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Fortescue Future Industries Pty Ltd.

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Revision	Review / Approval ID	Action Date
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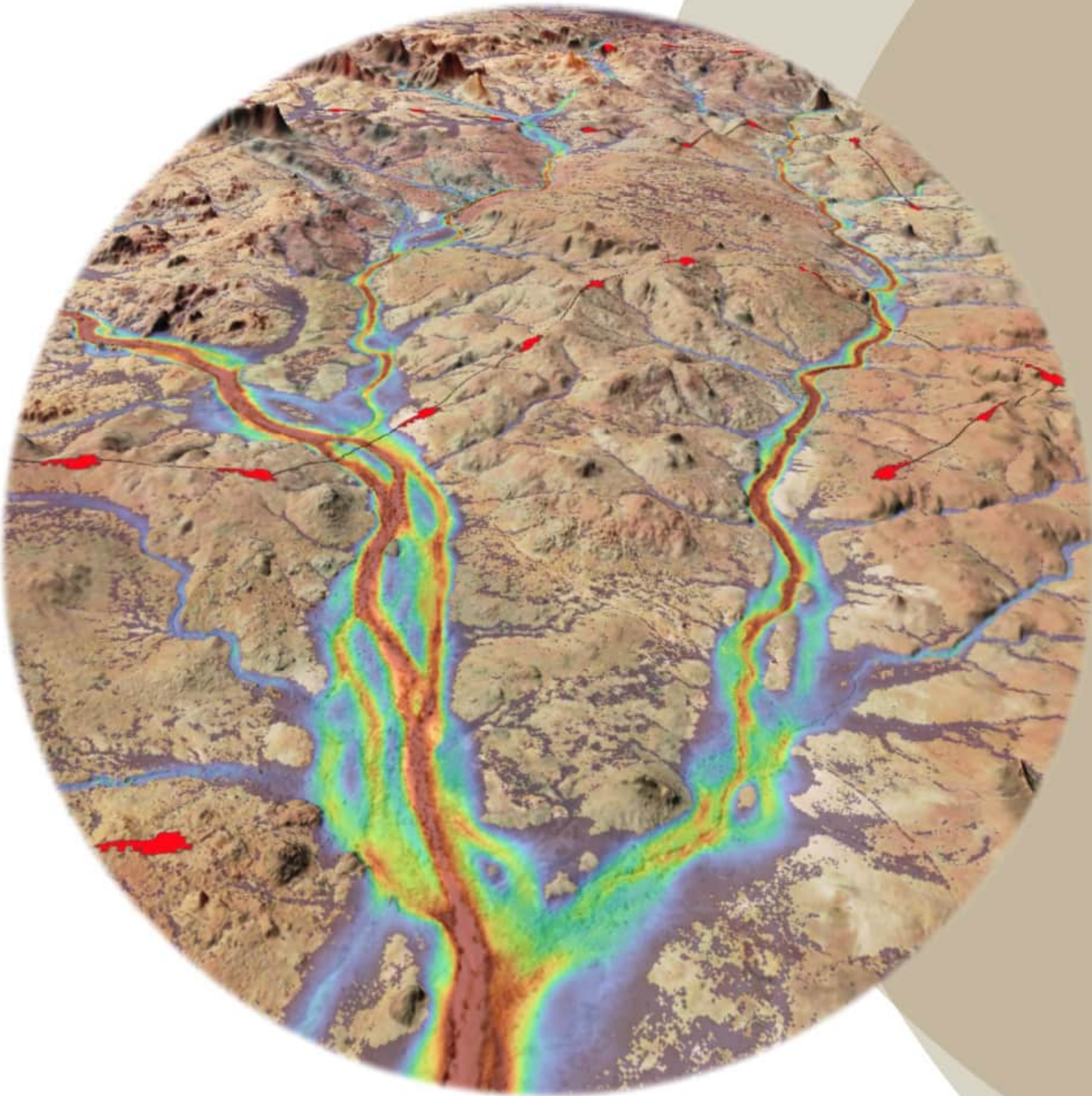

Pilbara Decarbonisation Project

Bonney Downs Baseline Hydrology Study

Fortescue Future Industries

11 August 2023

BONNEYD_HYD_REP_001
AUSS0003-0000-HG-REP-0001

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PROJECT 411012-00646 - BONNEYD_HYD_REP_001: Pilbara Decarbonisation Project - Bonney Downs Baseline Hydrology Study

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Executive summary

A baseline hydrological assessment was required to develop an understanding of surface water behaviour within and surrounding the Bonney Downs Project (the Study Area) in support of preliminary layout/design of wind turbines, associated infrastructure and initial regulatory approval submissions. The proposed Bonney Downs Project (which will support development of wind power generation) is located approximately 15 km south of Nullagine.

Flood Frequency Analysis (FFA) was completed for the streamflow gauge located at Nullagine on the Nullagine River and a RORB rainfall-runoff model previously developed for the East Pilbara Generation Hub (EPGH) project (Advisian, 2022) was used to undertake empirical loss reconciliation for use in the design flood analysis.

Rainfall-runoff and hydraulic behaviour predictions for the base (existing) case in the Study Area were undertaken using three rain on grid TUFLOW hydraulic models. The Study Area was separated into three models (BD1, BD2 and BD3) due to the large catchment areas and significant computational demand. Design rainfall events from the 50% AEP to the 0.5% (1 in 200) AEP event were assessed for the Study Area.

The proposed turbine hardstands are located mostly in headwater areas with some located near more significant watercourses. Modelling identified 165 proposed turbine hardstand locations within an area of peak flood depth of greater than 100 mm in the 1% AEP event. Of these locations 103 were shown to be within an area of at least 300 mm depth, with 17 of these locations having a peak flood depth of greater than 1 m in the 1% AEP event.

Flood risk at the majority of hardstand locations is likely able to be mitigated through either local site stormwater management to deal with stormwater (sheet flow) runoff around the pad, or alternatively a minor change in hardstand location or orientation.

Sensitivity analysis was also undertaken to assess peak flood behaviour sensitivity to the projected impacts on rainfall in the 2050 future climate scenario. This sensitivity was assessed for both the 1% AEP 2050 RCP4.5 and RCP8.5 scenarios. Model results indicated that increases in peak flood levels were typically less than 250 mm for most of the Study Area (the exception being in the lower extents of the Nullagine and Coongan Rivers where no infrastructure is currently proposed). Similarly, assessment of model results to increased floodplain roughness was undertaken, with model results showing up to 200 mm increases in peak flood levels within the Study Area. As a result, it is expected that the uncertainties and associated risks relating to future climate hydrological uncertainty and the exact floodplain roughness across the Study Area could be mitigated by adoption of a standard design freeboard of 300 mm (to mitigate either of the individual sensitivity scenarios).

Acronyms and abbreviations

Acronym/abbreviation	Definition
1D	One-dimensional
2D	Two-dimensional
AEP	Annual Exceedance Probability
AHD	Australian Height Datum
AM	Annual Maximum
ARF	Areal Reduction Factor
ARR2019	Australian Rainfall and Runoff (2019)
BoM	Bureau of Meteorology
CL	Continuing Loss
DEM	Digital Elevation Model
DWER	Department of Water and Environment Regulation
EPGH	East Pilbara Generation Hub
FFA	Flood Frequency Analysis
FFI	Fortescue Future Industries
HV	High Voltage
IFD	Intensity Frequency Duration
IL_B	Burst Initial Loss
IL_S	Storm Initial Loss
LPIII	Log Pearson III
MRWA	Main Roads Western Australia
OHTL	Overhead Transmission Line
PILF	Potentially Influential Low Flows
PEC	Priority Ecological Communities
RCP	Representative Concentration Pathway
RFFA	Regional Flood Frequency Analysis
RFFE	Regional Flood Frequency Estimation Model
RFFP	Regional Flood Frequency Procedure

1 Introduction

1.1 Background

Fortescue Future Industries, a wholly owned subsidiary of Fortescue Metals Group, is leading the company's decarbonisation and green product export agendas by developing a portfolio of projects, centred on producing renewable energy and other value-adding green export products, primarily hydrogen and ammonia. This portfolio of projects proposes to achieve 100% decarbonisation of Fortescue's operations by 2030.

To achieve this target, Pilbara Energy Connect (PEC), a wholly owned subsidiary of FMG, has been working on a series of power transmission projects, aimed at interlinking FMG's operational energy demands. Construction is currently underway to connect Solomon to Iron Bridge via a High Voltage (HV) Overhead Transmission Line (OHTL). It is anticipated that the expansion of the HV power network from Solomon to Eliwana, and Iron Bridge to Port Hedland, will soon follow.

FFI has identified multiple renewable energy generation hubs within the mine sites' vicinity, to reduce transmission line length and losses. The hub sites were determined based on several factors including, existing studies, environmental approvals pathways, wind resource, and accessible land.

One of these sites is the proposed Bonney Downs Project (the focus of this study) which will support development of wind power generation. The midpoint of the Development Envelope (herein referred to as the Study Area) is located approximately 30 km south of Nullagine (Figure 1-1).

A hydrological assessment is required to form a baseline understanding of surface water behaviour within the Study Area. This baseline hydrological assessment will support preliminary layout/design of infrastructure and initial regulatory approval submissions.

This report provides a summary of the baseline hydrological assessment works including site characteristics, design event hydrology and hydraulic modelling results.

1.2 Scope of works

The scope of works for this assessment as defined in the RFQ are:

1. Review existing publicly available, and Fortescue generated, hydrological data, surrounding environmental settings, potential sensitive receptors nearby, that would inform the development of the hydrological and hydraulic models and model boundaries.
2. Derive site specific Intensity-Frequency-Duration (IFD)/design rainfall, considering spatial variation in rainfall and appropriate areal reduction factors (ARFs), in accordance with the guidelines provided in ARR2019. The assessment shall be undertaken for design rainfall events ranging from 50 % to 0.5 % Annual Exceedance Probability (AEP).
3. Catchment delineation, flood hydrograph generation and peak flow rate estimation to all watercourses identified for the full range of AEPs. The assessment shall adopt appropriate infiltration losses and determine the critical rainfall duration, temporal rainfall patterns and flood estimates at the locations of interest for the purpose of hydraulic modelling, inundation mapping and regulatory reporting. Additionally, critical duration and temporal patterns shall be determined, or models developed that would enable future peak flow determination, for localised proposed infrastructure areas such that future design work can be undertaken.

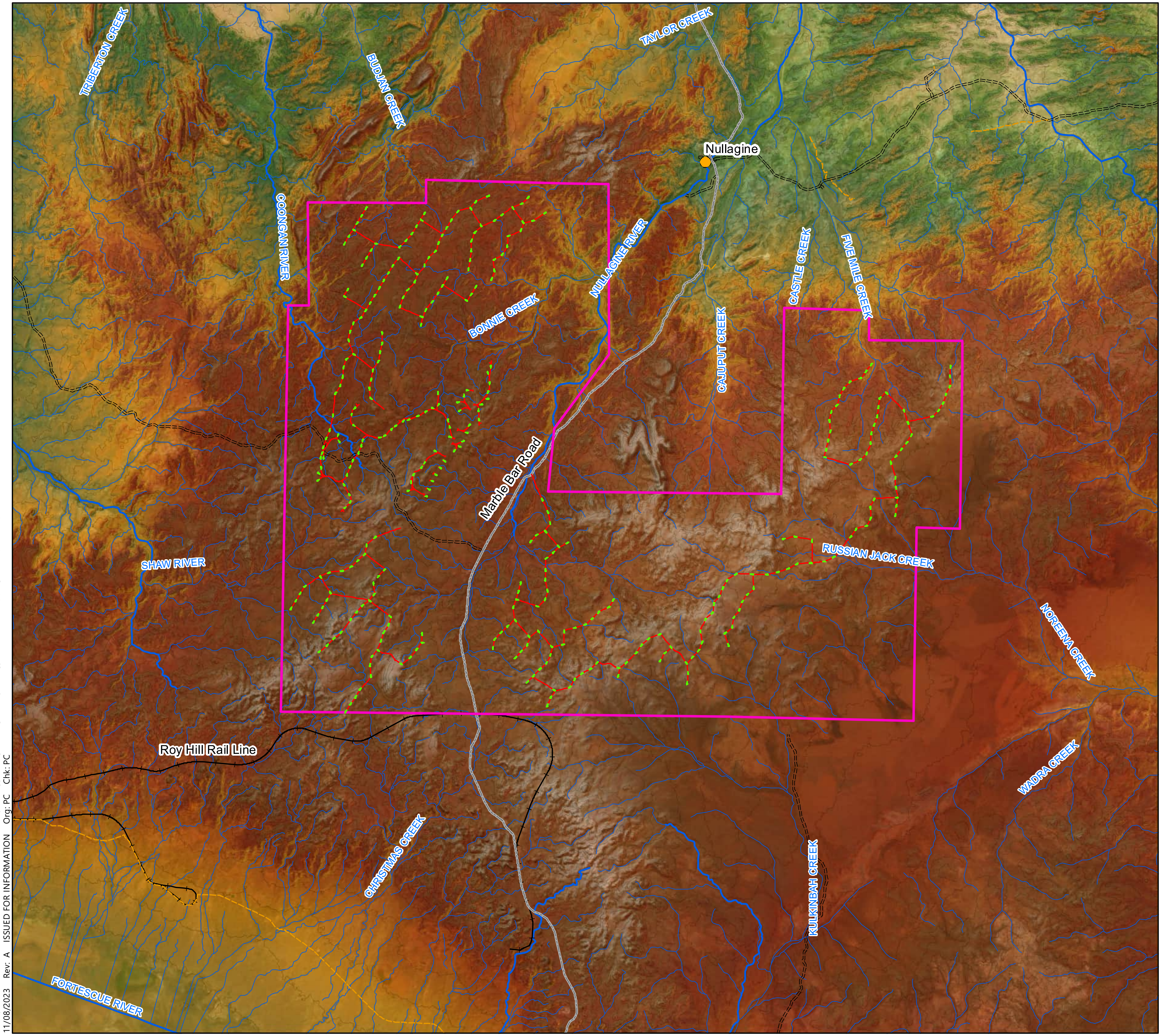
The assessment methodologies shall comprise of regional and rainfall-runoff routing methods/models including Regional Flood Frequency Procedure (RFFP), Region Flood Frequency Estimation (RFFE), RORB and TUFLOW, determined to be appropriate for the complexity of the hydrological regime of the catchment area, and the objectives of the study.

4. Undertake hydraulic modelling using TUFLOW (or similar software) to assess the baseline flooding regime of the project area. The extent of the model(s) shall consider the proposed infrastructure corridor and any sensitive surface water receptors such that they can be used to inform future surface water impact assessments.
5. Undertake calibration/verification of the hydrological and hydraulic models, or parameters thereof within the models, where data exists.
6. Undertake a climate change assessment on hydrological data by evaluation of region-suitable selected scenarios, representative concentration pathways and global climate models for selected time horizons. The assessment should take into consideration the potential impacts of climate change on rainfall depths/intensities and assess the sensitivity of the design flow for a selected rainfall event to climate change.
7. Conduct sensitivity analysis on key inputs or parameters within the models, such as Manning's n roughness, downstream boundary conditions and climate change influences etc, to assess and quantify changes to design flows.
8. Flood inundation mapping for the 20 %, 5 %, 1 % and 0.5 % AEP design events. Flood inundation maps shall include at a minimum the maximum flood depth, velocity, depth-velocity product, and flood hazard for the design events as identified above.
9. Develop a baseline hydrological assessment report documenting in detail:
   - Assessment objectives and requirements
   - Governance, i.e., applicable guidelines, standards, references
   - Catchment setting, characteristics, and surrounding environment
   - Data collection and review, availability, limitations, and assumptions
   - Hydrology study and hydraulic modelling methodologies, justification for suitability of the adopted methodologies
   - Climate change assessment
   - Calibration and sensitivity analysis
   - Analysis of results including flood mapping (flood depth, velocities, depth-velocity-product, and flood hazard) of the area for the 20 %, 5 %, 1 % and 0.5 % AEP design rainfall events, suitable for regulatory approval submission.

PILBARA DECARBONISATION PROJECT
BONNEY DOWNS
BASELINE HYDROLOGY STUDY

FIGURE 1-1

STUDY AREA



Legend

- Town
- Study Area
- Proposed Wind Turbine Hardstand
- Proposed Tracks
- State Road
- Local Road
- Miscellaneous Road
- Rail Network
- Major Waterway
- Minor Waterway
- 10 m Contour Interval

Shuttle Radar Topography Mission DEM (mAHD)

High : 700

Low : 300

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

N

Scale at A3 - 1:280,000

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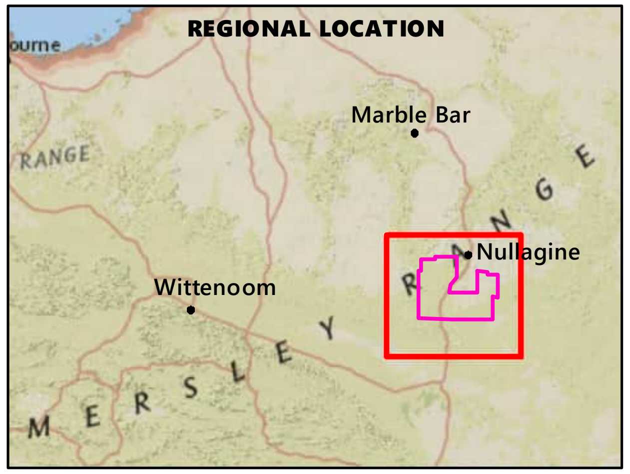
Kilometers



Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community
National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO,

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2 Information and data

2.1 FFI provided information

A summary of the key information provided by FFI for this assessment is presented in Table 2-1.

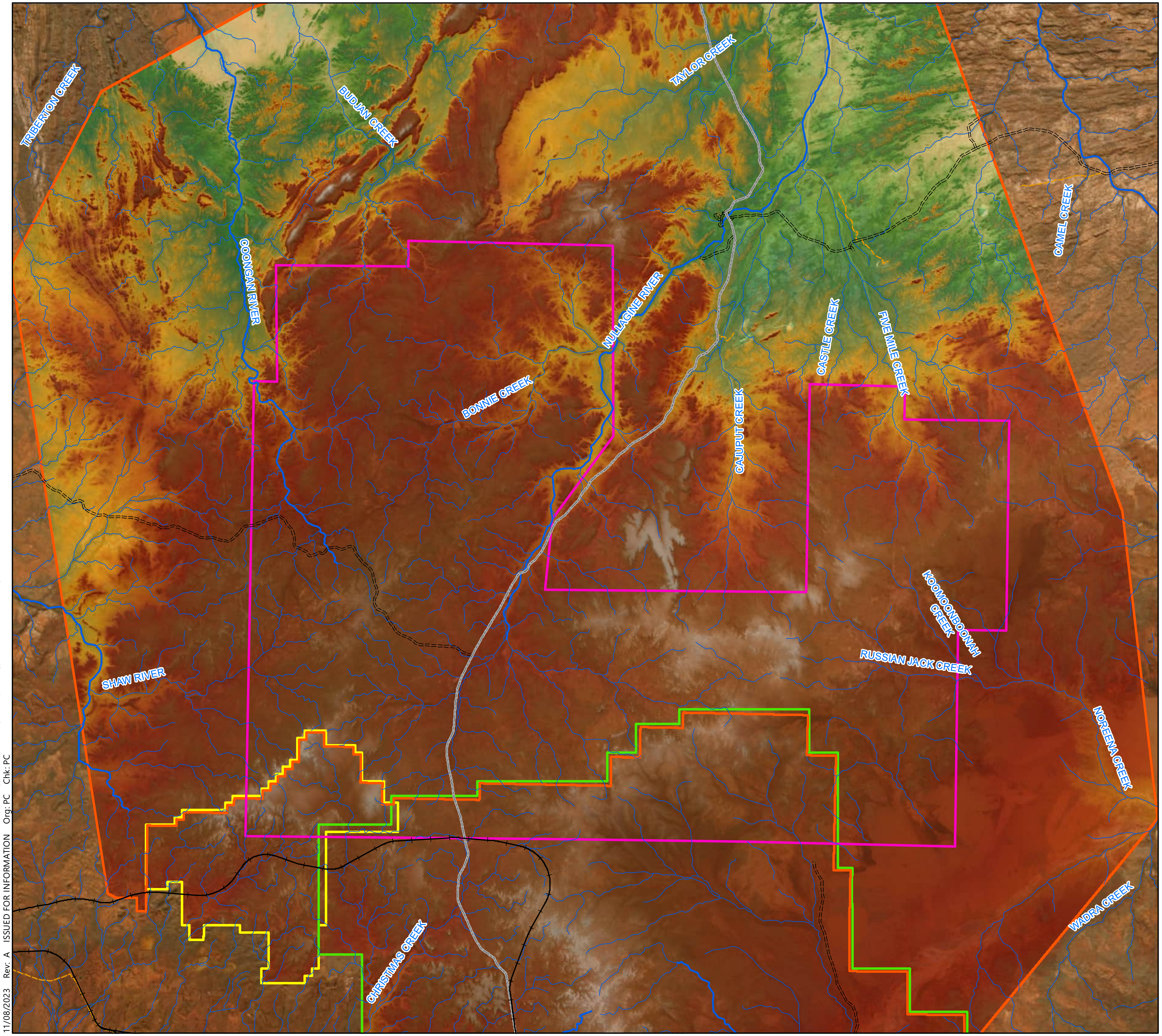
Table 2-1: Data utilised in this assessment

Data	Description	File / Format
Aerial Imagery and Topography		
Digital Elevation Model (DEM) – presented in Figure 2-1	1 m LiDAR derived DEM captured February 2023: Bonney Downs	PIL_ELEV_FMG_BONNEY_DOWNS_1M_DEM_FEB2023.tif
	1 m LiDAR derived DEM captured June 2020: Kutayi	PIL_ELEV_FMG_KUTAYI_1M_DEM_JUN2020.tif
	1 m LIDAR derived DEM captured June 2019: Kutayi	PIL_ELEV_FMG_KUTAYI_1M_DEM_JUN2019.tif
Imagery	Bonney Downs RGB imagery with GSD of 15cm	B_Downs_focused_15cm.ecw
	Bonney Downs RGB imagery with GSD of 2m	B_Downs_2m_Clip.tif
Planning		
Development areas	Proposed project development areas	Wider Bonney Downs Scoping Envelope.shp
Infrastructure layout	Proposed wind turbine layout	Proposed_Hardstand_Rev1.shp, G1_ to G7_Hardstand.shp
	Proposed tracks layout	Proposed_Track_Rev1.shp, G1_ to G7_Tracks.shp
Background Information		
Report	Bonney Downs - Geotechnical Desktop Assessment (FFI, 2023)	AUSS0003-0000-GE-REP-0005_A_IFR_Bonney Downs Geological Assessment (1).pdf

It is noted that the provided DEMs were reviewed and shown to provide detailed representations of the hillslope terrain features. Within the streambed of the Nullagine River, some artefacts were identified in the DEMs, potentially associated with the thick vegetation or standing water. It is noted that these areas were typically downstream of the proposed infrastructure locations. No metadata reports were provided with the DEMs, as such the relative accuracies of each dataset are unknown.

2.2 Publicly available data

Hydrology datasets including stream gauging and rainfall data were sourced from the Department of Water and Environmental Regulation (DWER), Bureau of Meteorology (BoM), and ARR2019 Datahub. Detailed drainage structure information for the Marble Bar Road were also obtained from Main Roads Western Australia (MRWA).



PILBARA DECARBONISATION PROJECT
BONNEY DOWNS
BASELINE HYDROLOGY STUDY

FIGURE 2-1

FFI PROVIDED HIGH RESOLUTION DIGITAL ELEVATION MODEL EXTENT

Legend

- Study Area
- Rail Network
- State Road
- Local Road
- Miscellaneous Road
- Major Waterway
- Minor Waterway
- BONNEY_DOWNS_1m_DEM_Feb2023
- KUTAYI_1m_DEM_June2019
- KUTAYI_1m_DEM_June2020

1 m Resolution Digital Elevation Model (mAHD)

High : 600

Low : 300

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

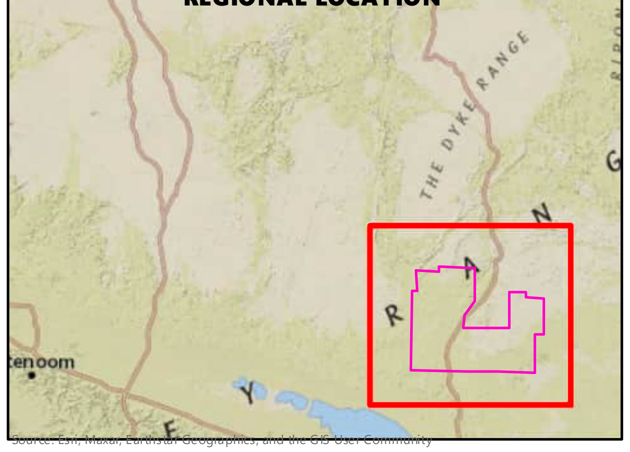
N

Scale at A3 - 1:250,000

0 4 8 12 16

Kilometers

REGIONAL LOCATION



Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community
National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO,

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3 Catchment characterisation

The hydrological behaviours of the contributing catchments to the Study Area are governed by the climate and physical characteristics of the catchment. This section provides a description of the catchment characteristics that informed the hydrological and hydraulic modelling.

3.1 Catchments

The majority of the Study Area is located in the headwaters of De Grey River catchment with a significantly smaller portion of the Study Area in the headwaters of the Fortescue River catchment. The main creek systems of the Study Area are presented in Figure 3-1 and include the Nullagine and Coongan rivers (De Grey River catchment) which drain in a northerly direction. Russian Jack Creek (Davis River catchment) drains in an easterly direction and Kulkinbah Creek (Fortescue River catchment) drains in a southernly direction. The general catchment characteristics for the larger creek systems contributing to the Study Area (at locations used for peak flow comparison to model results later in the report) are presented in Table 3-1 and shown in Figure 3-1.

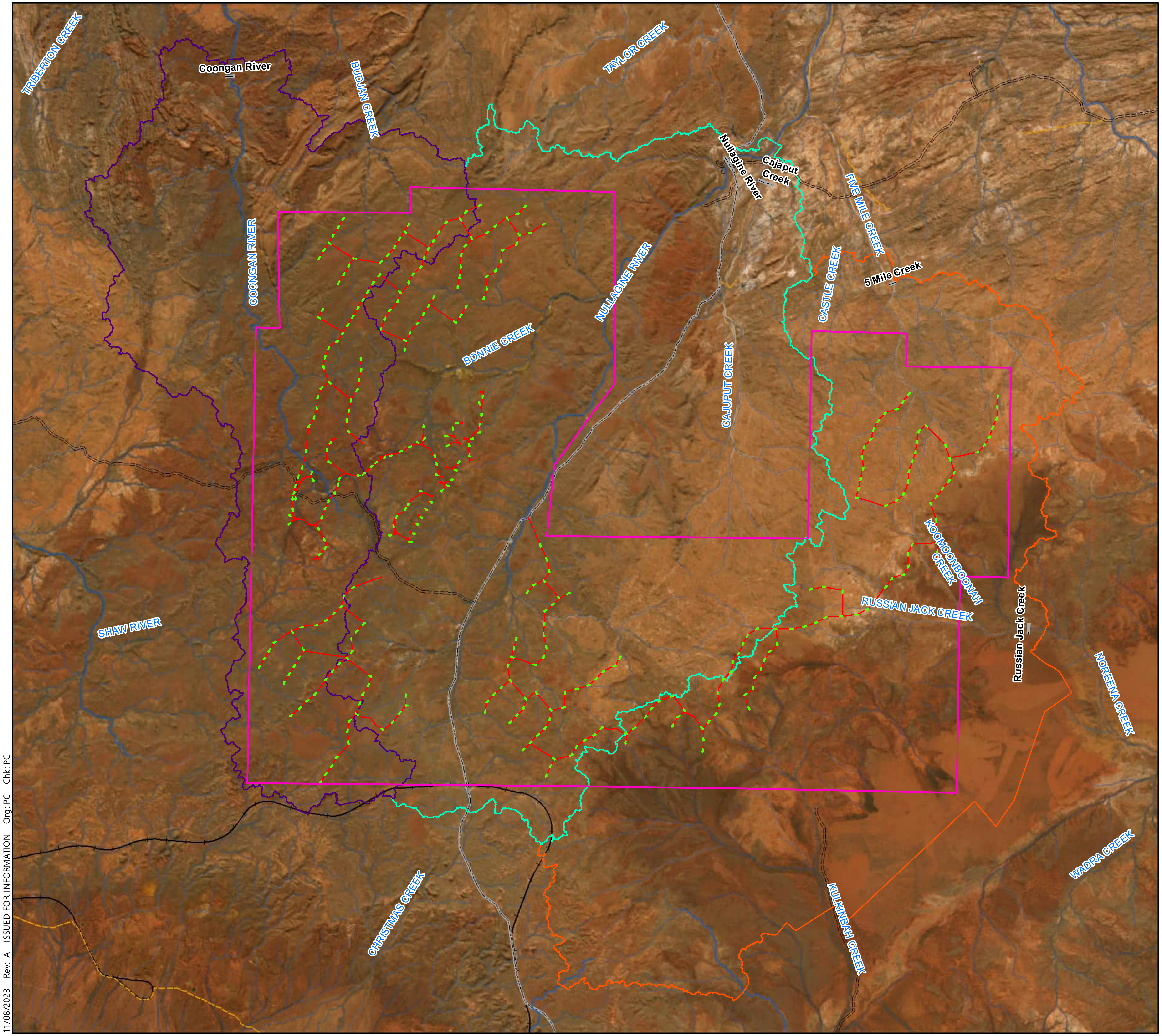
Table 3-1: Study Area catchment details

Catchment Name	Area (km^2)	Mainstream Length (km)	Centroid Latitude (°S)	Centroid Longitude (°E)	EA slope (m/km)	Shape Factor, L^2/A
Coongan River	419	41	21.98	119.79	3.75	3.9
Nullagine River	872	62	22.09	119.99	2.43	4.4
Cajaput Creek	253	30	22.04	120.12	3.58	3.6
Five Mile Creek	185	20	22.03	120.25	5.51	2.2
Russian Jack Creek	194	19	21.98	120.25	3.75	1.9

3.2 Climate

The Pilbara climate is characterised by very hot summers, mild winters and low but variable rainfall (Sudmeyer, 2016). The BoM Köppen climate classification system (Stern et al., 2000) defines the Study Area as a hot, persistently dry (grassland). Rainfall therefore occurs predominantly in the summer wet season (approximately November to March) from passing ex-tropical cyclones and low-pressure systems, with localised isolated convective thunderstorm activity also common. Owing to these mechanisms, rainfall is highly variable and extended periods of low rainfall are common.

The variability of rainfall is demonstrated in Figure 3-2 with mean monthly and annual rainfall totals at Bonney Downs (ID: 004006). The annual rainfall average (325.5 mm) is provided for the October to September water year (available from 1907 onwards). Mean monthly pan evaporation (SILO, 2022) at Bonney Downs (available from 1970 onwards) consistently exceeds mean monthly rainfall, signifying a water-limited environment (Table 3-2).



PILBARA DECARBONISATION PROJECT
BONNEY DOWNS
BASELINE HYDROLOGY STUDY

FIGURE 3-1

STUDY CATCHMENTS AND MODEL EXTENTS

Legend

- Catchment reporting location (refer Table 3-1)
- Project Development Envelope
- Proposed Wind Turbine Hardstand
- Proposed Tracks
- BD1 Model Extent
- BD2 Model Extent
- BD3 Model Extent
- Major Waterway
- Minor Waterway
- State Road
- Local Road
- Miscellaneous Road
- Rail Network

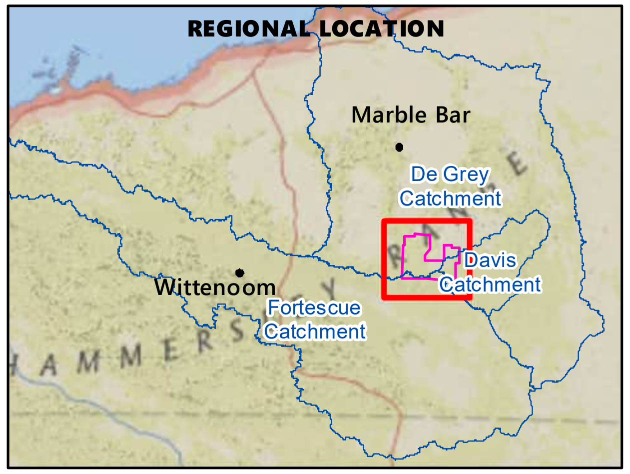
Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

N

Scale at A3 - 1:250,000

0 4 8 12 16
Kilometers

REGIONAL LOCATION



Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community
National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO,

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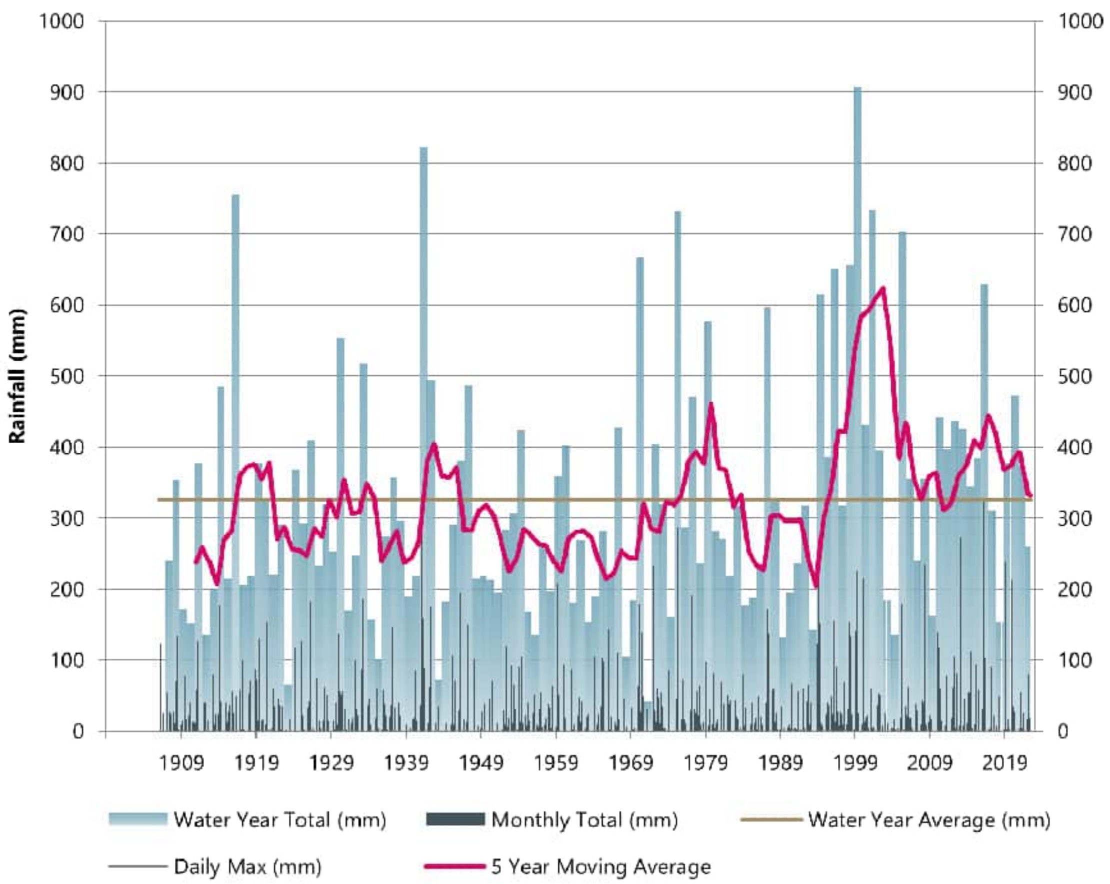
PILBARA DECARBONISATION PROJECT
BONNEY DOWNS
BASELINE HYDROLOGY STUDY

