Surface Water Drainage Report

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Eastern Leases Project
EIS Surface Water Drainage Report

Prepared for Hansen Bailey
on behalf of South32 Pty Ltd

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Contents

List of Figures

List of Tables

Glossary

annual exceedance probability (AEP)	the chance of a given rainfall total which is accumulated over a given time period will be exceeded in any one year.
Australian Height Datum (AHD)	a common national surface level datum approximately corresponding to mean sea level.
Australian Rainfall and Runoff (ARR)	a national guideline used for design flood estimation in Australia. Considered a key source of technical information for designing infrastructure to withstand the impact of extreme rainfall, flooding and storm surge.
average recurrence interval (ARI)	the average value of the period between exceedances of a given rainfall total accumulated over a given duration.
buffer	mine planning constraint that was developed for the protection of watercourses. For the purposes of this project, aligned to the 1% AEP flood extent in watercourses.
catchment	the land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
C_{10} value	runoff coefficient used in the Rational Method estimate relating to a 10% AEP event.
discharge	the measured volume of water that moves past a point in the river in a given amount of time.
flood	relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
floodplain	area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land. It is typically an area of land adjacent to a stream or river.

floodway areas	those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels.
Freeboard	provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the flood planning level is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc.
head cut	an erosional feature in some intermittent and perennial streams where an abrupt vertical drop off occurs.
historical flood	a flood which has actually occurred.
hydraulics	term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
hydrograph	a graph which shows how the discharge or stage/flood level at any particular location varying with time during a flood.
hydrology	the science that encompasses the occurrence, distribution, movement and properties of water and its relationship to the environment. It is a term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
mathematical / computer models	the mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.
peak discharge	the maximum discharge occurring during a flood event.
probability	a statistical measure of the expected chance of flooding (see annual exceedance probability).
risk	chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. It is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	the amount of rainfall which actually ends up as streamflow, also known as rainfall excess. Runoff can be affected by several factors such as slope, soil type, land use, catchment features and antecedent rainfall.

shear stress	provides a measure of the tractive force acting on sediment particles at the boundary of the stream, and is used to determine the threshold of motion for bed material. It is determined from the hydraulic depth and gradient.
stream power	is a function of discharge, hydraulic gradient and flow depth. It is the rate of energy dissipation against the bed and banks of a river or stream per unit downstream length.
stage	equivalent to the height of the water level in the river (both measured with reference to a specified datum).
stage hydrograph	a graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
tailwater	refers to waters located immediately downstream of the hydraulic model.
time of concentration	time taken from the start of the rainfall until all of the catchment is simultaneously contributing flow at the outlet, which is considered to be the travel time from the most remote point in the catchment to the outlet.
time step	time between calculations in the TUFLOW model simulation.
TUFLOW	1-dimensional and 2-dimensional flood simulation software. It simulates the complex movement of floodwaters across a particular area of interest using mathematical approximations to derive information on floodwater depths, velocities and levels.
velocity	the speed or rate of motion (distance per unit of time, e.g., metres per second) in a specific direction at which the flood waters are moving.
water surface profile	a graph showing the flood stage at any given location along a watercourse at a particular time.
XP-RAFTS	a rainfall runoff routing hydrological model that is used extensively throughout Australia for hydrologic and hydraulic analysis of stormwater drainage and conveyance systems. It incorporates subcatchment information such as area, slope, roughness and percentage impervious and is used in order to simulate the transformation of historic or design rainfall into runoff.

Abbreviations

AEP	Annual Exceedance Probability (%)
AHD	Australian Height Datum
ALS	Aerial Laser Scanning
ARI	Average Recurrence Interval
BoM	Bureau of Meteorology
D/S	Downstream
EIS	Environmental Impact Statement
EL	Eastern Lease
ELR	Exploration Licence in Retention
GDA94	Geocentric Datum of Australia 1994
GEMCO	Groote Eylandt Mining Company Pty Ltd
ha	Hectares
km	Kilometre
m	Metre
m^2	Square metre
m^3	Cubic metres
m^3 /s	Cubic metres per second
mAHD	Metres Australian Height Datum
N/m^2	Newtons per square metre (pascals)
TUFLOW	Two dimensional hydraulic modelling software
U/S	Upstream
V:H	Vertical : Horizontal
WRM	WRM Water and Environment Pty Ltd
WSL	Water Surface Level
W/m^2	Watts per square metre (power)
XP-RAFTS	Rainfall runoff routing model

1. Introduction

1.1. PROJECT OVERVIEW

WRM Water & Environment Pty Ltd (WRM) was commissioned by Hansen Bailey on behalf of BHP Billiton Manganese Australia Pty Ltd to complete a surface water drainage assessment as part of the Environmental Impact Statement (EIS) for the Eastern Leases Project (the project).

The project proponent is the Groote Eylandt Mining Company Pty Ltd (GEMCO), which has two shareholders, namely South32 Pty Ltd (60%) and Anglo Operations (Australia) Pty Ltd (40%). BHP Billiton Manganese Australia Pty Ltd was previously a shareholder in GEMCO, however its interest is now represented by South32.

The project involves the development of a number of open cut mining areas to the east of the existing GEMCO manganese mine on Groote Eylandt in the Gulf of Carpentaria, approximately 650 km south-east of Darwin (Figure **1**). The proposed additional mining areas are located on the Eastern Leases, which are two Exploration Licences in Retention (ELRs). ELR28161 is termed the Northern Eastern Lease (Northern EL) and ELR28162 is termed the Southern Eastern Lease (Southern EL).

The Eastern Leases are located 2 km east of the existing GEMCO mine at the closest point. The township of Angurugu is located approximately 6 km to the north-west of the Eastern Leases, and is the closest residential community (Figure 2). The Eastern Leases are located on Aboriginal land, scheduled under the *Aboriginal Land Rights Act (Northern Territory) 1976*. The land within the Eastern Leases comprises natural bushland, with the Emerald River and a small section of the Amagula River traversing the Northern EL and Southern EL, respectively.

The project involves:

- developing a number of open cut mining areas (termed “quarries”) within the Eastern Leases and mining manganese ore by the same mining methods that are in use at the existing GEMCO mine;
- constructing limited mine related infrastructure in the Eastern Leases (dams, water fill points, crib hut, truck park up areas and laydown storage areas); and
- transporting the ore by truck on a new haul road to be constructed between the existing GEMCO mine and the Eastern Leases.

Ore will be processed at the concentrator at the existing GEMCO mine and the concentrate would be transported to market via the existing port. No changes or upgrades to the existing GEMCO mine facilities are required as a result of the project. Ore mined from the Eastern Leases will supplement production from the existing GEMCO mine, but the project will not increase GEMCO’s annual production rate of approximately 5 Million tonnes per annum of product manganese. The EIS does not include any assessment of operations within the existing GEMCO mine, given that these operations are subject to existing environmental approvals, and will not be altered by the project.

The project site for the purposes of the EIS is the Northern and Southern ELs and the new section of haul road linking the Eastern Leases to the existing GEMCO mine. The project site is approximately 4,600 ha (Figure 2).

Mining in the Eastern Leases would take place concurrently with the operation of the existing GEMCO mine. According to current planning, construction in the Northern EL would commence in 2017 and mining activities would commence in 2018. Construction in the Southern EL is scheduled to commence approximately 4 years later in 2022 and mining would then take place in both of the tenements until approximately 2031. This equates to a total of 13 years of mining operations (i.e. mining of ore).

1.2. BACKGROUND TO ASSESSMENT

The regional catchment setting is shown on Figure 3. The Eastern Leases are located in the upper catchments of the Emerald River, Amagula River and Angurugu River. The Emerald River and its tributary watercourses drain the majority of the Northern EL and the western area of the Southern EL. The Amagula River drains the eastern area of the Southern EL via the main channel and two tributary watercourses. The Angurugu River does not traverse the project site. The site drainage is shown on Figures 4 and 5. Section 2 of this report describes the catchment and drainage setting of the project site, including a description of the Emerald River, the Amagula River and their tributaries. The geomorphic condition of the watercourses and drainage features are presented in the EIS Baseline Surface Water Monitoring Report.

The Emerald and Amagula Rivers, and their tributaries are considered culturally and environmentally sensitive. Mine planning was cognisant of these sensitivities and a strategy for mining in the vicinity of these surface waters was developed over a period of approximately 18 months. Integrated mine planning and environmental impact assessment was conducted to ensure the key watercourses traversing the project site were not significantly impacted while maintaining an efficient and economic mine plan.

The project has been designed to ensure that mining will not encroach on any of the significant watercourses traversing the project site. In particular, buffers have been defined around the main channels of the Emerald River, Amagula River and their tributaries. The mine plan and quarry extents were then designed to ensure no encroachment on the buffers, and to restrict mining to areas beyond the defined drainage channels and associated buffers.

The buffers were delineated by the predicted extent of the 1% Annual Exceedance Probability (AEP) flood extents. The buffers are shown on Figures 4 and 5.

The project has been designed to ensure that a stable free-draining post mining landform will be established with no final voids. The mine plan and mine schedule have been designed to ensure that all overburden will ultimately be placed in mined quarries, creating a final landform that is similar to the existing (i.e. pre-mining) landform. The project has avoided the need for elevated overburden emplacements and final voids through mine planning and scheduling. The post mining landform stability and flood behaviour was confirmed though detailed flood modelling under 1% and 0.1% flood events.

1.3. SCOPE OF WORK

This report provides detail on the flood modelling that was undertaken to delineate the buffers.

This report also provides detail on the flood modelling that was undertaken to assess the post mining landform flood behaviour, and includes an assessment of the potential impacts of surface drainage on the final landform stability.

This report is an appendix to the EIS, and is intended to support the project mine plan and the surface water assessment presented in the EIS Surface Water Section.

1.4. REPORT STRUCTURE

The report is structured as follows:

- Section 1 – Introduction: provides an overview of the project, and describes the background to the report including the project planning and design principles that guided the buffer development and final landform design. An overview of the scope of work is also provided.
- Section 2 – Surface Water Setting: outlines the drainage characteristics across the project site as well as the streamflow and topographic data used in this investigation.

- Section 3 – Assessment Methodology: outlines the potential surface water impacts. The methodology used to assess the impacts has also been provided.
- Section 4 – Model Development: provides a detailed description of the hydrological and hydraulic modelling undertaken.
- Section 5 – Pre-Mining Flooding and Drainage Conditions: provides the results of the modelling and describes the existing flow behaviour of the Emerald and Amagula Rivers.
- Section 6 – Performance of Drainage Buffers: provides the results of the modelling and describes the operation of drainage buffers in terms of the buffer objectives and flow behaviour of the Emerald and Amagula Rivers.
- Section 7 – Post Mining Drainage and Flooding: provides the results of the modelling and describes the post mining impacts on the flow behaviour of the Emerald and Amagula Rivers.
- Section 8 – Conclusions: presents an overview of the conclusions of the assessment.
- Section 9 - Figures.

2. Surface Water Setting

The project surface water setting has been provided by Hansen Bailey. The EIS Surface Water Section provides additional information on the surface water setting, including environmental values, water uses and baseline surface water monitoring data.

This section includes an overview of the regional catchment setting, and provides a detailed description of surface water drainage characteristics. This description draws upon watercourse monitoring data presented in the EIS Baseline Surface Water Monitoring Report.

For the purposes of this report, all rivers and tributaries shown on Figure 2 are termed watercourses.

2.1 REGIONAL CATCHMENT SETTING

The project site is located on Groote Eylandt, a 2,285 km^2 island in the Gulf of Carpentaria. The central areas of the island are characterised by elevated rock outcrops that form hills and escarpments with limited vegetation and soil cover. Between these hills and escarpments, the low-lying topography forms densely vegetated, gently sloping valleys that open into flat coastal plains. These hills and escarpments define the surface water catchments across the majority of the island. The relief of the landscape in the area surrounding the project is shown in Figures 3 to 5.

The Eastern Leases are located in the upper catchments of the Emerald River, Amagula River and Angurugu River (Figure 3). The Eastern Leases are located at the head of these catchments and site drainage is therefore highly ephemeral through the majority of the project site. Figures 3 to 5 show the drainage features within the catchments.

2.2 DRAINAGE SETTING

The local drainage setting is shown in Figures 4 and 5.

The majority of the project site drains towards the coast from elevated rock outcrops located at the periphery of the project site. Minor drainage features include a network of minor gullies in the steeper topography associated with elevated outcrops, and overland flow paths in the lower lying areas. These drainage features coalesce to form regionally significant watercourses in the flatter areas of the project site. The main watercourses are typically channelised through the project site and characterised by narrow rocky channels and chains of pools.

The Emerald River and its tributary watercourses drain the majority of the Northern EL and the western area of the Southern EL. The Amagula River drains the eastern area of the Southern EL via the main channel and two tributary watercourses. The Angurugu River does not traverse the project site.

2.1.1 Emerald River and Tributaries

The Northern EL is primarily drained by the upper reaches of the Emerald River and Emerald River – Tributary 1 (Figure 4).

Figure 6 shows represents cross sectional areas of the Emerald River taken at select locations within the Northern EL . These cross sections illustrate the pre-mining or existing conditions profile (slope and grade) of the channel of the upper reaches of the Emerald River. The predicted existing conditions 1% AEP flood level at each cross section, derived using the modelling described in Section 4, is also shown. The locations of the cross sections are shown in Figure 4.

Drainage from several incised gullies converges near the eastern upstream boundary of the Northern EL to form the Emerald River – Main Channel. The upstream catchment to this point is approximately 523 ha and is characterised by rock outcrops and relatively sparse vegetation. The main channel traverses the Northern EL east to west for 3.5 km in a gentle arc. The channel is typically well-defined for the majority of its length. The channel bedform and banks are largely controlled by exposed rock, with channel elevation falling 30 m across the project site as it follows the surface of the underlying rock. There is a head cut located in between cross sections ER1 and ER2 with contrasting channels upstream and downstream of the head cut. The downstream channel is deeper with steeper side slopes than the upstream channel which is more than likely as a result of the head cut.

The channel falls at a relatively consistent slope of about 0.75% downstream of the head cut and then becomes flatter further downstream of the Northern EL. The channel is 'perched' above the adjacent valley floodplain at cross section ER2 with the valley floor lower than the adjacent river bank. The local catchment flows, which are significant in these upper reaches, drain independently and parallel to the river channel for all but the major flood events before they enter the river channel via drainage gullies. The overbank areas can convey a significant proportion of the total catchment flow across the Northern EL. The overbank flows and river flows combine at cross section ER3 and ER4 and drain downstream as one water body.

The main channel continues south-west downstream of the Northern EL boundary, converging with the Emerald River – Tributary 1 and overland flowpaths approximately 2.3 km downstream of the Northern EL as the channel loses definition. This convergence is characterised by a locally extensive alluvial fan.

The catchment area of the Emerald River – Tributary 1 is 645 ha. This represents approximately 25% of the total Emerald River catchment at the confluence of these watercourses. The catchment and drainage channel are comparable to the main channel, with the tributary transitioning from incised gullies to an alluvial fan over a similar distance.

Approximately 1.1 km downstream of the Emerald River – Tributary 1 confluence (and 3.4 km downstream of the Northern EL), Emerald River – Tributary 3 enters the main channel from the north. The main channel and the inflowing tributary are both ephemeral at this point. The Emerald River – Tributary 3 sub-catchment has an area of 780 ha and is closely bounded on three sides by elevated rock outcrops. This catchment area represents only 20% of the total Emerald River catchment at the confluence of these watercourses. The tributary comprises a shallow incised gulley with a narrow rocky bed.

The main channel continues south-west from the Emerald River – Tributary 3 confluence. As the channel elevation decreases, groundwater baseflow supports perennial flow between pools connected by narrow rock chutes.

Emerald River – Tributary 2 enters the main channel 4.7 km downstream of Emerald River – Tributary 3. Emerald River – Tributary 2 has a catchment area of 2,393 ha. This sub-catchment contains the western portion of the Southern EL.

The Emerald River – Tributary 2 headwaters form in the western part of the Southern EL. Overland sheet flow follows unchannelised flow paths west across the undulating elevated area that forms the Amagula River catchment divide. These flowpaths coalesce and become a channelised as they flow north-west across the Southern EL. The channel transitions to an open network of slow moving perennial pools connected by narrow silted channels as it exits the northern boundary of the Southern EL.

The main channel continues 4.5 km south-west from the Emerald River – Tributary 2 confluence and enters the Gulf of Carpentaria approximately 12.6 km downstream of the Northern EL and 7 km downstream of the Southern EL (Figure 3). The estuarine reach of the Emerald River extends approximately 4 km upstream of the coastline.

Under the Strahler ordering system, the Emerald River is a 2nd to 3rd order drainage feature upstream of the Emerald River – Tributary 2 confluence, and a 4th order stream downstream of the confluence.

2.1.2 Amagula River and Tributaries

The eastern area of the Southern EL is drained by the Amagula River and its tributaries Amagula River – Tributary 1 and Tributary 2 (Figure 5).

The Amagula River – Main Channel enters the Southern EL from the east and traverses the south-eastern corner of the Southern EL. The river flows approximately 0.8 km across the Southern EL and exits to the south. The upstream catchment of the Amagula River at this location is approximately 10,942 ha. The main channel is characterised by broad rocky pools connected by rock chutes and bounded by rock outcrops and rocky banks. The bed of these pools contains a thin layer of mud and silt. The river has a base width of between 40 m and 50 m and is about 3 m to 4 m deep. The channel is relatively confined to a narrow floodplain of about 400 m wide. The main channel flows perennially through the Southern EL.

Amagula River – Tributary 2 flows ephemerally into the main channel at the boundary of the Southern EL. The Amagula River – Tributary 2 catchment comprises an area of 1,991 ha, which represents approximately 15% of the total Amagula River catchment at the confluence of these watercourses. The catchment is bounded by rock outcrops, with the channel geomorphically similar to the main river channel, albeit on a smaller scale. Figure 7 shows cross sections of the East Tributary across the Southern EL. The locations of the cross sections are shown in Figure 5. The Amagula River – Tributary 2 channel varies in depth between 5 m at cross section East 1 to about 2 m deep at cross section East 3. The channel falls at a gradient of about 0.2% between these sections. Downstream of the East 3 cross section, the channel falls at a much steeper gradient of 0.7% as it falls into the Amagula River. The channel along this reach is also much deeper.

From this confluence, the Amagula River – Main Channel flows west parallel to the Southern EL boundary. This reach of the main channel is characteristically rocky and receives inflows from overland flowpaths and a minor gully to the north.

Approximately 3 km downstream of the Amagula River – Tributary 2 confluence and 900 m south of the Southern EL, Amagula River – Tributary 1 flows perennially into the main channel from the north. The Amagula River – Tributary 1 catchment comprises 1,476 ha and is comparable to the Amagula River – Tributary 2.

A further 1.7 km downstream, the Amagula River – Main Channel becomes confined as it flows through an incised rock outcrop. As the river exits this area it becomes less confined, resulting in sediment deposition. A substantial sand bar has formed in this area on the inside of the main channel and forms part of the Leske Pools recreational area.

The Amagula River – Main Channel continues 17.4 km south and enters the Gulf of Carpentaria approximately 22 km downstream of the Southern EL (Figure 3). The estuarine reach of the Amagula River – Main Channel extends approximately 4 km upstream of the coastline and approximately 18 km downstream of the Southern EL.

Under the Strahler ordering system, the Amagula River is a 4^{th} order watercourse within the project site and upstream of the Amagula River – Tributary 2 confluence. It is a 5^{th} order watercourse downstream of the confluence.

2.1.3 Angurugu River

The Angurugu River catchment extends from the elevated rock outcrops present to the north and east of the Northern EL (Figure 4). A topographic saddle between these outcrops forms a catchment divide between the Emerald and Angurugu rivers in the north-east of the Northern EL.

The Angurugu River is located approximately 2 km north of the Northern EL and flows generally westward for 21.1 km from its headwaters in the centre of the island to its mouth at the coastline (Figure 3). The river mouth is located approximately 15 km north of the Emerald River estuary.

An area of 181 ha in the north-east of the Northern EL drains to the Angurugu River via minor drainage lines and overland sheet flow. This area will not be disturbed by project activities.

3. Assessment Methodology

As discussed in Section 1.3, this report comprises:

- A description of the flood modelling undertaken to delineate the buffers; and
- A description of the flood modelling that was undertaken to assess the post mining landform flood behaviour, including an assessment of the potential impacts of flood events on final landform stability.

Flood modelling comprised hydrological and hydraulic modelling of the pre and post mining landforms. The modelled extent of the 1% AEP flood event informed the buffers around each watercourse.

The proposed mining areas and rehabilitated final landform are located beyond these buffers and therefore beyond the 1% AEP flood envelope associated with any watercourses. Flood flows associated with watercourses will not traverse the final landform. The larger 0.1% AEP flood envelope was therefore adopted to assess the stability of the final landform during flood flows.

XP-RAFTS rainfall runoff routing models (XP Software, 2009) for the Emerald River and Amagula River catchments were developed to estimate design flood discharges in these rivers and the connected drainage features in the vicinity of the Eastern Leases. The XP-RAFTS model results were validated against design discharges estimated using the Rational Method in accordance with the procedures given in Australian Rainfall and Runoff (AR&R) (Pilgrim, 1998).

The TUFLOW model (WBM, 2010) was used to estimate the flooding behaviour along the two river systems and their floodplains within the vicinity of the Eastern Leases. TUFLOW estimates flood levels on a fixed grid pattern by solving the full two-dimensional depth averaged momentum and continuity equations for free surface flow. The model automatically calculates breakout points and flow directions within the model area.

The results of the TUFLOW model were used to describe the pre-mining flooding conditions, delineate the buffers and assess the flood behaviour of the post mining landform.

