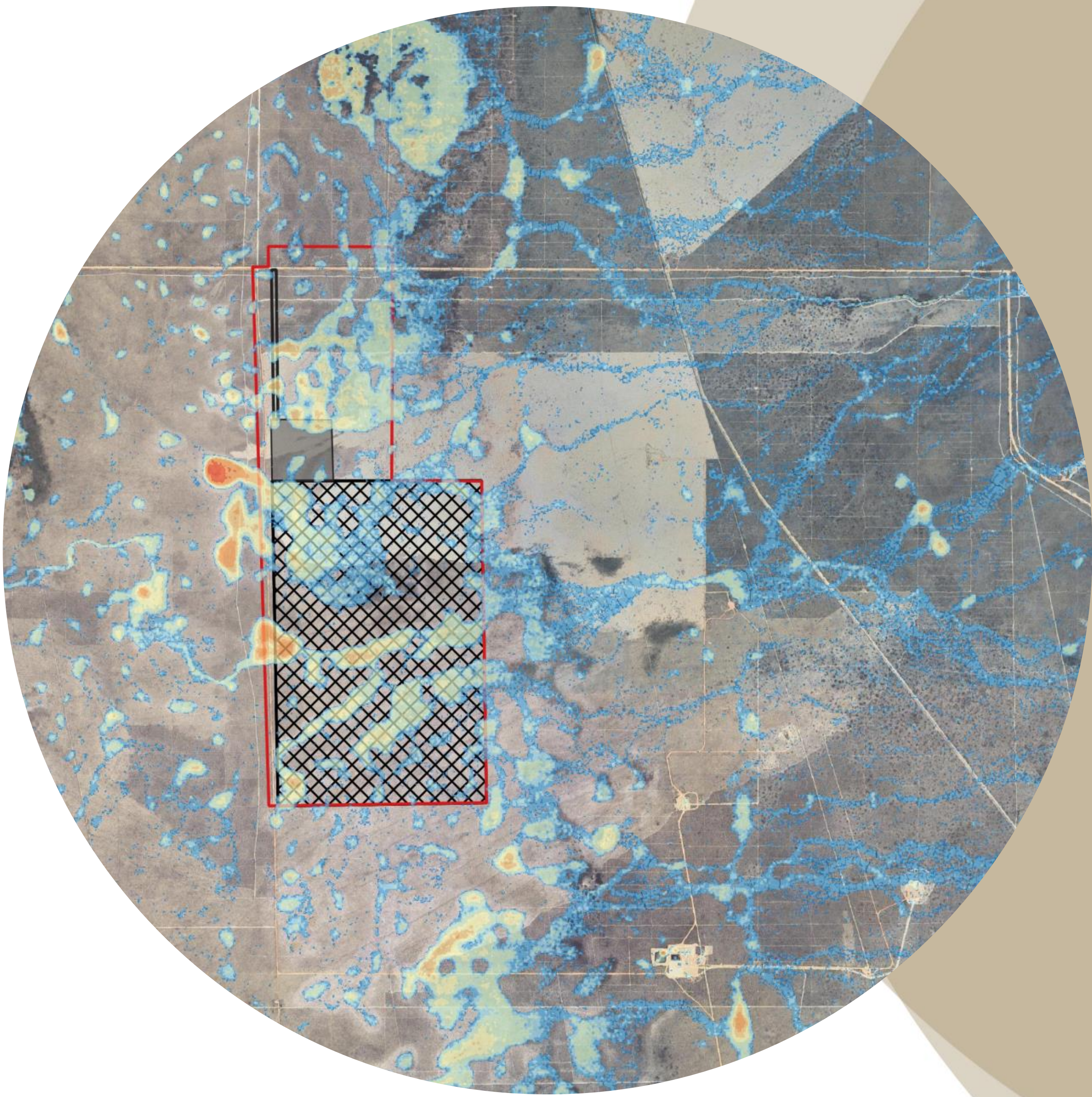

Beharra Silica Sand Project

Surface Water Assessment

Tetris Environmental Pty Ltd

3/03/2022

311012-00905

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Disclaimer

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PROJECT 311012-00905 - HY-001: Beharra Silica Sand Project - Surface Water Assessment

Rev	Description	Author	Review	Advisian approval	Revision date	Client approval	Approval date
A	Internal Review	T. Halton	R. Perrigo	S. Atkinson	24.01.22	-	27 Jan 22
B	Client Review	T. Halton	R. Perrigo	S. Atkinson	31.01.22		
0	Issued for Client Use	pp T. Halton	S. Atkinson	S. Atkinson	03.03.22		

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Executive Summary

The objective of the study is to complete 1% Annual Exceedance Probability (AEP) and 0.1% AEP (1 in 1,000 AEP) surface water modelling of the proposed Beharra Silica Sand Project (Project) under Existing and Post-development conditions and use the results to identify surface water management requirements for Operations and Closure and assess surface water impacts. The 0.1% AEP event was selected for Closure modelling given the sandy soil conditions, limited depth and extent of mining and associated risks at Closure.

A 2D TUFLOW model was developed and used to simulate following scenarios:

- Existing conditions (1% and 0.1% AEP); and
- Post-development conditions:
  - Operations: simulate 1% AEP event with proposed mine plan in place; and
  - Closure: simulate the 0.1% AEP event with proposed Closure design in place.

The Existing conditions modelling results were used to establish and characterize baseline hydrological conditions. The Post-development conditions modelling results were used to quantify risk, identify surface water management requirements for Operations and Closure.

Existing and Post-development flood modelling results are discussed below.

Existing Conditions

1% AEP Event

The 1% AEP flood maps in Figure 5-1 and Figure 5-2 show the site is sparsely inundated with floodwaters generally at low velocity. A large portion of the streamflow enters the Project area from the east via drainage lines and reports to topographic depressions, which appear to have capacity greater than the 1% AEP flood volume. Given the sandy soil conditions, floodwater accumulating in these depressions is expected to rapidly infiltrate to groundwater. Peak velocities are less than 2 m/s in the mine development area.

0.1% Event

The 0.1% AEP flood maps in Figure 5-3 show more widespread flooding and inundation of the Project area, when compared with the 1% AEP results. As with the 1% AEP event, floodwater accumulating in topographic depressions is expected to rapidly infiltrate to groundwater. Peak velocities are less than 2 m/s in the mine development area (Figure 5-4).

Operations

The 1% AEP flood depth and velocity maps are presented in Figure 5-5 and Figure *5-6* respectively. The results suggest the following:

- Diversion bunds and drains are required around the pit shell to redirect 1% AEP floodwater to topographic depressions north of the mine infrastructure area, where it will infiltrate. The location of diversion bunds and trapezoidal diversion drains are shown in Figure 5-7. The following concept designs were adopted to provide necessary freeboard to top of bund, in accordance with the Basis of Design (Section 3):

- Flood bund heights range between 1.5 and 3.4 m; and
  - Trapezoidal diversion drains range between 1.5 and 3.2 m depth (from drain invert to bund crest), with 5 m base and 1:3 side slopes.
- The 1% AEP velocities in the diversions range between 0.2 and 1.6 m/s. As the peak velocities are less than, 2 m/s rock protection is not required in accordance with the Basis of Design (Section 3).

Closure

The 0.1% AEP flood depth and velocity maps are presented in Figure 6-1 and Figure 6-2 respectively. The results suggest the following:

- The pit backfill design has reinstated pre-development flow paths at Closure. Floodwater accumulates in the topographic depressions and infiltrates, consistent with the Existing conditions scenario,
- Peak 0.1% AEP velocities entering the mine area are less than 2 m/s so rock protection is not required, and
- Peak flood depths and velocities outside the pit area are consistent with the Existing conditions scenario.

Surface Water Assessment Outcomes

<u>Operations</u>

Under Existing conditions, the delineated catchments are internally draining, meaning streamflow from seasonal rainfall-runoff events report to intermittent damplands located in topographic depressions. This runoff ponds and/or infiltrates within these dampland areas.

Given the highly permeable sandy soil present at the mine site and within the surrounding catchments, rainfall infiltrates without producing runoff for the more frequent events. Surface drainage lines do not flow on a regular basis within the Project area. Therefore, damplands within the Project area are expected to be dependent on direct rainfall-runoff only and not from inflows from surrounding regional drainage lines.

Damplands located outside of the mine disturbance footprint (pit shells, mine infrastructure area and roads) are not expected to be impacted by diversion of external drainage lines as they rarely contribute flow.

<u>Closure</u>

Under Existing conditions, the majority of floodwater in drainage lines flow from the east into the proposed pit area, before infiltrating.

Under Closure conditions, the pit void is partially backfilled and pre-development flow paths reinstated to allow the majority of floodwater to flow from the east into the partially backfilled pit area where it infiltrates, consistent with Existing conditions.

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Acronyms and abbreviations

Acronym/abbreviation	Definition
AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ARR1987	Australian Rainfall & Runoff, 1987 Edition (IEAust.,1987)
ARR2019	Australian Rainfall & Runoff, 2019 Edition (Ball *et al.*, 2019)
AVM	Average Variability Method
BoM	Bureau of Meteorology
DBCA	Department of Biodiversity, Conservation and Attractions
DEM	Digital Elevation Model
GIS	Geographic Information System
IFD	Intensity Frequency Duration
PEC	Perpetual Resource Ltd
PMP	Probable Maximum Precipitation
PMF	Probable Maximum Flood
RFFA	Regional Flood Frequency Analysis
RFFE	Regional Flood Frequency Estimation
RMSE	Root Mean Squared Error
RoC	Runoff Coefficient
ROG	Rain on Grid
SRTM	Shuttle Radar Topography Mission
WASG	Western Australian Soil Groups
2D	Two-dimensional

1 Introduction

1.1 Background

Perpetual Resources Ltd (PEC) is seeking approval to develop the greenfield Beharra Silica Sand Project (Project), located 25 km Southeast of Dongara, Western Australia. The resource is a high purity white sands deposit which is estimated at 111.3 Mt of 98.6% silica, which is above the water table. The area will be developed by progressively pre-stripping the surface, mining and returning tailings to the voids, re-shaping the surface, and re-vegetating the area (PEC, 2021). Supporting process and non-process infrastructure is to be located near the northern boundary of the deposit. Site access will be via a new access road from Mount Adams Road, constructed as part of the Project. The site location and Project area (defined by the development envelope) are shown in Figure 1-1.

Advisian were engaged by Tetris Environmental Pty Ltd to complete this hydrology study to inform stormwater management during Operations and Closure and assess associated surface water impacts.

1.2 Objective

The objective of the study is to complete 1% Annual Exceedance Probability (AEP) and 0.1% AEP (1 in 1000 AEP) surface water modelling of the Project area under Existing and Post-development conditions and use the results to identify surface water management requirements for Operations and Closure and assess surface water impacts. The 0.1% AEP event was selected for Closure modelling given the sandy soil conditions, limited depth and extent of mining and associated risks at Closure.

1.3 Scope of Work

The agreed scope of works for this assessment are:

- Collate and review all relevant site data, mapping, reports and mining plans to characterise the site and identify any gaps or limitations;
- Determine local catchments from available topographic survey data;
- Develop 1% AEP peak flow estimates for catchments in the Project area (defined by development envelope) using methods consistent with the recommendations in ARR2019;
- Select representative loss parameters from publicly available reports and data governing rainfall-runoff generation;
- Develop a 2D TUFLOW rainfall-runoff and hydraulic model, apply loss parameters to the model and simulate following scenarios:
  - Existing conditions (1% and 0.1% AEP); and
  - Post-development conditions:
    - <u>Operations:</u> simulate 1% AEP event with proposed mine plan in place; and
    - <u>Closure:</u> simulate the 0.1% AEP event with proposed Closure design in place.
- Prepare flood maps for the simulations above showing peak flood depths and velocities;
- Review the results of Existing and Post-development modelling and recommend surface water management measures to:
  - <u>Operations:</u> protect the mine from 1% AEP flooding assess impacts; and

- <u>Closure:</u> to minimise the risk of scour/erosion in the 0.1% AEP event and maintain long term stability of the Closure design.

- Use the modelling results to assess surface water impacts during Operations and at Closure. The results will be used by PEC to inform an Environmental Impact Assessment (EIA) for the project.

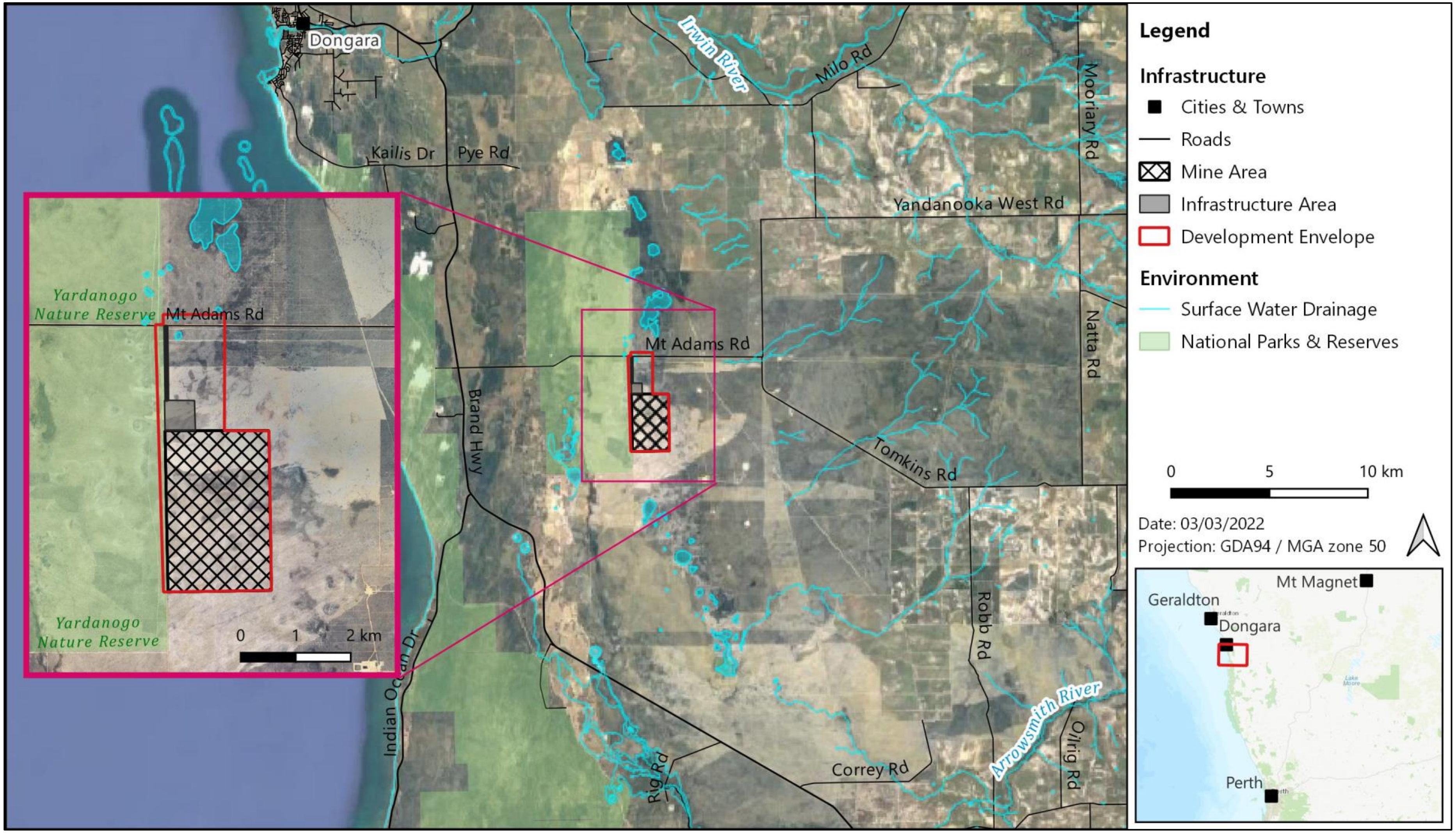

Figure 1-1. Site location and Project area (defined by development envelope) with mapping according to DBCA (2018).