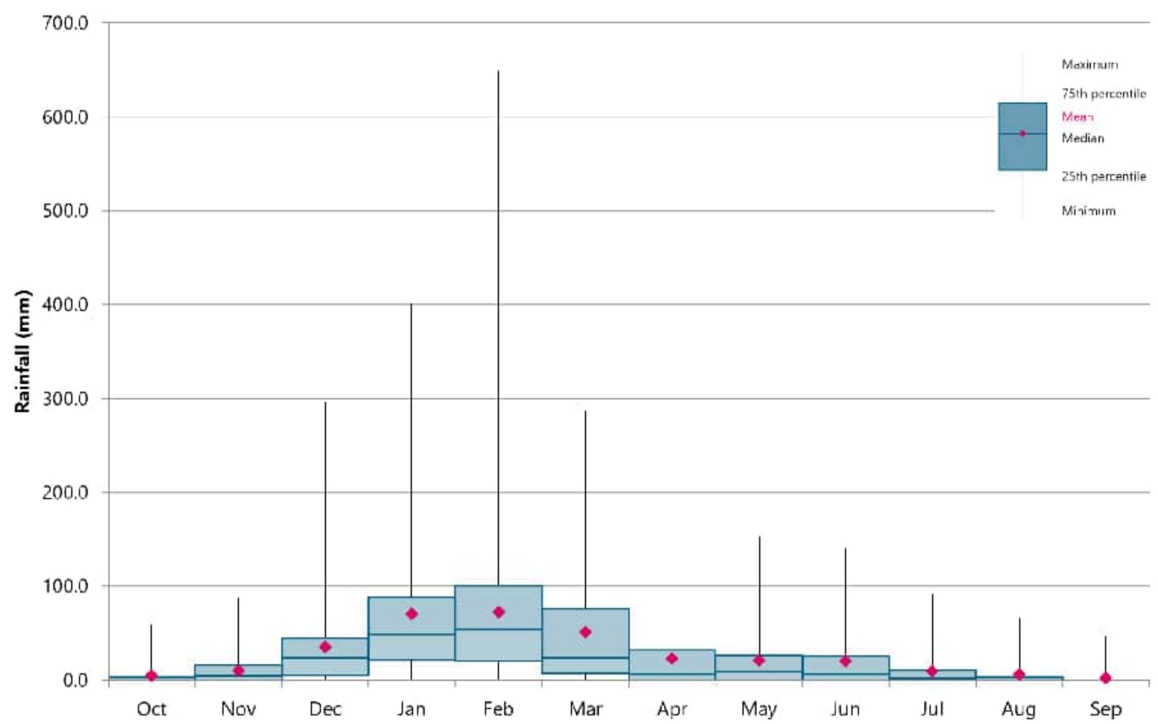
FIGURE 3-2

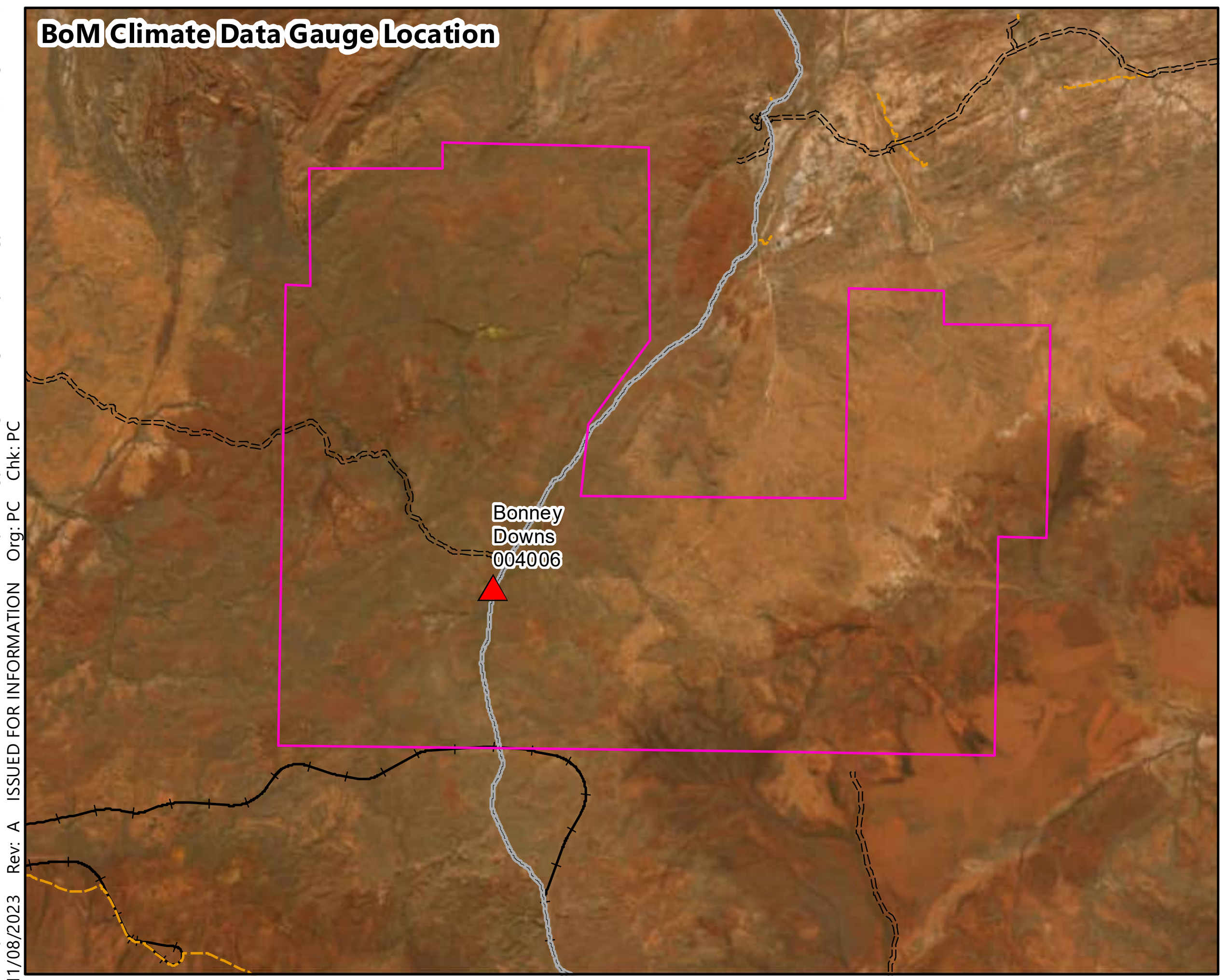
STUDY AREA CLIMATE DATA

Water Year and Monthly Rainfall Data

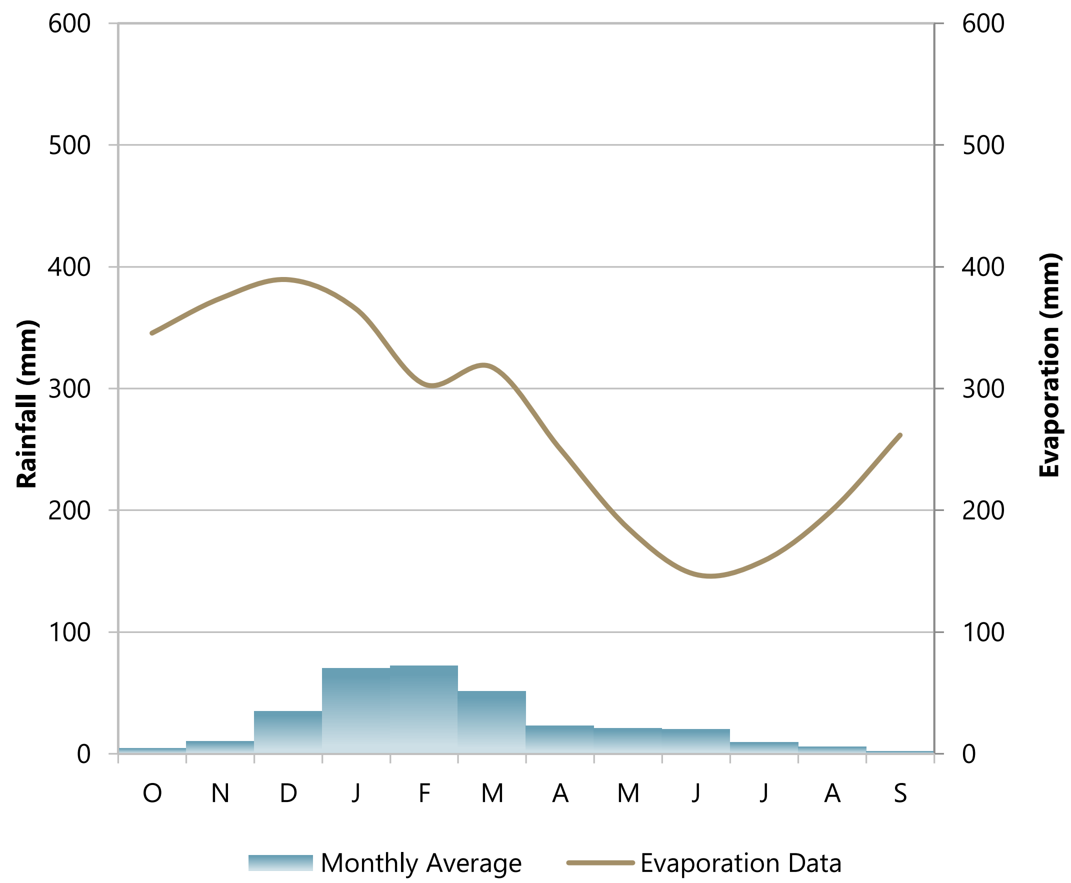


Monthly Data Box Plot





Rainfall and Evaporation Data



Legend

- Study Area
- Climate Data Gauge Site
- State Road
- Local Road
- Miscellaneous Road
- Rail Network

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

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Scale at A3 - 1:500,000

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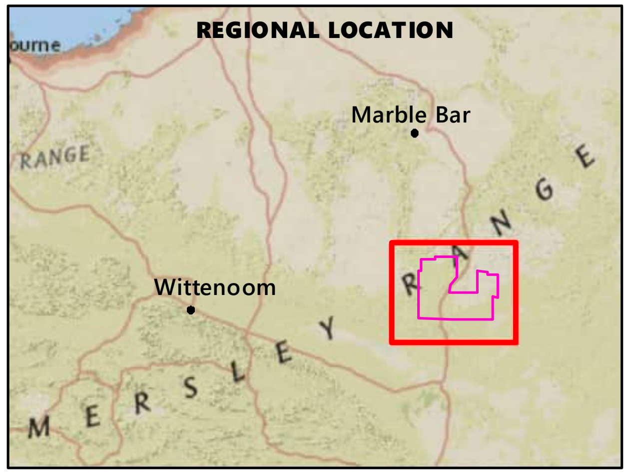
Kilometers



Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community
National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO,

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Table 3-2: Monthly evaporation and rainfall data (BoM, 2023)

Data	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Mean pan evaporation (mm) at Bonney Downs*	338	365	375	352	286	289	234	183	142	157	198	257	3,175
Mean rainfall (mm) at Bonney Downs#	4.5	10.3	34.9	70.2	72.2	51.4	23.1	21.1	20.2	9.5	6.1	2.0	325.5
Highest Rainfall (mm)	58.9	87.9	296.0	401.0	649.6	287.2	174.5	153.2	140.9	92.2	66.4	46.5	823.9
Lowest Rainfall (mm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Median Rainfall (mm)	0.0	4.7	23.9	48.9	53.7	23.8	6.1	9.0	6.0	1.8	0.0	0.0	286.5
Highest Daily Rainfall (mm)	58.9	40.0	119.6	152.4	306.0	154.9	158.8	73.7	83.6	88.6	61.6	40.5	306.0

**Denotes evaporation data from 1970 to 2023*
#Denotes rainfall data from 1907 to 2023

3.3 Soils

Regional mapping suggest soils within the Study Area are variable, with 'stony soils' and regions of 'clays shallow loamy duplexes' dominating the Northern and Western areas of the Study Area which include Coongan River and Nullagine Creek. The headwaters of Five Mile Creek primarily consist of 'shallow sands' whilst the southeast of the Study Area (located within model domain BD3) has a high variability of dominant soil groups which include 'coloured sands', 'shallow loams', 'deep loamy duplexes and earths', 'clays shallow loamy duplexes' and 'stony soils' (DPIRD, 2019).

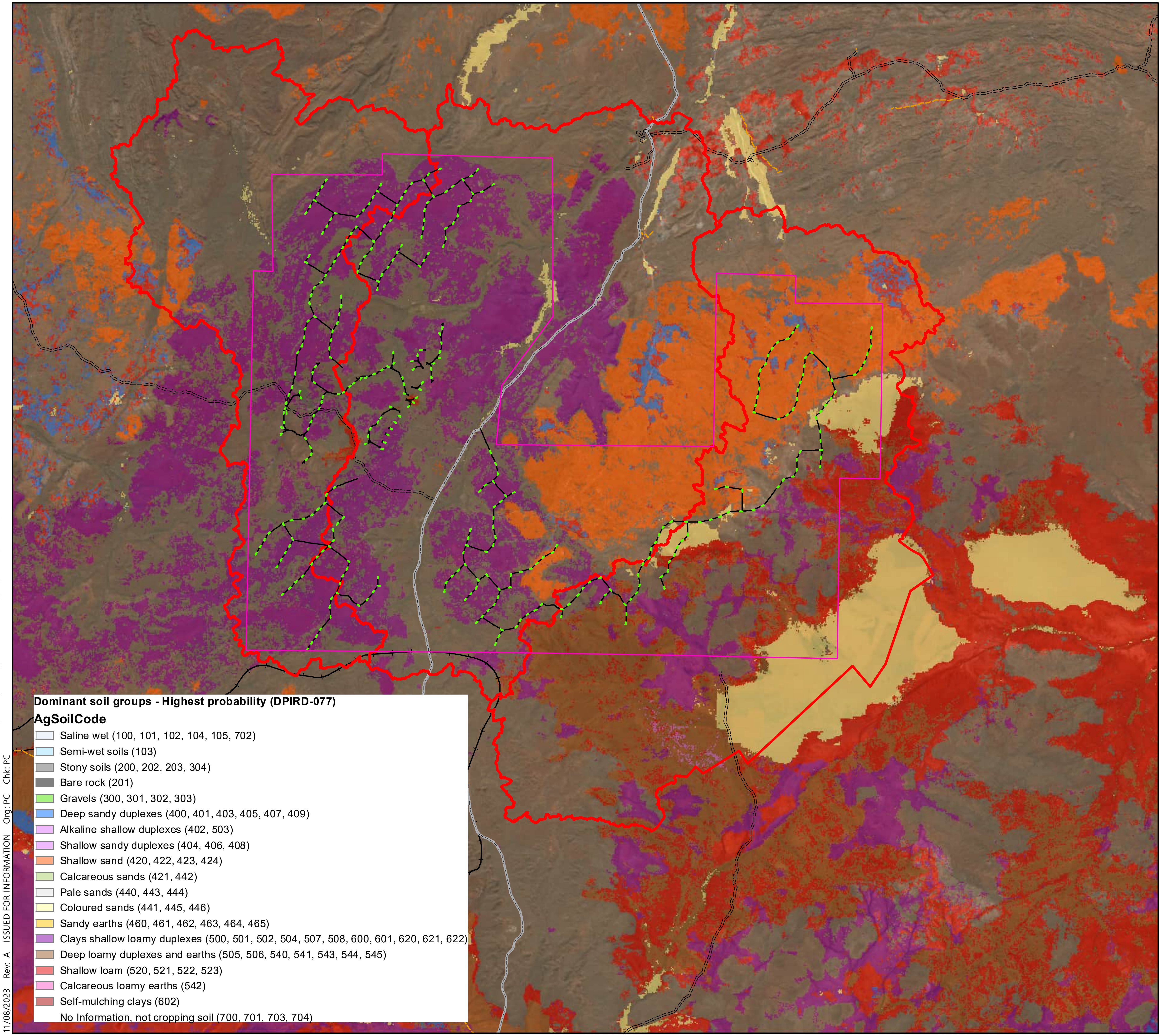
It is noted that whilst the highest probability mapping predicts shallow sands in the eastern Nullagine River catchment (Cajuput Creek), the confusion index is noted as being high for these areas. Review of aerial imagery, the FFI Geotechnical Desktop Report (2023), topography and second highest probability soil mapping suggests the majority of the area are more likely to be classified as 'stony soils' or rugged granitic landforms.

The highest probability soils mapping from DPIRD for the site as well as the wider region showing adjacent catchment areas is presented in Figure 3-3.

PILBARA DECARBONISATION PROJECT
BONNEY DOWNS
BASELINE HYDROLOGY STUDY

FIGURE 3-3

HIGHEST PROBABILITY SOILS (DPIRD) REGIONAL MAPPING



Legend

- Study Area
- Proposed Wind Turbine Hardstand
- Proposed Tracks
- Model Extent
- Rail Network
- State Road
- Local Road
- Miscellaneous Road

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
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Scale at A3 - 1:300,000

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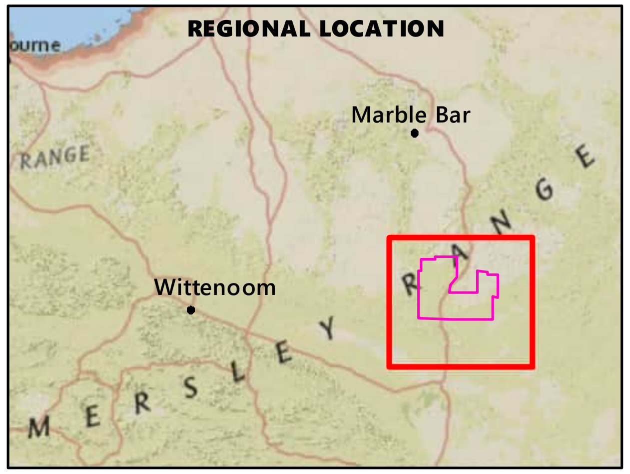
Kilometers



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3.4 Infrastructure

The main infrastructure located within the Study Area is presented in Figure 1-1 and includes:

- Marble Bar Road (Main Roads WA)
- Roy Hill Rail Line

3.5 Environmental values

Flows through the Study Area support environmental habitats including within the riparian corridors. Although unlikely, potential changes to surface water flows downstream of the proposed renewable energy activities due to proposed infrastructure has the potential to impact vegetation in the respective communities.

There are some areas of Priority Ecological Communities (PEC) noted within the Study Area according to the Department of Water and Environmental Regulation (DWER) mapping data, which are mostly concentrated in the west of the Study Area within the Nullagine River catchment and is presented in Figure 3-4.

Vegetation across most of the Study Area consists typically of Spinifex grasslands with kanji and snappy gum (and some tussock grasslands) (Tille, 2006).

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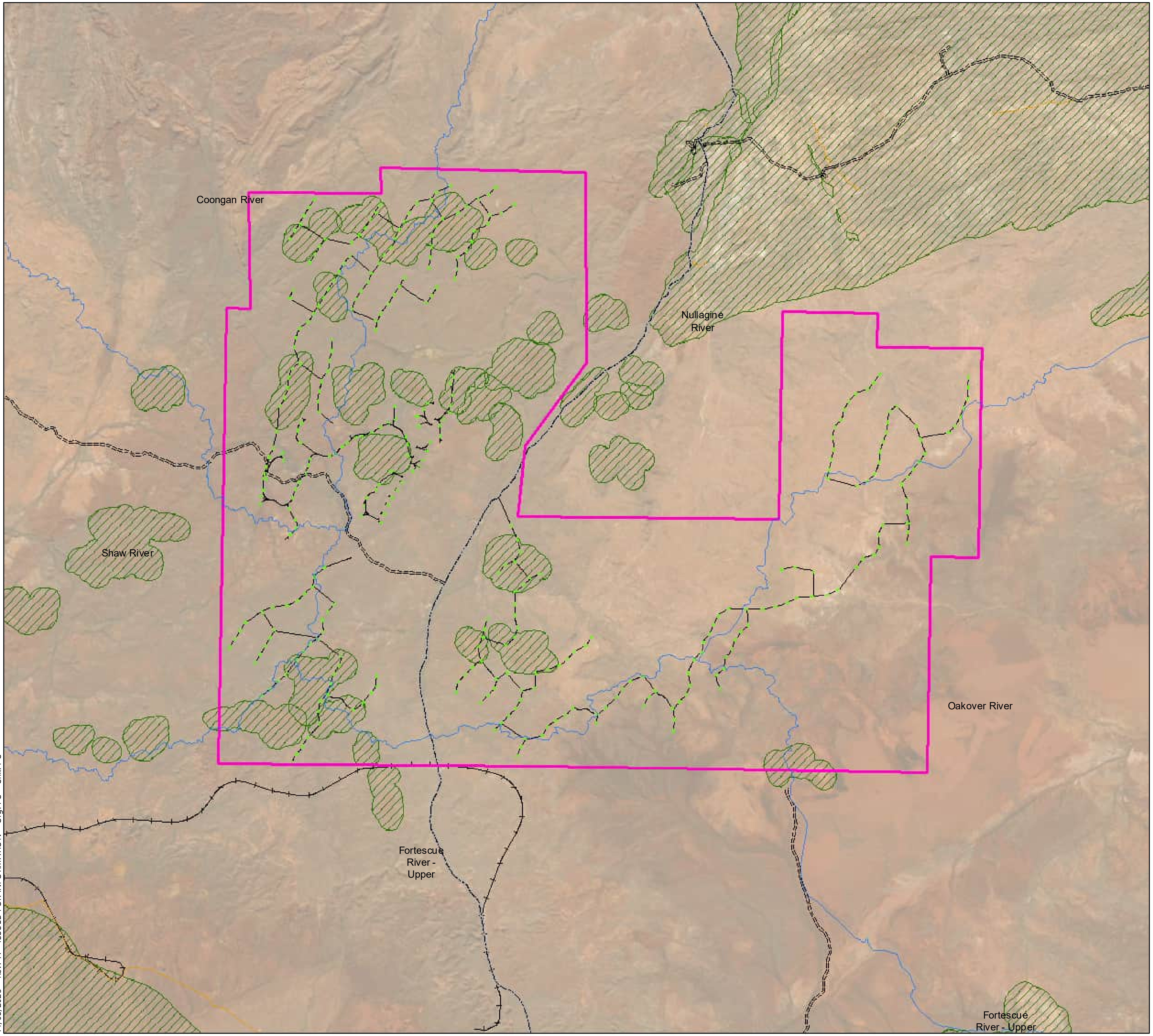
BASELINE HYDROLOGY STUDY

FIGURE 3-4

PRIORITY ECOLOGICAL COMMUNITIES



Legend

- Catchment boundary
- Study Area
- Proposed Wind Turbine Hardstands
- Proposed Tracks
- State Road
- Local Road
- Miscellaneous Road
- Rail Network
- Priority Ecological Communities

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

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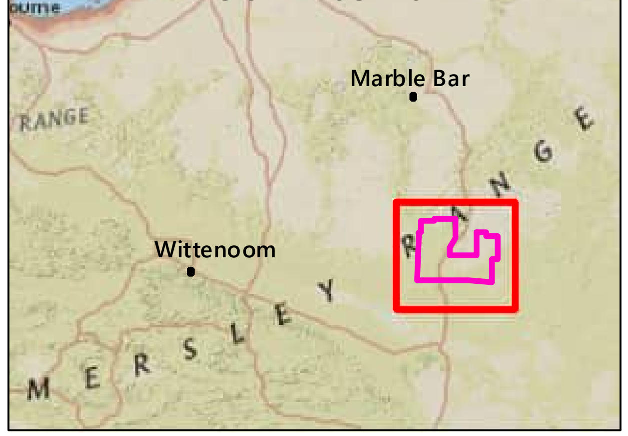
Scale at A3 - 1:250,000

0 4 8 12 16

Kilometers

REGIONAL LOCATION



Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community
National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO,

Fortescue. Advisian

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4 Regional rainfall-runoff characterisation

4.1 Background

Several hydrological modelling approaches were used to aid in characterising design event discharges and ultimately hydraulic behaviours in the Study Area. To enable the best estimate of empirical loss model parameters for the design event hydrological assessment in the Study Area, characterisation of the regional rainfall-runoff relationship was undertaken using available surrounding gauged watercourses. This approach used Flood Frequency Analysis (FFA) and a RORB rainfall-runoff model and is recommended by ARR in preference to regional estimates obtained from the ARR Datahub (Babister et al., 2016)

The hydrological modelling approach, input parameters, methodology and results of regional assessment are presented in the following sections.

4.2 Flood frequency analysis

Flood Frequency Analysis (FFA) has previously been undertaken for the Nullagine River at Nullagine as part of the FFI East Pilbara Generation Hub (EPGH) Baseline Hydrology Study (Advisian, 2022). Given that the majority of the Study Area falls within the Nullagine catchment and the gauge is approximately 15 km downstream of the Study Area (Figure 4-1), this gauge site and FFA analysis was used to inform key loss parameterisation.

The streamflow data was analysed to produce FFA quantiles. These quantiles were then reconciled against the RORB hydrological model Monte Carlo peak flow quantiles for the same location to derive a best estimate of empirical loss parameters for use in the Study Area.

4.2.1 Historic streamflow data

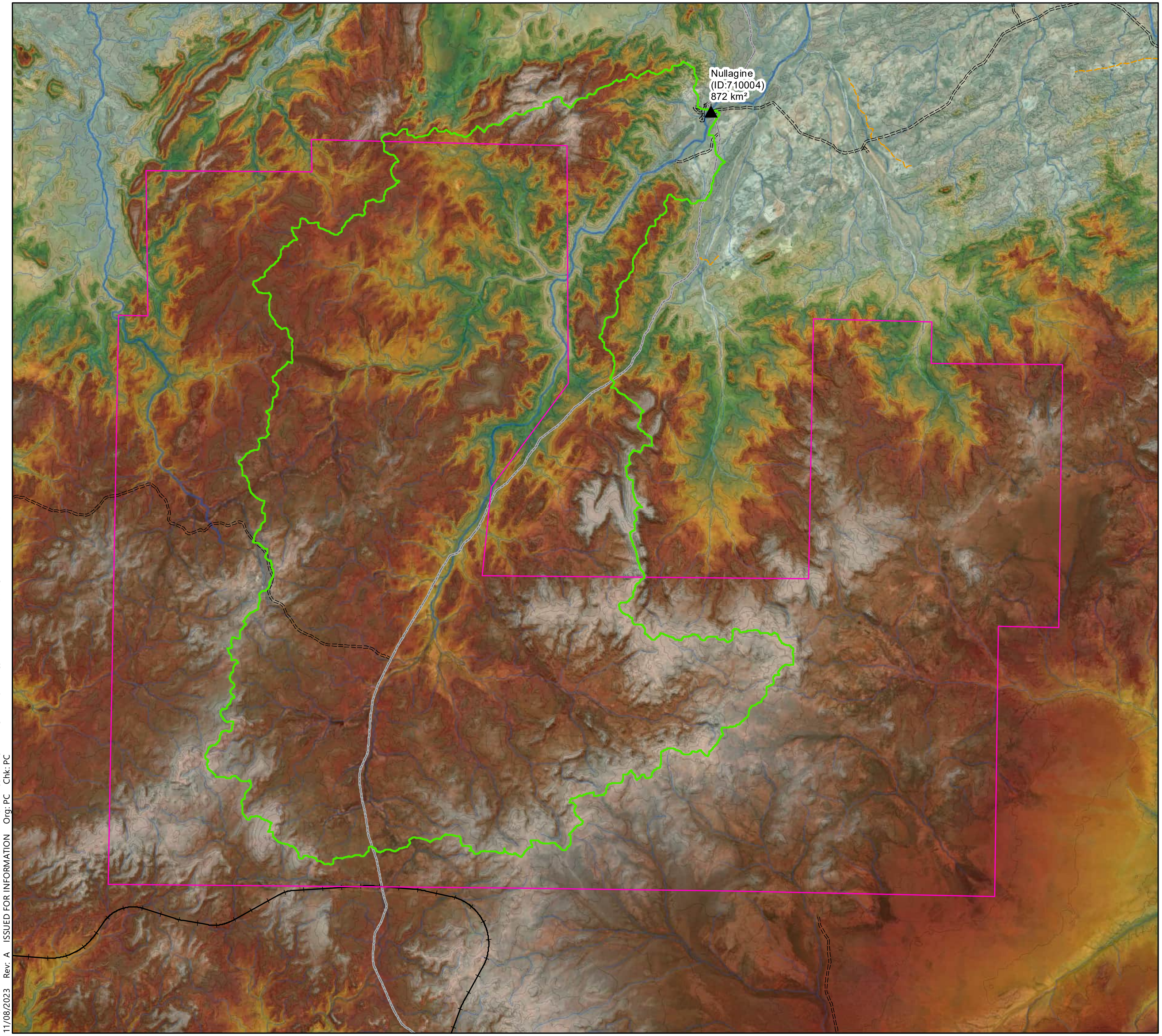
A summary of the DWER streamflow record for Nullagine River, utilised in this assessment, is presented in Table 4-1. The gauge location and associated catchment area is presented in Figure 4-1.

The FFA was undertaken for the gauged data using the TUFLOW FLIKE FFA software using Annual Maxima (AM) data for respective water years (October to September). There is a reasonable length of record available at the gauge (21 years) with nearly no periods of missed recordings.

The gauge has daily maximum discharge recordings available which were used to derive the water year AM for use in the FFA.

Table 4-1: Stream gauges used in this assessment

DWER Stream Gauge	Catchment Area (from DWER) (km²)	Start Date	End Date	Water Years
Nullagine River – Nullagine (710004)	872	15/12/1998	-	21



PILBARA DECARBONISATION PROJECT
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BASELINE HYDROLOGY STUDY

FIGURE 4-1

FLOOD FREQUENCY ANALYSIS
GAUGE LOCATION AND CATCHMENT

Legend

- Streamflow Gauge Site
- Nullagine River Catchment
- Study Area
- Rail Network
- State Road
- Local Road
- Miscellaneous Road
- Major Waterway
- Minor Waterway
- 10 m Contour Interval

Shuttle Radar Topography Mission DEM (mEGM96)

High : 600

Low : 400

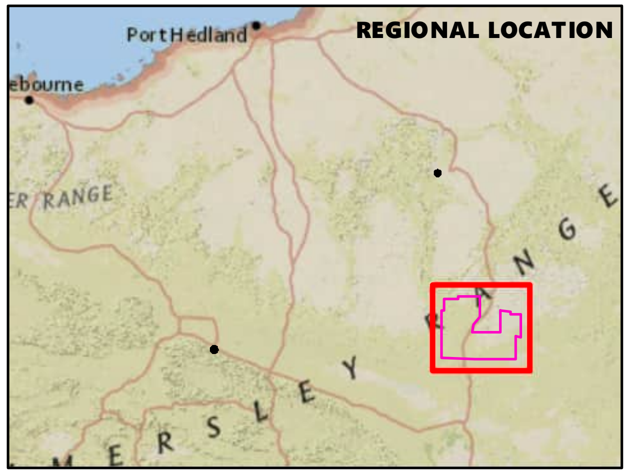
Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

N

Scale at A3 - 1:200,000

0 5 10 15

Kilometers



Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community
National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO,

Fortescue Advisian Worley Group

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4.2.2 Streamflow data review

As gauging stations record stream levels rather than flow a rating table is required to convert the recorded level into a flow estimate. Typically, the rating table is informed by manual gauging undertaken by hydrographers at varying streamflow levels to inform the stage-discharge relationship. These relationships get updated over time as new data and technologies become available.

The gauge site is located immediately upstream of the Marble Bar Road crossing of the Nullagine River and is typified by a mobile alluvial bed. Given the base material there may be some variability in the relationship between gauge height and a corresponding flow estimate (rating curve) that are derived from manual ratings at different times for lower magnitude flows. This is reflected in the changes to Cease to Flow (CTF) levels that occur at rating table updates, noting the shape of the rating curve (besides the most recent update – discussed further below) has remained consistent (a phase shift based on CTF level changes only).

Figure 4-2: Photo of the Nullagine gauge site on the Nullagine River (DWER)

Following the FFI EPGH Baseline Hydrology Study (Advisian, 2022) being completed, DWER updated the rating table at Nullagine on the 26/10/2022, considerably changing flow estimates for given gauge heights (e.g., the largest recorded Annual Maximum [AM] in 2002 increased from 1,800 m^3/s to 2,806 m^3/s). To assess the validity of the new (and previous) rating tables, assessment of the gauge site was undertaken in a detailed 2D TUFLOW hydraulic model.

Detailed topographic data was supplied by FFI for the gauge site and surrounding areas to assess the previous and current DWER rating curves. The TUFLOW model described in Section 5.4 was adapted to produce detailed (4 m grid cell size, 1 m SGS) 2D hydraulic modelling results at the Nullagine gauge location. The result of this analysis indicated that the updated DWER rating curve is overly conservative, and the previous rating curve more closely aligns to the hydraulic modelling results from this study.

In order to further confirm the appropriateness of the new DWER rating curve, a FFA was undertaken on the revised Annual Maximum (AM) values, and it was determined that when using appropriate design rainfall inputs in the previously developed RORB model (from the EPGH study) that replication of the FFA quantiles could not be achieved – even when using no continuing loss. These results are presented in Table 4-2

Table 4-2: FFA quantile estimates (latest DWER rating) and RORB MC estimates using conservative loss values

DWER Stream Gauge	50% AEP (m^3/s)	20% AEP (m^3/s)	10% AEP (m^3/s)	5% AEP (m^3/s)	2% AEP (m^3/s)	1% AEP (m^3/s)
Nullagine River – Nullagine (710004)	406	1207	1,990	2,907	4,300	5,471
RORB MC quantiles (20 mm IL, 0 mm CL)	646	1,332	1,807	2,322	3,006	3,611

Based on these findings, the previous DWER rating curve (pre-October 2022) was adopted for use in the FFA analysis.

4.2.2.1 *Hysteresis*

When a flood wave propagates through a gauge site, there is potential for higher discharges to be observed during rising stage than in falling stages (for the same stage level) resulting in looped rating curves. This is commonly referred to as hysteresis.

The potential impacts of hysteresis on rating curve accuracy were assessed via simulation and plotting of stage-discharge results at the gauge site for the 2020 historic event (N.B. the recorded hydrograph based on current DWER rating curve). The typically non-looped nature of the historic hydrograph for flows above approximately 300 m^3/s at the gauge site indicates that the effects of hysteresis are unlikely to impact the rating curve for the flows of interest in this study. The looped nature of the lower magnitude flows (<300 m^3/s) was considered likely an artifact of the downstream floodway, LiDAR accuracy and associated undulations under the thick riparian zone canopy (around where the sensor is located), the effects of which significantly diminish in higher flood stages (flows). This is presented in Figure 4-3.

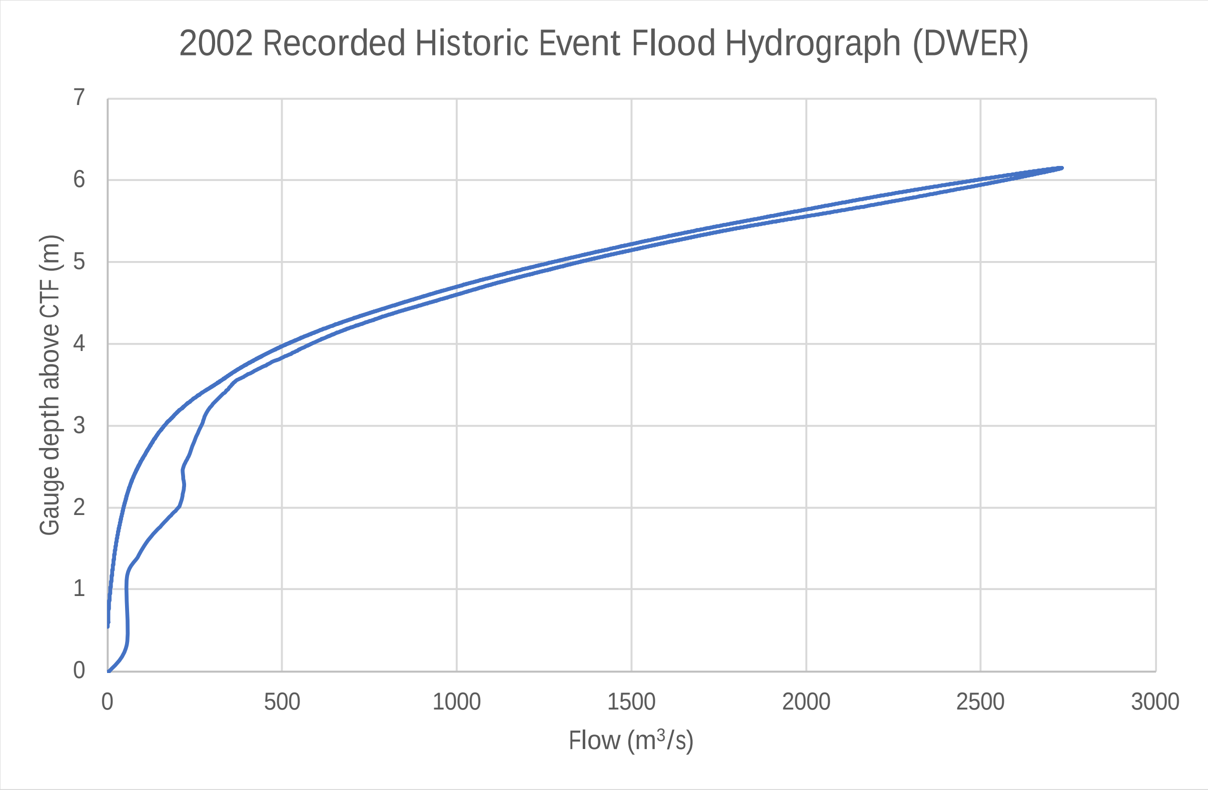

Figure 4-3: Plot of 2002 recorded flood hydrograph (DWER) simulated within TUFLOW model

4.2.3 Periods of missed recordings

A manual review of the gauge record was undertaken for any periods of missed recordings that may influence the FFA. No significant periods of missed recordings were identified and only the first incomplete (1998) water year was excluded from the analysis.

4.2.4 Low flow censoring

Runoff in the Study Area is ephemeral, mostly in direct response to rainfall and is therefore highly seasonal and variable. This means that there are often years in which there are no floods. The AM records from these years are therefore not representative of the population of floods and can unduly influence the fit of the right-hand tail (larger magnitude events) of the frequency distribution. These lower magnitude flows are often referred to as Potentially Influential Low Flows (PILF). Censoring of PILFs was undertaken for the gauge record using the multiple Grubbs-Beck test as described in Book 3 Chapter 2 ARR2019 (Ball et al., 2019). This resulted in a PILF threshold of 57.1 m^3/s.

4.2.5 FFA results

The FFA results for the Nullagine gauge site are presented in Appendix A whilst tabulated results are presented in Table 4-3. The AM data was fit using the Log Pearson III (LPIII) probability model and Bayesian inference method with no prior information available for the region from the ARR Datahub (Babister et al., 2016).

Table 4-3: FFA quantile estimates

DWER Stream Gauge	50% AEP (m^3/s)	20% AEP (m^3/s)	10% AEP (m^3/s)	5% AEP (m^3/s)	2% AEP (m^3/s)	1% AEP (m^3/s)
Nullagine River – Nullagine (710004)	232	738	1,198	1,698	2,376	2,895

4.3 Regional rainfall-runoff modelling

Rainfall-runoff modelling software RORB (version 6.45) was used to simulate rainfall-runoff for the gauged Nullagine River catchment for a range of Annual Exceedance Probability (AEP) events.

The RORB model was previously developed for the EPGH study (Advisian, 2022) and was used as a basis to derive and validate empirical loss model parameter estimates for the Study Area by reconciliation to the Nullagine gauge FFA results. The RORB model schematisation including the nodal-network arrangement is presented in Figure 4-4.