The main hydraulic characteristics of interest for these descriptions and assessments are flood depth, velocity, bed shear and stream power. A brief description of each of these hydraulic characteristics is provided below:

- **Flood depths** have been used to show the extent of inundation for both pre-mining and post mining conditions. The depth of water also directly relates to the force exerted on soil particles and therefore erosion potential.
- **Stream velocity** provides a measure of the speed of water draining across the floodplain. There is no direct relationship between velocity and the force exerted on soil particles at the boundary, and therefore stream power and shear stress are used as more reliable indicators of erosion potential. However, it provides a recognisable characteristic that can be used to identify a potential change in stream behaviour.
- **Shear stress** provides a measure of the tractive force acting on sediment particles at the boundary of the stream, and is used to determine the threshold of motion for bed material. It is determined from the hydraulic depth and gradient and provides an indication of the potential for erosion of cohesive sediments or movement of non-cohesive sediments at the channel boundary.
- **Stream power** is a function of discharge, hydraulic gradient and flow depth. It represents the energy that is available to do work in and on the channel. High stream powers are indicative of elevated erosion potential.

4. Model Development

4.1 HYDROLOGICAL MODELLING

4.1.1 Overview

This section presents details of the hydrologic modelling undertaken to estimate design discharges.

The XP-RAFTS model was used to estimate design discharges for the 1% (1 in 100) and 0.1% (1 in 1,000) AEP flood events. The Emerald River and Amagula River catchment boundaries and the XP-RAFTS model subcatchments are shown in Figure 9 and Figure 10, respectively. The Amagula River and Emerald River XP-RAFTS model sub-catchment boundaries were delineated using the available LiDAR data and mine planning information.

Runoff discharges from areas impacted by proposed mining activities were estimated by applying direct rainfall over the surface of the TUFLOW model. This ensures that the local flow rates, volumes and directions can be accurately represented by changes in the TUFLOW model. The Amagula River and Emerald River direct rainfall areas are shown in Figure 9 and Figure 10.

The following section presents the methodology and results of the hydrological model validation for the Emerald River and Amagula River catchments.

4.1.2 Model validation

The Emerald River and Amagula River models were validated against the Rational Method estimates at 6 nominal locations within each catchment. The routing parameters of the model were then 'fine-tuned' via a joint calibration of the hydrologic and hydraulic models to match the rate and timing of the discharge hydrographs at the downstream boundaries of the model. This has ensured that both XP-RAFTS and TUFLOW models produce consistent discharge hydrographs along the main waterways.

The two water level gauging stations located within the Emerald and Amagula River catchments are shown in Figure 3. The details of these stations are outlined below:

- Amagula River at Ripplestone Gorge (G9290005): 1969 – 1978
- Emerald River at Old BHP Camp (G9290211): 1969 - 1988

Both stations have been decommissioned and WRM was informed by the Northern Territory Department of Land Resource Management that the data at these stations could not be verified. As such, the recorded data at the Amagula River at Ripplestone Gorge and Emerald River at Old BHP Camp were not used in this investigation.

4.1.3 Model Parameters

The XP-RAFTS model uses physical parameters such as catchment slope, vegetation characteristics (PERN 'n') and percent impervious to determine the runoff characteristics from each sub-area. It then uses routing parameters based on the channel length and slope to determine the travel time between each sub-area. Rainfall losses and the 'bx' factor are used as a calibration factor. The following is considered note-worthy with respect to configurations common to both models:

- Average catchment slopes were calculated from available topographic data.
- A PERN 'n' of 0.065 was adopted based on a fully vegetated catchment.
- A percent impervious of 0% was adopted.
- An initial loss and continuing loss of 10 mm and 1.4 mm/hr was adopted.
- A global 'Bx' factor of 1.0 was adopted.

4.1.4 Emerald River XP-RAFTS Model

Figure 9 shows the Emerald River XP-RAFTS model configuration, consisting of 26 nodes and associated sub-catchments areas including:

- 14 Emerald River – Main Channel sub-catchments totalling 1,662 ha (C01 to C13 & C26);
- 9 overland flow sub-catchments totalling 768 ha (C14 to C20 and C23 to C24); and
- 3 Emerald River - Tributary 1 sub-catchments totalling 457 ha (C21, C22 and C25).

Table 4.1 shows the area and catchment slope for each sub-catchment in the Emerald River XP-RAFTS model. Runoff from sub-catchment areas C11, C12, C13, C17, C19, C20 and C24 were estimated using direct rainfall in the TUFLOW model.

4.1.5 Amagula River XP-RAFTS Model

Figure 10 shows the Amagula River XP-RAFTS model configuration, consisting of 34 nodes and associated sub-catchments areas including:

- 11 Amagula River - Tributary 2 sub-catchments totalling 2,056 ha (A02 to A10);
- 19 Amagula River - Tributary 1 sub-catchments totalling 1,565 ha (A12 to A30); and
- 4 Amagula River – Main Channel sub-catchments totalling 12,043 ha (A01, A11, A31 & A32).

Table 4.2 shows the area and catchment slope for each sub-catchment in the Amagula River XP-RAFTS model. Runoff from sub-catchment SW158, A10, A23, A25, A27 and A29 were estimated using direct rainfall in the TUFLOW model.

4.1.6 Emerald River – Tributary 2 XP-RAFTS Model

Figure 10 shows the Emerald River – Tributary 2 XP-RAFTS model configuration, consisting of 16 nodes and associated sub-catchments areas.

Table 4.3 shows the adopted sub-catchment parameters for the Emerald River – Tributary 2 XP-RAFTS model. Runoff from sub-catchment area SW15 was estimated using direct rainfall in the TUFLOW model.

4.1.7 Design Rainfalls and Temporal Patterns

Design rainfall depths and temporal patterns (Zone 4) were derived in accordance with Australian Rainfall and Runoff (Pilgrim, 1998).

4.1.8 Model Validation

The Amagula River and Emerald River XP-RAFTS models were validated against Rational Method discharge estimates at 12 locations. Rational Method estimates were made using the methodology recommended in AR&R (Pilgrim, 1998) for the Northern Territory. The models were validated at the following model node locations (see Figure 9 and Figure 10):

- For the Amagula River model:
  - Sub-catchment A01;
  - Sub-catchment A02;
  - Sub-catchment A04;
  - Sub-catchment A05;
  - Sub-catchment A18; and
  - Sub-catchment A23.
- For the Emerald River model:
  - Sub-catchment C01;

- Sub-catchment C02;
- Sub-catchment C03 + C04;
- Sub-catchment C09;
- Sub-catchment C18; and
- Sub-catchment C21.

The Rational Method discharges were calculated using the following parameters:

- A catchment C_{10} value of 0.9 was assigned to each catchment in accordance with AR&R (Pilgrim, 1998); and
- The time of concentration for each catchment was calculated using the Bransby-Williams equation as described in AR&R. This equation uses catchment area and slope to determine the time of concentration.

Table 4.1 - Emerald River XP-RAFTS Model Sub-Catchment Parameters

Emerald River Model					
Sub-catchment	Sub-Catchment Area (ha)	Sub-Catchment Slope (%)	Sub-catchment	Sub-Catchment Area (ha)	Sub-Catchment Slope (%)
C01	270.0	11.4	C14	46.7	13.0
C02	181.8	10.9	C15	56.2	13.3
C03	120.0	9.4	C16	54.6	12.7
C04	30.8	8.0	C17	116.2	3.8
C05	13.3	13.1	C18	40.6	9.7
C06	22.3	9.5	C19	134.1	3.2
C07	28.4	5.9	C20	114.3	2.8
C08	18.7	10.1	C21	273.0	13.1
C09	36.0	3.7	C22	59.2	10.0
C10	4.9	10.3	C23	24.6	7.3
C11	103.1	4.5	C24	181.0	2.9
C12	31.2	3.0	C25	124.4	6.3
C13	155.0	3.9	C26	646.2	5.5

Table 4.2 - Amagula River XP-RAFTS Model Sub-Catchment Parameters

Amagula River Model					
Sub-catchment	Sub-Catchment Area (ha)	Sub-Catchment Slope (%)	Sub-catchment	Sub-Catchment Area (ha)	Sub-Catchment Slope (%)
A01	10955.0	7.0	A16	149.6	9.9
A02	896.5	12.0	A17	94.0	8.8
A03	45.7	7.2	A18	268.1	5.8
A04	119.4	7.6	A19	21.0	10.1
A05	443.2	11.0	A20	29.5	8.9
A06	220.0	7.4	A21	122.6	9.0
A06a	29.3	7.5	A22	59.8	7.7
A06b	39.9	2.4	A23	262.4	3.7
A07	34.6	4.9	A24	27.9	12.4
A08	110.4	2.7	A25	75.5	3.3
A09	83.5	6.8	A26	5.7	13.7
A10	33.5	4.0	A27	69.8	3.4
A11	515.4	9.7	A28	48.9	9.4
A12	28.3	7.2	A29	166.6	3.6
A13	51.0	6.8	A30	16.0	9.3
A14	41.2	8.3	A31	199.0	7.8
A15	27.7	10.4	A32	374.3	10.0

Table 4.3 - Emerald River – Tributary 2 XP-RAFTS Model Sub-Catchment Parameters

Emerald River – Tributary 2 Model					
Sub-catchment	Sub-Catchment Area (ha)	Sub-Catchment Slope (%)	Sub-catchment	Sub-Catchment Area (ha)	Sub-Catchment Slope (%)
SW01	53.0	8.41	SW09	61.1	1.86
SW02	49.8	8.21	SW10	40.9	3.75
SW03	59.2	8.91	SW11	75.1	3.08
SW04	92.1	5.33	SW12	31.8	4.89
SW05	23.1	8.48	SW13	71.6	6.49
SW06	34.9	7.95	SW14	65.4	5.89
SW07	29.7	6.67	SW15	845.3	0.98
SW08	48.0	2.47	SW16	453.6	0.91

Table 4.4 compares the 1% AEP design discharges estimated using the Rational Method and XP-RAFTS model at each of the 12 locations. The comparison shows that the XP-RAFTS peak discharges for all sub-catchments match the Rational Method discharges. The critical duration storm is the 60 minute event for the Emerald River catchments, and the 120 minute event for the Amagula River catchments. The XP-RAFTS discharge results are generally slightly higher than those calculated using Rational Method and have been conservatively adopted for this assessment.

Table 4.4 - Comparison of Rational Method and XP-RAFTS Model 1% AEP Peak Discharges

Amagula River			Emerald River		
Inflow Location	1% AEP Peak Discharge (m^3/s)		Inflow Location	1% AEP Peak Discharge (m^3/s)	
	Rational Method	XP-RAFTS		Rational Method	XP-RAFTS
A01	1,191	1,230	C01	95	102
A02	223	236	C02	72	72
A04	240	284	C03+ C04	183	215
A05	134	144	C09	55	51
A18	200	193	C18	22	21
A23	246	270	C21	98	109

4.2 HYDRAULIC MODELLING

4.2.1 Overview

The TUFLOW hydrodynamic model (WBM, 2010) was used to simulate flow behaviour across the Northern and Southern ELs and at nominated downstream locations for both pre-mining and post mining conditions. TUFLOW represents hydraulic conditions on a fixed grid by solving the full two-dimensional depth averaged momentum and continuity equations for free surface flow. The model automatically calculates breakout points and flow directions within the model extents.

4.2.2 Model Extent

Separate TUFLOW models were developed to estimate flood depths and extents in the Amagula River and the Emerald River and their associated tributaries. The configuration of each model is shown in Figure 11, Figure 12 and Figure 13. The extents of each model were selected to provide coverage of the likely extents of any project impacts.

The Emerald River TUFLOW models used a 2 second time step. The Amagula River, which featured a greater change in elevation, used a 1 second time step. The three models were developed using a 5 m grid.

4.2.3 Adopted Bed Roughness

The TUFLOW model uses Manning's 'n' values to represent hydraulic resistance (notionally channel or floodplain roughness). Manning's 'n' values were based on the typical published values given in Chow (1959), which is an industry standard for the derivation of Manning's 'n' values. The Manning's 'n' values applied to all modelled events were:

- Thick vegetation: 'n' = 0.09
- Sparse vegetation: 'n' = 0.05

- Thick scrub: ‘n’ = 0.07
- Dirt roads: ‘n’ = 0.03
- Water bodies: ‘n’ = 0.04

4.2.4 Inflow Boundaries

The topography of the floodplain suggests that a proportion of catchment runoff drains as overland sheet flow, independently of the main drainage channels. This is particularly evident in the Northern EL. To properly characterise the flow behaviour at the two sites, a combination of XP-RAFTS inflows at the model boundary and direct rainfall inflows within the model area were used for the assessment. The direct rainfall approach applies rainfall directly to each TUFLOW cell allowing the model to determine the distribution of flow across the floodplain whereas the XP-RAFTS model provides inflow at a single location. The direct rainfall replaces the XP-RAFTS inflows in these locations, ensuring there is no duplication of flow. An initial and continuing loss of 10 mm and 1.4 mm/hr, respectively, was applied to the direct rainfall data ensuring consistency with the XP-RAFTS model calibration.

4.2.5 Tailwater Conditions

Normal depth tailwater boundary conditions were applied to both hydraulic models using flood gradients that were representative of the bed slopes at the model boundaries. These tailwater slopes were:

- Emerald River – Main Channel: 0.002 m/m
- Amagula River – Main Channel: 0.003 m/m
- Amagula River - Tributary 1 Outlet: 0.004 m/m

4.2.6 Pre-mining Topography

Topographic aerial survey data for the project site is shown in Figure 4 and Figure 5. The aerial laser scanning (ALS) data, which was obtained from a fixed wing aircraft in June 2013, was supplied in a thinned ground ASCII space delimited format which has a derived point accuracy of +/- 0.15 m. This data was converted into a digital elevation model (DEM) for use in the hydraulic modelling and mapping tasks.

4.2.7 Post-Mining Topography

The ground levels within the pre-mining case hydraulic models were amended to include the proposed post-mining landforms. The post-mining landform was supplied by GEMCO. The only changes to the pre-mining model conditions are the ground levels within the proposed quarries. Figure 6 to Figure 8 show cross sections of the waterways and adjacent floodplains for pre-mining conditions and the post mining conditions.

The adopted hydrology, Manning’s ‘n’ values and tailwater conditions, outlined in Section 4.2.3 and 4.2.5, were identical to those included in the pre-mining scenario models. The model has been developed on the basis that the post mining landform will be profiled and rehabilitated to a state consistent with surrounding topography and pre-mining landform.

5. Pre-Mining Flooding and Drainage Conditions

The TUFLOW model was used to determine the pre-mining 1% AEP design flood levels, depths, extents and velocities across the Northern and Southern ELs.

These pre-mining conditions were used as the basis for confirming the performance of the drainage buffers (Section 6) and providing a baseline for assessing impacts from the post mining landform (Section 7).

5.1 NORTHERN EL

Figure 14 shows the pre-mining landform conditions extent and depth of flooding in the Northern EL for the 1% AEP design event. The 1% AEP peak flood velocities are shown in Figure 15. The following is of note with respect to the 1% AEP event:

- Site drainage within the Northern EL is typically via wide shallow sheet flow in areas where there are no defined channels resulting in more than 80% of the flood extent inundated to a depth of 0.5 m or less.
- Flooding within the Northern EL is more confined in the Emerald River main channel and the Emerald River - Tributary 1. The 1% AEP flow is entirely confined to the Emerald River channel through the proposed quarry area.
- Flood waters within the Emerald River main channel reach a maximum depth of 5 m in its lower reach and approximately 3 m in its upper reach.
- Overland flows from the surrounding catchment generally drain parallel to the Emerald River main channel across the proposed quarry area draining into the Emerald River at only isolated locations (Figure 14). The overland flows and channel flows combine downstream of the proposed quarry area, and flow downstream as one water body.
- The 1% AEP flow is confined to the Emerald River - Tributary 1 for much of its length. The tributary overflows at the downstream extent of the proposed quarry area.
- The Emerald River main channel and Emerald River - Tributary 1 flood flows coalesce between the proposed quarry areas and at the western boundary of the Northern EL.
- Runoff from the northern part of the Northern EL drains as overland flow and does not combine with the Emerald River until approximately 500 m downstream of the Northern EL boundary. Flood depths are typically less than 1.0 m in this area.
- Peak velocities along the centre of the Emerald River channel across the Northern EL vary between 1.9 m/s to 2.5 m/s (80^{th} percentiles) with an average of 2.2 m/s (Figure 15). Higher velocities occur at the location of the head cut described in Section 2.
- Overbank velocities are generally below 1m/s.

5.2 SOUTHERN EL

Figure 16 shows the pre-mining landform conditions, extent and depth of flooding in the Southern EL for the 1% AEP design event. The 1% AEP peak flood velocities are shown in Figure 17. The following sections discuss the existing flooding and drainage conditions, relevant to the Southern EL.

5.2.1 Amagula River and Tributaries

- Site drainage within the Southern EL is typically via wide shallow sheet flow in areas where there are no defined channels, with more than 58% of the flood extent inundated to a depth of 0.5m or less.
- Flooding within the Southern EL is relatively confined to the Amagula River – Tributary 1 and the Amagula River - Tributary 2.
- The 1% AEP flow is confined to a corridor approximately 200 m wide along the Amagula River - Tributary 1 and approximately 300 m to 400 m wide along the Amagula River - Tributary 2, which runs adjacent to the proposed quarry areas.
- Flood flows associated with the Amagula River main channel cross the southeastern corner of the Southern EL and then continue to inundate an area immediately south of the Southern EL. Flood flows do not extend to within 500 m of any proposed quarry area.
- In the proposed quarry area, overland sheet flows drain directly to the Amagula River main channel and the Amagula River – Tributary 1 and 2 channels.
- Peak velocities along the centre of the Amagula River - Tributary 1 across the Southern EL vary between 1.4 m/s to 1.8 m/s (80th percentiles) with an average of 1.8m/s (Figure 15). Higher velocities occur near the southern boundary of the Southern EL as the channel becomes larger and deeper.
- Peak velocities along the centre of the Amagula River - Tributary 2 across the Southern EL vary between 1.4 m/s to 2.4 m/s (80th percentiles) with an average of 1.8 m/s.
- The velocities along the Amagula River main channel are moderately higher, averaging 3.5 m/s.
- Overland velocities are generally below 1m/s.

5.2.2 Emerald River – Tributary 2

- Overland flows in the headwaters of the Emerald River - Tributary 2 drain as sheet flow within the proposed quarry area and then concentrate at the downstream limit of proposed mining. Peak flood depths are typically less than 1 m in this area and locally increase to 2.0 m as sheet flows concentrate at the downstream extent of the proposed quarry area.
- These headwaters become more confined immediately downstream of the proposed quarry area and is generally confined to a 150 m corridor. The peak flood depth in this corridor is up to 5 m.
- The velocities in the headwaters of the Emerald River - Tributary 2 are typically less than 1 m/s, increasing to less than 1.5 m/s in concentrated flows downstream of the proposed quarry area.

6. Performance of Drainage Buffers

This section summarises the performance of the proposed drainage buffers.

6.1 DESIGN OBJECTIVES

The drainage buffers were designed and located to minimise the operational impacts of the project by limiting the interaction between proposed quarries and flooding events.

This approach also provides the quarries with protection from watercourse flooding for all events up to and including the 1% AEP flood event.

6.2 OPERATIONAL DRAINAGE ASSESSMENT

The performance and potential impacts of each drainage buffer has been assessed against the pre-mining 1% AEP flood conditions described in Section 5.

The assessment of each drainage buffer is summarised as follows:

- Emerald River – Main Channel:
    - The proposed quarry areas in both the Northern and Southern ELs have been designed so as not to impact or cause environmental harm to the Emerald River, and as a result unimpeded flows throughout the length of the main drainage corridor will continue to be maintained. The project will not constrain the predicted 1% AEP flood extent from the Emerald River.
    - Flooding in the Emerald River main channel is not predicted to inundate the proposed quarries.
- Emerald River - Tributary 1:
    - Proposed quarry areas in the Northern EL have been designed to maintain unimpeded flows along the majority of the drainage corridor.
    - A minor area on the western side of the proposed quarry area may interact with flood waters in the Emerald River - Tributary 1. Flood depths on average are expected to be less than 0.5 m in this area.
- Amagula River – Tributary 1 and Tributary 2:
    - Proposed mine plans for the Southern EL have been designed to maintain unimpeded flows along the length of the Amagula River drainage corridors. It is not expected that flood waters will be constrained by the project.
    - Flooding in the Amagula River – Tributaries 1 and 2 are not predicted to inundate the proposed quarries.

In addition, flood modelling shows that the extents of the proposed quarry areas in the Southern EL are limited to headwaters of the Emerald River – Tributary 2, upstream of the point where this tributary becomes a defined channel.

7. Post Mining Drainage and Flooding

7.1 OVERVIEW

This section presents the assessment of the impacts of the project on drainage and flooding over the final landform and on downstream drainage features.

The TUFLOW model results for the final landform were compared with pre-mining baseline conditions and against TUFLOW model results for the 1% AEP event. This was undertaken in order to quantify potential project related impacts on surrounding properties and stream geomorphology. Post mining flooding conditions and changes to peak water levels, flow velocities, bed shear stress and stream power are discussed in the following sections for the 1% AEP event.

In addition, the potential for flood flows within the key river channels to inundate the backfilled quarries under extreme flood conditions have been assessed using the 0.1% flood event.

7.2 NORTHERN EL

Figure 18 and Figure 19 show the extent and depth of flooding over the final landform for the 1% and 0.1% AEP design events respectively. The 1% AEP peak flood velocities are shown in Figure 20. Figure 24 and Figure 25 show the extent of the impact of the project on 1% AEP flood levels and velocities in the Northern EL respectively.

