, which may have positive impacts including the establishment of pools and a reduction in the available sediment for transport into downstream reaches. Large or sustained deficits may have negative impacts including upstream and downstream progressing stream bed degradation (deepening) and related exposure and potential scour of bank material and damage to infrastructure.

Other potential impacts of subsidence on stream form and geomorphic processes include:

- Gully incision of minor tributaries
- Stream bed incision of major tributaries and potential subsequent widening and meander migration
- Trunk stream widening associated with deepening
- Meander cut-offs or channel avulsions

Sediment transport analysis has been undertaken using the same 1D HEC-RAS models used for in-channel hydraulic analysis. The 1D model provides a simple sediment budgeting tool based on channel cross-sectional capacity to estimate the STC for each cross-section over a range of flows. The 1D assessment is discussed below.

Figure 2-7. Typical geomorphic response to sediment extraction



Schematic effects of extracting sediment from a stream bed.
In A, where there is a large sediment load, the pit migrates downstream, but overall bed lowering is small. In B, where sediment load is small, the pit fills slowly and the bed lowers considerably.

Adopted from Rutherford, I.D., Jerie, K. and Marsh, N. 2000. Stream Rehabilitation Manual, Vol.2, Land and Water Australia

In this figure depicting the effects of extracting sediment t_0, t_1, t_2 and t_3 represent intervals of time:

- t_0 - initial conditions of the bed after sediment extraction.
- t_1 – the pit will begin to fill with sediment coming from upstream.
- t_2 – Since bedload is trapped in the pit, the flow will pick up material downstream of the pit, leading to erosion downstream of the pit.
- t_3 – If there is no downstream hydraulic control (such as a weir, constriction etc), then the scour downstream of the pit will produce an increase in water slope that will then trigger upstream progressing erosion. Erosion will progress upstream until there is a smooth bed profile up and downstream of the pit. The bed is lowered by the same volume of sediment that was extracted from the pit.

2.3.5.1 1D sediment budgeting

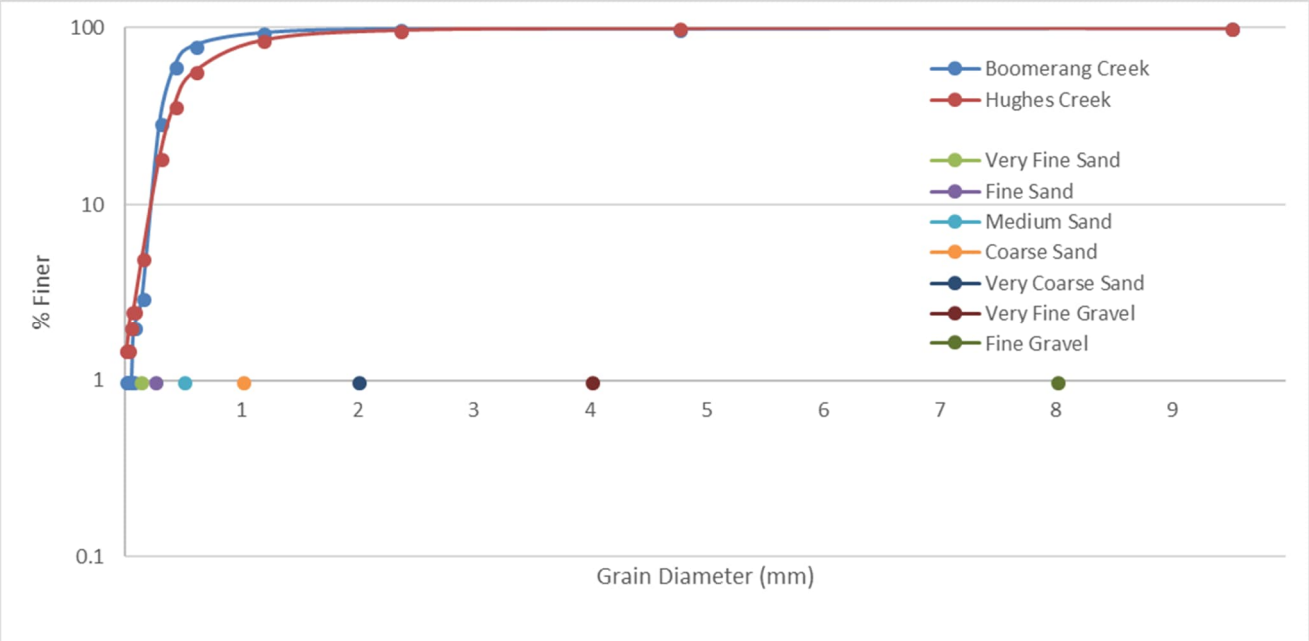
Based on existing hydraulic parameters and known bed sediment properties, the sediment transport capacity can be estimated by the application of empirical functions. The sediment transport analysis of Boomerang Creek, Plumtree Creek and Hughes Creek has been undertaken using the Toffaletti function for its application to fine and coarse sands, which are the dominant size fractions for the mobile bed sediments throughout the study area.

The capacity of stream flows to mobilise and transport sediment is influenced, in part, by the size of particles forming the bed and bank materials that may be entrained during flow events. The particle size distribution is

a required stream characteristic for modelling sediment transport. Sediment samples were taken from Hughes Creek and Boomerang Creek during a site visit in September 2016. Samples were sent to an external National Association of Testing Authorities (NATA) accredited testing laboratory to determine particle size distribution, the percent passing, median particle size and soil particle density using the shaker method. Four samples were analysed: two from Boomerang Creek and two from Hughes Creek. The results for the two samples for each creek were averaged to obtain a representative particle size distribution and density for STC modelling for that creek. Due to the similar nature of the bed material and location, sediment data derived from Boomerang Creek was deemed suitable for use in Plumtree Creek modelling, in the absence of stream specific data.

The particle size distribution for Hughes Creek and Boomerang Creek shows most of the mobile sediment is a fine to medium-grained sand (Figure 2-8). Coal fragments observed in the samples, generated from MLs upstream of the Project Site, are likely to have skewed the grain size distribution resulting in an over-estimate of the proportion of the largest grain size. This skewing of grain size distribution may lead to an underestimate of the sediment transport capacity of the streams. This may not be critical in terms of assessing impacts under current conditions where the streams are transport limited due to the high sediment inputs from the upper catchment. However, if sediment inputs were to reduce this may become important.

Figure 2-8. Particle size distribution of mobile sand bed of Boomerang Creek and Hughes Creek



Model inputs required for the Toffaletti function are summarised in Table 2-8.

Table 2-8. Test conditions for the adopted sediment transport functions

Transport function	Diameter absolute range (mm)	Slope (m/m)	Velocity (m/s)	Comments
Toffaletti	0.062-4	0.000002 - 0.0011	0.21-2.38	Within grain range and velocity range

Grain size gradation has been modelled as identical on the left overbank, main channel and the right over bank. In lieu of additional site grain gradation data, this approach is suitable for estimating the sediment transport capacity of each creek. Existing conditions and post-subsidence scenarios have been modelled this way to evaluate changes that may occur due to panel subsidence.

The sediment transport capacity has been calculated for all grains in the channel between the left and right overbank, including the channel bed. Sediment rating curves have been produced for all streams showing the relationship between flow rate and sediment transport capacity. Each stream has been divided into upstream,

subsidence and downstream reaches to identify whether subsidence causes consequential changes in any of the reaches when comparing pre- and post-subsidence modelling. Curves for Hughes Creek include diversion and non-diversion reaches to identify if the sub-reaches are affected differently by subsidence.

The sediment transport capacity decreases from upstream to downstream in Boomerang Creek (Figure 2-9), and Plumtree Creek (Figure 2-10).This trend is expected given the typical reduction in bed profile and channel capacity from upstream to downstream.

The sediment transport capacity in Hughes Creek also decreases from upstream to downstream in the natural reaches, however the diversion reach has a substantially larger sediment transport capacity (Figure 2-11). The diversion contains flows within a narrow channel cross-section with elevated hydraulic stream parameters and consequently has increased capacity to transport sediment.

The scale of the subsidence depression created relative to sediment transport capacity is an established tool (Alluvium, 2008) to assess likelihood and location of potential instability in alluvial streams in response to subsidence.

Figure 2-9. Sediment transport potential for Boomerang Creek, existing conditions

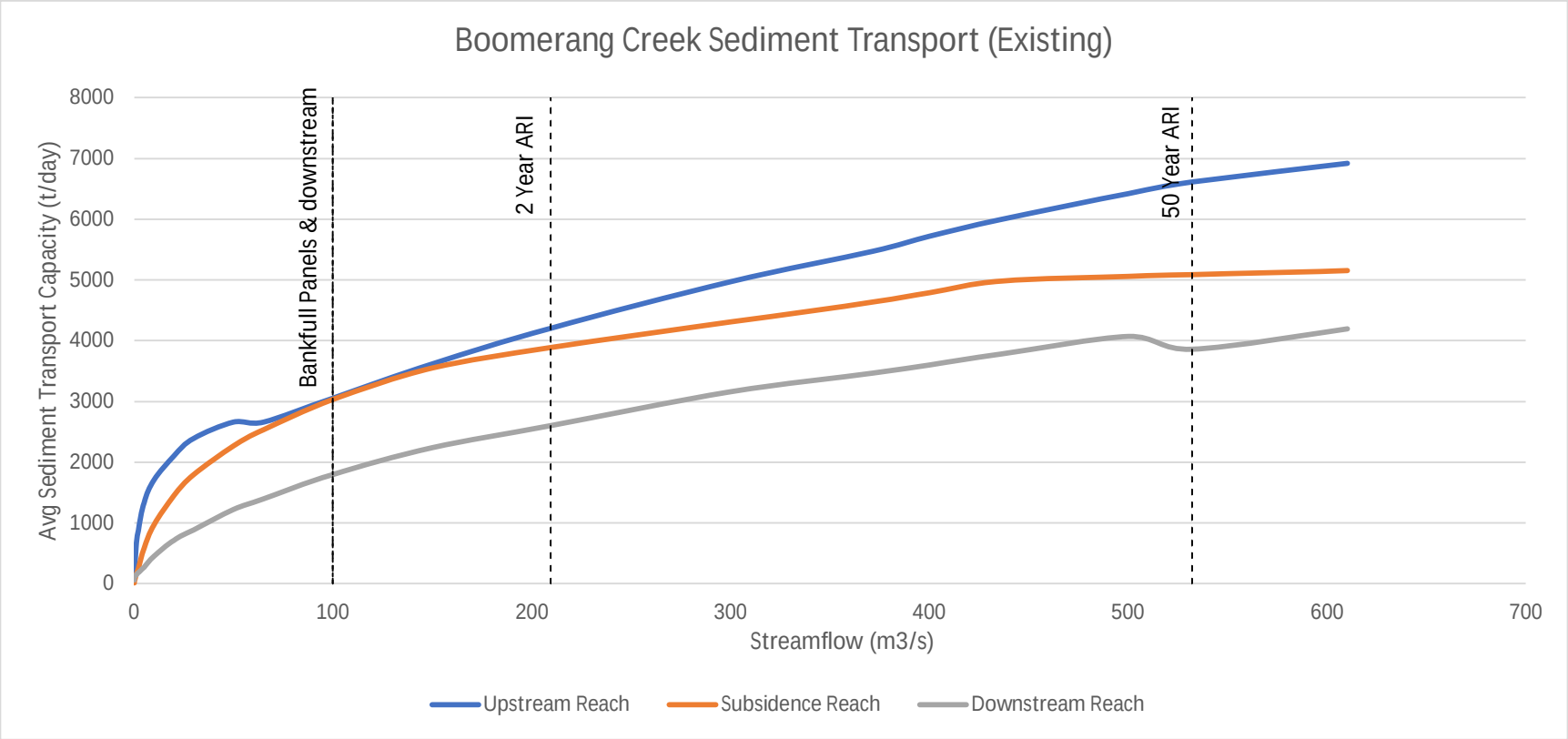


Figure 2-10. Sediment transport potential for Plumtree Creek, existing conditions

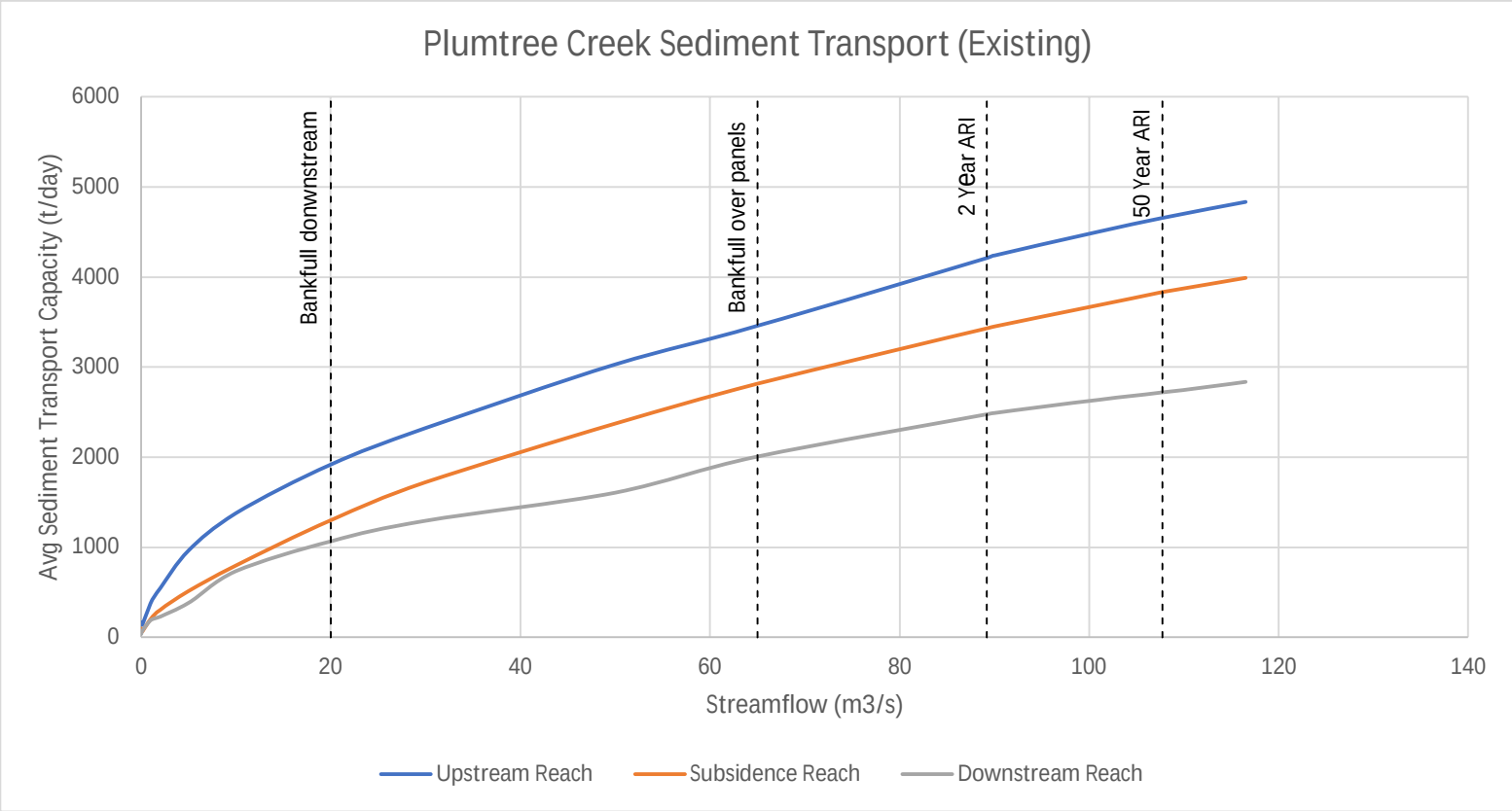
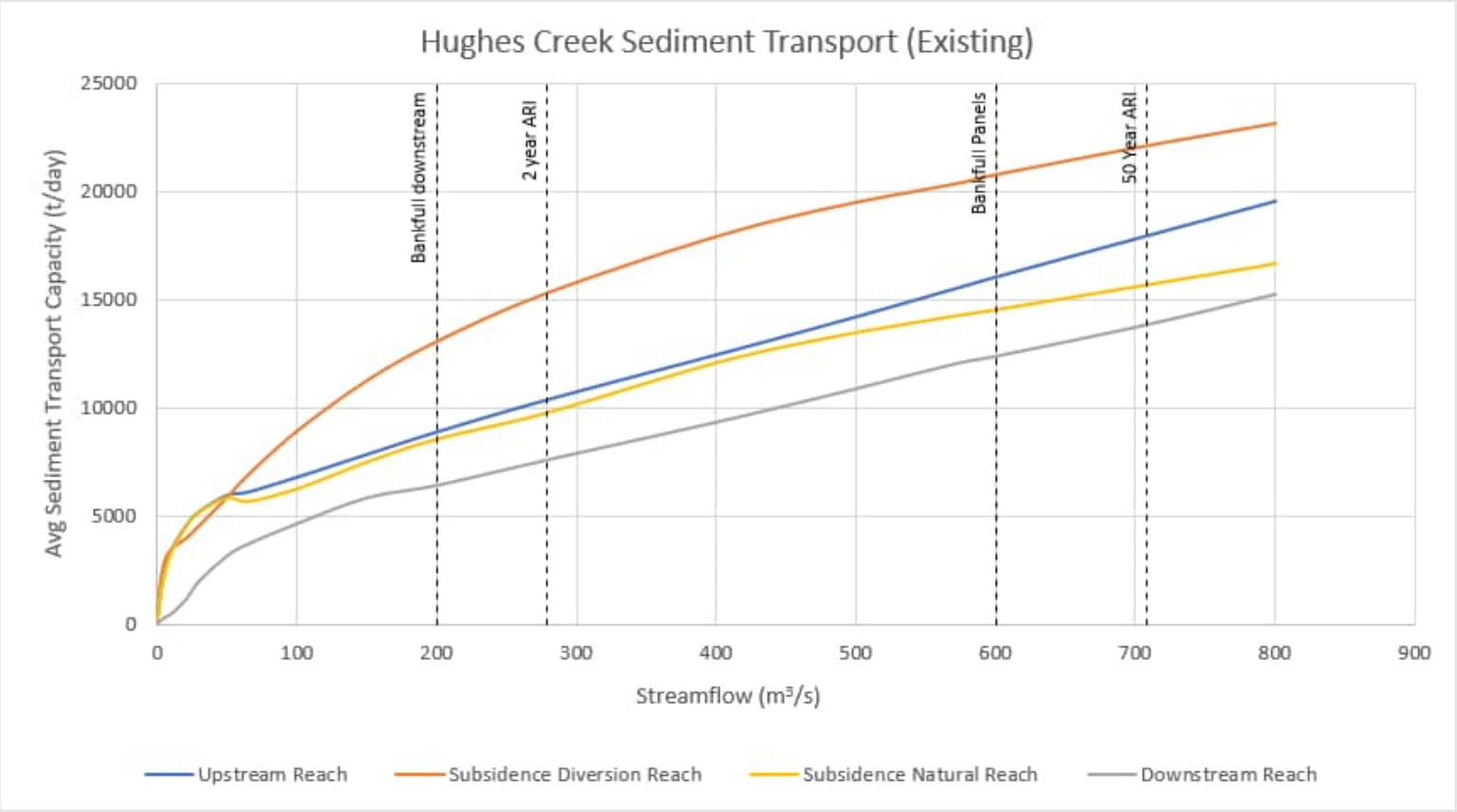


Figure 2-11. Sediment transport potential for Hughes Creek, existing conditions



2.4 2D Hydraulic modelling

Two-dimensional (2D) hydraulic modelling has been undertaken to assess flooding characteristics of the Project Site under existing conditions. A range of flow events were modelled to understand flood behaviour under existing conditions and compare that to post-subsidence conditions at Year 10 and Year 20 of subsidence. The 2D model outputs have also provided valuable input to the geomorphic assessment.

2.4.1 2D hydraulic model extent

The 2D hydraulic model extents lie primarily within ML 70383 and part of ML1775. Multiple downstream model boundaries are located at or downstream of MLA 70383, approximately 3 km downstream of the Project Site, prior to the Isaac River confluence. Model extents (Figure 2-12) were selected to ensure the effects of subsidence on the conveyance and storage of the Hughes Creek and Boomerang Creek floodplains were captured in the 2D model.