Sub-catchment areas were delineated using topographic data and manually inspected for conformance to expected catchment divides (aerial imagery).

4.3.1 Model inputs and parameters

RORB models are characterised by a number of input parameters such as rainfall, rainfall losses, temporal patterns, areal reduction factors and pre-burst rainfall as well as two additional parameters to derive storage-discharge relationships which are detailed below.

4.3.1.1 Design rainfall data

The latest IFD data for the catchment centroid were obtained from the BoM Design Rainfall Data System (BoM, 2016). The centroid locations and resultant IFD values adopted in this assessment are presented in Appendix B.

As the catchment is larger than 20 km^2, spatial distribution of the design rainfall was undertaken to capture the variability across the catchment as recommended in ARR2019. Regionalised gridded IFD data for the critical duration 12-hour event (1% AEP) was extracted for the region to assess spatial variability of the design rainfall estimates in the model. The difference between the overall catchment mean and sub-area mean was used to determine a rainfall factor for each sub-area to represent the spatial variability.

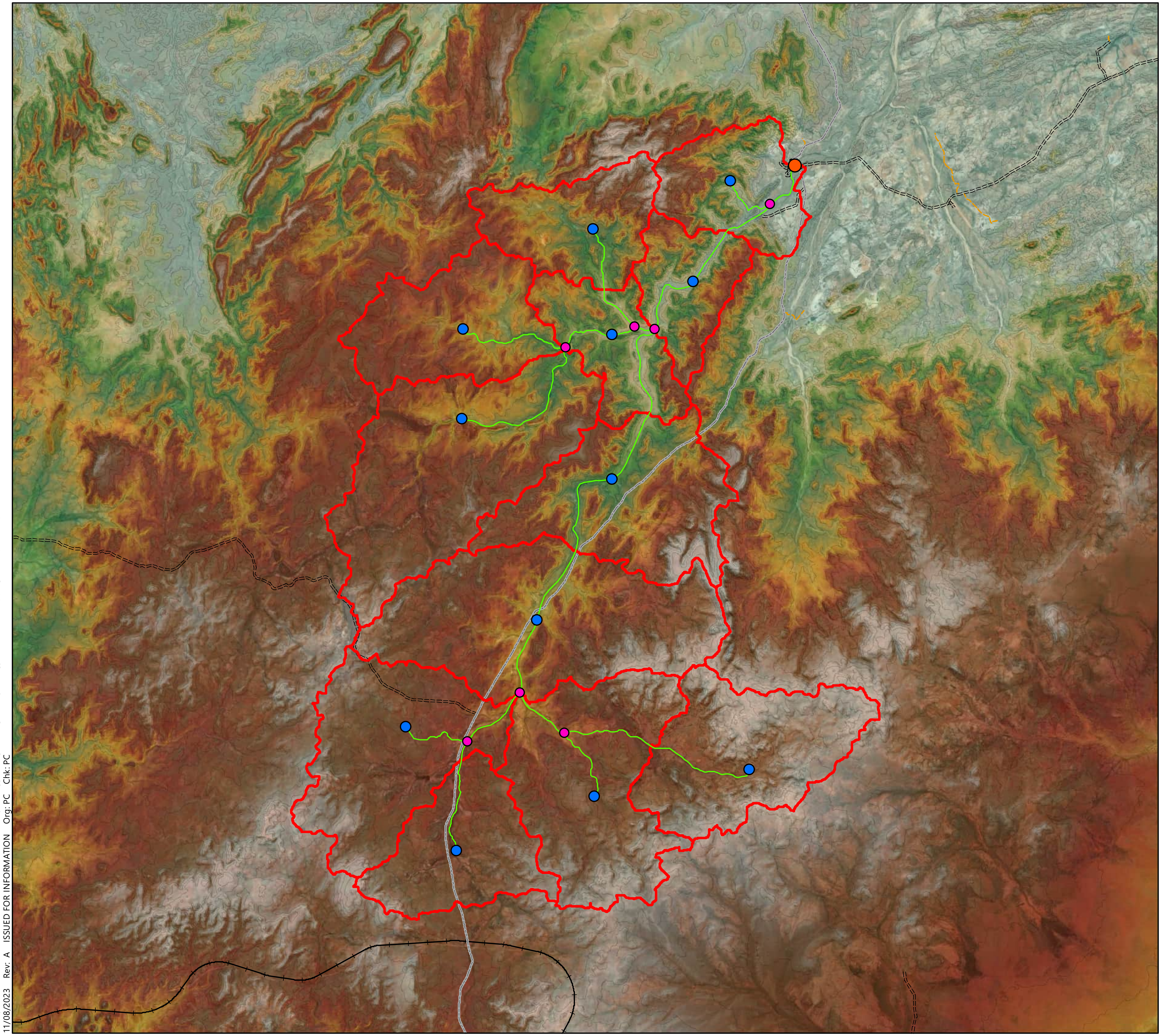

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FIGURE 4-4

RORB MODEL ARRANGEMENT

Legend

- Nullagine River Catchment Sub-areas
- Junction
- Sub-area Centroid
- Outlet
- RORB Routing Link
- State Road
- Local Road
- Miscellaneous Road
- Rail Network
- 10 m Contour Interval

Shuttle Radar Topography Mission DEM (mEGM96)

Value

High : 600

Low : 400

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

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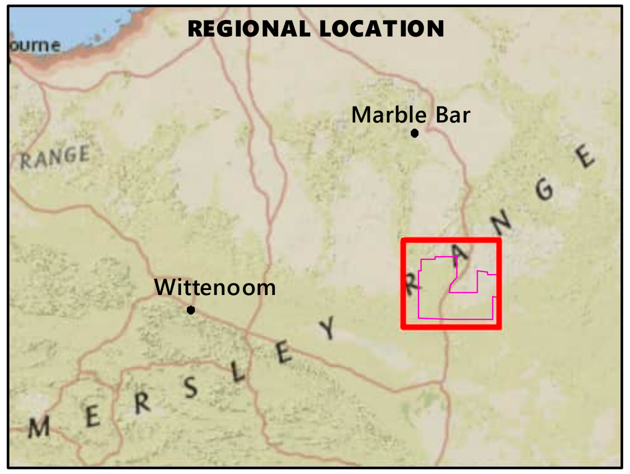
Scale at A3 - 1:200,000

0 5 10 15

Kilometers



Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community
National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO,

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Median pre-burst rainfall depths were extracted from ARR Datahub (Babister et al., 2016). Pre-burst rainfall was removed from the Storm Initial Loss (IL_S) prior to simulation in the model to represent the Burst Initial Loss (IL_B).

4.3.1.2 *Areal reduction factors*

Given the large size of the subject catchment, it is unlikely that the spatial coverage of a high intensity storm burst will be consistent across the entire catchment area. To address this issue, it is typical to apply an Areal Reduction Factor (ARF) to the IFD estimates to ensure the preservation of a probability neutral transition between the design rainfall and the design flood characteristics (ARR2019) (Ball et al., 2019). The procedures outlined in ARR2019 (and automated in RORB) were adopted to determine the duration and AEP-varying ARFs for the Nullagine River catchment.

4.3.1.3 *Loss model*

An Initial Loss (*IL*) / Continuing Loss (*CL*) empirical loss model was adopted for the regional loss validation assessment. Adopted values are discussed in Section 4.3.2.

4.3.1.4 *Storage-discharge parameterisation*

RORB is characterised by two critical parameters to enable calculation of its reach storage-discharge relationship. These are the exponent m, often referred to as the non-linearity parameter and the coefficient K_c, often referred to as the reach storage parameter. These parameters have significant impact on estimating a catchment's response to runoff (both peak flow estimates and hydrograph shape). Producing accurate estimates for these parameters is critical in producing accurate design flow estimation.

Importantly, accurate storage-discharge parameter estimation also aids in producing accurate empirical loss parameter estimates, as these loss parameters can often be used to compensate for inaccurate storage-discharge parameterisation when comparing peak flow estimates to FFA quantiles or through historic event calibration. For natural channels (as is representative of the Study Area) the relationship between storage and outflow in RORB is given by:

$$S_i = \frac{k_c}{d_{av}} L_i Q_i^m$$

Where:

S_i = sub area storage (m^3)
K_c = empirical coefficient
d_{av} = average distance from each sub area to the catchment outlet (or defined 'dummy' gauging station at user-defined points of interest)
L_i = reach length
Q_i = sub-area discharge (m^3/s)
m = non-linearity parameter

The standard m value of 0.8 was adopted in the RORB model. The K_c value in the initial model development as part of the EPGH study was informed by the historic event calibration-derived value from Pearcey et al. (2014) ($C_{0.8}$ of 0.58). However, as detailed topographic information for the entire catchment to the gauge site was now available for this study, the K_c value was validated through direct comparison to a detailed TUFLOW rain on grid model. It was considered that the paucity of rainfall data across the Nullagine River catchment meant that representation of the spatio-temporal variability of rainfall in each historic event across the catchment may not be defined to a suitable level of accuracy to inform accurate K_c estimation, and hence use of the TUFLOW was seen as confirming the appropriateness of the K_c value derived from historic events.

The approach adopted for this study intends to inform K_c by assessing the resultant hydrograph shape (i.e., close alignment of rising and falling limbs, with peak flow alignment a secondary consideration) between each model output for an identical set of hydrological inputs. Identical hydrological inputs are used to produce an identical rainfall-excess hyetograph, which is converted to a hydrograph, for routing through each respective model and hence allow an exact comparison of reach storage and delay time at key locations. Due to the different approaches adopted by either model suite, matching of peak flow values is a secondary consideration and not the intent of the approach. However, experience has shown that typically a strong match in hydrograph shape also produces a relative strong match in peak flows.

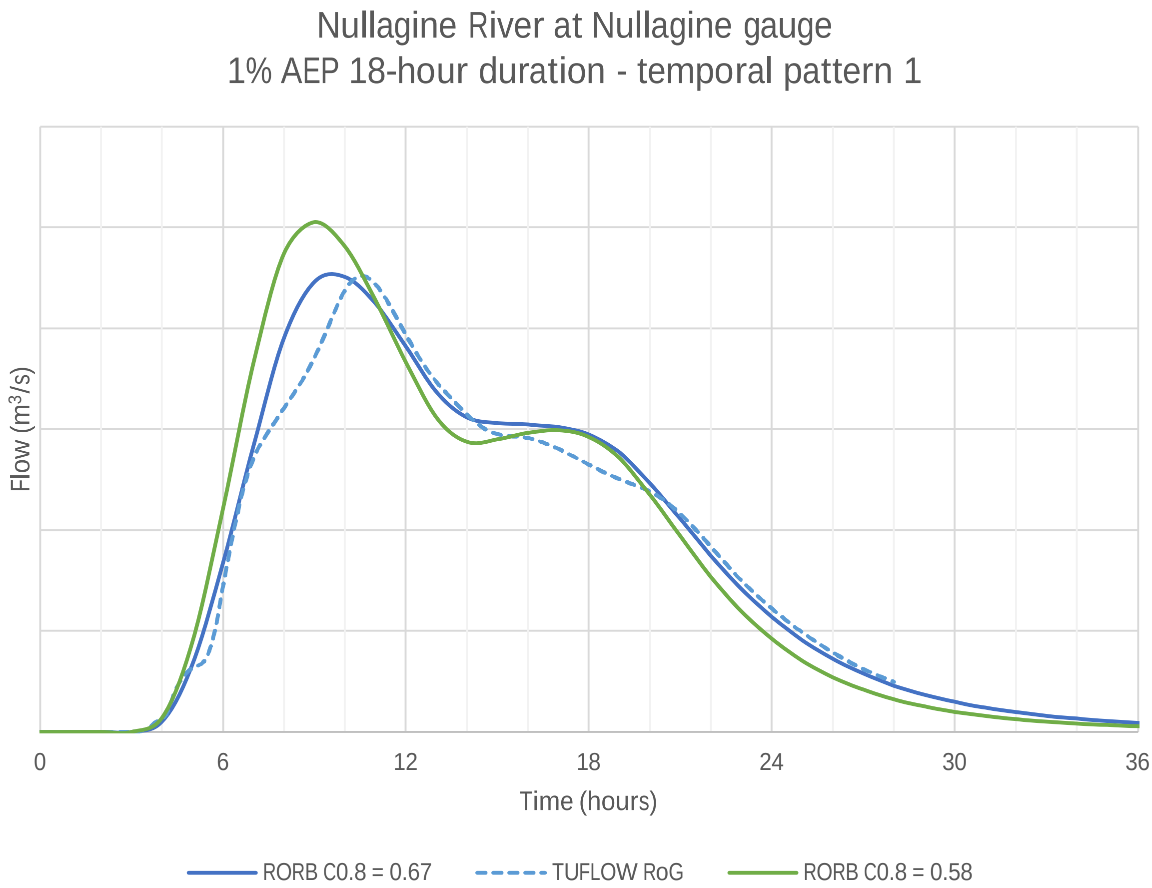


Figure 4-5: Kc validation results using the TUFLOW rain on grid model

The TUFLOW validation showed that a higher $C_{0.8}$ value was warranted when using a consistent set of hydrological inputs between models to determine catchment routing and storage characteristics. Both the rising and falling limbs of the resultant hydrographs showed better alignment with the TUFLOW model when using the revised $C_{0.8}$ value of 0.67.

Based on the above results and upon agreement with FFI, the revised $C_{0.8}$ value of 0.67 was adopted for use in the rainfall-runoff/FFA reconciliation works.

4.3.1.5 Temporal patterns

The Study Area mostly lies within the Rangelands Temporal Pattern Region. Given the size of the catchment area to the gauge site, all events were simulated using the Rangelands areal ensemble temporal patterns extracted from the ARR Datahub (Babister et al., 2016).

To maintain consistency with the proposed approach in the TUFLOW modelling, no temporal pattern filtering was adopted for the analysis.

4.3.1.6 Simulation approach

The assessment of the catchment response to rainfall used a Monte Carlo assessment approach for flood quantile estimation.

The Monte Carlo approach provides a framework for simulating the natural variability in the key processes that influence flood runoff: all important flood producing factors are treated as stochastic variables, and the less important ones are fixed. The primary advantage of the method is that it allows the exceedance probability of the flood characteristic to be determined without bias (subject to the representativeness of the selected inputs) (ARR2019) (Ball et al., 2019). The approach is conceptualised in Figure 4-6.

For this assessment, temporal patterns and initial loss were stochastically sampled.

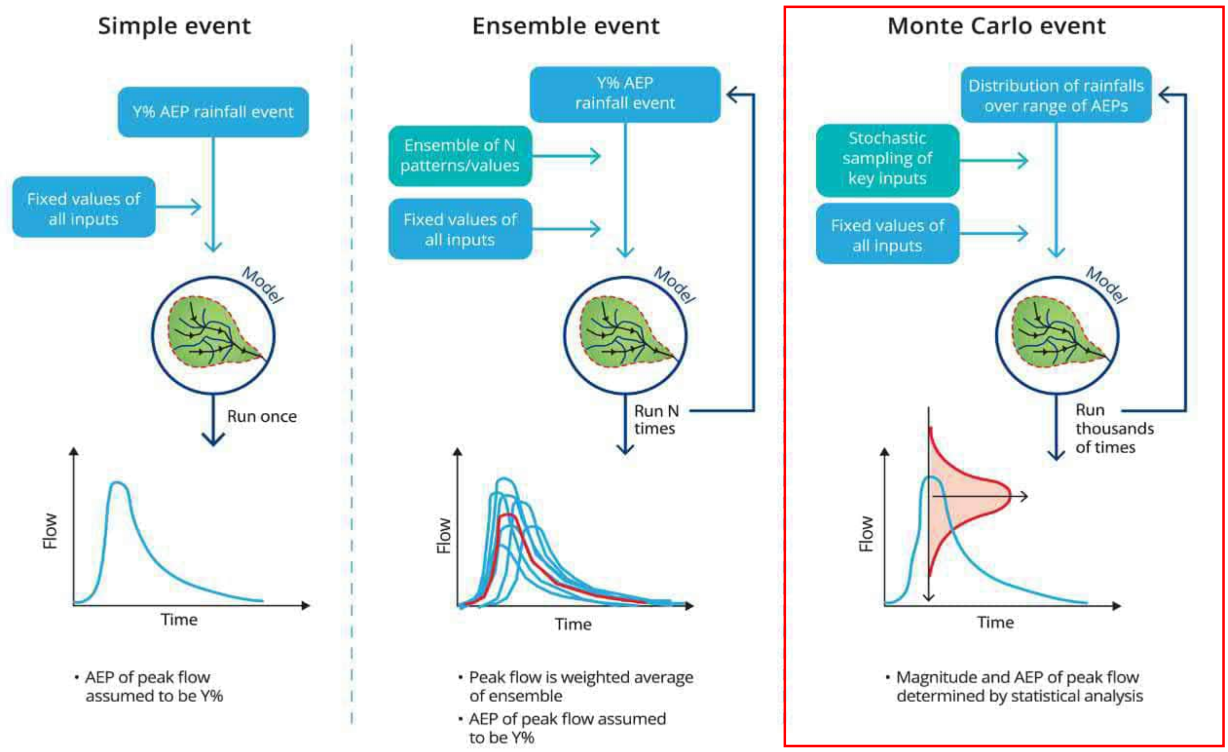


Figure 4-6: Monte Carlo approach conceptual model (Ball et al., 2019)

4.3.2 Results discussion

4.3.2.1 Nullagine River

Several Storm Initial Loss (IL_s) and Continuing Loss (*CL*) combinations were tested using a trial-and-error process which provided similar, reasonable AEP quantile estimate matches to the FFA results in the 20% AEP to the 1% AEP range. A IL_s of 20 mm and *CL* of 2.6 mm/hr resulted in the best fit across the AEP range of interest.

Table 4-4 presents the tabulated comparison of FFA and RORB Monte Carlo flow quantiles and these are also graphically presented in Appendix A.

Table 4-4: Estimated peak flow quantiles at Nullagine gauge

Design Storm	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
RORB MC Peak flow quantile (m^3/s)	757	1,196	1,684	2,386	2,977
FFA Peak flow quantile (m^3/s)	738	1,198	1,698	2,376	2,895

4.3.3 Design loss adoption for Study Area

Results from the Nullagine River FFA and RORB validation exercise, as well as considering the previous works completed on the Nullagine gauging station showed strong consistency for the derived IL_s value of 20 mm. The previous works (EPGH study) also found that a *CL* of 3 mm/hr was appropriate for the Nullagine River catchment. However, as the $C_{0.8}$ was revised in this study (increase in routing storage), minor compensatory reductions in *CL* were required to maintain the strong match in MC to FFA quantiles. As such and as noted previously, a *CL* of 2.6 mm/hr was found to produce the best fit in the empirical loss reconciliation works.

Review of topography and regional soil mapping across the Study Area indicates that the majority of the Study Area is likely to be able to be informed by the loss parameters derived from the Nullagine River RORB Monte Carlo and FFA quantile reconciliation works. Some regions of shallow sands are predicted in the eastern Nullagine River catchment (Cajuput Creek) however, it is noted that the confusion index is high for these areas. Review of aerial imagery, the FFI Geotechnical Desktop Report (2023), topography and second highest probability soil mapping suggests the majority of the area classified as shallow sands in the highest probability soils mapping is potentially the dominant ‘stony soils’ or even granitic landforms, hence the losses derived for the main arm of Nullagine River (to the gauge site) would likely still be applicable.

Mapping, aerial imagery and the Geotechnical Desktop Report (FFI, 2023) indicate sandy soils in the lower reaches of the Fortescue and Davis River catchment areas, just within the Study Area. It is noted that the areas where regional mapping suggests sandy soils may be prevalent in the Nullagine and Davis River catchment areas are typically downstream from the proposed infrastructure layouts being assessed in this project. Hence, the adoption of the reconciled loss estimates across the entire Study Area would, potentially, result in some conservatism in the peak flood estimates for these regions toward the lower Study Area and potentially (if the regional soil mapping is accurate) provide some conservatism to estimated peak flow rates and hence flood levels in this area.

Therefore, and as agreed with FFI, the final adopted design event loss parameters determined from the regional loss validation exercise for the entire Study Area are presented in Table 4-5.

Table 4-5: Adopted design event loss parameters for use in the Study Area

Parameter	Value
Storm Initial Loss (IL_s)	20 mm
Continuing Loss (*CL*)	2.6 mm/hr

5 Study Area design event hydrology

5.1 General approach

As baseline hydrology results were required across the entire Study Area, hydrological and hydraulic modelling of the local catchments was undertaken using TUFLOW (version 2023-03-AA). TUFLOW is a linked 1D/2D hydrodynamic computational engine for simulating free-surface long wave propagation processes (tides, floods, tsunamis, dam breaks) by solving the full one- and two-dimensional versions of the Navier-Stokes equations incorporating all physical terms including inertia (1D and 2D) and sub-grid turbulence (2D) (BMT, 2018).

The assessment used three separate TUFLOW models to cover the entire Study Area at a reasonable model resolution. The adopted model extents for the domains were named BD1, BD2 and BD3 and are presented in Figure 5-1.

5.2 Simulation approach

The assessment of the catchment response to rainfall for the TUFLOW models used an ensemble assessment approach for flood quantile estimation.

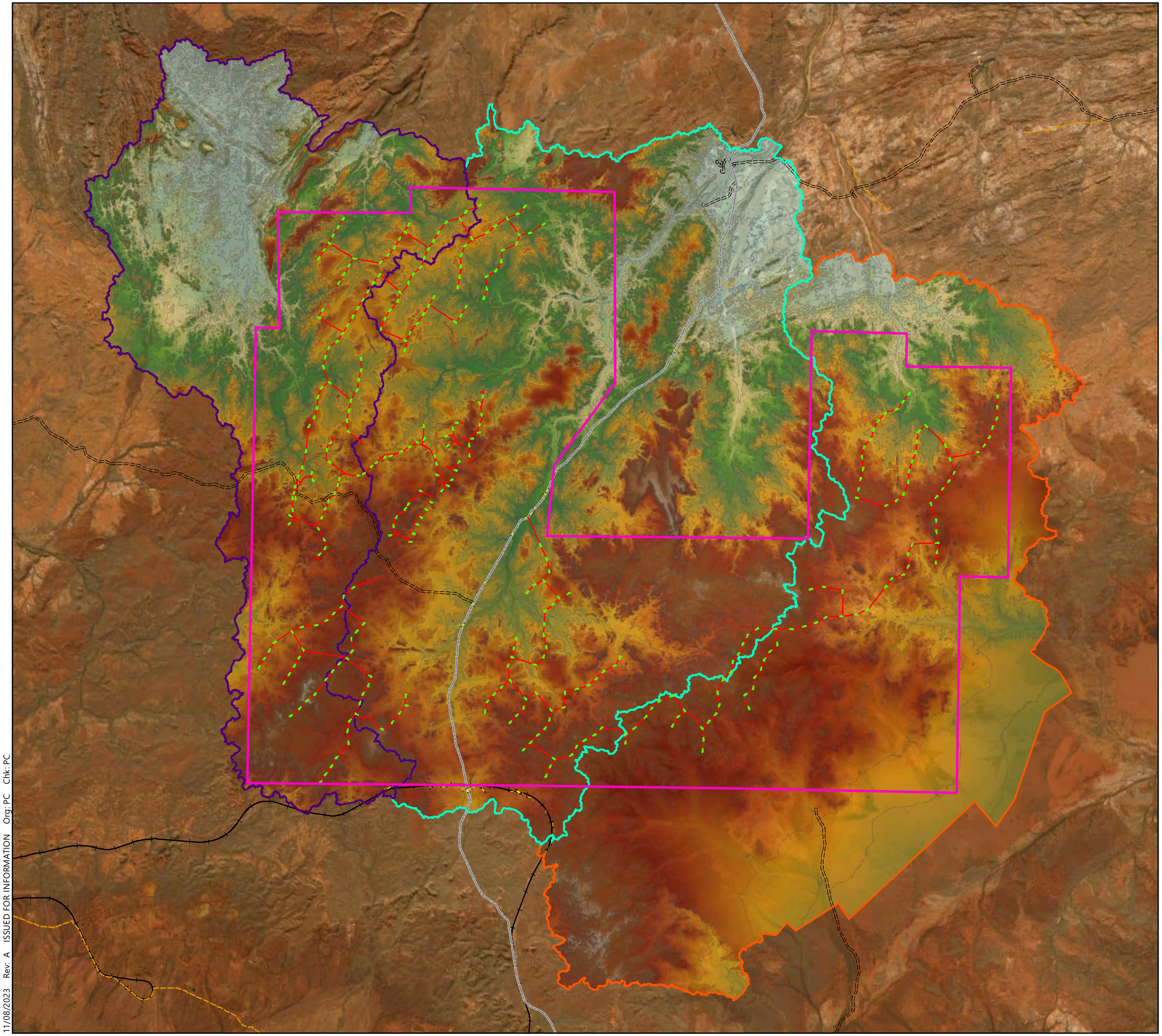
Flood magnitudes are generally very sensitive to temporal patterns and thus the ensemble approach provides a straightforward means of avoiding the introduction of bias due to this source of variability (Ball et al., 2019). A range of design storm durations were simulated in the TUFLOW model to determine the critical storm duration (the storm duration resulting in the highest mean peak flow from the 10 temporal patterns) at various locations in the catchments. The approach is conceptualised in Figure 5-2.

5.3 Design events

Table 5-1 summarises the design storms assessed in the TUFLOW models. The longest storm durations were assessed to ensure that the critical duration for larger catchments was identified.

Table 5-1: Design storms assessed in TUFLOW and RORB models

Storm detail	Events assessed
Annual Exceedance Probabilities (AEPs)	0.5%, 1%, 2%, 5%, 10%, 20% and 50%
Design Storm Durations (minutes)	30, 60, 120, 180, 360, 720, 1080



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BASELINE HYDROLOGY STUDY

FIGURE 5-1

TUFLOW MODEL EXTENT AND ARRANGEMENT

Legend

- Study Area
- Proposed Wind Turbine Hardstand
- Proposed Tracks
- BD1 Model Extent
- BD2 Model Extent
- BD3 Model Extent
- Culvert (1D Network)
- State Road
- Local Road
- Miscellaneous Road
- Rail Network
- 10m Interval Contours

TUFLOW Model Topography (mAHD)

Value

High : 600

Low : 400

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

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Scale at A3 - 1:250,000

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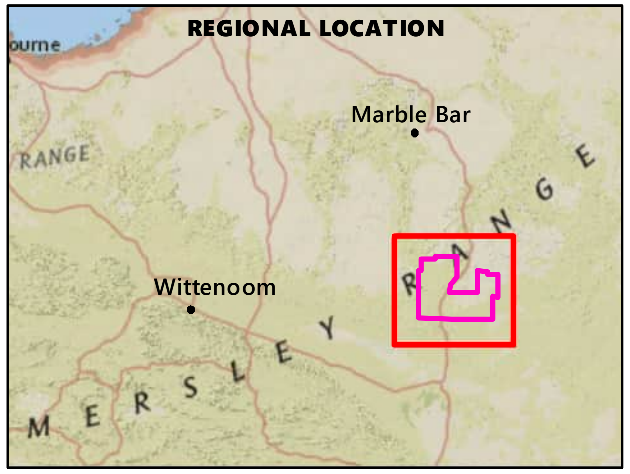
Kilometers

REGIONAL LOCATION



Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community
National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO,

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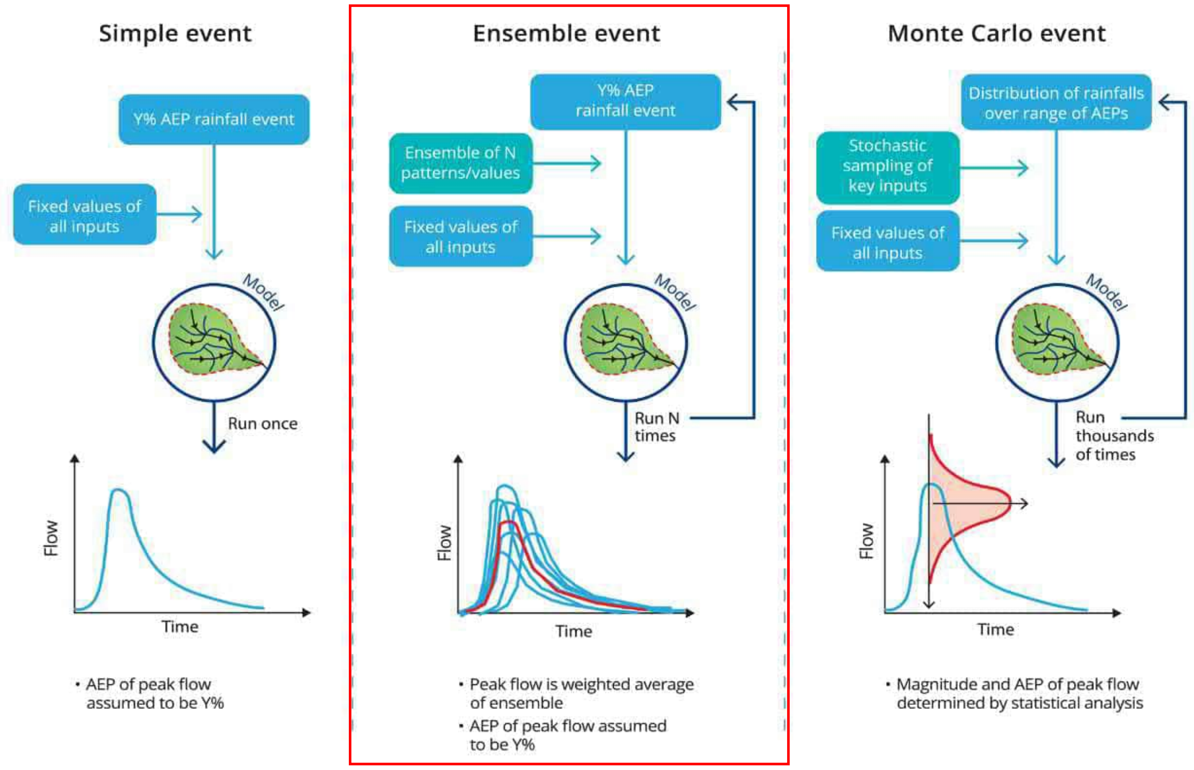

Figure 5-2: Ensemble approach conceptual model (Ball et al., 2019)

5.4 TUFLOW models

The TUFLOW models are characterised by a number of input parameters which are summarised in Table 5-2. Areal reduction factors, floodplain roughness and culverts are discussed further in Sections 5.4.1, 5.4.3 and 5.4.4 respectively.

The model terrain was developed using a mosaic of three 1 m LiDAR derived DEMs (described in Section 2.1). Due to the large model domain sizes (~1,220 km²) and required number of simulations, the models were simulated with relatively coarse grid size (40 m) within the general Study Area, with discrete areas of higher resolution (20 m) over the proposed turbine hardstands and linear infrastructure such as road and railways. SGS functionality was used to sample the baseline topographic data at 1 m resolution and maximise hydrologic routing accuracy and hence hydrologic estimate convergence between cell sizes.

It is noted that due to the well-defined channels and topographic variation of the catchments and previous experience in similar studies, that pre-wetting was not used, as it typically results in a negligible number of wet cells on the catchment surface at simulation commencement.

Table 5-2: TUFLOW model parameter summary

Item	Model Details
Rainfall	
Rainfall depths for direct rainfall boundary condition	Extracted from BoM Design Rainfall Data System (BoM, 2016) using TUFLOW ARR2016 QGIS plugin. Due to the catchment sizes, spatial distribution was undertaken based on gridded IFD datasets from BoM.
Pre-burst	Median pre-burst rainfall depths were extracted from ARR Datahub (Babister et al., 2016). Pre-burst rainfall was removed from the Storm *IL* (IL_S) prior to simulation in the model to represent the Burst *IL* (IL_B). Where pre-burst exceeded IL_S an IL_B of zero was adopted for simplification. It is noted that this approach was only relevant for the 6-hour duration event for the 2% and 1% AEP events.
Losses	IL_S: 20 mm *CL*: 2.6 mm/hr Approach: Rainfall excess (materials layer)
Pre-wetting catchment	No pre-wetting was used due to the well-defined topographic nature of most of the Study Area and minimal observed micro-storage.
Temporal patterns	Point temporal patterns were adopted for catchments less than 75 km^2. For larger catchments greater than 75 km^2, Areal TPs were adopted. All temporal patterns adopted were for the Rangelands region.
Catchment Area	BD1: 690 km^2 BD2: 1220 km^2 BD3: 990 km^2
ARF	Determined using parameters extracted from the ARR Datahub (Babister et al., 2016) for the Northern Coastal region and based on catchment areas within model domains (described further in Section 5.4.1)
Terrain	
Terrain	Developed from 1 m LiDAR derived DEMs (Section 2.1)
Base grid size (SGS sample distance) Quadtree grid sizes (SGS sample distance	40 m (1 m) – General Study Area 20 m (1 m) – Proposed infrastructure areas, roads and rail
Manning's *n* value (Depth Layer 1 (m), Manning's *n* Layer 1, Depth Layer 2 (m), Manning's *n* Layer 2) N.B. Depth for all layers is relative to the bed	Typical Pilbara grasslands/main catchment areas (0.1, 0.1, 0.2, 0.04) Medium density riparian vegetation (0.06) Higher density riparian vegetation (0.08)
External Boundary conditions	
External inflow boundary	N/A
Outflow boundary	Automated stage-discharge curve (HQ) with stream bed slope used as a proxy for water surface slope

5.4.1 0.5% AEP Temporal Patterns

For the 0.5% AEP event simulations, Jordan et al. (2005) temporal patterns were simulated for representative short duration events for the proposed infrastructure areas. Analysis of peak flows at reporting locations indicated that ARR Rangelands temporal patterns had slightly smoother progression in peak flow growth through the AEP range and produced slightly higher flows when compared to the Jordan et al temporal patterns. The ARR Rangelands temporal patterns were therefore adopted for the 0.5% AEP events.

5.4.2 Areal reduction factors

Given the low empirical loss estimates associated with the Study Area and with most of the conceptual infrastructure located within headwater areas, most of the areas of interest surrounding the proposed hardstand locations were initially identified as being likely dominated by short duration design events.

To enable a reasonable estimate of flood risk across a large Study Area, a duration dependant ARF approach was adopted. The ARF values are presented in Table 5-3 which were based on initial modelling works for the 1% AEP event undertaking assessment of critical durations and contributing catchment areas as well as the recommended point of transition from point to areal temporal patterns (75 km^2). The adopted major catchment ARFs are additionally shown in Figure 5-5. The adopted ARF approach was agreed with FFI before simulation of the suite of runs required for the study.