Figure 26 shows longitudinal profiles of peak flood level and velocity and Figure 27 shows longitudinal profiles of peak bed shear and stream power along the centreline of the Emerald River. The following provides for a summary of information presented in these figures:

7.2.1 Flood Extents and Depths

- The 1% AEP flood flow (Figure 18) is confined to the Emerald River main channel for its entire length through the final landform. Figure 24 shows that this is essentially unchanged from pre-mining conditions.
- The separation between overland sheet flows and the Emerald River main channel flows adjacent to the final landform is predicted to remain post mining. Under post mining conditions, the overland sheet flows do not drain into the Emerald River until they reach the western extent of the final landform, approximately 200 m further downstream than under pre-mining conditions.
- Peak flood levels along the Emerald River channel are expected to fall by a maximum of 0.27 m between chainage 1,000 m and 1,500 m due to the final landform reducing overbank flows draining into the river (Figure 24).
- There are no changes in peak flood levels (or velocities) upstream or downstream of the quarry areas as a result of mining.
- The post mining landform will result in a moderate reduction in extent of flooding immediately to the north of the Emerald River due to the changed ground levels (Figure 24). In this area, peak flood levels are also predicted to fall because of the reduced ground elevations (up to 1.5m). Consequently peak flood depths across the proposed final landform are expected to be similar to pre-mining conditions.
- The 1% and 0.1% AEP flow is confined to the Emerald River - Tributary 1 for much of its length. This is essentially unchanged from the pre-mining conditions.
- Following rehabilitation and closure of the operations, runoff from the northern areas of the Northern EL will continue to drain overland, and will not combine with the Emerald River until well downstream of the Northern EL boundary. This is essentially unchanged from pre-mining conditions.

7.2.2 Flow Velocities, Bed Shear Stress and Stream Power

- Following rehabilitation and closure of the operations, the peak flood velocities along the centre of the Emerald River channel are predicted to be between 1.9m/s to 2.5m/s (80th percentiles) with an average of 2.1m/s. This predicted peak flood velocity is marginally (0.1m/s) lower than peak flood velocities during pre-mining conditions.
- Overland velocities are currently below 1m/s and are predicted to be similar following mine closure.
- The peak flood velocities, bed shear and stream power are predicted to be moderately reduced between chainage 1,000 m and 1,500 m due to the reduction in flow (Figure 26 and Figure 27). These reductions would be imperceptible in the Emerald River and would not result in any long term impacts on the river.
- Immediately to the north of the Emerald River, overbank flows are predicted to drain in a more confined manner post mining, resulting in a slight increase to flood velocities (Figure 20). However, the velocities in this area are considered to be no greater than other overbank locations, and therefore vegetation within this area should be able to withstand the increased velocities should they occur.

7.2.3 Final Landform Extreme Flood Inundation

- The Emerald River 0.1% AEP flows (Figure 19) are confined to the Emerald River main channel for all of its length through the proposed quarry area, which is similar to the 1% AEP flood conditions (Figure 24). That is, the Emerald River is not predicted to overflow into the rehabilitated and mined quarry areas during the 0.1% AEP flood event following the cessation of mining. All quarries therefore have a high level of immunity from Emerald River flood flows.
- Overland flows free-drain across the final landform as sheet flow in a similar manner to existing conditions.

7.3 SOUTHERN EL

Figure 21 and Figure 22 show the extent and depth of flooding over the final post mining landform for the 1% and 0.1% AEP design events, respectively. The 1% AEP peak flood velocities are shown in Figure 23. Figure 28 and Figure 29 show the extent of the impact of the project on 1% AEP flood levels and velocities in the Southern EL, respectively.

Figure 30 and Figure 31 shows longitudinal profiles of peak flood levels and velocity along the centreline of the Amagula River – Tributaries 1 and 2. Figure 32 and Figure 33 show the longitudinal profiles of peak bed shear and stream power along these tributaries.

The following provides for a summary of information presented in these figures:

7.3.1 Flood Extents and Depths

- The flood flow depths and extents (Figure 21) along the Amagula River – Tributaries 1 and 2 are essentially unchanged as a result of mining. There are no measurable differences in peak flood levels along the Amagula River – Tributaries 1 and 2.
- Minor differences in peak flood levels (up to 0.3m) across the Emerald River - Tributary 2 catchment caused as a result of mining are deemed to be insignificant.
- There is a moderate reduction in flood extent across the final landform (Figure 28). However, the differences are minor.
- Overland flows will continue to free-drain across the final post mining landform as sheet flow in a similar manner to pre-mining conditions (Figure 21).

7.3.2 Flow Velocities, Bed Shear Stress and Stream Power

- The range of peak velocities along the centre of the Amagula River main channel and its tributaries is essentially the same as for pre-mining conditions (Figure 30 and Figure 32).
- There is a minor reduction in peak velocity along the Amagula River - Tributary 1 due to overbank flows being diverted further downstream. The difference would be imperceptible at less than 0.1m/s (Figure 29).
- In a similar manner, there would be an imperceptible change in peak bed shear and stream power along the tributaries (Figure 32 and Figure 33).
- On this basis, the project is not expected to impact on the long term geomorphic characteristics of the Amagula River tributaries (or the Amagula River).

7.3.3 Final Landform Extreme Flood Inundation

- The Amagula River – Tributary 1 and 2 flows are confined to their drainage corridors for the 0.1% AEP event and only cross into the proposed quarry area near the Amagula River – Tributary 2 at chainage 1,800m (Figure 22). As part of the mine planning process, the final landform ground levels in this area are no different to the existing conditions and therefore there will be no change to the flooding or channel characteristics of the Amagula River tributaries.
- Overland sheet flows free-drain across the final landform, similar to pre-mining conditions.

8. Conclusions

WRM Water & Environment were engaged to undertake a drainage and flood assessment to support the development of a mine plan for the project and inform the surface water assessment presented in the EIS.

This assessment included flood modelling to delineate the buffers around watercourses within the Eastern Leases, and confirm post mining landform flood behaviour.

This assessment included consideration of the potential impacts of surface drainage on the final landform stability.

The key conclusions drawn from this assessment are summarised below.

8.1 NORTHERN EL

The Emerald River main channel and the Emerald River - Tributary 1 drain through the Northern EL. A buffer equivalent to the 1% AEP flood extent was provided for each of these watercourses. Modelling results confirm that:

- There are no changes in peak flood levels or velocities upstream or downstream of the quarry area for a 1% AEP event. This indicates that the project does not result in upstream of downstream geomorphology or flooding impacts.
- The 1% AEP flood flows are confined to the Emerald River main channel and Emerald River - Tributary 1 channels for most of their lengths for both the pre and post mining phases of the project. Minor predicted changes will not result in adverse impacts on the channel morphology of these watercourses.
- Overland flows from the surrounding catchment drain parallel to the Emerald River through the proposed quarry area, entering the Emerald River in only isolated locations. The project will lower ground levels by up to 1.5 m along the overbank area. This is expected to increase the separation of overland flows from the local catchment and river flows. The reduction in overland flows draining to the Emerald River reduces the peak 1% AEP flood levels by a maximum of 0.27 m. Flood depths in the affected area currently exceed 4 m and therefore a reduction of 0.27 m in flood depth levels would be imperceptible. These overland flows drain into the river approximately 200 m further downstream. There is therefore no overall loss of downstream flow to the Emerald River.
- Peak flood velocities, bed shear and stream power moderately reduce between chainage 1,000 m and 1,500 m due to the reduction in flow. The reductions would be imperceptible in the river during a 1% AEP event and are not likely to result in any long term geomorphic impacts on the river.
- There is a moderate reduction in flood extent across the quarry area immediately to the north of the Emerald River due to the changed ground elevation. The overbank flows are predicted to drain in a more confined manner as a result of the post mining land surface, resulting in a moderate increase in flood velocities. However, the post mining flood velocities in this area are not predicted to be higher than other overbank locations and therefore vegetation within this area should be able to mitigate the increased velocities with no geomorphic impacts.

Based on the modelling results, the project is not expected to impact on the geomorphic characteristics or erosion potential of the Emerald River main channel, the Emerald River - Tributary 1 or the overbank areas at the completion of mining (once rehabilitated).

8.2 SOUTHERN EL

The Amagula River main channel and Amagula River – Tributaries 1 and 2 drain the eastern area of the Southern EL. A drainage buffer equivalent to the 1% AEP flood extent was provided for each of these tributaries. Mining is not proposed within 700 m of the Amagula River main channel.

The headwaters of the Emerald River – Tributary 2 drain the western area of the Southern EL. These headwaters drain as overland sheet flow and have no defined channel. These headwaters concentrate as they flow west and form a defined channel in the west of the Southern EL. The proposed quarry layout does not intersect the defined channel of the Emerald River - Tributary 2.

- The 1% AEP flow is confined to a corridor approximately 200 m wide along the Amagula River - Tributary 1 and within 300 m to 400 m wide along the Amagula River - Tributary 2 adjacent to the proposed quarry area.
- There are no measurable differences in peak 1% AEP flood levels along the Amagula River – Tributaries 1 and 2 and no differences along the Amagula River – Main Channel.
- There is a minor reduction in peak velocity along the Amagula River - Tributary 1 due to overbank flows being diverted further downstream. The difference is less than 0.1m/s and would be imperceptible.
- There would be an imperceptible change in the peak bed shear and stream power along the tributaries as a result of the project.
- There is a moderate reduction in flood extent from the local catchment flows across the quarry area. However, the differences are minor.

On this basis, the project is not expected to impact the long term geomorphic characteristics of the Amagula River, the Amagula River – Tributaries 1 and 2, or the overbank areas post mining.

10. References

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Pilgrim (1998)	'*Australian Rainfall and Runoff, A Guide to Flood Estimation*', Revised Edition, Institution of Engineers, Australia, 1998.
Strahler, A.N, (1952)	'*Hypsometric (area-altitude) analysis of erosional topography*', Geological Society of America Bulletin 63 (11), pp. 1117 – 1142.
WBM (2010)	'*Tuflow User Manual, GIS Based 2D/1D Hydrodynamic Modelling*' Build 2012-05-AE-IDP-W64, BMT WBM 2008