1.4 Sources of Information

The following available data, summarised in Table 1-1, was relied upon for this study:

- Beharra Silica Project, PFS Report (PEC, 2021);
- Mine and infrastructure layouts, Closure designs, development envelopes (GIS polygons);
- Landgate and SRTM topographic data and DEM's;
- BoM rainfall and streamflow data; and
- DPIRD (2019), soil classification data.

Table 1-1. Datasets adopted for the study

Data Type	Description	Source	Date Acquired
Operational Pits and Infrastructure Layouts	GIS polygons delineating: • Development envelope • Access road alignment • Mine pit designs • Infrastructure layout/area	Tetris Environmental Pty Ltd	6th Dec 2021
Closure Designs	Pit backfill design assumes pit walls backfilled to 8 degrees. All other infrastructure decommissioned and reinstated to pre-development topographic conditions.	PEC (2021)	10th Feb 2022
Landgate DEM	Topography data for the project area and contributing catchment. • Grid Size: 5 x 5 m • Vert accuracy: 2 m • Horizontal Accuracy: 5 m • Capture Date: 27th Nov 2016	Landgate	7th Dec 2021
SRTM DEM	Hydrologically enforced topography data (SRTM-H) for the surrounding region: • Grid Size: 1 arc-second (approx. 30 x 30 m) • Vert accuracy: up to 9.73 m RMSE • Capture Date: 2000	Geoscience Australia (2011)	18th Nov 2021
Daily Rainfall Records	Green Grove (ID 8057): recorded 1951 – 2021 Arena (ID 8273): recorded 1980 – 2021 Irwin House (ID 8276): recorded 1982 – 2021	BoM	17th Dec 2021
Continuous Streamflow Record	Arrowsmith River – Robb Crossing (ID 701005) 29 years of data (1972 – 2001)	BoM	18th Nov 2021

Data Type	Description	Source	Date Acquired
Design Rainfall Depth	IFD tables and georeferenced grid data extracted from BoM website for 1987 and 2016 datasets	BoM (1987, 2016)	20th Dec 2021
Western Australian Soil Groups (WASG)	GIS polygons of soil group classifications according to WASG (Schoknecht & Pathan, 2013)	DPIRD (2019)	17th Dec 2021
Dampland Mapping	GIS polygons provided by Tetris, based on work by	Tetris	9th Feb 2022
Operational Life of Mine (LoM)	LoM = 30 years (PEC, 2021)	Tetris	9th Feb 2022

1.5 Terminology

Average Recurrence Interval (ARI) was previously used to define the probability of design flood events as stipulated in Australian Rainfall and Runoff (ARR1987). In the 2019 revision of Australian Rainfall and Runoff (ARR2019), the terminology to define rainfall intensity probabilities was changed to AEP. This new terminology meets the requirements of Engineers Australia's National Committee on Water Engineering and provides clarity of meaning, technical correctness and practicality and acceptability.

The conversion of event likelihood equivalence across the different nomenclature styles is presented in Table 1-2. For events greater than the 10% AEP the conversion from ARI to AEP is approximately equivalent to the inverse of the ARI. ARR (2021) provides a more detailed description of the latest ARR probability terminology and comparison of ARI and AEP equivalence. The % AEP terminology has been adopted throughout this report.

Table 1-2. Summary of AEP and ARI equivalence

Annual Exceedance Probability (AEP)		Average Recurrence Interval (ARI in years)
(% AEP)	(1 in X AEP)	
63.2%	~1	1
50%	2	~2
20%	5	~5
10%	10	~10
5%	20	20
2%	50	50
1%	100	100
0.1%	1000	1000

2 Project Setting

2.1 Topography

Topographic survey data listed in Section 1.4 was used to generate a DEM for the Project area (defined by development envelope). The resulting DEM (Figure 2-1) shows ground elevations varying between 25 m AHD in depressions between Mt Adams Road and the Infrastructure Area and approximately 34 m AHD at high points within the Mine Area.

2.2 Climate

2.2.1 Rainfall

The Project is located in a sub-tropical climate system, characterised by distinctly dry summers, and cooler, wet winters. Three BoM weather stations are located near the Project area at the locations shown in Figure 2-4. The rainfall data recorded at each of these stations is summarised in Table 2-1 and the average monthly rainfall plotted and compared in Figure 2-2.

The rainfall data suggests that the coastal plains receive higher mean annual rainfall (Green Grove: 483 mm), which reduces as you move inland to the east. The majority of rainfall (75-80%) falls in the winter months, from May to September.

The Green Grove rainfall data is considered representative of the mine site area, as it is located on the coastal plain.

Table 2-1. Mean annual rainfall recorded at nearby BoM weather stations

Gauge ID	Gauge Name	Period of record (years)	Distance to Project Area (km)	Distance to Coast (km)	Approx. Altitude (mAHD)	Mean Annual Rainfall (mm)
8057	Green Grove	70	13.8	7.9	27.6	483
8273	Arena	41	33.9	46.4	287.2	399
8276	Irwin House	39	22.8	18.5	58.1	424

2.2.2 Evaporation

Monthly evaporation data for Geraldton is considered representative of the mine site. The SILO database (Queensland Government, 2022) was used to extract monthly pan evaporation data for Geraldton which is plotted in Figure 2-2. Comparison of evaporation and rainfall data suggests that evaporation far exceeds rainfall in summer. Evaporation totals in the cooler winter months are similar to monthly rainfall totals.

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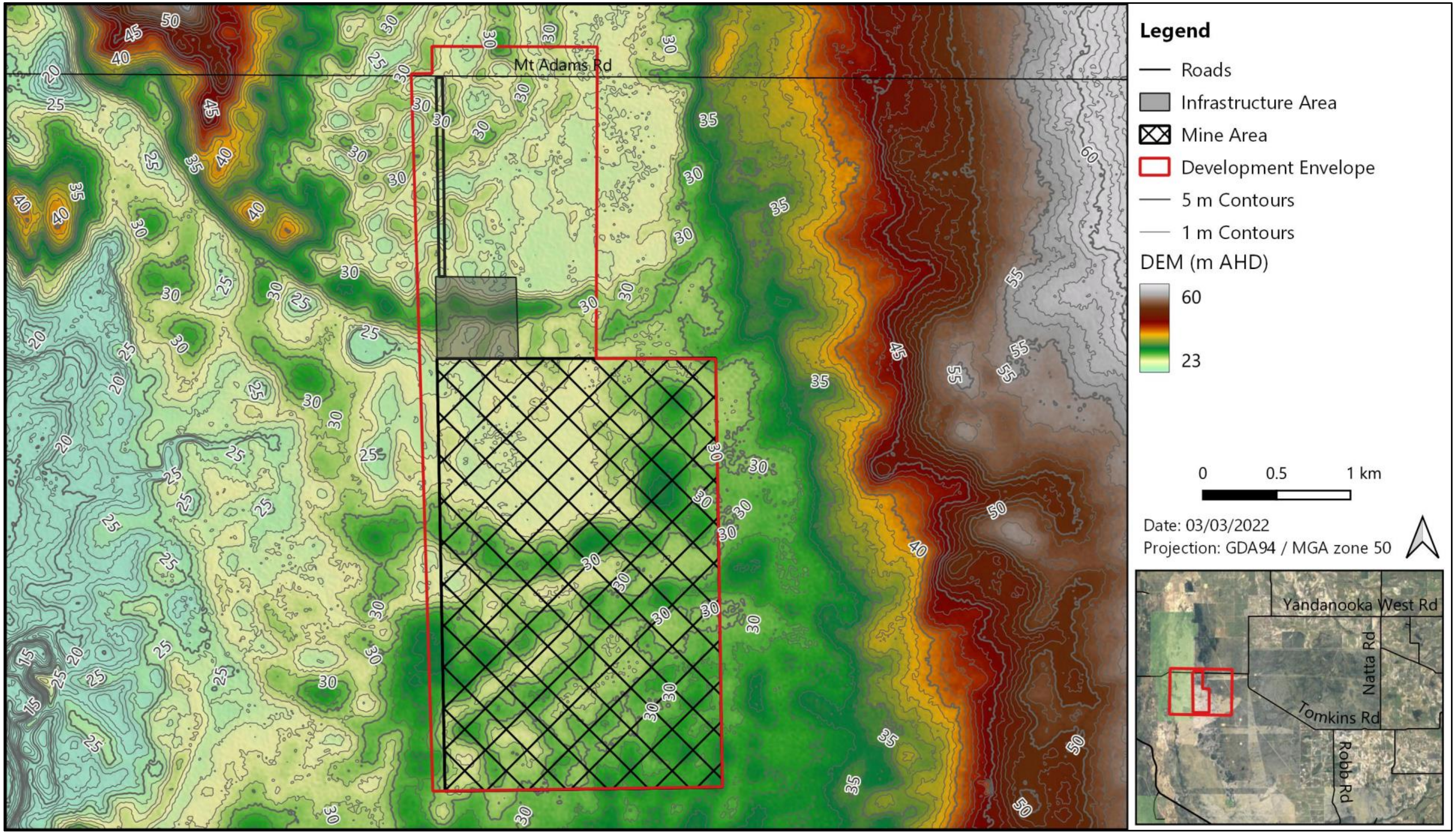
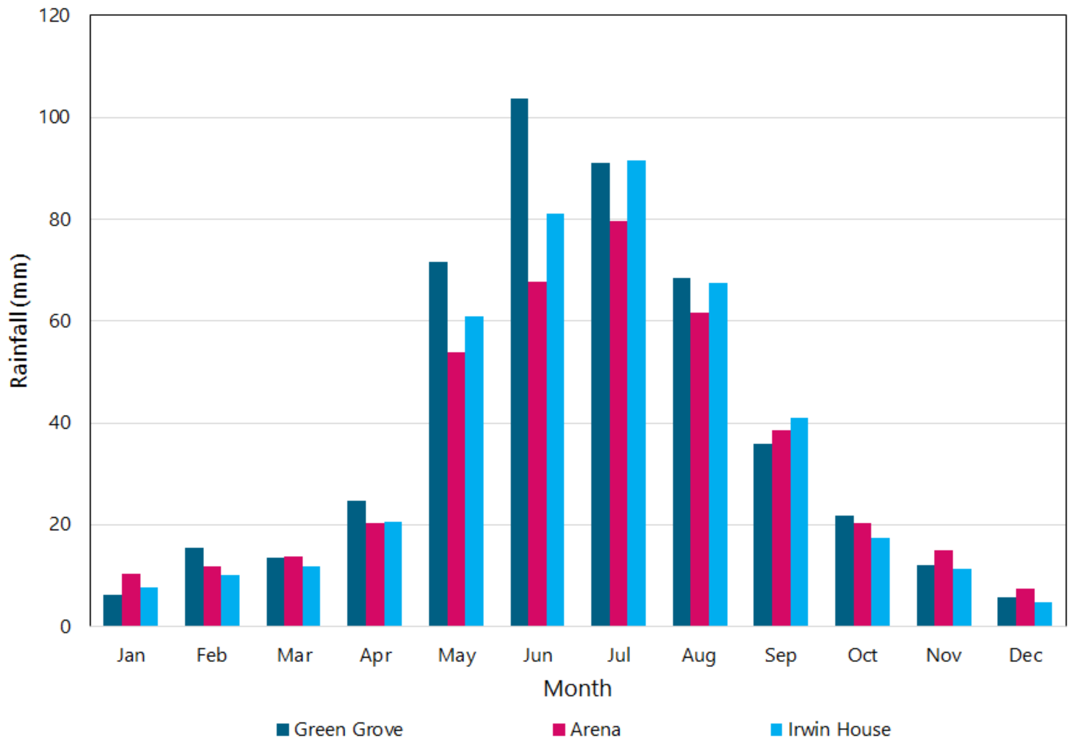


Figure 2-1. Digital Elevation Model (DEM) for the Project area.



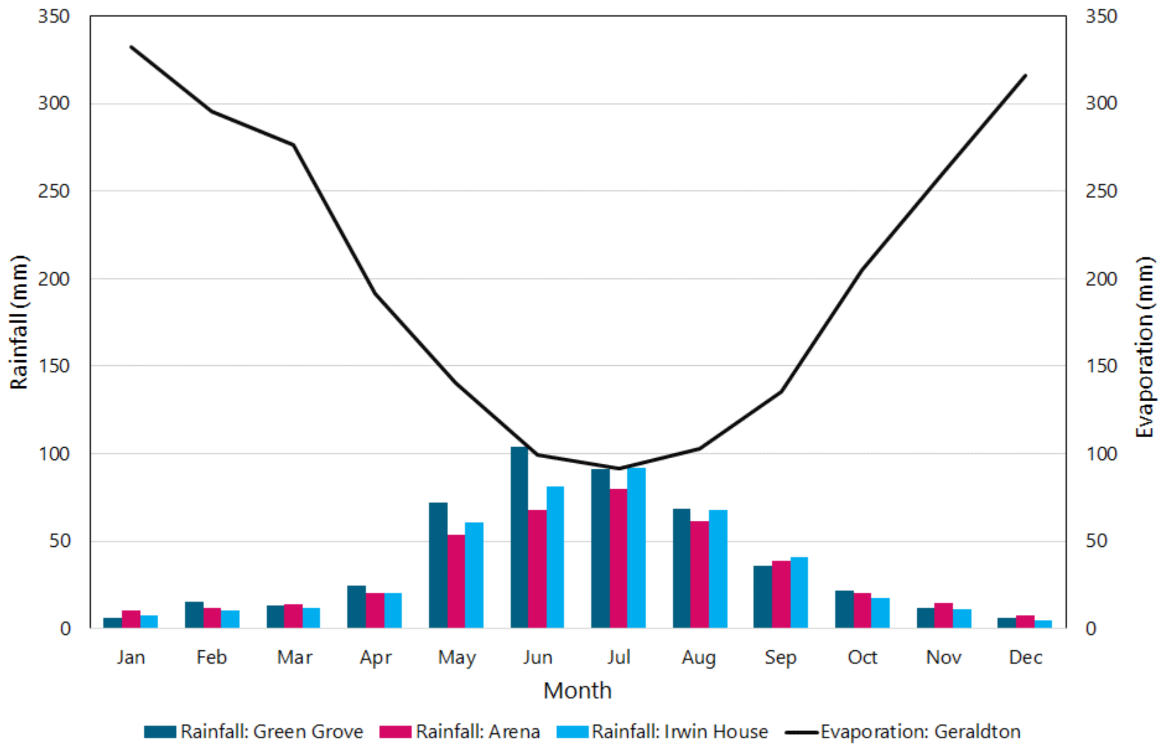


Figure 2-2. Average monthly rainfall data (top) and comparison with monthly evaporation data (bottom)

2.3 Soil Characteristics

According to the Western Australian Soil Group (WASG) classification, as shown in Figure 2-3, the dominant soil groups in catchment area are Pale and Yellow Deep Sands (Schoknecht & Pathan, 2013). Site photographs are provided in Plate 2-1, showing the highly sandy and permeable nature of the surfical soils across the Project area. The sandy soils are characterised by high infiltration losses and saturated conductivity rates, producing negligible rainfall runoff in storm events. There are also some loam soils in the upper catchment of the Arrowsmith river, but this catchment is also predominantly sandy. Given the similarity in soil types, the Arrowsmith and Project catchments are anticipated to have similar infiltration rates.

