Report

Surface Water Impact Assessment

Eliwana Rail Project

June 2018

750ES-3100-AS-HY-0002

	Surface Water Impact Assessment		
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TABLE OF CONTENTS

List of Tables

List of Graphs

No table of figures entries found.

List of Plates

No table of figures entries found.

List of Schematic Maps

No table of figures entries found.

List of Examples

No table of figures entries found.

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ATTACHMENTS

No table of figures entries found.

1. INTRODUCTION

This report provides an overview of the hydrologic regime and catchment context for the Proposed Eliwana rail project. It also describes the potential impacts to surface water as a result of the proposed action and contains a summary of associated hydrologic and hydraulic modelling.

2. CATCHMENT & HYDROLOGIC REGIME CHARACTERISATION

The Eliwana rail project spans the Lower Fortescue River and Ashburton River basins, with the majority of rail infrastructure located within the Ashburton basin (as shown in Figure 1). Within these basins, the rail traverses the Weelumurra Creek subcatchment and a small portion of the Zalamea Creek subcatchment of the Lower Fortescue River and the Duck Creek subcatchment of the Ashburton River. The catchment areas of these basins and associated named subcatchments are summarised in Table 1 and described in more detail below.

Table 1: Eliwana Subcatchment Areas

Catchment	Area (sq. km)
Lower Fortescue River Basin	**18 607**
Zalamea Creek (upstream of Alluvial Fan))	86
Weelumurra Creek (at confluence with Fortescue River)	2290
Weelumurra Creek (at downstream end of Weelumurra Plain)	*1220*
Ashburton River Basin	**78 777**
Duck Creek (at confluence with Ashburton)	6800
Duck Creek (at Confluence with Boolgeeda Creek)	*3692*
Boolgeeda Creek	*1658*
Caves Creek	*1535*
Barnett Creek	*520*
Wackilina Creek	*210*

2.1 Catchment Descriptions

2.1.1 Zalamea Creek

The Eliwana rail starts within the upper reaches of the Zalamea Creek catchment, where the rail transitions from the Frederick section of Fortescue's Solomon project area. The Zalamea catchment is characterised by deeply incised channels flowing to a main channel, which forms a gorge that drains in a north easterly direction prior to discharging via an alluvial fan into the Southern Branch of the Lower Fortescue River. A segment of the catchment divide between the Kangeenarina Creek and Zalamea Creek at the top of the Solomon Kings deposit is poorly defined and flow paths in this area are not distinct (and now disturbed by Solomon mining). Zalamea Creek has a catchment area of 86 km^2. Further information on the hydrology of Zalamea Creek can be located in the *Solomon Life of Mine Surface Water Strategy*, which was appended to the *Solomon Sustaining Production PER*.

2.1.2 Weelumurra Creek

The Weelumurra Creek catchment exhibits a significant degree of variability across the catchment. The upper reaches consist of steep hillslopes with a well-defined stream network, however the floodplain of Weelumurra Creek is very flat with broad shallow channels and many anabranches. The eastern branch of Weelumurra Creek shares a floodplain with the Fortescue River South Branch. During flood events the two systems combine for a 14 km stretch of floodplain before splitting into separate branches. Further down the catchment to the north, the Weelumurra Creek disperses into a large area of low relief terrain (due north of Tom Price). This area exhibits a number of small, discontinuous drainage channels and other areas with undefined channels and flow direction, known informally as Weelumurra plain. Immediately north of the Weelumurra plain the channel becomes deeply incised and increases in size dramatically as it flows north. This section north of the rail contains a series of pools and receives inflow from a number numerous subcatchments as it flows north towards the confluence with the Lower Fortescue River.

The Eliwana rail crosses the Weelumurra Creek at the northern, downstream end of Weelumurra Plain just prior to the creek forming a defined channel again. The Weelumurra Creek catchment is approximately 1,220 km^2 upstream of the crossing location at the downstream end of the Weelumurra Plain. The Weelumurra Creek eventually flows into the Fortescue River, with a catchment area upstream of the confluence of 2,290 km^2, as summarised in Table 1 and shown in Figure 2.

At the western extent of the Weelumurra Plain, the Caves Creek floodplain also interacts with Weelumurra Creek. This section of low relief terrain is intersected by the Rio rail embankment, which includes a series of culverts to convey floodplain flows.

2.1.3 Duck Creek (including Caves Creek)

The Duck Creek catchment area is approximately 6,800 km^2 at the confluence with the Ashburton River. Major tributaries of Duck Creek include Boolgeeda Creek and Caves Creek (Figure 2), with Barnett Creek and Wackilina Creek forming the upper section of Caves Creek. Catchment areas for Duck Creek and Boolgeeda Creek are summarised in Table 1. The proposed railway is located in the upper section of Duck Creek.

The Duck Creek catchment includes a variety of physiographic types. In the eastern parts of the catchment, the upper sections of Caves Creek includes part of the Weelumurra Palin and other low relief terrain areas north of Tom Price, where banded vegetation types indicative of sheetflow and flat cracking clay grasslands are common. In the central Duck Creek catchment, the terrain becomes more undulating and channels more confined, with gorges formed in many areas. Pools are common along Duck Creek in this area suggesting regular outcropping of bedrock. The confluence of Duck Creek and Ashburton River is beyond the western extent of Hamersley range where low relief terrain dominates.