11. Figures

Figure 1 - Project Location, Groote Eylandt

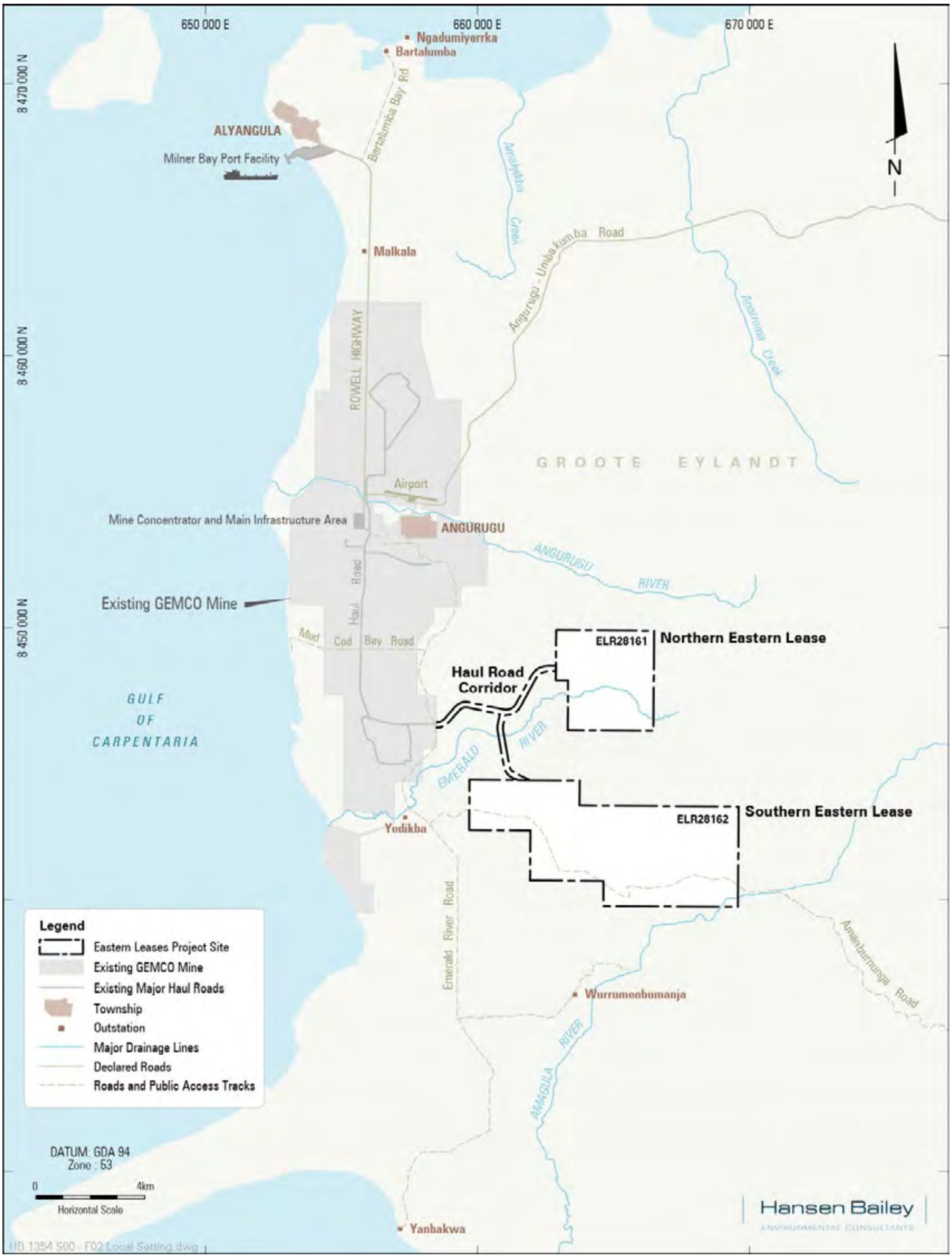

Figure 2 - Local Setting

Figure 3 - Surface Water Catchments

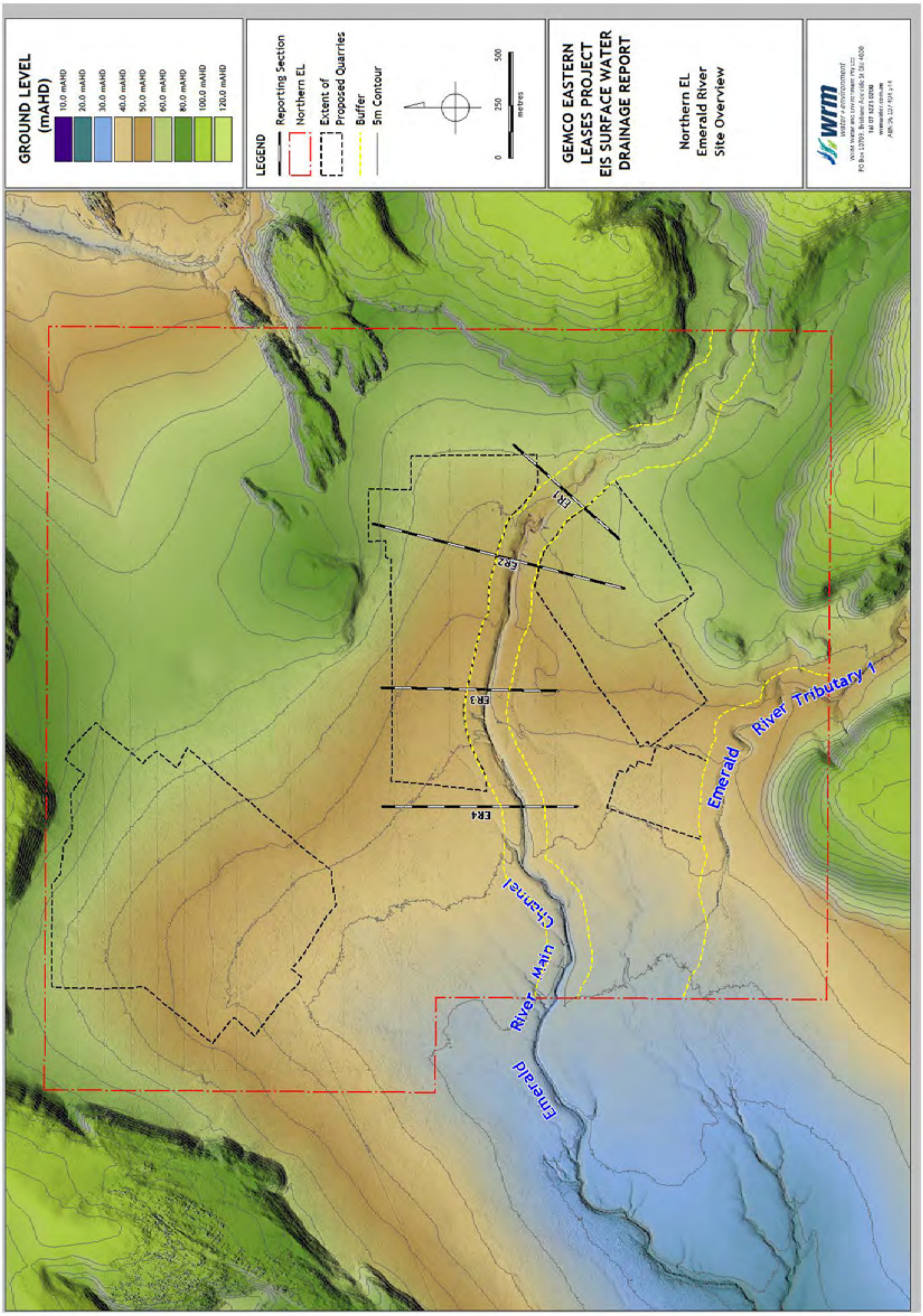

Figure 4 - Northern EL area

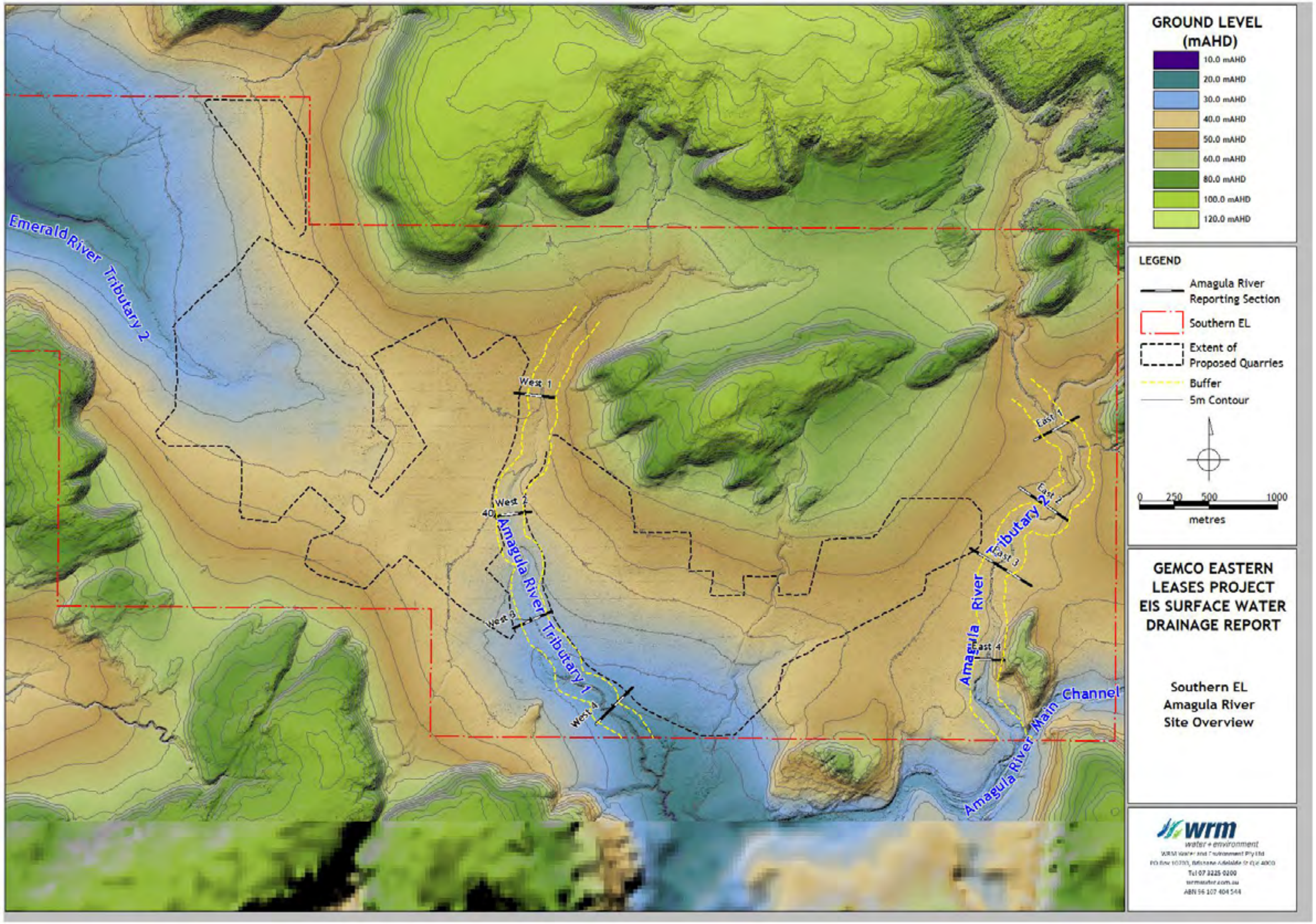

Figure 5 - Southern EL Area

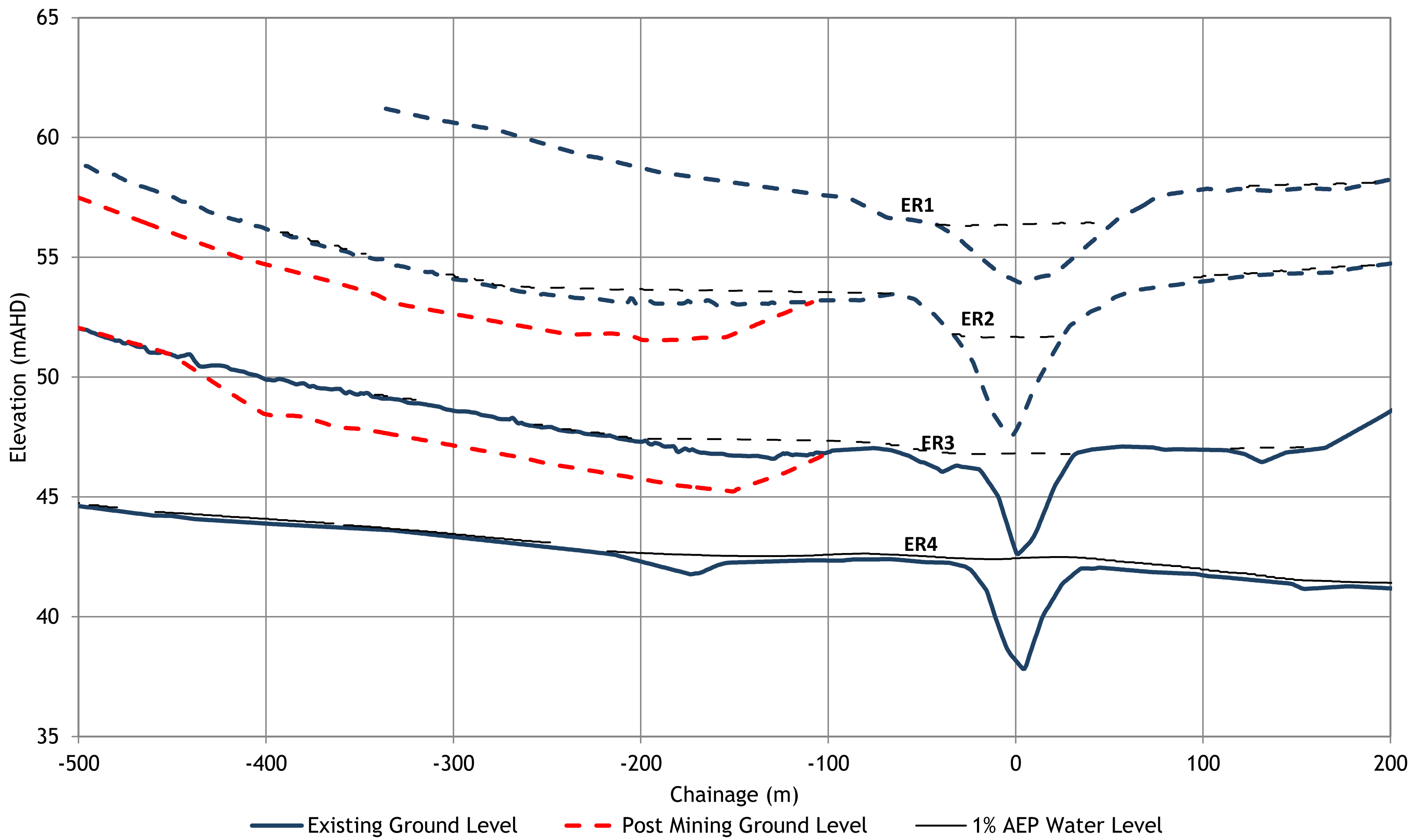

Figure 6 - Emerald River - Main Channel Cross Sections

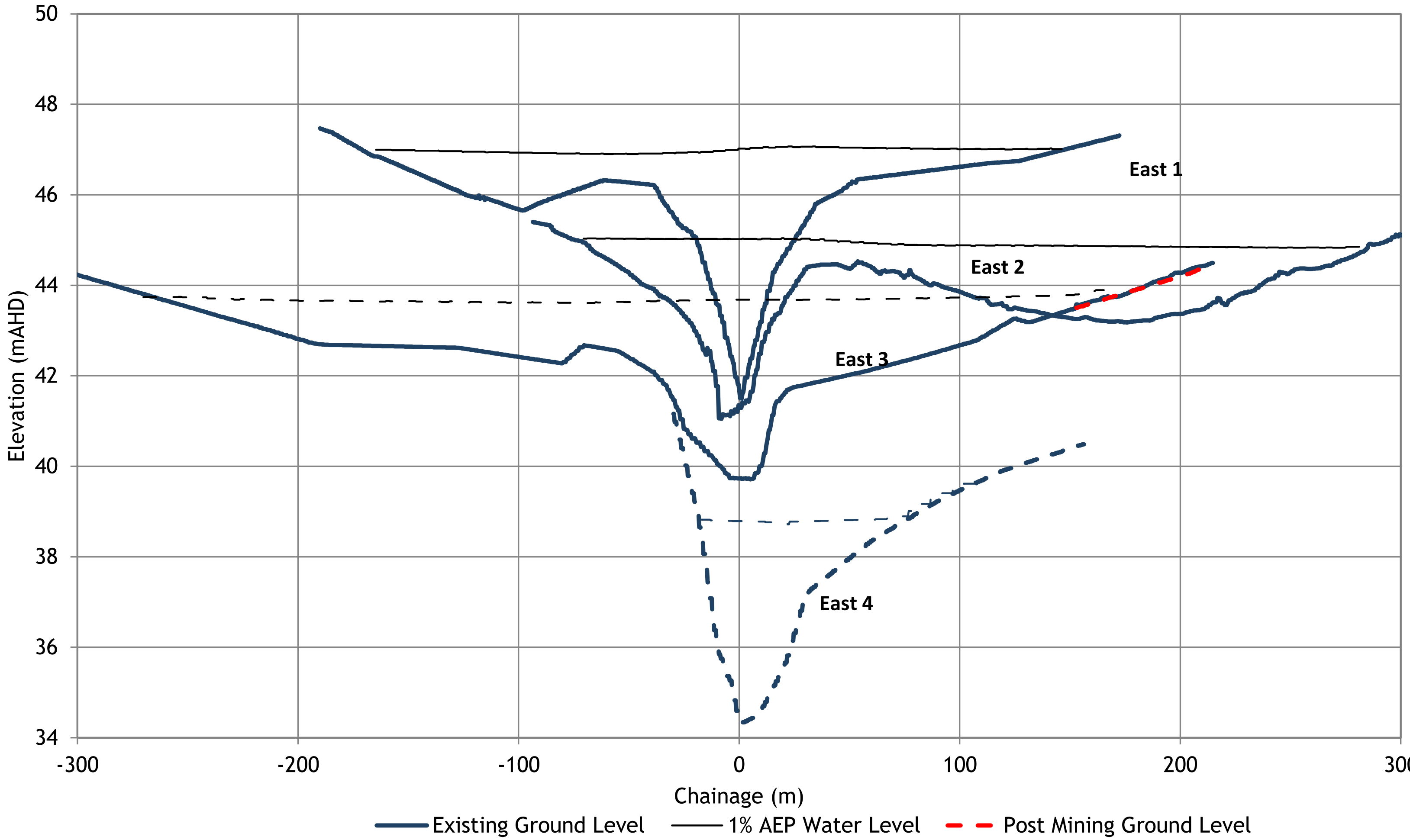

Figure 7 - Amagula River - Tributary 2 Cross Sections

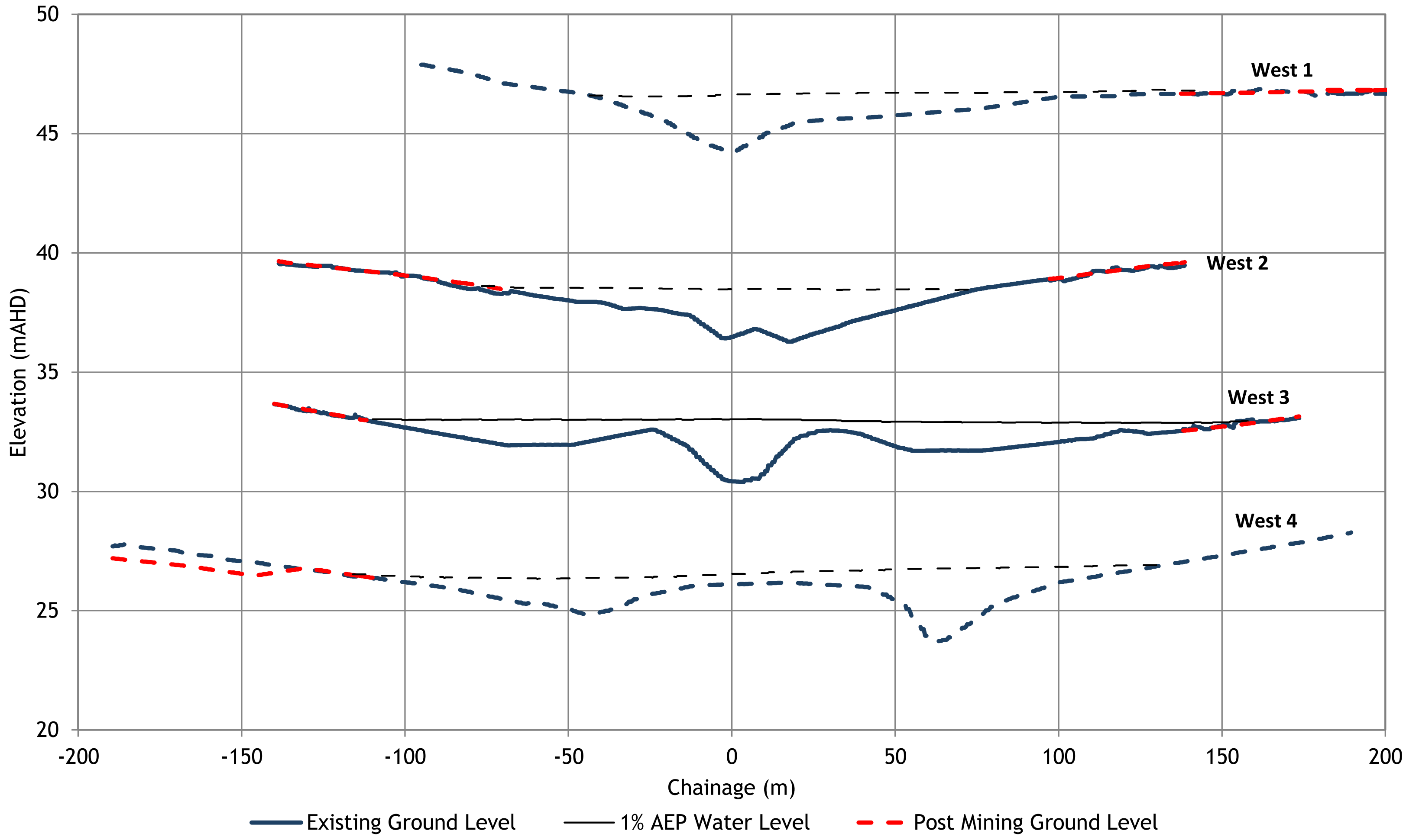

Figure 8 - Amagula River - Tributary 1 Cross Sections

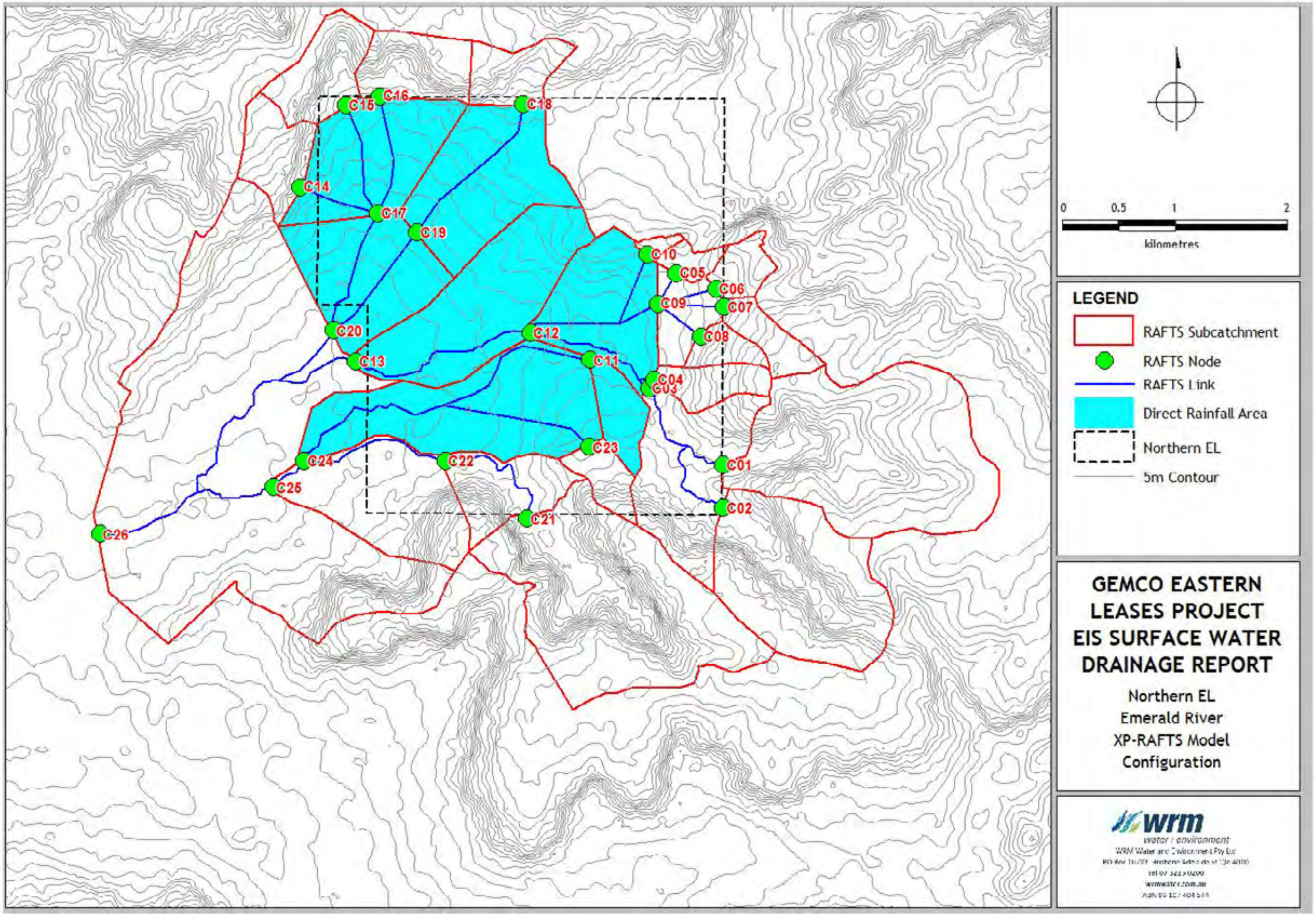

Figure 9 – Northern EL XP-RAFTS Model Configuration