Table 5-3. ARF areas adopted

Storm durations	ARF areas adopted		
0.5, 1-hour (point temporal patterns)	No ARF		
2-hour (point temporal pattern)	20 km^2		
3-hour (point temporal patterns)	40 km^2		
6-hour (point temporal patterns)	60 km^2		
12-hour + (areal patterns) (mainstream reaches)	Model BD1 Coongan River Notes: 419 km^2 total model catchment area (refer Figure 5-5) ~195 km^2 to approx. mid-point of interest Adopted ARF – 200 km^2	Model BD2 Nullagine River Notes: ~872 km^2 (to gauge) Bonnie Creek to Nullagine River confluence (~260 km^2) Marble Bar Road (adjacent to mainstream) (~380 km^2) Track crossing of headwater creek (~125 km^2) Adopted ARF – 400 km^2	Model BD3 Five Mile Creek Notes: ~185 km^2 (to location downstream of DE boundary refer Figure 5-5) Adopted ARF – 100 km^2
		Cajaput Creek Notes: ~253 km^2 total catchment Adopted ARF – 150 km^2	Russian Jack Creek Notes: ~132 km^2 (to DE boundary) Adopted ARF – 75 km^2

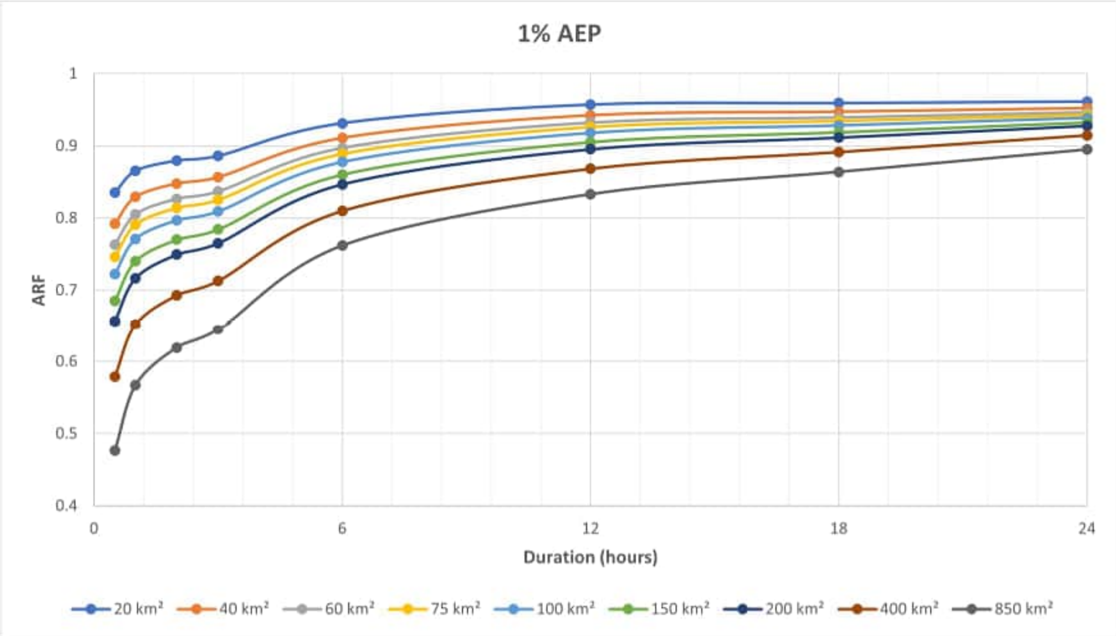

Figure 5-3: Comparison of adopted ARFs for different storm durations for the 1% AEP events

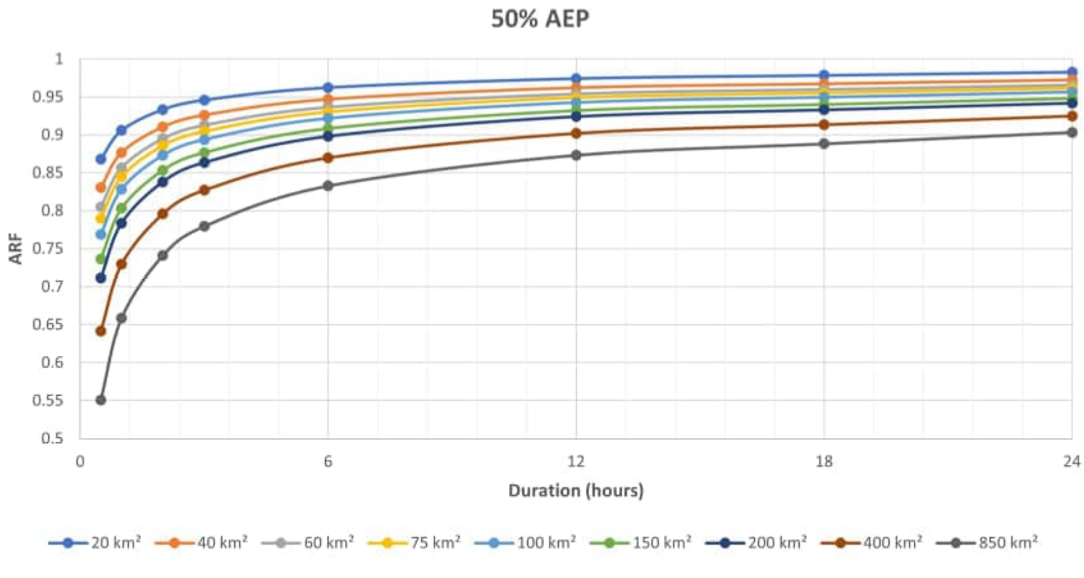

Figure 5-4. Comparison of adopted ARFs for different storm durations for the 50% AEP events

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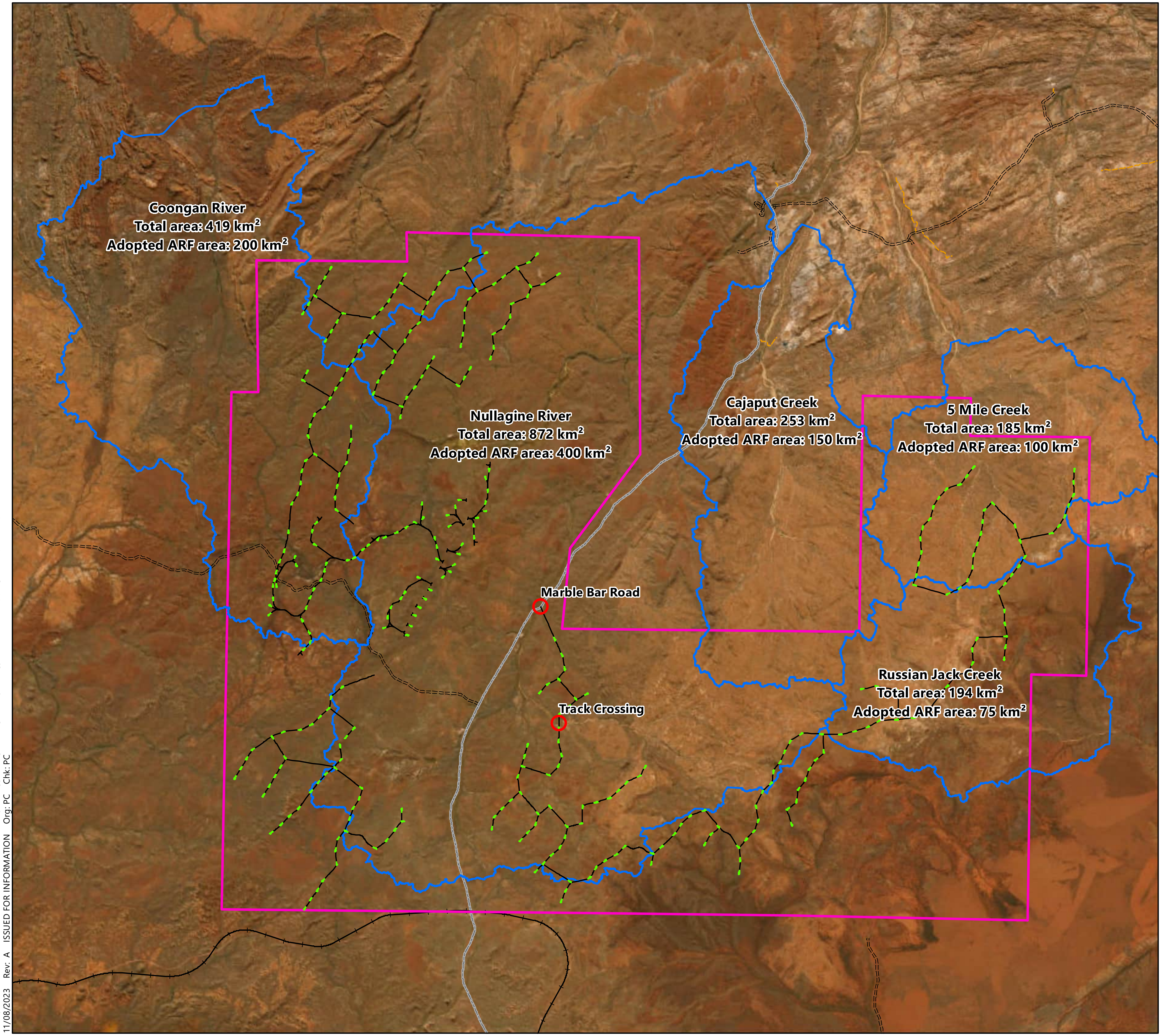
FIGURE 5-5

MAJOR CATCHMENT DETAILS & ADOPTED ARFs



Legend

- Adopted Wind Turbine Hardstand
- Study Area
- Major Catchment Extents
- Adopted Tracks
- Rail Network
- State Road
- Local Road
- Miscellaneous Road

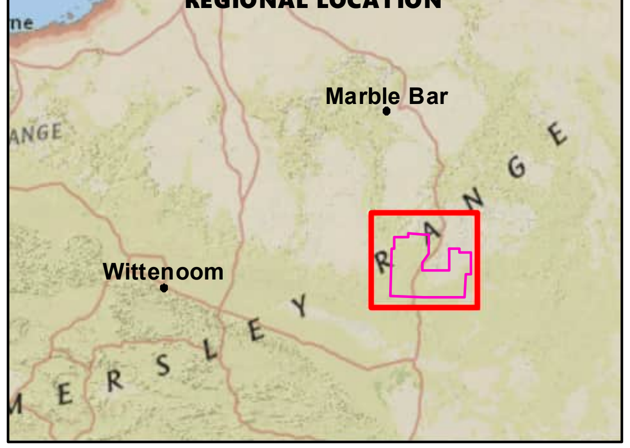
Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

N

Scale at A3 - 1:220,000

0 5 10 15
Kilometers

REGIONAL LOCATION



Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community
National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO,

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5.4.3 Floodplain roughness

Floodplain roughness delineation was undertaken using Sentinal-2 satellite data. Sentinel-2 carries the Multispectral Imager. This sensor delivers 13 spectral bands ranging from 10 m to 60 m resolution.

10 m resolution data of the Study Area consisting of B4 (red) and B8 (visible and near infrared [VNIR]) bands was used to create a normalised vegetation index grid.

This was then compared to aerial imagery to define classification bands to assign areas of similar vegetative density a material ID (used in TUFLOW) and ultimately an associated Manning's *n* roughness value. Most of the delineation and classification centred around riparian vegetation, with most hillslope areas adopting the global upper-level Manning's *n* value of 0.04 (as defined in Table 5-2) using the depth varying approach. As the riparian vegetation roughness areas were typically associated with higher flow depths and were typically of limited coverage, these areas were assigned a single (not depth-varying) value.

This approach allows for a consistent floodplain roughness delineation and parameterisation methodology to be adopted across the entire extensive model area. This is preferred to a manual delineation approach which can be subject to user interpretation and inconsistency. Cross reference against higher resolution aerial imagery (B_Downs_2m_Clip) was also undertaken to ensure extents were representative of expected changes in roughness. Some variance was observed between wet season and dry season data captures from Sentinal-2 however this was not deemed significant enough to result in any major changes to adopted classification bands or extents.

An example of the classified vegetation index grid and aerial imagery is presented in Figure 5-6.

5.4.4 Culverts

Main Roads WA (MRWA) controlled crossings of watercourses in the Study Area (Marble Bar Road) were obtained from MRWA. This consisted of publicly available GIS data with locations and sizes of culverts (noting that there are no bridges within the Study Area). Invert levels were estimated using the provided LiDAR topographic data. Some sections of Marble Bar Road were recently upgraded and hence the culvert details in these areas were estimated from high resolution aerial imagery and LiDAR data supplied by FFI. The same estimation approach was adopted for the Roy Hill railway culvert features.

All culvert features were included in the hydraulic model as 1D (ESTRY) inserts within the TUFLOW model. Table 5-4 summarises the parameters used across all 55 culverts in the Study Area.

Table 5-4: Adopted culvert hydraulic parameters

<table>
<tr><th>Culvert/Headwall Type</th><th>Manning's n</th><th>Adopted Inlet Loss (K_e)</th><th>Adopted Outlet Loss (K_o)</th></tr>
<tr><td>CSP / Protruding (no headwall)</td><td>0.024</td><td>0.9</td><td rowspan="3">1</td></tr>
<tr><td>RCP / Concrete headwall with wingwalls</td><td rowspan="2">0.013</td><td>0.5</td></tr>
<tr><td>RCBC / Concrete headwall with wingwalls</td><td>0.4</td></tr>
</table>

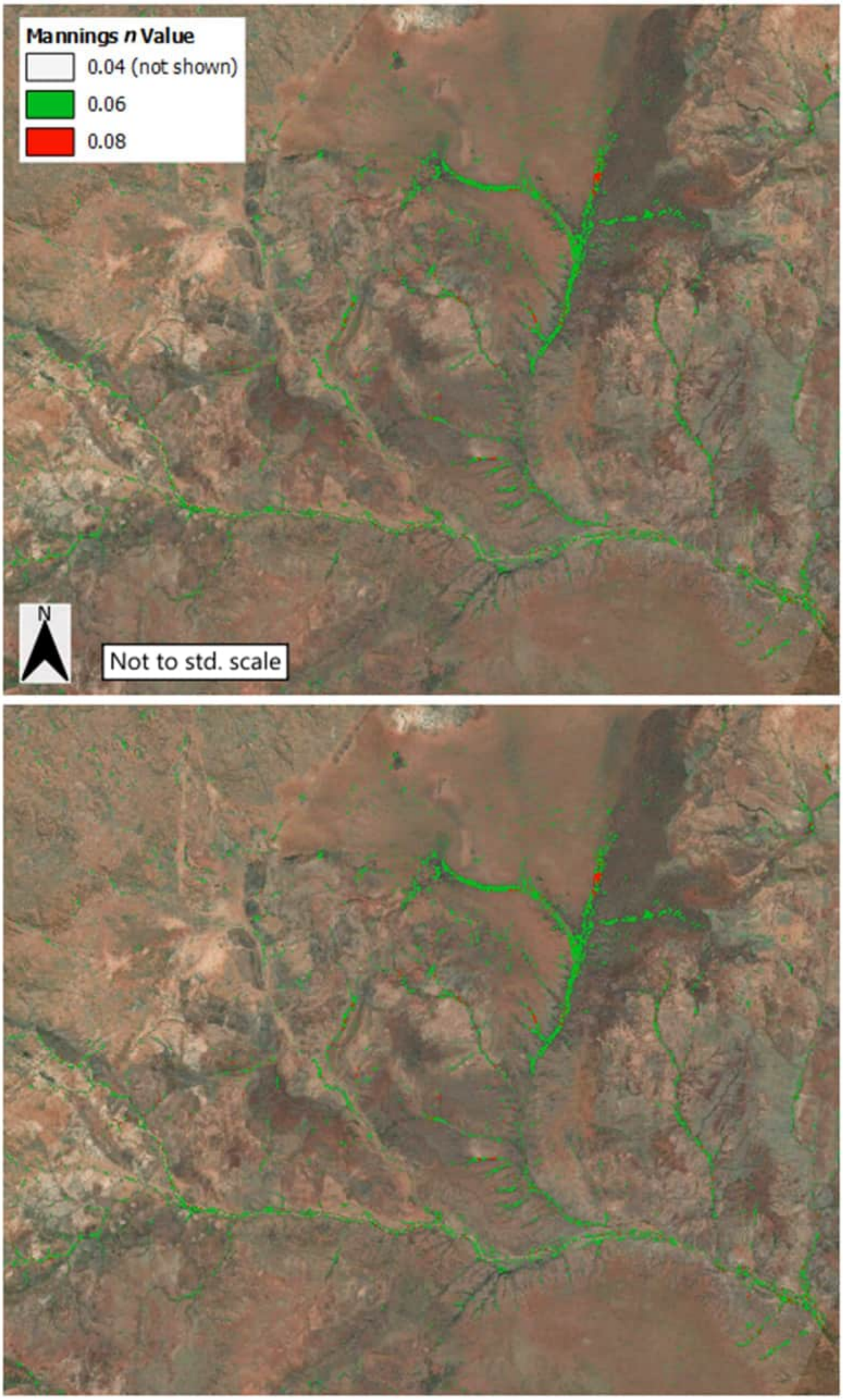

Figure 5-6: Example of spatial roughness delineation using Sentinal-2 data (veg index above) and aerial (below)

5.5 Sensitivity analysis

5.5.1 Climate change

The assessment of sensitivity to climate change impacted design rainfall was undertaken utilising the projected changes to rainfall intensity in accordance with ARR2019 guidance for the 2050 climate horizon using the Representative Concentration Pathways (RCP) 4.5 and 8.5 projections (Ball et al., 2019).

"RCPs are prescribed pathways for greenhouse gas and aerosol concentrations, together with land use change, that are consistent with a set of broad climate outcomes used by the climate modelling community. The pathways are characterised by the radiative forcing produced by the end of the 21st century. Radiative forcing is the extra heat the lower atmosphere will retain as a result of additional greenhouse gases, measured in Watts per square metre (W/m²)." (Climate Change in Australia, 2020)

There are four pathways: RCP8.5, RCP6, RCP4.5 and RCP2.6. The numbers in each RCP refer to the amount of radiative forcing produced by greenhouse gases in 2100. For example, in RCP8.5 the radiative forcing is 8.5 (W/m²) in 2100 [reaching a CO_2 concentration of 940 parts per million (ppm)]. For the RCPs specifically considered in this assessment:

- RCP4.5 is described by the Intergovernmental Panel on Climate Change (IPCC) as an intermediate scenario. Emissions in RCP4.5 peak around 2040, then slowly decline; and
- For RCP8.5, emissions continue to rise throughout the 21st century. RCP8.5 is generally taken as the basis for worst-case climate change scenario.

The projected changes to rainfall intensities extracted from the ARR Data Hub for the 2050 design horizon are presented in Table 5-5 and were applied to the design rainfall burst depths (as presented in Appendix C).

Table 5-5: Adopted design rainfall factors for climate change

Design Horizon (Year)	RCP4.5	RCP8.5
2050	7.7%	10.3%

This sensitivity analysis was used to determine if the predicted increase in flow estimates in the 2050 future climate scenarios had tangible impact on flood elevations and extents and hence pose any additional flood risk to proposed infrastructure localities.

Results from the climate change sensitivity assessment are presented in Section 6.4.1.

5.5.2 Point rainfall

A comparison between a point rainfall approach and the adopted duration dependent ARF approach was undertaken. The 1% 6-hour TP06 event was adopted for the purpose of this comparison which was a critical duration and median TP for PO reporting location BD2-8. The increase in total rainfall was 11.5% when using the point rainfall compared to the adopted approach. The analysis has been used to demonstrate the increase in accuracy that is achieved by adopting the duration dependent ARF approach and the results of this analysis are present in Section 6.4.2.

5.5.3 Floodplain roughness

The model sensitivity to Manning's *n* roughness was tested by simulating the 1% AEP event with an increase in Manning's *n* values of a nominal 25%. This was applied to the adopted design hydraulic roughness values (i.e., upper depth value for depth-varying areas, with the lower roughness value unchanged) to assess hydraulic sensitivity to Manning's *n* parameters. Typically, the upper value dominates most of the key hydrological and hydraulic behaviours (such as peak flow and hydraulic behaviours) with the lower depth value typically having negligible impact in well-defined waterways such as is evident in the study area, commonly only producing a minor delay in the rising limb of the hydrograph.

It is noted that as the model uses the rain on grid approach, increasing Manning's *n* will affect the conveyance of a given waterway geometry, and hence result in some impacts to both peak flow and hydraulic estimates (e.g., peak flood elevation).

This sensitivity analysis was used to determine if an increase in flood levels as a result of increases in floodplain roughness had a significant impact on flood elevations and extents and hence pose any additional potential flood risk to proposed infrastructure localities.

Table 5-6: Adopted floodplain roughness values and sensitivity analysis values

Description	Manning's *n* Design value	Manning's *n* Sensitivity value
General Pilbara catchment	0.040	0.050
Medium density riparian vegetation	0.060	0.075
Thick density riparian vegetation	0.080	0.100

Results from the floodplain roughness sensitivity assessment are presented in Section 6.4.3.

6 Results

6.1 Hydrology

Locations were selected across the respective model areas to quantify peak flows and allow comparison to desktop-based regional methods. This includes comparison to the Regional Flood Frequency Procedure (RFFP) (Flavell, 2012) and the Regional Flood Frequency Estimation Model (RFFE) (ARR2019). The comparison locations for the model domains are presented in Figure 6-1 and discussed below.

6.1.1 BD1 model

A comparison of peak flow estimates between the three regional methods and that obtained from the mean of the ensemble for the critical duration at reporting locations BD1-4, BD1-11 and BD1-17 are presented in Table 6-1.

Table 6-1: Ensemble mean peak flow (m^3/s) results – BD1

Reporting Location	Results	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
BD1-4 Unnamed Creek (9.4 km^2)	Mean peak flow (m^3/s)	12	29	46	64	89	110
	Critical duration (hours)	6	2	2	1	1	1
	RFFP (m^3/s)	13	20	27	42	74	115
	RFFE (m^3/s)	6	16	26	38	55	68
BD1-11 Unnamed Creek (37 km^2)	Mean peak flow (m^3/s)	39	95	142	195	294	355
	Critical duration (hours)	6	3	3	3	3	3
	RFFP (m^3/s)	77	97	112	176	318	499
	RFFE (m^3/s)	14	40	64	93	135	168
BD1-17 Coongan River (419 km^2)	Mean peak flow (m^3/s)	176	601	926	1,271	1,787	2,168
	Critical duration (hours)	18	12	12	12	12	12
	RFFP (m^3/s)	154	294	464	744	1,387	2,233
	RFFE (m^3/s)	58	163	263	383	550	691

6.1.2 BD2 model

A comparison of peak flow estimates between the three regional methods and that obtained from the mean of the ensemble for the critical duration at reporting locations BD2-10, BD2-22, BD2-8 and BD2-37 are presented in Table 6-2. The FFA results are presented for comparison at BD2-37 which is located at the Nullagine gauging station. It is noted that the marginally higher peak flows predicted by the TUFLOW model are likely a result of the conservative ARF adopted for this domain for the longer duration storms (>12 hrs) (400 km^2 ARF adopted for the overall 872 km^2 catchment due to the locations of interest being in the mid-catchment area).

Table 6-2: Ensemble mean peak flow (m^3/s) results – BD2

Reporting Location	Results	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
BD2-10 Unnamed Creek (9.5 km^2)	Mean peak flow (m³/s)	17	34	55	76	105	125
	Critical duration (hours)	6	1	1	1	1	1
	RFFP (m³/s)	10	17	25	39	70	108
	RFFE (m³/s)	5	16	26	37	54	67
BD2-22 Bonnie Creek (44 km^2)	Mean peak flow (m³/s)	36	93	133	177	268	326
	Critical duration (hours)	6	6	6	3	3	3
	RFFP (m³/s)	37	59	83	130	235	369
	RFFE (m³/s)	15	41	67	97	141	176
BD2-8 Unnamed Creek (90 km^2)	Mean peak flow (m³/s)	70	167	246	309	453	525
	Critical duration (hours)	6	6	6	6	6	6
	RFFP (m³/s)	45	78	116	184	336	532
	RFFE (m³/s)	18	52	84	122	177	221
BD2-37 Nullagine Gauging Station on Nullagine River (872 km^2)	Mean peak flow (m³/s)	239	812	1,272	1,750	2,602	3,279
	Critical duration (hours)	18	18	18	18	12	12
	FFA (m³/s)	232	738	1,198	1,698	2,376	2,895
	RFFP (m³/s)	209	407	655	1,059	1,992	3,231
	RFFE (m³/s)	74	208	336	489	703	882

6.1.3 BD3 model

A comparison of peak flow estimates between the three regional methods and that obtained from the mean of the ensemble for the critical duration at reporting locations BD3-02, BD3-07 and BD3-09 are presented in Table 6-3.

Table 6-3: Ensemble mean peak flow (m^3/s) results – BD3

Reporting Location	Results	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
BD3-02 Five Mile Creek (185 km²)	Mean peak flow (m^3/s)	165	398	558	741	1,002	1,229
	Critical duration (hours)	12	12	12	12	12	12
	RFFP (m^3/s)	197	289	377	600	1,105	1,766
	RFFE (m^3/s)	34	94	152	221	317	398
BD3-07 Russian Jack Creek (194 km²)	Mean peak flow (m^3/s)	111	294	436	600	841	1,042
	Critical duration (hours)	12	12	12	12	12	12
	RFFP (m^3/s)	151	207	257	410	756	1,209
	RFFE (m^3/s)	30	84	136	198	286	358
BD3-09 Unnamed Creek (53 km²)	Mean peak flow (m^3/s)	36	108	169	232	336	414
	Critical duration (hours)	6	3	3	3	3	3
	RFFP (m^3/s)	91	99	104	163	296	467
	RFFE (m^3/s)	13	36	59	85	124	154

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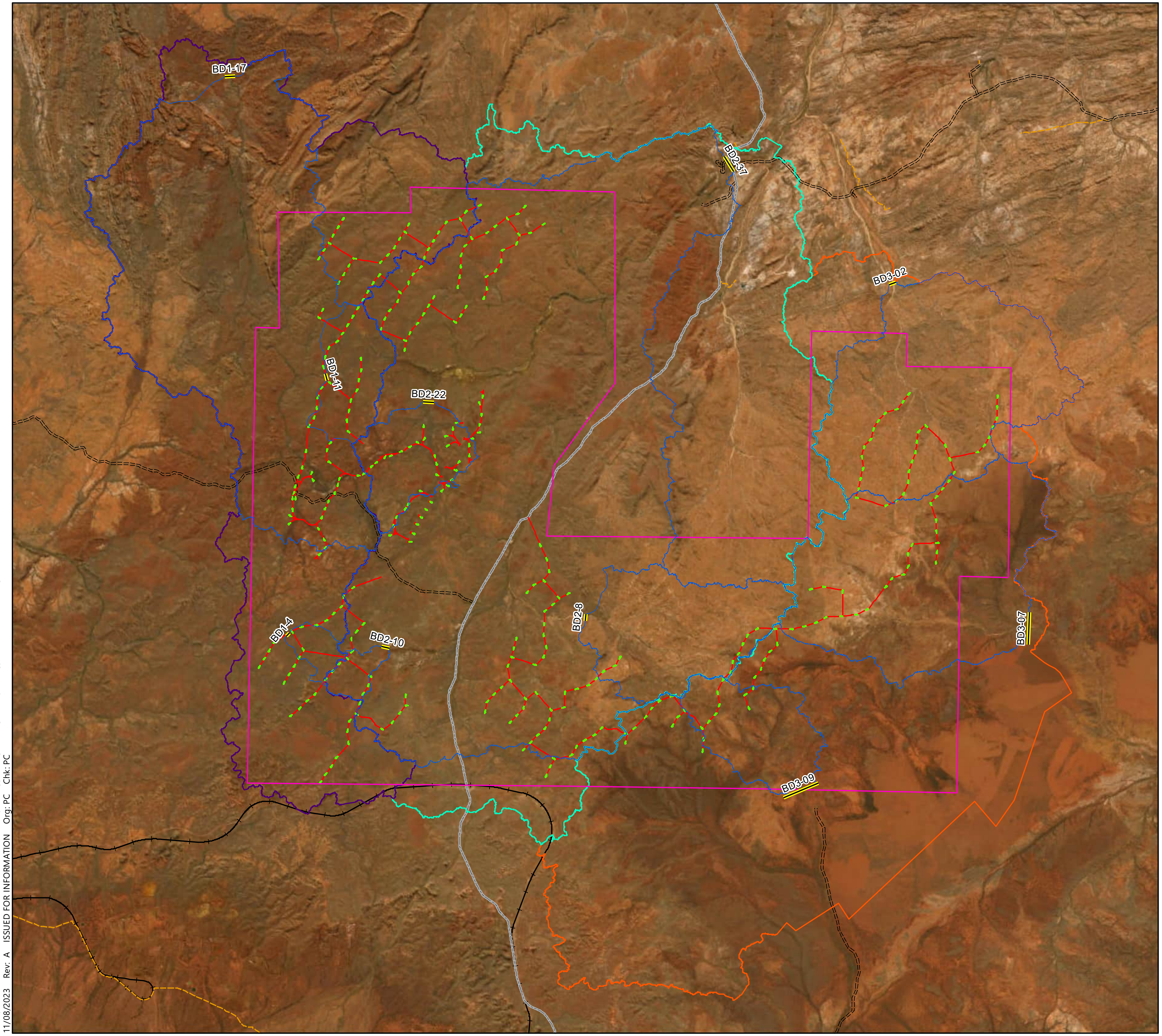
FIGURE 6-1

FLOW REPORTING LOCATIONS



Legend

- Study Area
- Flow Reporting Locations
- Proposed Wind Turbine Hardstand
- Flow Reporting Catchment
- Proposed Tracks
- BD1 Model Extent
- BD2 Model Extent
- BD3 Model Extent
- State Road
- Local Road
- Miscellaneous Road
- Rail Network

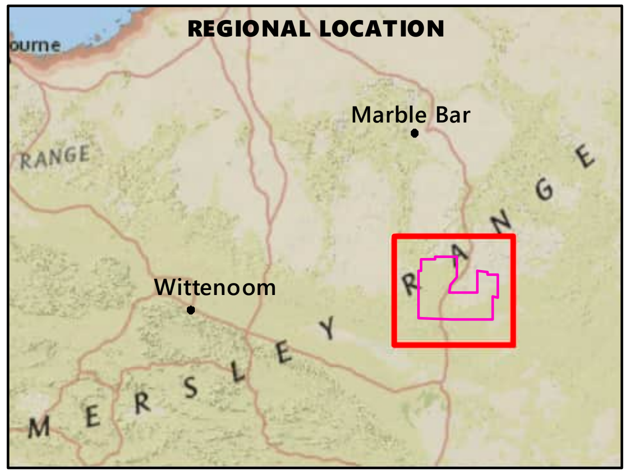
Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

N

Scale at A3 - 1:250,000

0 4 8 12 16
Kilometers

REGIONAL LOCATION



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6.1.4 Peak flow results discussion

Peak flow results presented in Table 6-1, Table 6-2 and Table 6-3 show that peak flow estimates from the three models typically align well with the RFFP regional peak flow derivation method. The RFFE regional method predictions for all locations are lower than those produced from the modelling as well as the RFFP approaches. This is typical for the Pilbara where the RFFE tool often produces lower than expected estimates.

Larger variances in the model peak flow estimates from the RFFP regional method was shown to occur for the smaller magnitude events up to approximately the 5% AEP. In these events, higher flows were estimated by the modelling when compared to those obtained from the RFFP.

The higher peak flow estimates of the model results compared to the regional methods are likely based on a number of factors. Generally conservative ARF selection for catchment areas (to allow for reasonable flow estimates across a large project area) means rainfall inputs are likely somewhat conservative, leading to higher-than-expected flows when considered in the context of the regional flow estimates. The steeper headwater regions and incised waterways that dominate much of the Study Area likely also result in less catchment storage and alluvial infiltration potential when compared to the larger gauged catchments used to inform many of the regional method regression equations, potentially resulting in a more pronounced rainfall-runoff relationship.

6.2 Sensitivity analysis – climate change

The mean of the ensemble peak flow estimates and critical durations at the previously reported locations for the design case 1% AEP and 2050 future climate 1% AEP RCP4.5 and RCP8.5 scenarios are presented in Table 6-4.

Descriptions of hydraulic impacts resulting from the projected peak flow increases in the 2050 future climate scenarios are discussed in Section 6.4.1.

Table 6-4: 2050 design horizon climate change sensitivity results

Reporting Location	Results	1% AEP	1% AEP 2050 RCP4.5	1% AEP 2050 RCP8.5
BD1-4 Unnamed Creek (9.4 km^2)	Mean peak flow (m³/s)	110	124 (+12.7%)	129 (+17.3%)
	Critical duration (hours)	1	1	1
BD1-11 Unnamed Creek (37 km^2)	Mean peak flow (m³/s)	355	393 (+10.7%)	405 (+14.1%)
	Critical duration (hours)	3	3	3
BD1-17 Coongan River (419 km^2)	Mean peak flow (m³/s)	2,168	2,376 (+9.6%)	2,446 (+12.8%)
	Critical duration (hours)	12	12	12
BD2-10 Unnamed Creek (9.5 km^2)	Mean peak flow (m³/s)	125	142 (+13.6%)	147 (+17.6%)
	Critical duration (hours)	1	1	1
BD2-22 Bonnie Creek (44 km^2)	Mean peak flow (m³/s)	326	368 (+12.9%)	381 (+16.9%)
	Critical duration (hours)	3	3	3
BD2-8 Unnamed Creek (90 km^2)	Mean peak flow (m³/s)	525	577 (+9.9%)	593 (+13.0%)
	Critical duration (hours)	6	3	3
BD2-37 Nullagine River (872 km^2)	Mean peak flow (m³/s)	3,279	3,616 (+10.3%)	3,732 (+13.8%)
	Critical duration (hours)	12	12	12
BD3-02 Five Mile Creek (185 km^2)	Mean peak flow (m³/s)	1229	1,378 (+12.1%)	1,392 (+13.3%)
	Critical duration (hours)	12	12	12
BD3-07 Russian Jack Creek (194 km^2)	Mean peak flow (m³/s)	1,042	1,152 (+10.6%)	1,189 (+14.1%)
	Critical duration (hours)	12	12	12
BD3-09 Unnamed Creek (53 km^2)	Mean peak flow (m³/s)	414	463 (+11.8%)	479 (+15.7%)
	Critical duration (hours)	3	3	3

In all model areas, results show that the projected increase in rainfall intensity for the 1% AEP 2050 future climate scenario using the RCP4.5 and RCP8.5 scenarios typically resulted in increases in peak flow that were higher than the corresponding rainfall intensity increase (7.7% and 10.3% respectively).

For the 1% AEP 2050 RCP4.5 scenario, projected increases in peak flow rates ranged between approximately 9-13%, whilst in the 1% AEP 2050 RCP8.5 scenario, projected increases in peak flow rates were approximately 12-17%.

The impact of projected peak flow increases on flood levels and hence flood risk is discussed in Section 6.4.1.

6.3 Hydraulics

6.3.1 Accuracy limitations

The assessment outcomes and associated data in this report are based on information sourced from FFI, external sources, a series of informed hydrological input assumptions based on engineering judgement as well as other data that was available in the public domain at the time or times outlined in this report.

The results of the hydraulic assessment are therefore inherently reliant on the accuracy of all the available input data. For example, toward the southeast region of the Study Area, a different topographic dataset was used from a different capture date and potentially supplier, which contained minor discrepancies to the primary dataset with respect to elevation.

The datasets and their relative vertical accuracies and potential difference may impact on the absolute vertical accuracy of peak flood level results however it is noted most of these impacts are located in areas away from the proposed turbine locations (and outside the Study Area).

6.3.2 GIS mapping

Peak flood depth, velocity and depth velocity product and hazard vulnerability classification (Smith et al., 2014) mapping for the 0.5%, 1%, 5% and 20% AEP events are presented in Appendix D.

The presented data was draped over the supplied 1 m terrain data to aid in improved visualisation of key drainage features across the sites.

Within the BD2 and BD3 model areas, shorter duration runs appeared to dominate the ensemble analysis to an unreasonable extent along the main creeks of Nullagine River, Cajuput River, Five Mile Creek and Russian Jack creek. To rectify this, 75 km² catchments were delineated and differences between point and areal gridded results were compared to inform an AEP dependent clipping and merging process to ensure appropriate areal results were adopted where required. It is noted that no areas that required this manipulation are in proximity to the proposed turbine locations.

Given the high spatial variability of flood modelling results across the Study Area, generalised descriptions are provided in the following sections. For detailed analysis of specific locations within the Study Area, interrogation of model result raster GIS data is recommended.

6.3.3 BD1 model area

Given the steep and incised nature of the landforms in the BD1 model domain, flood extents are typically predicted to be well contained within the respective valley floors. Whilst the proposed turbines are located in the upper reaches of the catchments, several of the provided turbine (and associated hardstand) locations fall within the extent of smaller creeks and are subject to various levels of flooding as discussed in Section 6.3.6.

6.3.4 BD2 model area

The BD2 model domain exhibits landforms that are both similar to the steep, incised nature seen in the BD1 model but transition to flatter landforms towards the lower reaches of both Nullagine River and Cajaput Creek (this is primarily observed outside of the Study Area).

Whilst the proposed turbines are located in the upper reaches of the catchments, several of the provided turbines and associated hardstand locations fall within the extent of smaller creeks and are subject to various levels of flooding as discussed in Section 6.3.6. Respective embankments for Marble Bar Road and the Roy Hill Rail Line cause some localised backwater effects, but this is not expected to impact any of the proposed turbines.

6.3.5 BD3 model area

The BD3 Model has two distinct areas of varying hydraulic behaviour. The northern catchment of Five Mile Creek has similar hydraulic behaviour to the majority of BD1 and BD2 typical of the Nullagine Creek headwaters, with steep, incised terrain restricting the floodplain to the creek lines. The southern extent of the model is located in the headwaters of the Fortescue and Davis Rivers and widespread shallow sheet flow is observed downstream of where the conceptual turbines are proposed. Flood risk to conceptual turbine hardstand locations within this model domain is typically lower than the observed flood risks to turbine hardstands located in BD1 and BD2.

6.3.6 Conceptual hardstand flood risk locations

Several of the proposed hardstand locations provided by FFI are predicted to be within or near the creeks and hence are subject to flood risk in their current proposed location. As no individual turbine identification was included in the provided shapefile, no individual listing of proposed asset IDs can be provided however maps showing the maximum predicted peak flood depth and the Hazard Classification (Smith et al, 2014) for each of the hardstand locations in the 1% AEP event are presented in Appendix E. Note that the flood results used in this analysis were filtered to remove areas of ponding that are not associated with creek flow paths.

Analysis of the 1% AEP results and the provided hardstand locations indicates that:

- 165 conceptual turbine hardstand locations are within an area of peak flood depth of greater than 0.1 m. 103 of these locations were shown to be located in an area with 0.3 m depth or greater, with 17 of these locations having a peak flood depth of greater than 1 m in the 1% AEP event.
- 168 conceptual turbine hardstand location are within an area of peak flood velocity of greater than 0.3 m/s. 53 of these locations were shown to be located in an area with 0.6 m/s velocities or greater, with 13 of these locations having a peak flood velocity of greater than 1 m/s.
- Using the Smith et al. (2014) Hazard Classification method, 3 proposed hardstand locations are classified as H5. 3 hardstands locations are classified as H4, 6 hardstands locations are classified as H3, 29 hardstands are classified as H2 and the remaining hardstands are classified as H1.

Flood risk at the majority of hardstand locations is likely able to be mitigated through either local site stormwater management to deal with stormwater (sheet flow) runoff around the pad, or alternatively a minor change in hardstand location or orientation.

6.4 Sensitivity analysis

6.4.1 Climate change

The peak flow increases as detailed in Section 6.2 for the 2050 future climate correspondingly result in increases in peak flood levels. Peak flood depth maps for the climate change scenarios assessed are presented in Appendix F.

For the 1% AEP 2050 RCP4.5 scenario, increases in peak flood levels are typically up to 100 mm in the smaller headwater waterways flowing nearby most of the conceptual turbine hardstand locations. Larger increases in peak flood levels were noted in the medium to larger mainstreams, with increases of up to typically 150 mm common. Increases of up to 250 mm were noted in the largest of watercourses within the Nullagine River and Coongan River towards the lower extent of the Study Area.

For the 1% AEP 2050 RCP8.5 scenario, projected increases in peak flood levels were again typically up to 100 mm in the smaller headwater waterways flowing through the project. Larger increases in peak flood levels were noted in the medium to larger mainstreams, with increases of up to typically 200 mm common. Increases of up to 300 mm were noted in the largest of watercourses within the Nullagine River and Coongan River towards the lower extent of the Study Area.

Based on the results of the assessment, it is anticipated that the uncertainty and risk associated with the future climate and general hydrological uncertainty in the Study Area could be typically mitigated by adoption of a standard design freeboard of 300 mm though this is subject to further detailed hydrological analysis.

6.4.2 Point Rainfall Comparison

A comparison between a point rainfall approach and the adopted duration dependent ARF approach was undertaken. The 1% 6-hour TP06 event was adopted for the purpose of this comparison which represented an increase in total rainfall of 11.5%. Peak flow rates for the adopted event have been reported at BD2-8 where this event is reflective of the upper mean (rank 6) and are presented in Table 6-5.