2.2 Rail Catchment Area

The Eliwana rail starts within the upper reaches of the Zalamea Creek catchment at the boundary of the Frederick section of the Solomon project. The rail then runs west through the foothills on the north-eastern boundary of the Weelumurra Creek catchment before heading south west across the Weelumurra Plains, crossing the low relief terrain area with poorly defined channels, before entering the Caves Creek catchment.

The rail crosses Caves Creek as it comes off the plain and the channel starts to gain more definition. In this area the Caves Creek channel is still relatively small, but with a large, well vegetated floodplain area above the main channel. The rail runs south west across a number of smaller tributaries of the Caves Creek catchment, before turning due west and entering the top of the Duck Creek catchment.

This upper part of Duck Creek catchment has small but relatively well defined channels that increase in size as tributaries converge and flow west. After crossing the upper part of the Duck Creek channel just upstream of the Rio Tinto road crossing, the rail turns south west and traverses numerous tributaries of Duck creek for the remainder of the alignment. Catchments related to the rail are shown in Figure 2.

2.3 Pilbara Catchment Response

Pilbara creeks are typically ephemeral, and with the exception of pools and groundwater fed springs, are dry for the majority of the year. Pilbara soils typically have high initial infiltration rates for dry catchment conditions, i.e. when the antecedent moisture content of the soils is low. Significant streamflow usually occurs when antecedent moisture content of the soils is high, which is caused by significant rainfall in the days or weeks preceding a storm event. There are typically two different types of climatic events which cause flood response in the Pilbara, namely: Cyclonic activity/Tropical Low Pressure Systems and localised diurnal thunderstorms.

Cyclonic activity can result in severe and widespread flooding generally on a river catchment scale; this flooding activity can be forecast in advance (albeit with significant uncertainty). This type of flooding typically produces large peak flows and may result in damage to infrastructure due to magnitude of flows and total volume of water. However, not all cyclones will result in severe flooding.

Isolated thunderstorms have the potential to create fast and localised flooding, referred to as flash flooding. These events are much harder to predict as they can occur in the upper reaches of catchments. These events generally have a lower potential for widespread damage as the extent and magnitude of flooding is much smaller than cyclonic events.

2.4 Monitoring

There are several active Department of Water and Environmental Regulation (DWER) stream gauging stations on the Ashburton River, but only one (Nanutarra - 706003) located downstream of the Eliwana project area (refer Figure 1). Despite the high quality data and long record available at the gauge, the contributing area is 71,387 km^2, significantly larger than the catchment areas of the Eliwana rail project. Similarly, there is an active stream gauging station located on the Lower Fortescue River at Gregory Gorge (708002), also with high quality data and long record, however this gauge has a catchment area of 14,629 km^2, which is also significantly larger than those upstream of the Eliwana rail.

The physiographic characteristics of the catchments within the project area are also different to the characteristics of the catchments of the DWER gauges. This results in these DWER gauges not being suitability representative of the flood response of the smaller subcatchments that are crossed by the railway, as such catchment attributes that can be derived through analysis of the gauge data are not relevant to the Eliwana project area.

3. WATER QUALITY AND MONITORING

3.1 Regional Water Quality Review

Water samples in the Ashburton and Lower Fortescue catchments from the DWER's *Water Information Reporting* database have been analysed and compared against available Pilbara wide surface water quality data.

The DWER data was used to illustrate the potential range of variation that could be expected under event conditions. Available data from the DWER dataset has been presented in Table 2 and includes the range across all Pilbara watercourses as well as the range within the Ashburton and Lower Fortescue River basins.

Table 2: Surface Water Quality Data

	Pilbara Wide (DWER)		Ashburton		Lower Fortescue River (DWER)	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
pH (pH units)	5.2	9.4	6.7	8.8	6	9.2
EC (µS/cm)	3	6090	83	6090	3	4600
Turbidity (NTU)	0.1	3200	0.5	3200	0.1	1460
Alkalinity (mg/L)	3.6	420	35	274	6.5	358
TDS (mg/L)	22	3932	70	2618	22	3350
Nitrate as N (mg/L)	0.05	32	1	3	1	4
Hardness (mg/L)	3.6	1538	48.9	1539	6.8	1050
Dissolved Silica (mg/L)	1	68	7.7	22	1	51

The ephemeral creeks of the Pilbara typically have high bed loads in their natural state with many instances of significant erosion on existing stream banks and notable areas of instability in the natural environment. This demonstrates that erosion is a naturally occurring process in Pilbara watercourses, which is reflected by the range of Turbidity values in the DWER water quality data. This range of conditions is illustrated visually in Figure 3 with examples at Hamersley Gorge (Southern Fortescue River) and Weeli Wolli Creek. These photos are not intended for direct comparison as they show slightly different locations, but rather are provided to illustrate different scenarios that have been observed in the same reach of Weeli Wolli Creek (in the vicinity of Waterloo Bore gauging station), and in the same reach of the Southern Fortescue River at different times.

The photos provide a contrast between flooding conditions where flows are wide (bank full) and fast (as can be seen from wake of trees) with an opaque, red colouring due to highly turbid flows, with conditions after flooding has receded where water levels and velocities are lower, and the water is translucent with moderate-low turbidity.

3.2 Proposed Monitoring

Currently there is no monitoring of the rail catchments within the Ashburton catchment due to a lack of suitable access. To supplement regional water quality data, Fortescue will implement a monitoring program to develop a water quality baseline when suitable ground access has been established to the sites of interest, as the creeks cannot be access safely to install and collect monitoring data until this time.