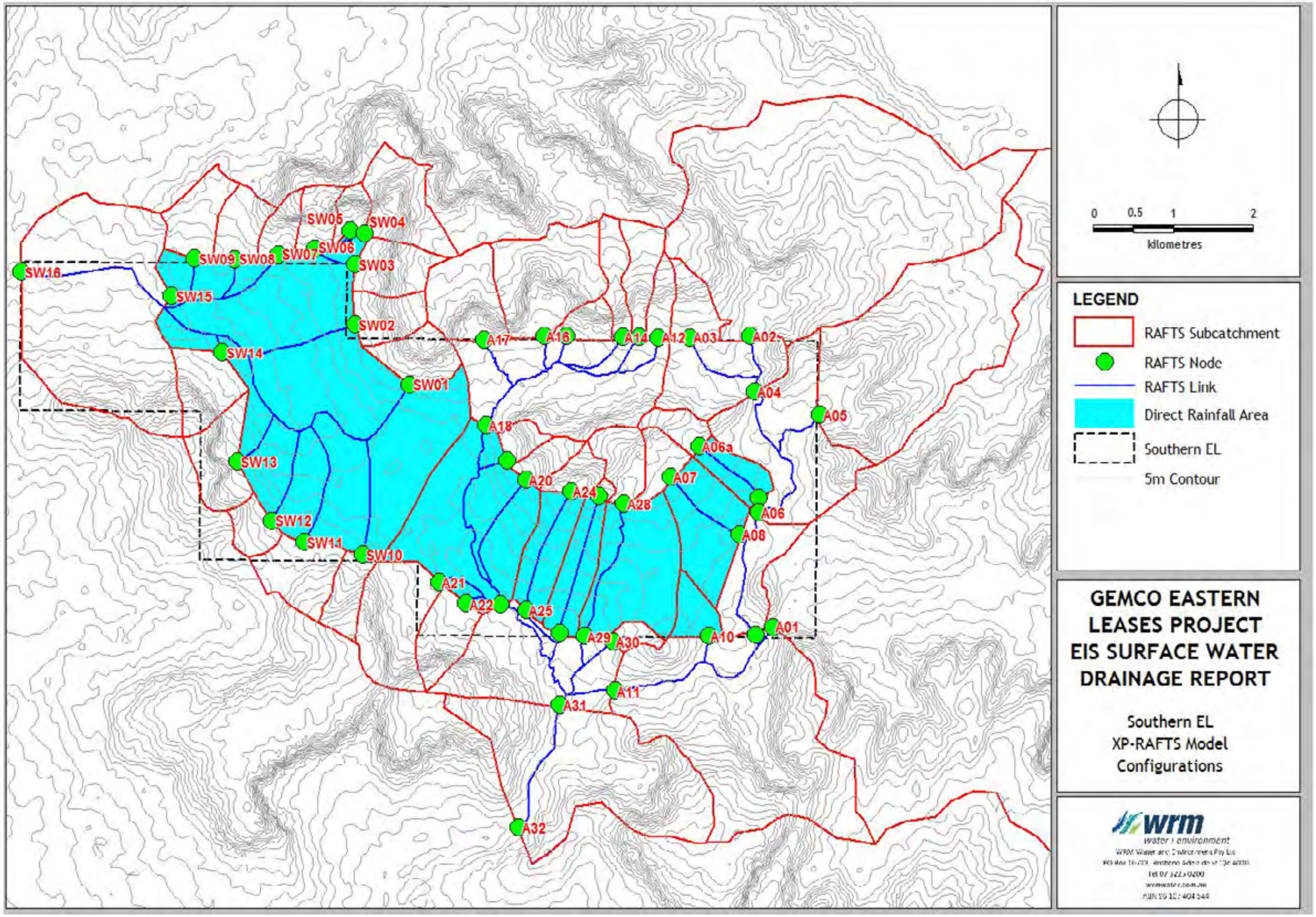

Figure 10 - Southern EL XP-RAFTS Model Configurations

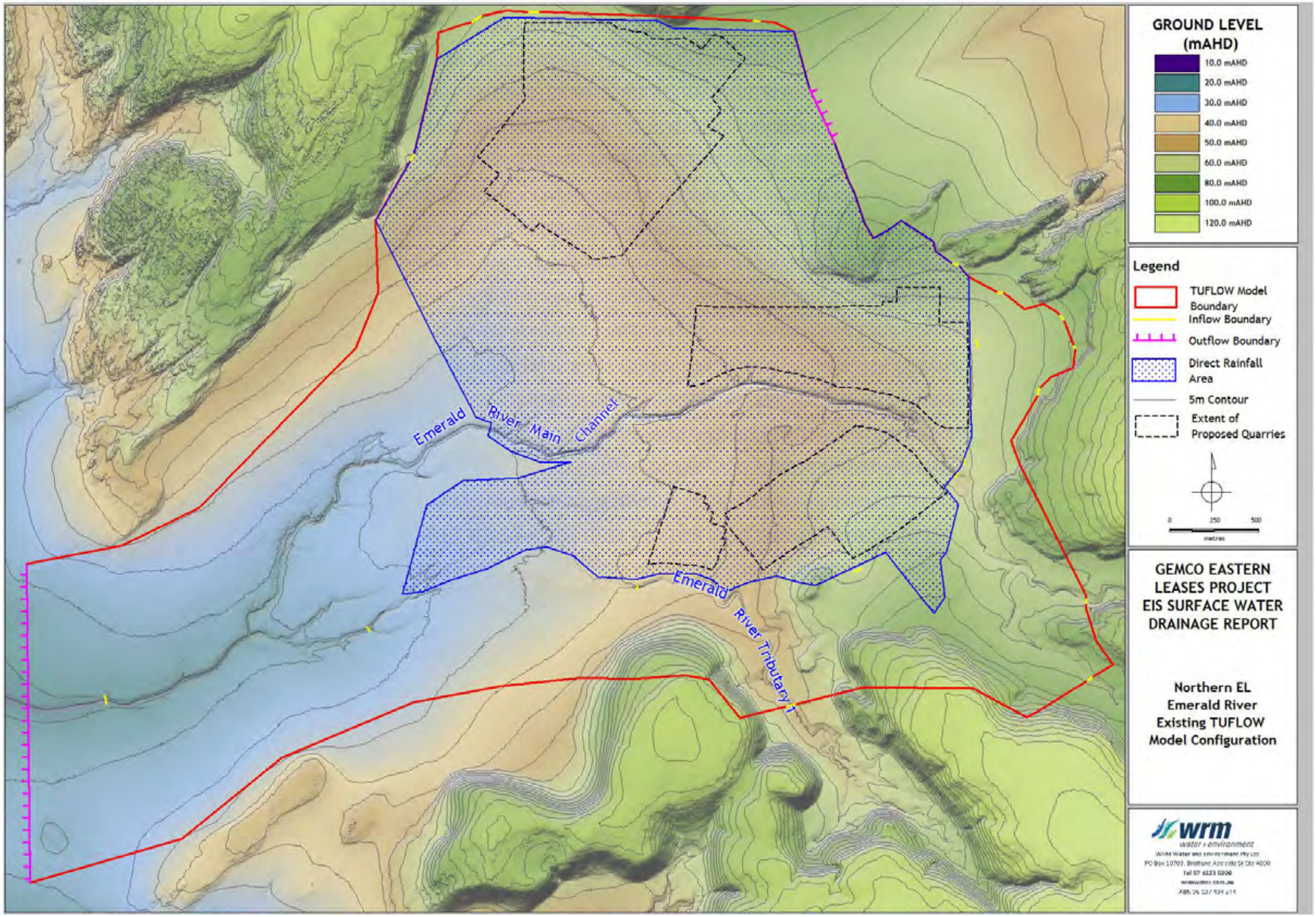

Figure 11 - Emerald River Pre-Mining TUFLOW Model Configuration

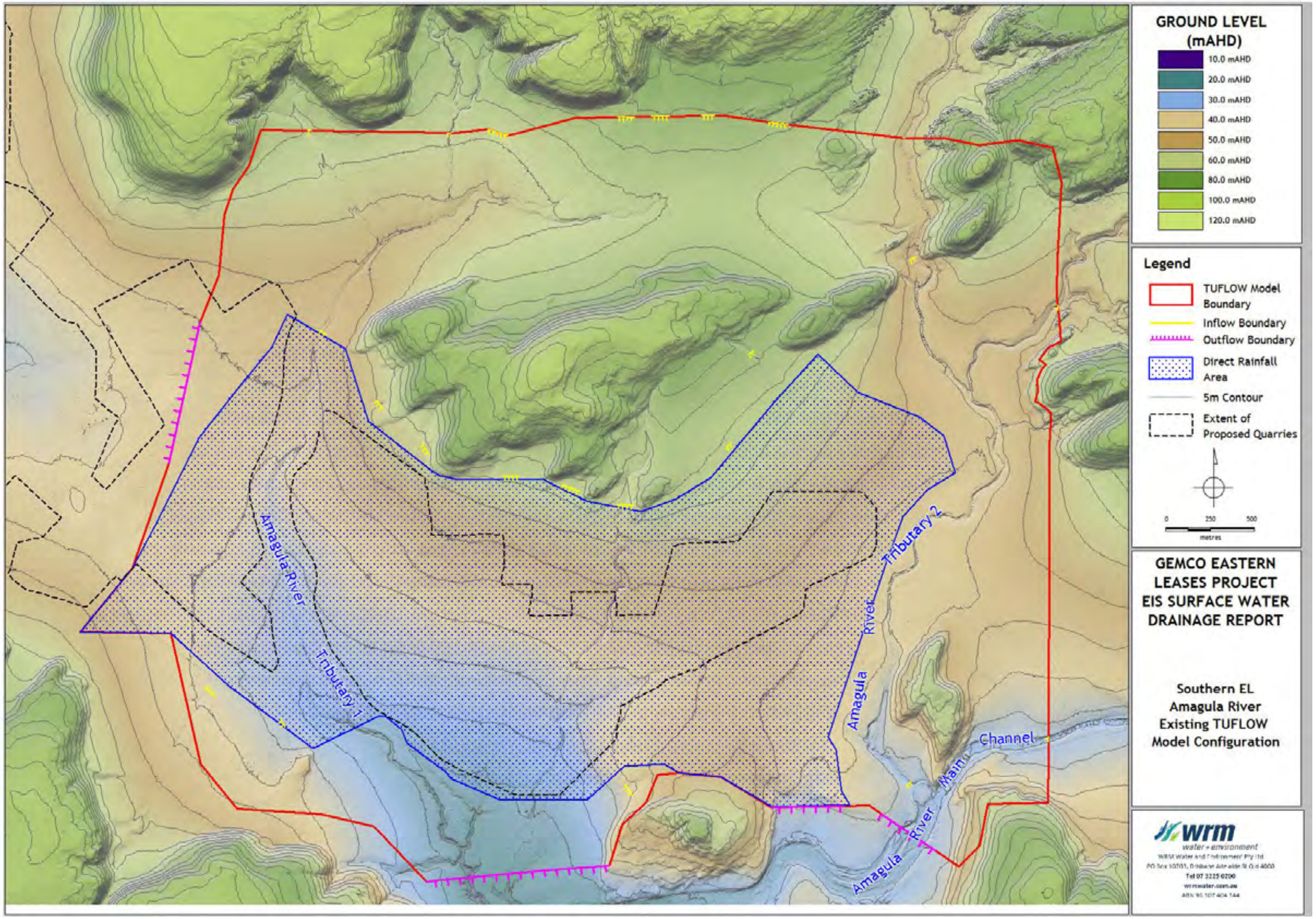

Figure 12 - Amagula River Pre-Mining TUFLOW Model Configuration

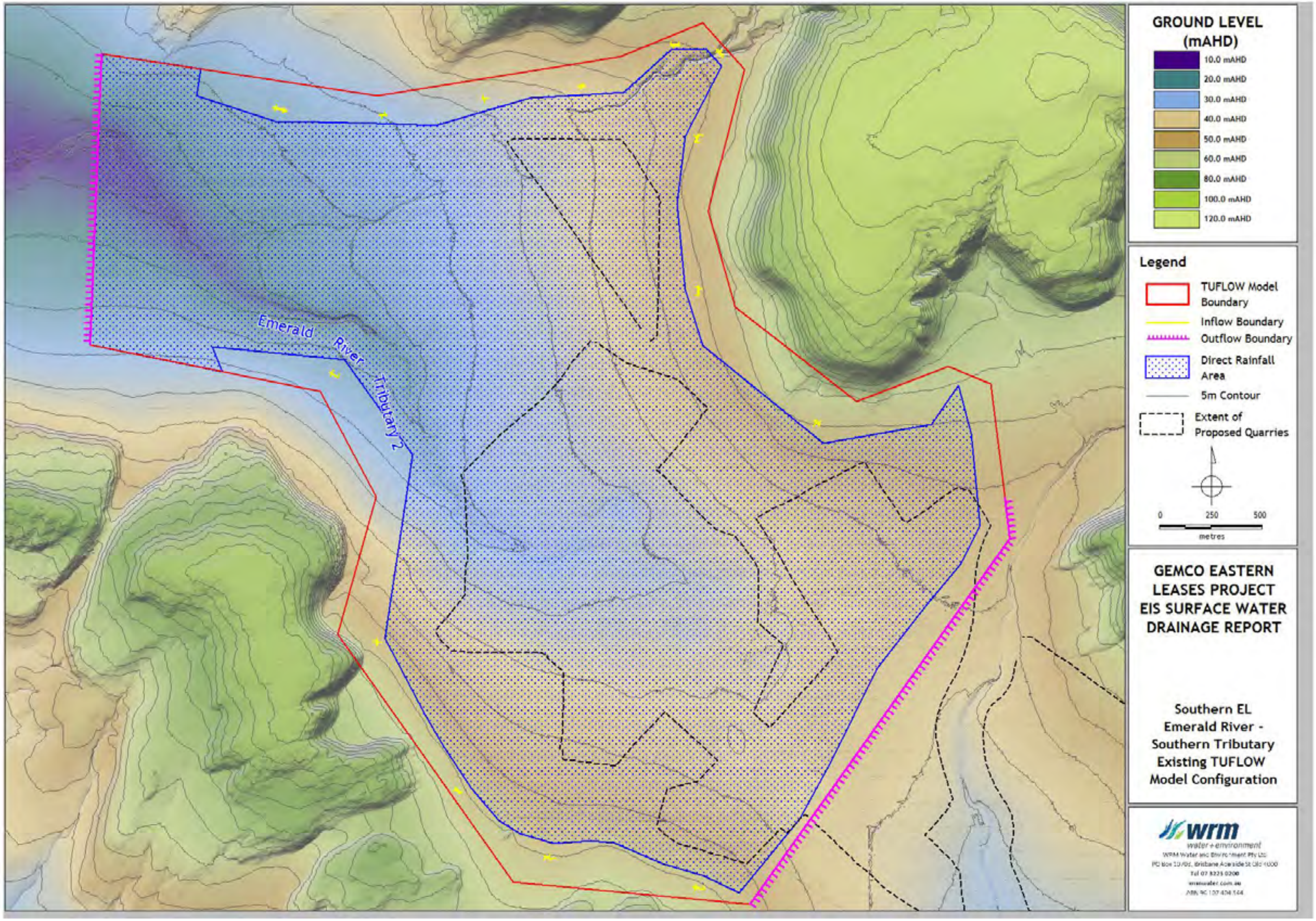

Figure 13 – Emerald River - Tributary 2 Pre-Mining TUFLOW Model Configuration

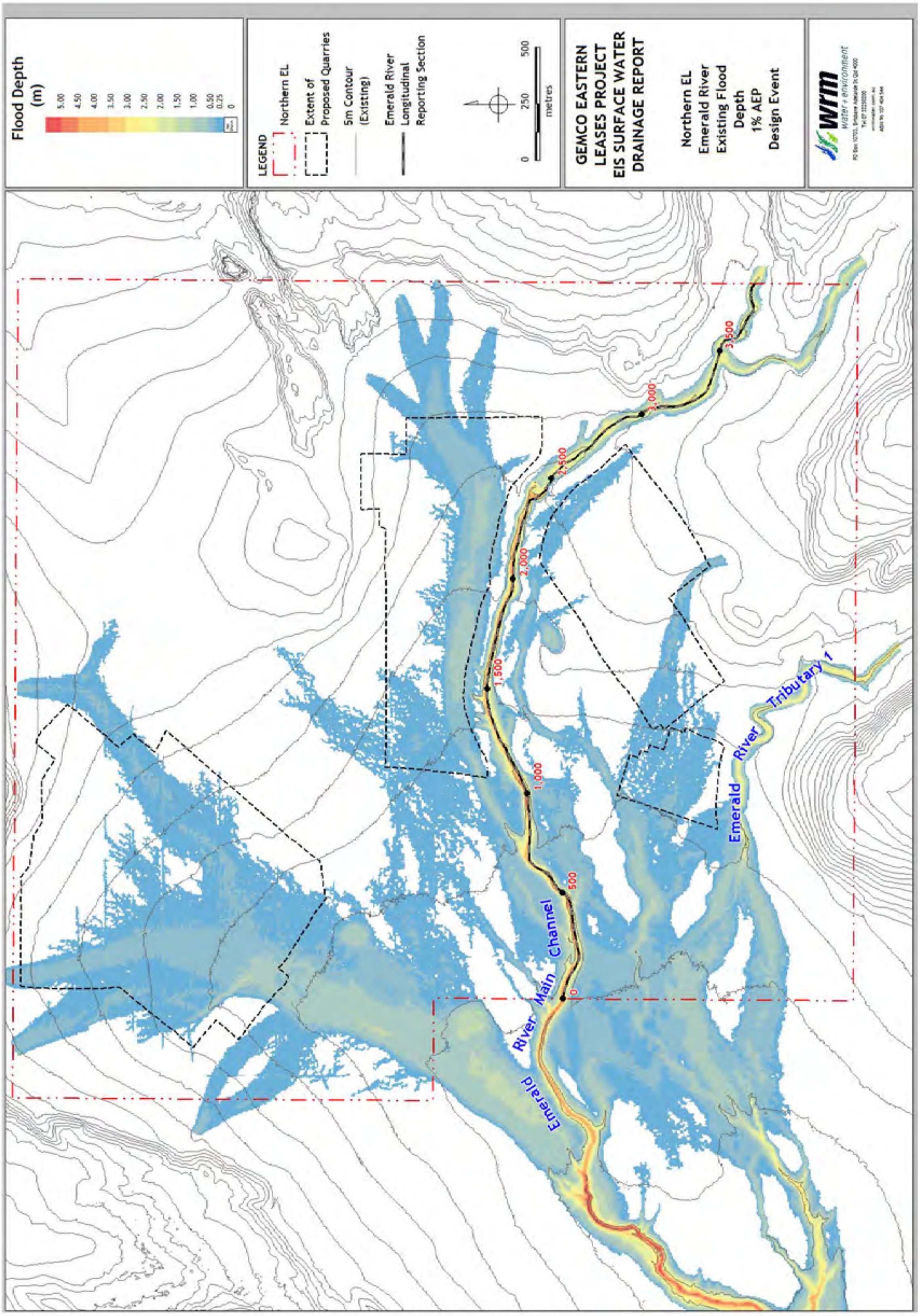

Figure 14 - Emerald River 1% AEP Pre-Mining Flood Depth

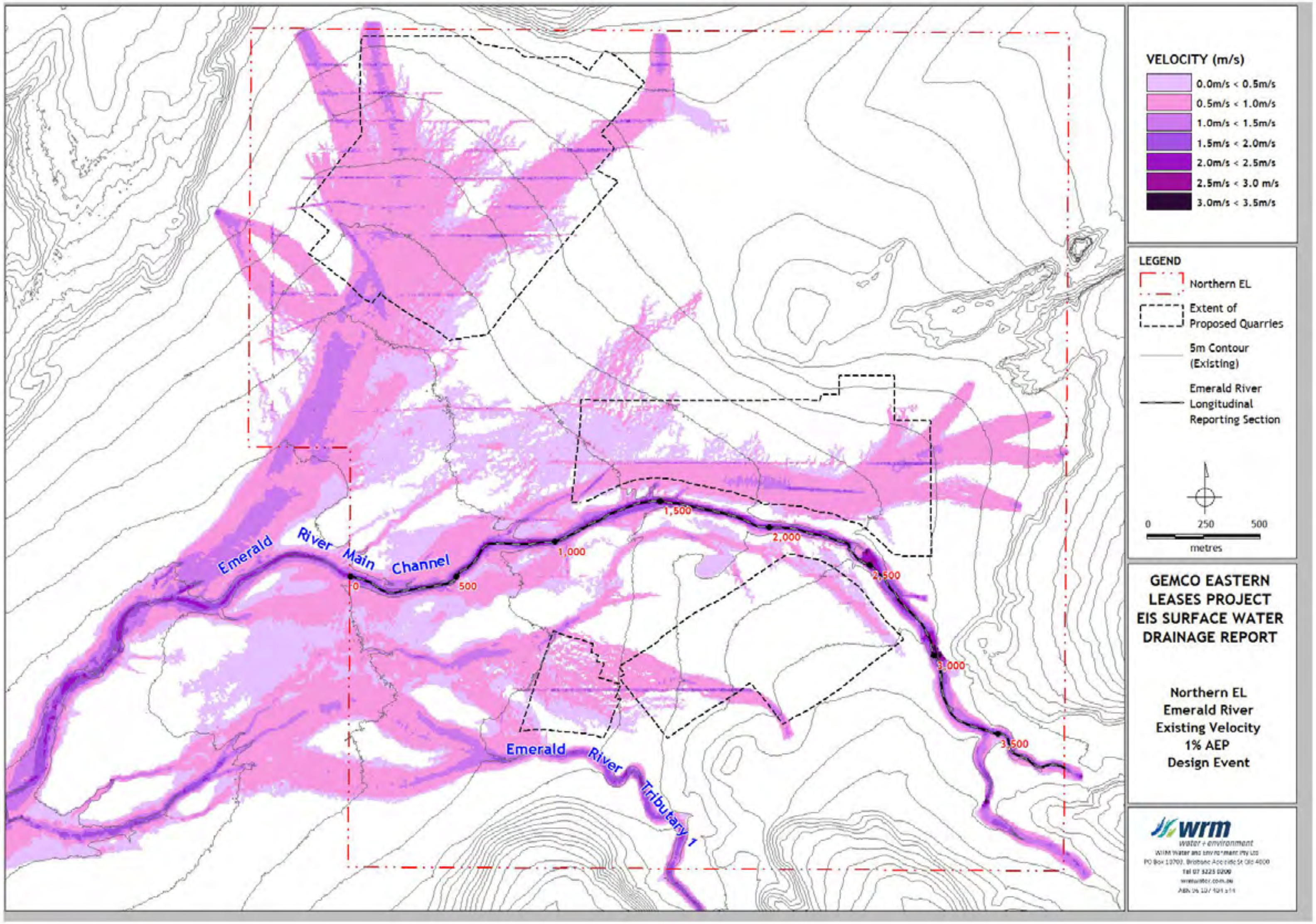

Figure 15 - Emerald River 1% AEP Pre-Mining Flood Velocity

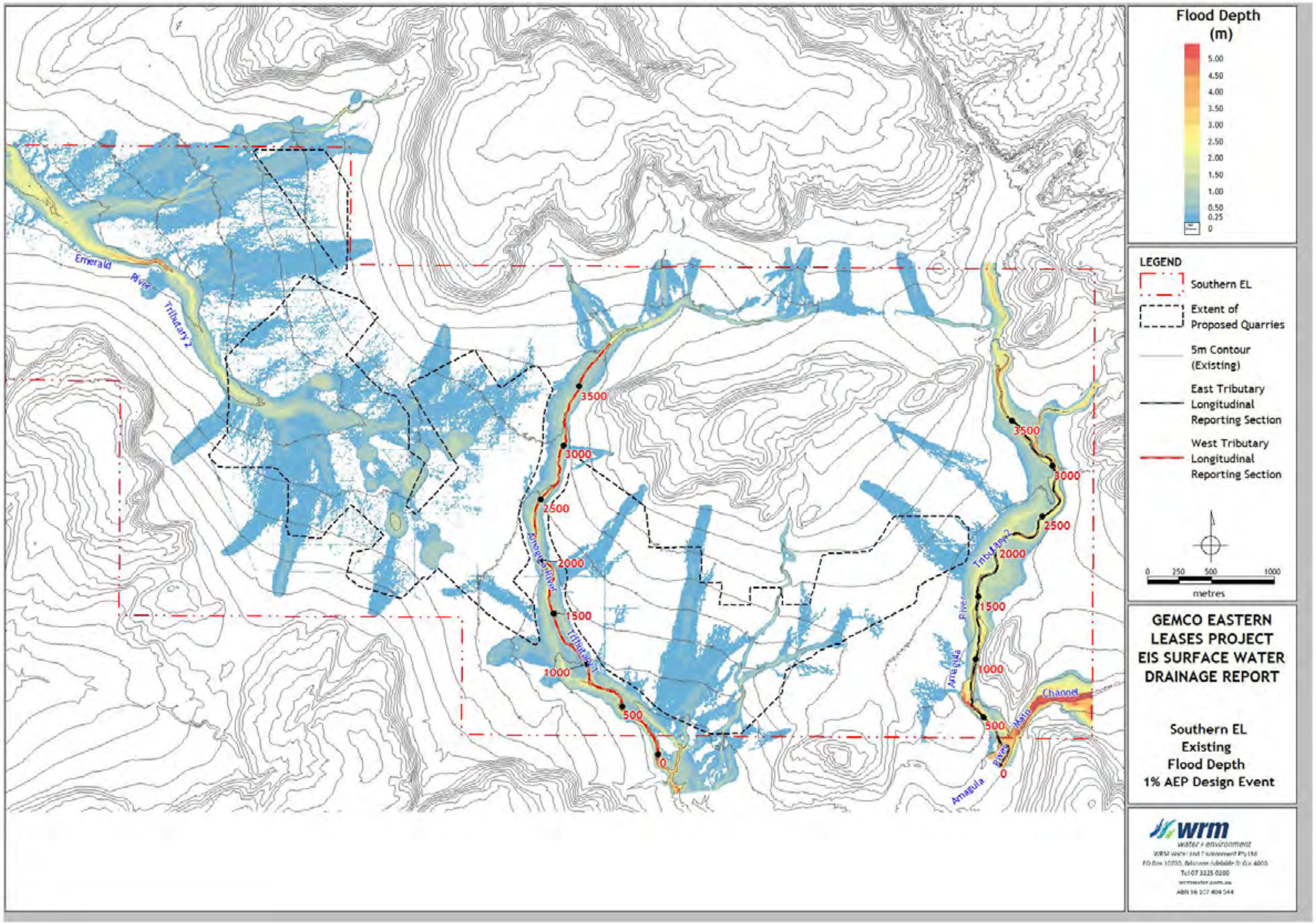