Table 6-5. Adopted duration dependent ARF approach comparison to point rainfall approach

Location	Variable	1% AEP 6-hour TP06 Adopted ARF	1% AEP 6-hour TP01 Point Rainfall
BD2 Model Domain	Total Rainfall[1] (mm)	120	134 (+11.5%)
BD2-8 Unnamed Creek (90 km^2)	Mean peak flow (m^3/s)	554	626 (+13%)

[1]Before spatial distribution has been applied

The results from the sensitivity analysis show that, as expected, a minor increase in peak flow is expected when adopting unfactored point rainfall. Both peak flow estimates are shown to be reasonable when compared to regional estimates (presented in Table 6-2).

6.4.3 Floodplain roughness

The adoption of a 25% increase in floodplain roughness across the model areas resulted in increased flood levels in the main creek systems, as is to be expected.

Within the larger waterways of the Study Area, this increase in floodplain roughness typically results in peak flood level increases of up to approximately 200 mm. Within headwater areas where proposed turbine locations are typically located, the increase in flood levels were predicted to be less than 150 mm.

Based on the results of the assessment, it is expected that uncertainty and risk associated with the difference between the adopted and actual floodplain roughness values across the Study Area could typically be mitigated by adoption of a standard design freeboard of 300 mm.

7 Conclusions

This study represents a baseline assessment of the hydrological and hydraulic conditions throughout the Study Area using the latest industry assessment methods and data.

The assessment used the Nullagine River streamflow site located immediately downstream of the Study Area to aid in characterising appropriate design event loss parameterisation for rain on grid hydraulic modelling to estimate the hydrological and resultant hydraulic conditions across the site. The assessment approach and methods are consistent with ARR2019 (Ball et al., 2019), the latest industry guidance on the derivation of hydrological estimates and flood risk.

It can be concluded from the analysis that:

- Whilst there are no streamflow gauging sites located within the Study Area itself, there is a long-term gauging station immediately downstream on the Nullagine River. This enabled reconciliation of empirical loss estimates from rainfall-runoff modelling in a Monte Carlo environment to FFA results to ensure appropriate loss parameters were adopted.
- DWER rating curves developed for the Nullagine gauge site were reviewed using a detailed TUFLOW model. The review indicated that the recent update to the Nullagine rating curve results in very conservative flows for the gauge stage and seemingly produced unrealistic FFA quantiles for the catchment. The previously used rating curve by DWER produced a significantly closer match to that obtained from the TUFLOW model and was therefore adopted, which additionally maintains consistency with the EPGH study (Advisian, 2022).
- The RORB model developed for the Nullagine River catchment to the Nullagine gauge site as part of the EPGH study was used, with validation works undertaken on the storage-discharge parameterisation against a regional TUFLOW rain on grid model. This showed an increase in the $C_{0.8}$ value was warranted based on a comparison of hydrograph shape and peak flow.
- The RORB model was then simulated in a Monte Carlo environment and flow quantiles reconciled to those obtained from the FFA from the Nullagine streamflow gauge record. Due to the increased $C_{0.8}$ value adopted in this study compared to that used in the EPGH study, a minor reduction in *CL* was applied (from 3 mm/hr to 2.6 mm/hr) to enable a strong match to FFA quantiles across the entire AEP range of interest. This, in conjunction with consideration of catchment landform and geomaterial homogeneity, resulted in an agreed empirical loss parameter set for use across the entire Study Area of 20 mm IL_S and 2.6 mm/hr *CL.*
- Conceptual turbine locations are located in a combination of headwater areas and near more significant watercourses. Through analysis of the 1% AEP flood modelling results the following can be concluded:
  - 165 conceptual turbine locations are shown to be within an area of peak flood depth of greater than 100 mm. 103 of these locations were shown to be within an area of at least 300 mm depth, with 17 of these locations having a peak flood depth of greater than 1 m.
  - 168 conceptual turbine hardstand location are within an area of peak flood velocity of greater than 0.3 m/s. 53 of these locations were shown to be located in an area with 0.6 m/s velocities or greater, with 13 of these locations having a peak flood velocity of greater than 1 m/s.
  - Using the Smith et al. (2014) Hazard Classification method, three proposed hardstand locations are classified as H5. Three hardstand locations are classified as H4, six hardstand

locations are classified as H3, 29 hardstand locations are classified as H2 and the remaining hardstand locations are classified as H1.

- Sensitivity assessment of the 2050 future climate scenario using projected rainfall intensity increases for the RCP4.5 (intermediate scenario) and RCP8.5 (worst-case scenario) in the modelling identified an increase in the 1% AEP peak flows within all waterways of between 9% and 13% for the 2050 RCP4.5 scenario and between 12% and 17% for the 2050 RCP8.5 scenario. Corresponding peak flood levels were typically less than 250 mm for most of the Study Area, the exception being in the lower extents of the Nullagine and Coongan Rivers (where no infrastructure is currently proposed).
- Assessment of model results to increased floodplain roughness indicated up to 200 mm increases in peak flood levels within the Study Area. As a result, it is expected that the uncertainties and associated risks relating to future climate hydrological uncertainty and the exact floodplain roughness across the Study Area could be mitigated by adoption of a standard design freeboard of 300 mm (to mitigate either of the individual sensitivity scenarios).

8 Recommendations

Considering the data review, technical assessment and conclusions of this study, the following recommendations are made to support further planning and design:

- Where conceptual placement of wind turbine infrastructure is proposed within the flood extents developed as part of this assessment, alternate placement of wind turbines should be considered – particularly those identified as being subject to higher flood hazard (as an example, H1 or H2 classification). The exact hazard threshold adopted by FFI for moving proposed turbine locations would depend on detailed site analysis, potential for flood mitigation implementation amongst other engineering trade-off considerations.
- Given the predicted range of soils in regional mapping across the Study Area, infiltrometer or similar testing should be undertaken for a number of sample locations as part of further geotechnical studies to facilitate a better understanding of infiltration potential in the upper soil profile and further validate hydrological model parameterisation.
- The TUFLOW models should be adopted by FFI as an assessment tool and refined with additional data that becomes available for the site.
- Discrete areas of higher hydraulic model resolution using Quadtree functionality or alternatively smaller, discrete model builds are recommended for future project stages where more detail is required such as the detailed design of linear infrastructure or critical flood mitigation infrastructure.
- Flood resilience of various infrastructure may need to be considered including locality of key/critical infrastructure based on the outcomes of this assessment (including susceptibility to increased flood risk from projected climate change).

9 References

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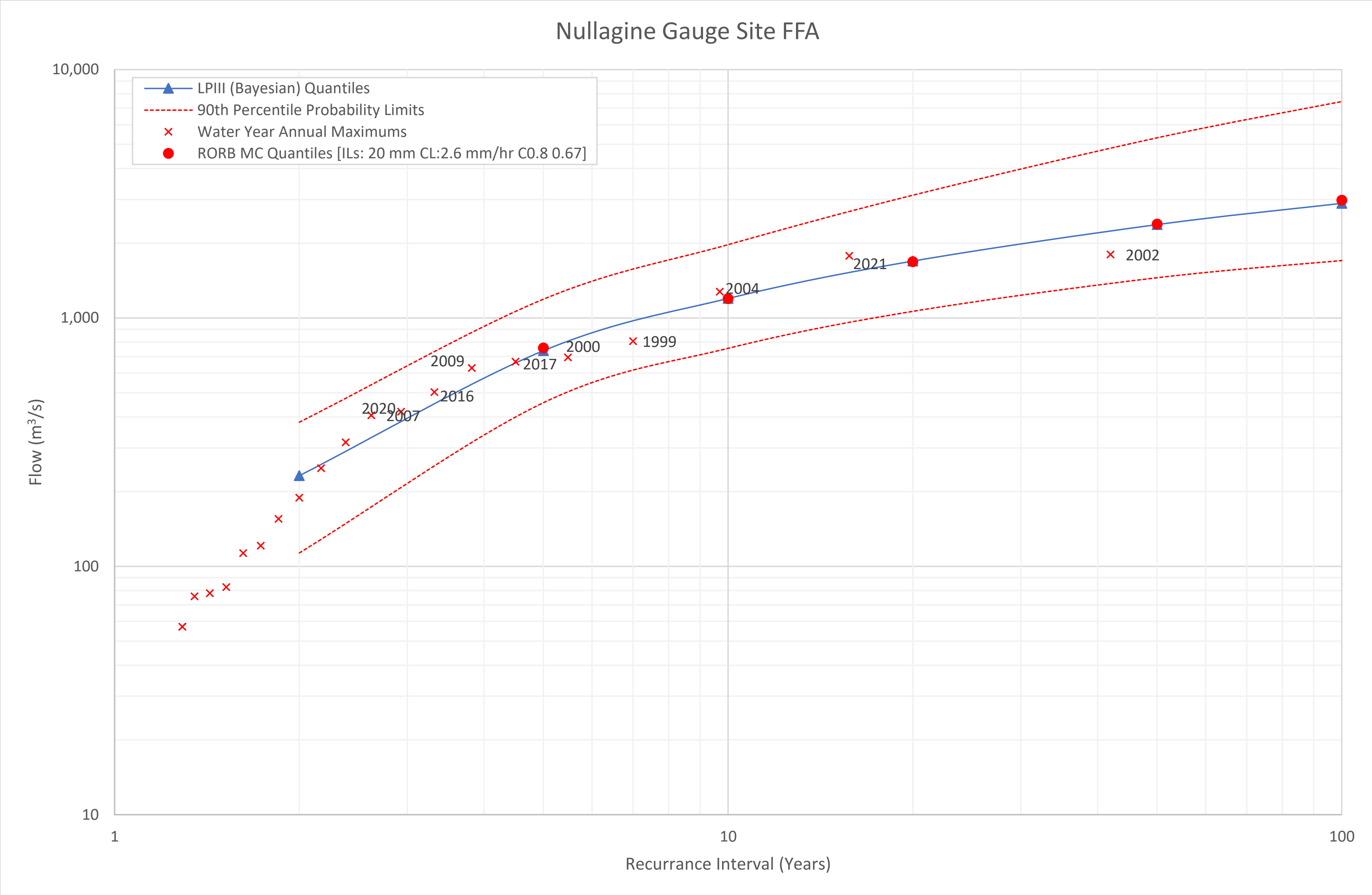
Appendix A
Nullagine River Flood Frequency Analysis Plot



Nullagine Gauge Site FFA
LPIII (Bayesian) Quantiles
90th Percentile Probability Limits
Water Year Annual Maximums
RORB MC Quantiles [ILs: 20 mm CL:2.6 mm/hr C0.8 0.67]
10,000
1,000
100
10
Flow (m³/s)
1
10
100
Recurrance Interval (Years)
2002
2021
2004
1999
2000
2017
2009
2016
2020
2007

Appendix B
Design Rainfall (IFD) Data – Nullagine RORB Model

Nullagine River Point IFD

	Rainfall Depth (mm)						
Duration	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP
12-hour	54.3	82.4	103	125	155	181	209
18-hour	61.3	94.2	118	144	180	210	242
24-hour	66.6	103	129	157	197	229	264
36-hour	74	115	144	174	218	252	289
48-hour	79.1	122	153	184	228	263	298
72-hour	85.5	131	163	194	238	271	304

Nullagine River Median Pre-Burst

	Rainfall Depth (mm)						
Duration	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP*
12-hour	-	0.7	1.1	1.5	8.6	13.9	16.1
18-hour	-	0.3	0.4	0.6	7.0	11.8	13.6
24-hour	-	0.4	0.7	1	3.4	5.2	6.1
36-hour	-	-	-	-	0.7	1.2	1.4
48-hour	-	-	-	-	-	-	-
72-hour	-	-	-	-	-	-	-

* For the 1 in 200 AEP, pre burst has been determined using 1% AEP pre-burst percentages applied to the relevant design rainfall to derive the representative IL_B as recommended in Book 8 of ARR2019 (Ball et al., 2019).

Appendix C
Design Rainfall (IFD) – TUFLOW Models

BD1 Point IFD – centroid location -22.02380S, 119.80765E

	Rainfall Depth (mm)						
Duration	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP
0.5-hour	20.6	29	34.5	39.9	46.7	51.9	59.6
1-hour	26.5	37.3	44.5	51.5	60.6	67.5	77.4
2-hour	32.6	46.3	55.8	65.1	77.5	87.2	100
3-hour	36.5	52.5	63.7	75	90.2	102	117
6-hour	44.3	65.6	80.9	96.7	119	137	157
12-hour	54.1	82.5	103	125	157	182	210
18-hour	60.9	94	119	144	181	211	243
24-hour	66	103	130	158	198	231	265

BD1 Median Pre-Burst

	Rainfall Depth (mm)						
Duration	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP*
0.5-hour	0.5	0.8	1.1	1.3	1.7	2.1	2.4
1-hour	0.6	1.1	1.4	1.7	2.3	2.7	3.1
2-hour	0.3	0.7	0.9	1.1	2.4	3.3	3.8
3-hour	0	0.7	1.1	1.6	5.7	8.8	10.1
6-hour	0	1.3	2.2	3	20	32.7	37.5
12-hour	0	0.8	1.4	1.9	7.3	11.4	13.2
18-hour	0	0.2	0.3	0.4	5.6	9.5	10.9
24-hour	0	0.4	0.7	1	2.4	3.5	4.0

* For the 1 in 200 AEP, pre burst has been determined using 1% AEP pre-burst percentages applied to the relevant design rainfall to derive the representative IL_B as recommended in Book 8 of ARR2019 (Ball et al., 2019).

BD2 Point IFD – centroid location -22.08000S, 120.01265E

	Rainfall Depth (mm)						
Duration	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP
0.5-hour	20.1	28.4	33.9	39.2	46	51.1	58.8
1-hour	25.7	36.3	43.4	50.3	59.2	65.9	75.8
2-hour	31.7	45.1	54.3	63.4	75.4	84.8	97.5
3-hour	35.6	51.3	62.2	73.1	87.9	99.5	115
6-hour	43.8	64.6	79.6	95	117	134	155
12-hour	54.3	82.3	103	124	155	180	208
18-hour	61.5	94.4	119	144	180	210	242
24-hour	66.9	103	130	158	198	230	265

BD2 Median Pre-Burst

	Rainfall Depth (mm)						
Duration	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP*
0.5-hour	0.8	1.1	1.3	1.5	1.8	2.0	2.3
1-hour	1.0	1.4	1.7	1.9	2.3	2.6	3.0
2-hour	0.5	0.8	0.9	1.1	2.1	2.8	3.2
3-hour	0.3	1.3	2.0	2.7	5.4	7.5	8.6
6-hour	0.0	1.4	2.3	3.2	18.3	29.7	34.4
12-hour	0.0	0.7	1.1	1.5	8.6	13.9	16.0
18-hour	0.0	0.3	0.4	0.6	7.0	11.8	13.6
24-hour	0.0	0.4	0.7	1.0	3.4	5.2	4.0

* For the 1 in 200 AEP, pre burst has been determined using 1% AEP pre-burst percentages applied to the relevant design rainfall to derive the representative IL_B as recommended in Book 8 of ARR2019 (Ball et al., 2019).

BD3 Point IFD – centroid location -22.197400S, 120.18995E

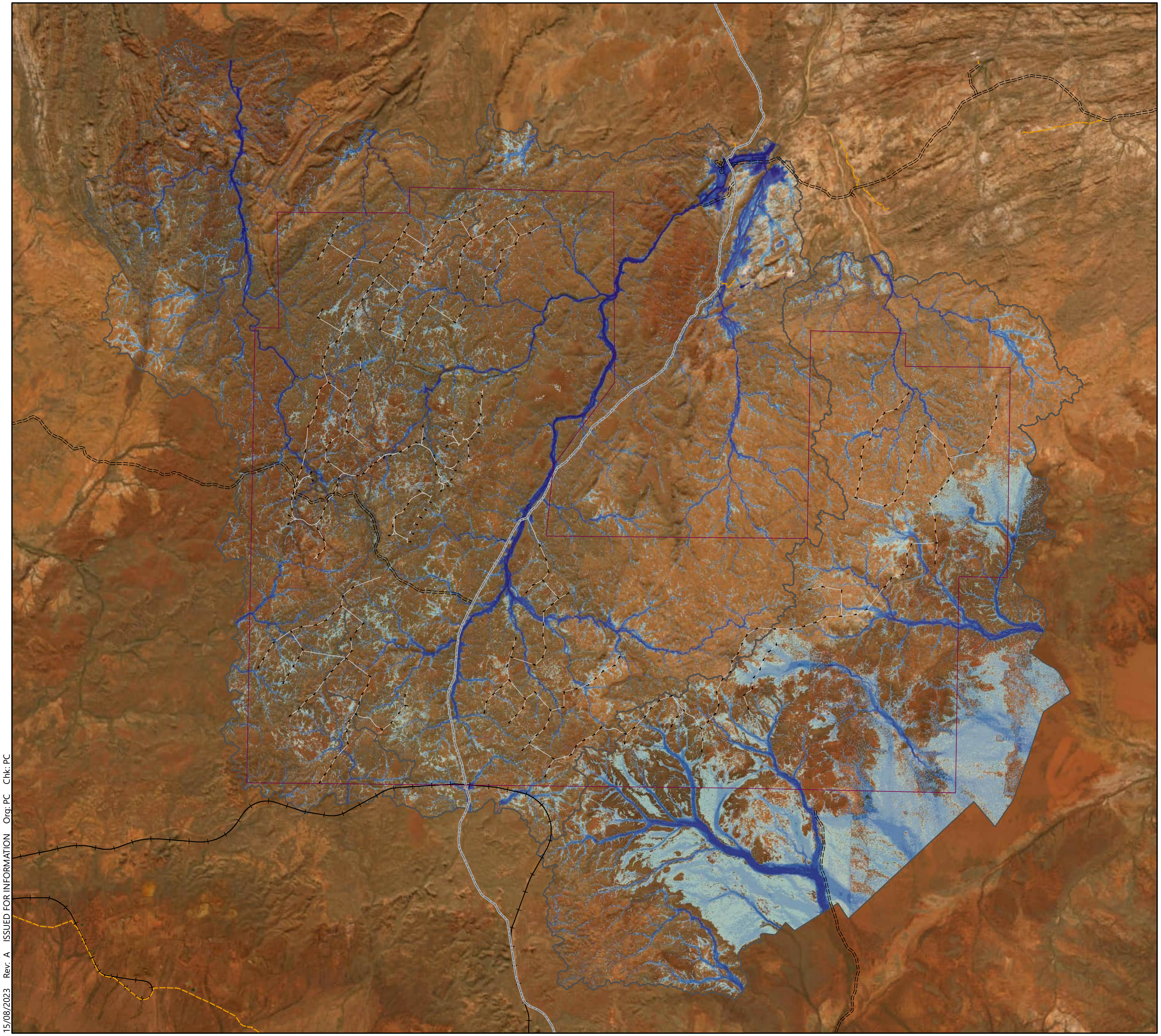
	Rainfall Depth (mm)						
Duration	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP
0.5-hour	19.6	27.8	33.3	38.5	45.3	50.4	58
1-hour	25.1	35.5	42.5	49.2	58	64.6	74.2
2-hour	30.8	44	53	61.9	73.6	82.7	95
3-hour	34.7	50	60.7	71.3	85.7	97	112
6-hour	42.8	63.3	78	93.1	114	131	151
12-hour	53.4	81.1	101	123	153	178	205
18-hour	60.6	93.2	117	142	178	208	240
24-hour	65.9	102	129	156	196	228	262

BD3 Median Pre-Burst

	Rainfall Depth (mm)						
Duration	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP*
0.5-hour	0.9	1.4	1.7	2.0	2.0	2.0	2.3
1-hour	1.1	1.8	2.2	2.6	2.5	2.5	2.9
2-hour	0.9	1.0	1.1	1.3	2.0	2.6	3.0
3-hour	0.4	1.9	2.8	3.7	5.0	6.0	6.9
6-hour	0.0	1.4	2.3	3.1	16.9	27.1	31.3
12-hour	0.0	0.8	1.3	1.8	6.8	10.6	12.1
18-hour	0.0	0.2	0.3	0.4	6.9	11.7	13.5
24-hour	0.0	0.3	0.6	0.8	3.4	5.4	6.2

* For the 1 in 200 AEP, pre burst has been determined using 1% AEP pre-burst percentages applied to the relevant design rainfall to derive the representative IL_B as recommended in Book 8 of ARR2019 (Ball et al., 2019).

Appendix D
Design Event Flood Mapping



PILBARA DECARBONISATION PROJECT
BONNEY DOWNS
BASELINE HYDROLOGY STUDY

FIGURE 1

EXISTING CASE
0.5% AEP PEAK FLOOD DEPTH

Legend

- Study Area
- Proposed Wind Turbine Hardstand
- Proposed Tracks
- State Road
- Local Road
- Miscellaneous Road
- Rail Network
- Hydraulic Model Boundary

Peak Flood Depth (m)

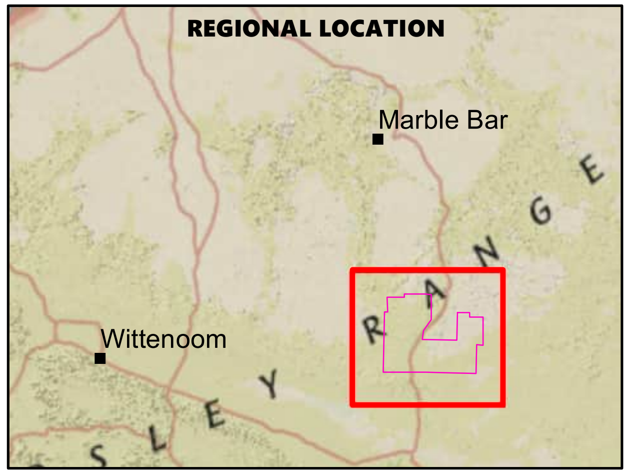
- <0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 3
- >3

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

N

Scale at A3 - 1:250,000

0 5 10 15
Kilometers



Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community
National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO,

Fortescue. Advisian

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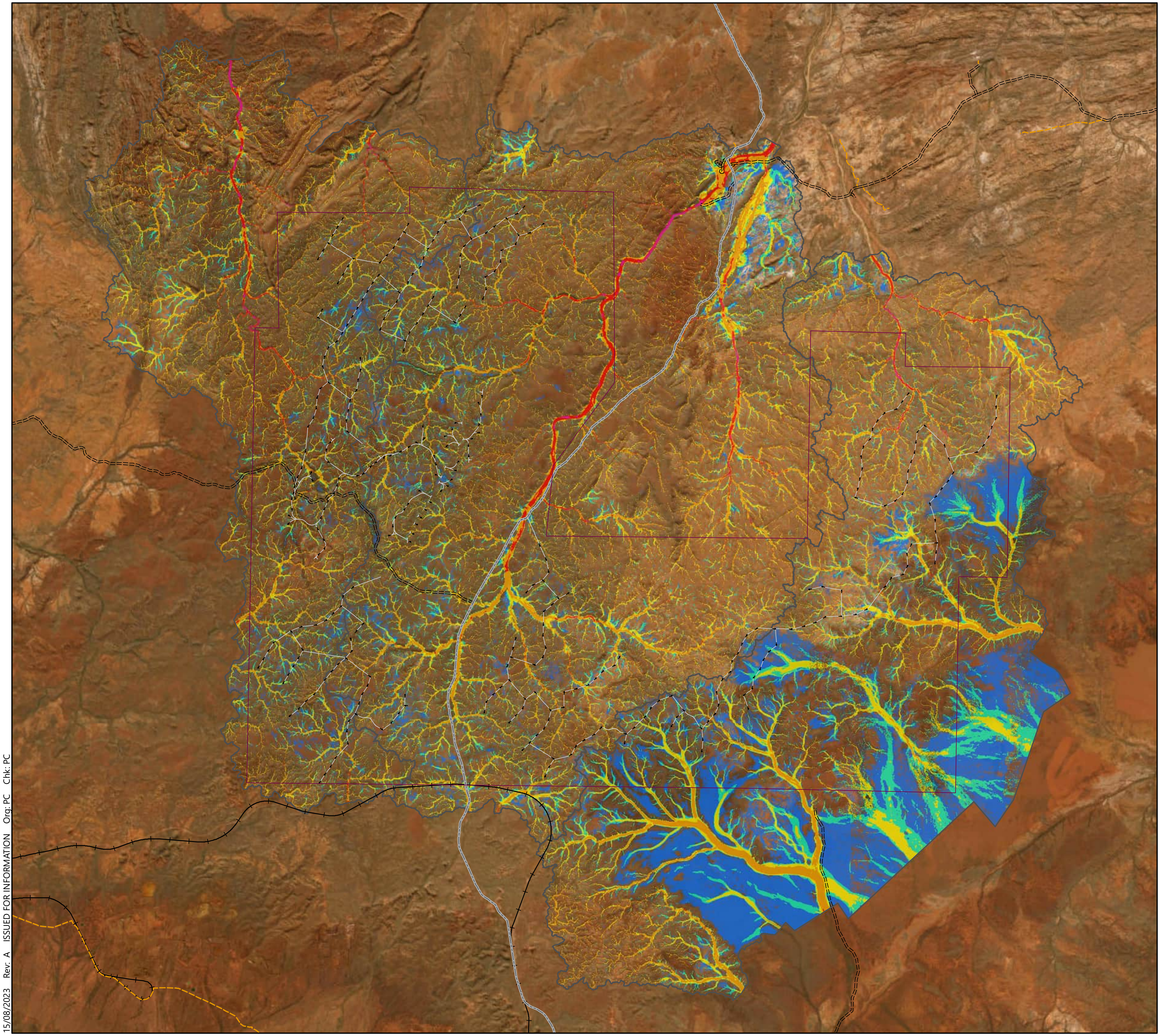


PILBARA DECARBONISATION PROJECT
BONNEY DOWNS
BASELINE HYDROLOGY STUDY

FIGURE 2

EXISTING CASE
0.5% AEP PEAK FLOOD VELOCITY

Legend

- Study Area
- Proposed Wind Turbine Hardstand
- Proposed Tracks
- State Road
- Local Road
- Miscellaneous Road
- Rail Network
- Hydraulic Model Boundary

Peak Flood Velocity (m/s)

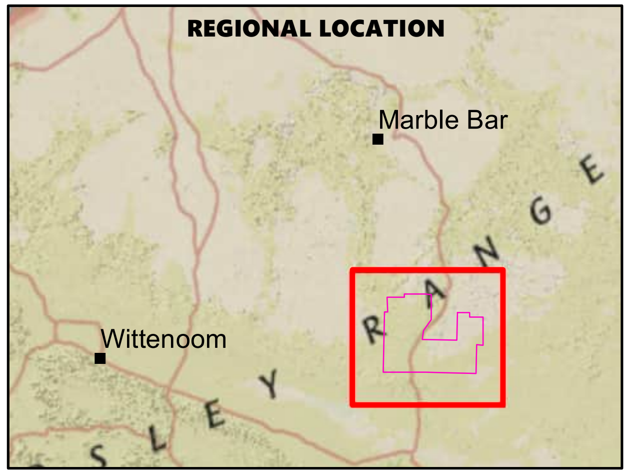
- 0 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 3
- >3

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

N

Scale at A3 - 1:250,000

0 5 10 15
Kilometers



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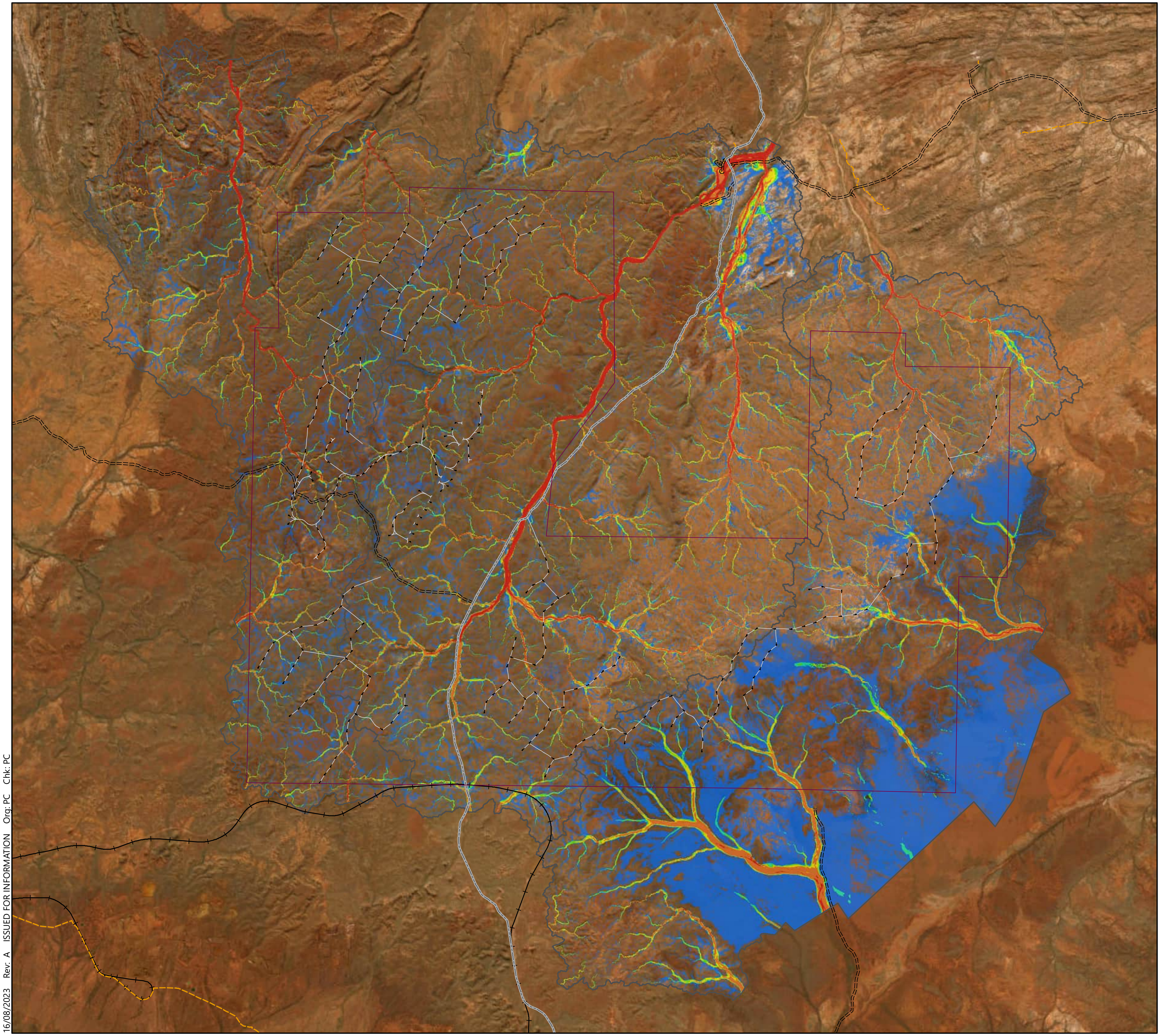
PILBARA DECARBONISATION PROJECT
BONNEY DOWNS
BASELINE HYDROLOGY STUDY

FIGURE 3
EXISTING CASE
0.5% AEP PEAK FLOOD
VELOCITY DEPTH PRODUCT



Legend

- Study Area
- Proposed Wind Turbine Hardstand
- Proposed Tracks
- State Road
- Local Road
- Miscellaneous Road
- Rail Network
- Hydraulic Model Boundary

Peak Flood Velocity Depth Product (m²/s)

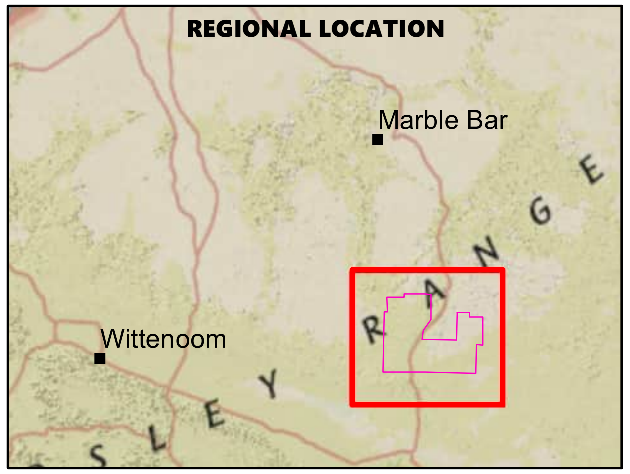
- 0 - 0.3
- 0.3 - 0.4
- 0.4 - 0.6
- 0.6 - 1
- 1 - 3
- >3

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

N

Scale at A3 - 1:250,000

0 5 10 15
Kilometers



Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community
National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO,

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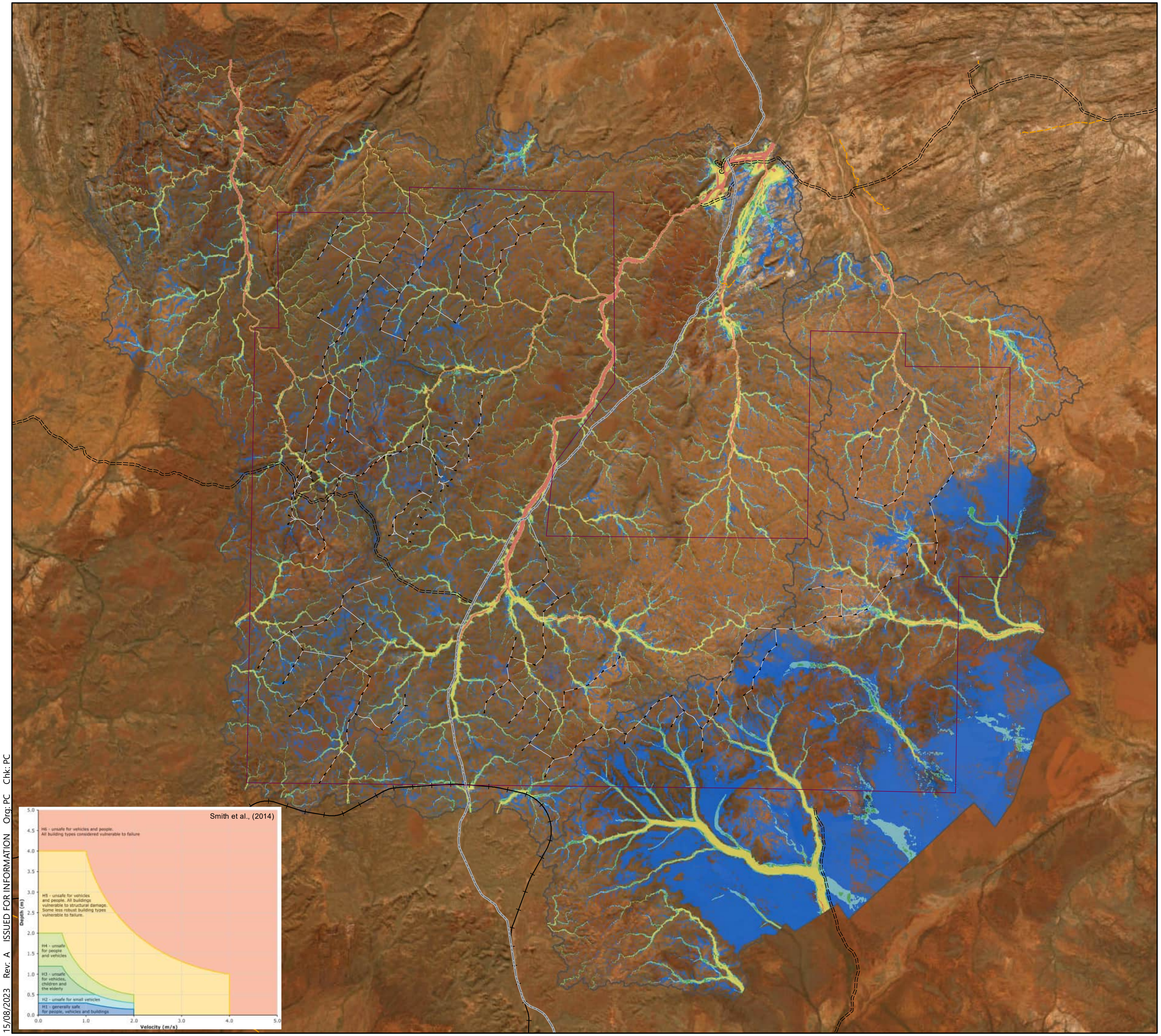
BONNEY DOWNS
BASELINE HYDROLOGY STUDY

FIGURE 4
EXISTING CASE
0.5% AEP PEAK FLOOD
HAZARD VULNERABILITY CLASSIFICATION



Legend

- Study Area
- Proposed Wind Turbine Hardstand
- Proposed Tracks
- State Road
- Local Road
- Miscellaneous Road
- Rail Network
- Hydraulic Model Boundary

Peak Flood Hazard Vunerability Classification (Smith et al., 2014)

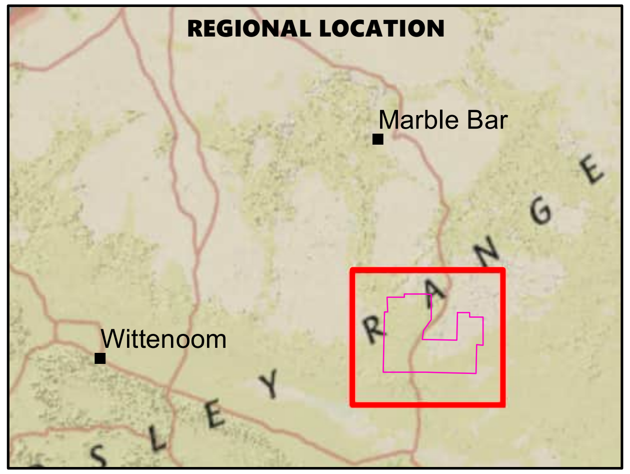
- H1
- H2
- H3
- H4
- H5
- H6

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

N

Scale at A3 - 1:250,000

0 5 10 15
Kilometers



Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community
National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO,