Fortescue will draw upon demonstrated experience in monitoring along its existing rail network, as documented in Surface Water Quality Summary Report – July 2017 Rail Operations (R-RP-EN-1104) (Fortescue 2017), which demonstrates ability to develop baseline data and suggests there are no impacts to surface water quality from operation of the existing railway. This experience will be used to develop a monitoring program for the proposed Eliwana railway to develop a water quality baseline. Due to the difficulties associated with sampling unpredictable ephemeral watercourse, water sampling will be collected using passive sampling equipment, which allows for collection of samples during events from otherwise inaccessible locations, as described below from (Fortescue 2017):

Water quality samples are collected during flow events via stormwater samplers, which are fitted with sampling bottles that are located within purpose fabricated housing, and seal automatically once filled. Usually, after significant rainfall events that result in stream flows, access roads are flooded and closed to traffic. Therefore samples are often not collected until several days or even weeks after the actual rainfall/ streamflow event. This results in an exceedance in some of the holding times for the analysis of the samples, which cannot be avoided.

A sampling program will be implemented prior to the commencement of the 2018 wet season (i.e. December 2018), for sites that are accessible and where Fortescue have appropriate authorisation to install monitoring equipment. The sites will be selected based on locations that are suitable and representative, with consideration of the proposed railway design. It is noted that the program may be limited in its initial extent due to the minimal number of locations where Fortescue can safely access and have authorisation to install equipment. Consequently, the program may be expanded as necessary as additional access becomes available. Note that the data available from this program will be dependent on the occurrence of flood events in the coming wet seasons.

4. SURFACE WATER IMPACTS & MITIGATION MEASURES

4.1 Design Philosophy and Approach to Impact Avoidance

The overall objective for the rail drainage design is to provide surface water management infrastructure for conveyance to surface water flows under the rail embankment with no infrastructure damage and minimal disruption to the hydrologic regime.

The general philosophy of the rail design is placement of culverts wherever there is an existing flow path (where the rail is in fill). In cases where the rail is in cut, or there is insufficient embankment depth to accommodate a culvert, there will be provision of a drain to convey flows to the nearest adjacent culvert. Cases where this occurs are typically limited to small catchment areas. Levees may also be added in locations where they are required to ensure large flows don't move between catchments.

Culverts are typically installed with rock protection at the downstream end to dissipate the increased velocities that arise from large flood events flowing through culverts, limiting erosion impacts downstream of the culverts. Rock protection is also used in drains on around embankments to mitigate erosion in areas where there is predicted to be high velocities around the rail infrastructure.

The drainage design for the proposed rail is based on analysis of flow paths using existing mapping, LiDAR survey, Aerial imagery and hydraulic modelling where required, for reasons outlined below in context of the catchment morphology across the rail.

4.1.1 Catchment Morphology – Defining Flow paths

The Weelumurra Creek and upper part of Caves Creek catchment (i.e. upstream of the confluence of Wackalina Creek) span in a very flat plain with complex flow paths and dynamics, which has sections of catchment interaction where flow paths discontinuous and are non-linear. The Duck Creek catchment that covers the remainder of the rail has more linear flow paths and catchment morphology follows typical dendritic patterns. This difference is illustrated visually by the contrast between Figure 4 and Figure 5 and explained as follows.

In Figure 4, the very low contour density where the rail traverses the Weelumurra and Caves Creek catchments, the lack of distinct contour divide between the Caves and Weelumurra catchments and discontinuities in the mapped watercourses across the plain all highlight the complexity of this area. This is exacerbated by the presence of the existing north-south orientated railway line in the area. This catchment complexity and existing rail line drove selection of 2d hydraulic modelling as the appropriate tool to assess the flow paths in Weelumurra Creek and Caves Creek catchments.

This modelling was then used to facilitate engineering design and environmental impact assessment which provided an appropriate control for the risk associated with higher degree of complexity in catchment hydrology. The two model domains are shown in the context of these catchments in Figure 4. Domain 1 was used to assess flow paths around crossings flows associated with Caves Creek and Weelumurra Creek, as well as adjacent hillslope areas on the flanks of the catchment. Domain 2 was used to assess some additional hillslope areas, where flow paths were more complex owing to the lateral expansion of flows as the flow from the hills onto the plain. The development of these two hydraulic model domains helped to develop sufficient understanding of these flat catchments with indistinct flow paths and existing rail infrastructure adjacent to the proposed railway.

In contrast the area towards the western extent of Figure 4, and within the Duck Creek catchment in Figure 5, the contour density is noticeably higher, and watercourses are continuous and follow a more typical dendritic pattern. As these catchments have a significantly lower degree of complexity, modelling is not required to determine flow paths around the proposed rail alignment and that the potential for impact in these areas is considered low risk, as more simplistic, widely accepted hydraulic design approaches can be applied to evaluate the required drainage infrastructure. This approach is consistent with that which was taken for design and assessment of Fortescue’s existing rail network of over 400km of existing rail lines, which spans areas with comparable catchment characteristics to the western portion of the proposed Eliwana rail line.

The methodology and approach to hydrologic assessment in Fortescue’s internal guidelines has been developed in accordance with guidance in Australian Rainfall and Runoff (Ball et al. 2016). This methodology has been applied to this assessment of the proposed Eliwana railway.