Plate 2-1. Site photographs showing the highly permeable surficial sands across the Project area

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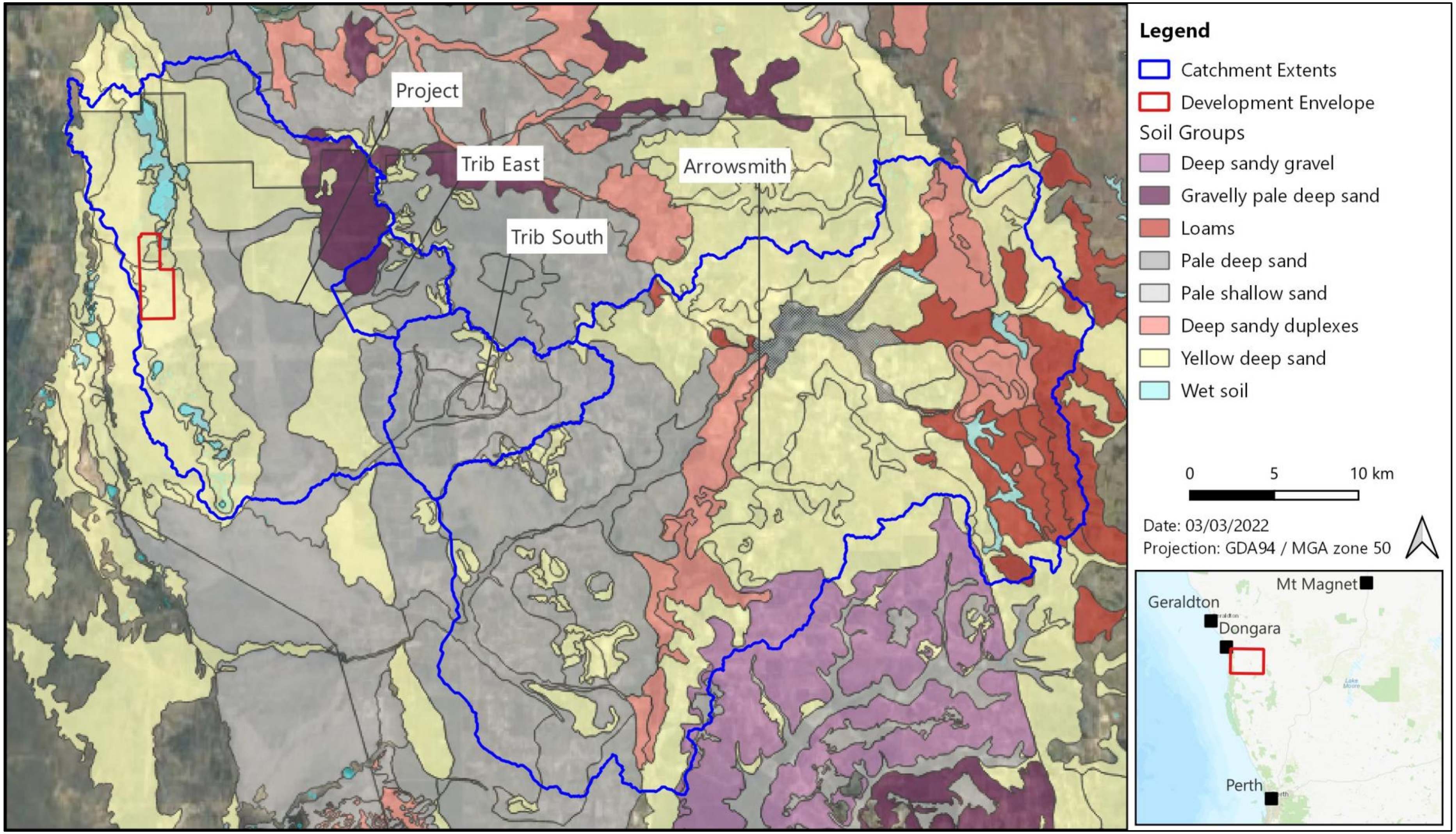

Figure 2-3. Soil classifications within the Project area and surrounding regional catchments

2.4 Hydrology

2.4.1 Catchment Analysis

Available topographic survey data (Table 1-1) was used to develop a regional DEM and delineate the catchment area and drainage lines reporting to the Project area and inform regional hydrological and flood modelling. The catchment area and drainage lines reporting to the Project area are shown in Figure 2-4. Figure 2-5 shows the associated sub-catchments (Project, Tributary East and Tributary South), as well as the adjacent Arrowsmith River catchment area upstream of the Robb Crossing stream gauge (discussed further in Section 2.4.2). Delineated catchment parameters are presented in Table 2-2.

The topographic data shows the delineated catchments are internally draining, meaning streamflow from seasonal rainfall-runoff events report to ephemeral damplands located in topographic depressions. Most of the streamflow in the Project area is from the east flowing into the projects pit and infrastructure area via east-west orientated drainage lines. This runoff ponds and/or infiltrates depending on the nature of the damplands.

The Project area is located on the Eneabba Sand Plain, which has generally flat terrain and characterised by interconnected, intermittent damplands, wetlands and lakes located in local interdunal depressions. Figure 2-6 shows some damplands located in the Project area based on mapping and assessments by Endemic (2012) and Semeniuk (1994). These are defined by Semeniuk (1994) as intermittent damplands: interdunal depressions experiencing seasonal waterlogging in response to rainfall events.

Given the highly permeable sandy soil (refer Section 2.3) present at the Project area and within the surrounding catchments, rainfall infiltrates without producing runoff for the more frequent events. Surface drainage lines do not flow on a regular basis within the Project area (that is, the watercourses are ephemeral). This is supported by anecdotal evidence of flooding in Mt Adams Creek, which suggests that only a single streamflow event was recorded between 2007 and 2012 (Endemic, 2012). Therefore, the damplands within the Project area are sustained by direct and localised rainfall-runoff and not from inflows from surrounding regional drainage lines or groundwater.

Table 2-2. Catchment parameters

Catchment Name	Area (km^2)	EA Slope (m/km)	Outlet Lat. (°S)	Outlet Long. (°E)	Centroid Lat. (°S)	Centroid Long. (°E)	Shape Factor	Clearing (%)
Project	488	4.00	29.431	115.093	29.438	115.193	0.44	~20
Trib East	29.2	11.1	29.445	115.225	29.435	115.257	0.61	~2
Trib South	87.1	9.14	29.52	115.255	29.494	115.309	0.64	~55
Arrowsmith	810	3.32	29.618	115.289	29.535	115.479	0.72	~95

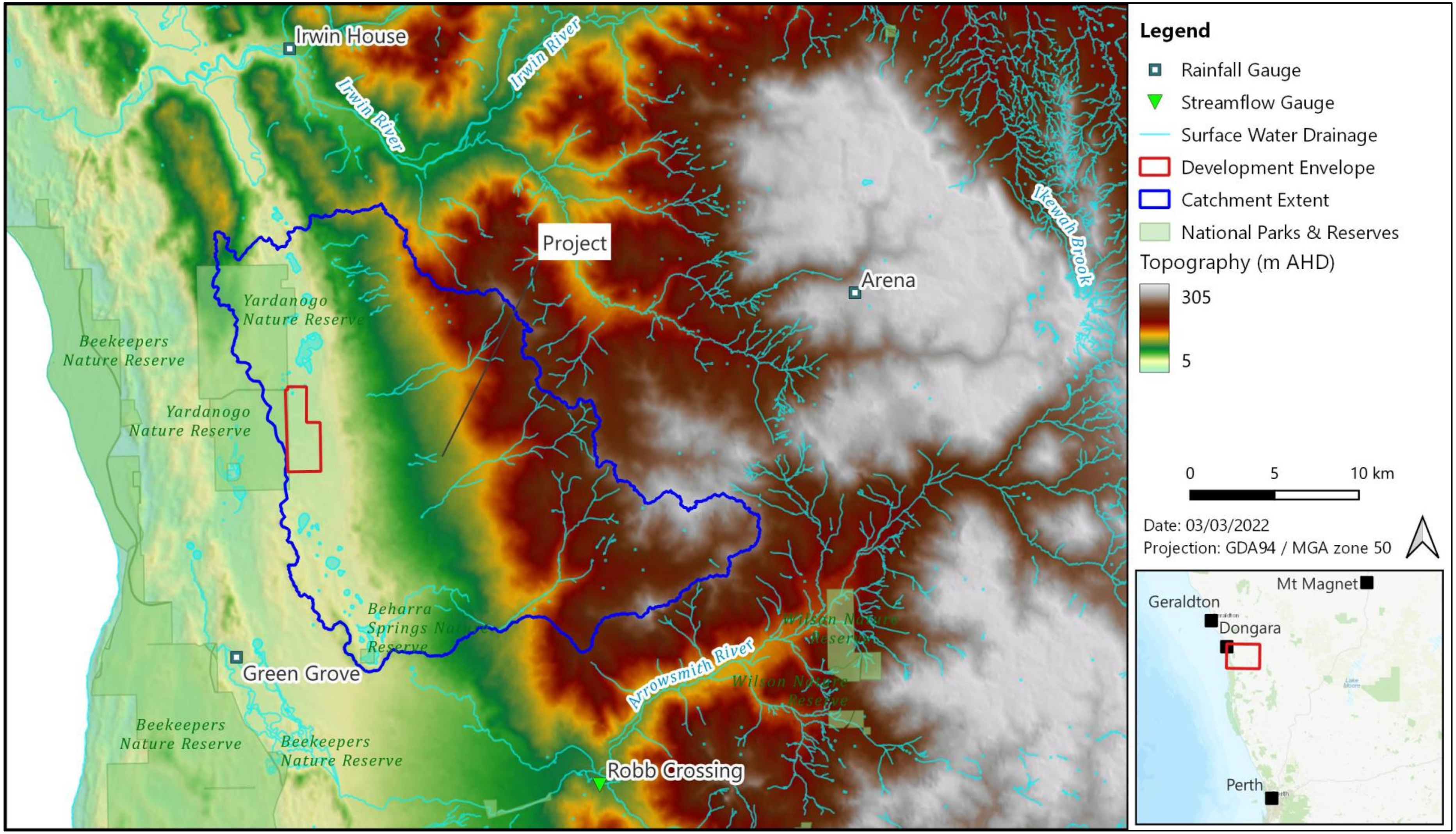

Figure 2-4. Delineated catchment area and drainage lines reporting to the Project area and nearby streamflow gauge locations.

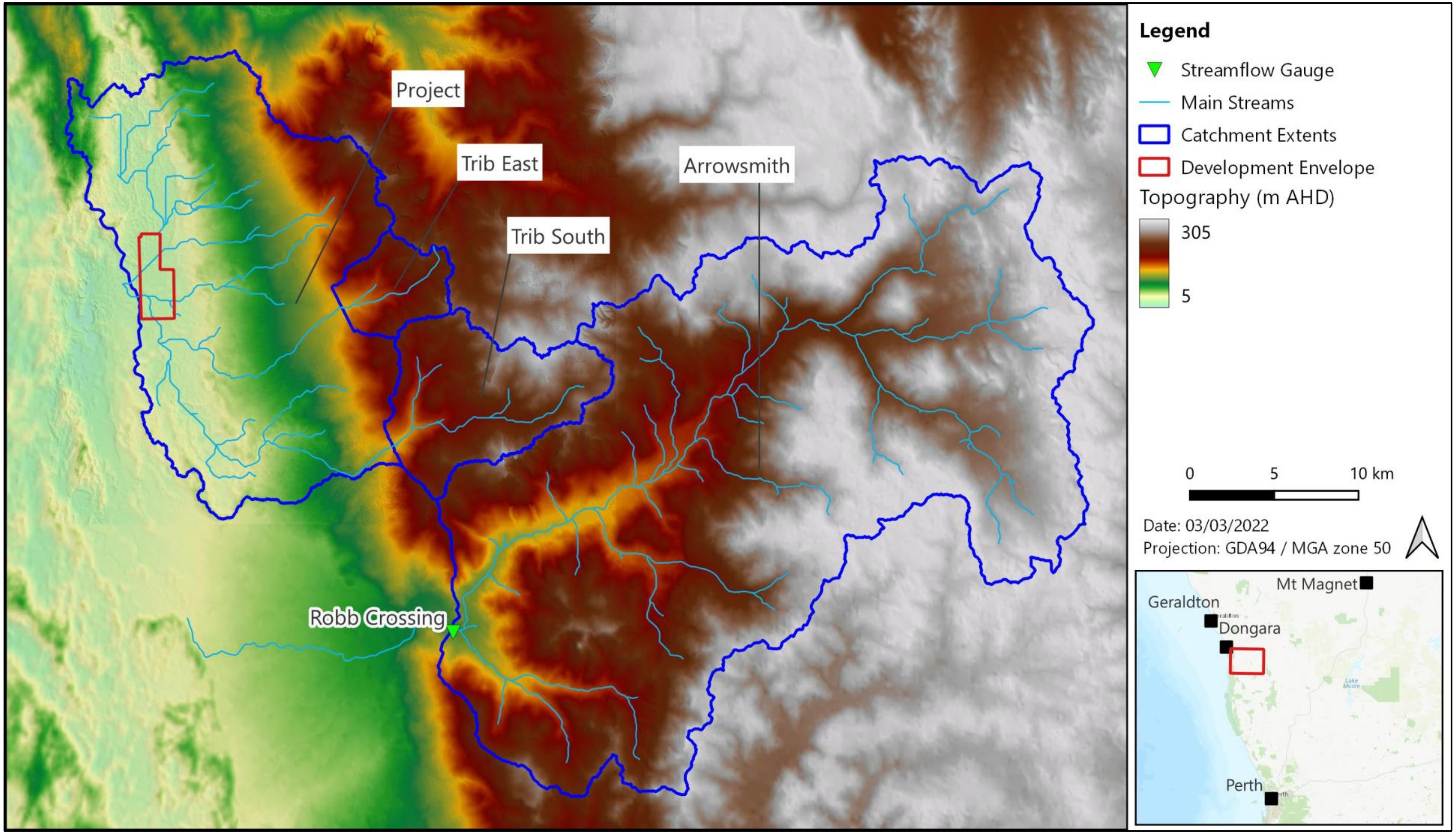

Figure 2-5. Project area sub-catchments (Project, Trib East and Trib South) and the Arrowsmith catchment area