2.4.2 Roughness

The model uses Manning's 'n' roughness coefficients to represent channel and floodplain hydraulic roughness. The coefficients adopted for flood modelling are presented in Table 2-9. These coefficients reflect the general land uses and vegetation present (Figure 2-13) within the model extent, based upon aerial photography and available site inspection data.

Table 2-9. Manning's n roughness values for 2D model*

Material ID	Description	Depth 1	n1	Depth n2	n2
1	Water bodies	-	0.02	-	-
2	Unpaved roads	0.03	0.1	0.1	0.03
3	Waterway minimal vegetation	0.03	0.1	0.1	0.035
4	Moderate dense vegetation	0.03	0.1	0.1	0.06
5	Dense Vegetation	0.03	0.1	0.1	0.1
6	Default	0.03	0.1	0.1	0.04
7	Mining	0.03	0.1	0.1	0.06

*Note the roughness values differ slightly to those used in the 1D model, which focuses on the in-channel area. In the 2D model, attribution of roughness values occurs at a much larger scale to capture more of the spatial variation in roughness across the large floodplain area.

2.4.3 Application of hydrologic modelling outputs to the 2D model

Design hydrographs were input into the model at the locations shown in Figure 2-12 to represent inputs from the catchments external to the 2D domain. The peak values of each location are presented in Table 2-5, page 15.

In addition to the hydrograph, direct rainfall polygons were applied to the model to represent the rainfall and runoff generated locally in each catchment. This approach has been adopted as it takes advantage of the 2D model's ability to model overland flows that can be affected by mining and other influences that alter the land surface and allows a single hydrologic configuration to be used for both the current and future scenarios.

2.4.4 Terrain model configuration

The existing topography within the model domain was developed from the following sources:

- Pre- and post-subsidence LiDAR provided
- Historic terrain data
- Shuttle Relay Topography Mission (SRTM) data (only used for hydrologic modelling).

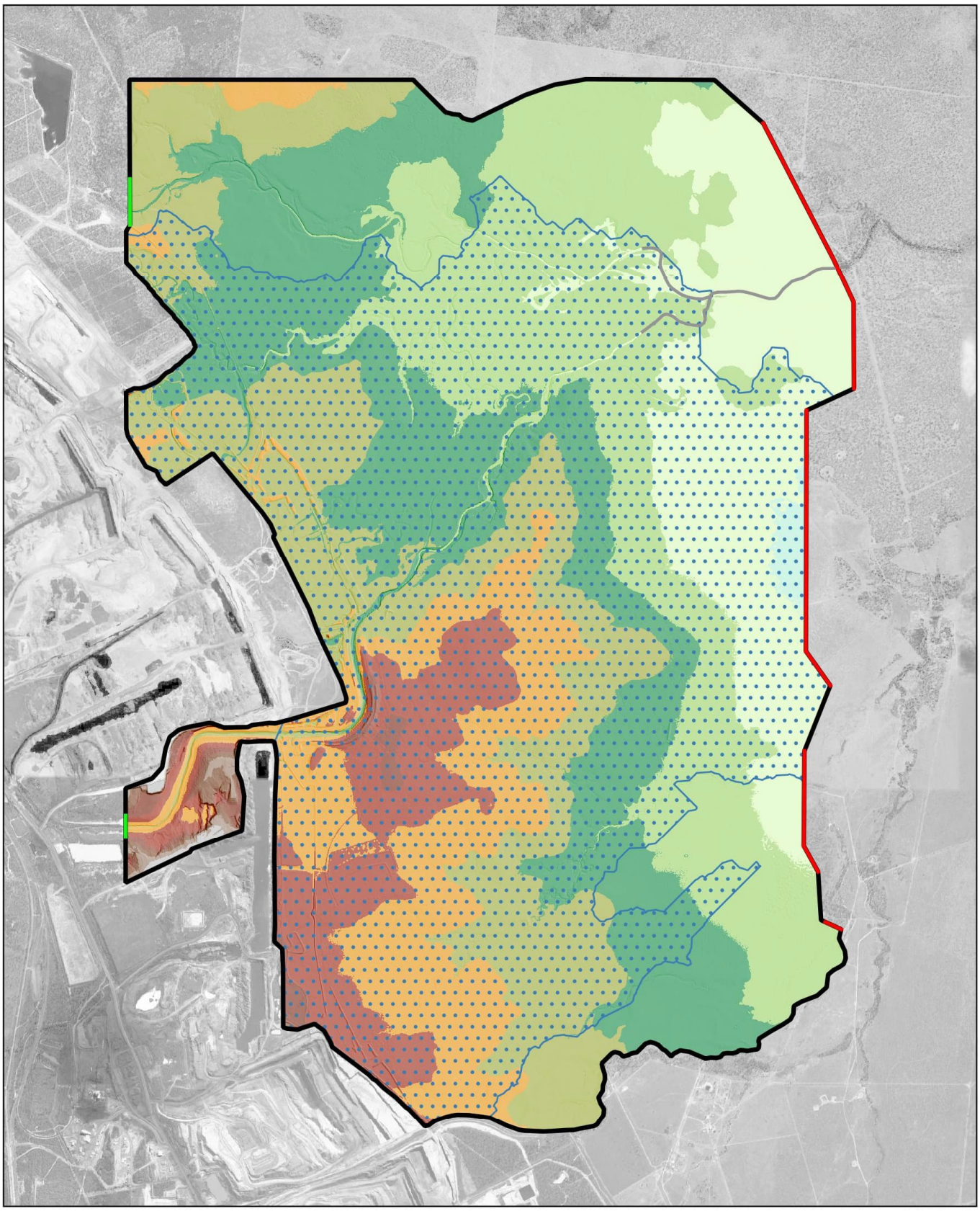
2.4.5 Flood extents

Modelling was undertaken to determine the nature and extent of flood behaviour under existing conditions. The maximum predicted water depth across the Project Area has been mapped for the 2-year ARI (Figure

2-14), 50-year ARI (Figure 2-15), 100 year ARI (Figure 2-16) and 1000-year ARI (Figure 2-17) events. The lower limit of mapping has been set at 0.2 m deep to avoid capturing puddles that result from direct rainfall.

Results indicate that for the 2-year ARI event, flows are contained within the channels except in the northeast corner of the Project Area, where floodplain inundation occurs near the Hughes Creek and Boomerang Creek confluence. The extent and depth of inundation increases for each larger flow event modelled. Overland flow paths south of Hughes Creek also become more prominent under larger flows.

Figure 2-12. 2D hydraulic model setup (existing conditions)



LEGEND

- Inflow Boundaries
- Outflow Boundaries
- Thalweg - Enforced
- Rainfall Boundary
- TUFLOW Model Extent

Terrain Level (mAHD)

- <= 175
- 175 - 180
- 180 - 185
- 185 - 190
- 190 - 195
- 195 - 200
- 200 - 205
- 205 - 210
- 210 - 215
- 215 - 220
- 220 - 225
- > 225

0 1 2 km

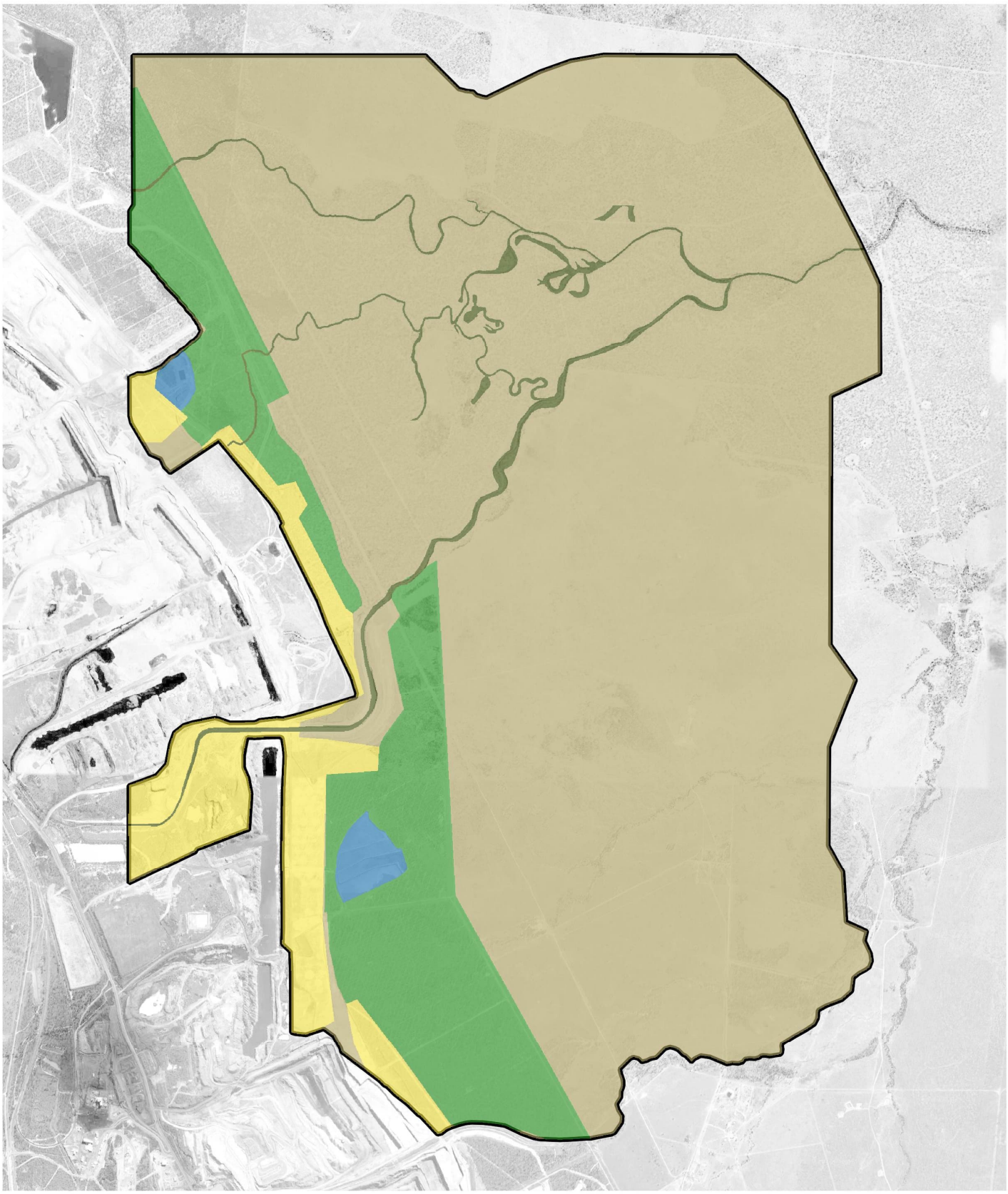
n

SARAJI EAST EIS:
TUFLOW MODEL SETUP

Coordinates: GDA94 MGA Zone 55
Created: 2/8/2022
Scale:1:50,000 (A4)

Originator: CB
Checked: GE
Approved: RL

Figure 2-13. 2D hydraulic roughness



LEGEND

Model Extent

Material Type
- Water Bodies
- Riparian Zone
- Medium Density Vegatation
- Grassland
- Mining Areas

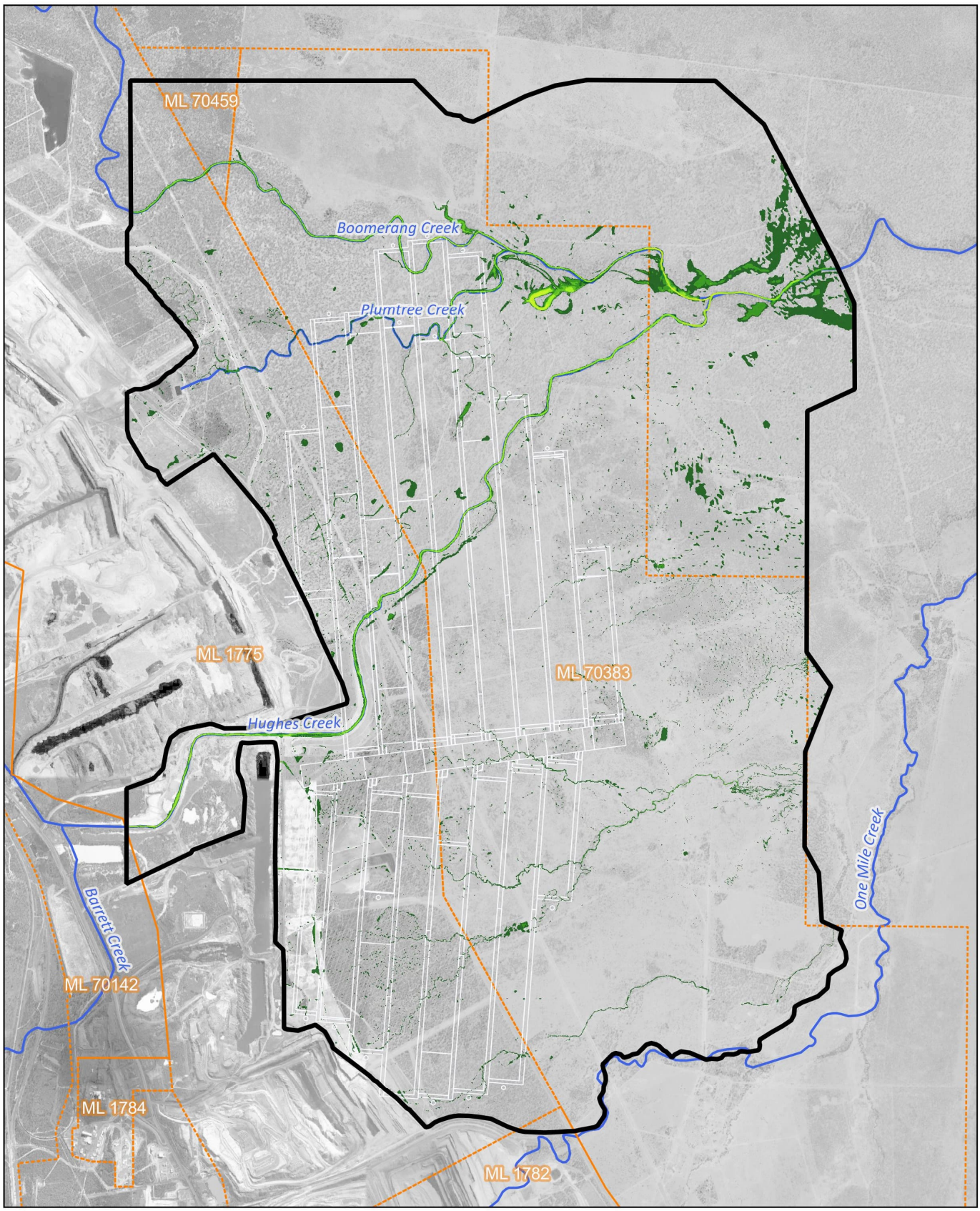
0 1 2 km

SARAJI EAST EIS:
TUFLOW MATERIAL TYPES

Coordinates: GDA94 MGA Zone 55
Created: 11/8/2022
Scale:1:50,000 (A4)

Originator: CB
Checked: GE
Approved: RL

Figure 2-14. Peak flood depth 39% AEP (pre-subsidence)



LEGEND

- Panel Extents
- Watercourses
- Mining Leases
- TUFLOW Model Extent

Flood Depth (m)

- 0.1 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 2.5
- 2.5 - 3
- 3 - 3.5
- 3.5 - 4
- 4 - 5
- 5 - 6
- > 6

0 1 2 km

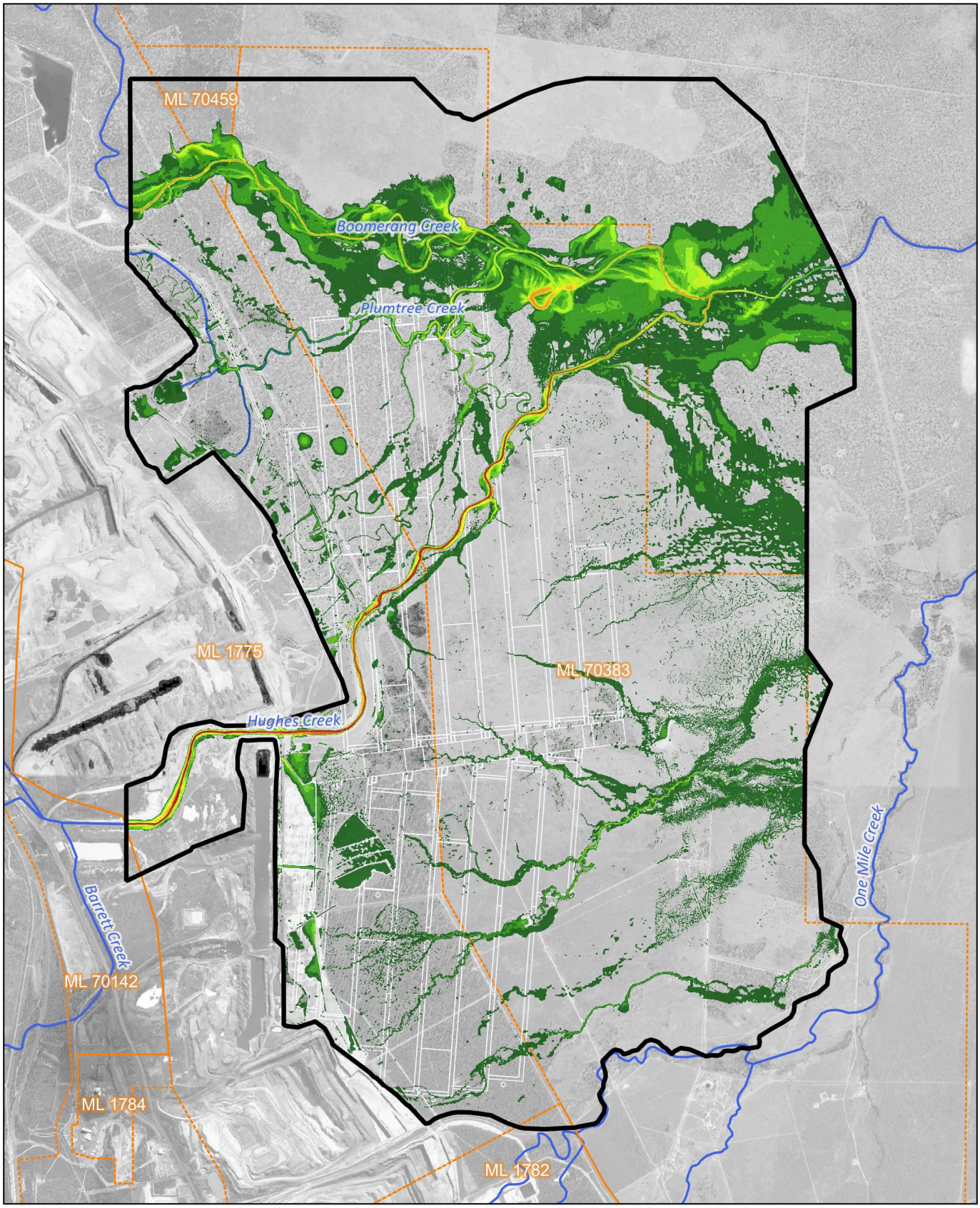
n

SARAJI EAST EIS:
PEAK FLOOD DEPTH
39% AEP EVENT

Coordinates: GDA94 MGA Zone 55
Created: 7/12/2022
Scale:1:50,000 (A4)

Originator: CB
Checked: GE
Approved: RL

Figure 2-15. Peak flood depth 2% AEP (pre-subsidence)



LEGEND

- Panel Extents
- Watercourses
- Mining Leases
- TUFLOW Model Extent

Flood Depth (m)

- 0.1 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 2.5
- 2.5 - 3
- 3 - 3.5
- 3.5 - 4
- 4 - 5
- 5 - 6
- > 6