4.2 Modelling Assessment of Impacts

As described above, 2d hydraulic modelling was used to assist with understanding of flow paths in the Caves and Weelumurra catchments to assist the placement and design of surface water management infrastructure for the main crossings of the major watercourses, along with their tributary catchments.

There are several small tributaries of Weelumurra and Caves Creek catchments above the Weelumurra plain that intersect the Eliwana rail. A number of these small tributaries intersect the rail in locations where culverts are unlikely to be accommodated due to the very flat topography and the presence of some rail cuttings. This results in some shadowing effects to the areas immediately downstream of the culverts. The hydraulic modelling that was undertaken to assess the spatial extent of these impacts, and this modelling is described in Appendix 1.

Modelling was used to contrast the current flooding conditions with the modified flooding conditions impacted by the Eliwana rail project. The two scenarios were compared to quantify the impact on flood depths and velocities upstream and downstream of the proposed rail embankment and associated culverts.

Results showed that in frequent, smaller events there was a minor redistribution of flows from the smaller tributaries aligning with the location of culverts under the rail embankment. Then in larger, less frequent events there is some impact on the depth of flood flows both downstream and immediately upstream of the rail alignment. However, these impacts are confined to the area above broader Weelumurra Plain, with minimal impact to overall hydrological regime. Appendix 1 includes details on the flood model setup and hydrological analysis used for the impact assessment and results are presented in Appendix 2 and 3.

4.3 Sediment Management

During construction, there is potential for increased sediment load in surface water generated in areas cleared of vegetation. Given construction timeframes for the rail, there is limited opportunity for this to occur. Windrows can be used to mitigate risks areas where there is a significant likelihood of sediment increases due to construction clearing and works in areas prone to flooding are typically limited in wet season wherever practicable.

Following construction, there is potential for increased sediment load due to increased velocities through flow constructions associated with drainage infrastructure (e.g. culverts). However, drainage infrastructure such as culverts are designed in accordance with industry standard methodologies, which involve the use of rock protection downstream of the culverts. The logic that has determined the length of rock protection from an industry standpoint is to extend to a point where the velocity increase due to the constriction has dissipated. This enables dissipation of energy on the rough surface of the rock and provides protection of the natural surface to prevent increased sediment transport due to the increased velocities. This approach of the use of rock protection in areas of high velocity (based on calculated design velocities) due to drainage infrastructure will be applied on the Eliwana railway line and as such the velocity changes around drainage infrastructure are not expected to have a material impact on sediment load in associated watercourses.

The risk of environmental impacts from changes to erosion and sediment load and erosion are likely to be very low with the rock protection controls proposed. This is in line with findings from Monitoring along the Fortescue's existing rail network, documented in the 2016 State of the Environment Report Rail Operations (R-RP-EN-1097) (Equinox Environmental 2017) and Surface Water Quality Summary Report – July 2017 Rail Operations (R-RP-EN-1104) (Fortescue 2017). There reports indicate that there has been no evidence of impacts on surface water flows and associated vegetation to date from the existing rail, and that there have been no significant differences between upstream, mid-stream and downstream water samples, and that results and tends are comparable between the streamflow sites.

4.4 Predicted Outcome

As railways are fixed infrastructure with a long asset life, the drainage infrastructure is inherently designed to provide conveyance to surface water flows with as little disruption as possible to reduce the likelihood of damage to the rail infrastructure. This approach results in an outcome with very minimal changes to the existing hydrologic regime.

Overall there are expected to be minimal impacts to the hydrologic regime of the catchments associated with the proposed Eliwana rail. Fortescue has significant experience building and managing railways in the Pilbara without significant impact on hydrologic processes and this experience will be drawn upon to ensure the successful implementation of the proposed Eliwana rail proposal.

Monitoring along the existing network, documented in the 2016 State of the Environment Report Rail Operations (R-RP-EN-1097) (Equinox Environmental 2017) and Surface Water Quality Summary Report – July 2017 Rail Operations (R-RP-EN-1104) (Fortescue 2017), indicates that there has been no evidence of impacts on surface water flows and associated vegetation to date from the existing rail. This demonstrated experience Fortescue has in successfully designing and constructing railways to avoid impacts to surface water, which will be applied in the design of Eliwana rail.