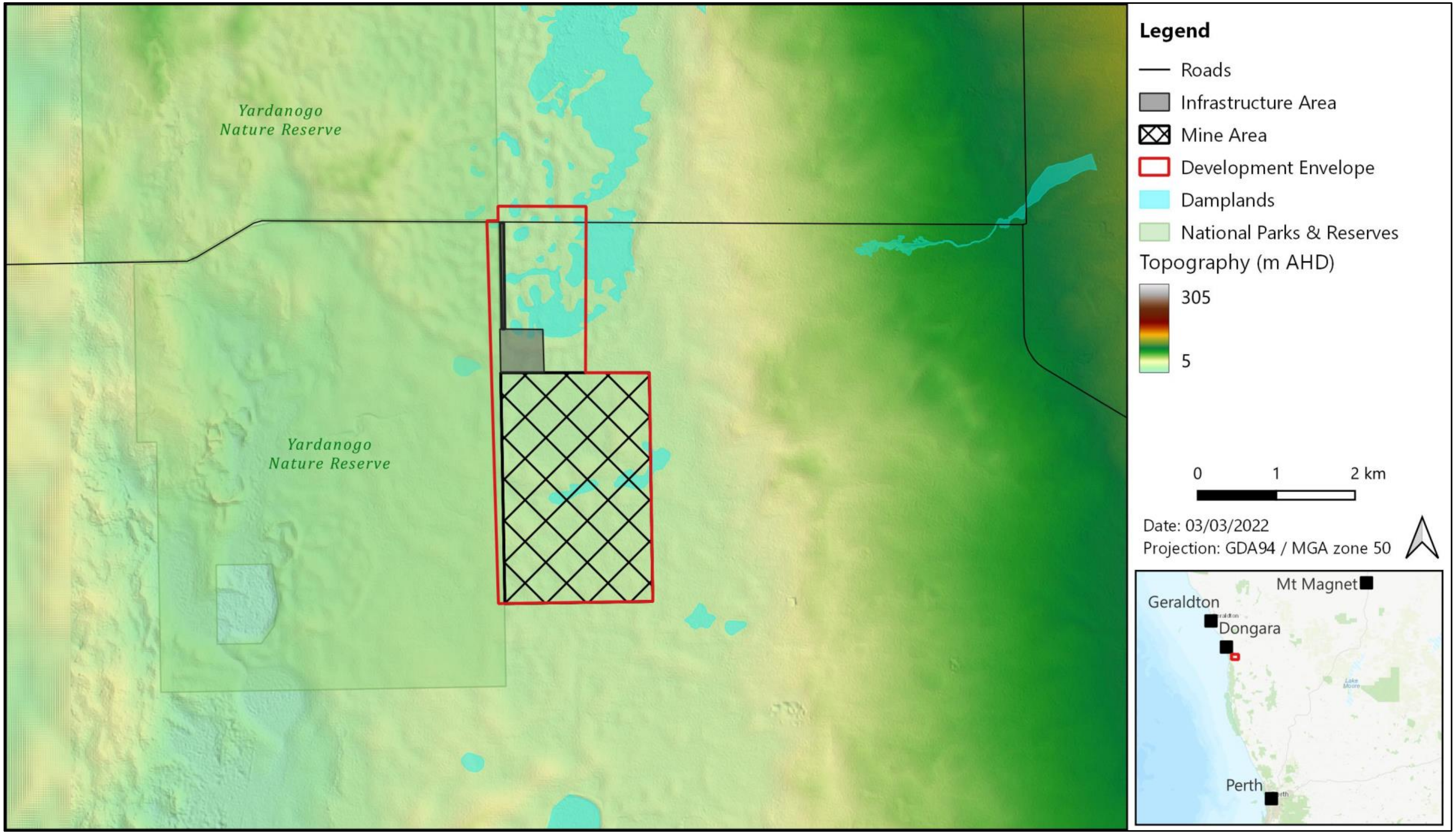

Figure 2-6. Intermittent damplands located in the Project area based on mapping and assessments by Endemic (2012) and Semeniuk (1994).

2.4.2 Streamflow Data

There is no publicly available streamflow data available within the Project area and associated catchments. Endemic (2012) refers to streamflow data recorded in Mt Adams Creek however that data is understood to be privately owned so was not available for this study.

However, there is streamflow data available in the adjacent Arrowsmith River, which has been collected by DWER at Robb Crossing between 1972-2001 (Site Ref # 701005). The location of this streamflow gauging station is shown in Figure 2-4. There is also a co-located rainfall gauging station at Rob Crossing (Site Ref #508024) covering the same period

2.4.3 Peak Flow Estimation

Three regional peak flow estimation techniques were adopted to estimate peak flows for this study, using the catchment parameters from Table 4-1:

- Regional Flood Frequency Estimation (RFFE) Model;
- Transposition of gauged FFA quantiles; and
- Regional Flood Frequency Analysis (RFFA).

The Regional Flood Frequency Procedure (Flavell, 2021) is not applicable to this region. The results are presented and discussed in the following sections.

2.4.3.1 Flood Frequency Analysis (FFA)

As there are no streamflow gauges located in the Project area and associated catchments, Flood Frequency Analysis (FFA) of streamflow data recorded in the adjacent Arrowsmith River at Robb Crossing was completed and the results transposed to the Project area catchments using the following relationship:

$$Q_{trib} = Q_{Arrowsmith} * \left(\frac{A_{trib}}{A_{Arrowsmith}}\right)^{0.7}$$

Where:

- Q = peak flow (m^3/s)
- A = area (km^2)

This technique was considered applicable as the catchment show comparable shape, slope, soil, and land use properties to the gauged catchment.

FFA of the streamflow data was undertaken using the FLIKE software (Kuzcera, 1999). Annual peak flow maxima were fit to a Log-Pearson III statistical distribution with using L-moments to produce the FFA estimates plotted in Figure 2-7.

The 1% AEP peak flows estimated using FFA are presented in Table 2-3 for the Project area catchments and the Arrowsmith catchment.

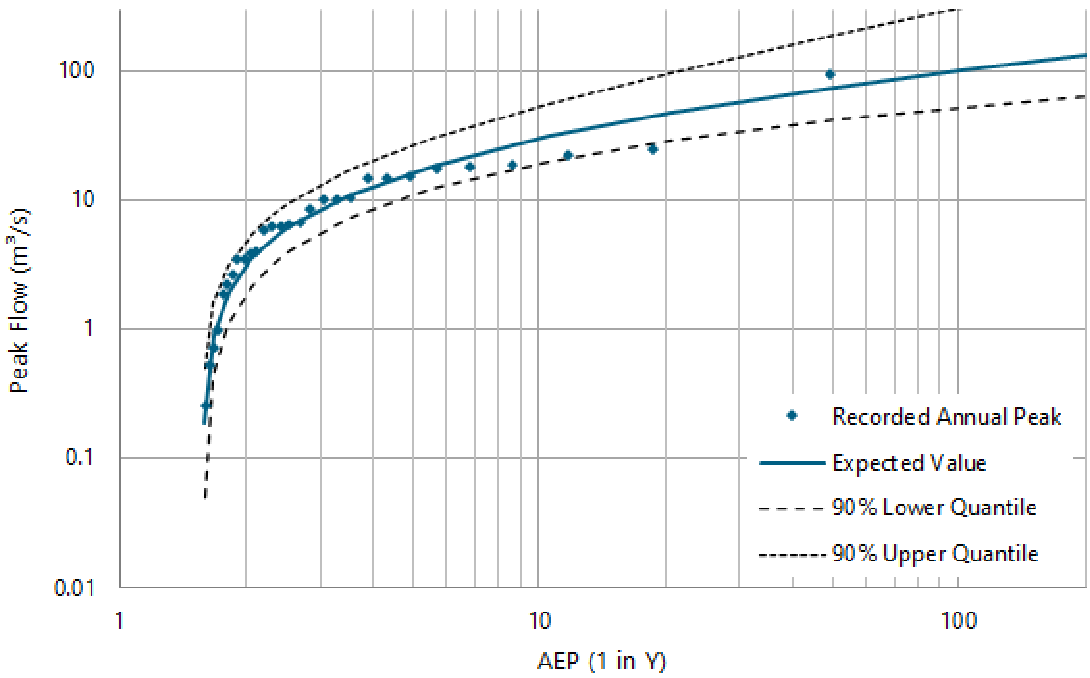

Figure 2-7. Flood frequency analysis of streamflow data at Arrowsmith River – Robb Crossing

Table 2-3. 1% AEP peak flow estimates (m^3/s) using FFA

Catchment Name	Area (km^2)	FFA	Transposed FFA
Project	488	*No Data*	70.5
Trib East	29.2	*No Data*	9.8
Trib South	87.1	*No Data*	21.1
Arrowsmith	810	100	*N/A*

2.4.3.2 RFFE Method

For the project area, the RFFE method (Haque *et al.*, 2015) uses an Index Flood based on 11 gauging stations in the Pilbara region, with the 10% AEP as the index flood. The model does not account for floodplain storage, catchment slope, soils and geology, and catchment land use, thus requiring critical analysis of the resulting flood quantiles (Rahman *et al.*, 2019).

The 1% AEP peak flows estimated using this method are presented in Table 2-4 for the Project area catchments and Arrowsmith catchment.

Table 2-4. 1% AEP peak flow estimates (m^3/s) using the RFFE method

Catchment Name	Area (km^2)	RFFE
Project	488	303
Trib East	29.2	62
Trib South	87.1	115
Arrowsmith	810	349

2.4.3.3 RFFA Method

The RFFA method was developed by Davies and Yip (2014) as an updated index flood method for the Pilbara region using annual maximum series data from 10 gauged catchments, including the Arrowsmith River – Robb Crossing gauge, with the 5-year ARI (~20% AEP) as the index flood.

The 1% AEP peak flows estimated using this method are presented in Table 2-5 for the Project area catchments and Arrowsmith catchment.

Table 2-5. 1% AEP peak flow estimates (m^3/s) using the RFFA method

Catchment Name	Area (km^2)	RFFA
Project	488	146
Trib East	29.2	22
Trib South	87.1	42
Arrowsmith	810	138

2.4.4 Comparison of Design Flow Estimates

The 1% AEP estimates for the Project area catchments using the regional methods outlined above are compared in Table 2-6.

The RFFE and RFFA methods produce higher 1% AEP peak flow estimates for the Project area catchments when compared with the transposed FFA method. The peak flow estimates for the Arrowsmith catchment suggests that the RFFA method produces a closer fit to the 1% AEP estimate using FFA. The RFFA peak flow estimates were considered the most appropriate regional estimates for this study and have been used to validate the rainfall-runoff model in Section 5.1.

Table 2-6. 1 % AEP peak flow estimates using regional methods and adopted design flow estimates

Catchment Name	Area (km^2)	1% AEP Peak Flows (m3/s)			
		FFA	RFFE	RFFA	Adopted Flow Estimates for Project area
Project	488	70.5 *	303	146	146
Trib East	29.2	9.8 *	62	22	22

Catchment Name	Area (km^2)	1% AEP Peak Flows (m3/s)			
		FFA	RFFE	RFFA	Adopted Flow Estimates for Project area
Trib South	87.1	21.1 *	115	42	42
Arrowsmith	810	100	349	138	N/A

** Transposed FFA of Arrowsmith River streamflow data*

3 Basis of Concept Design

The following surface water management design criteria and assumptions have been adopted for this study.

3.1 Rock Protection

Austroads (2019) provides guidance on the hydraulic design of waterway structures, which includes methods for the selection and design of rock protection of earth embankments. Rock classes recommended by Austroads (2019) are presented in Table 3-1. The peak velocity maps produced for the Project area were used to identify areas potentially requiring rock protection to protect operational flood control measures and Closure designs from scour/erosion during Operations and at Closure respectively. Table 3-1 suggests rock protection is not required when peak velocities are less than 2 m/sec.

Table 3-1. Design of rock slope protection (Austroads, 2019).

Velocity Range (m/sec)	**Class of Rock Protection, Wc** (tonne)	**Section Thickness, T** (m)
<2	None	-
2.0 – 2.6	Facing	0.50
2.6 – 2.9	Light	0.75
2.9 – 3.9	¼	1.00
3.9 – 4.5	½	1.25
4.5 – 5.1	1.0	1.60
5.1 – 5.7	2.0	2.00
5.7 – 6.4	4.0	2.50
>6.4	Special	-

3.2 Diversions

Floodwater cannot enter a pit void in an uncontrolled manner as it poses a risk to Operations and will also cause head cut erosion leading to upstream environmental impacts. Clean floodwater from undisturbed catchments should also be directed around disturbed areas (pits and mine infrastructure) to minimise the risk of mobilisation and transport of suspended sediment to downstream environments.

Diversions are therefore required to redirect 1% AEP floodwater around mine pits and key mine infrastructure and minimise disruptions to Operations and minimise adverse environmental impacts.

Diversions use a combination of a trapezoidal drain cut into in-situ material and the cut material used to construct a bund on the pit side of the drain. The diversions shall be sized to provide 1 m freeboard from the top of bund crest to the 1% AEP flood levels. The concept diversion design adopted in this study is presented in Figure 3-1. The adopted bund heights and drain widths are selected to limit peak velocities to less than 2 m/s where possible. The batter slopes and bund crest widths are nominal and dependent on material properties and construction methods.

It is recommended that geotechnical assessments of proposed bund construction material are conducted to confirm suitability for use, prior to detailed design.

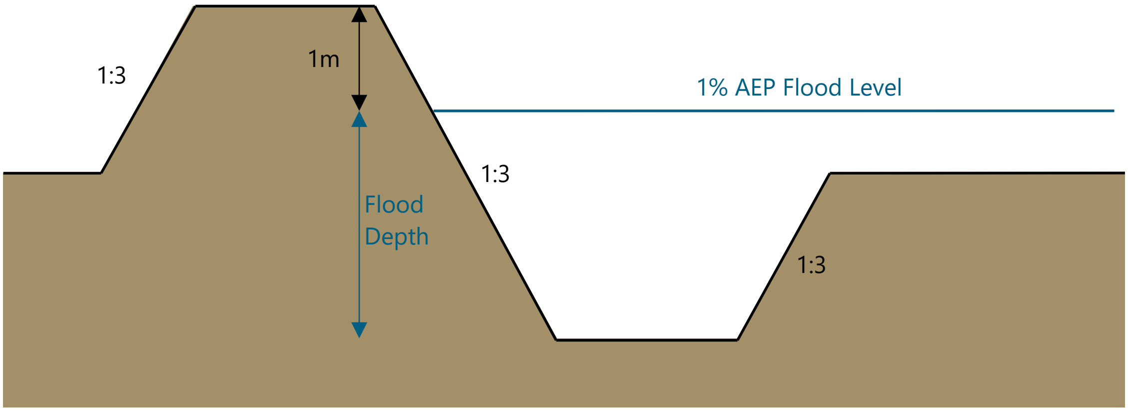

Figure 3-1. Concept diversion design

3.3 Access Roads

Given the highly permeable sandy soil present at the mine site and within the surrounding catchments, rainfall infiltrates without producing runoff for the more frequent events. Therefore, surface drainage lines do not flow on a regular basis within the Project area.

The access roads are therefore assumed to be constructed at natural grade and floodway crossings located where the roads cross drainage lines to maintain flows in the larger and less frequent rainfall-runoff events. No culverts are to be adopted for road design.

3.4 Closure Design

The following assumptions were made for Closure, which have formed the basis of flood modelling and surface water assessments in this report:

- The current Closure design has the pit walls backfilled to 8 degrees to reinstate pre-development flow paths; and
- All other infrastructure is assumed to be decommissioned and reinstated to pre-development topographic conditions.

4 Hydrological Modelling

4.1 Model Set Up

Hydrological and hydraulic modelling of the Project area was completed using 2D TUFLOW software (version 10-2020) and the direct rainfall modelling approach. The model was developed using a combination of Landgate topographic data for the Project area and SRTM data covering the remaining external catchment areas (refer to Section 1.4).

The model was initially set up to simulate flooding under Existing conditions and select loss parameters that produced similar flows to the design flow estimates presented in Section 2.4.4.

The use of a direct rainfall modelling approach involves application of rainfall excess (rainfall minus losses) to the 2D model domain and the resulting runoff routed through the model domain using the hydraulic model. The adopted model parameters are summarised in Table 4-1. The model extent, boundary conditions, nested grid area and infrastructure locations are presented in Figure 4-1.

Table 4-1. Summary of TUFLOW model parameters.