Figure 16 - Amagula River 1% AEP Pre-Mining Flood Depth

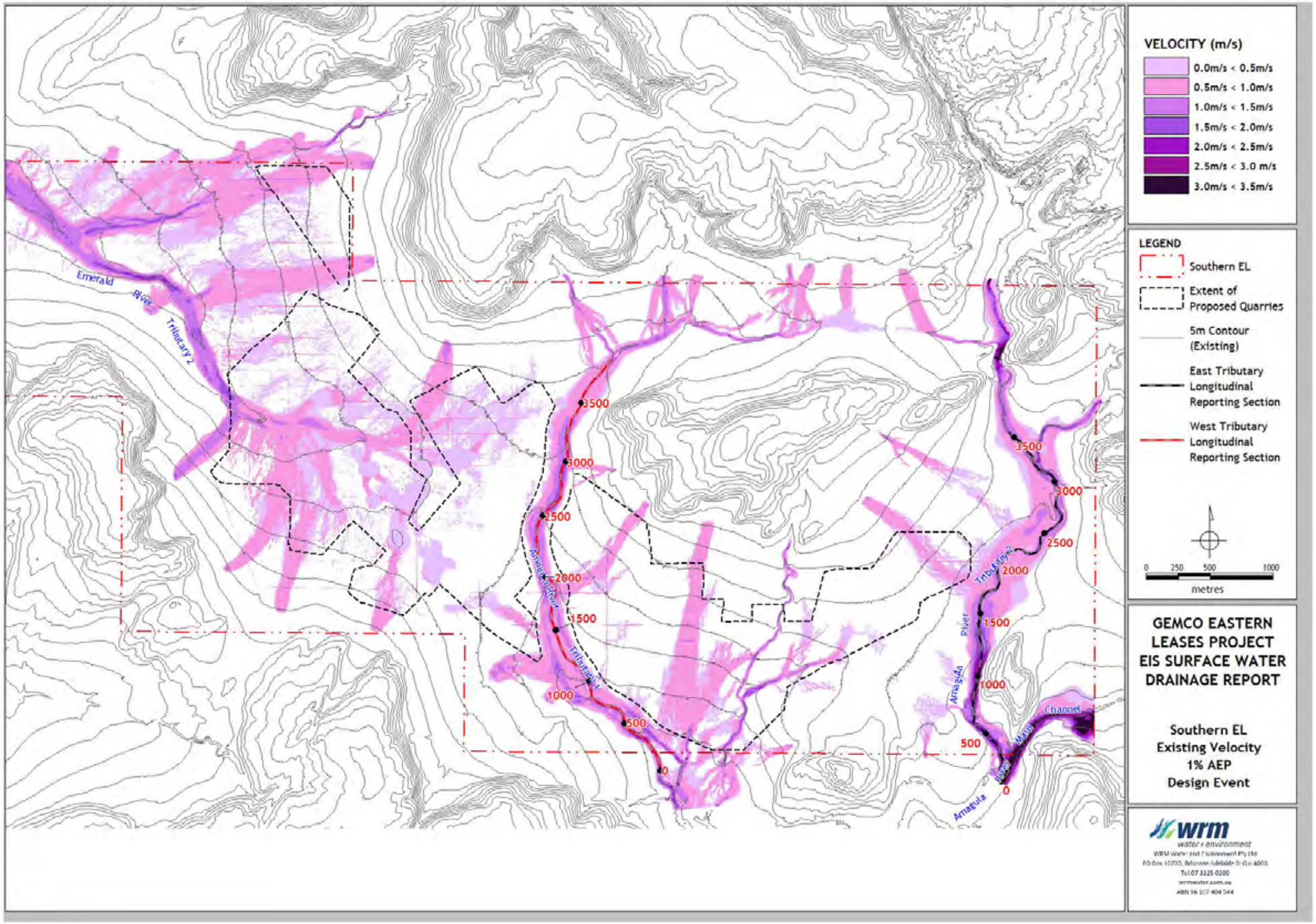

Figure 17 - Amagula River 1% AEP Pre-Mining Flood Velocity

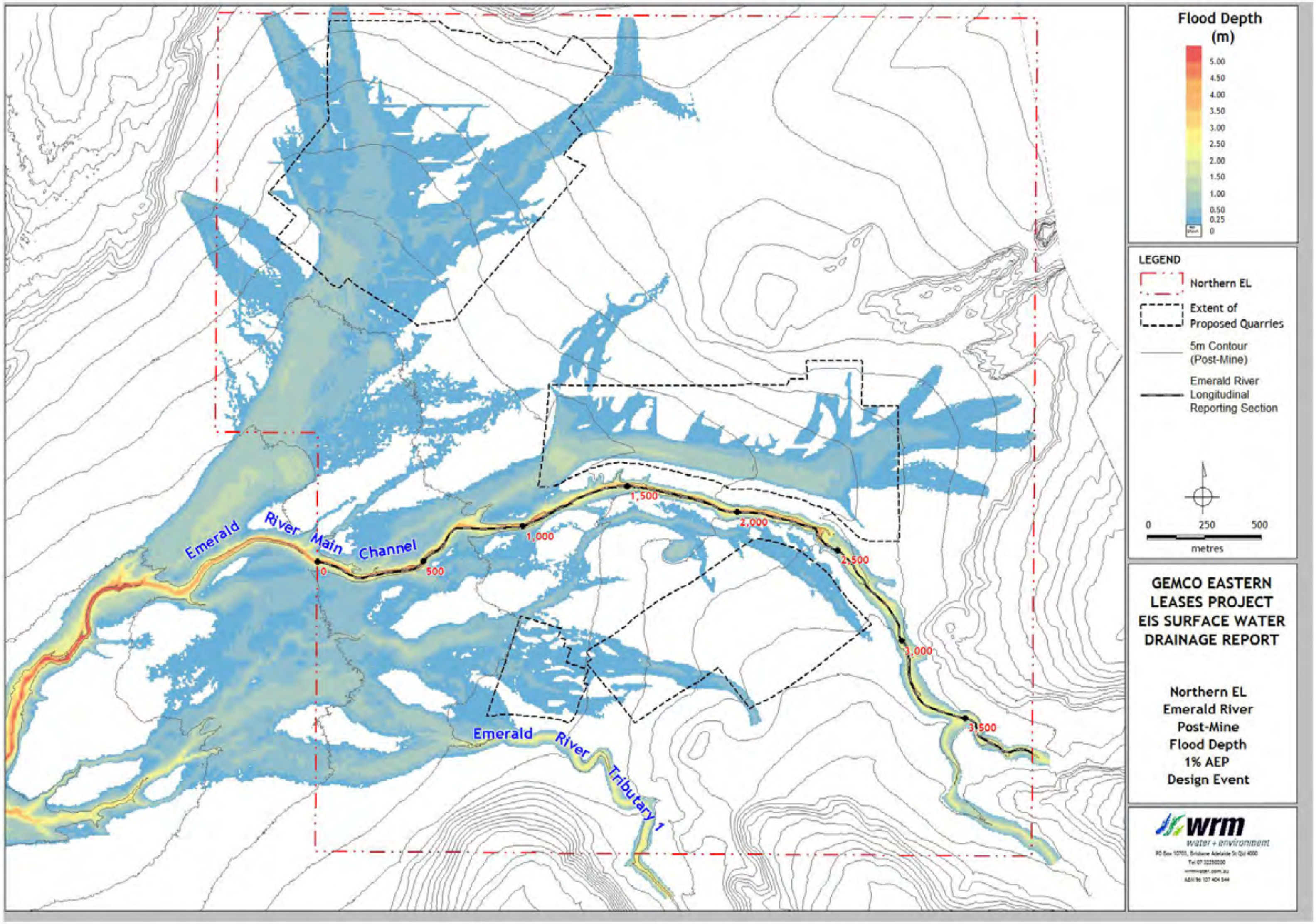

Figure 18 - Emerald River 1% AEP Post Mining Flood Depth

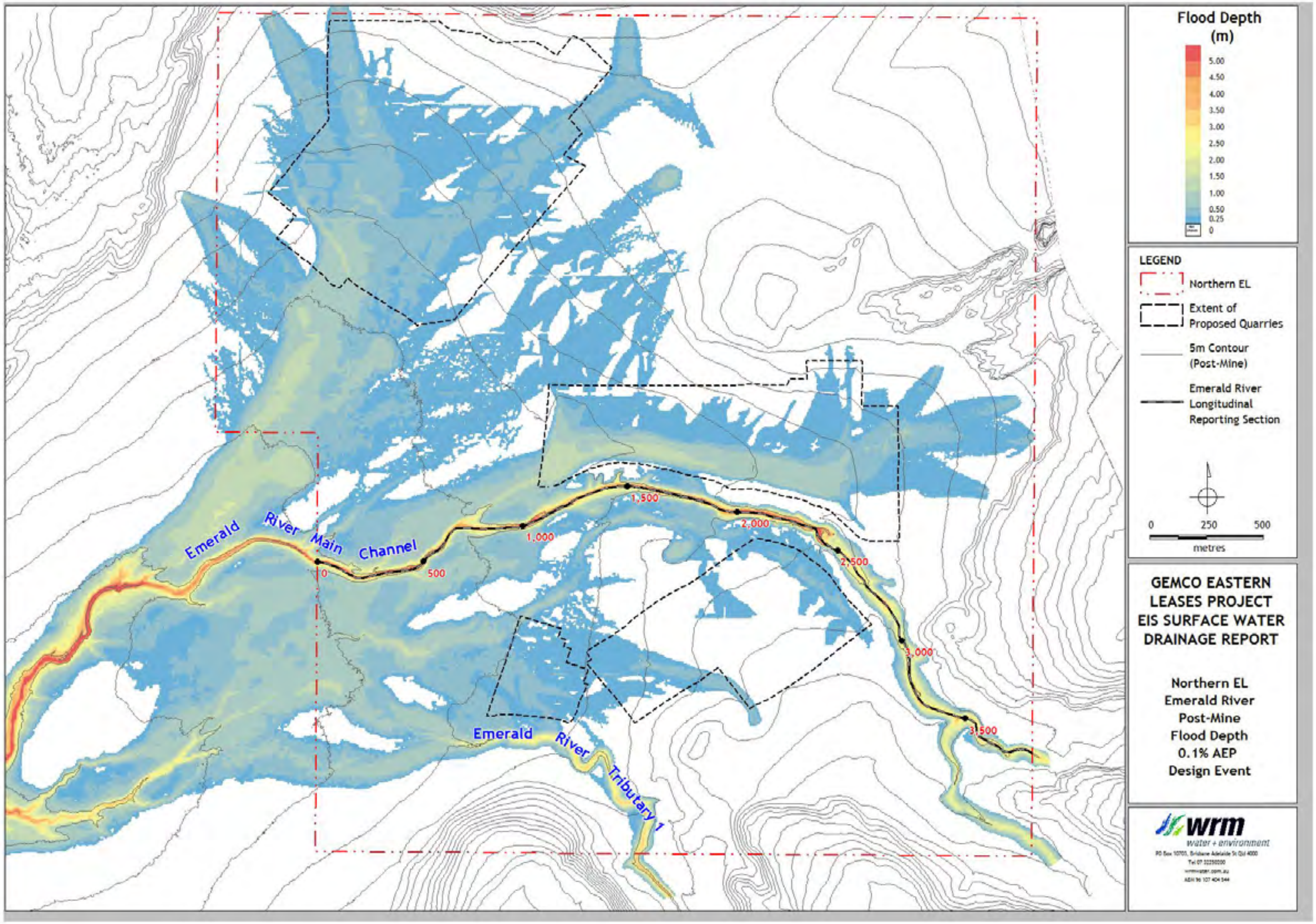

Figure 19 - Emerald River 0.1% AEP Post Mining Flood Depth

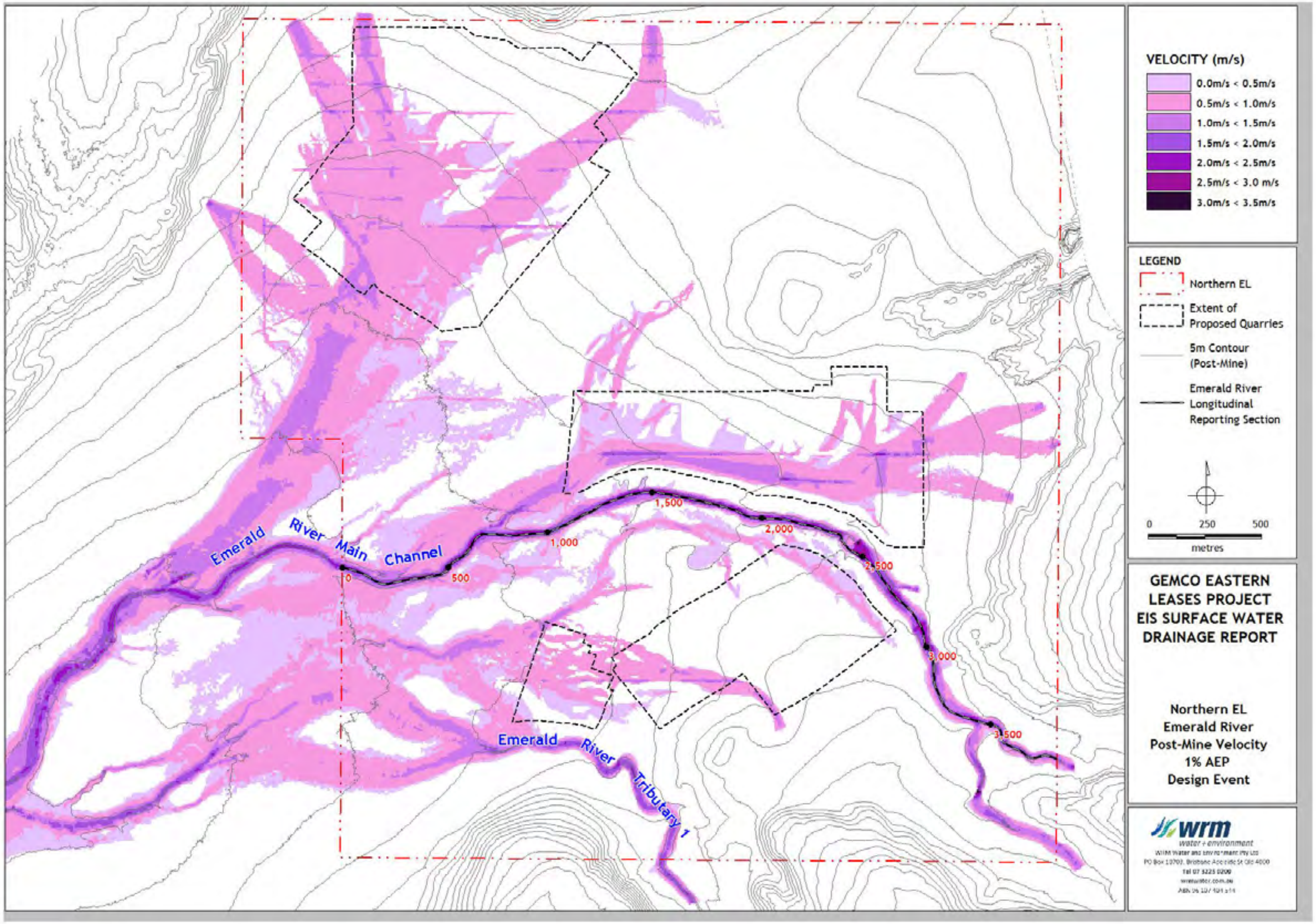

Figure 20 - Emerald River 1% AEP Post Mining Flood Velocity

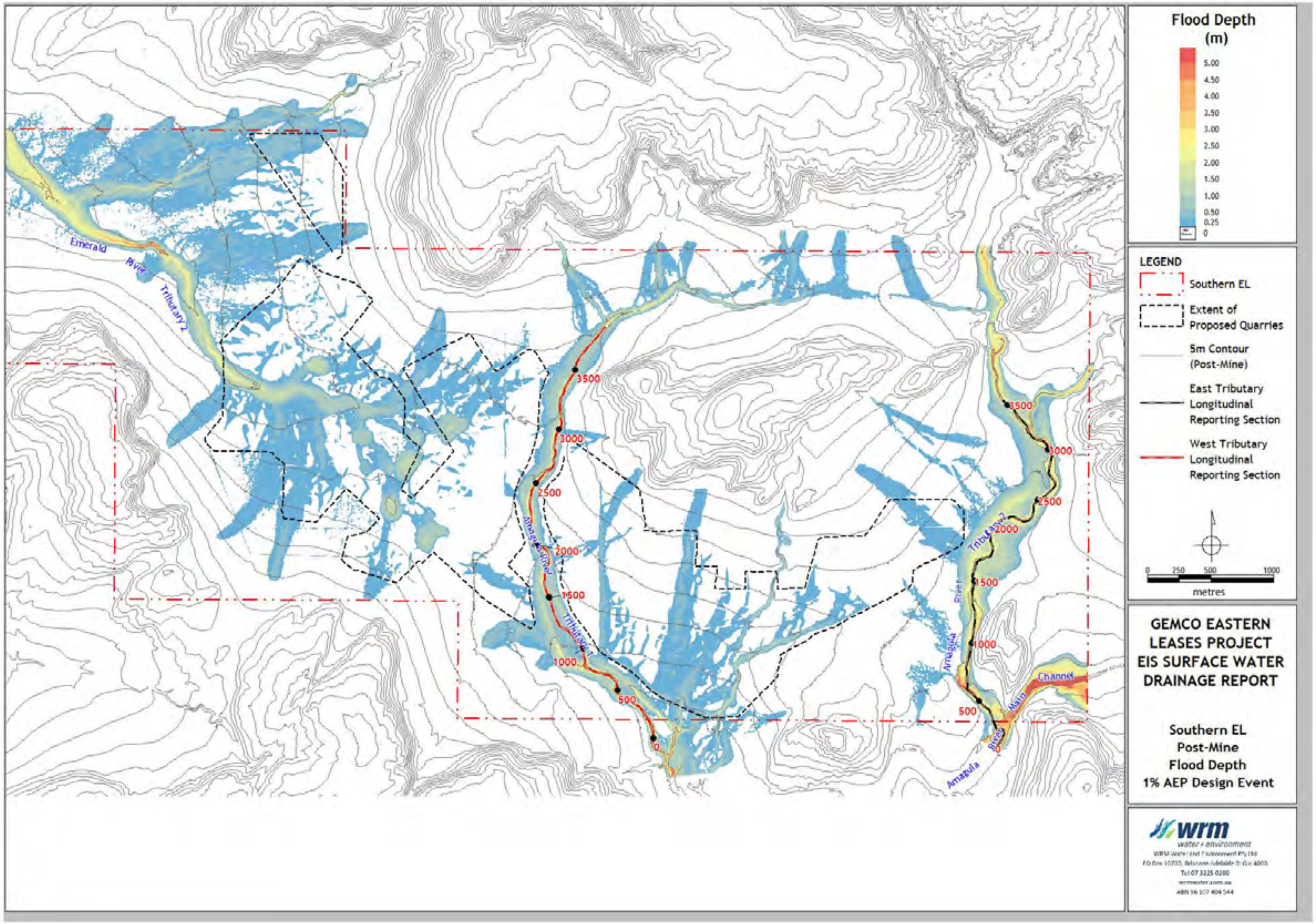

Figure 21 - Amagula River 1% AEP Post Mining Flood Depth

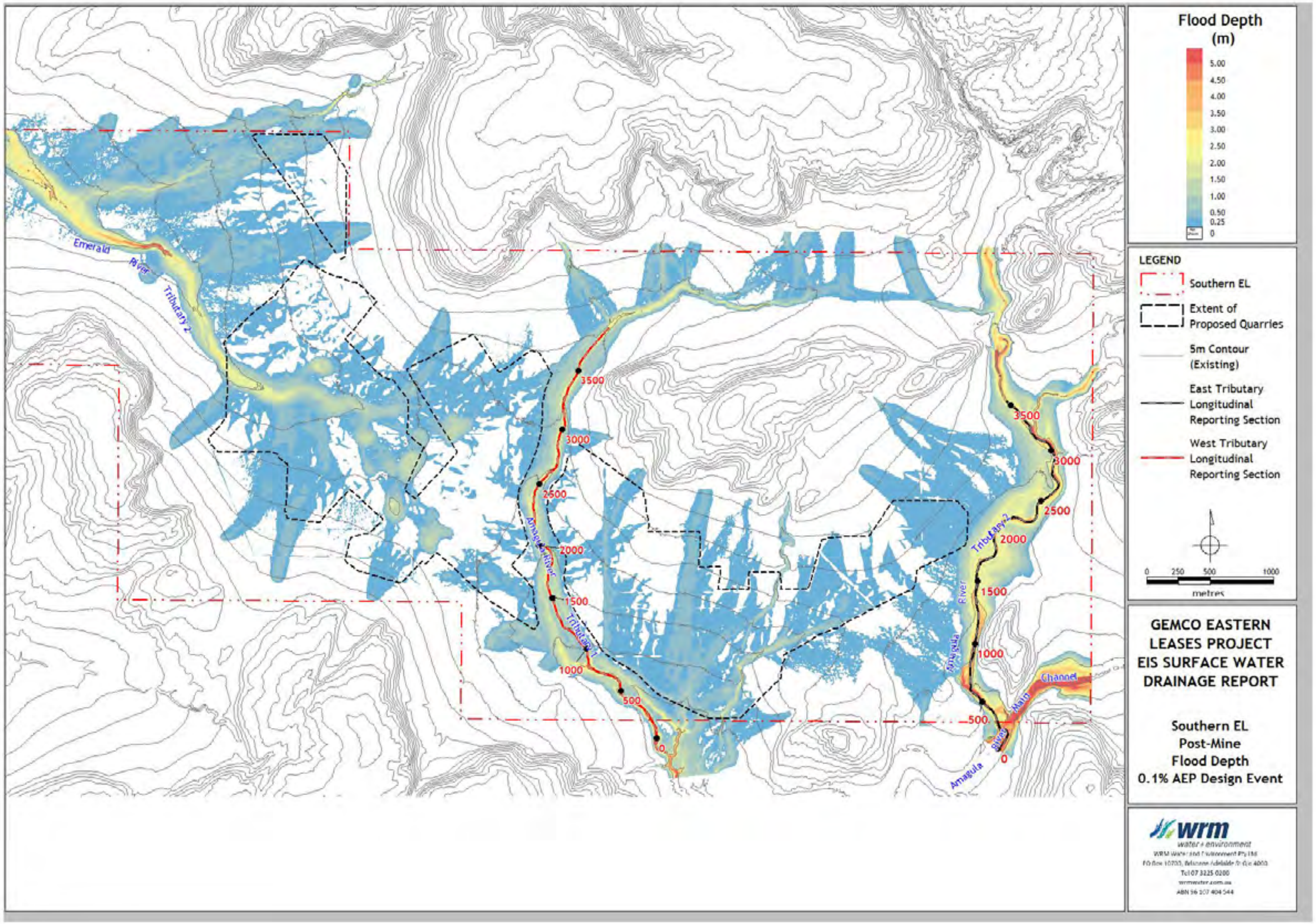

Figure 22 - Amagula River 0.1% AEP Post Mining Flood Depth