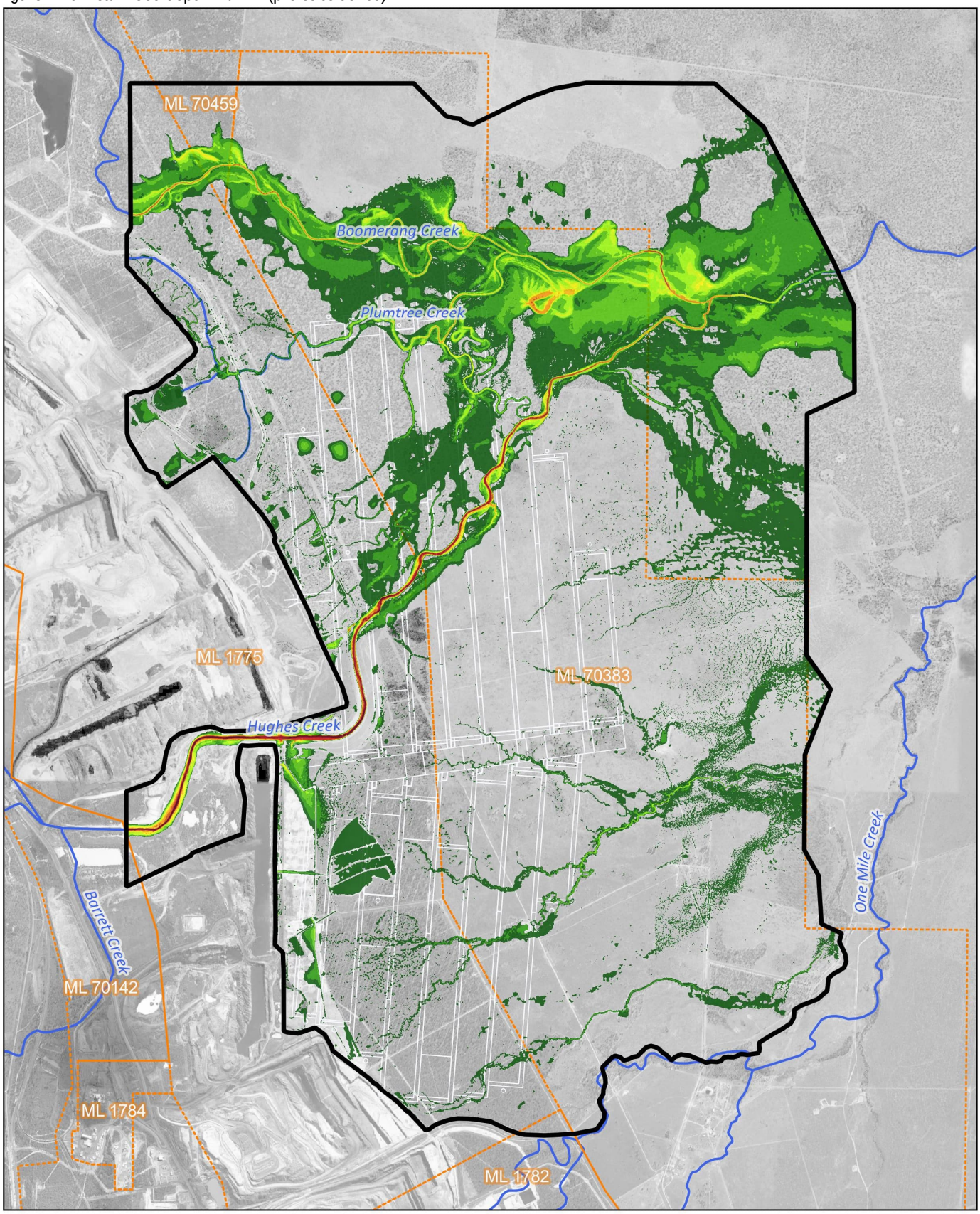
0 1 2 km

SARAJI EAST EIS:
PEAK FLOOD DEPTH
2% AEP EVENT

Coordinates: GDA94 MGA Zone 55
Created: 5/8/2022
Scale:1:50,000 (A4)

Originator: CB
Checked: GE
Approved: RL

Figure 2-16. Peak flood depth 1% AEP (pre-subsidence)



LEGEND

- Panel Extents
- Watercourses
- Mining Leases
- TUFLOW Model Extent

Flood Depth (m)

- 0.1 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 2.5
- 2.5 - 3
- 3 - 3.5
- 3.5 - 4
- 4 - 5
- 5 - 6
- > 6

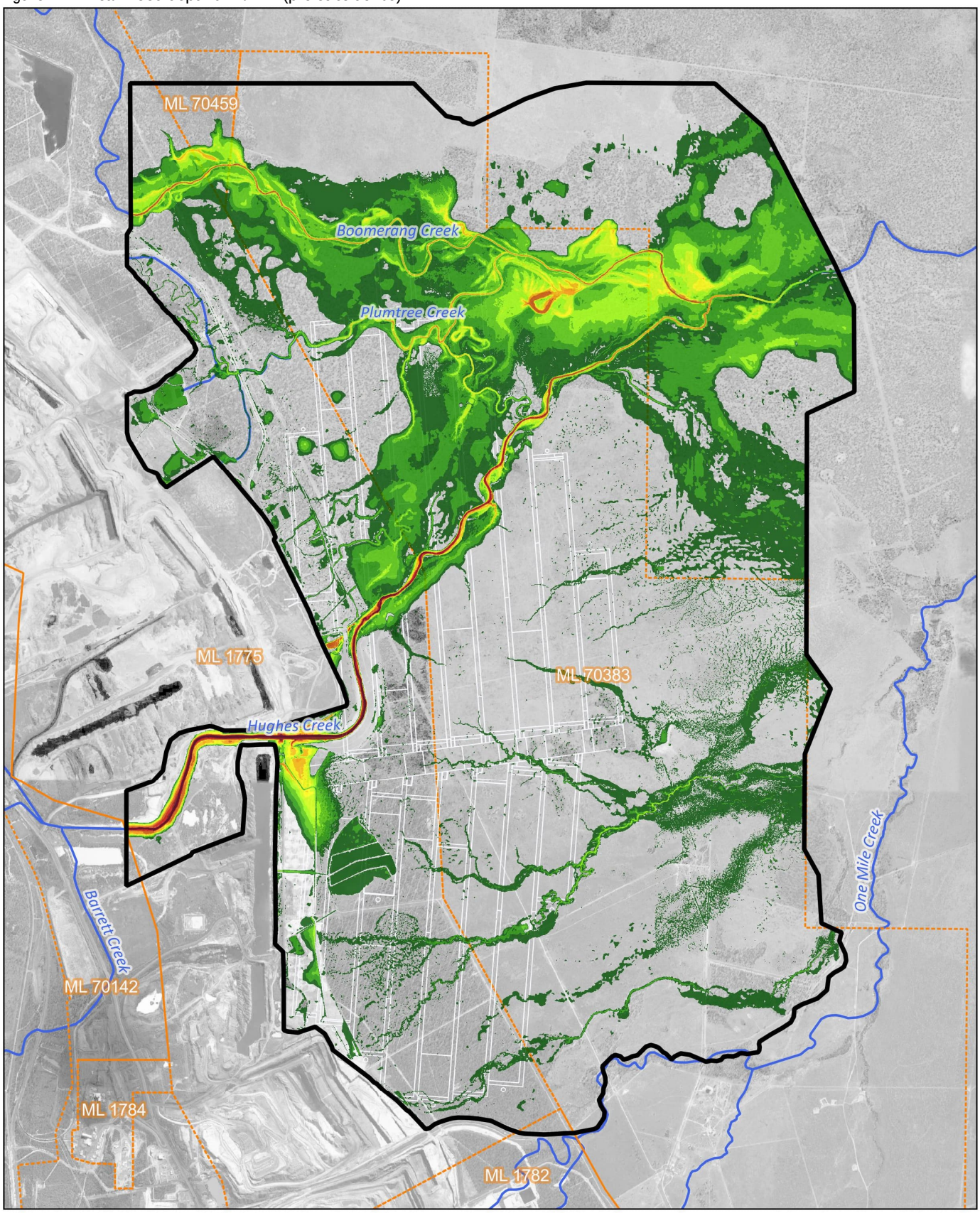
0 1 2 km

SARAJI EAST EIS:
PEAK FLOOD DEPTH
1% AEP EVENT

Coordinates: GDA94 MGA Zone 55
Created: 5/8/2022
Scale:1:50,000 (A4)

Originator: CB
Checked: GE
Approved: RL

Figure 2-17. Peak flood depth 0.1% AEP (pre-subsidence)



LEGEND

- Panel Extents
- Watercourses
- Mining Leases
- TUFLOW Model Extent

Flood Depth (m)

- 0.1 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 2.5
- 2.5 - 3
- 3 - 3.5
- 3.5 - 4
- 4 - 5
- 5 - 6
- > 6

0 1 2 km

SARAJI EAST EIS:
PEAK FLOOD DEPTH
0.1% AEP EVENT

Coordinates: GDA94 MGA Zone 55
Created: 5/8/2022
Scale:1:50,000 (A4)

Originator: CB
Checked: GE
Approved: RL

3 Potential impacts of subsidence

Potential impacts resulting from the Project's activities and the infrastructure associated with development of the Project Site have been identified to enable the development of appropriate mitigation and management measures. Assessing the potential impacts of the Project on the waterways and flooding characteristics of the Project Site involved modelling of the post-subsidence terrain after 10 years and 20 years of mining and comparing results with those from pre-subsidence (existing conditions) modelling. This was achieved by replicating the 1D and 2D models used to establish existing conditions and replacing the existing surface terrain with the predicted post-subsidence surface terrain for each scenario. The predicted subsidence in the Project Site will not substantially alter the contributing catchment areas and therefore there was no requirement to revise hydrological estimates of flows entering the Project Site.

This section of the report discusses three levels of impact from subsidence:

- The direct effects of subsidence (Section 3.1)
- The predicted geomorphic response to subsidence (Section 3.2)
- The predicted impacts to water quantity and flooding (Section 3.3)

The direct effects of subsidence as predicted by Minserve (2022) are discussed in terms of the implications for geomorphic responses and flooding behaviour. These implications are then evaluated through the assessment of the geomorphic response to subsidence, which involved catchment mapping to identify potential changes to overland flow paths and modelling to quantify changes in channel hydraulics and sediment transport. This section finishes with an assessment of the potential impacts to water quantity and flood behaviour through 2D flood modelling.

3.1 Direct effects of subsidence

Development of the longwall panels will cause deformation of the land surface. Deformation will involve the formation of surface depressions above the panels with the surface above the pillars remaining unchanged. This differential lowering of the land surface often results in the development of surface cracks, associated with tension, and buckling, associated with compression, of the surface. The nature and extent of cracking and buckling is a function of the depth of the longwall panel from the surface, the thickness of the panel extracted and the overlying geology. The nature of the subsidence has been predicted through modelling (Minserve 2022) to identify variation over the Project Site and the likely extent of subsidence beyond the mine plan. The assessment used 3D deformation modelling to predict the maximum depth of subsidence and create subsidence contours for the post-mining landform.

A summary of the findings relevant to potential impacts on the watercourses is presented in Table 3-1.

Table 3-1. Subsidence predictions summarised from modelling report (Minserve 2022)

Subsidence Feature	Subsidence Prediction
Variation within panel	Subsidence profile varies along and across each panel
Variation between panels	No two panels display the same subsidence profile
Subsidence depth in southern panels	1.4 m to 3.4 m
Subsidence depth in northern panels	0.75 m to 2.25 m
Cracking beyond longwall panels	Up to 400 m
Maximum subsidence depth beneath creek	~1 m (Boomerang Creek), ~1.3 (Plumtree Creek), ~3.4 m (Hughes Creek)

Differences in pre- and post-subsidence terrain models have been used to estimate and map the depth of subsidence along each longwall panel. The maximum subsidence is typically along the centre of the panel with negligible change along the pillars. Subsidence depth is more variable in the southern panels with typical differentials from panel to pillar of several metres. The subsidence in the eastern half of the northern panels is relatively atypical with no differential subsidence predicted between pillars and panels, creating a large single depression (Figure 3-1).

Subsidence of around 2 m is substantial where watercourse depth shallows to a similar magnitude and floodplain connectivity occurs. The formation of preferential flood flow paths and closed basins in the subsidence depressions is likely. These may provide both positive and adverse environmental outcomes.

3.1.1 Surface tensile cracking and buckling compression

The nature and extent of cracking is a function of the depth of the longwall panel from the surface and the thickness of the panel extracted, the nature of the overburden strata and the characteristics of surficial soils. The implications of surface cracking for geomorphic response are discussed in Section 3.2.

Figure 3-1. Predicted subsidence depths below existing surface (Year 10)

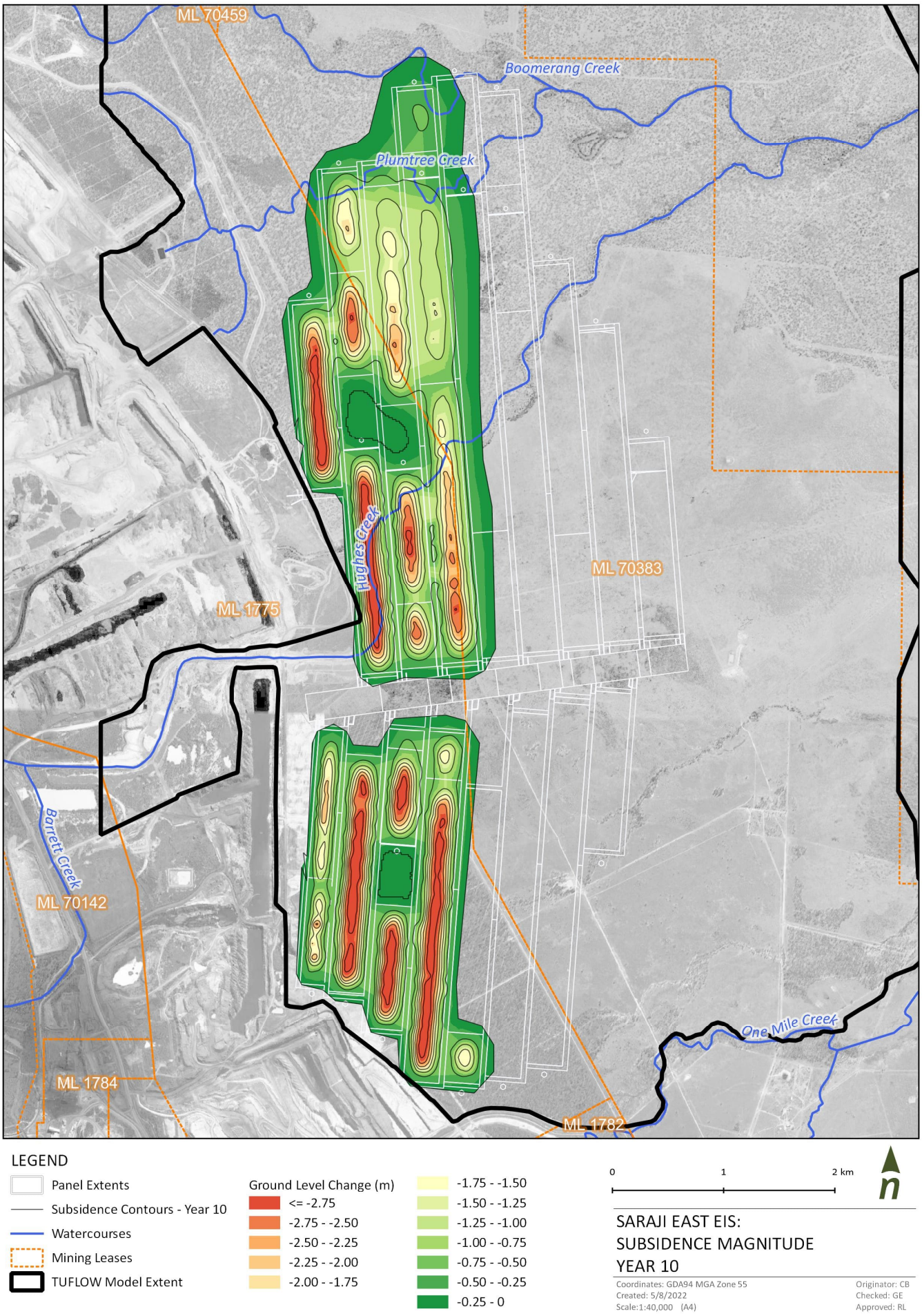
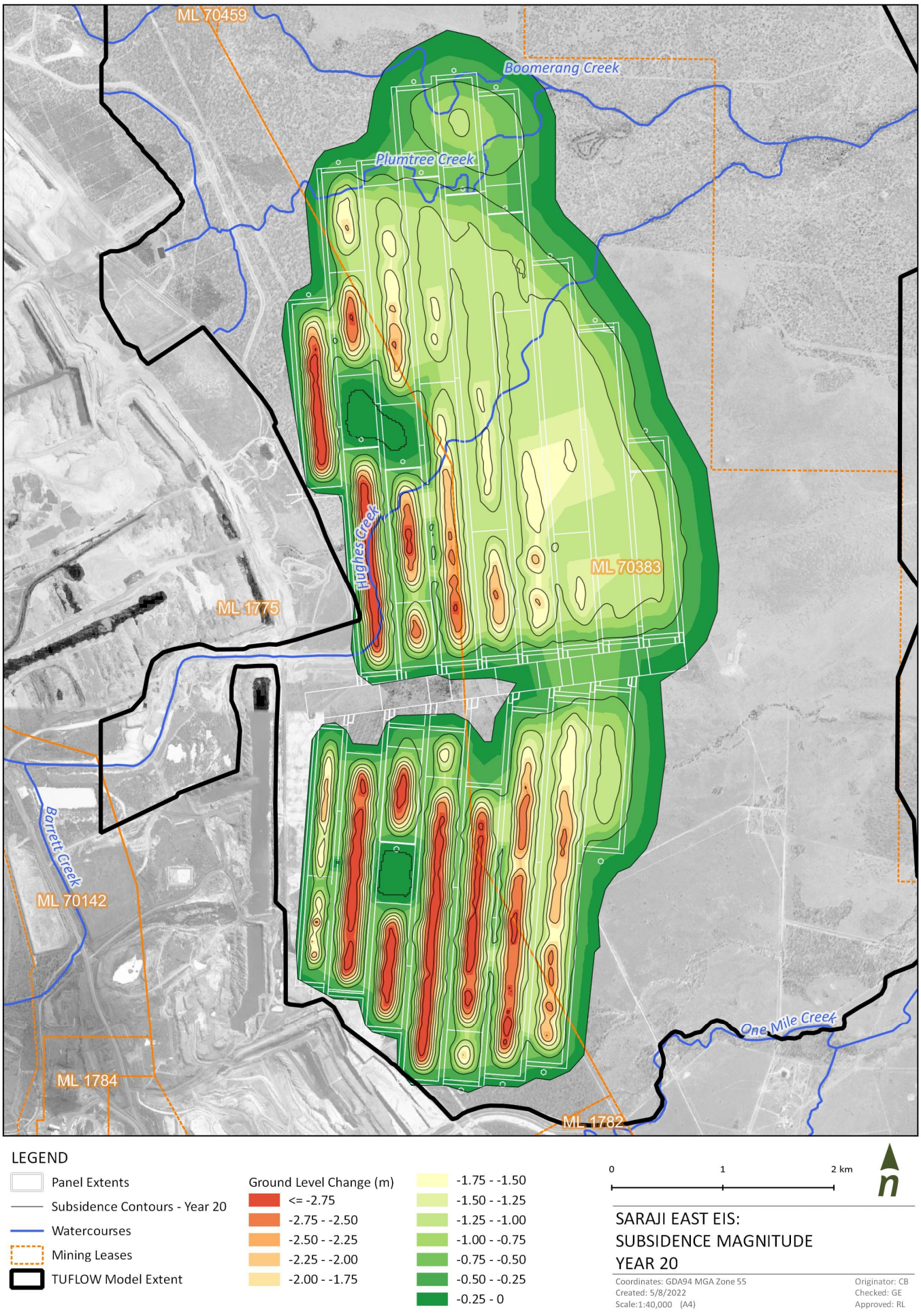


Figure 3-2. Predicted subsidence depths below existing surface (Year 20)



3.2 Predicted geomorphic response of surface water systems to subsidence

The pre- and post-subsidence terrain models have been used to determine potential changes to surface flow paths in the Project Site resulting from subsidence. The three streams being assessed all pass across the northern panels. The southern panels don't intercept any mapped watercourses, however, minor flow paths are present across all panels. Flow paths for both pre- and post-subsidence terrain were derived at the same scale using the program CatchmentSIM to enable a direct comparison. The subsidence associated with longwall mining creates panel catchments on the floodplain with flow paths often forming down the centre of the panel. This appears to be a likely scenario for the southern half of the southern panels. These realignments appear to affect only minor flow paths with most larger flow paths continuing along their original course. Realignment of flow paths in the northern panels appears a less likely scenario, due to the shallower subsidence predicted and less differential in subsidence between panel and pillar.