Item	Adopted
Grid size	Regional area: 40m based on SRTM topographic survey data. Local catchment area around mine site: 10m based on Landgate survey data. 5m Sub-Grid Sampling (SGS) along primary flow paths to represent sub-grid scale features and improve shallow depth flow conveyance.
Manning's n roughness	Roads and cleared areas = 0.025 Pasture/agricultural land = 0.04 Vegetated floodplains and hillslopes = 0.045 to 0.07
Rainfall	BoM IFD rainfall depths (BoM, 2016)
Losses	Initial loss and continuing loss parameters presented in Section 4.1.3.
Areal reduction factor (ARF)	ARR2019
Temporal Patterns	1% AEP: Southern and South Western Flatlands West (Ball *et al.,* 2019) PMP: GSDM and GTSMR patterns

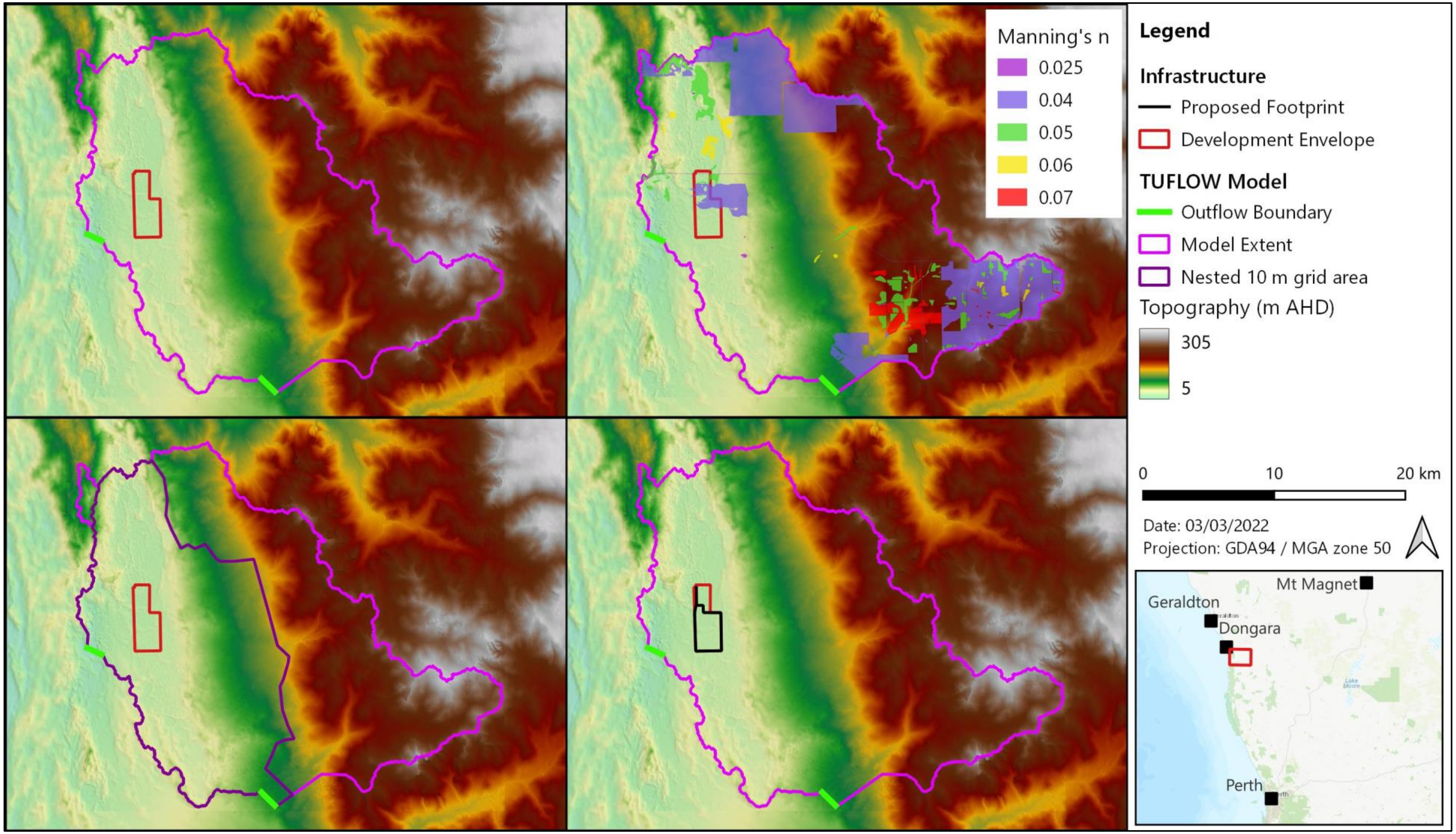

Figure 4-1. TUFLOW model set-up. Top right: model extent and outlet boundary conditions. Top right: manning's roughness values (default value =0.045). Bottom left: nested area of 10 m grid resolution. Bottom right: infrastructure locations

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4.1.1 Terrain

The SRTM and Landgate topographic survey date described in Section 2.1 was used to develop the Existing conditions TUFLOW model. The total TUFLOW model area was 498 km^2. The 10m grid and 5m sub-grid sampling was applied to a 255 km^2 area around the mine site to capture hydraulic behaviour more accurately in the areas of interest.

4.1.2 Design Rainfall

Point 1% and 0.1% AEP rainfall data was extracted from the BoM Design Rainfall Data System (BoM, 2016). Rainfall depths were simulated using temporal patterns for the Project area as provided by the ARR Datahub (ARR, 2019). ARF's were applied in accordance with ARR2019. The 1% and 0.1% AEP rainfall depth-duration curves adopted for TUFLOW modelling are presented in Figure 4-2.

4.1.3 Loss Parameters

4.1.3.1 1% AEP Event

A proportional loss model was implemented in the TUFLOW model through a runoff coefficient (RoC), which is the percentage of the incident rainfall that is converted to runoff. RoC's ranging from 10% to 50% were applied in the TUFLOW model and the resulting peak flows compared with the RFFA 1% AEP peak flow estimates at the Tributary East and Tributary South catchments outlets shown in Figure 2-5. A RoC of 33% was adopted for TUFLOW modelling as it produced the closest fit with the RFFA estimates. The modelling results are presented and discussed in more detail in Section 5.

4.1.3.2 0.1% AEP Event

The RoC for the 0.1% AEP event was estimated by interpolating between RoC's estimated for the 1% AEP and Probable Maximum Precipitation (PMP) events. This involved the following steps.

PMP Estimation

Complete PMP calculations using the guidelines outlined in the following BoM's guideline documents:

- The Generalised Short Duration Method (GSDM) which is applicable to catchment areas less than 1,000 km^2 and produces design depths for durations up to 6 hours (BoM, 2003), and
- The Revised Generalised Tropical Storm Method (GTSMR), estimating longer duration events driven by tropical storms rather than short duration events such as thunderstorms (BoM, 2005).

Both methods were considered due to the presence of significant storages which increased the critical storm duration north of the proposed mine site. The resulting PMP depth envelope developed for TUFLOW modelling is presented in Figure 4-2.

A single design storm PMP temporal pattern was adopted for both the GSDM and GTSMR methods (BoM, 2003 and BoM, 2005). The PMP rainfall depths were then applied to the temporal patterns. Areal reduction factors were not applied to PMP estimates as the method for PMP estimation already considers catchment area. The critical storm duration of the catchments reporting to the mine site Section 5 was 24 hours with an associated PMP rainfall depth of 660mm.

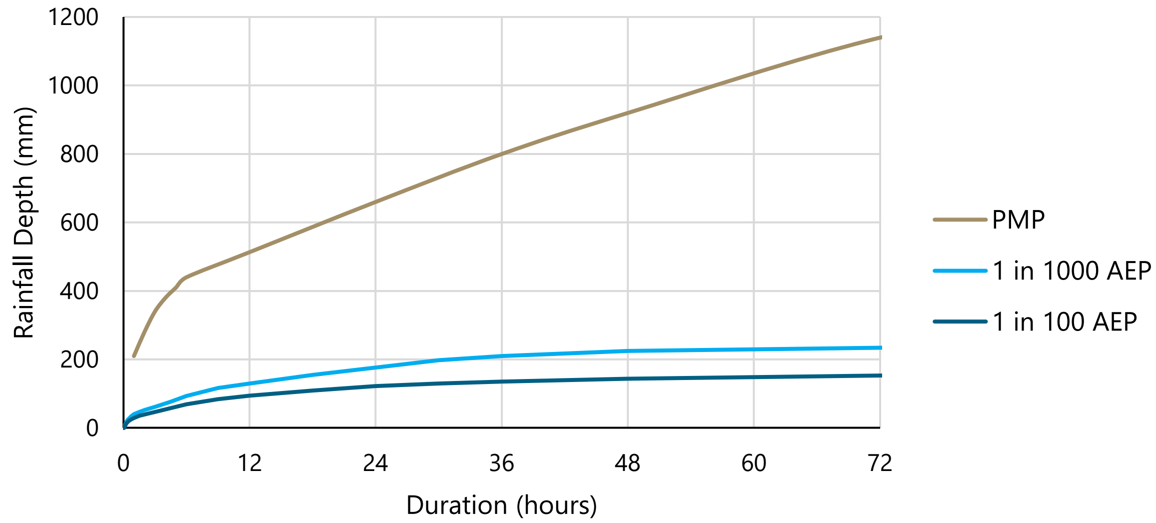

Figure 4-2. 1% AEP, 0.1% AEP and PMP rainfall depth-duration curves adopted for TUFLOW modelling

PMP Loss Estimation

ARR2019 provides guidance on initial loss (IL) and continuing loss (CL) loss parameters to be adopted for PMP/PMF flood modelling. The recommended PMP/PMF loss parameters are provided in Table 4-2. If 660mm of PMP rainfall falls over a 24 hour period, this equates to 27.5mm/hr. ARR2019 recommends a CL value of 1 mm/hr. Therefore, this equates to 4% rainfall loss every hour (1/27.5) or a runoff coefficient (RoC) of 96%.

ARR2019 provides a method for estimating the AEP equivalence for the PMP event, based on catchment area. The PMP is estimated to be equivalent to the 0.00005% AEP event using this method.

Table 4-2. Rainfall loss parameters (ARR2019)

Design Event	IL (mm)	CL (mm/hr)
PMP/PMF	0	1

0.1% AEP Loss Estimation

The RoC for the 0.1% AEP event was estimated by interpolating between RoC's estimated for the 1% AEP and PMP events, using the relationship shown in Figure 4-3. The 0.1% RoC estimated using this relationship is 48%.

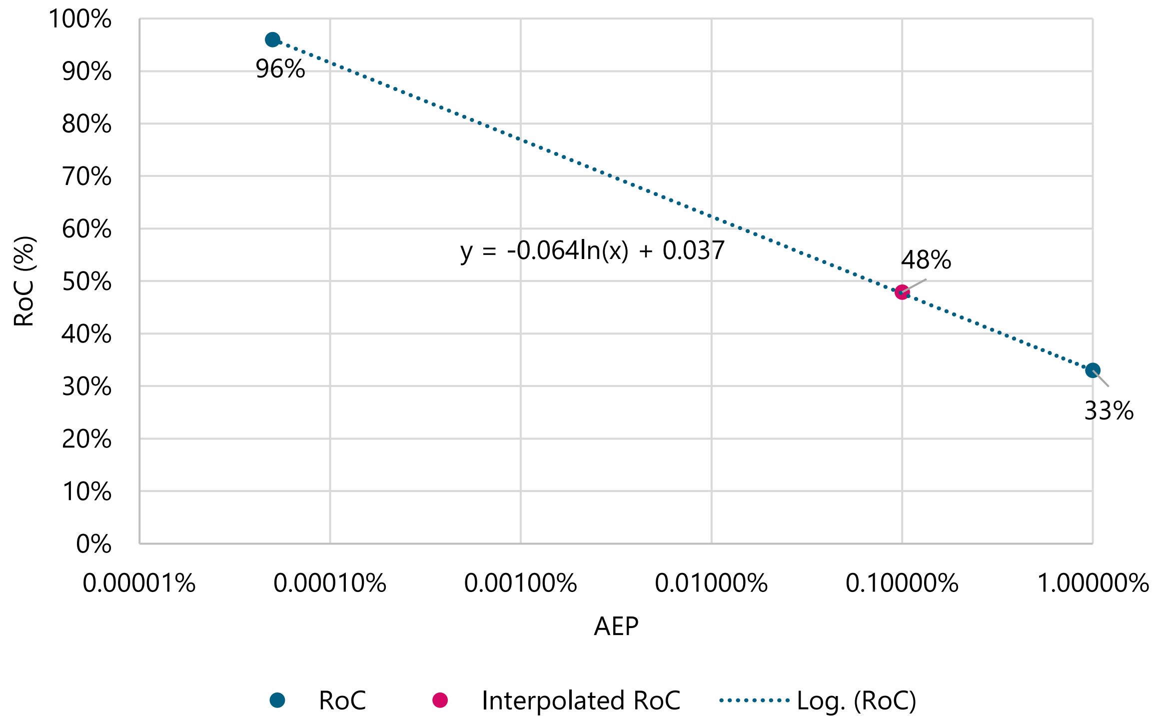

Figure 4-3. Interpolation of 0.1% RoC using RoC's estimated for the 1% AEP and PMP events

4.1.4 Manning's n Roughness

Manning's n roughness was adopted for the catchment area as well as main creek lines based on analysis of aerial imagery. Adopted Manning's n values are presented in Table 4-1 and Figure 4-1.

4.1.5 Boundary Conditions

Downstream boundary conditions were set at the catchment outlets. The adopted approach automatically creates a stage-discharge relationship for the nominated boundary based on the boundary cross section geometry, delineated floodplain roughness and a user defined water surface slope (commonly bed slope adopted as a proxy). The downstream boundaries were located at sufficient distance downstream of the areas of interest to eliminate the potential effects of the adopted boundary conditions on the areas of interest, as shown in Figure 4-1.

4.2 Modelling Approach

The "Ensemble" modelling approach described in ARR2019 was adopted when modelling the 1% and 0.1% AEP events in TUFLOW. This approach involves running an ensemble temporal patterns and selecting the pattern closest to average (flow or volume) at the locations of interest (Figure 4-4). ARR Datahub (ARR, 2019) – a web-based data portal developed as part of ARR2019 – provides a range of 10 temporal patterns across different storm durations for use in design.

The temporal patterns were simulated in TUFLOW using rain-on-grid, for a range of storm durations to ensure critical storm durations for larger regional and small local catchments were captured. The storm duration resulting in the maximum flow at the locations of interest around the Project area was then selected for design flood event modelling.

Flood depth map results presented in subsequent sections were developed by using GIS processing tools to extract the maximum flood depths at each cell in the model.

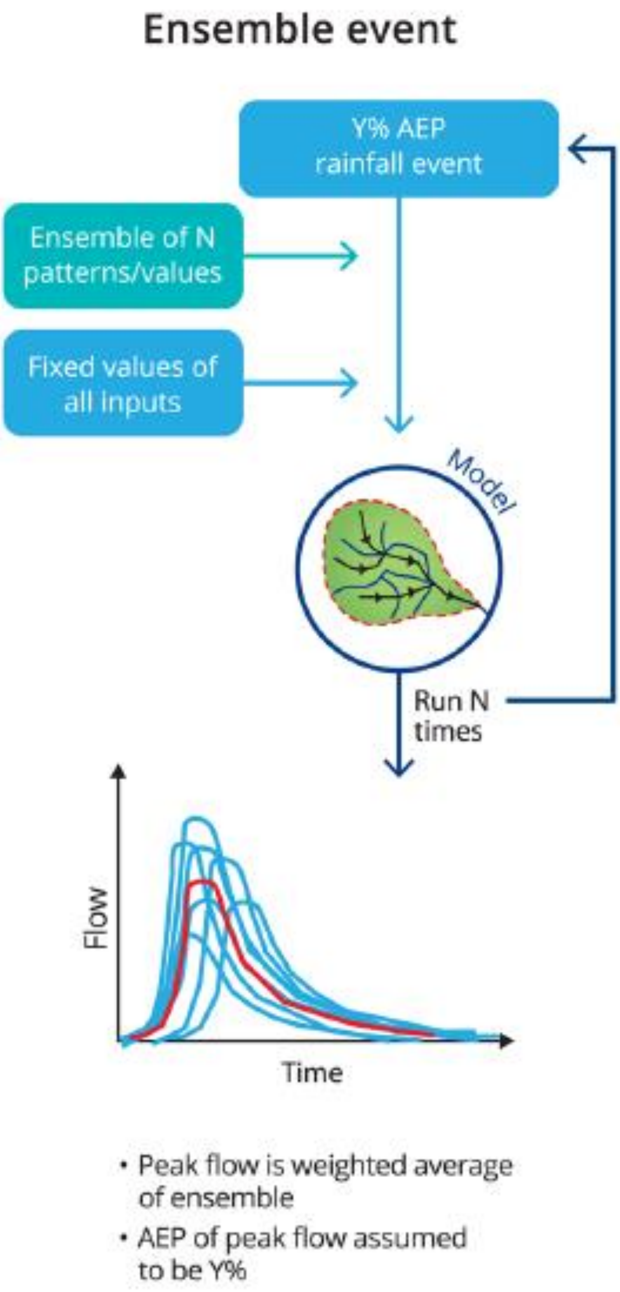

Figure 4-4. Ensemble modelling approach (Ball et al., 2019)

4.3 Adopted Design Flows

The TUFLOW model was used to simulate the 1% AEP flood event with the peak flow estimates compared with the RFFA estimates in Table 4-3. The results show a good fit between estimates at the Tributary East catchment. The peak flow estimated by TUFLOW in the Tributary South catchment was less than the RFFA estimate due to the storage effects in the upper catchment. Storage is not accounted for by the RFFA method so a lower resulting peak flow is expected. The results therefore validate the TUFLOW model performance.