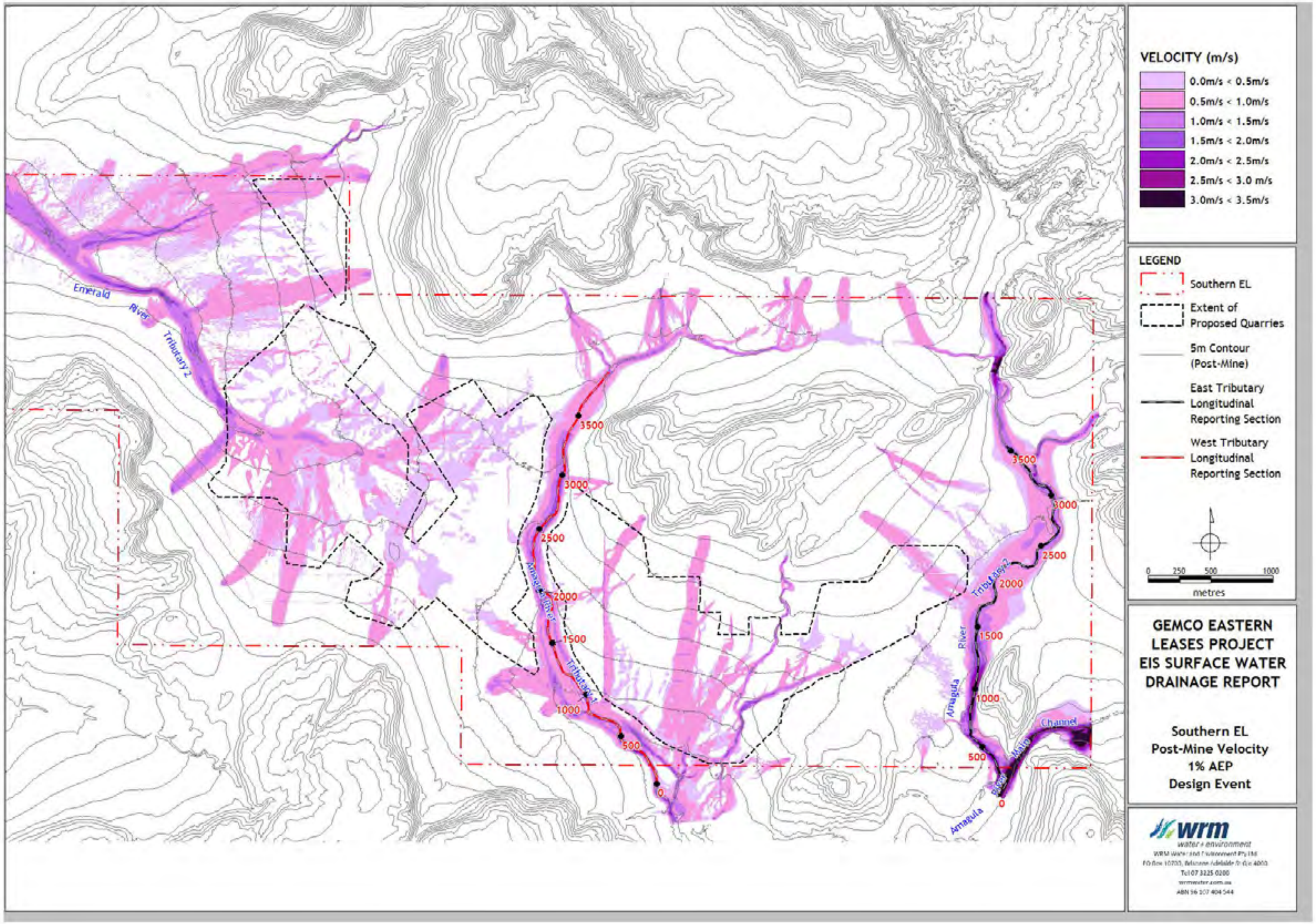

Figure 23 - Amagula River 1% AEP Post Mining Flood Velocity

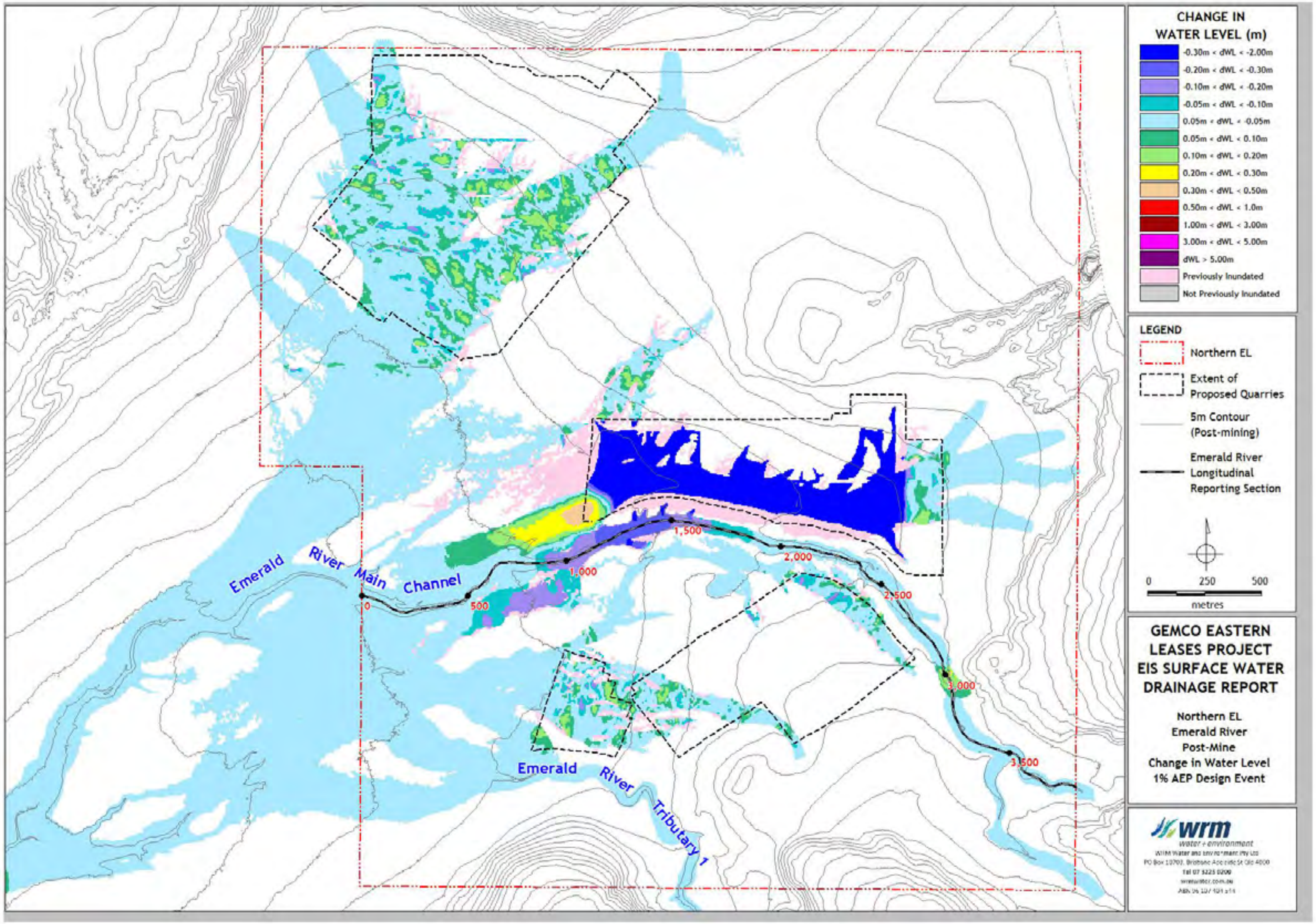

Figure 24 - Emerald River 1% AEP Post Mining Change in Water Level

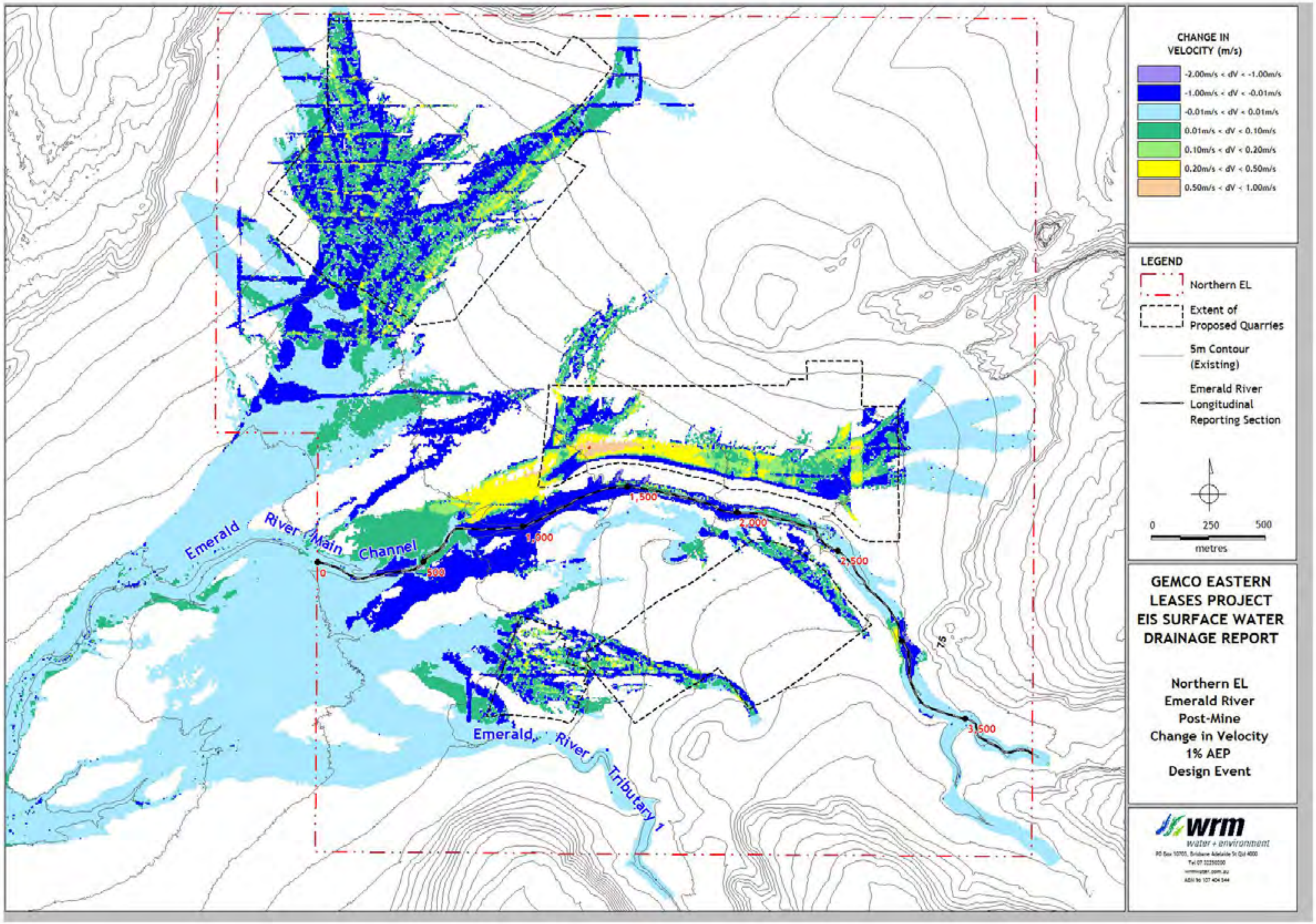

Figure 25 - Emerald River 1% AEP Post Mining Change in Peak Velocity

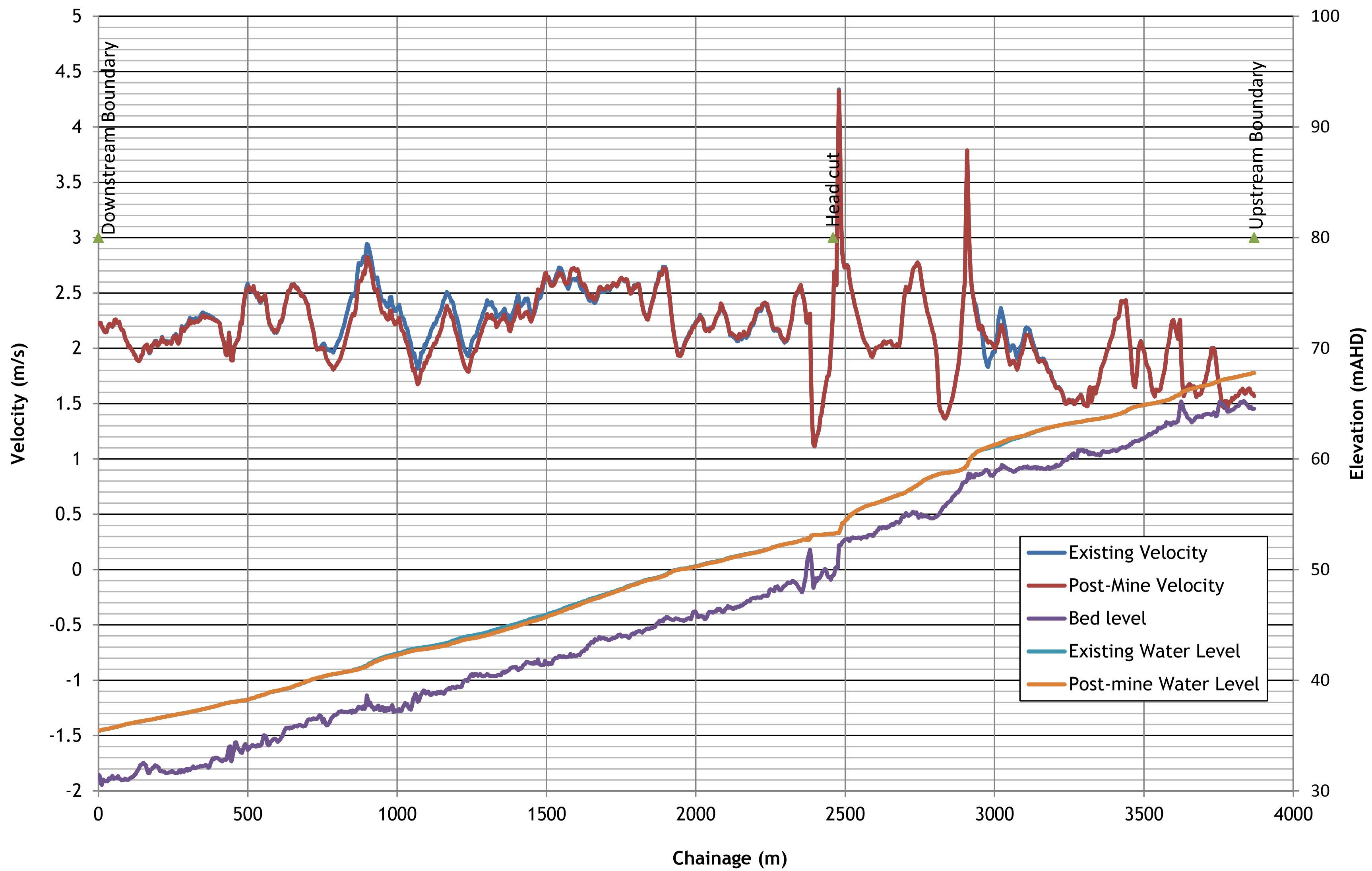

Figure 26 - Emerald River 1% AEP Peak Flood Level and Velocity Longitudinal Profiles, Pre-Mining and Post Mining Conditions

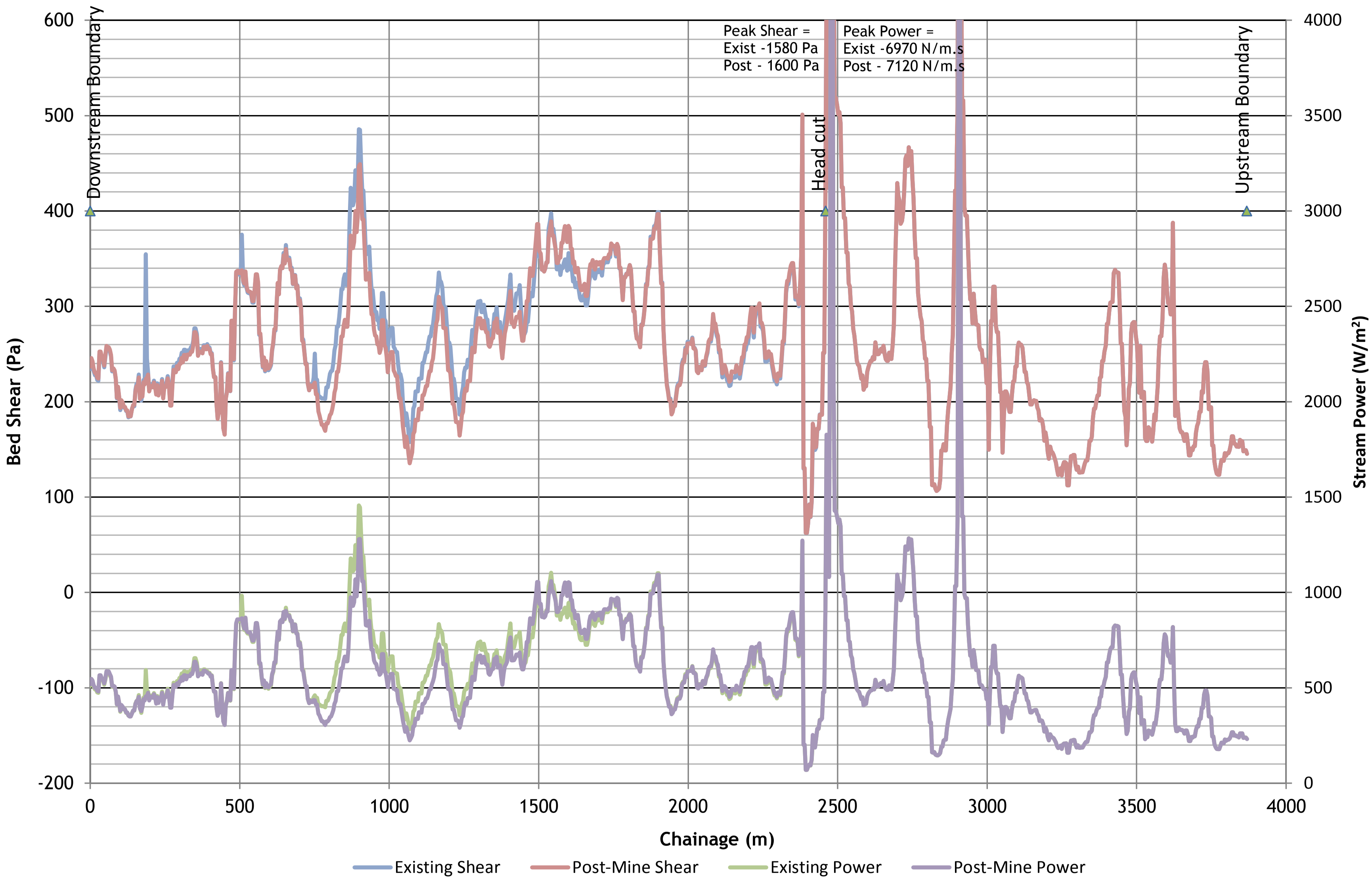

Figure 27 - Emerald River 1% AEP Peak Bed Shear and Stream Power Longitudinal Profile, Pre-Mining and Post Mining Conditions