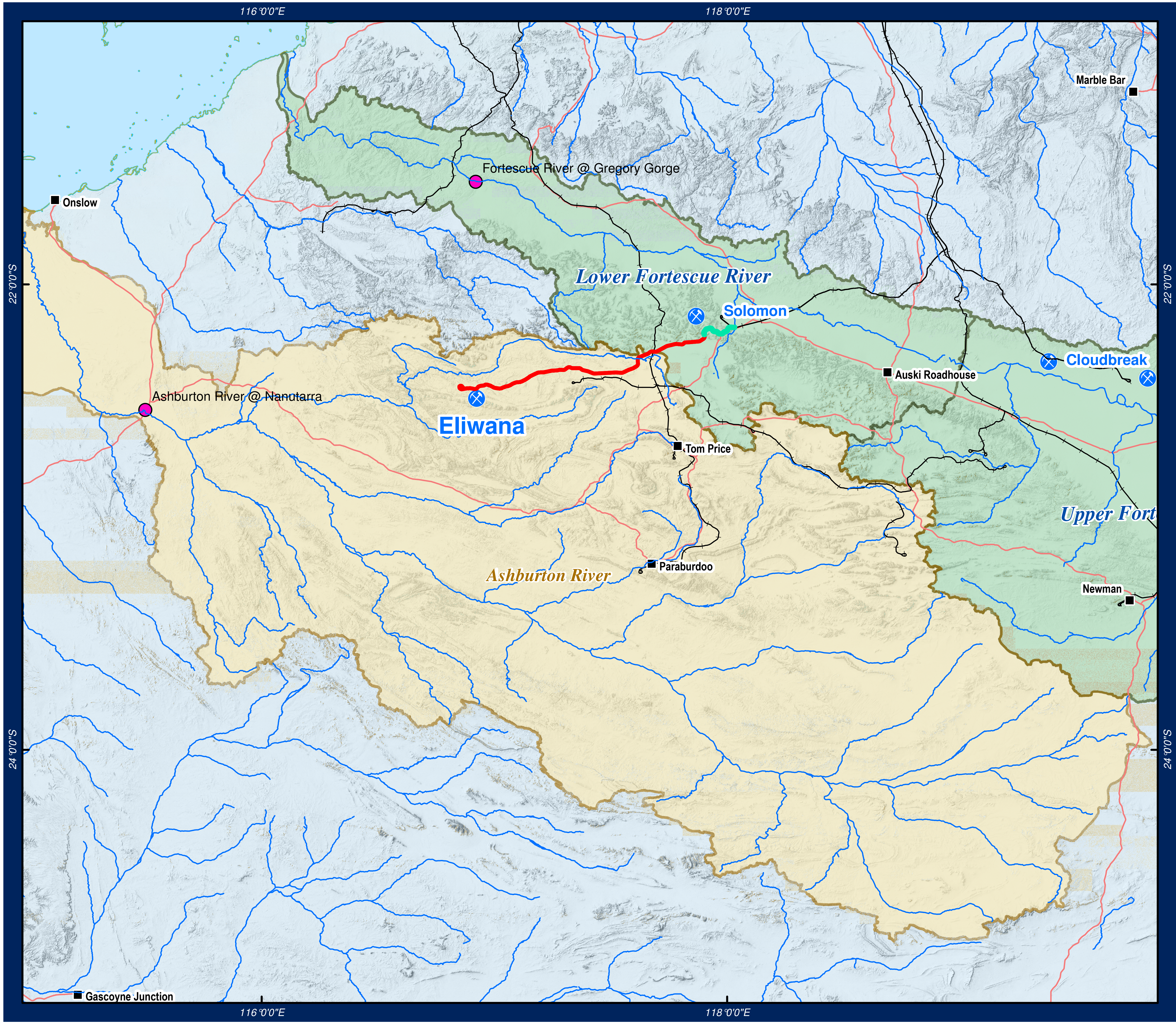
REFERENCES

Ball, J et al., 2016, *Australian Rainfall and Runoff: A Guide to Flood Estimation,* Commonwealth of Australia, Available from: http://arr.ga.gov.au/arr-guideline

Equinox Environmental, 2017, 2016 State of the Environment Report Rail Operations (R-RP-EMN1097), Fortescue Metals Group, Perth.

Fortescue, 2017, Surface Water Quality Summary Report – July 2017 Rail Operations (R-RP-EN-1104), Fortescue Metals Group, Perth.

FIGURES



LEGEND

- Major Drainage

Regional Catchment Name

- Ashburton River
- Fortescue River Catchment
- Towns
- Railways
- Roads
- FMG Proposed Rail Alignment
- Approved Frederick Rail Spur
- DWER Stream Monitoring

N

0 20 40 60 80 100

Kilometres

Eliwana Regional Catchments
Western Australia

Date: 2/02/2018
Size: A3L
Revision: 2
Confidentiality: 1

Drawn By: Ryan Warrington
Scale: 1:1,750,000
Coordinate System: GCS GDA 1994
Document Name: Figure 1 - Regional Catchment_Rev2

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Figure 2 - Eliwana Rail Catchments