Some panel catchments will pond water until they fill and spill. Despite the creation of subsidence depressions, the spill point in most cases is similar to the pre-subsidence flow path due to the overriding topography. Subsidence may have local attenuation effects on low flows through temporary storage in panels, however since the subsidence is confined to relatively small sections of the major streams, the impact to downstream flows is negligible.

The development of avulsion paths, meander cut offs and head cuts may occur in areas where the energy gradients are increased by subsidence, particularly flow paths which drop into subsided panel zones over pillars or end walls. Hughes Creek diversion will have a drop of nearly 3 m into the first panel it intercepts with the potential for major instability when the channel bed responds by attempting to regrade to a more stable gradient.

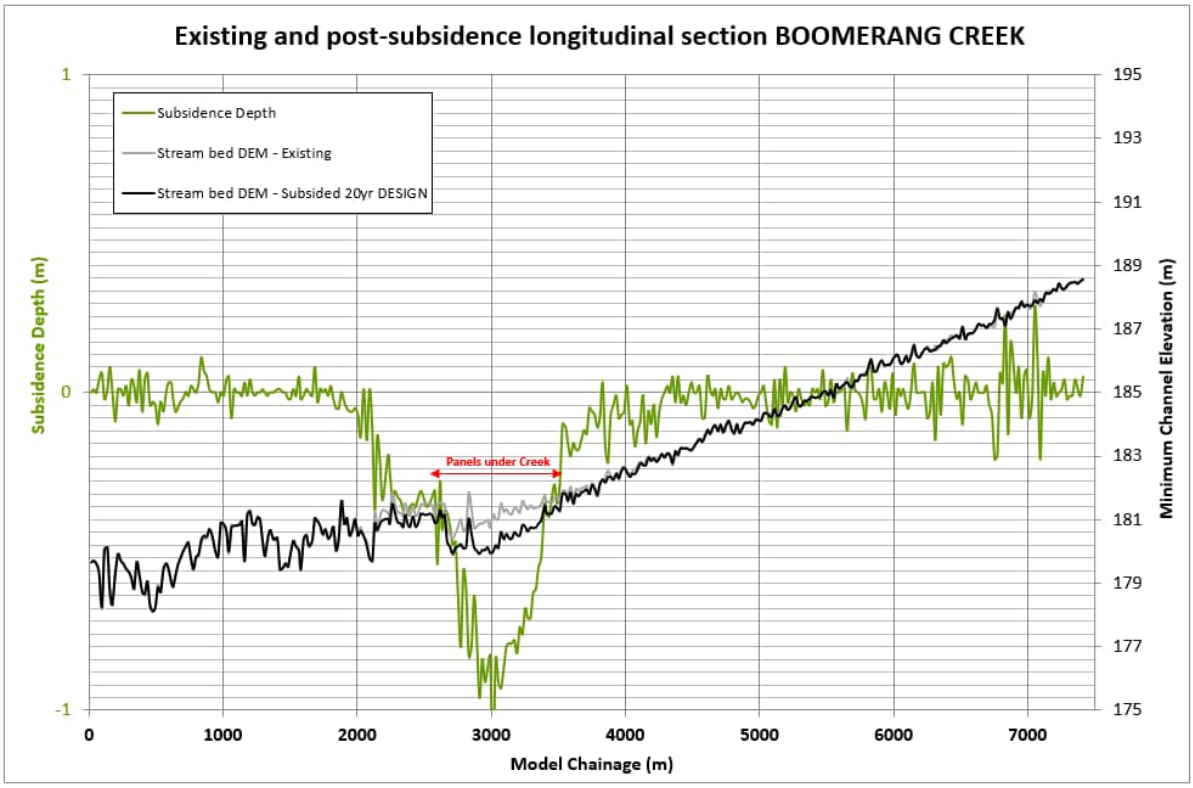
The geomorphic response of surface water systems to subsidence impacts has been assessed through 1D hydraulic modelling to evaluate changes in channel hydraulics and sediment transport. Assessment has been undertaken on the 10-year and 20-year subsidence surfaces to quantify changes from existing conditions. Subsidence will create an undulating bed profile that may cause localised variation in stream hydraulics.

3.2.1 Boomerang Creek

Boomerang Creek will be directly impacted by two longwall panels, affecting approximately one km of creek. It will not be directly impacted by subsidence until Year 10. A comparison of existing and post-subsidence (Year 20) longitudinal sections for Boomerang Creek indicates maximum subsidence of just over 1 m above the centre of the panels (Figure 3-3), which occurs towards the upstream end of its interception with the mine plan. Towards the downstream end of the subsided reach the predicted subsidence is close to 0.5 m where the channel runs across the end of a panel.

Most of the area that will be subject to subsidence has a flatter bed grade than upstream, so steepening of the bed grade from subsidence is unlikely to exceed the upstream bed grade. Impacts to Boomerang Creek stability and flow behaviour are expected to be local and minor from subsidence of its channel.

Figure 3-3. Boomerang Creek existing and post-subsidence longitudinal section



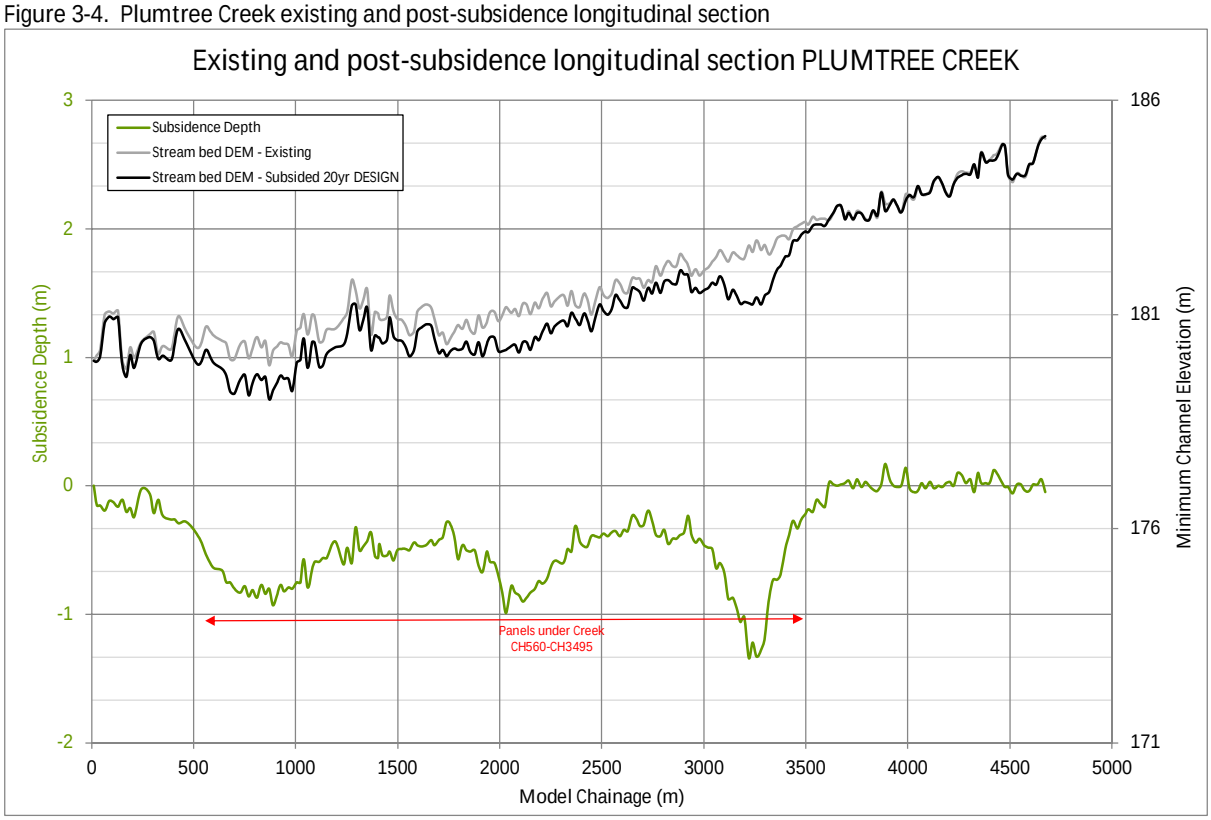
3.2.2 Plumtree Creek

Approximately 2.9 km of Plumtree Creek will be subsided by five panels. It will not be directly impacted by subsidence until year 4. A profile of Plumtree Creek to its confluence with Boomerang Creek shows that subsidence is predicted to vary between 0.3 m and 1 m deep for most of the reach intercepted by panels (Figure 3-4). The deepest subsidence is around 1.3 m where the channel is intersected by the most upstream (westerly) panel. The downstream 1200 m of the reach affected has a flatter bed grade and subsidence depth is less variable through this area.

Some incision of the channel bed upstream from subsidence would be expected where the steepening of bed grade into the panels is greatest, however open cut mining upstream has reduced the catchment area and, consequently, the flows produced. Impacts from subsidence are expected to be minor.

The downstream 500 m to 1 km of Plumtree Creek is likely to become a pool because of subsidence with potential to increase in depth over time as deposition at its confluence with Boomerang Creek is likely to raise the confluence level. This pool may be similar in nature to that in Plate 4.

Figure 3-4. Plumtree Creek existing and post-subsidence longitudinal section

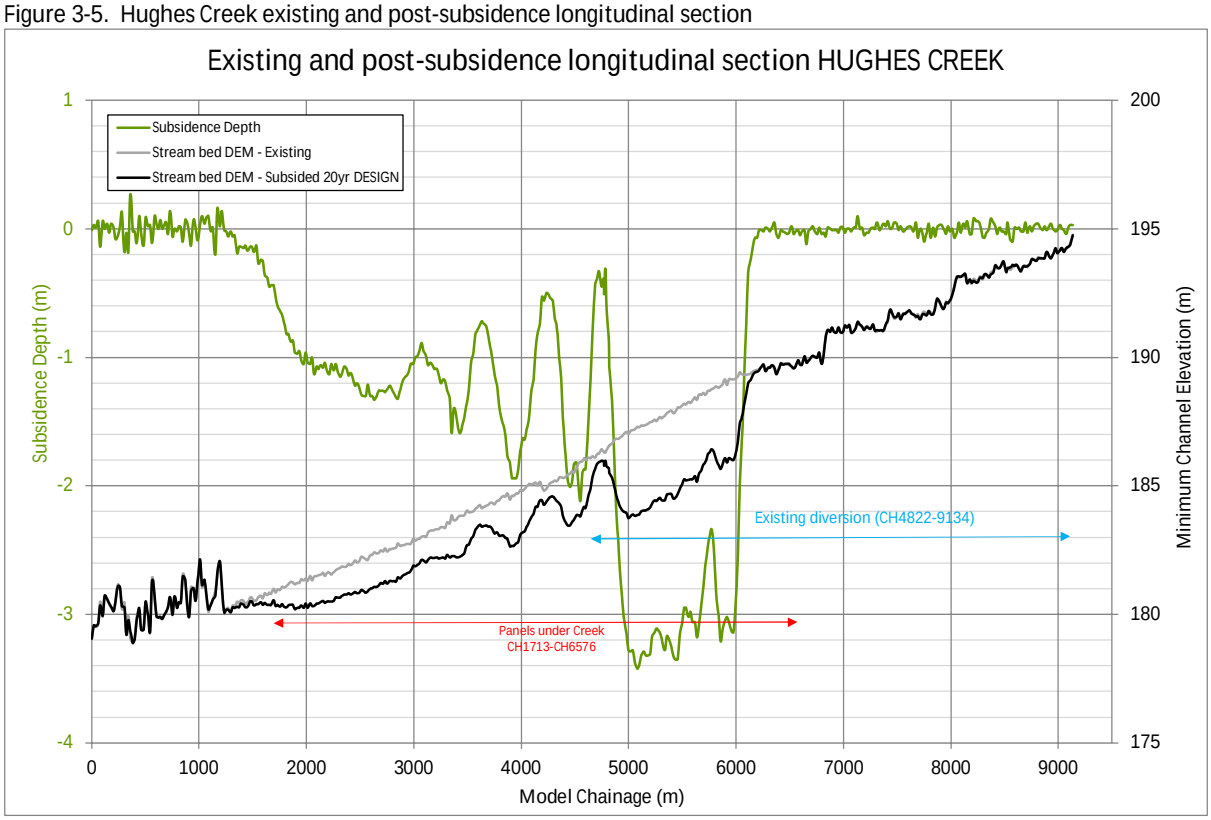


3.2.3 Hughes Creek

The longitudinal profile of Hughes Creek indicates that approximately 4.9 km of the waterway will be affected by six subsided panels. The Hughes Creek diversion makes up approximately 1.75 km of the affected reach. Hughes Creek will not be directly impacted by subsidence until sometime between year 4 and year 6. The reach to be subsided currently has a similar bed grade to the upstream reach, though steeper than the 1.2 km downstream reach, prior to the Boomerang Creek confluence (Figure 3-5). Subsidence typically exceeds 1 m depth through the subsidence reach, exceeding 3 m in the upstream part of the reach where the panel is aligned with the creek.

The transition from the upstream reach into the subsidence reach where the channel bed will subside by more than 3 m represents the highest risk of instability developing in the channel. In the absence of in-situ bedrock controls this will initiate channel bed deepening to propagate upstream that will in turn destabilise channel banks. The subsided zone will act as a sink for sediment delivered from upstream.

Figure 3-5. Hughes Creek existing and post-subsidence longitudinal section



3.2.4 Hydraulic modelling results

1D hydraulic modelling has been undertaken to quantify the geomorphic assessment of subsidence impacts during the 2-year ARI and 50-year ARI events. Models of the subsided surface have been created from the DTM provided for an intermediate timeframe, Year 10, and end of mine timeframe, Year 20. The models do not use eroded surfaces or sequential mine progression. Reach average values for shear stress, stream power and velocity have been estimated for each stream, under both subsidence scenarios and both flow events.

3.2.4.1 Boomerang Creek

Modelling predicts that there will be minor parameter increases in the upstream reach, moderate increases in the subsidence reach and moderate decreases in the downstream reach for the Year 20 subsidence scenario (Table 3-2). Parameter changes are the same for the Year 10 subsidence scenario except for the subsidence reach where parameters are predicted to decrease slightly. Stream power and shear stress are subject to the greatest change, likely due to increased bed slope resulting from subsidence. Velocity is barely affected.

Reach-average values largely satisfy Bowen Basin diversion criteria in the upstream and subsidence reaches but the values in the downstream reach are well below criteria. Parameter values are predicted to exceed the guidelines at points immediately upstream of the subsided panels due to the sudden drop in the creek bed surface. This will lead to localised erosion as the bed seeks to regrade. The predicted reduction in already low parameter values in the downstream reach is likely to increase aggradation.

3.2.4.2 Plumtree Creek

Modelling predicts a different response than that for Boomerang Creek. The upstream reach shows a minor increase in shear stress and a moderate increase in stream power for both Year 10 and Year 20 subsidence scenarios. In the subsidence reach, there is a minor decrease in shear stress and minor increase in stream power for both subsidence scenarios, though the changes is greatest for the Year 10 scenario (Table 3-2). Velocity changes are negligible in the upstream and subsidence reaches. The downstream reach is likely to see moderate to large declines in shear stress, stream power and velocity with the largest declines occurring in the Year 20 scenario.

Reach-average values remain below Bowen Basin diversion criteria. The increase in values upstream of subsidence occurs because of localised bed steepening and may instigate incision and localise erosion. The

reduction in values in the subsidence reach will increase the likelihood of aggradation. The predicted reduction in already low parameter values in the downstream reach is likely to increase aggradation.

3.2.4.3 Hughes Creek

Modelling predicts minor increases in shear stress and velocity and moderate to large increases in stream power in the upstream reach for both subsidence scenarios, with the greatest change in the Year 20 scenario (Table 3-2). Through the diversion and natural subsidence reaches, shear stress is predicted to decrease slightly with stream power to increase substantially for the Year 20 subsidence scenario. Modelling of the Year 10 scenario predicts negligible change in shear stress and velocity but large increases in stream power for the diversion subsidence reach, whereas all parameters are predicted to decrease in the natural subsidence reach. This is because the natural subsidence reach is not directly impacted by subsidence until after Year 10. In the downstream reach, shear stress and stream power are predicted to decrease slightly. Velocity changes are negligible through the downstream reach.

Reach-average stream power is well above the Bowen Basin diversion criteria in the diversion subsidence reach for both scenarios and exceeds diversion criteria in the upstream and natural subsidence reaches for the Year 20 scenario. This elevation in stream power is due to the 3.4 m drop in stream bed elevation at the first panel subsidence zone and is potentially exacerbated by the right-angle corner in the existing creek diversion. The transition from the upstream reach into the subsided surface presents a potential risk of instability developing in the channel. Management measures specific to this are discussed further in Section 4.

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Table 3-2. Reach average values for key hydraulic parameters for pre- and post-subsidence scenarios

	Shear stress (N/m²)		Stream power (N/m.s)		Velocity (m/s)	
	2yr	50yr	2yr	50yr	2yr	50yr
Bowen Basin diversion criteria	<40	<80	35-60	80-150	<1.0 (no veg)	<2.5
					<1.5 (with veg)	
Boomerang Creek						
Upstream reach	28.6 28.4 (28.0)	40.7 40.1 (39.9)	54.8 54.3 (52.9)	94.3 92.6 (91.7)	1.6 1.6 (1.6)	2.0 2.0 (2.0)
Subsidence reach (1,000m)	27.3 20.5 (24.0)	38.4 26.0 (30.2)	49.3 32.4 (41.1)	86.9 46.2 (57.4)	1.6 1.4 (1.5)	2.0 1.7 (1.8)
Downstream reach	6.5 8.1 (8.1)	7.6 10.7 (10.7)	6.3 9.5 (9.5)	8.5 15.6 (15.6)	0.6 0.7 (0.7)	0.7 0.9 (0.9)
Plumtree Creek						
Upstream reach	21.5 21.5 (18.5)	23.2 23.2 (20.2)	32.8 32.8 (25.8)	37.7 37.7 (30.1)	1.4 1.4 (1.3)	1.4 1.4 (1.4)
Subsidence reach (2,935m)	14.6 13.4 (15.4)	16.1 14.7 (17.0)	20.1 18.0 (19.8)	23.3 20.5 (23.1)	1.1 1.1 (1.2)	1.2 1.1 (1.3)
Downstream reach	5.2 9.1 (8.9)	5.4 9.2 (9.1)	3.6 8.3 (8.1)	3.8 8.5 (8.2)	0.6 0.8 (0.8)	0.6 0.8 (0.8)
Hughes Creek						
Upstream reach	44.9 41.1 (39.2)	66.1 55.0 (51.1)	122.1 91.4 (85.3)	231.4 153.1 (137.2)	2.1 2.1 (2.0)	2.8 2.6 (2.6)
Subsidence reach – diversion (1,754m)	42.3 41.9 (43.9)	72.2 72.0 (73.3)	140.6 139.8 (101.1)	301.0 300.5 (234.6)	1.9 1.9 (2.2)	2.8 2.8 (3.0)
Subsidence reach – natural (3,099m)	34.0 30.0 (34.9)	44.2 39.0 (47.9)	133.9 60.1 (72.4)	376.0 96.4 (124.5)	1.9 1.8 (1.9)	2.3 2.2 (2.4)
Downstream reach	26.9 28.1 (28.3)	43.1 45.0 (44.9)	53.1 55.8 (56.9)	119.6 126.1 (125.4)	1.5 1.5 (1.5)	1.9 2.0 (2.0)

Year 20 SUBSIDED – bold
Year 10 SUBSIDED – normal text
Existing conditions – (parenthesis)

3.2.4.4 Predicted changes in hydraulic parameters

The predicted change in key hydraulic parameters of shear stress, stream power and velocity, resulting from subsidence, is shown graphically for each of the waterways in Figure 3-6 to Figure 3-11. The magnitude and

percentage of change between existing conditions and the Year 20 subsidence scenario are presented for the maximum, average and median values for the subsidence reach of each stream in Table 3-3.