The adopted design flows and flow hydrographs for the Tributary East and South catchments are presented in Table 4-3 and Figure 4-5.

Table 4-3. Comparison of 1% AEP peak flows (m³/s) using TUFLOW and RFFA method

Catchment ID	RFFA Method	TUFLOW Model RoC = 33%	Adopted Design Flows
Tributary East	22.0	19.9	19.9
Tributary South	42.0	36.4	36.4

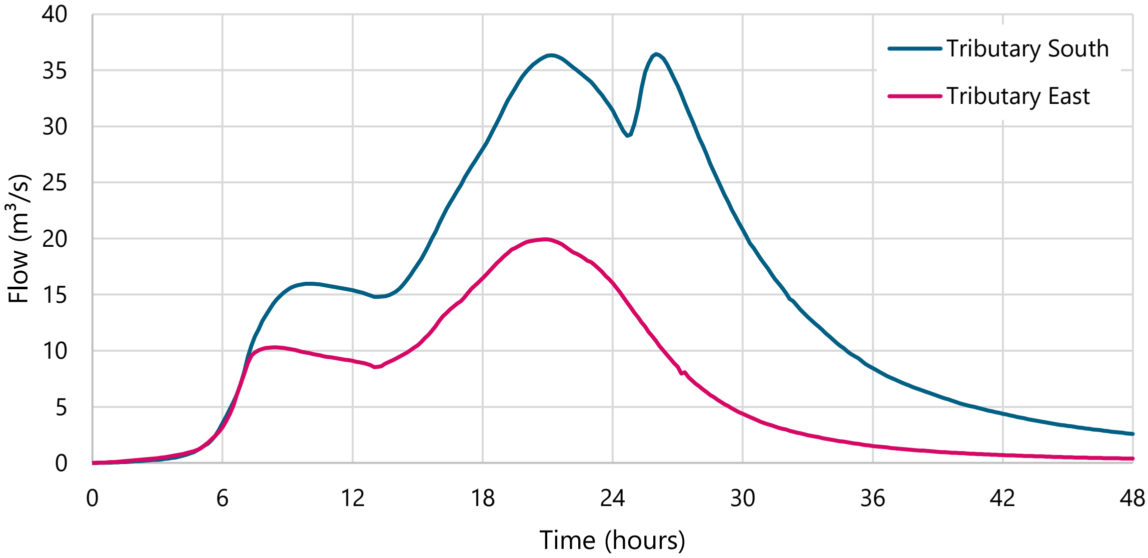

Figure 4-5. 1% AEP flow hydrographs for the Tributary East and South catchments

5 Flood Modelling Results

This section presents the results of Existing and Post-development conditions flood modelling and describes flood behaviour. The Post-development conditions scenario has surface water management measures in place in accordance with the Basis of Design (Section 3) and the performance of these measures is also discussed.

5.1 Existing Conditions

The critical storm duration for the mine site is 24 hours and the results from modelling this storm event were assessed for both the 1% and 0.1% AEP events.

The 1% AEP flood maps in Figure 5-1 and Figure 5-2 show the site is sparsely inundated with floodwaters generally at low velocity. A large portion of the streamflow enters the Project area from the east via drainage lines and reports to topographic depressions, which appear to have capacity greater than the 1% AEP flood volume. Given the sandy soil conditions, floodwater accumulating in these depressions is expected to rapidly infiltrate to groundwater. Peak velocities are less than 2 m/s in the mine development area.

The 0.1% AEP flood maps in Figure 5-3 and Figure 5-4 show more widespread flooding and inundation of the Project area, when compared with the 1% AEP results. As with the 1% AEP event, floodwater accumulating in topographic depressions is expected to rapidly infiltrate to groundwater. Peak velocities are less than 2 m/s in the mine development area.

Figure 5-1 also shows flow extraction locations (blue polylines) set up in the model to extract peak flow and hydrograph data. The peak flows and critical durations at these flow locations for the 1% and 0.1% AEP events are presented in Table 5-1.

Table 5-1. Existing Conditions: 1% AEP and 0.1% peak flows estimates across the Project area

Location *	1% AEP	0.1% AEP
FLOW2	27.2	60.1
FLOW3	1.0	15.3
FLOW8	16.4	28.2
FLOW9	12.7	34.9
FLOW10	10.2	33.8
FLOW13	13.7	37.9
FLOW_SpillOut	15.7	51.2

** Refer to Figure 5-1 for locations*

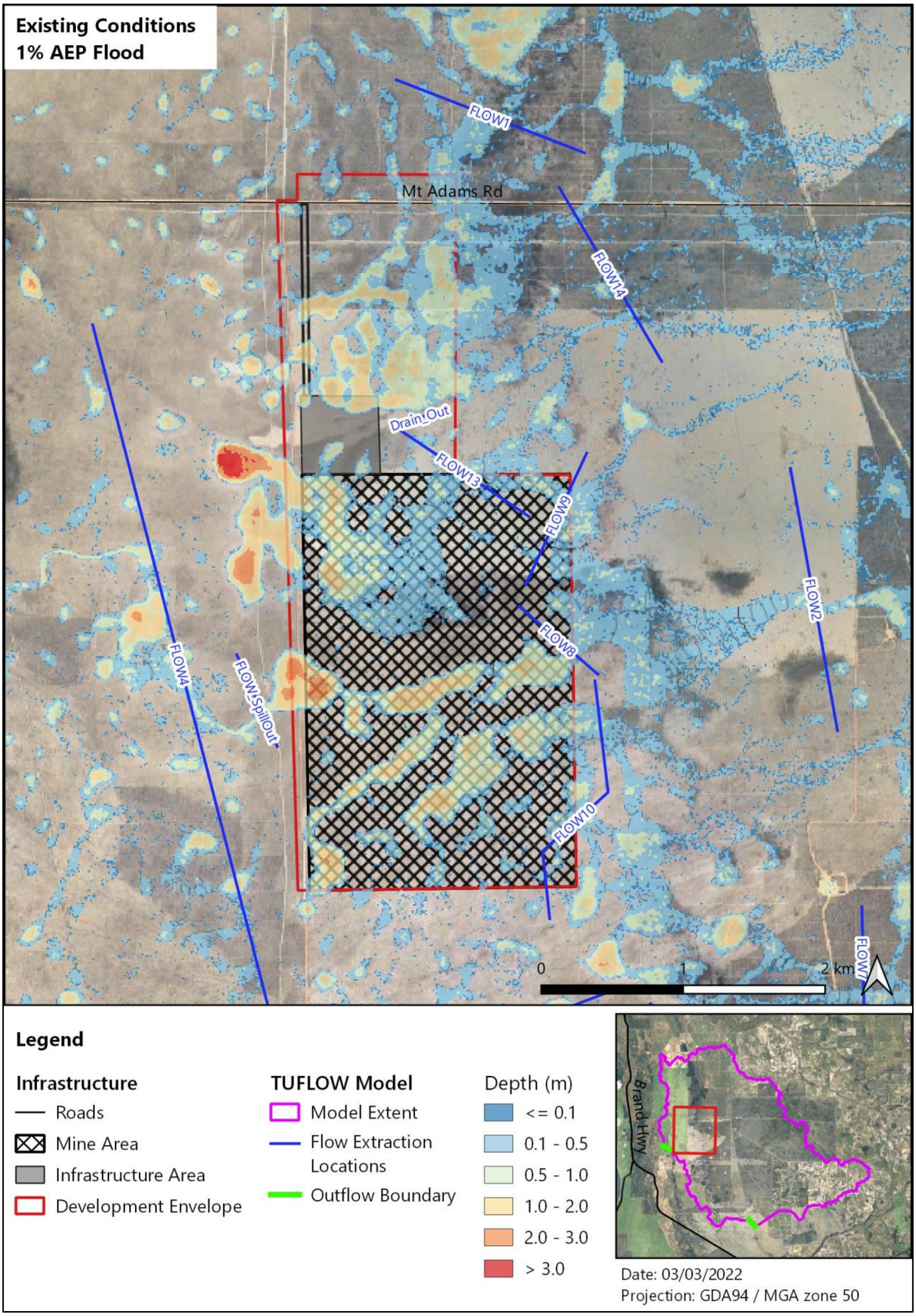

Figure 5-1. Hydraulic model results for the 1% AEP flood depth under Existing conditions.

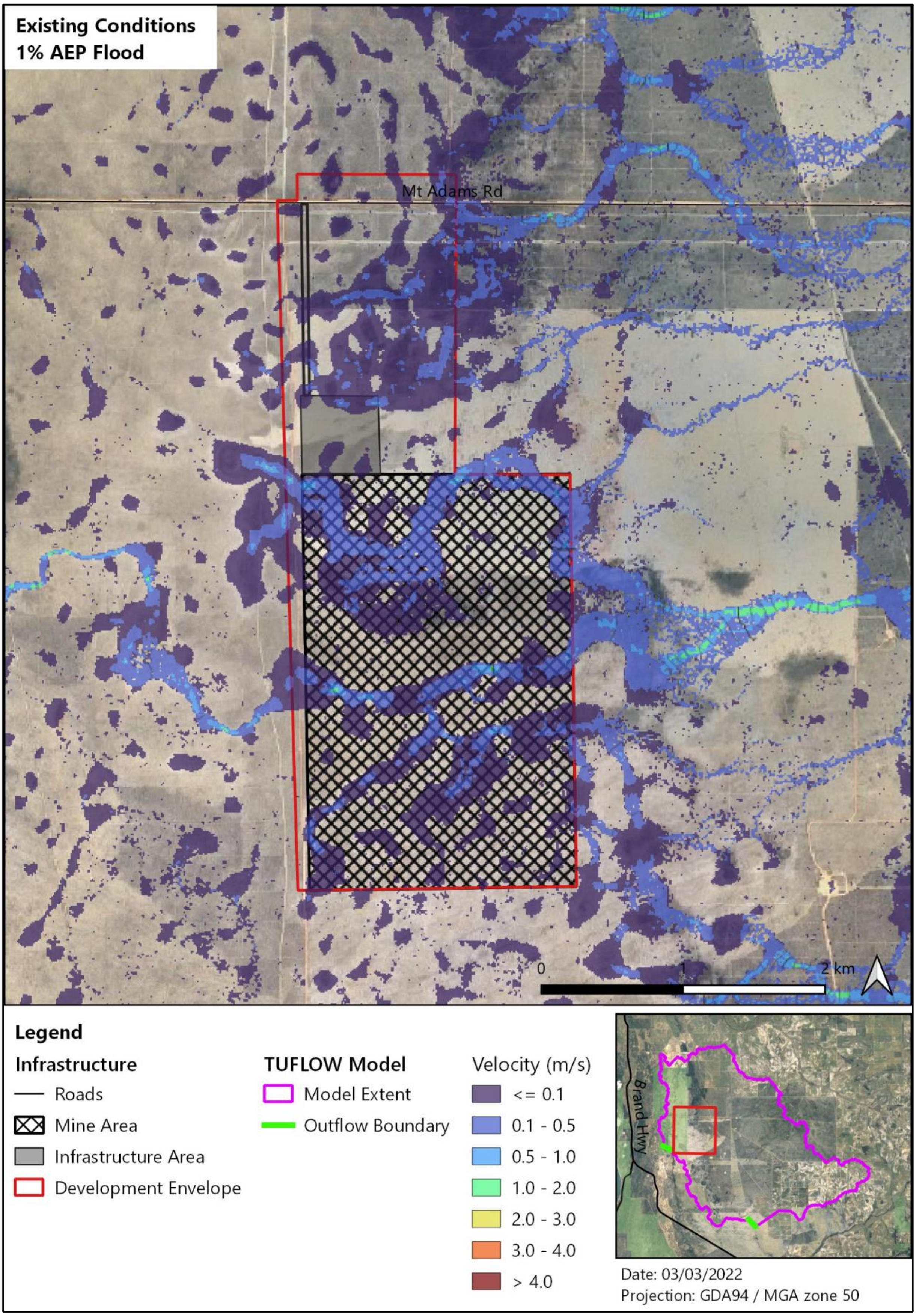

Figure 5-2. Hydraulic model results for the 1% AEP flood velocity under Existing conditions.

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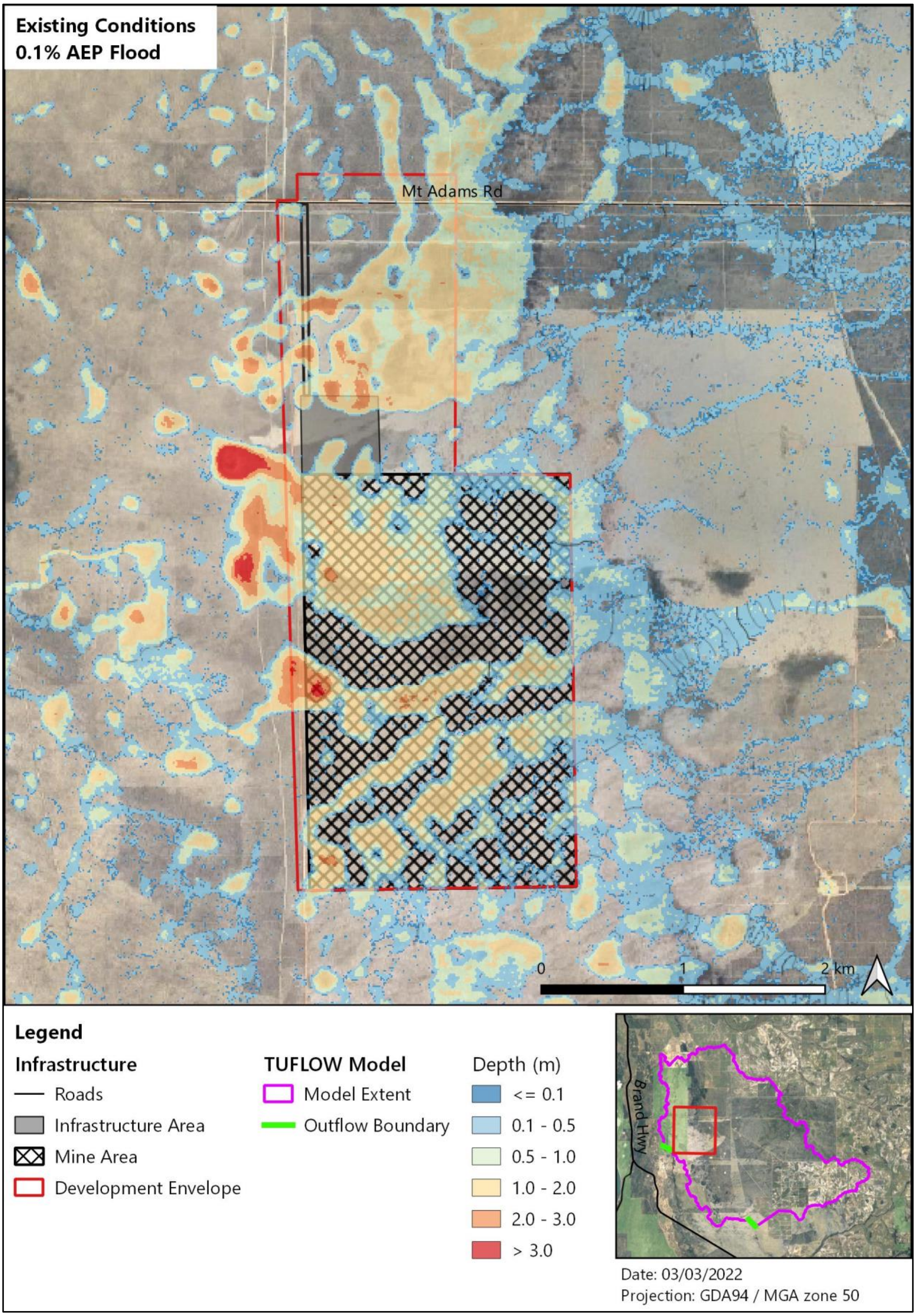

Figure 5-3. Hydraulic model results for the 0.1% AEP flood depth under Existing conditions.