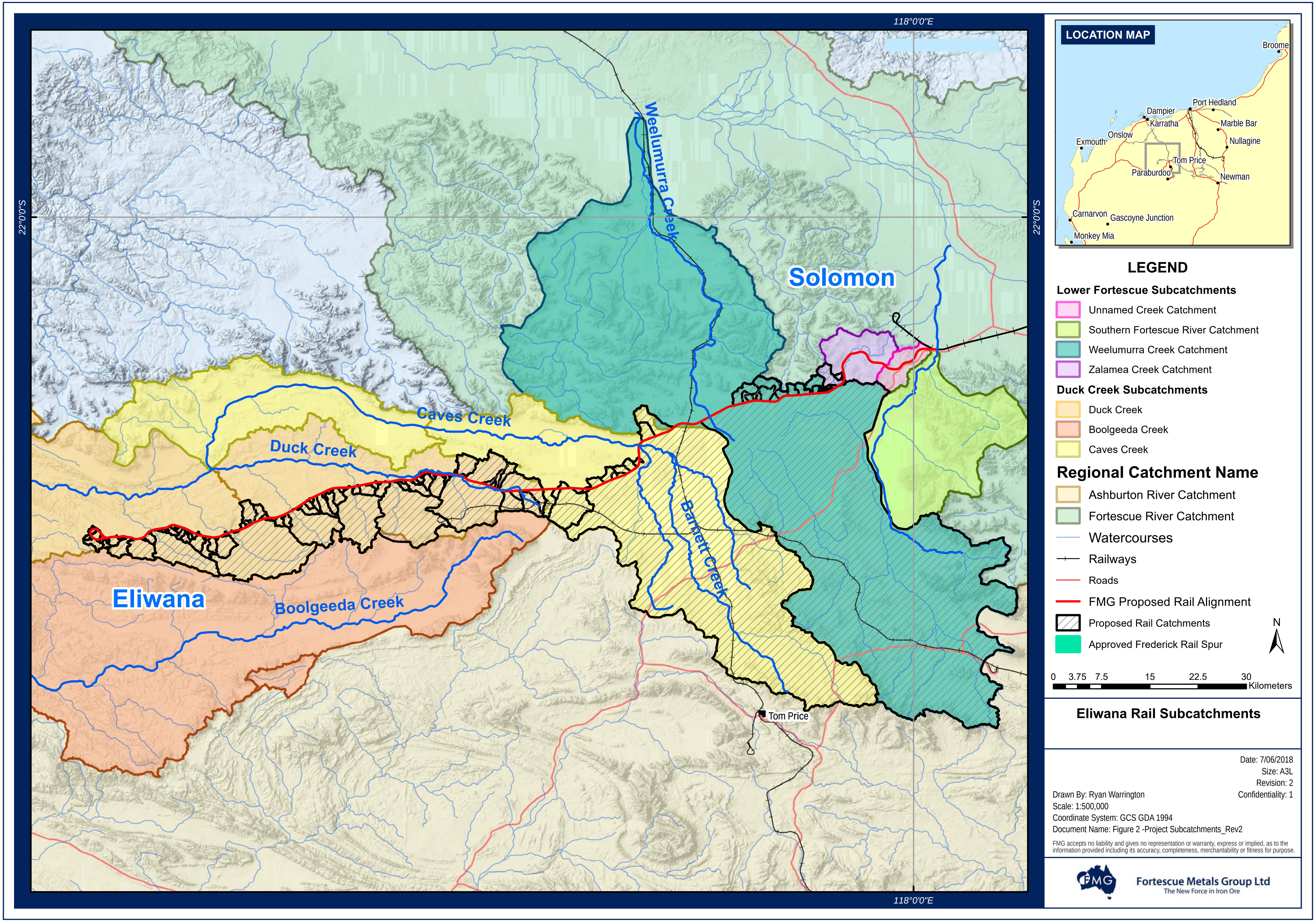
118°0'0"E
22°0'0"S
Weelumurra Creek
Solomon
Caves Creek
Duck Creek
Barnett Creek
Eliwana
Boolgeeda Creek
Tom Price
LOCATION MAP
Broome
Port Hedland
Dampier
Karratha
Marble Bar
Onslow
Exmouth
Nullagine
Tom Price
Paraburdoo
Newman
Carnarvon
Gascoyne Junction
Monkey Mia
LEGEND
Lower Fortescue Subcatchments
Unnamed Creek Catchment
Southern Fortescue River Catchment
Weelumurra Creek Catchment
Zalamea Creek Catchment
Duck Creek Subcatchments
Duck Creek
Boolgeeda Creek
Caves Creek
Regional Catchment Name
Ashburton River Catchment