Boomerang Creek intersects the northern end of the panels where subsidence causes an increase in hydraulic parameters as flows enter the zone of subsidence. Parameters decrease through the second panel as the depth of subsidence decreases and again as flows exit the zone of subsidence. The large maximum changes are typically isolated peaks through the subsidence reach and shortly upstream, indicating some risk of incision developing in the subsidence and upstream reaches.

Plumtree Creek traverses through the north end of the northern longwall panels in an easterly direction. Minor subsidence has little effect on hydraulics. Estimated flow rates for Plumtree are quite small for the 2-year and 50-year ARI events, because mining activities upstream have substantially reduced the contributing catchment. The capacity of the existing creek can buffer the change in hydraulic parameters resulting from subsidence. The lack of upstream catchment will however reduce the recovery of bed subsidence due to reduced supply of sediment.

Flowing in a north-easterly direction, Hughes Creek traverses across the centre of most northern panels. The upper section of Hughes creek has an existing diversion of which almost 1.8 km is located above the underground panels. Just over 1,400 m of the diversion is located directly above the first panel and runs north/south in line with the orientation of this panel. The stream bed elevation drops significantly as this panel is subsided causing a sharp increase, then decrease in hydraulic values. As the creek continues downstream hydraulic parameters vary as it crosses the remaining pillars and panels, returning to pre-subsidence values downstream of the subsidence zone. The initial drop into the first subsidence panel poses the largest risk to developing channel incision that would propagate into the upstream reach.

For each stream, subsidence is predicted to cause the greatest change to hydraulic parameters in the subsidence reach and immediately upstream. The implications of these changes on sediment transport and channel stability are discussed in Sections 3.2.5 and 3.2.6.

Figure 3-6. Predicted change in hydraulic parameters post-subsidence for Boomerang Creek 2-year ARI flow

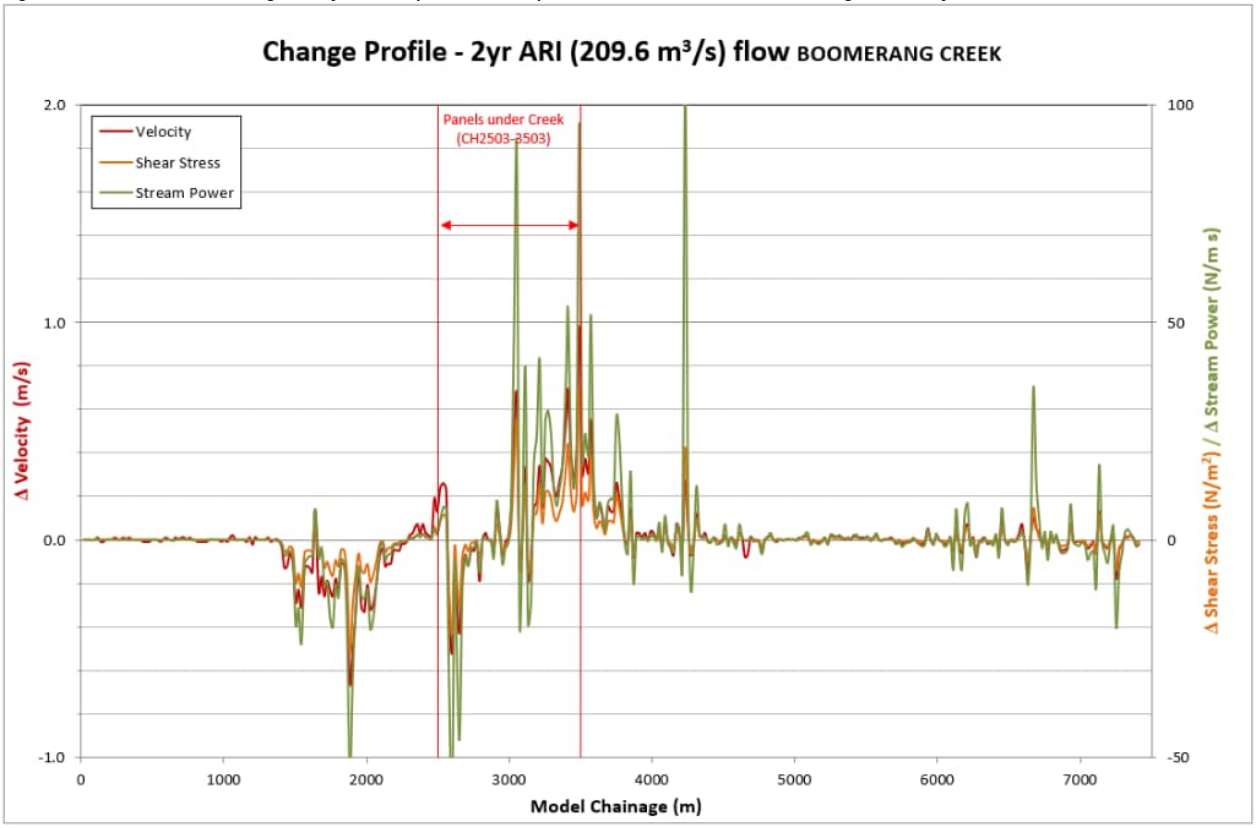


Figure 3-7. Predicted change in hydraulic parameters post-subsidence for Boomerang Creek 50-year ARI flow

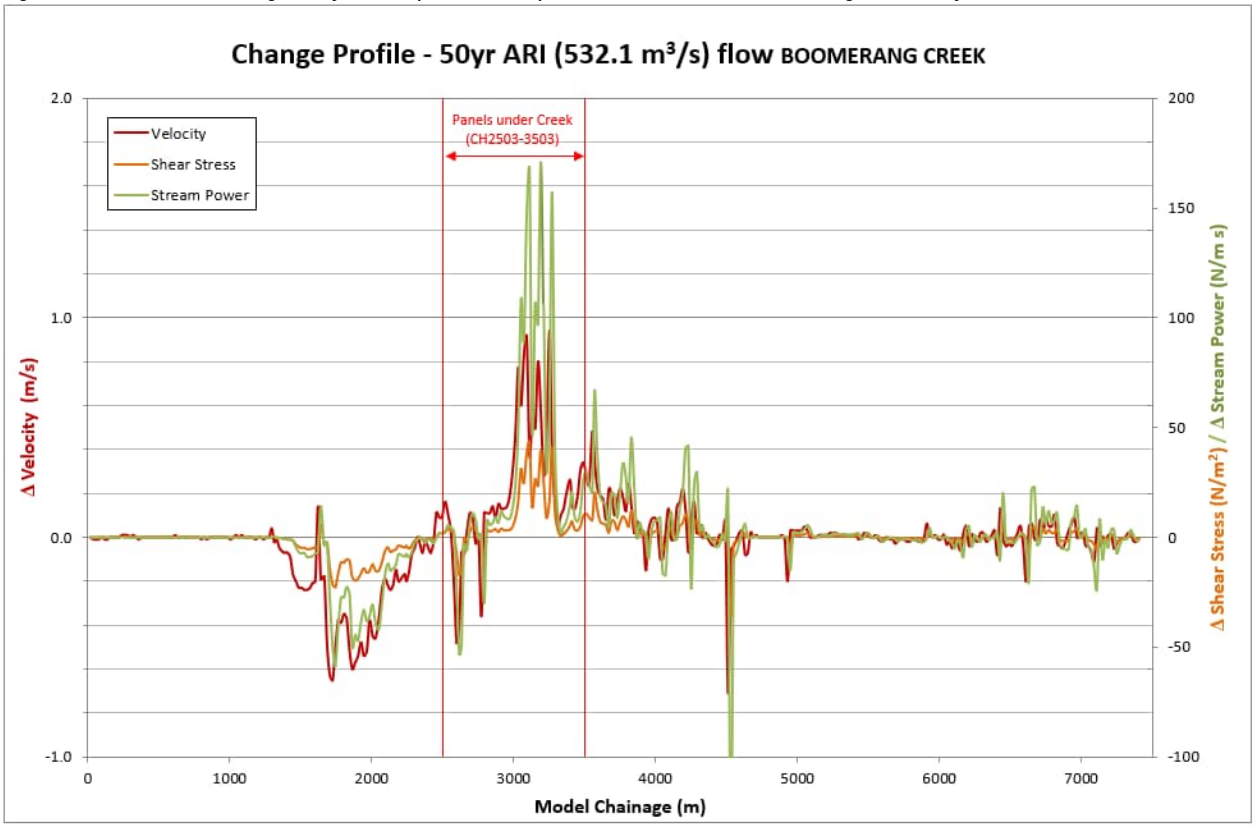


Figure 3-8. Predicted change in hydraulic parameters post-subsidence for Plumtree Creek 2-year ARI flow

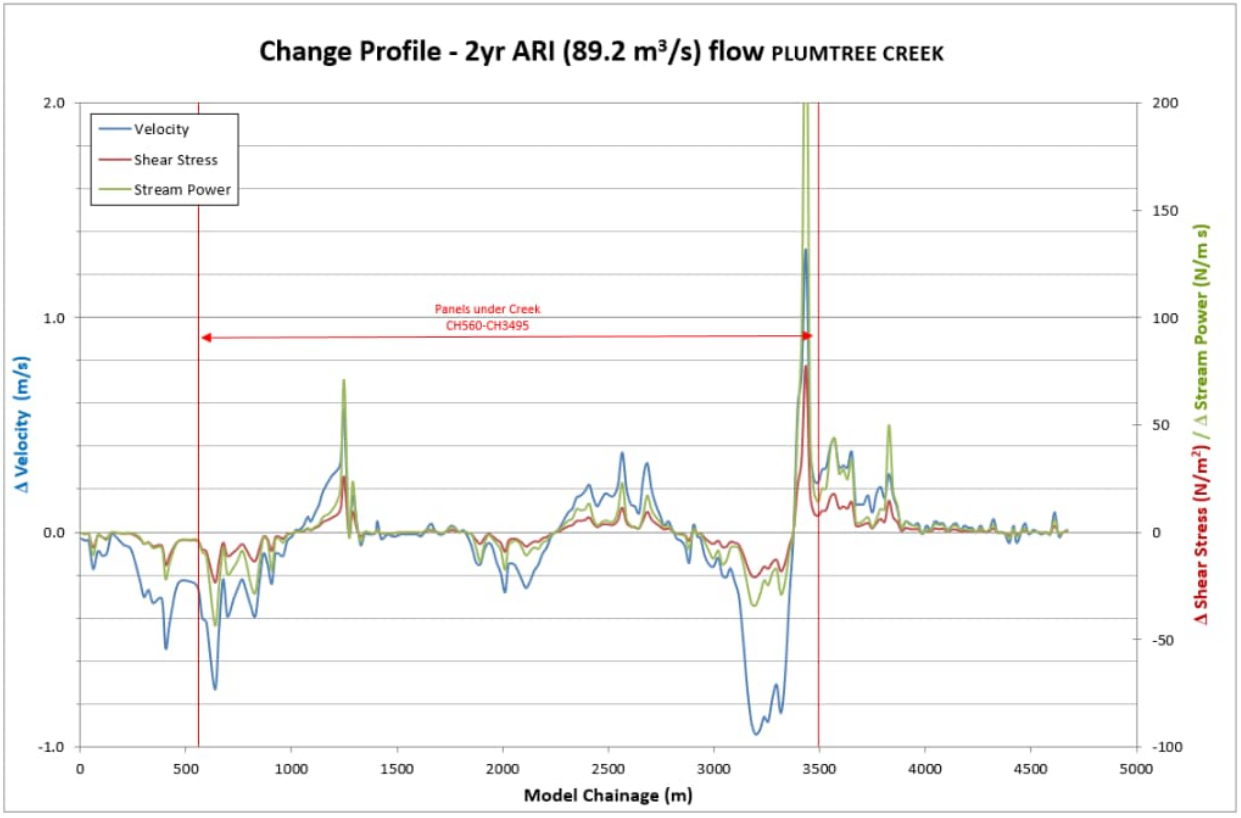


Figure 3-9. Predicted change in hydraulic parameters post-subsidence for Plumtree Creek 50-year ARI flow

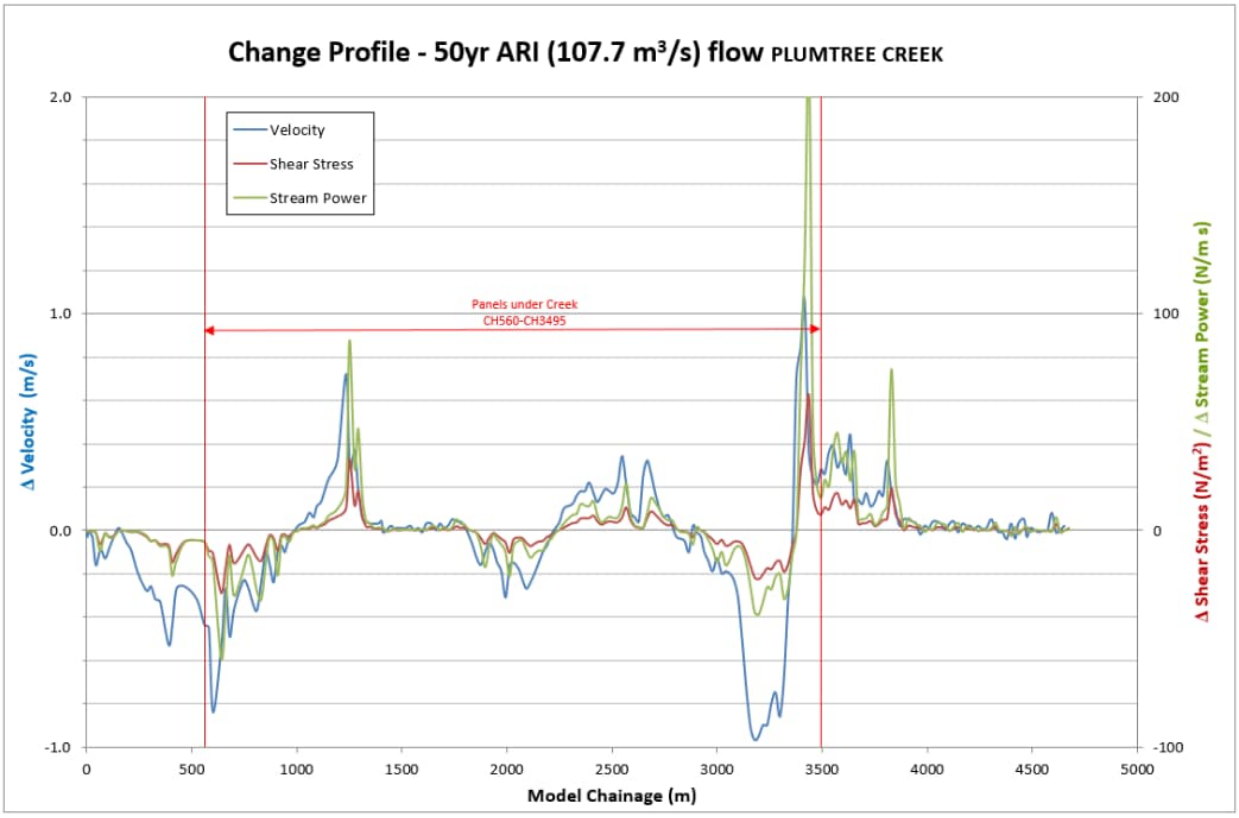


Figure 3-10. Predicted change in hydraulic parameters post-subsidence for Hughes Creek 2-year ARI flow

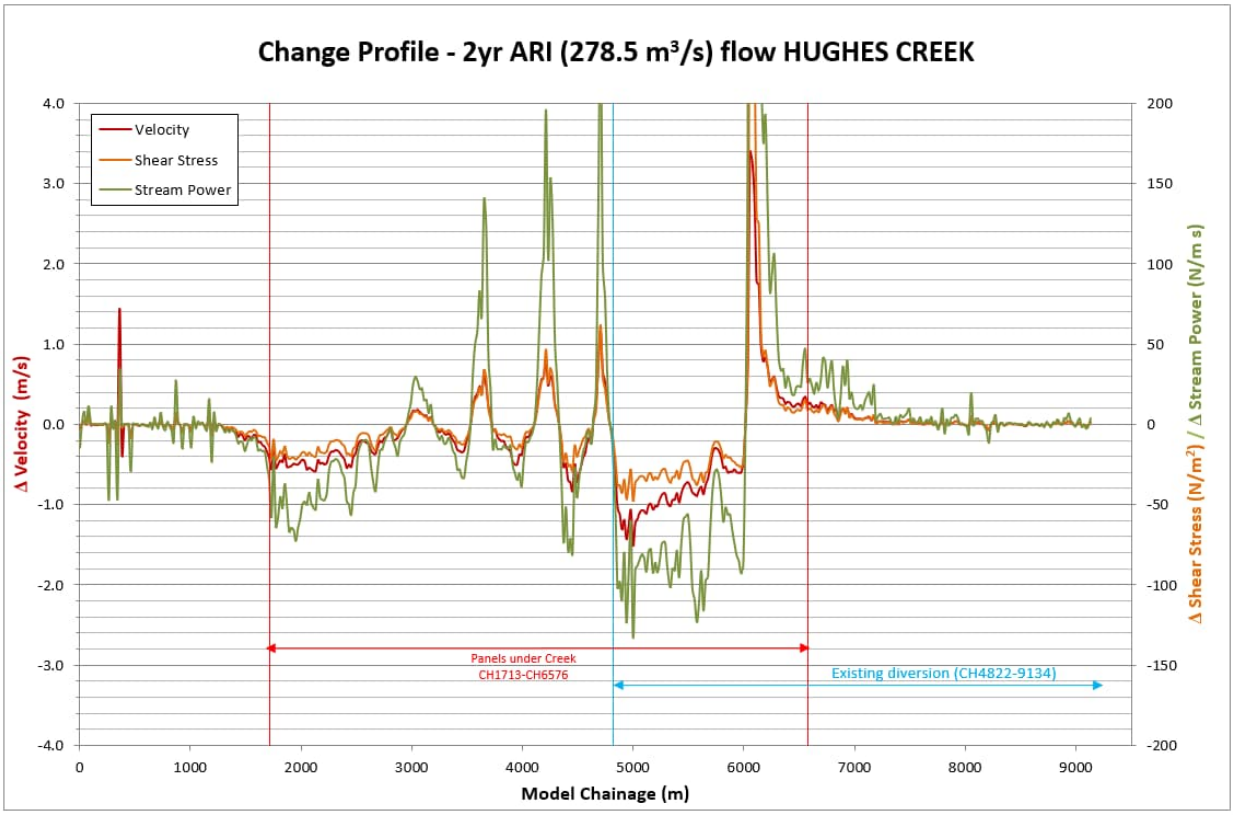


Figure 3-11. Predicted change in hydraulic parameters for post-subsidence for Hughes Creek 50-year ARI flow

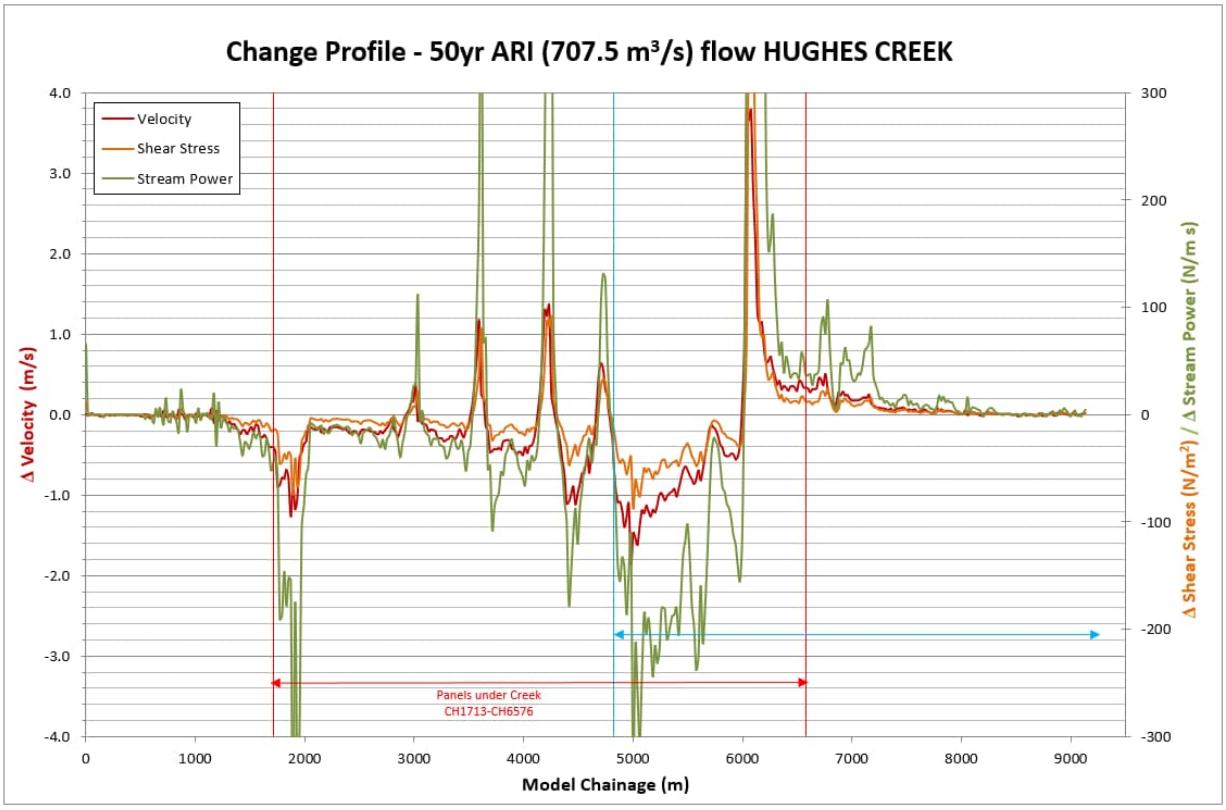


Table 3-3. Predicted change in hydraulic values, within the subsided reaches, when compared to existing conditions for 2-year and 50-year ARI flows – Year 20 subsidence scenario