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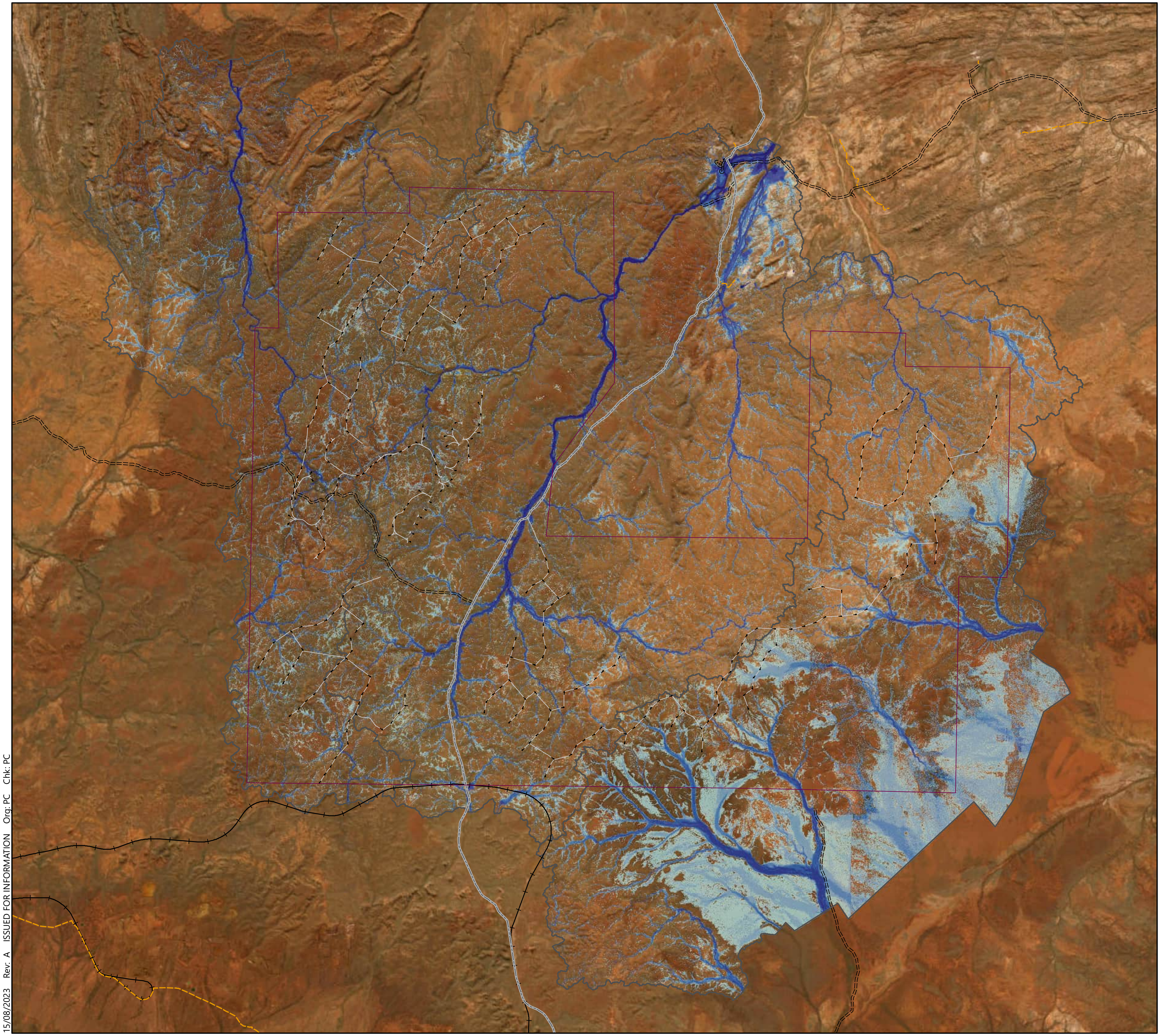

PILBARA DECARBONISATION PROJECT
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BASELINE HYDROLOGY STUDY

FIGURE 5

EXISTING CASE
1% AEP PEAK FLOOD DEPTH

Legend

- Study Area
- Proposed Wind Turbine Hardstand
- Proposed Tracks
- State Road
- Local Road
- Miscellaneous Road
- Rail Network
- Hydraulic Model Boundary

Peak Flood Depth (m)

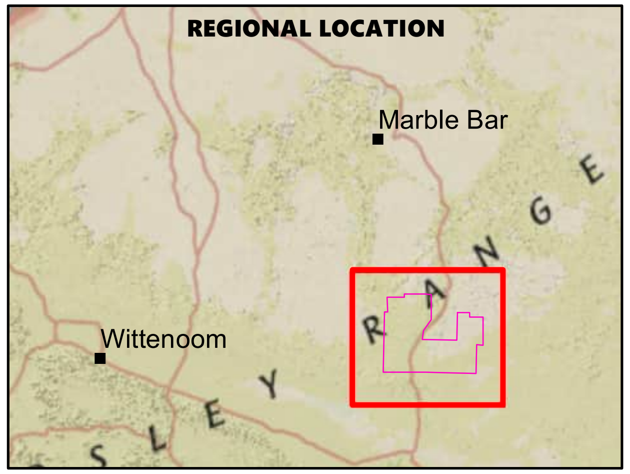
- <0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 3
- >3

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

N

Scale at A3 - 1:250,000

0 5 10 15
Kilometers



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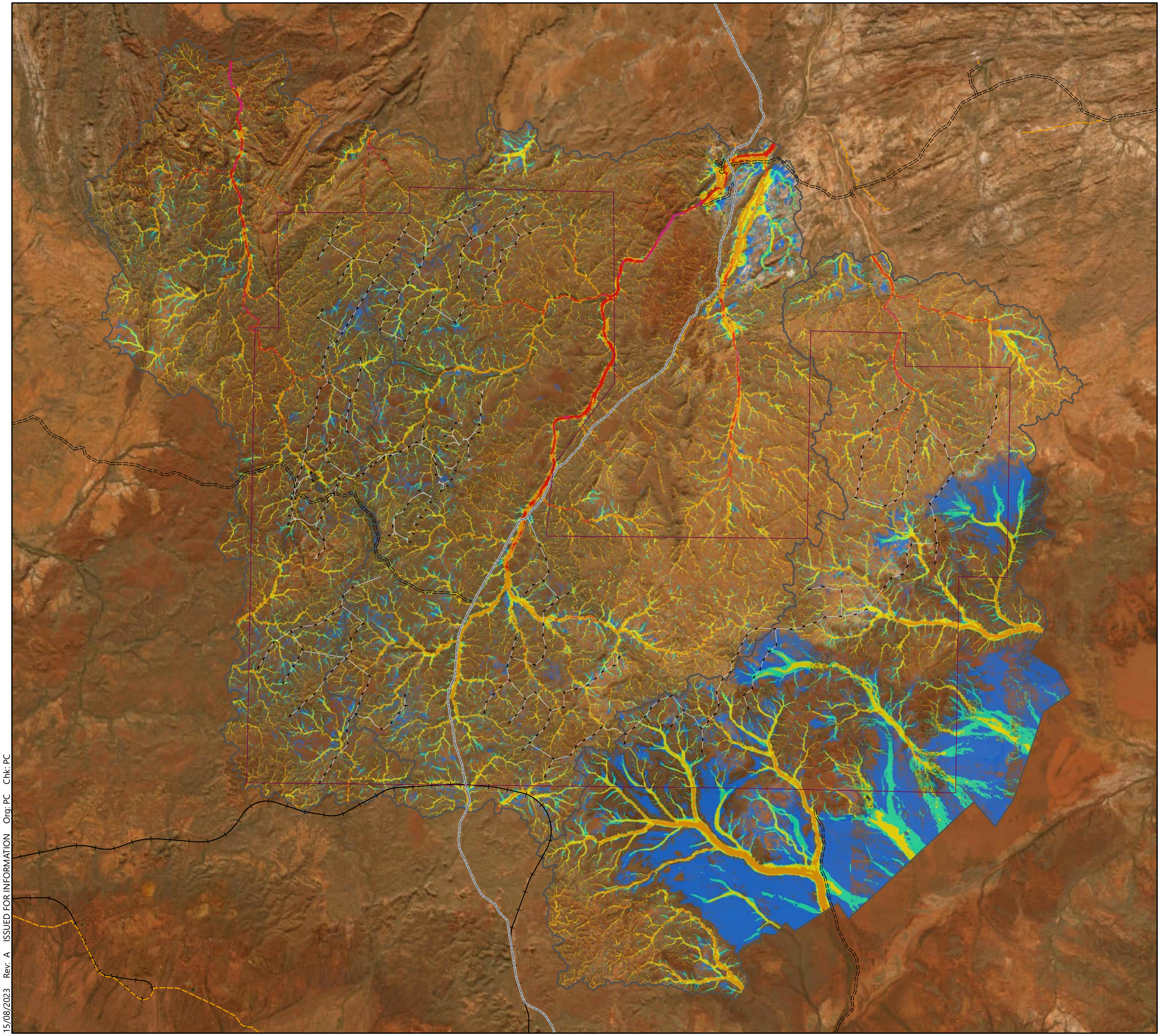

PILBARA DECARBONISATION PROJECT
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BASELINE HYDROLOGY STUDY

FIGURE 6

EXISTING CASE
1% AEP PEAK FLOOD VELOCITY

Legend

- Study Area
- Proposed Wind Turbine Hardstand
- Proposed Tracks
- State Road
- Local Road
- Miscellaneous Road
- Rail Network
- Hydraulic Model Boundary

Peak Flood Velocity (m/s)

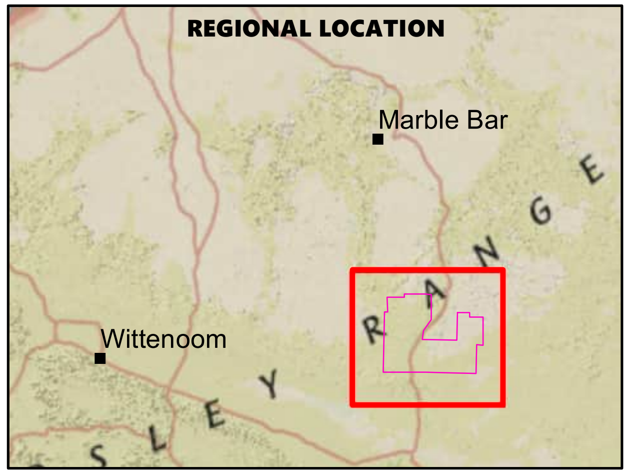
- 0 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 3
- >3

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

N

Scale at A3 - 1:250,000

0 5 10 15
Kilometers



Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community
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PILBARA DECARBONISATION PROJECT
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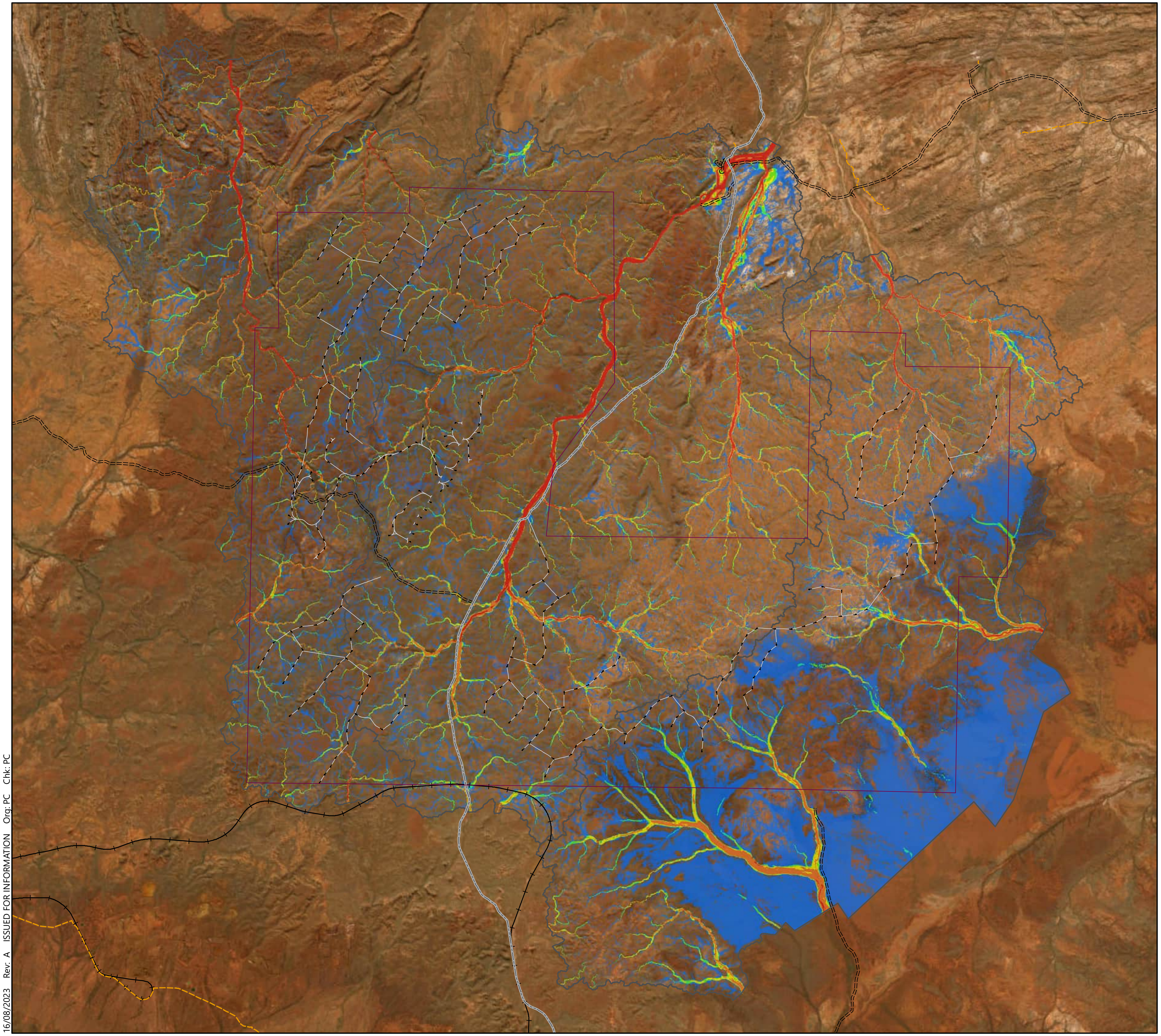
FIGURE 7
EXISTING CASE
1% AEP PEAK FLOOD
VELOCITY DEPTH PRODUCT



Legend

- Study Area
- Proposed Wind Turbine Hardstand
- Proposed Tracks
- State Road
- Local Road
- Miscellaneous Road
- Rail Network
- Hydraulic Model Boundary

Peak Flood Velocity Depth Product (m²/s)

- 0 - 0.3
- 0.3 - 0.4
- 0.4 - 0.6
- 0.6 - 1
- 1 - 3
- >3

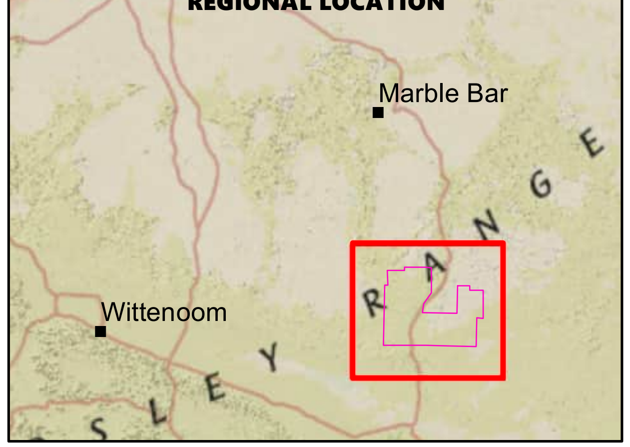
Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

N

Scale at A3 - 1:250,000

0 5 10 15
Kilometers

REGIONAL LOCATION



Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community
National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO,

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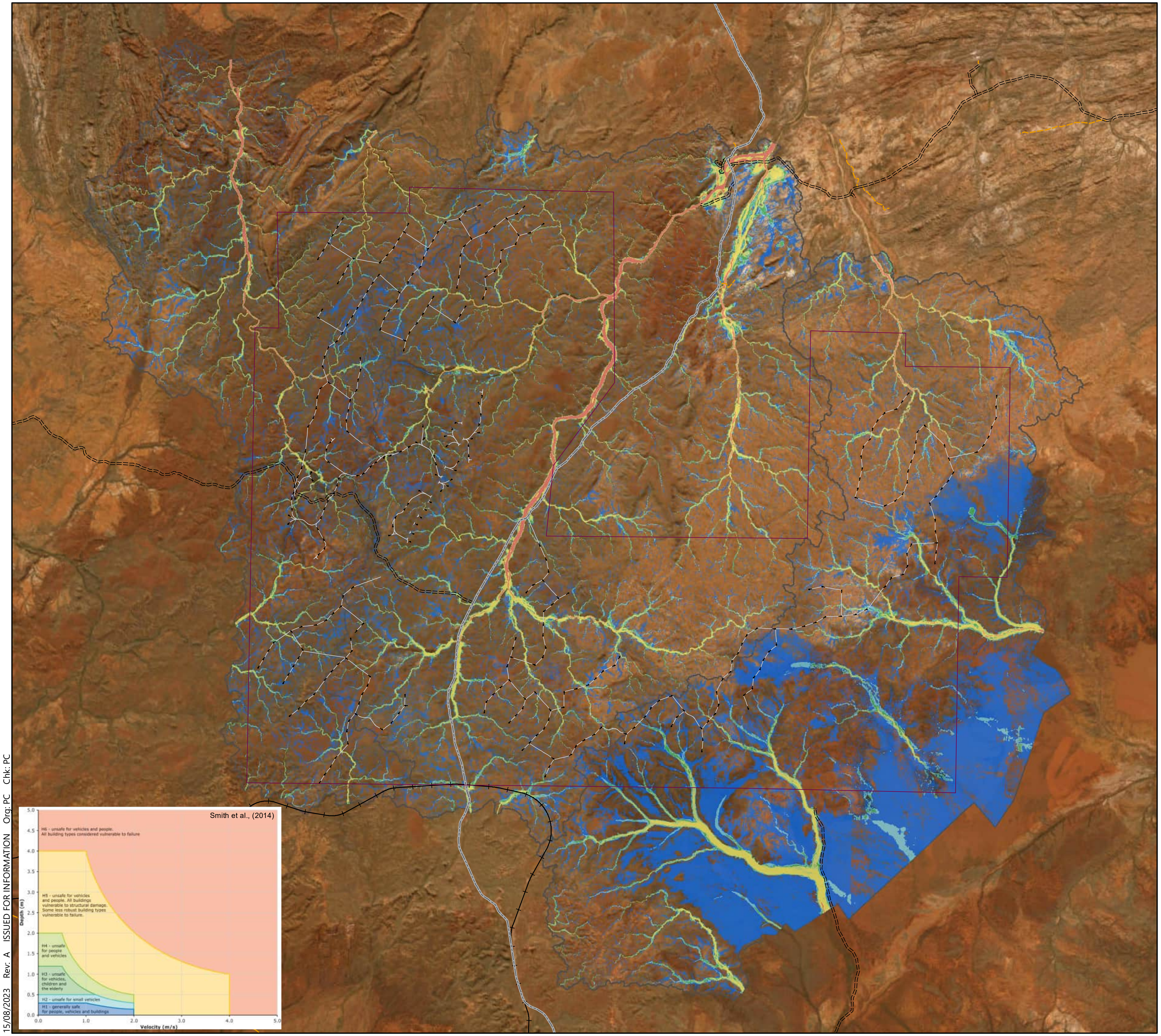


PILBARA DECARBONISATION PROJECT
BONNEY DOWNS
BASELINE HYDROLOGY STUDY

FIGURE 8
EXISTING CASE
1% AEP PEAK FLOOD
HAZARD VULNERABILITY CLASSIFICATION

Legend

- Study Area
- Proposed Wind Turbine Hardstand
- Proposed Tracks
- State Road
- Local Road
- Miscellaneous Road
- Rail Network
- Hydraulic Model Boundary

Peak Flood Hazard Vunerability Classification (Smith et al., 2014)

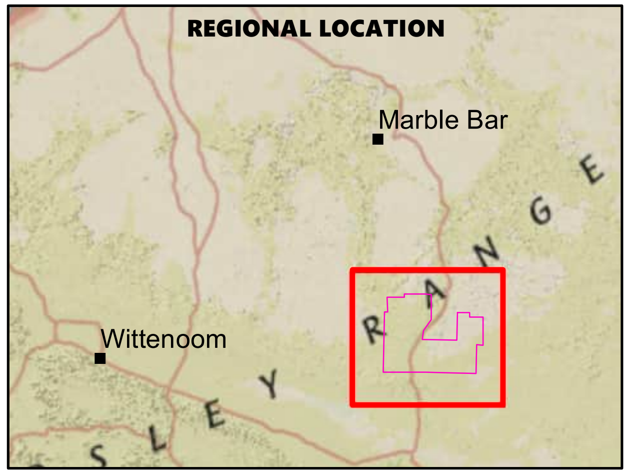
- H1
- H2
- H3
- H4
- H5
- H6

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

N

Scale at A3 - 1:250,000

0 5 10 15
Kilometers



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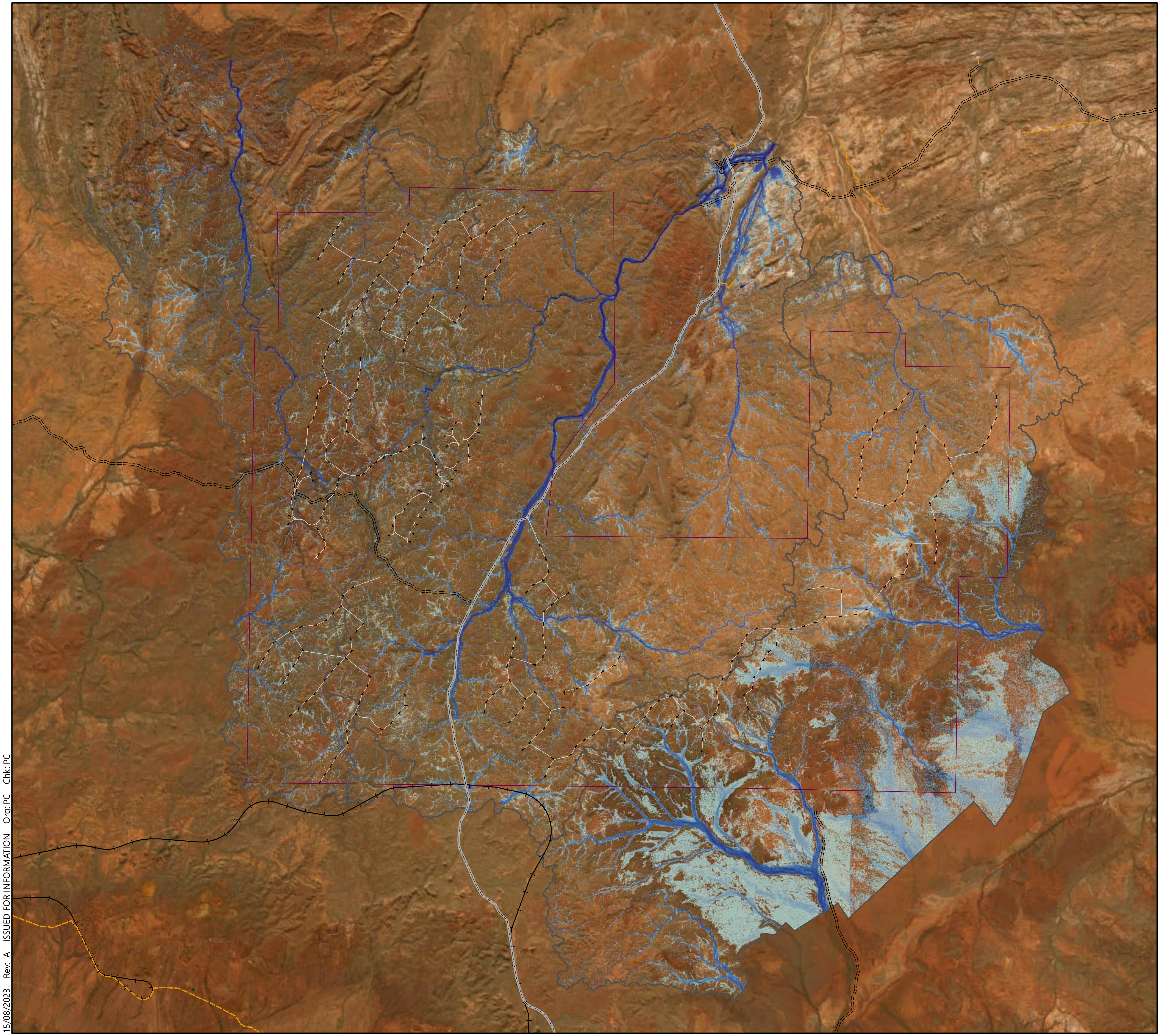

PILBARA DECARBONISATION PROJECT
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BASELINE HYDROLOGY STUDY

FIGURE 9

EXISTING CASE
5% AEP PEAK FLOOD DEPTH

Legend

Study Area
Proposed Wind Turbine Hardstand
Proposed Tracks
State Road
Local Road
Miscellaneous Road
Rail Network
Hydraulic Model Boundary

Peak Flood Depth (m)

<0.1
0.1 - 0.25
0.25 - 0.5
0.5 - 1
1 - 3
>3

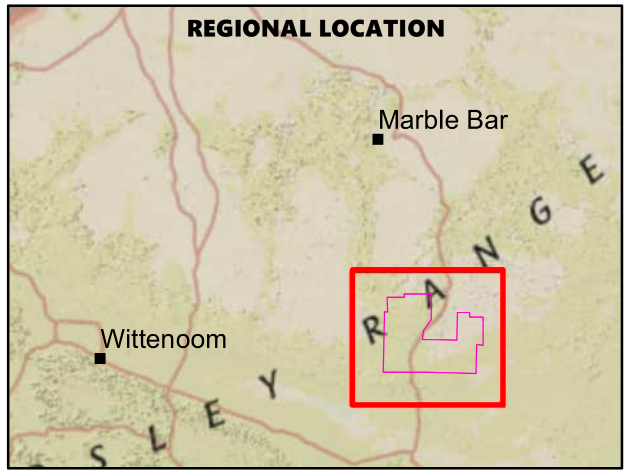
Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

N

Scale at A3 - 1:250,000

0 5 10 15
Kilometers

REGIONAL LOCATION



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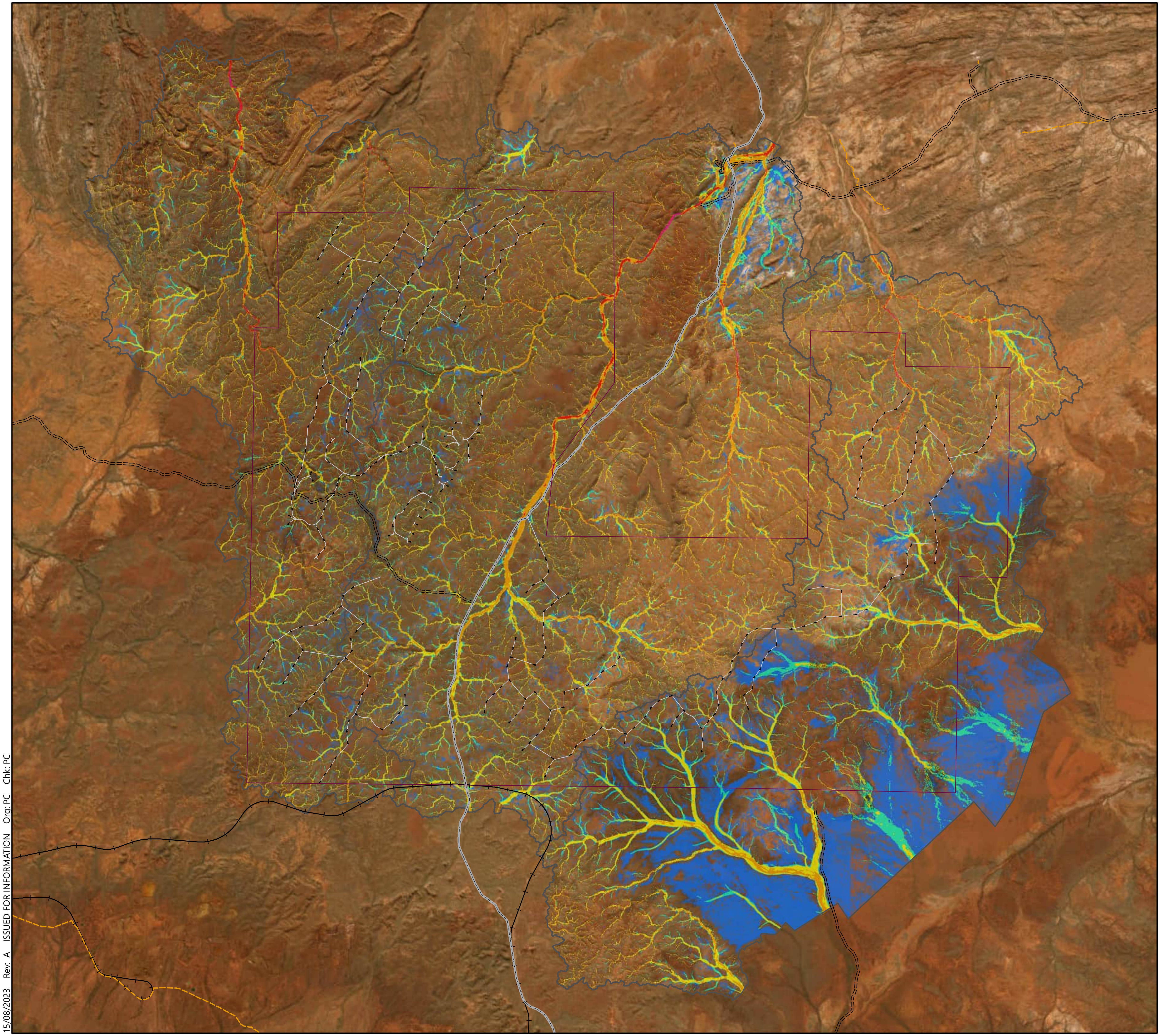
15/08/2023 Rev: A ISSUED FOR INFORMATION Org: PC Chk: PC



PILBARA DECARBONISATION PROJECT
BONNEY DOWNS
BASELINE HYDROLOGY STUDY

FIGURE 10

EXISTING CASE
5% AEP PEAK FLOOD VELOCITY

Legend

- Study Area
- Proposed Wind Turbine Hardstand
- Proposed Tracks
- State Road
- Local Road
- Miscellaneous Road
- Rail Network
- Hydraulic Model Boundary

Peak Flood Velocity (m/s)

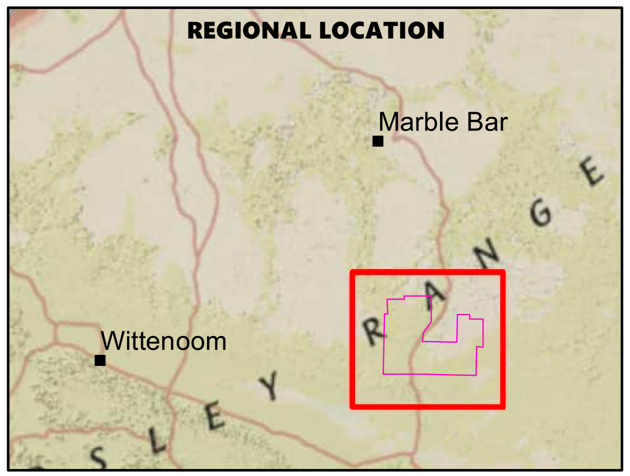
- 0 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 3
- >3

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

N

Scale at A3 - 1:250,000

0 5 10 15
Kilometers



Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community
National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO,

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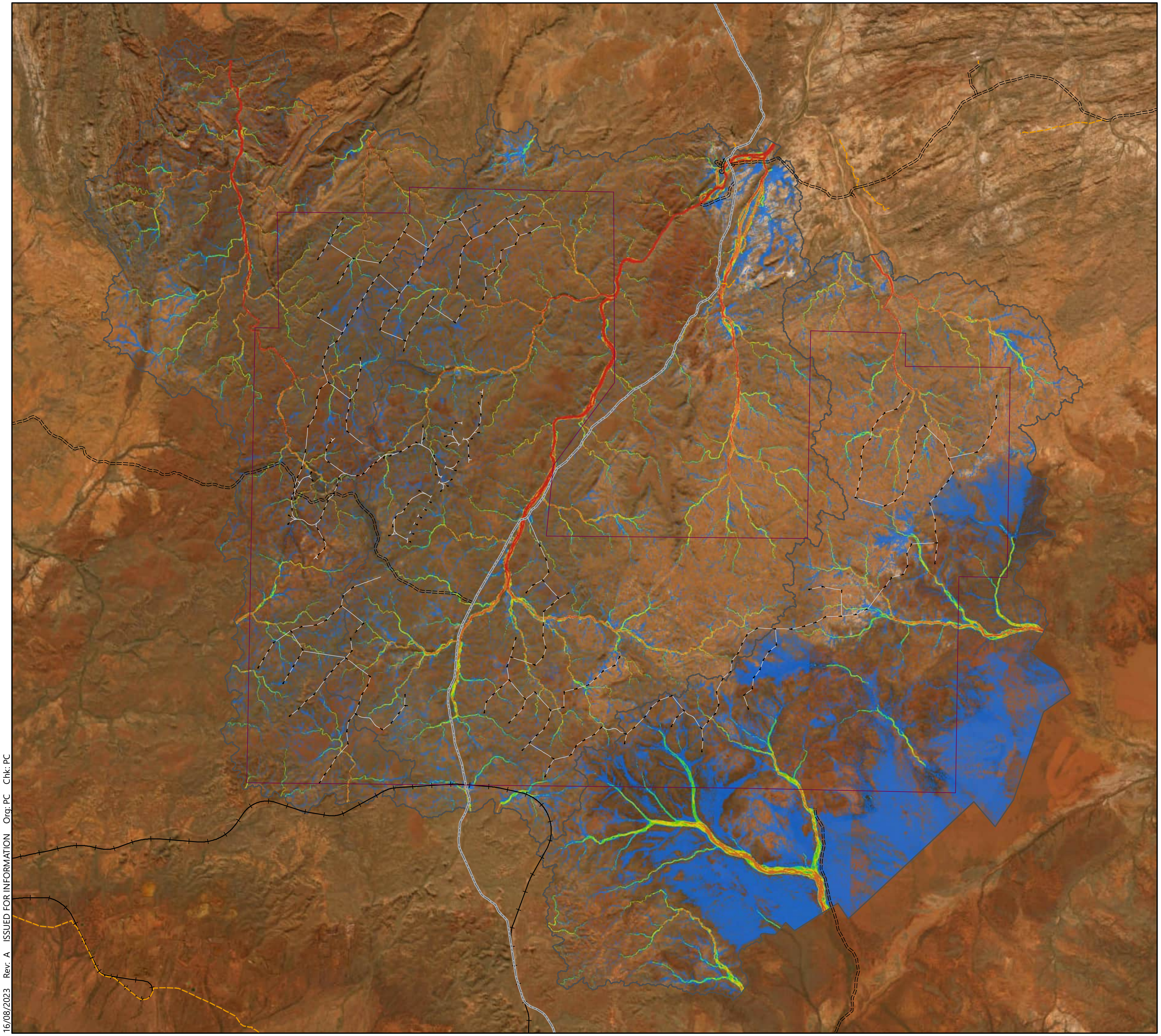
PILBARA DECARBONISATION PROJECT
BONNEY DOWNS
BASELINE HYDROLOGY STUDY

FIGURE 11
EXISTING CASE
5% AEP PEAK FLOOD
VELOCITY DEPTH PRODUCT



Legend

- Study Area
- Proposed Wind Turbine Hardstand
- Proposed Tracks
- State Road
- Local Road
- Miscellaneous Road
- Rail Network
- Hydraulic Model Boundary

Peak Flood Velocity Depth Product (m²/s)

- 0 - 0.3
- 0.3 - 0.4
- 0.4 - 0.6
- 0.6 - 1
- 1 - 3
- >3

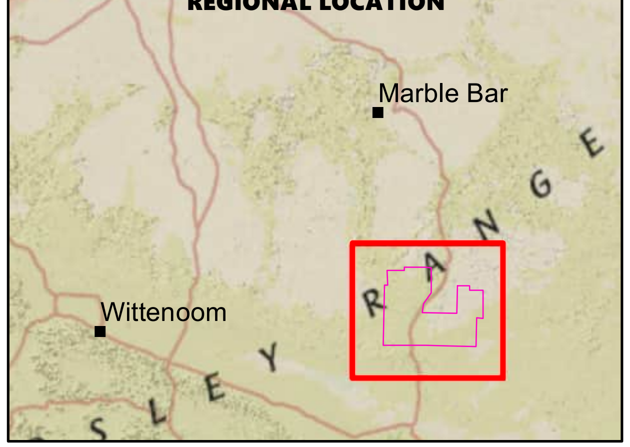
Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

N

Scale at A3 - 1:250,000

0 5 10 15
Kilometers

REGIONAL LOCATION



Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community
National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO,