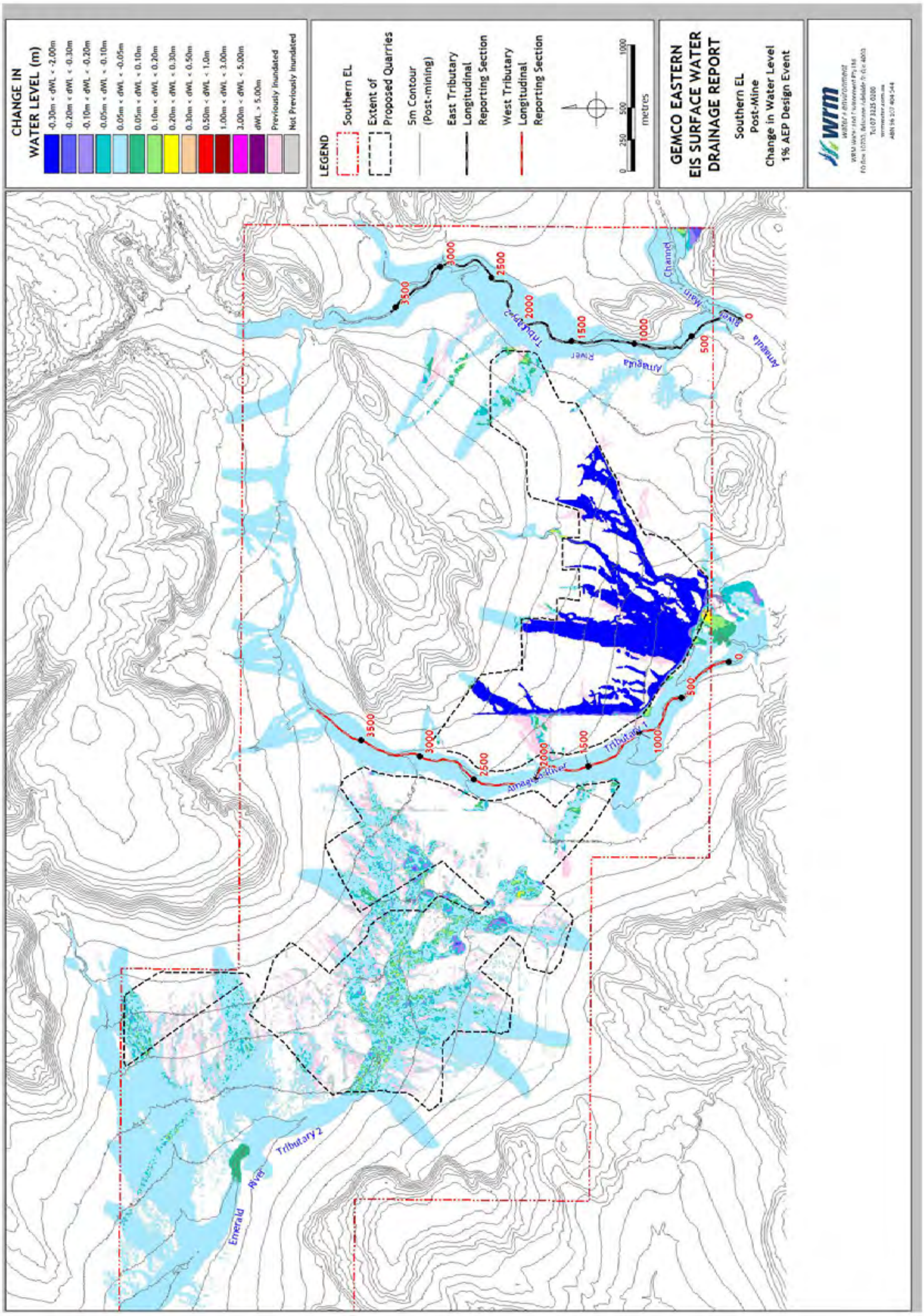

Figure 28 - Amagula River 1% AEP Post-Mining Change in Water Level

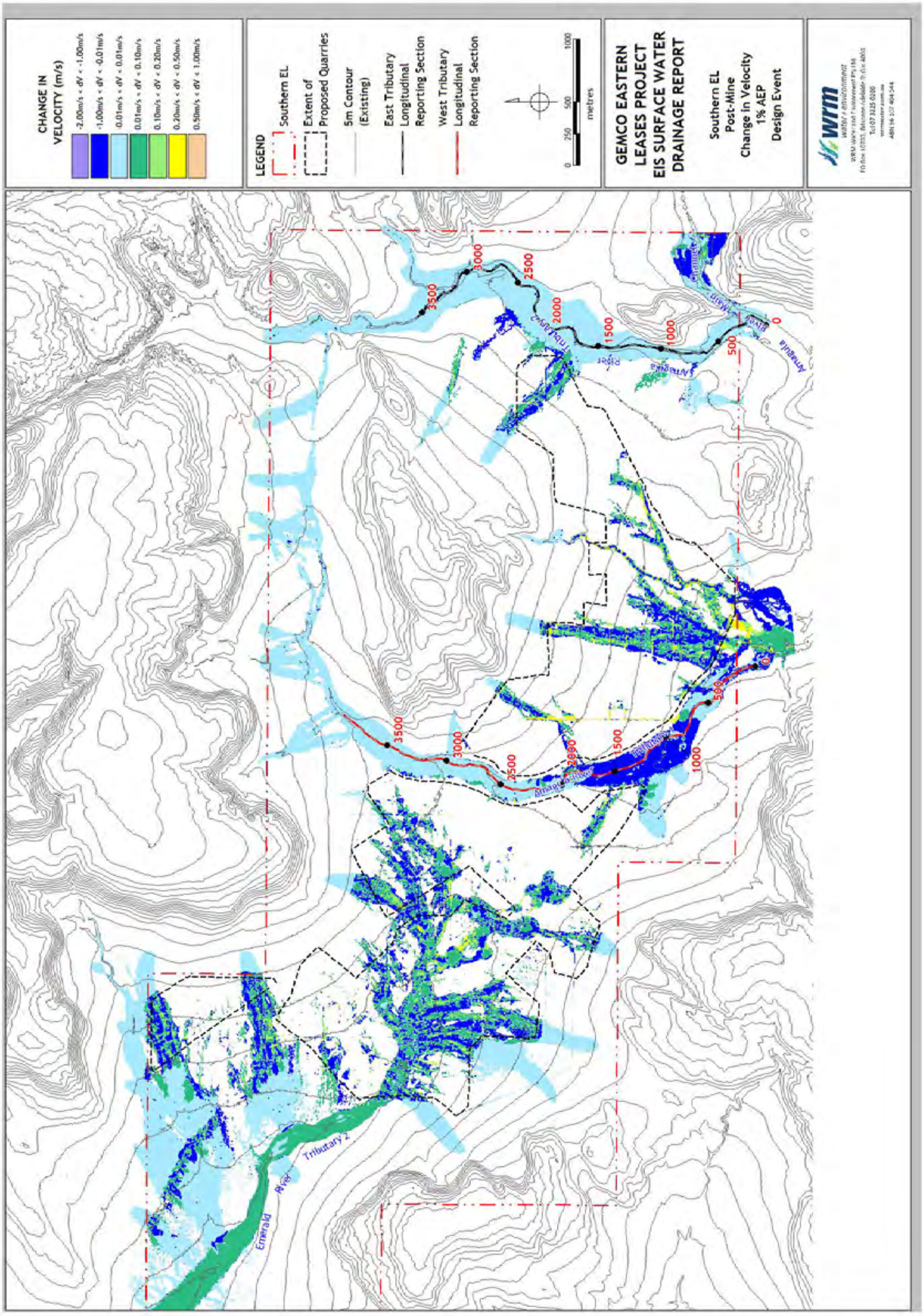

Figure 29 - Amagula River 1% AEP Post-Mining Change in Velocity

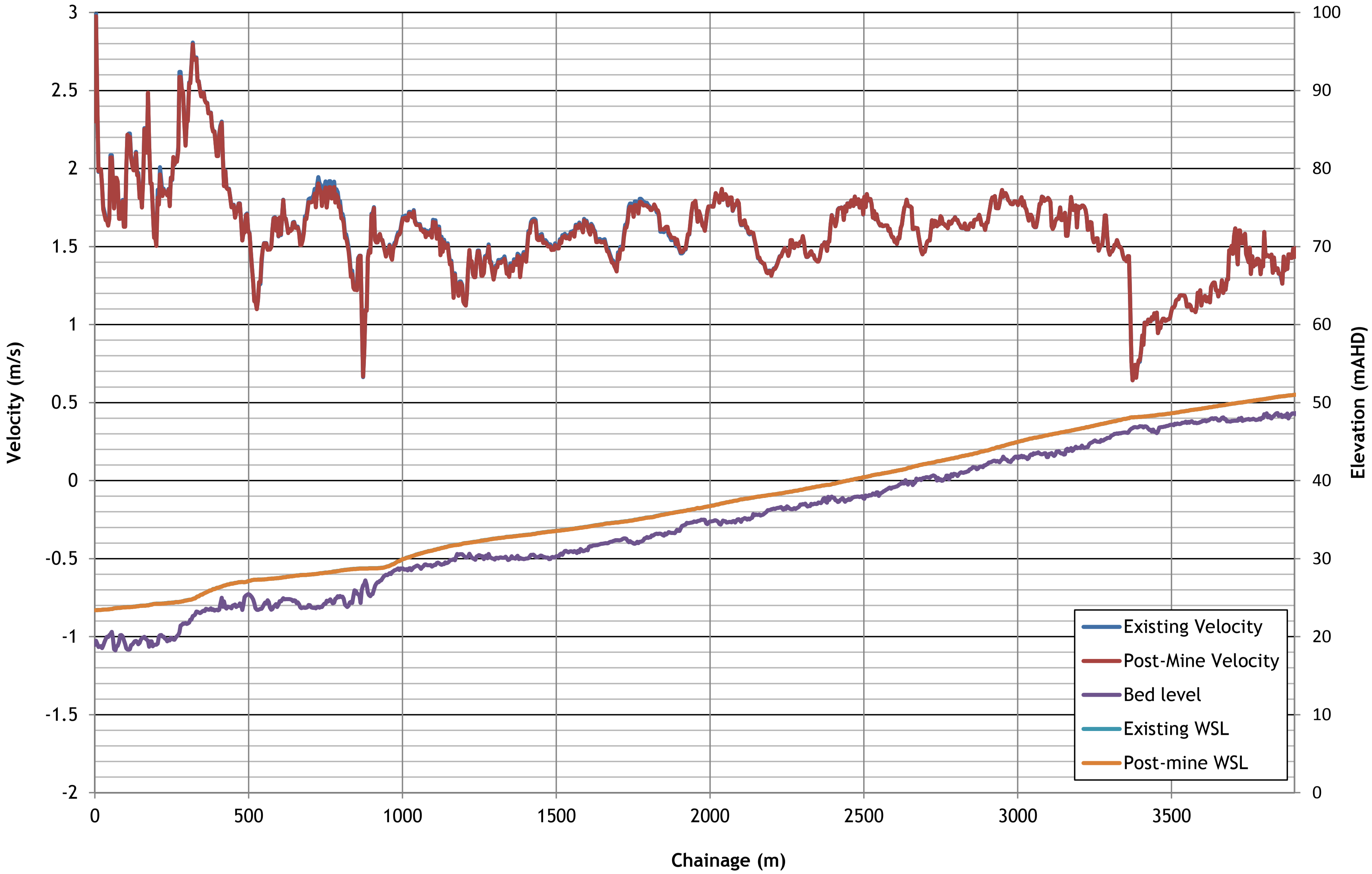

Figure 30 - Amagula River - Tributary 1 1% AEP Peak Flood Level and Velocity Longitudinal Profiles, Pre-Mining and Post Mining Conditions

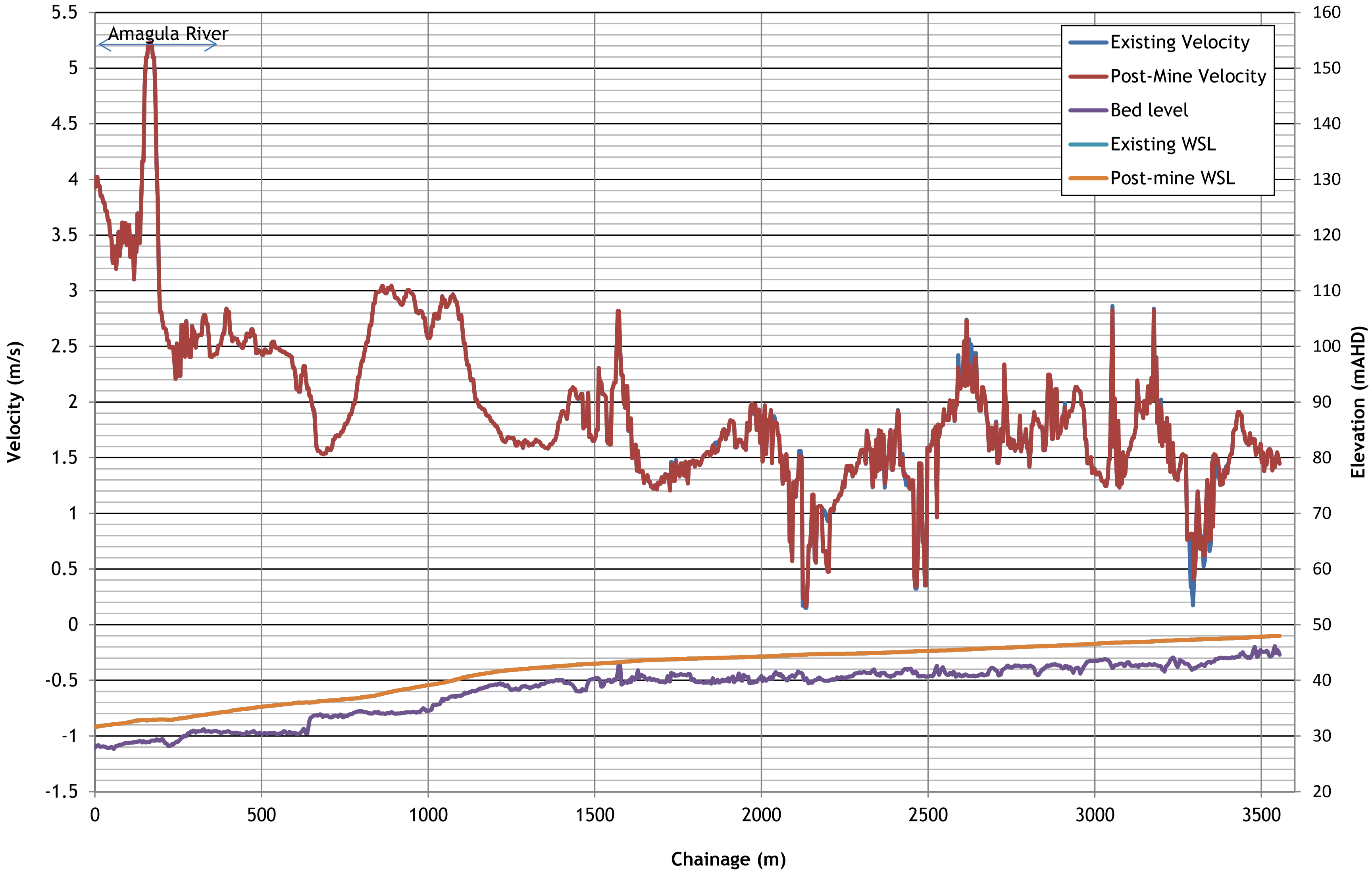

Figure 31 - Amagula River - Tributary 2 1% AEP Peak Flood Level and Velocity Longitudinal Profiles, Pre-Mining and Post Mining Conditions

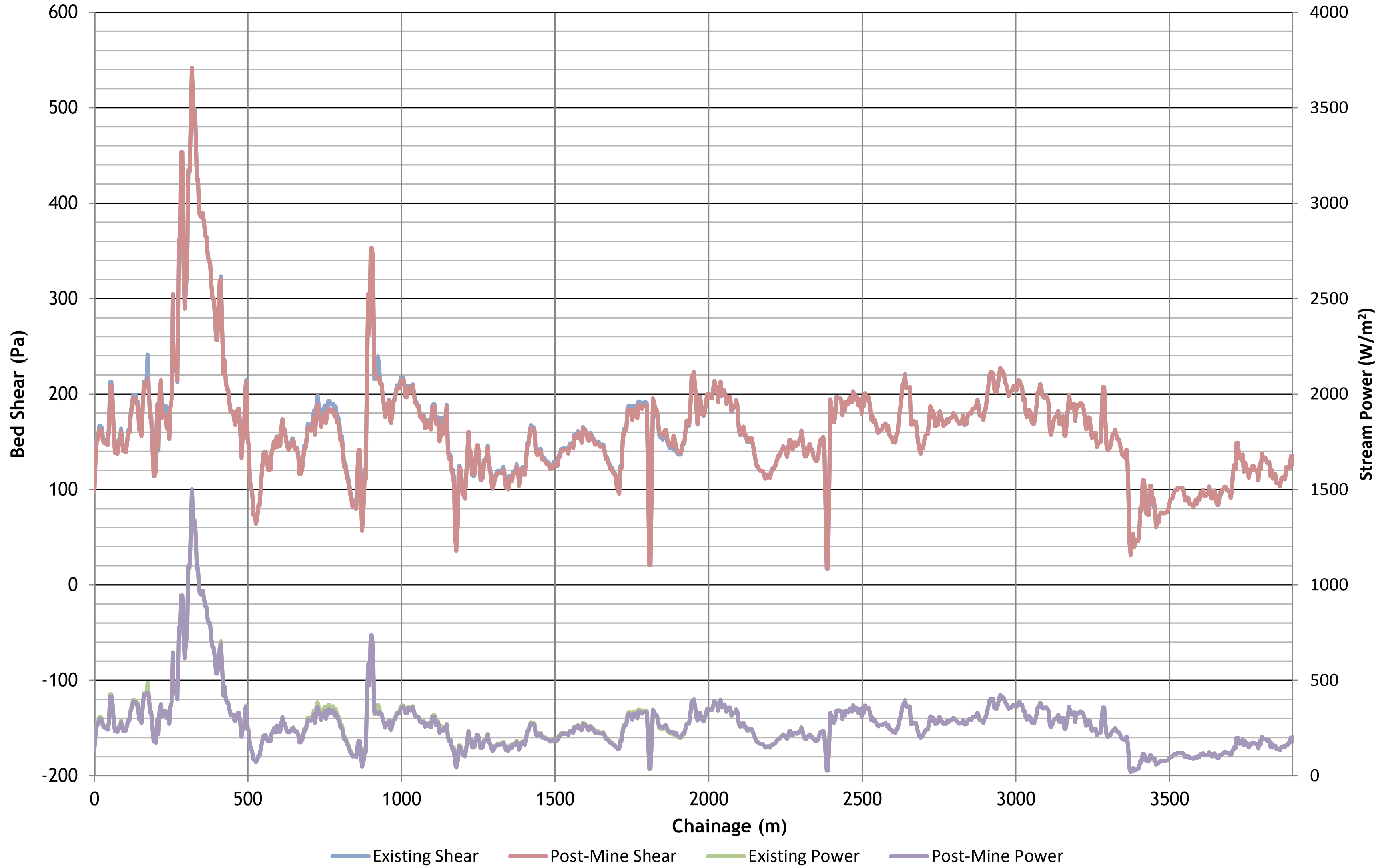

Figure 32 - Amagula River - Tributary 1 1% AEP Peak Bed Shear and Stream Power Longitudinal Profiles, Pre-Mining and Post Mining Conditions

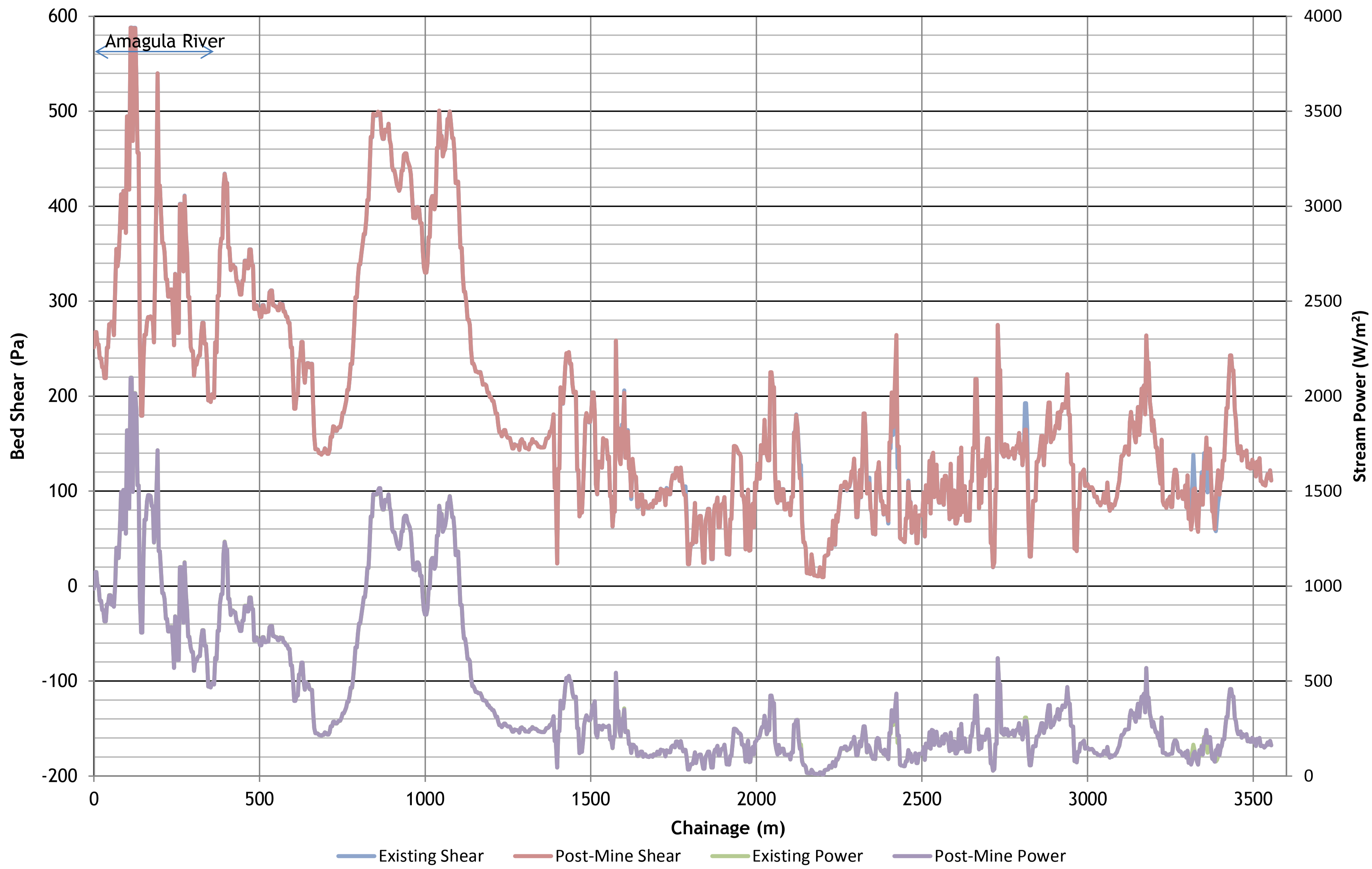

Figure 33 - Amagula River - Tributary 2 1% AEP Peak Bed Shear and Stream Power Longitudinal Profiles, Pre-Mining and Post Mining Conditions