Boomerang Creek	Velocity (m/s)		Shear Stress (N/m^2)		Stream Power (N/m.s)	
			2yr ARI flow			
Maximum change	0.98	75%	34.83	205%	95.9	434%
Average change	0.12	11%	3.23	25%	8.23	48%
Median change	0.09	5%	1.86	7%	3.63	13%
			50yr ARI flow			
Maximum change	0.9	46%	43	105%	170.8	199%
Average change	0.21	12%	8.20	25%	29.49	44%
Median change	0.14	9%	3.46	17%	9.13	27%

Plumtree Creek	Velocity (m/s)		Shear Stress (N/m^2)		Stream Power (N/m.s)	
			2yr ARI flow			
Maximum change	1.3	77%	77.1	256%	272.2	533%
Average change	-0.07	-5%	-0.88	-3%	0.23	3%
Median change	-0.02	-2%	-0.43	-3%	-0.63	-4%
			50yr ARI flow			
Maximum change	-0.97	-65%	62.3	175%	219.2	332%
Average change	-0.07	-4%	-0.82	-1%	0.19	5%
Median change	0.00	0%	0.06	0%	0.08	1%

Hughes Creek	Velocity (m/s)		Shear Stress (N/m^2)		Stream Power (N/m.s)	
			2yr ARI flow			
Maximum change	3.4	135%	306.3	573%	1990.7	1477%
Average change	-0.21	-10%	-3.23	-11%	10.25	0%
Median change	-0.30	-17%	-8.82	-34%	-21.10	-45%
			50yr ARI flow			
Maximum change	3.8	118%	373.1	466%	3116.1	1137%
Average change	-0.23	-9%	-5.02	-11%	11.65	-4%
Median change	-0.25	-11%	-9.49	-23%	-28.46	-31%

3.2.5 In-channel sediment transport assessment

Bed sediment transport capacity was calculated using the HEC-RAS hydraulic model for a range of flows up to bank full. Modelling was undertaken for both the Year 10 and Year 20 subsidence scenarios. Sediment transport capacities are generally predicted to reduce by greater than an order of magnitude through subsidence troughs for each of the waterways (Figure 3-12 to Figure 3-14).

Figure 3-12. Bed material transport capacities for 100 m³/s flows for Boomerang Creek

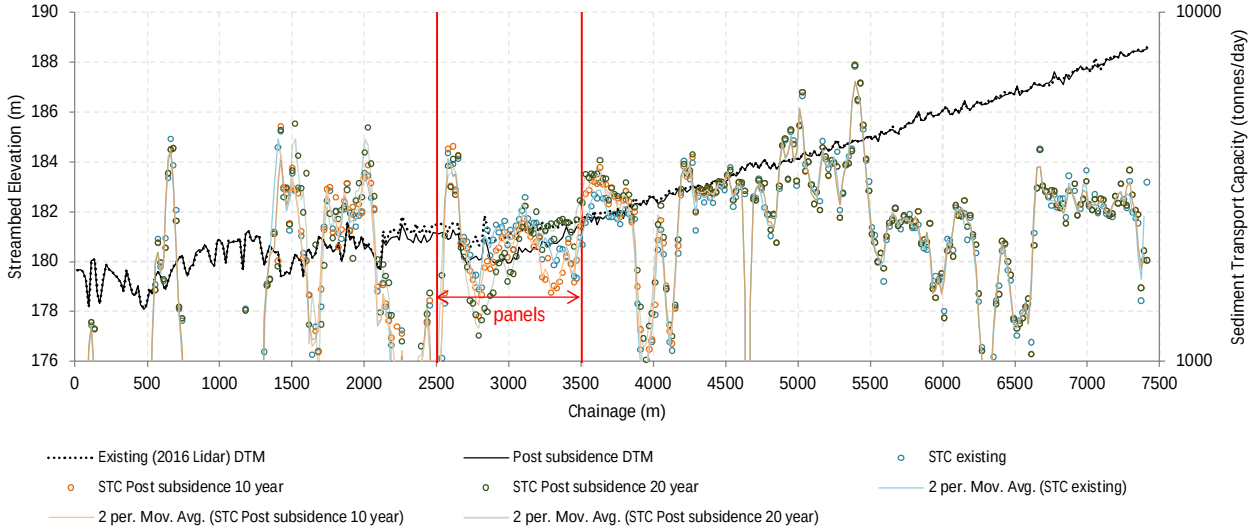


Figure 3-13. Bed material transport capacities for 100 m³/s flows for Plumtree Creek

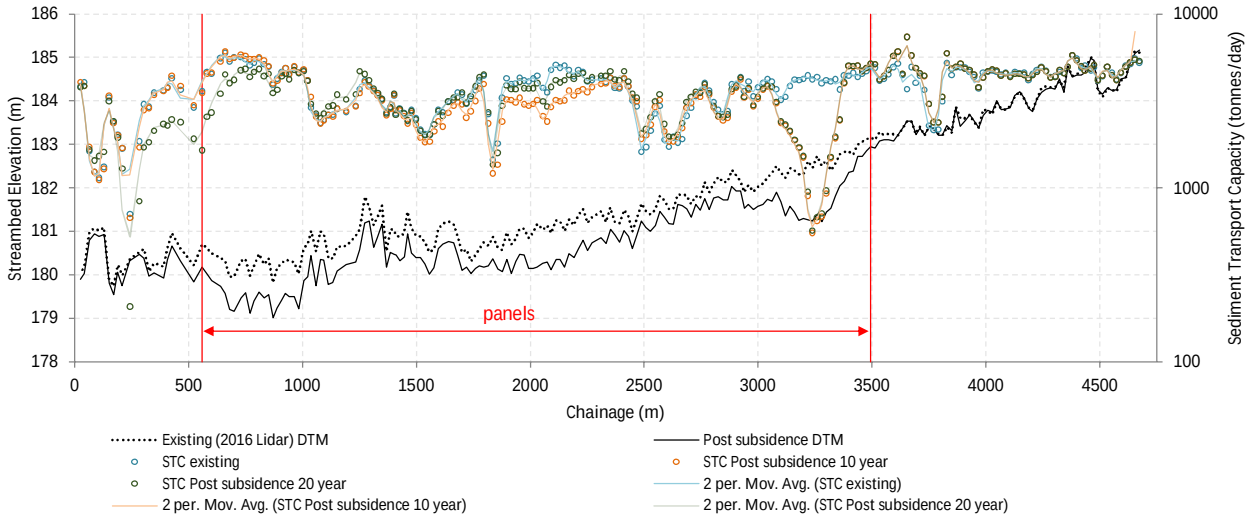
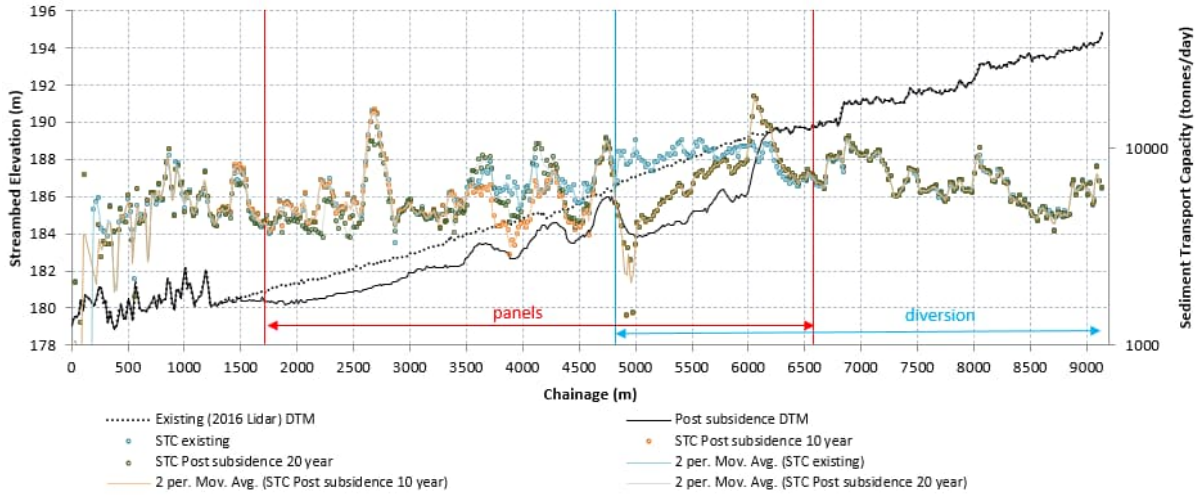


Figure 3-14. Bed material transport capacities for 100 m³/s flows for Hughes Creek

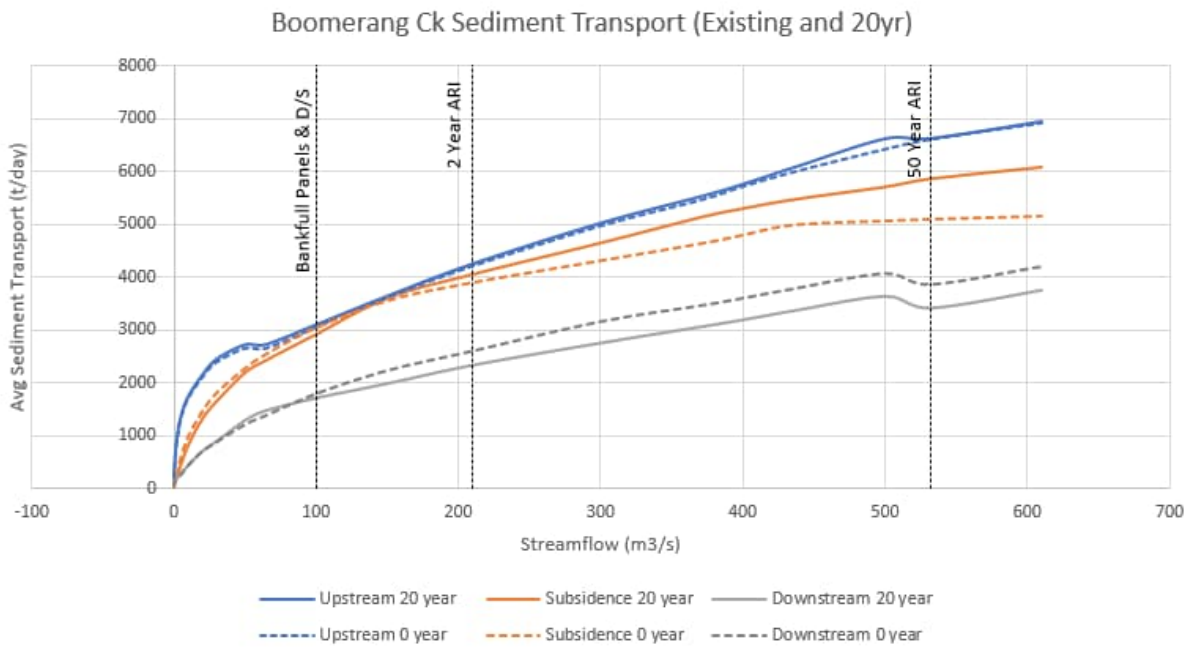


3.2.5.1 *Sediment transport capacity*

The average sediment transport capacity (STC) and its relationship to stream flow, pre- and post-subsidence, has been derived for each stream over a range of flows. Comparisons of existing conditions and the Year 20 subsidence scenario are presented below for each stream.

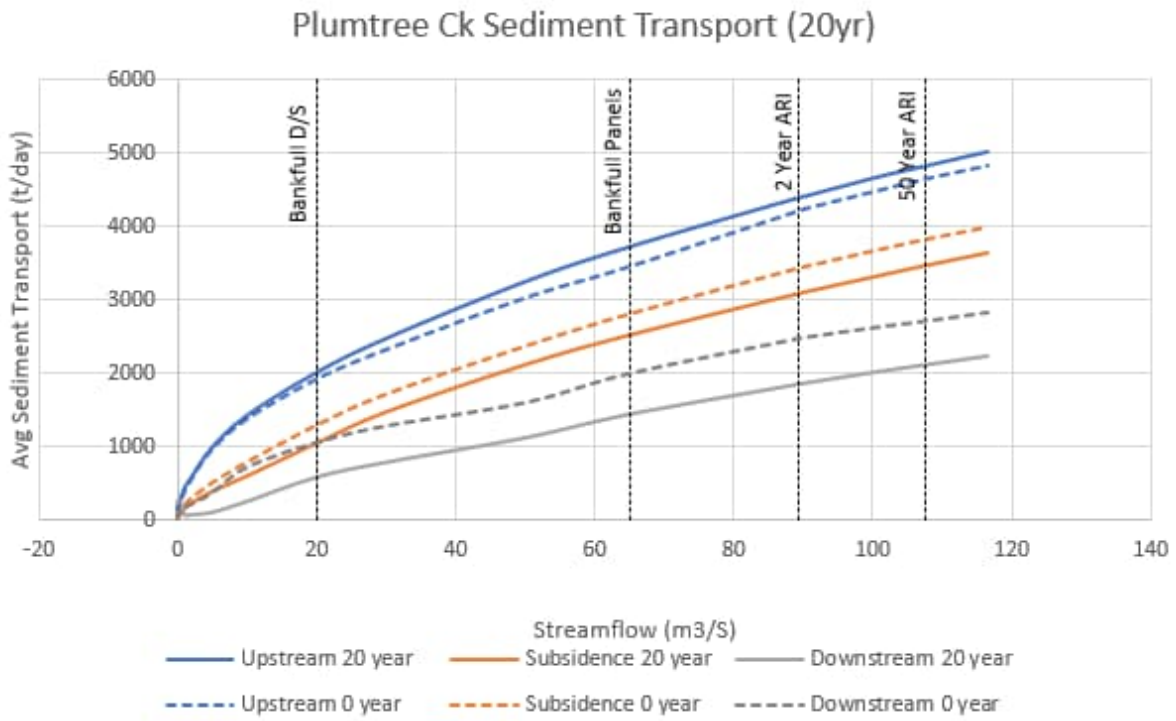
In Boomerang Creek, subsidence results in a decrease in STC in the downstream reach, a moderate increase in STC through the diversion, and barely any change in the upstream reach (Figure 3-15). The changes increase with streamflow.

Figure 3-15. Bed sediment transport capacity (STC) rating curves for Boomerang Creek using the Toffaletti function



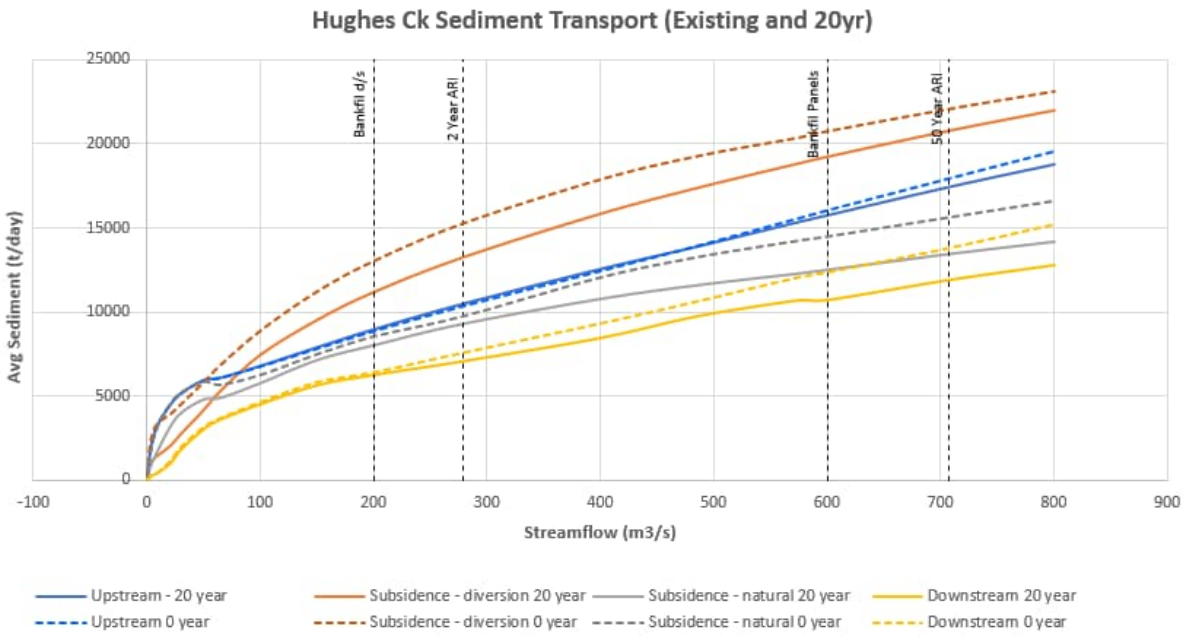
For Plumtree Creek, subsidence causes a moderate decrease in STC through the downstream reach, a slight decrease in STC through the subsidence reach and a slight increase in STC upstream of subsidence (Figure 3-16). The changes increase with streamflow.

Figure 3-16. Bed sediment transport capacity (STC) rating curves for Plumtree Creek using the Toffaletti *function*



The Hughes Creek diversion forms part of the upstream reach and the subsidence reach of the model. Due to differences in response, the diversion through the subsidence zone has been displayed as a separate STC rating curve (orange) in Figure 3-17. Subsidence causes minor to moderate reductions in STC through each reach, though the changes in the upstream reach are very minor. In the upstream reach, modelling predicts small increases in STC for low to moderate flows and a decrease in STC for larger flows. The diversion reach through the subsidence zone has a substantially larger STC than the other reaches and, though it will be reduced by subsidence, it will remain much greater than the remainder of the channel through the subsidence zone.

Figure 3-17. Bed sediment transport capacity (STC) rating curves for Hughes Creek using the Toffaletti function



3.2.6 Summary of impacts

Subsidence is predicted to cause changes to channel hydraulics and sediment transport dynamics. Across substantial portions of the intersect of the mine plan and waterways this will mean increased potential for deposition due to subsidence-lowered gradients. However, at the upstream edge of the mine plan where the waterways will be substantially steepened, the potential for erosion will increase following subsidence. Major instability may develop in the Hughes Creek diversion where it will be subject to a 3 m drop into the first panel it intercepts. This will cause, in the absence of in situ bedrock, channel bed deepening and subsequent bank erosion.

Infilling of the stream bed will occur progressively as the longwall panels are subsided. In general, the sediment rating curves show the bed sediment transport capacity increases with stream flow. Upstream bed sediment transport capacities are higher than the downstream sediment transport capacities in Boomerang Creek and Plumtree Creek, which will lead to increased aggradation downstream. In contrast, the subsidence diversion reach in Hughes Creek has a higher STC than the upstream reach, which may contribute to the development of instabilities in the upstream reach.