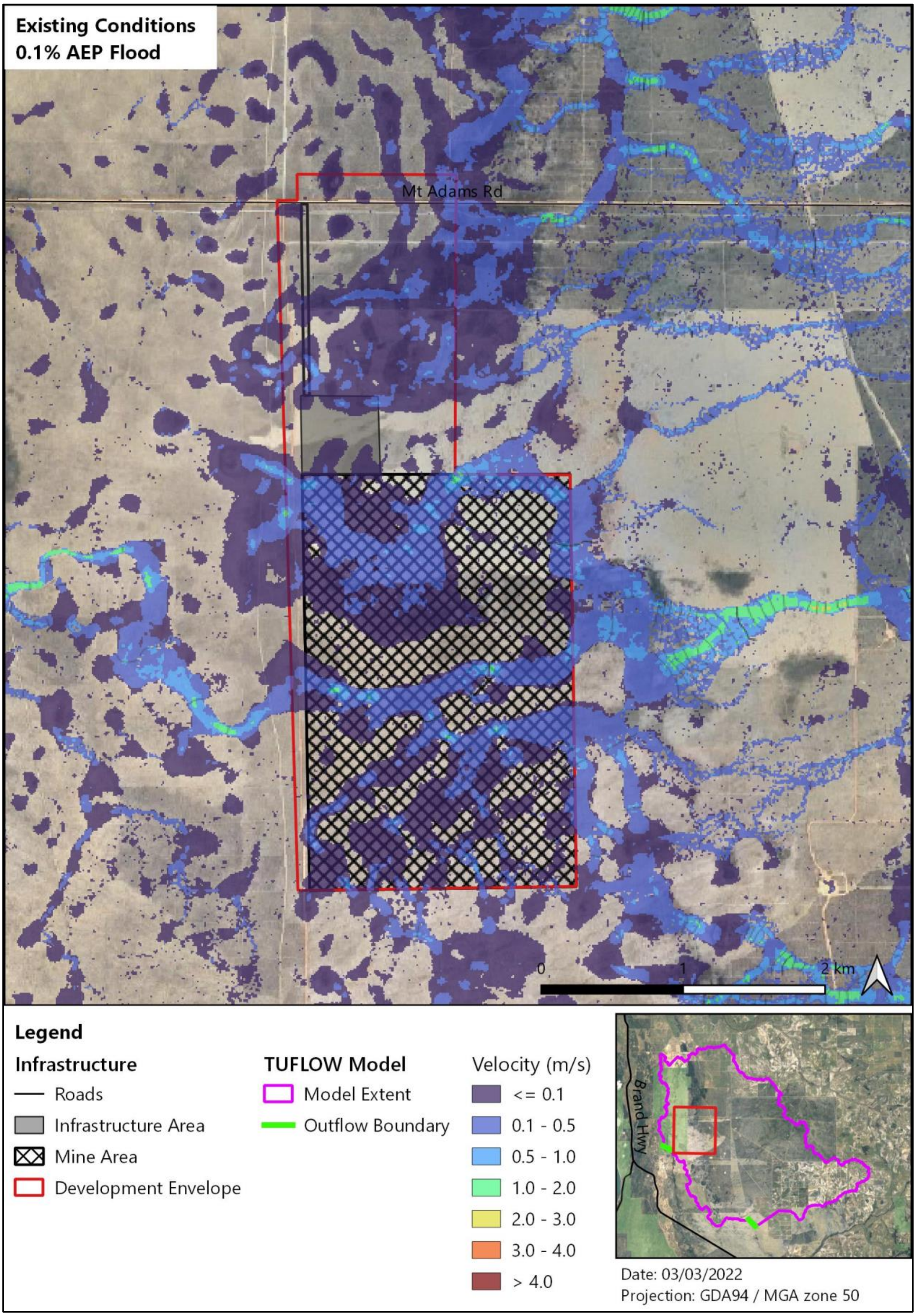

Figure 5-4. Hydraulic model results for the 0.1% AEP flood velocity under Existing conditions.

5.2 Post-Development Conditions

The Existing conditions TUFLOW model was updated to simulate the 1% and 0.1% AEP events under Operational and Closure conditions respectively, using the proposed mine pits and infrastructure layouts and Closure designs provided for use in this study (refer to Section 1.4).

The results are presented below and used to quantify risk and identify surface water management requirements for Operations and Closure.

5.2.1 Operations

The 1% AEP flood depth and velocity maps are presented in Figure 5-5 and Figure *5-6* respectively. The results suggest the following:

- Diversion bunds and drains are required around the pit shell to redirect 1% AEP floodwater to topographic depressions north of the mine infrastructure area, where it will infiltrate. The location of diversion bunds and trapezoidal diversion drains are shown in Figure 5-7. The following concept designs were adopted to provide necessary freeboard to top of bund, in accordance with the Basis of Design (Section 3):
  - Flood bund heights range between 1.5 and 3.4 m; and
  - Trapezoidal diversion drains range between 1.5 and 3.2 m depth (from drain invert to bund crest), with 5 m base and 1:3 side slopes.
- The 1% AEP velocities in the diversions range between 0.2 and 1.6 m/s. As the peak velocities are less than, 2 m/s rock protection is not required in accordance with the Basis of Design (Section 3).

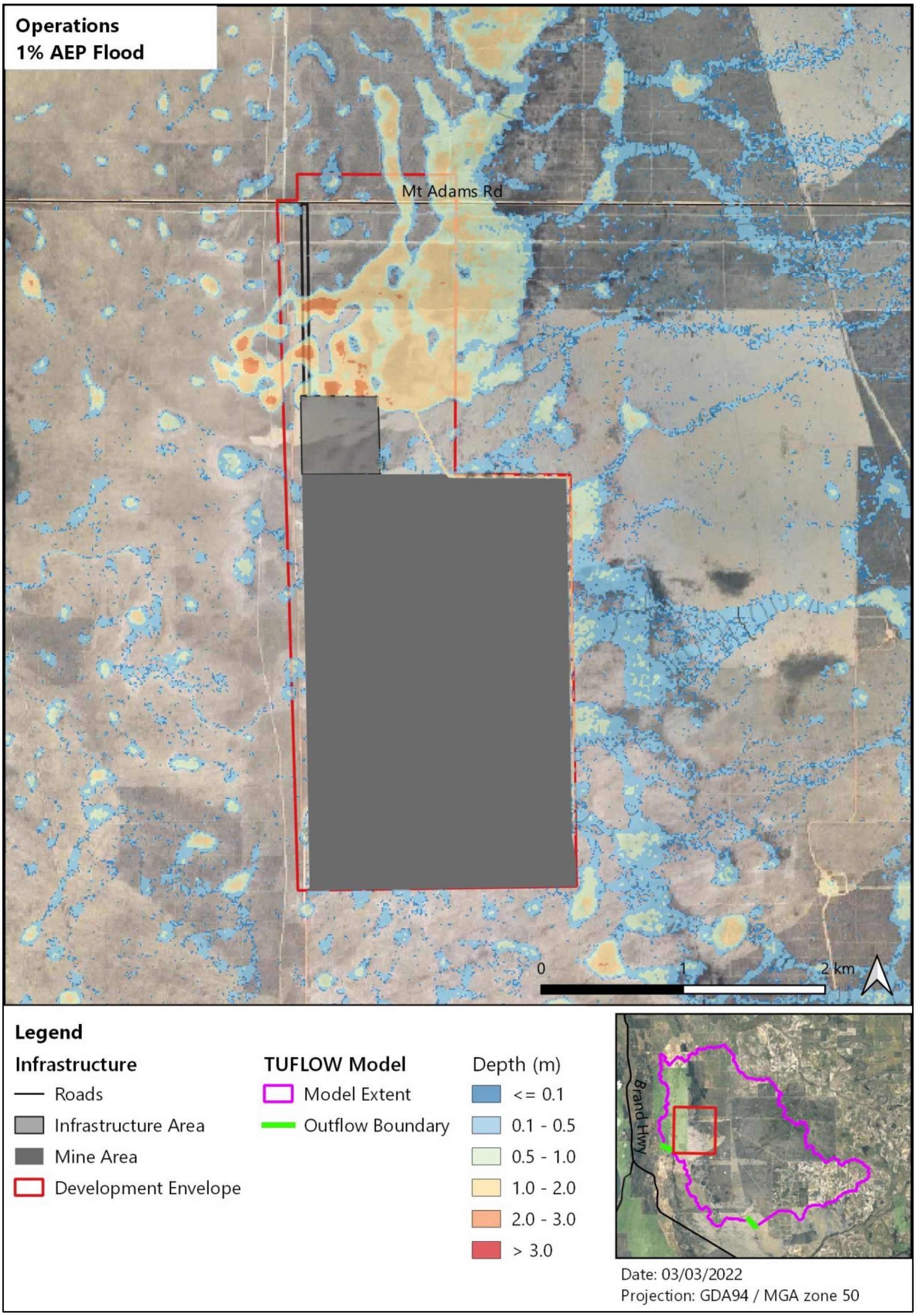

Figure 5-5. Hydraulic model results for the 1% AEP flood depth under Operations conditions

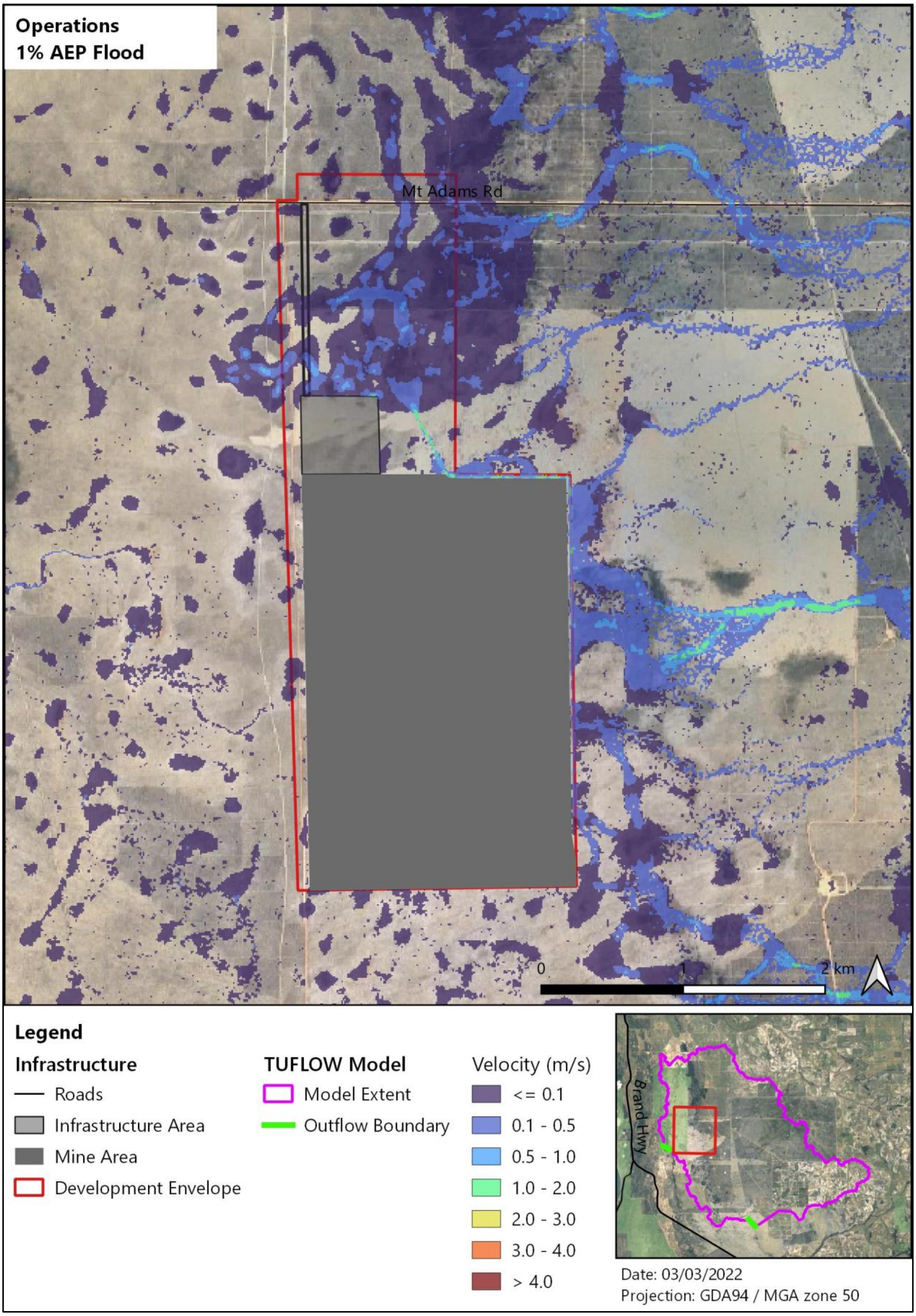

Figure 5-6. Hydraulic model results for the 1% AEP flood velocity under Operations conditions