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PILBARA DECARBONISATION PROJECT
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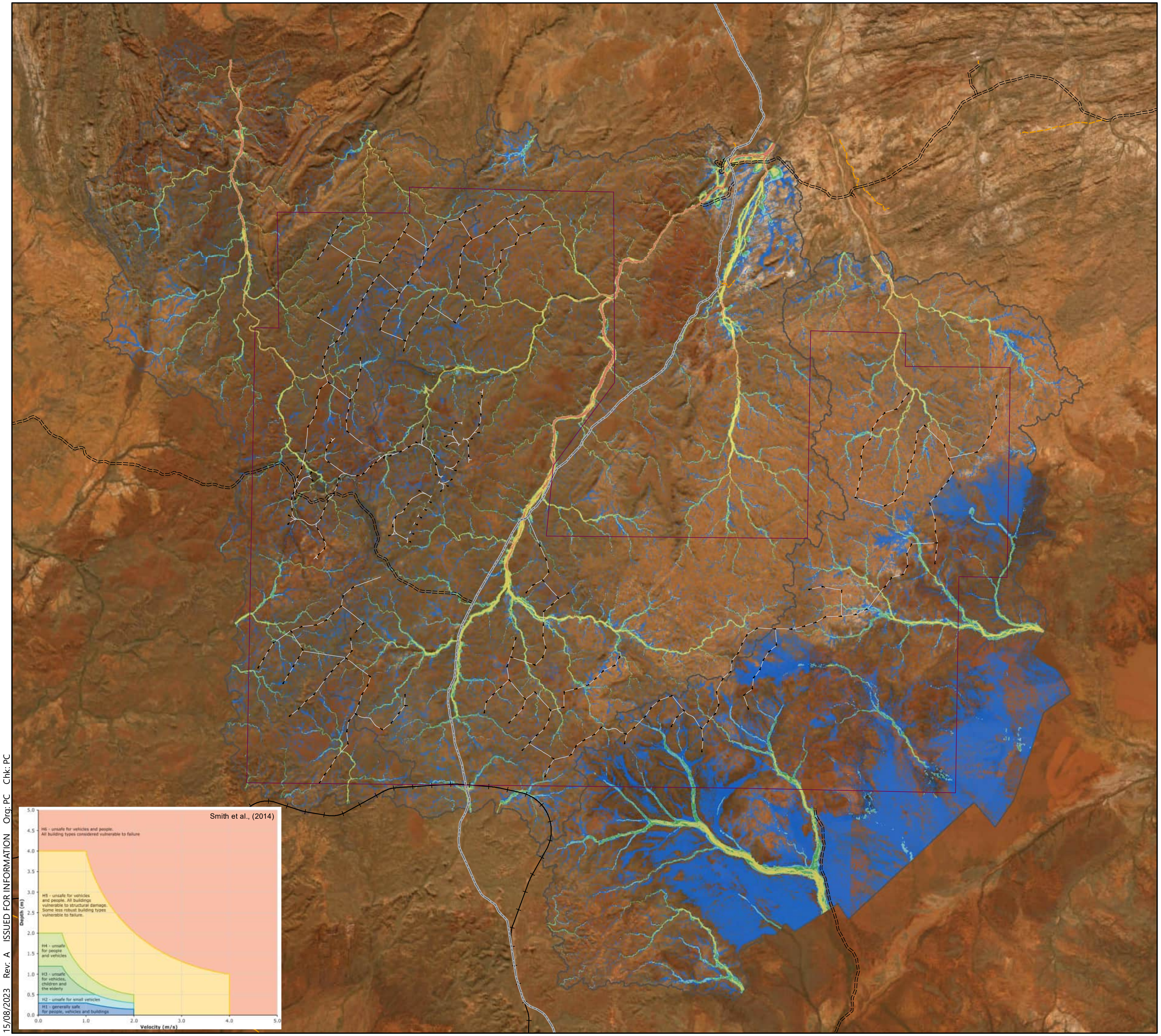
FIGURE 12
EXISTING CASE
5% AEP PEAK FLOOD
HAZARD VULNERABILITY CLASSIFICATION



Legend

- Study Area
- Proposed Wind Turbine Hardstand
- Proposed Tracks
- State Road
- Local Road
- Miscellaneous Road
- Rail Network
- Hydraulic Model Boundary

Peak Flood Hazard Vunerability Classification (Smith et al., 2014)

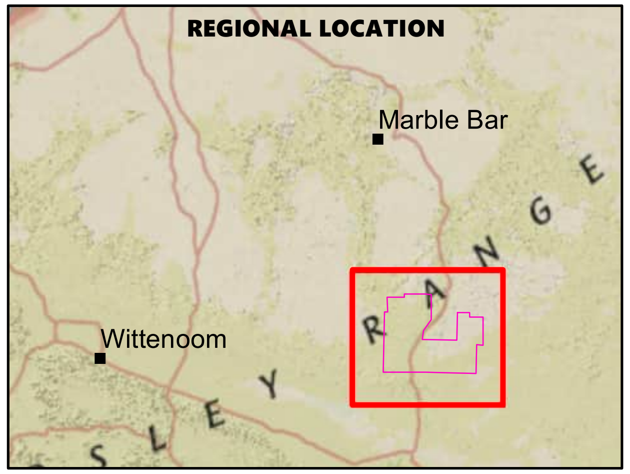
- H1
- H2
- H3
- H4
- H5
- H6

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

N

Scale at A3 - 1:250,000

0 5 10 15
Kilometers



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National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO,

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PILBARA DECARBONISATION PROJECT
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FIGURE 13

EXISTING CASE
20% AEP PEAK FLOOD DEPTH

Legend

- Study Area
- Proposed Wind Turbine Hardstand
- Proposed Tracks
- State Road
- Local Road
- Miscellaneous Road
- Rail Network
- Hydraulic Model Boundary

Peak Flood Depth (m)

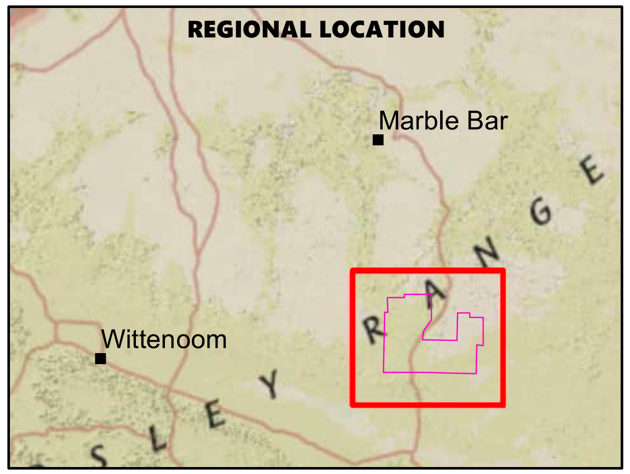
- <0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 3
- >3

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

N

Scale at A3 - 1:250,000

0 5 10 15
Kilometers



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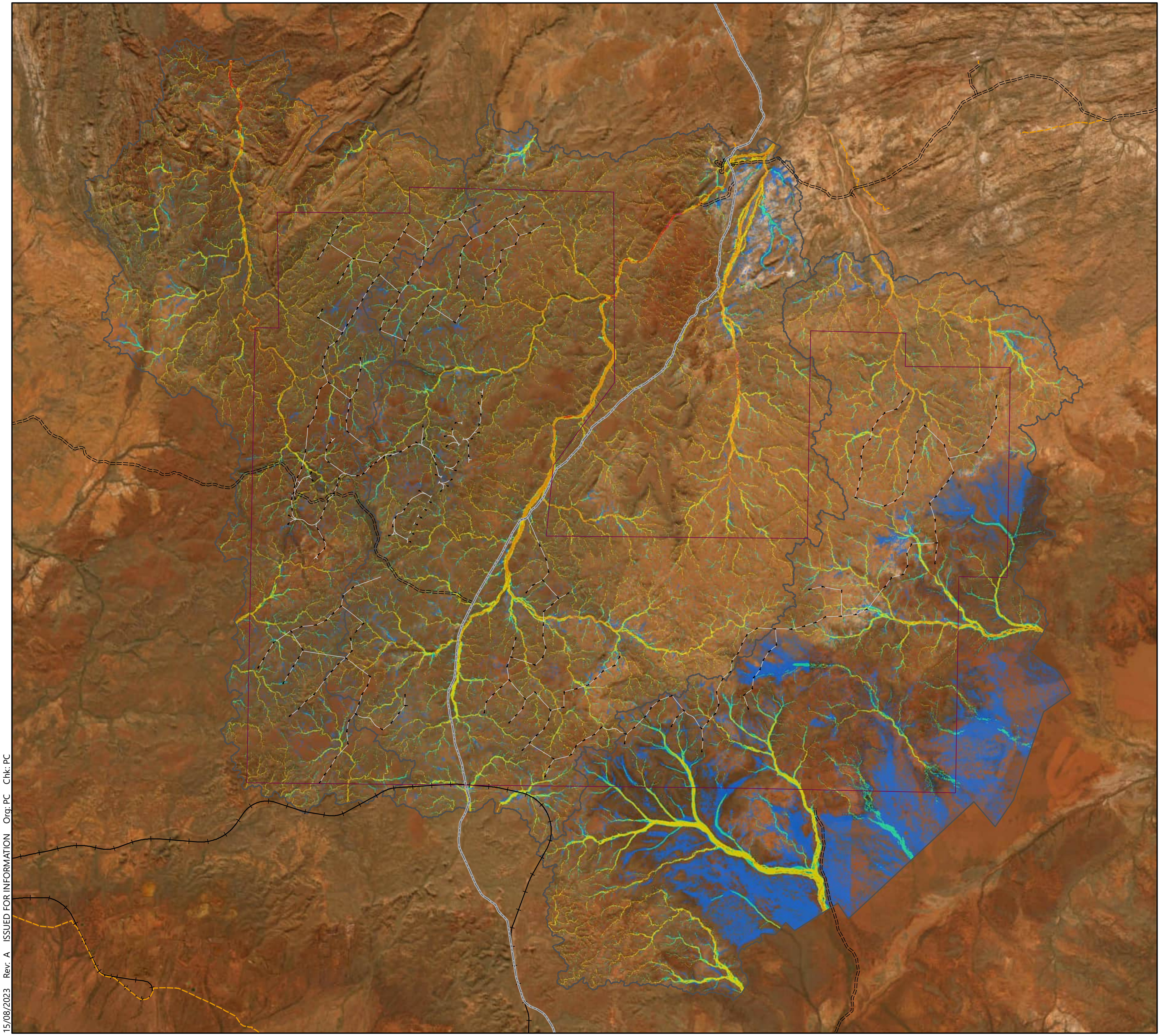

PILBARA DECARBONISATION PROJECT
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BASELINE HYDROLOGY STUDY

FIGURE 14

EXISTING CASE
20% AEP PEAK FLOOD VELOCITY

Legend

- Study Area
- Proposed Wind Turbine Hardstand
- Proposed Tracks
- State Road
- Local Road
- Miscellaneous Road
- Rail Network
- Hydraulic Model Boundary

Peak Flood Velocity (m/s)

- 0 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 3
- >3

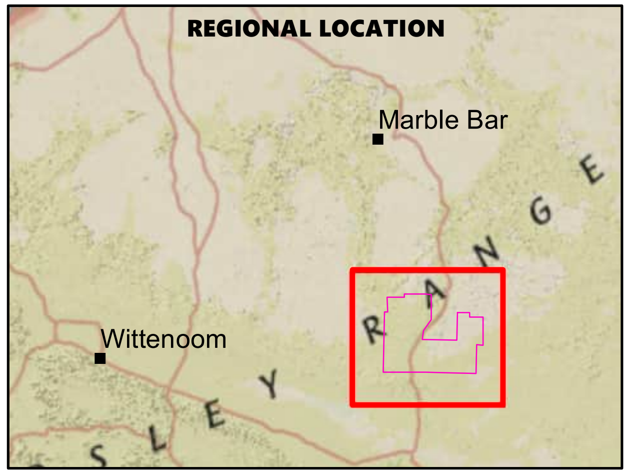
Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

N

Scale at A3 - 1:250,000

0 5 10 15

Kilometers



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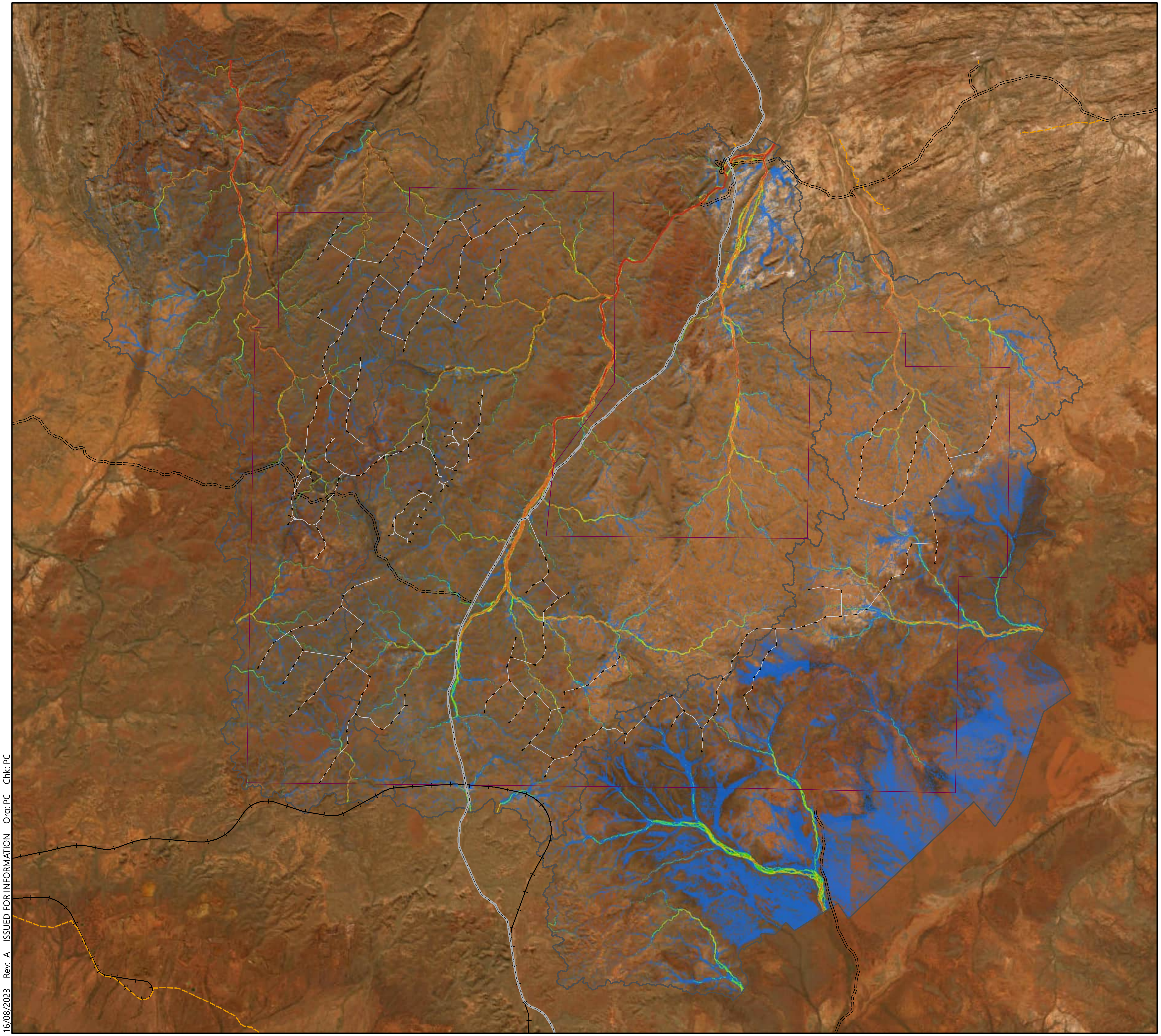
PILBARA DECARBONISATION PROJECT
BONNEY DOWNS
BASELINE HYDROLOGY STUDY

FIGURE 15
EXISTING CASE
20% AEP PEAK FLOOD
VELOCITY DEPTH PRODUCT



Legend

- Study Area
- Proposed Wind Turbine Hardstand
- Proposed Tracks
- State Road
- Local Road
- Miscellaneous Road
- Rail Network
- Hydraulic Model Boundary

Peak Flood Velocity Depth Product (m²/s)

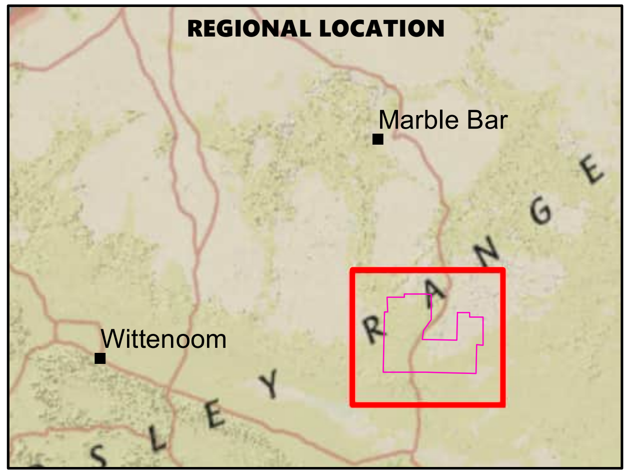
- 0 - 0.3
- 0.3 - 0.4
- 0.4 - 0.6
- 0.6 - 1
- 1 - 3
- >3

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

N

Scale at A3 - 1:250,000

0 5 10 15
Kilometers



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National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO,

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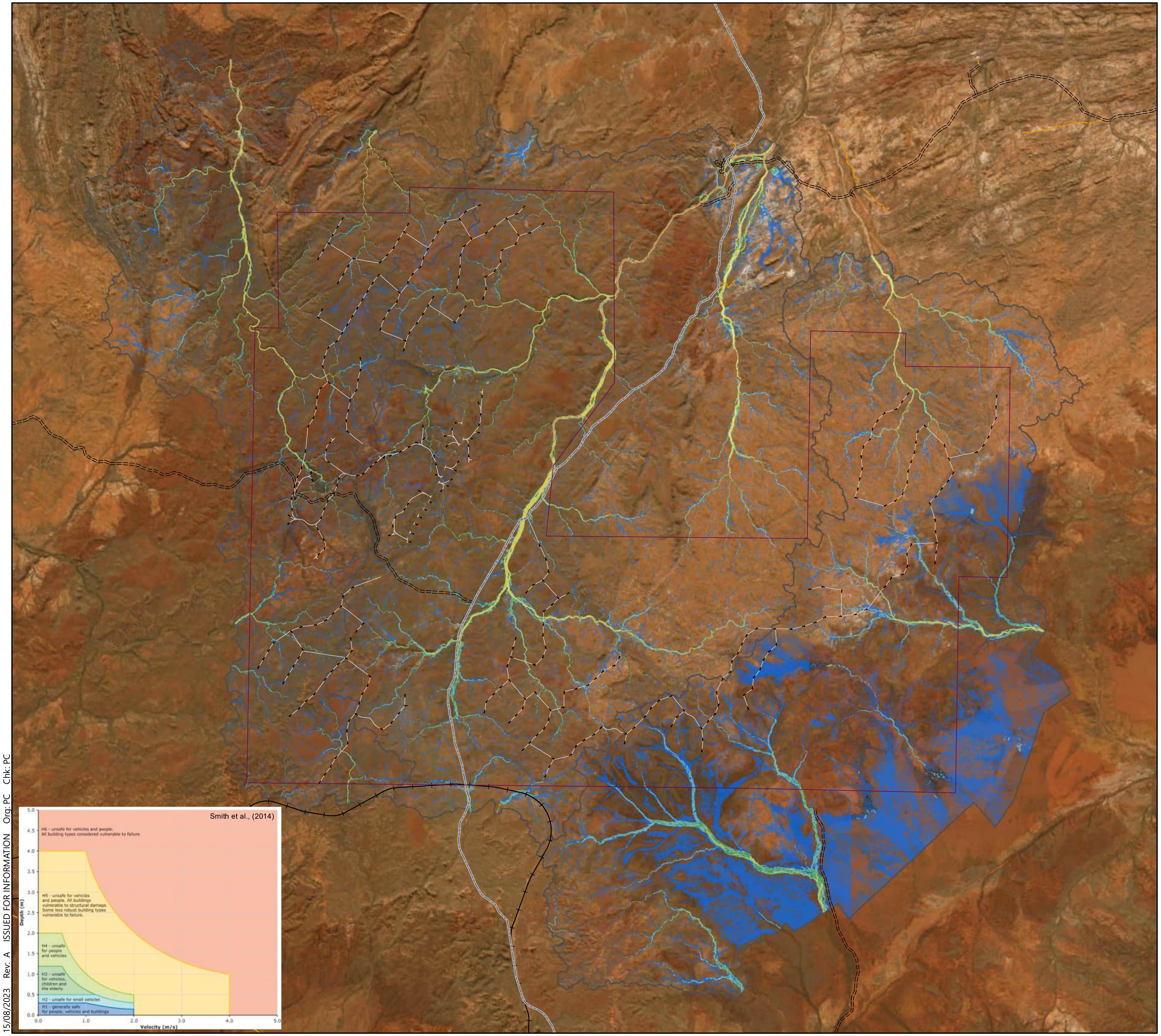
PILBARA DECARBONISATION PROJECT
BONNEY DOWNS
BASELINE HYDROLOGY STUDY

FIGURE 16
EXISTING CASE
20% AEP PEAK FLOOD
HAZARD VULNERABILITY CLASSIFICATION



Legend

- Study Area
- Proposed Wind Turbine Hardstand
- Proposed Tracks
- State Road
- Local Road
- Miscellaneous Road
- Rail Network
- Hydraulic Model Boundary

Peak Flood Hazard Vunerability Classification (Smith et al., 2014)

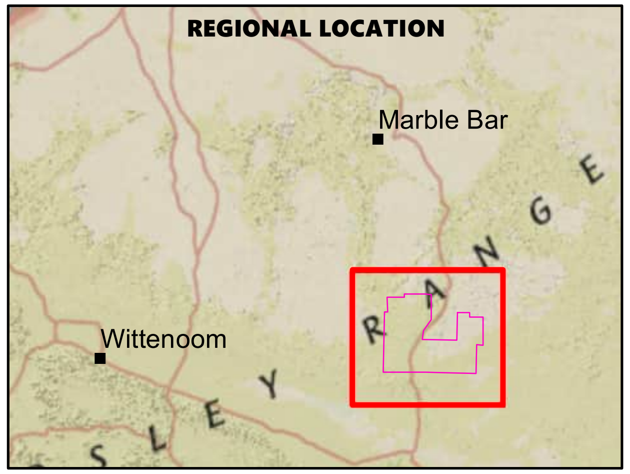
- H1
- H2
- H3
- H4
- H5
- H6

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

N

Scale at A3 - 1:250,000

0 5 10 15
Kilometers



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National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO,

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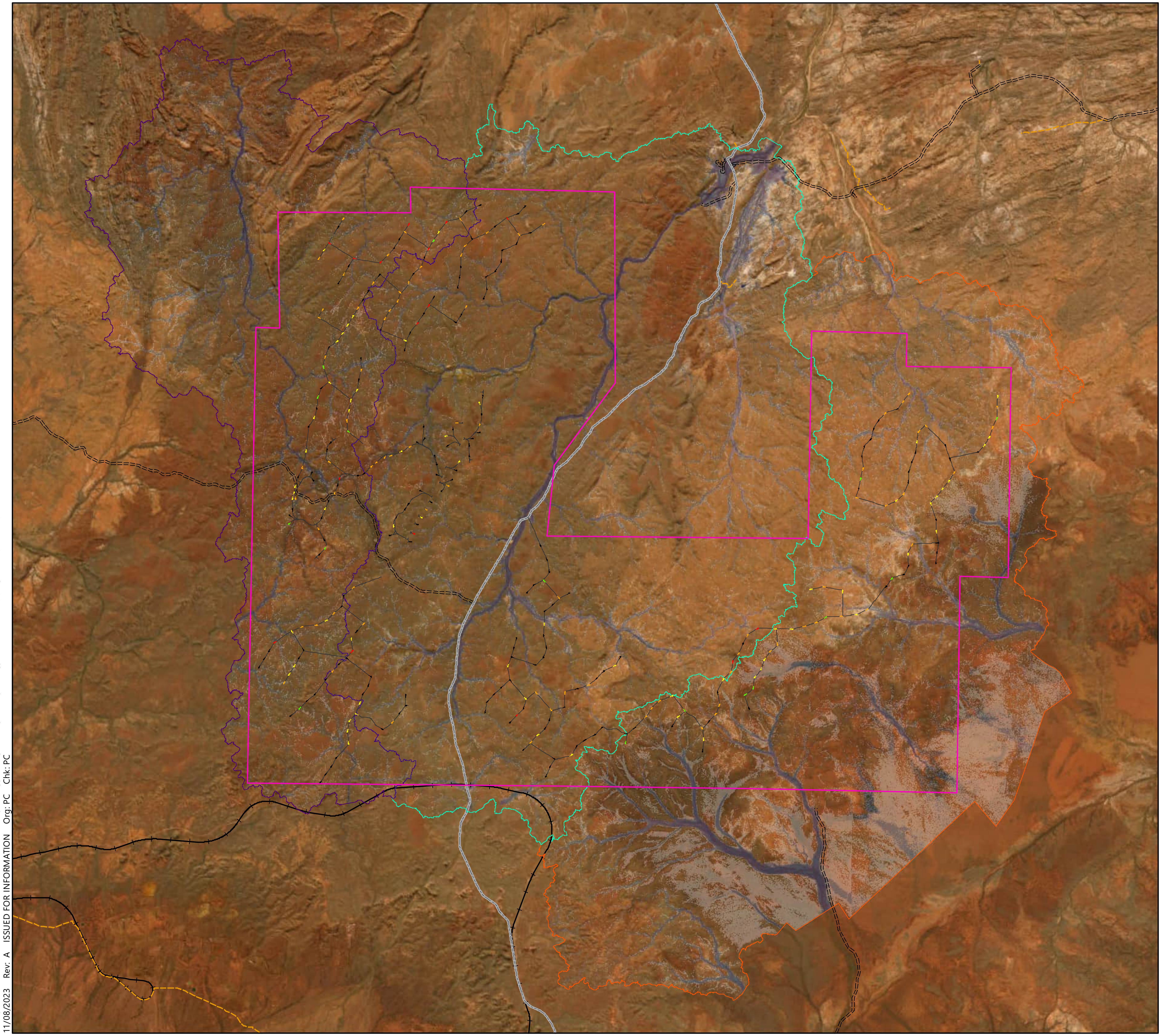
Appendix E
Inundated Proposed Turbine Locations



PILBARA DECARBONISATION PROJECT
BONNEY DOWNS
BASELINE HYDROLOGY STUDY

FIGURE 1
INUNDATED TURBINE LOCATIONS
1% AEP FLOOD

Legend

Estimated Hardstand Inundation Depth

- Nil
- > 0.1 m
- 0.1 m to 0.3 m
- 0.3 to 1 m
- > 1 m
- Study Area
- Proposed Tracks
- BD1 Model Extent
- BD2 Model Extent
- BD3 Model Extent
- State Road
- Local Road
- Miscellaneous Road
- Rail Network

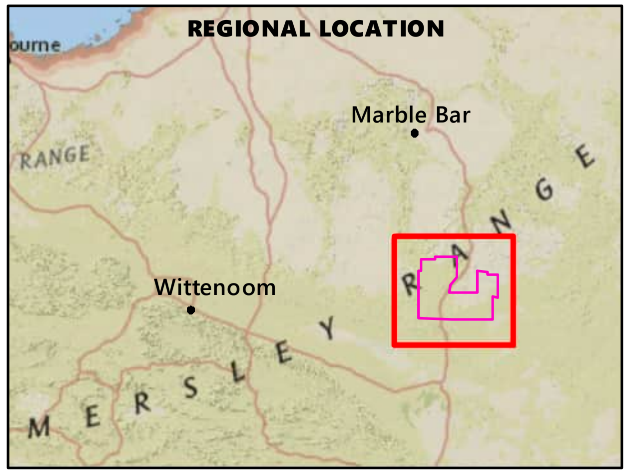
Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

N

Scale at A3 - 1:250,000

0 4 8 12 16

Kilometers



Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community
National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO,

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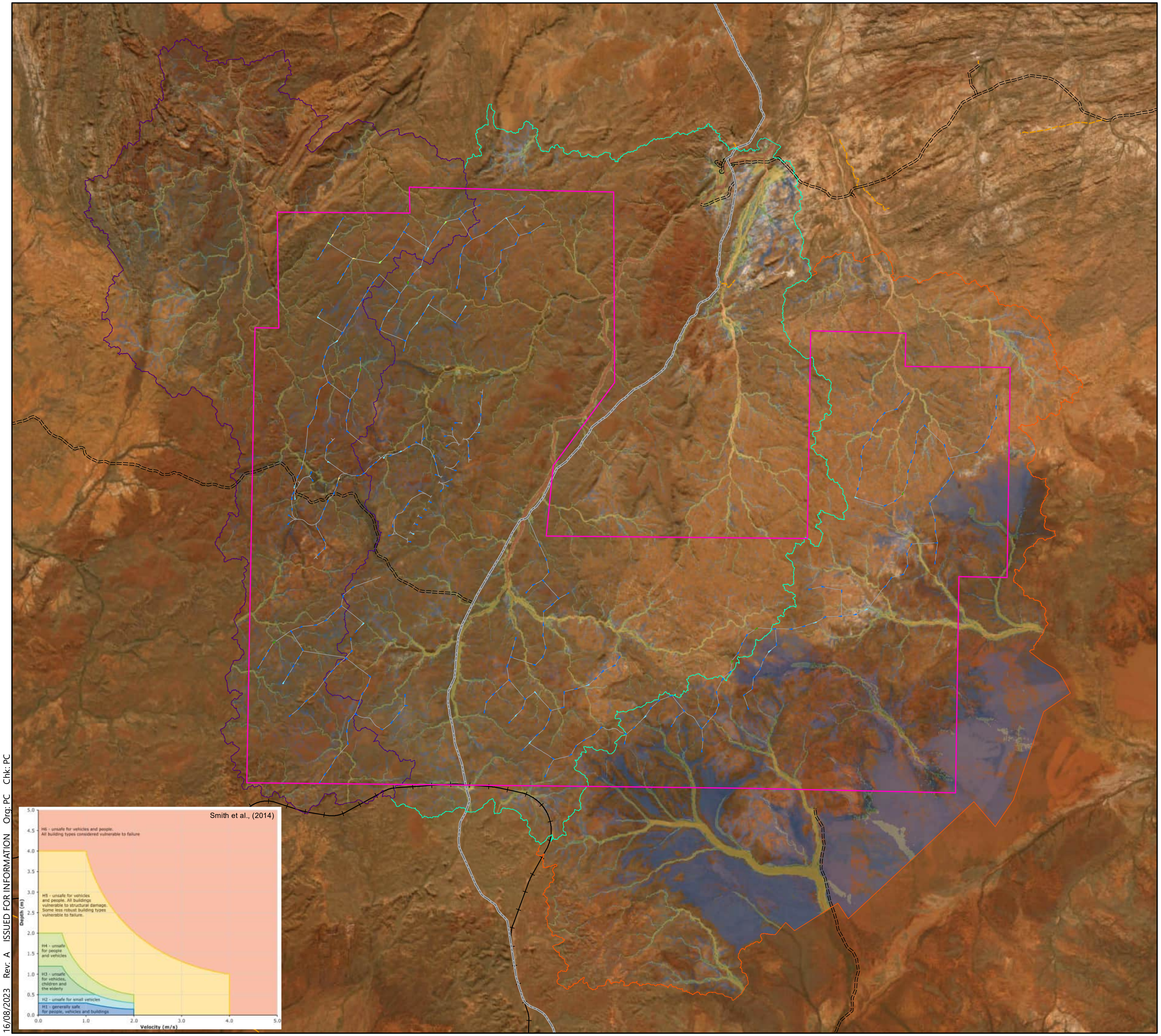
PILBARA DECARBONISATION PROJECT
BONNEY DOWNS
BASELINE HYDROLOGY STUDY

FIGURE 2
HAZARDOUS TURBINE LOCATIONS
1% AEP FLOOD HAZARD



Legend

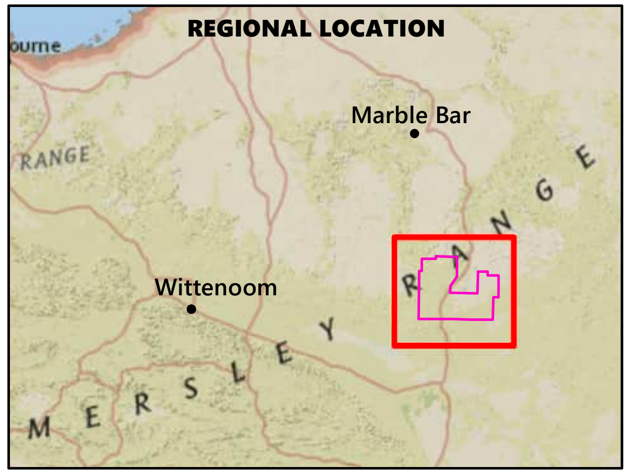
- Study Area
- **Estimated Hazard Classification (Smith et al., 2014)**
- H1
- H2
- H3
- H4
- H5
- H6
- Proposed Tracks
- BD1 Model Extent
- BD2 Model Extent
- BD3 Model Extent
- State Road
- Local Road
- Miscellaneous Road
- Rail Network

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

N

Scale at A3 - 1:250,000

0 4 8 12 16
Kilometers



Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community
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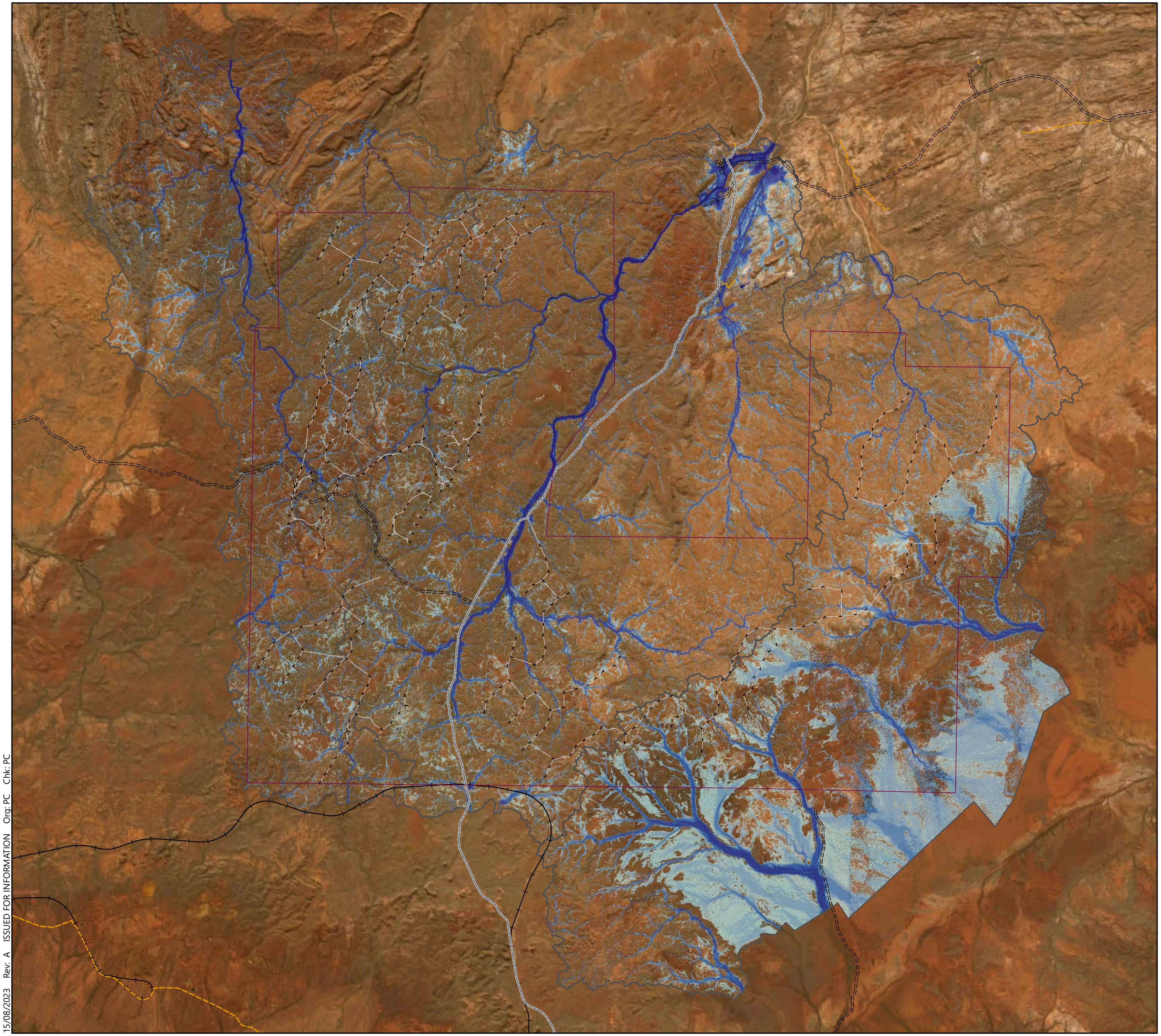
Appendix F
Climate Change Flood Mapping



PILBARA DECARBONISATION PROJECT
BONNEY DOWNS
BASELINE HYDROLOGY STUDY

FIGURE 1
EXISTING CASE
1% AEP 2050 RCP4.5
PEAK FLOOD DEPTH

Legend

- Study Area
- Proposed Wind Turbine Hardstand
- Proposed Tracks
- State Road
- Local Road
- Miscellaneous Road
- Rail Network
- Hydraulic Model Boundary

Peak Flood Depth (m)

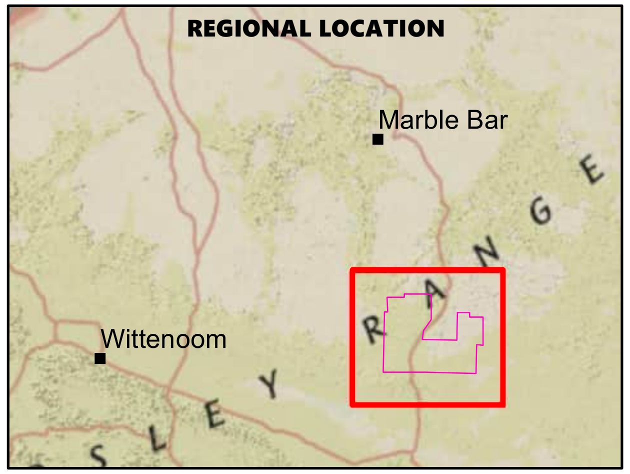
- <0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 3
- >3