Waterways will also be subject to local incision and bank erosion processes over pillar zones between panels in the first flow events until the sand bedload infills and re-establishes the near constant sand bed grade that is currently present. The time it takes for the infilling to occur is dependent on the mining sequence relative to flows, i.e. the number of panels that have subsided determines the size of the subsidence depression relative to the transport capacity of the flow. Sediment supply to cause this infilling is unlikely to be an issue given the elevated rates of erosion present in the upstream catchments. Infilling of the pools created by subsidence eliminates one of the positive environmental impacts: creation of aquatic habitat in a system largely devoid of aquatic habitat. However, as observed at other longwall operations in the Bowen Basin, the elevated sediment supply eventually overwhelms the pools.

Other areas with potential for local instabilities are on the floodplain where minor flow paths or overland flow drop into subsidence depressions. The locally steep terrain may cause incision and gully development at these locations. A comparison of pre- and post-subsidence mapping of flow paths determined using CatchmentSIM has enabled the identification of several locations that may be at risk of instabilities developing (shown in red circles on Figure 3-18).

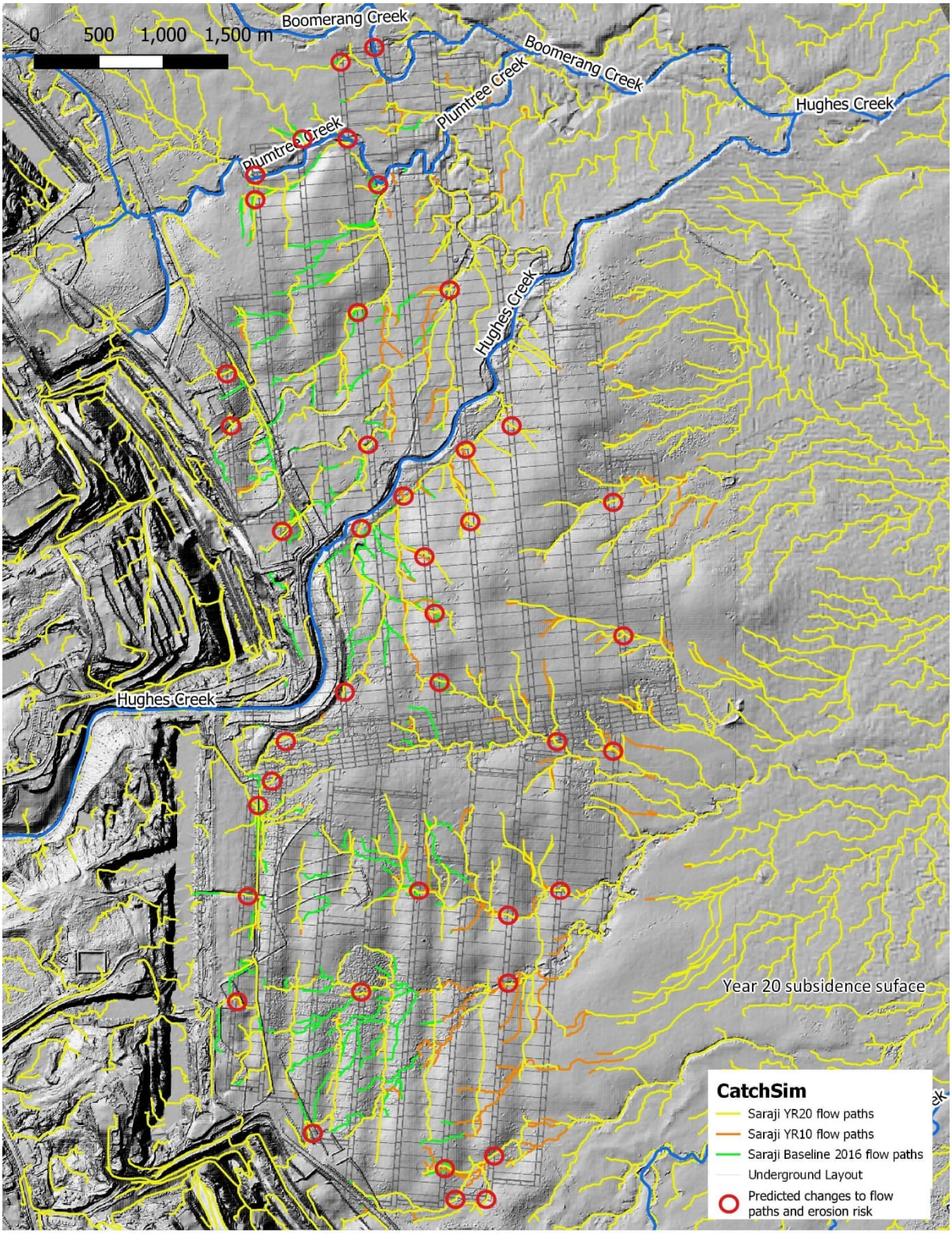
Downstream of the mine plan, Hughes and Boomerang Creek will potentially be subject to reduced bedload for a period, due to capture by subsidence depressions, which would elevate the risk of bank erosion (similar to the clear water effect of a weir). The likelihood of this occurring is related to the timing of flows and mining and the infilling through the panels. Erosion would persist until the bedload overwhelms the subsidence depression upstream. The response of Hughes Creek is likely to produce some impact downstream of the mine footprint through to Boomerang Creek confluence for a period of years to possibly decades. This impact may also provide positive outcomes in the form of pool creation.

Subsidence cracks are likely to develop in the soils present in the vicinity of Hughes Creek where some relief is already present and differential subsidence of pillar to panel occurs. These have the potential to enlarge where lighter textured soils associated with the *Eucalyptus populnea* vegetation communities (e.g. Regional Ecosystem 11.3.2) are present and runoff is concentrated to the crack, such as around tracks.

More broadly across the Project Site, areas of low relief and high sand content that develop cracks are not likely to show crack enlargement and a self-battering process of crack faces is likely to occur based on observation at other sites in the Isaac River catchment

Management of the identified types of impacts is successfully undertaken at other underground mines in the area.

Figure 3-18. Predicted changes to flow paths and erosion risk areas post-subsidence



Predicted changes to flow paths and erosion risk areas post-subsidence

alluvium

Project Number 221028
Date 9 December 2022
Projection GDA94 Zone 55
Prepared by Vanessa Warrington

3.3 Predicted impacts to water quantity

Assessment of potential impacts to surface water utilises two-dimensional hydrodynamic modelling to identify changes to flooding extents, depths, velocities and volumes as a result of predicted subsidence.

3.3.1 2D hydraulic modelling

2D Hydraulic modelling was undertaken to assess the flood behaviour for the 39%, 2%, 1% and 0.1% AEP design flood events under baseline and subsided conditions (Year 10 and Year 20). A 2D model was developed to encompass the area of predicted subsidence using TUFLOW software.

The model extends beyond the predicted extent of subsidence to capture any impact to conveyance and storage within the catchment and floodplain outside the extent of subsidence. The model used inflow hydrographs generated from the RORB hydrologic model to represent flow generated in the upstream catchment and direct rainfall to represent the rainfall and runoff within the model extent.

A comparison of pre- and post-subsidence modelling demonstrates expected response to subsidence (Figure 3-19 to Figure 3-22). Ponding within the subsided panels is expected to occur in all panels and in all events however the overall extent of flooding is unchanged from pre-subsidence conditions. Noticeable changes in flood extent do occur in the 1% AEP event where the extent of flooding on the left bank of Hughes Creek is significantly expanded post-subsidence within LW103-105. Ponding within the extents of the southern panels is clear in the model results however this has not resulted in significant changes in peak flood levels and extents on the drainage lines south of Hughes Creek.

In the 0.1% AEP event, the largest increases in peak flood depth were seen within the Hughes Creek floodplain in LW102 with increases up to 3.1 m. Within the channel itself, increases of up to 2.2 m were seen in the model results. The increased steepness of Hughes Creek at the edge of LW102 resulted in localised reductions in peak depth of 2.5 m with smaller reduction in depth propagating upstream for 1 km.

At the downstream extent of Plumtree Creek, the increases in peak depth are consistently 500-600 mm and located in the northern limits of LW105-106.

Figure 3-24 shows the extent of residual ponding in the 0.1% AEP event. The western panels are expected to have the greatest depth and extent of residual ponding – in particular, LW201, 202, 203, 204 and LW101 and 102. Within these panels, ponding is shown to a depth of over 3 m in some instances though more typically depths of 1-2 m are seen.

Figure 3-19. Peak flood depth 39% AEP event pre-subsidence (left) and post-subsidence (right)

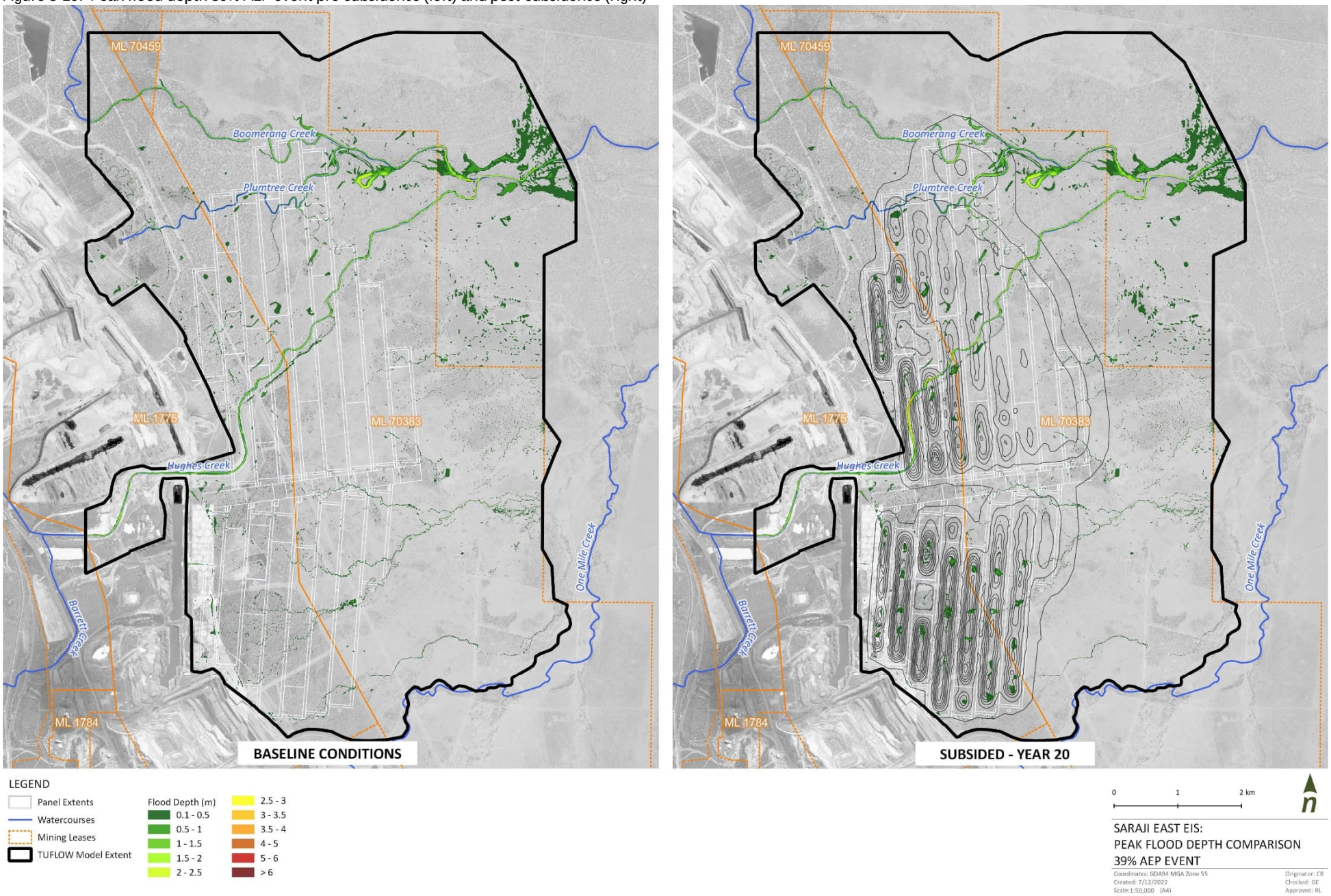


Figure 3-20. Peak flood depth 2% AEP event pre-subsidence (left) and post-subsidence (right)

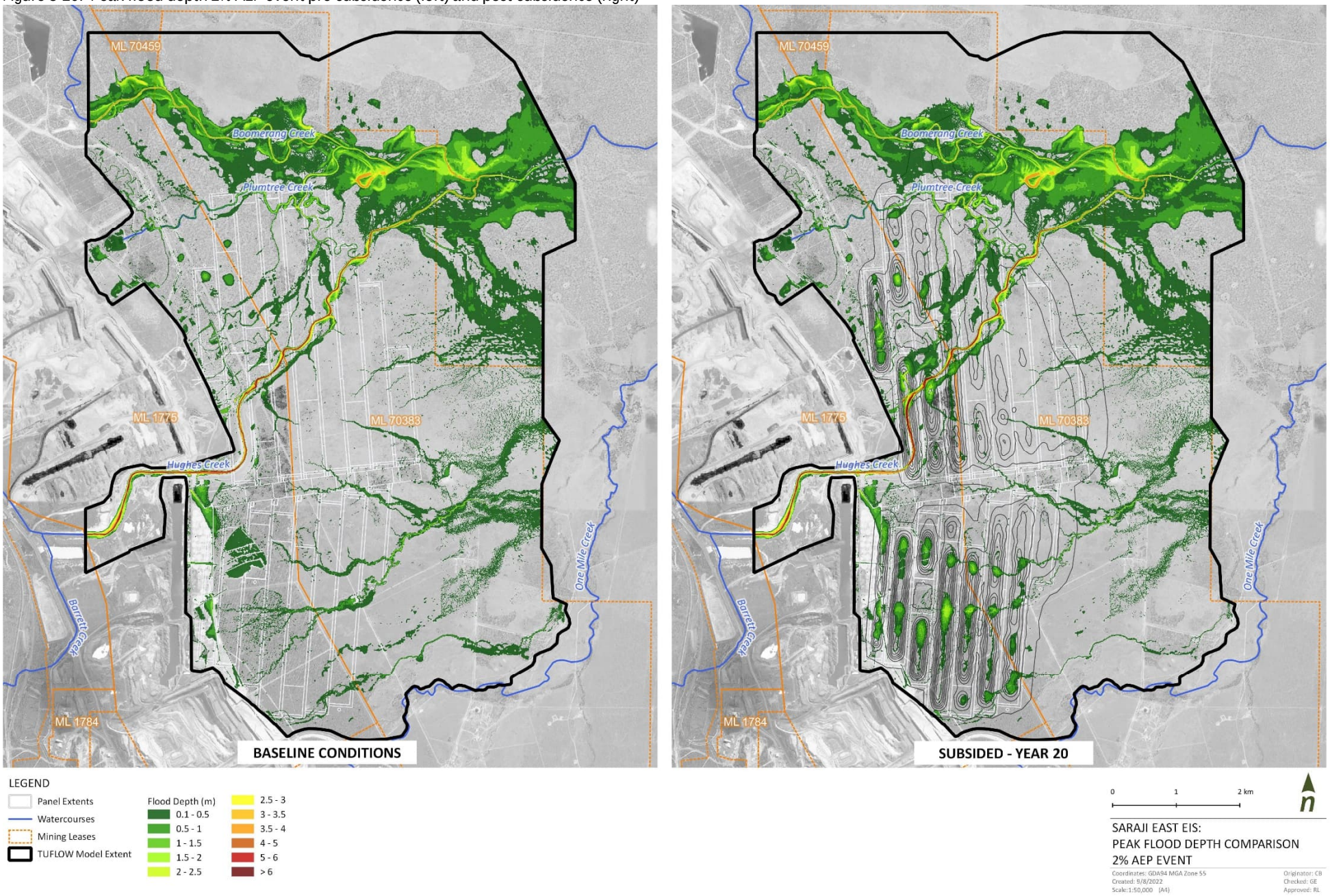


Figure 3-21. Peak flood depth 1% AEP event pre-subsidence (left) and post-subsidence (right)

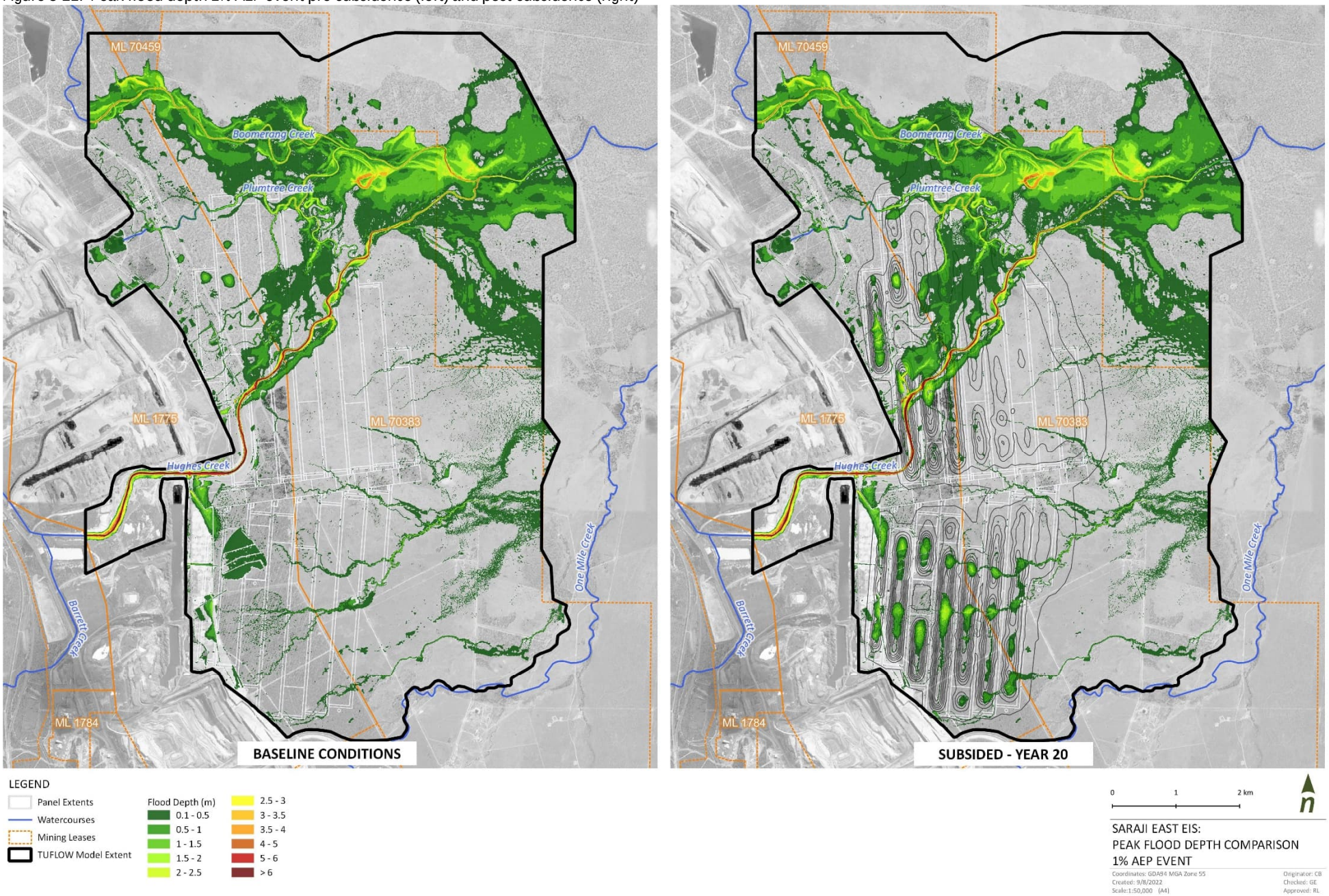
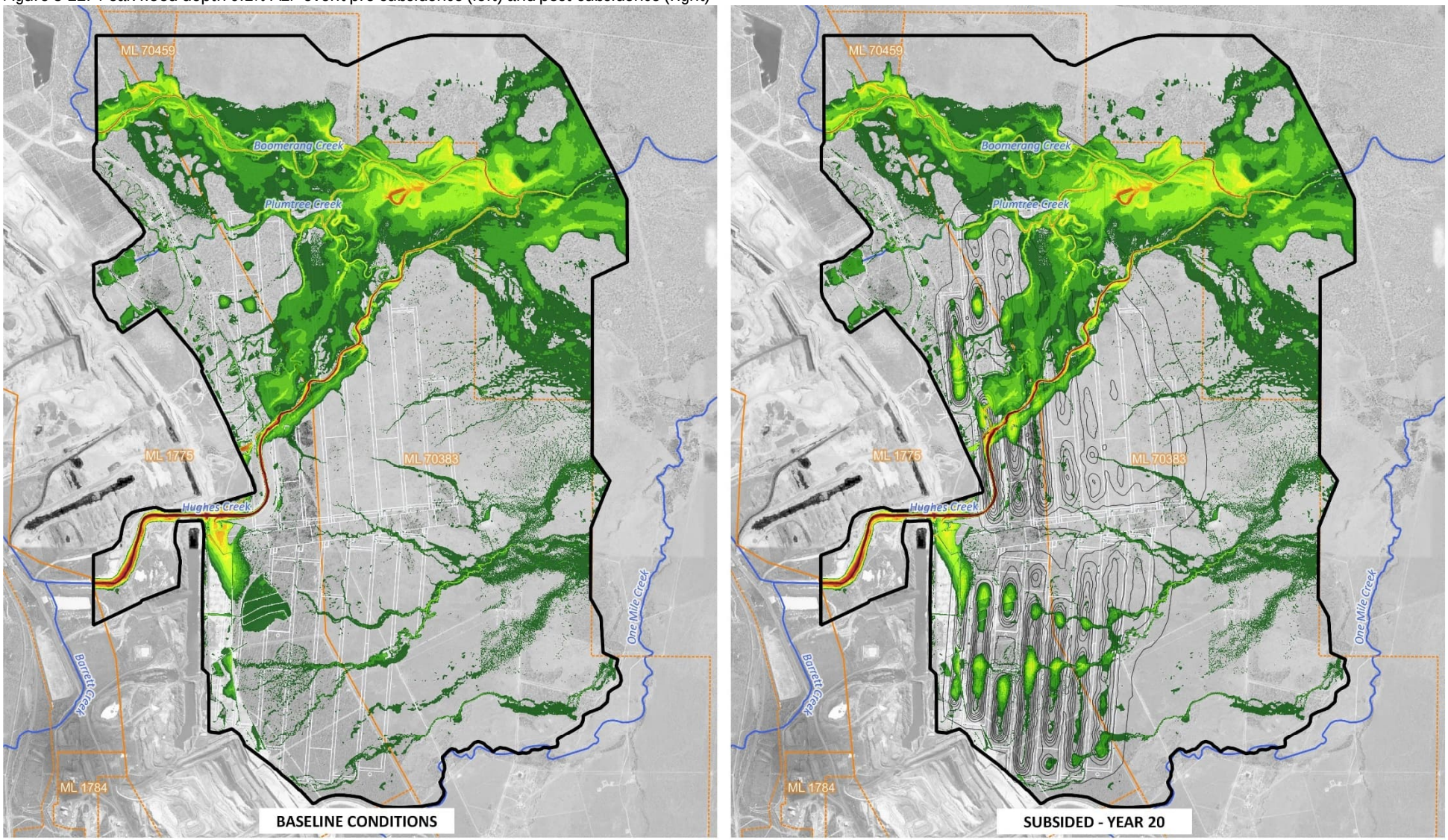