Fortescue River Catchment
Watercourses
Railways
Roads
FMG Proposed Rail Alignment
Proposed Rail Catchments
Approved Frederick Rail Spur
N
0 3.75 7.5 15 22.5 30
Kilometers
Eliwana Rail Subcatchments
Date: 7/06/2018
Size: A3L
Revision: 2
Confidentiality: 1
Drawn By: Ryan Warrington
Scale: 1:500,000
Coordinate System: GCS GDA 1994
Document Name: Figure 2 -Project Subcatchments_Rev2
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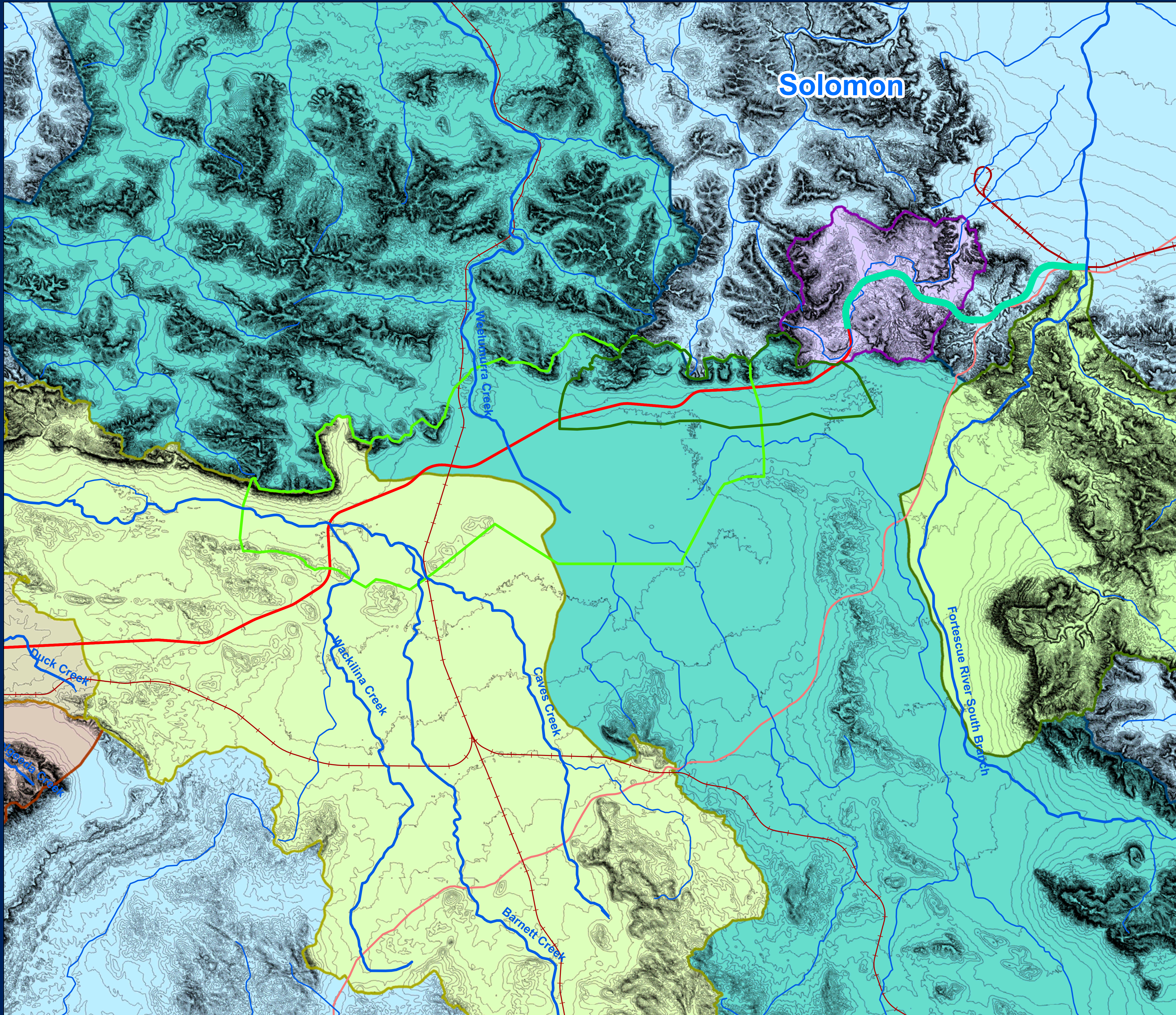
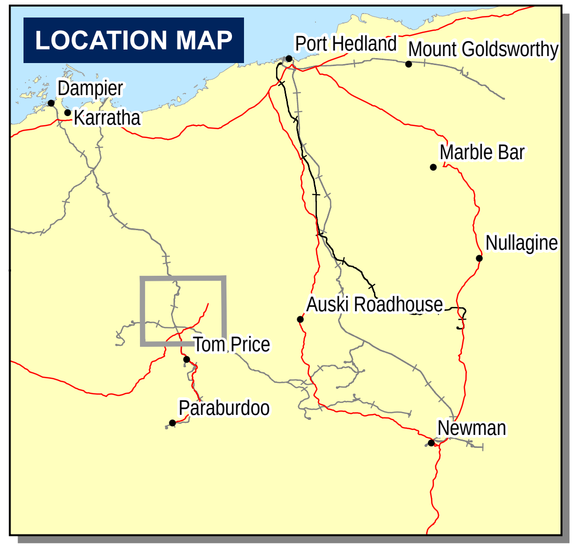
Figure 3 - Pilbara Turbidity Examples