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

N

Scale at A3 - 1:250,000

0 5 10 15
Kilometers



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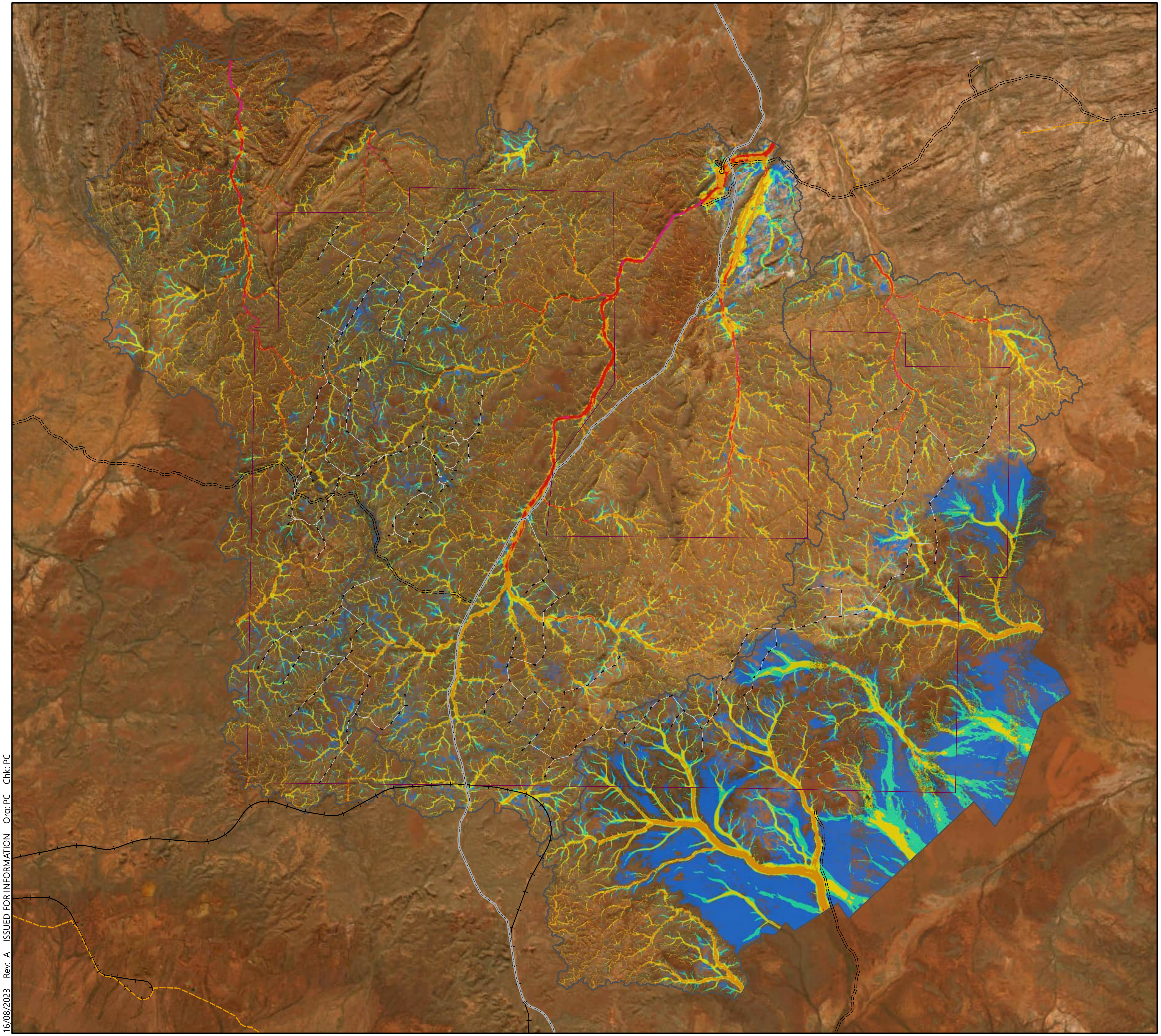


PILBARA DECARBONISATION PROJECT
BONNEY DOWNS
BASELINE HYDROLOGY STUDY

FIGURE 2
EXISTING CASE
1% AEP 2050 RCP4.5
PEAK FLOOD VELOCITY

Legend

- Study Area
- Proposed Wind Turbine Hardstand
- Proposed Tracks
- State Road
- Local Road
- Miscellaneous Road
- Rail Network
- Hydraulic Model Boundary

Peak Flood Velocity (m/s)

- 0 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 3
- >3

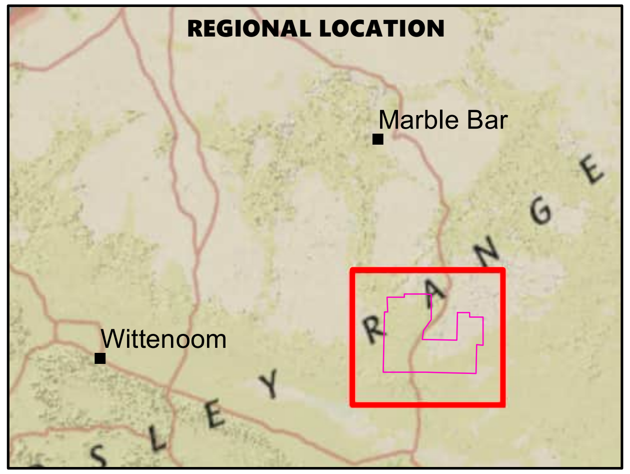
Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

N

Scale at A3 - 1:250,000

0 5 10 15
Kilometers

REGIONAL LOCATION



Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community
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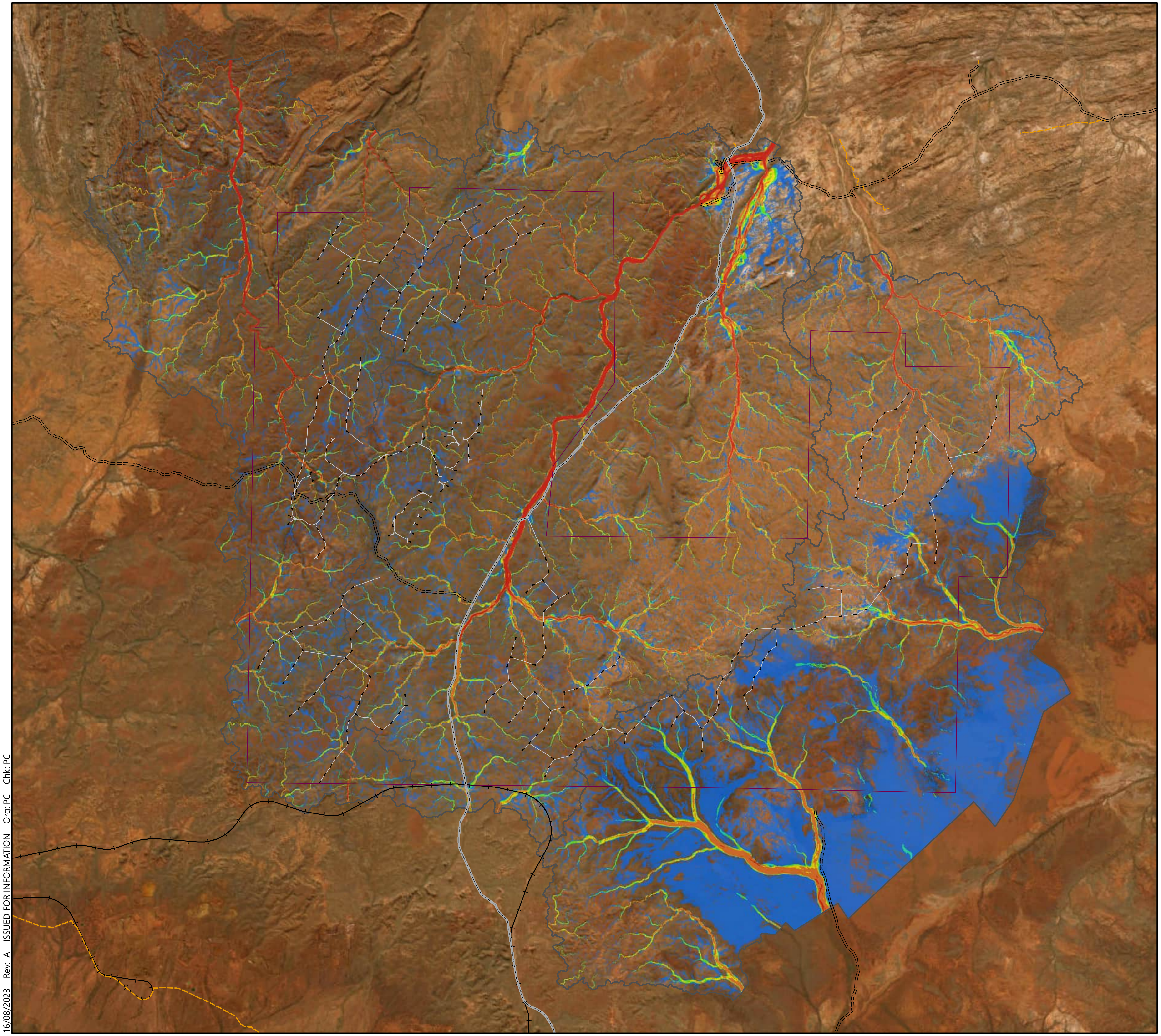


PILBARA DECARBONISATION PROJECT
BONNEY DOWNS
BASELINE HYDROLOGY STUDY

FIGURE 3
EXISTING CASE
1% AEP 2050 RCP4.5 PEAK FLOOD
VELOCITY DEPTH PRODUCT

Legend

- Study Area
- Proposed Wind Turbine Hardstand
- Proposed Tracks
- State Road
- Local Road
- Miscellaneous Road
- Rail Network
- Hydraulic Model Boundary

Peak Flood Velocity Depth Product (m²/s)

- 0 - 0.3
- 0.3 - 0.4
- 0.4 - 0.6
- 0.6 - 1
- 1 - 3
- >3

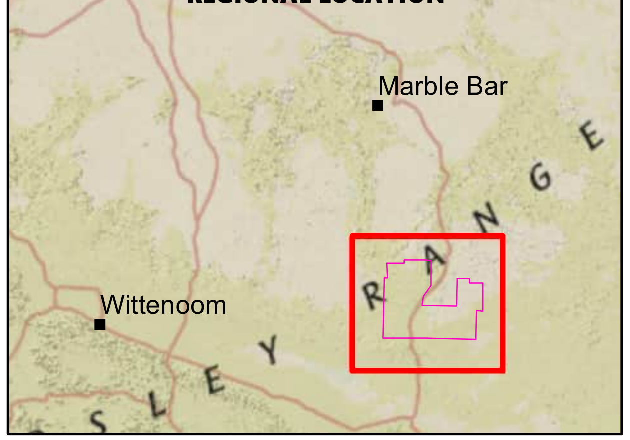
Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

N

Scale at A3 - 1:250,000

0 5 10 15
Kilometers

REGIONAL LOCATION



Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community
National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO,

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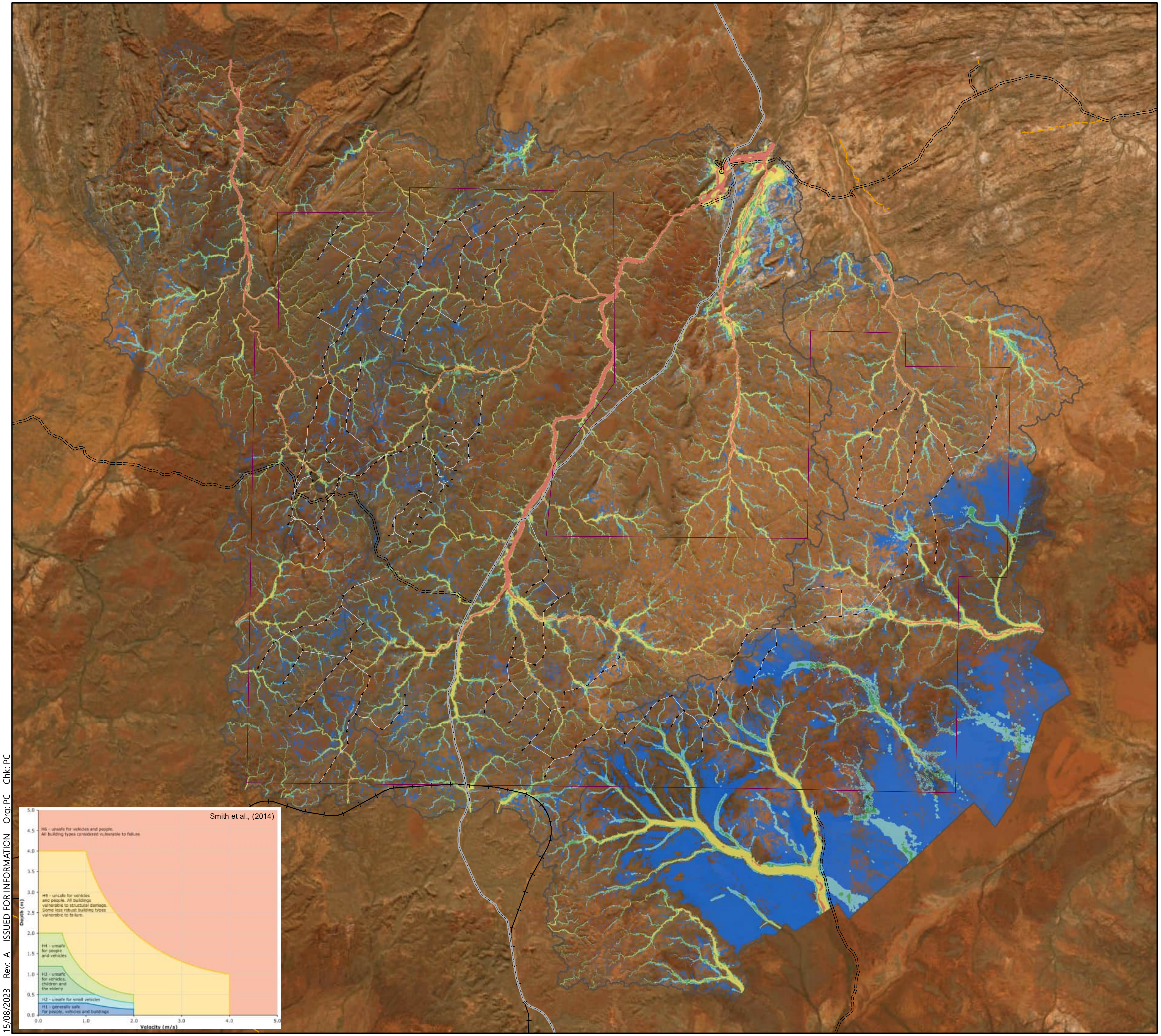
PILBARA DECARBONISATION PROJECT
BONNEY DOWNS
BASELINE HYDROLOGY STUDY

FIGURE 4
EXISTING CASE
1% AEP 2050 RCP4.5 PEAK FLOOD
HAZARD VULNERABILITY CLASSIFICATION



Legend

- Study Area
- Proposed Wind Turbine Hardstand
- Proposed Tracks
- State Road
- Local Road
- Miscellaneous Road
- Rail Network
- Hydraulic Model Boundary

Peak Flood Hazard Vunerability Classification (Smith et al., 2014)

- H1
- H2
- H3
- H4
- H5
- H6

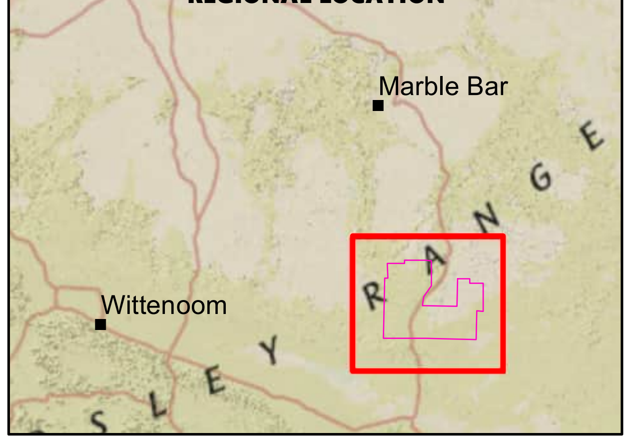
Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

N

Scale at A3 - 1:250,000

0 5 10 15
Kilometers

REGIONAL LOCATION



Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community
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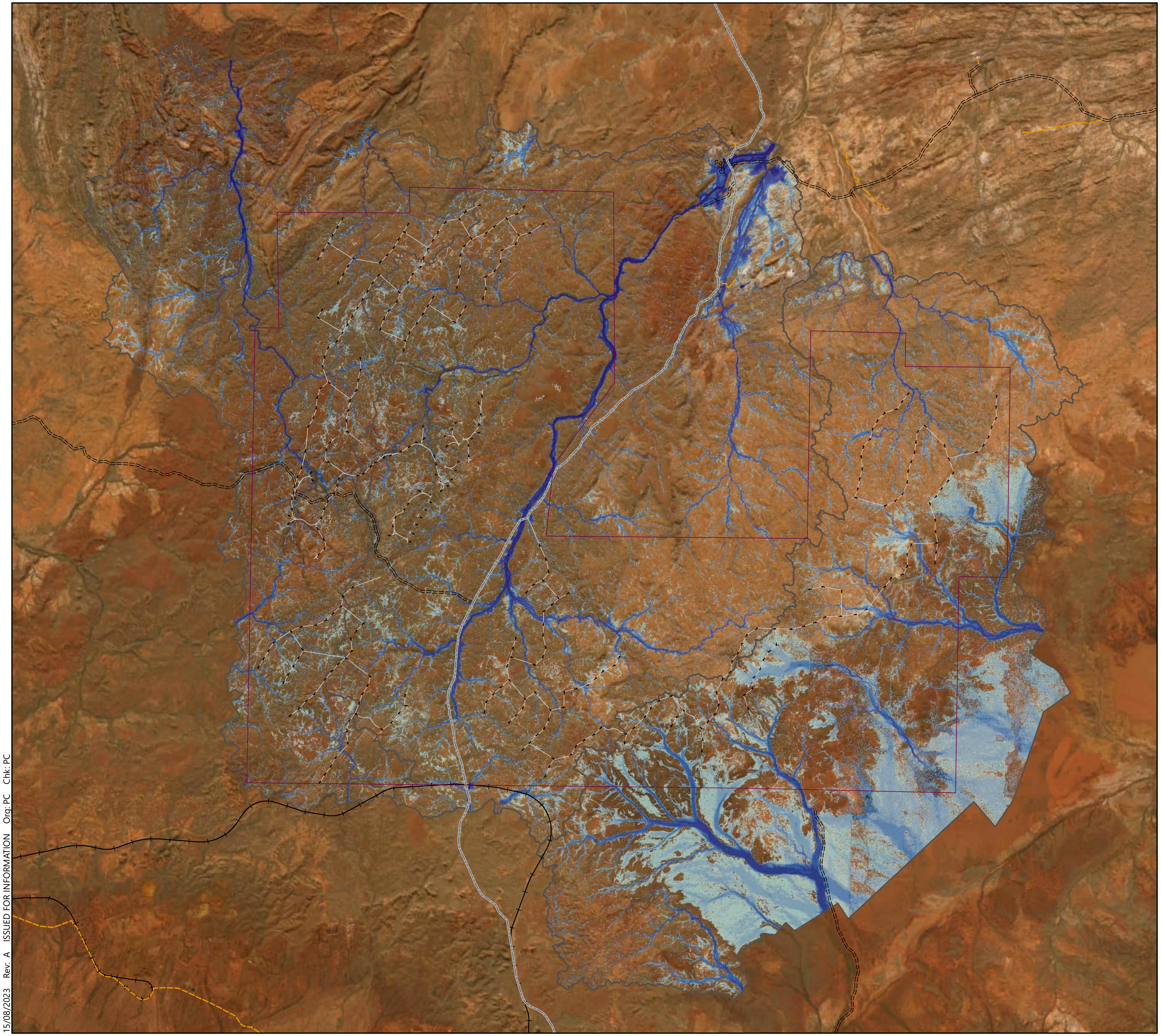


PILBARA DECARBONISATION PROJECT
BONNEY DOWNS
BASELINE HYDROLOGY STUDY

FIGURE 5
EXISTING CASE
1% AEP 2050 RCP8.5
PEAK FLOOD DEPTH

Legend

- Study Area
- Proposed Wind Turbine Hardstand
- Proposed Tracks
- State Road
- Local Road
- Miscellaneous Road
- Rail Network
- Hydraulic Model Boundary

Peak Flood Depth (m)

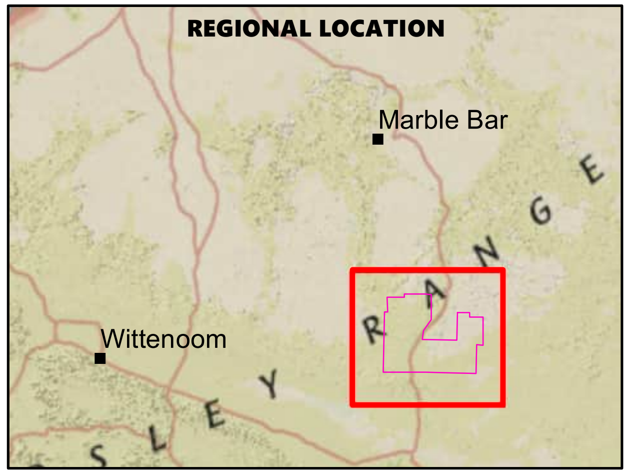
- <0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 3
- >3

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

N

Scale at A3 - 1:250,000

0 5 10 15
Kilometers



Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community
National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO,

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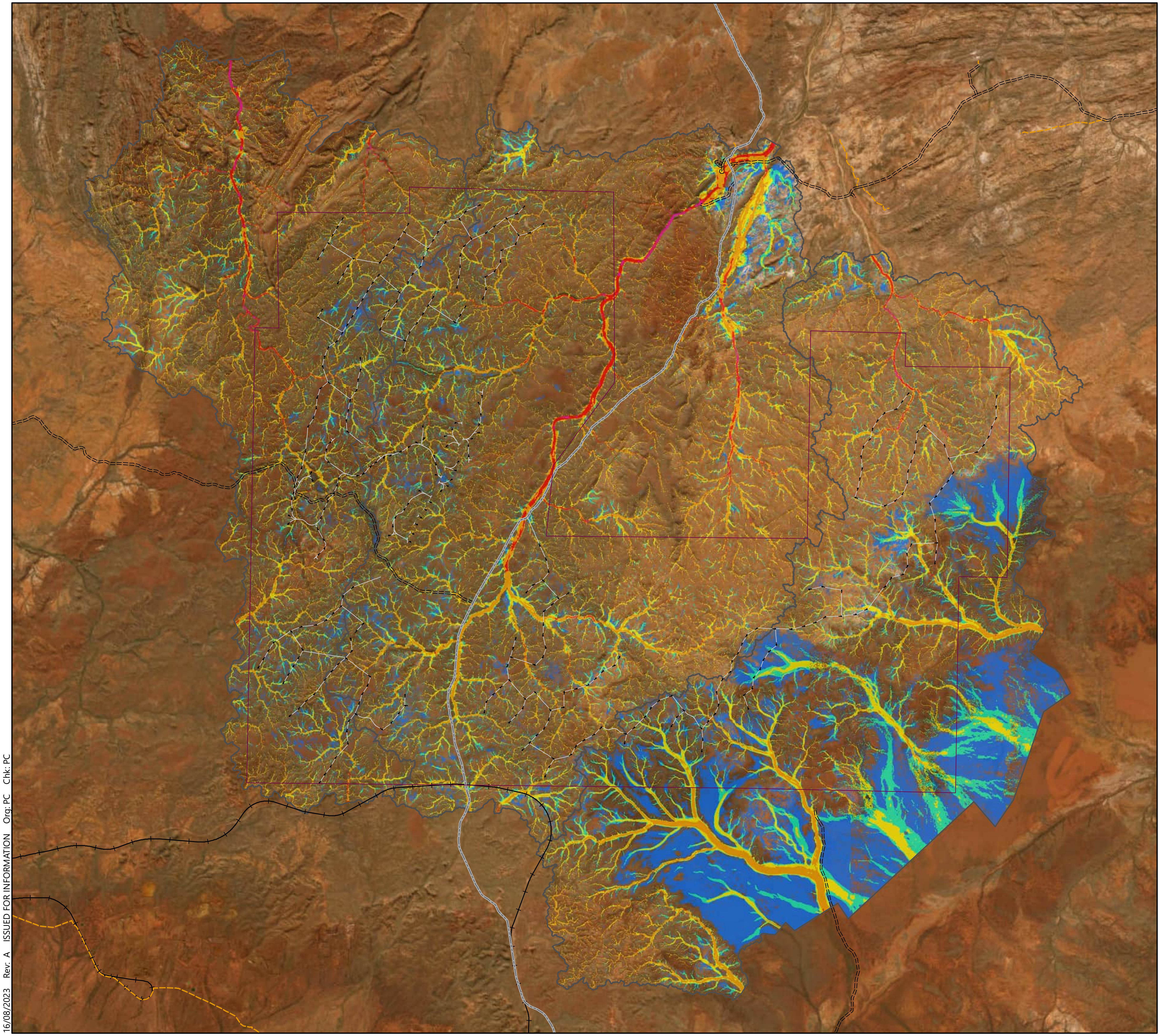
PILBARA DECARBONISATION PROJECT
BONNEY DOWNS
BASELINE HYDROLOGY STUDY

FIGURE 6
EXISTING CASE
1% AEP 2050 RCP8.5
PEAK FLOOD VELOCITY



Legend

- Study Area
- Proposed Wind Turbine Hardstand
- Proposed Tracks
- State Road
- Local Road
- Miscellaneous Road
- Rail Network
- Hydraulic Model Boundary

Peak Flood Velocity (m/s)

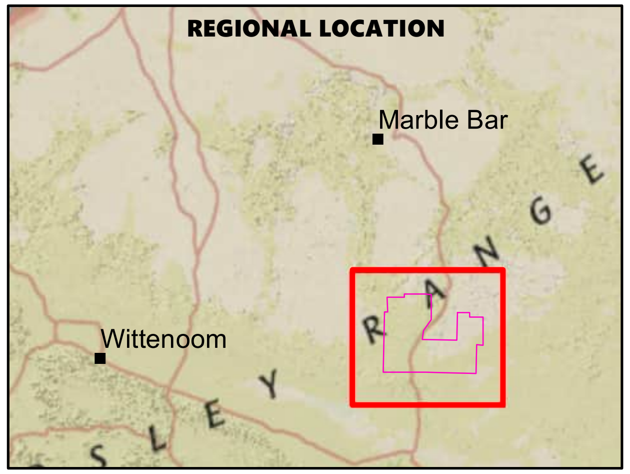
- 0 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 3
- >3

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

N

Scale at A3 - 1:250,000

0 5 10 15
Kilometers



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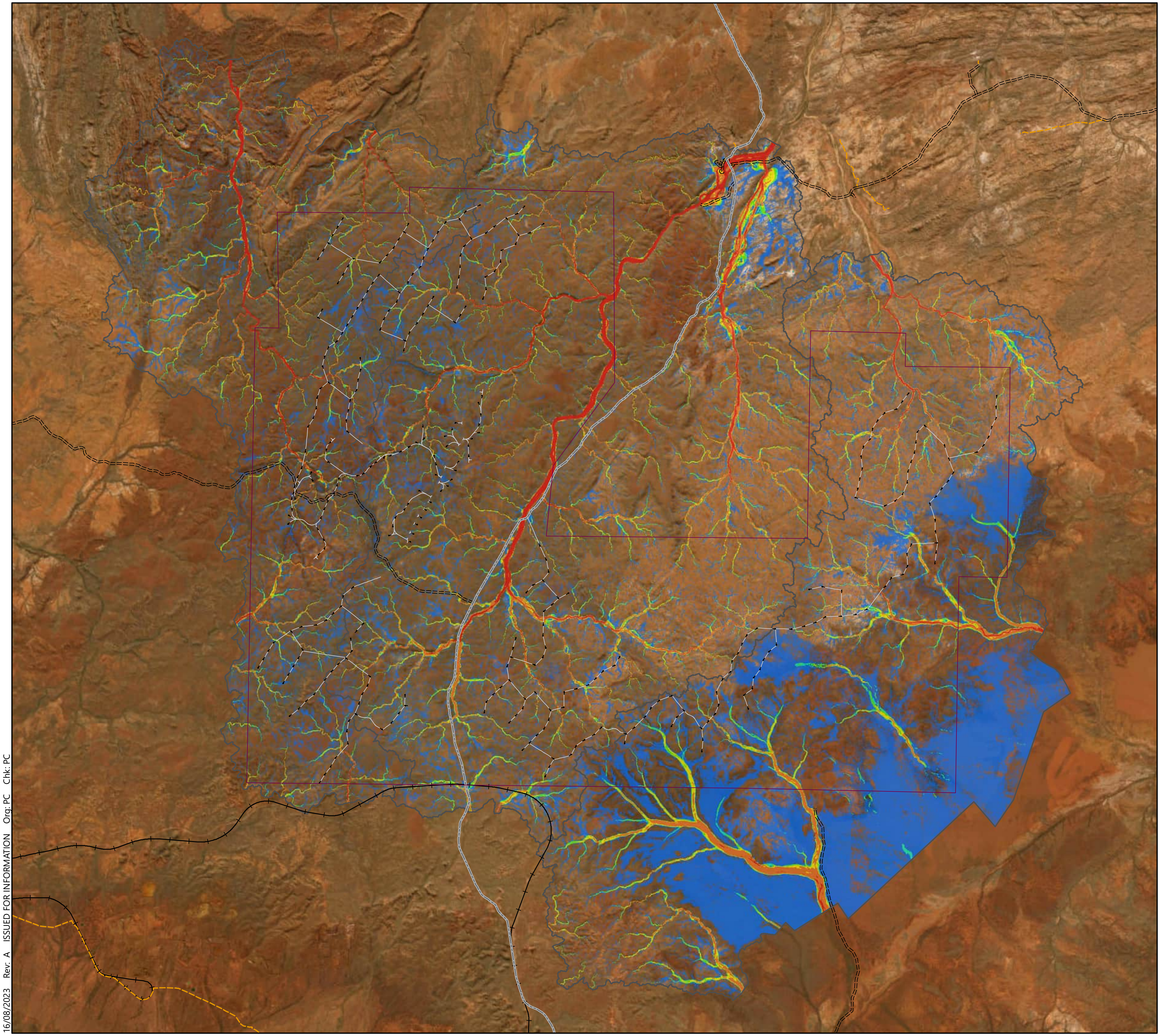


PILBARA DECARBONISATION PROJECT
BONNEY DOWNS
BASELINE HYDROLOGY STUDY

FIGURE 7
EXISTING CASE
1% AEP 2050 RCP8.5 PEAK FLOOD
VELOCITY DEPTH PRODUCT

Legend

- Study Area
- Proposed Wind Turbine Hardstand
- Proposed Tracks
- State Road
- Local Road
- Miscellaneous Road
- Rail Network
- Hydraulic Model Boundary

Peak Flood Velocity Depth Product (m²/s)

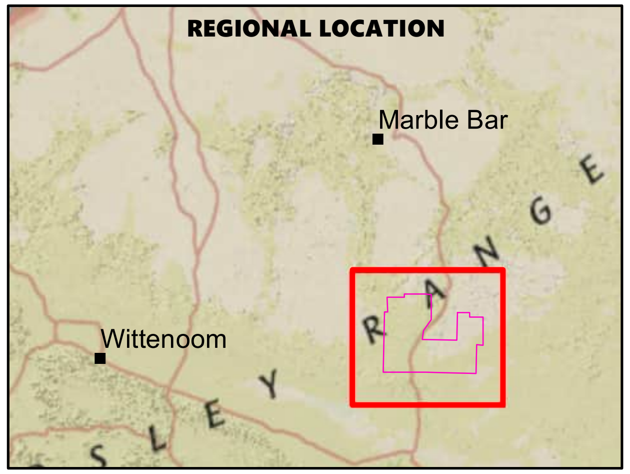
- 0 - 0.3
- 0.3 - 0.4
- 0.4 - 0.6
- 0.6 - 1
- 1 - 3
- >3

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

N

Scale at A3 - 1:250,000

0 5 10 15
Kilometers



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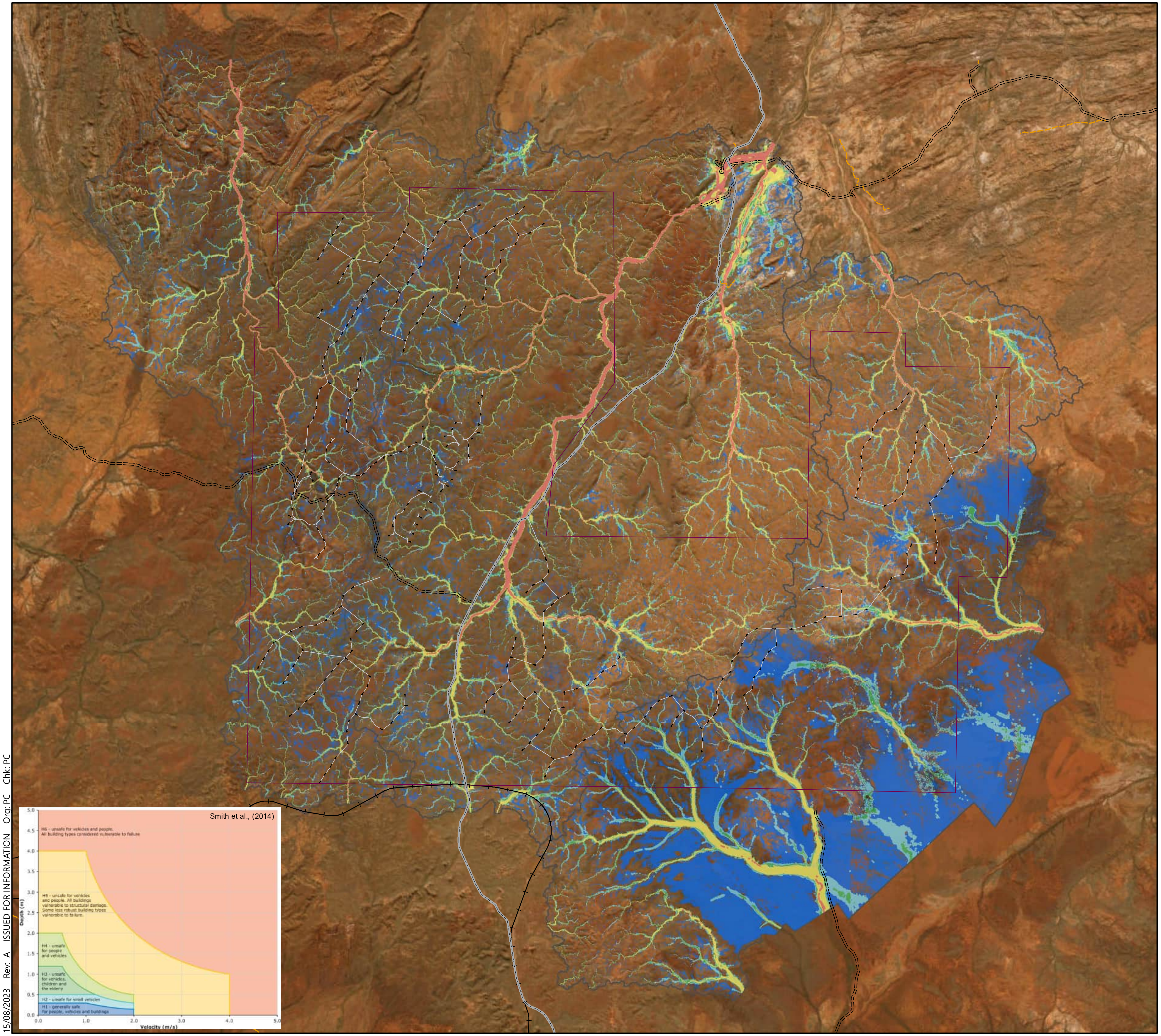
PILBARA DECARBONISATION PROJECT
BONNEY DOWNS
BASELINE HYDROLOGY STUDY

FIGURE 8
EXISTING CASE
1% AEP 2050 RCP8.5 PEAK FLOOD
HAZARD VUNERABILITY CLASSIFICATION



Legend

- Study Area
- Proposed Wind Turbine Hardstand
- Proposed Tracks
- State Road
- Local Road
- Miscellaneous Road
- Rail Network
- Hydraulic Model Boundary

Peak Flood Hazard Vunerability Classification (Smith et al., 2014)

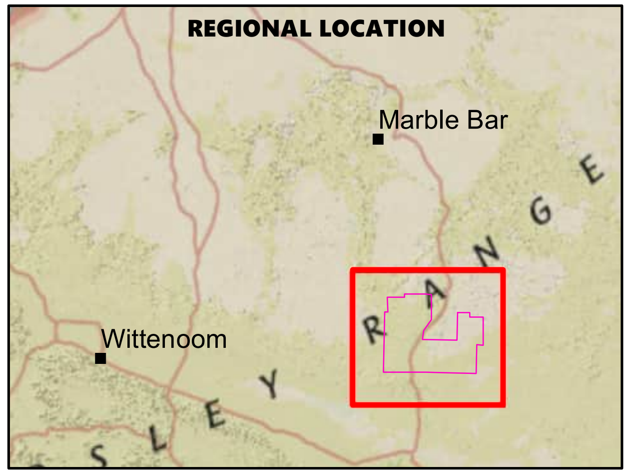
- H1
- H2
- H3
- H4
- H5
- H6

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
False Easting: 500,000.0000

N

Scale at A3 - 1:250,000

0 5 10 15
Kilometers



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