Figure 3-22. Peak flood depth 0.1% AEP event pre-subsidence (left) and post-subsidence (right)



LEGEND

- Panel Extents
- Watercourses
- Mining Leases
- TUFLOW Model Extent

Flood Depth (m)

- 0.1 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 2.5
- 2.5 - 3
- 3 - 3.5
- 3.5 - 4
- 4 - 5
- 5 - 6
- > 6

0 1 2 km

SARAJI EAST EIS:
PEAK FLOOD DEPTH COMPARISON
0.1% AEP EVENT

Coordinates: GDA94 MGA Zone 55
Created: 11/8/2022
Scale: 1:50,000 (A4)
Originator: CB
Checked: GE
Approved: RL

3.3.2 Changes to hydrograph at downstream model boundary

The subsided landscape will change flow behaviour from upstream to downstream of the Project Site. This will have different effects at different magnitude flow events. The general effects are a reduction in total flow through the site (Table 3-4), more notable for the most frequent and extreme events, and a delay in flow associated with the increased attenuation capacity of the subsided landscape (Figure 3-23 and Figure 3-24). The increase in floodplain volume captured by subsidence is significant, however, it represents a small proportion of water flowing through the site.

Residual pools will occur in parts of the landscape post-subsidence (without erosion or management intervention, which is not modelled) and will account for the attenuation and reduction in flow volume leaving the Project Site. The development of such pools in the system are generally seen as a positive environmental impact as most ephemeral wetlands or in-channel pooling has been lost to erosion and deposition. In time, subsidence pools in Boomerang Creek and Hughes Creek will be infilled with bedload sediment and ponded volumes on the floodplain will decrease.

Table 3-4. Estimated change in floodplain volume post-subsidence

	39% AEP	2% AEP	1% AEP	0.1% AEP
Floodplain Volume - Pre-Subsidence (m^3)	82,500	311,000	354,100	425,100
Subsidence Year 10				
Floodplain Volume (m^3)	144,700	691,900	818,500	1,035,500
% Change	+75%	+122%	+131%	+144%
Subsidence Year 20				
Floodplain Volume (m^3)	181,200	786,000	915,400	1,127,500
% Change	+120%	+153%	+159%	+165%

Figure 3-23. Pre- and post-subsidence hydrographs on Hughes Creek downstream of confluence (in channel)

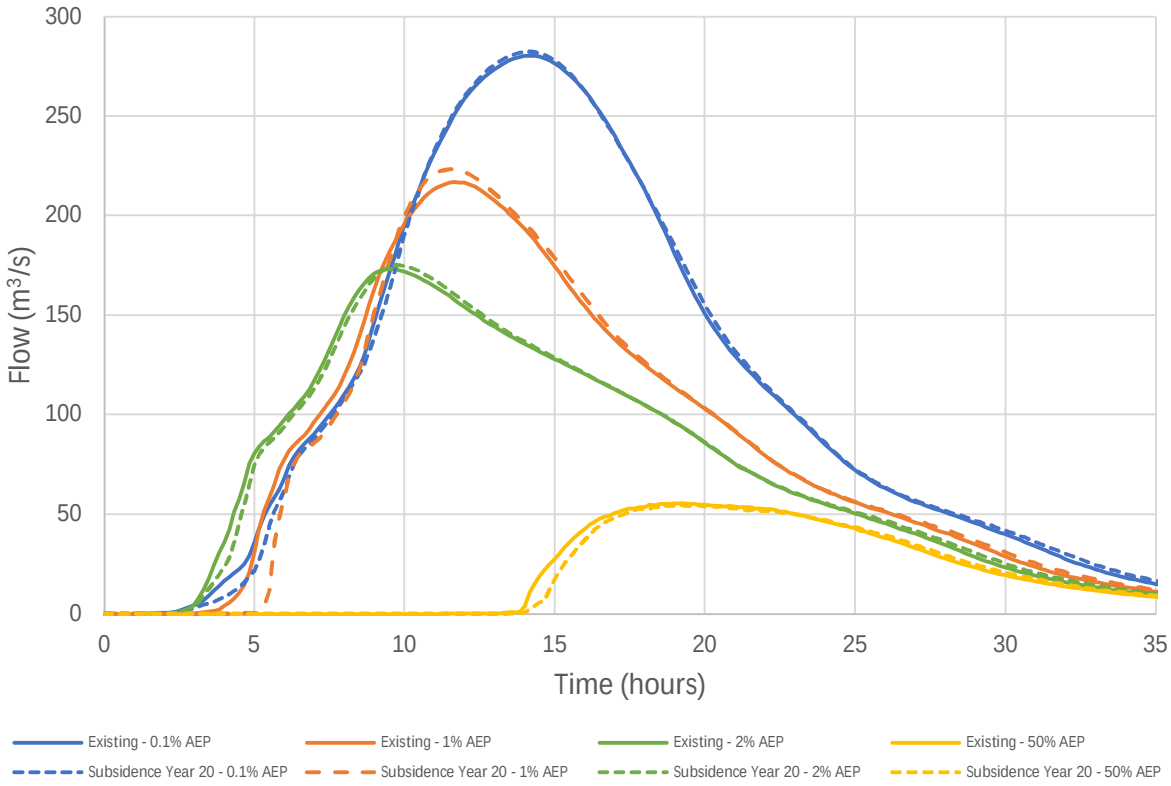
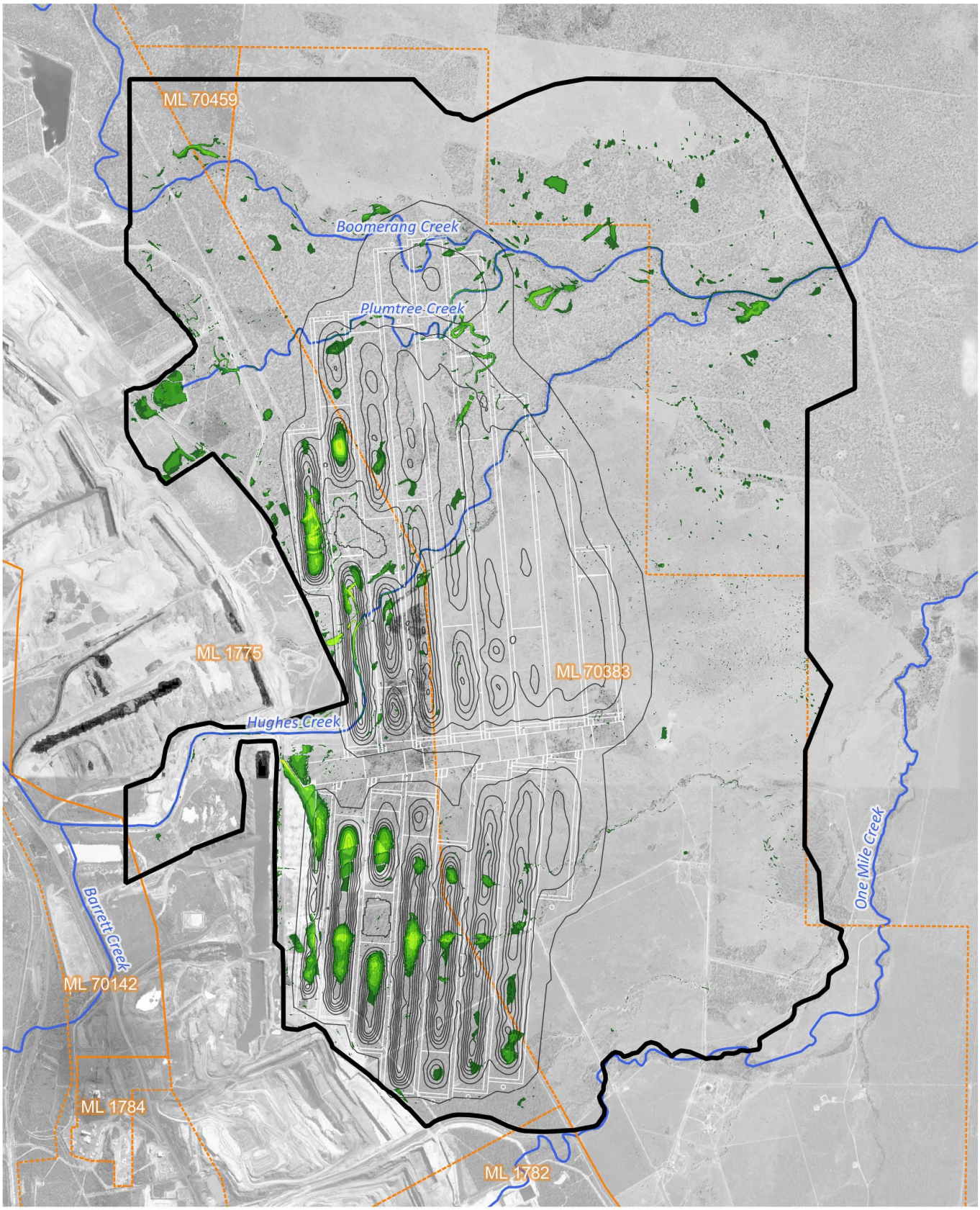


Figure 3-24. Residual pooling in the subsided landscape 0.1% AEP Event – Subsidence Year 20



LEGEND

- Panel Extents
- Subsidence Contours - Yr 20
- Watercourses
- Mining Leases
- TUFLOW Model Extent

Flood Depth (m)

- 0.1 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 2.5
- 2.5 - 3
- 3 - 3.5
- 3.5 - 4
- 4 - 5
- 5 - 6
- > 6

0 1 2 km

SARAJI EAST EIS:
ULTIMATE FLOOD DEPTH
0.1% AEP - YR 20 SUBSIDENCE

Coordinates: GDA94 MGA Zone 55
Created: 11/8/2022
Scale:1:50,000 (A4)

Originator: CB
Checked: GE
Approved: RL

3.3.3 Summary of impacts

Some residual ponding will occur over the subsided landscape providing the positive impact of increased aquatic habitat in a region where such habitat has been lost to land use activities and the erosion and deposition they have instigated. It should be noted that the volume retained in the subsidence represents approximately 2.5% of the storm volume in the 39% AEP event and 0.95% of the storm volume in the 0.1% AEP event at Year 20 post subsidence.

The changes to hydrographs predicted for post-subsidence conditions will reduce in time as pools and the channel infill and ephemeral wetlands slowly accrete. The magnitude of the peak flow varied between -0.56% and +3% in Year 10 post subsidence and -1.33% to +3.05% in the Year 20 post subsidence which are not considered material impacts. No significant changes in the timing of events is observable in the model results.

Some change in flood behaviour will occur between Hughes and Boomerang Creek with the potential for increased frequency of conveyance through lower Plumtree Creek, however these processes already occur, and any change is likely to be minor outside of the rare events where this change in behaviour has been observed in model results.

4 Subsidence management

Managing the potential impacts of subsidence should involve multiple complementary approaches which may include adaptive management of existing issues, development of a subsidence management strategy/plan and monitoring of the actual impacts as mining progresses. In waterway management and applicable to this Project, an adaptive management framework is often adopted as the timing and duration of impacts cannot always be accurately forecast.

4.1 Adaptive management

The principles of adaptive management are:

1. Assess the risk
2. Design operational treatments (mitigation measures)
3. Implement treatments
4. Monitor key response indicators
5. Re-evaluate effectiveness of implemented mitigation measures
6. Adjust policies and/or practices

The adaptive management approach accommodates the complexity involved with stream processes, including the high variability of flow events and stream response to management intervention. Mine plans may also be subject to change with time as is the nature and amount of subsidence, as it's highly dependent on strata and depth of extraction. A subsidence management plan would be a combination of short and long-term measures aimed at creating self-sustaining, healthy functioning waterways through the Project Site suitable for relinquishment of management responsibility at or before life of mine.

Identified issues and management actions captured by a monitoring program would be evaluated following annual monitoring data collection and management recommendations.

In the longer term it is likely that management of subsidence impacts and existing condition issues for the waterways will involve creating a self-sustaining waterway that has the resilience to cope with impacts and promotes potential to maintain the positive impacts of subsidence on river health.

4.2 Subsidence management plan

A subsidence management plan (SMP) has been prepared for the Project. It provides a plan for documenting and reporting annual progress and management of impacts against objectives. The SMP can be found in Appendix K-1 Rehabilitation and Subsidence Management Plans of the EIS. The key components of the SMP are:

- Ongoing subsidence monitoring, evaluation, review and improvement program
- Managing bed and bank stability
- Vegetation management
- Panel catchment management, including rehabilitation of subsidence cracking
- Infrastructure protection or relocation, where necessary.

4.3 Mitigation and management options

A summary of mitigation options appropriate to predicted geomorphic responses to subsidence are provided below (Table 4-1).

Table 4-1. Summary of possible mitigation options to address probably impacts of geomorphic responses

Feature / Environmental Value	Geomorphic Response	Potential impact	Mitigation Options	Residual Risk
Major streams	Upstream deepening	• Bed and bank instability	Implement toe of bank protection and/or channel bed armouring measures at upstream limit of subsidence. Occasional bedrock control will naturally limit the progression of deepening upstream.	Known to be low residual risk at existing longwall operations. The particular case for Hughes Creek diversion remains elevated risk due to the configuration of the diversion and severity of the drop into the first panel. Re-configuration of the diversion longer term to achieve a stable watercourse suitable for closure may be required.
	Downstream deepening due to medium term loss/reduction of bed sediment supply due to subsidence depressions	• Bed and bank instability downstream of the Boomerang/Hughes Creek confluence	Develop and implement a management strategy. The strategy will need to account for predicted changes to the sediment supply conditions. Implement toe of bank protection measures downstream of the mine plan at or before the time those reaches become bedload starved.	Known to be low residual risk at existing longwall operations.
	Deepening/erosion over the pillar zones	• Bed and bank instability	Implement toe of bank protection measures over pillar zones.	Known to be low residual risk at existing longwall operations.
Tributaries	Deepening/erosion at upstream limit of subsidence and over pillar zones	• Bed and bank instability	No mitigation recommended prior to subsidence. Monitoring of risk areas proposed. Grade control (e.g. rock chutes) and bank protection techniques may need to be implemented immediately after full subsidence has occurred and prior to wet season where practical.	Known to be low residual risk at existing longwall operations.
	Accelerated erosion processes	• Avulsion of stream (none identified at this stage)	High density vegetation cover should be maintained in areas identified as at risk. Clearing for infrastructure or gas drainage lines on pillar zones may elevate the risk of erosion.	Maintain or establish healthy vegetation communities with woody stem densities corresponding to benchmark condition for the RE's present.
Un-channelised waterways & flow paths	Incision and erosion headcut instigation	• Substantial sediment generation • Loss of inherent environmental values	Treated with appropriate grade control and flow management immediately after any headcuts are instigated following subsidence. Standard gully management grade control rock chute techniques are appropriate.	Known to be low residual risk at existing longwall operations.
Ephemeral wetland areas	Panel catchments (low energy, fill and spill environment) created in areas of overland flow or unchannelised flow paths	• Vegetation changes (more wetland species) • Increased water storage on the floodplain.	None proposed for geomorphic impacts, may be required due to overall impacts on low flow regime of Isaac or due to impacts on flora/fauna by extended ponding. Constructed drainage may cause more environmental harm than benefit (5th order impact) and should be considered on a case by case basis for best environmental and operational safety outcome.	Maintain ephemeral wetlands wherever possible for net gain in environmental values in the region.
	Creation of pools in channel from subsidence depressions	• Aquatic habitat • Temporary due to excess sediment inputs into Isaac River system	Maintaining the positive impact in the long term would require reduction in sediment inputs on a catchment scale, which is beyond the control of the proponent.	Maintain ephemeral wetlands wherever possible for net gain in environmental values in the region.

4.4 Incremental impacts of subsidence

This technical report provides an assessment of predicted impacts by comparing modelling of pre-subsidence and post-subsidence landscapes. The mine production schedule spans 20 years which equates to approximately one panel mined per year. This means there is potential for incremental impacts as panels are developed, which are not addressed by this assessment. To accommodate incremental impacts, changes to panels and alterations in schedules, SMPs are often updated on an annual basis. The level of assessment in this report does not account for incremental impacts.

Gradual development of panels will not necessarily alter the predicted overall impact on flow and sediment capture provided the final subsidence area is similar in size to that predicted. Actual subsidence may differ from that predicted and therefore any changes could affect the estimated total subsided area. Actual and predicted subsidence need to be compared annually to incorporate changes into the SMP and revise modelling of potential impacts as required.

The production schedule shows panels being developed in an east to west direction, from upstream to downstream for the waterways. The assessment of post-subsidence does not account for direction of panel development. A notable affect will be the potential to starve sections of Hughes Creek of bedload, by capture in the panels upstream, then when subsided, the potential for bank erosion in the sequential downstream moving panels is increased. The potential for this to occur is largely linked to the timing of subsidence and flow events that are either capable of infilling panels (large events) or capable of only partially infilling panels but still capable of mobilising bed sediment and eroding banks (moderate events).

Surface water flow paths can be substantially altered by subsidence such that changes that occur early in the production schedule may result in final surface flow paths that differ considerably from that predicted by using the post-subsidence landform. This is not likely to have much influence on hydrology or flood behaviour but could have implications for potential mitigation works.

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