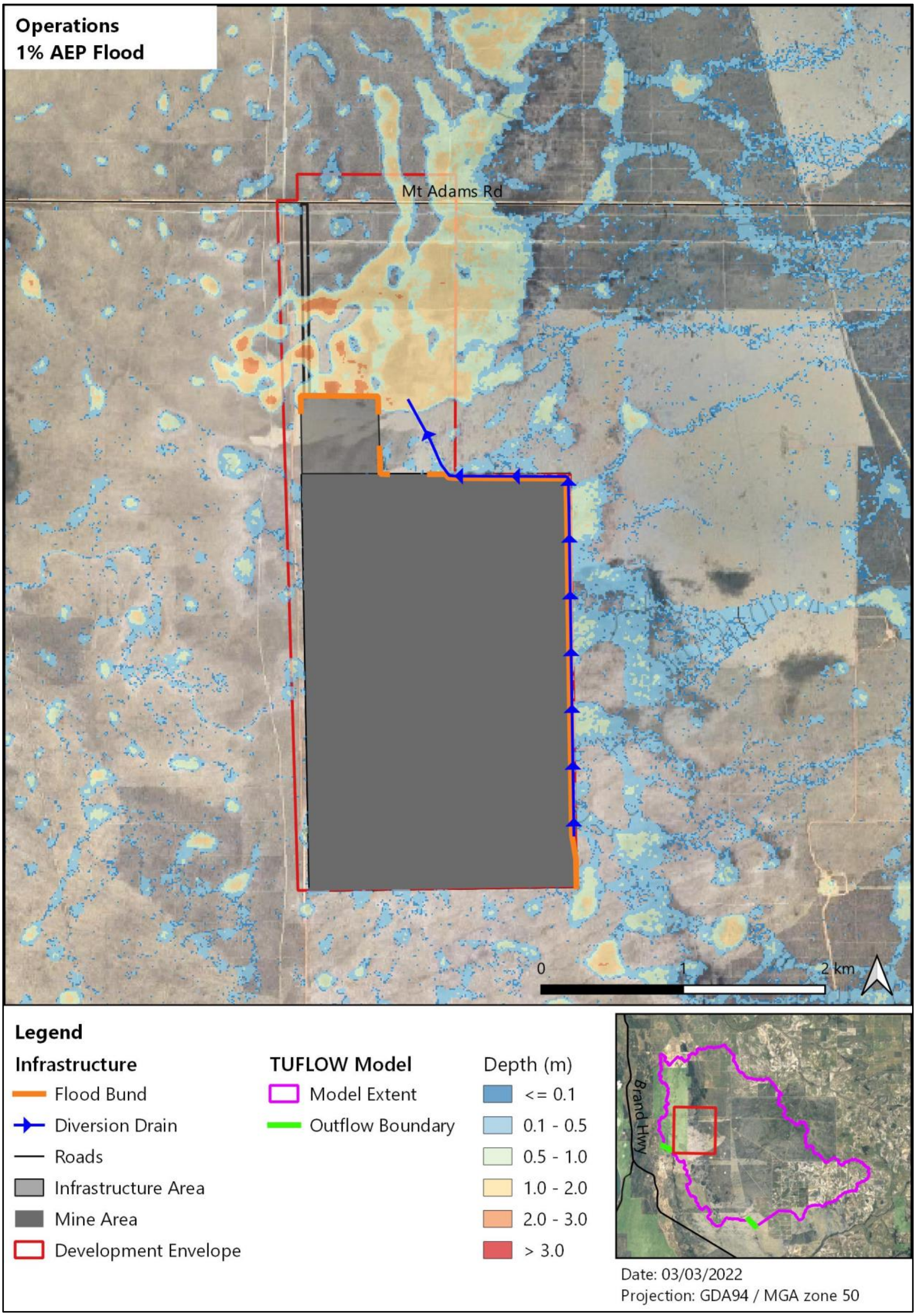

Figure 5-7. Location of flood bunds and trapezoidal diversion drains

5.2.2 Closure

The 0.1% AEP flood depth and velocity maps are presented in Figure 6-1 and Figure 6-2 respectively. The results suggest the following:

- The pit backfill design has reinstated pre-development flow paths at Closure. Floodwater accumulates in the topographic depressions and infiltrates, consistent with the Existing conditions scenario,
- Peak 0.1% AEP velocities are less than 2 m/s within the backfilled pit so rock protection is not required, and
- Peak flood depths and velocities outside the pit area are consistent with the Existing conditions scenario.

6 Surface Water Assessment Outcomes

6.1.1 Operations

Under Existing conditions, the delineated catchments are internally draining, meaning streamflow from seasonal rainfall-runoff events report to intermittent damplands located in topographic depressions. This runoff ponds and/or infiltrates within these dampland areas.

Given the highly permeable sandy soil present at the mine site and within the surrounding catchments, rainfall infiltrates without producing runoff for the more frequent events. Surface drainage lines do not flow on a regular basis within the Project area. Therefore, damplands within the Project area are expected to be dependent on direct rainfall-runoff only and not from inflows from surrounding regional drainage lines.

Damplands located outside of the mine disturbance footprint (pit shells, mine infrastructure area and roads) are not expected to be impacted by diversion of external drainage lines as they rarely contribute flow.

6.1.2 Closure

Under Existing conditions, the majority of floodwater in drainage lines flow from the east into the proposed pit area, before infiltrating.

Under Closure conditions, the pit void is partially backfilled and pre-development flow paths reinstated to allow the majority of floodwater to flow from the east into the partially backfilled pit area where it infiltrates, consistent with Existing conditions.

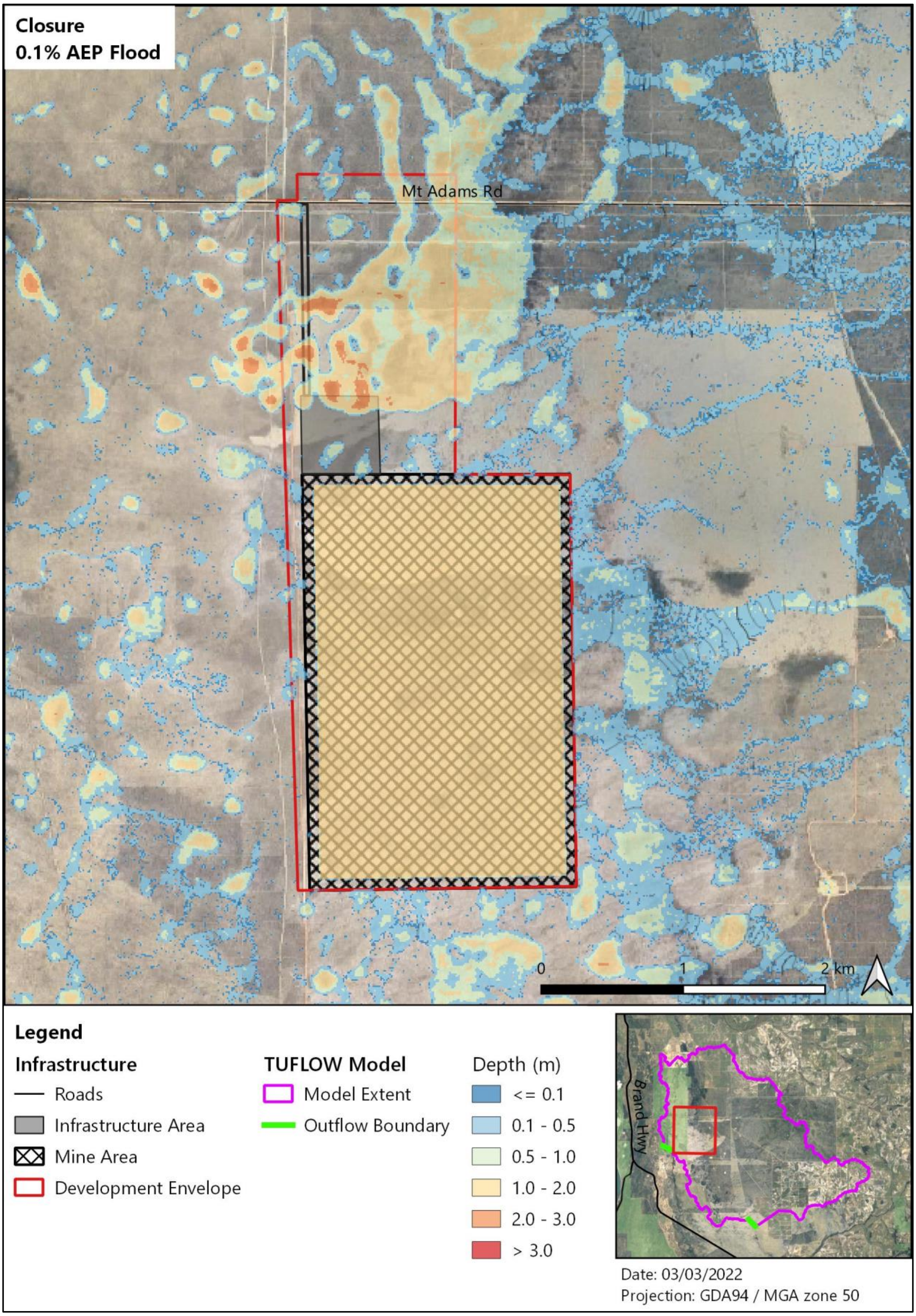

Figure 6-1. 0.1% AEP flood depth for Closure scenario

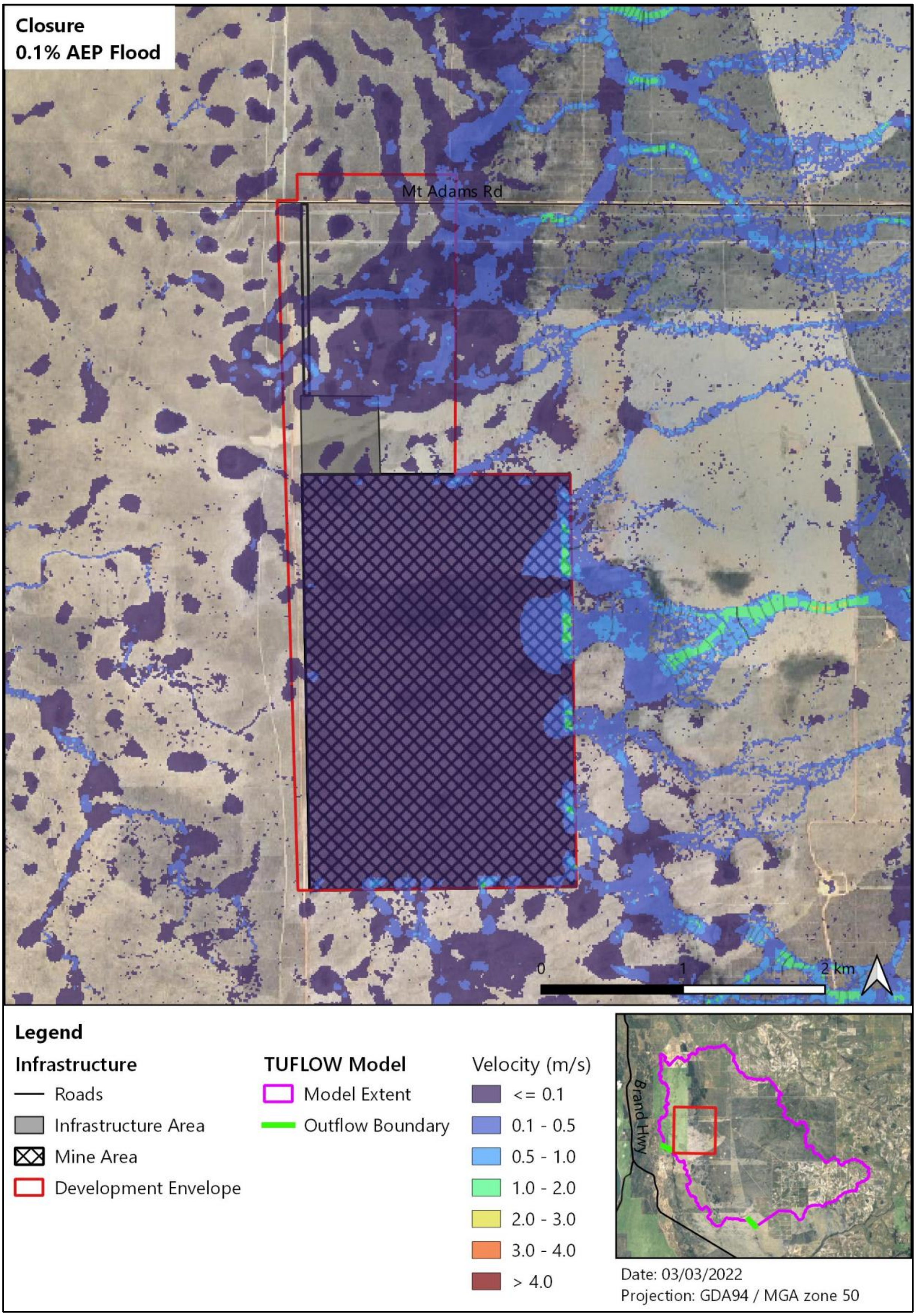

Figure 6-2. 0.1% AEP flood velocity for Closure scenario

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7 References

ARR, 2021. *New ARR probability terminology*. http://arr.ga.gov.au/__data/assets/pdf_file/0006/40398/New-ARR-Probability-Terminology_final.pdf

ARR, 2019. *ARR Data Hub*. Available at: http://data.arr-software.org/

Austroads, 2019. *Guide to Bridge Technology Part 8: Hydraulic Design of Waterway Structures*.

Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors), 2019. *Australian Rainfall and Runoff: A Guide to Flood Estimation*, Commonwealth of Australia (Geoscience Australia).

Bureau of Meteorology, 2003. *The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method.* Hydrometeorological Advisory Service, Bureau of Meteorology, June. *http://www.bom.gov.au/hydro/has/gsdm_document.shtml*

Bureau of Meteorology, 2005. *Guidebook of the Estimation of Probable Maximum Precipitation: Generalised Tropical Storm Method*, Included on compact disc 'Guide to the Estimation of Probable Maximum Precipitation: Generalised Tropical Storm Method', Hydrometeorological Advisory Service, Bureau of Meteorology, September.

Bureau of Meteorology, 2016. *Design Rainfall Data System*. Retrieved from http://www.bom.gov.au/water/designRainfalls/revised-ifd/

Davies, J. R., and Yip, E., 2014. *Pilbara Regional Flood Frequency Analysis*. 35th Hydrology and Water Resources Symposium. Perth, WA, 2014.

DBCA, 2018. *Directory of Important Wetlands in Australia - Western Australia (DBCA-045).* Environmental Management Branch. Department of Biodiversity, Conservation and Attractions. Last updated 27th April 2018. https://catalogue.data.wa.gov.au/dataset/directory-of-important-wetlands-in-western-australia

Endemic, 2012. *Revised Wetland Mapping and Management Mt Adams Road, Dongara*. Prepared for TiWest Pty Ltd.

Flavell, D., 2012. *Design Flood Estimation in Western Australia,* Australian Journal of Water Resources, 16(1), 1-20.

Geoscience Australia, 2011. *1 second SRTM Digital Elevation Model (DEM)*. Bioregional Assessment Source Dataset. Viewed 18 November 2021, http://data.bioregionalassessments.gov.au/dataset/9a9284b6-eb45-4a13-97d0-91bf25f1187b.

Haque, M. M., Rahman, A., Haddad, K., Kuczera, G., and Weeks, W., 2015. *Development of a regional flood frequency estimation model for Pilbara, Australia*. 21st International Congress on Modelling and Simulation, Gold Coast, Australia. https://www.mssanz.org.au/modsim2015/L6/haque.pdf

IEAust, 1987. *Australian Rainfall and Runoff: A Guide to Flood Estimation*, Vol. 1, Editor-in-chief D.H. Pilgrim, Revised Edition 1987 (Reprinted edition 1998), Barton, ACT.

Kuczera, G., 1999. *Comprehensive at-site Flood Frequency Analysis using Monte Carlo Bayesian inference*. Water Resources Research, 35(5), 1551-1557.

PEC, 2021. *Beharra Silica Project, Pre-Feasibility Study (PFS) Report*. 17th March 2021.

Queensland Government, 2022. *SILO: Australian climate data from 1889 to yesterday*. https://www.longpaddock.qld.gov.au/silo/

Schoknecht, N. and Pathan, S., 2013. *Soil Groups Of Western Australia: A simple guide to the main Soils of Western Australia.* Fourth Edition. Resource Management Technical Report 380. Department of Agriculture and Food. Government of Western Australia.

Semeniuk Research Group, 1994. *Ecological assessment and evaluation of wetlands in the System 5 region*. Unpublished report prepared for the Australian Heritage Commission.

TUFLOW, 2018. *TUFLOW Classic/HPC User Manual*. BMT Group Ltd. https://www.tuflow.com/Download/TUFLOW/Releases/2018-03/TUFLOW%20Manual.2018-03.pdf