Pilbara Turbidity Examples (Top: Hamersley Gorge 31/3/10, 17/1/11, 23/3/11, 7/5/11. Bottom: Weeli Wolli Creek 13/1/12, 19/1/12)

Figure 4 - Catchment Morphology 1 of 2





LEGEND

Lower Fortescue Subcatchments

- Southern Fortescue River Catchment
- Weelumurra Creek Catchment
- Zalamea Creek Catchment

Duck Creek Subcatchments

- Duck Creek
- Boolgeeda Creek
- Caves Creek
- GOV Contours 10m
- Watercourses
- Railways
- Roads
- FMG Proposed Rail Alignment
- Approved Frederick Rail Spur
- Modelling Domain 1
- Modelling Domain 2

N

0 1.5 3 6 9 12 Kilometers

Eliwana Rail Catchment Morphology
Map 1 of 2

Date: 1/06/2018
Size: A3L
Revision: 2
Confidentiality: 1

Drawn By: Ryan Warrington
Scale: 1:215,000
Coordinate System: GDA 1994 MGA Zone 50

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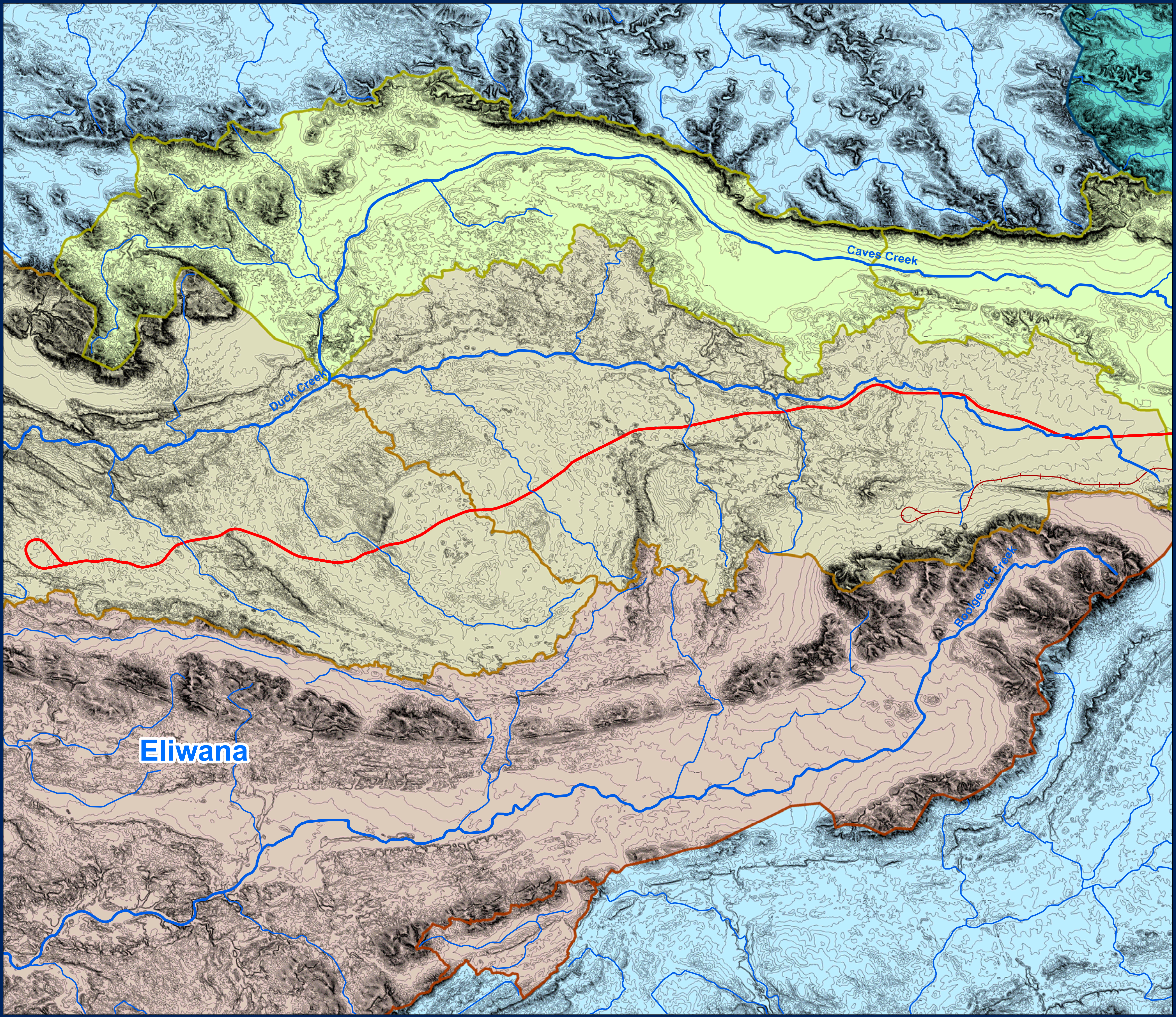
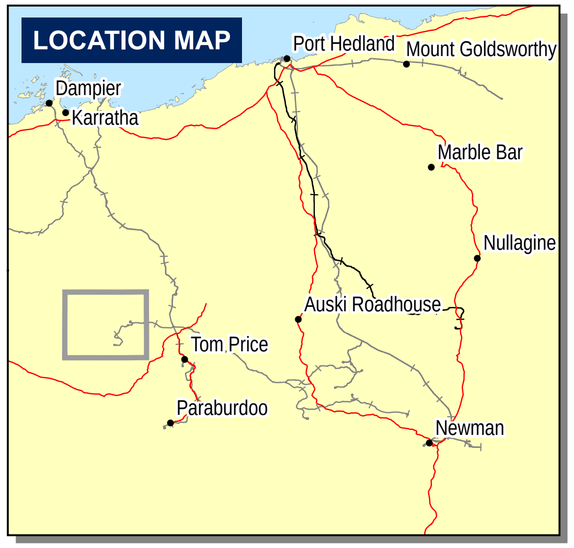
Figure 5 - Catchment Morphology 2 of 2





LEGEND

Lower Fortescue Subcatchments

- Southern Fortescue River Catchment
- Weelumurra Creek Catchment
- Zalamea Creek Catchment

Duck Creek Subcatchments

- Duck Creek
- Boolgeeda Creek
- Caves Creek
- GOV Contours 10m
- Watercourses
- Railways
- Roads
- FMG Proposed Rail Alignment

N

0 1.5 3 6 9 12 Kilometers

Eliwana Rail Catchment Morphology
Map 2 of 2

Date: 1/06/2018
Size: A3L
Revision: 2
Confidentiality: 1

Drawn By: Ryan Warrington
Scale: 1:215,000
Coordinate System: GDA 1994 MGA Zone 50

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Appendix 1: Hydraulic Modelling Summary

1. INTRODUCTION

Modelling has been undertaken to characterise flow paths in the Caves and Weelumurra Creek Catchments and to understand changes flood patterns in small hillslope tributaries of these catchments, as a result of the proposed rail. Modelling was undertaken using a combination of RORB rainfall runoff modelling and TUFLOW two-dimensional hydraulic modelling. As these catchments are ungauged, with no historical flood information available, a variety of flood estimation techniques were applied to determine the appropriate modelling approach. The application of these techniques has used guidance from the 2016 revision of Australian Rainfall and Runoff (ARR 2016) (Ball, et al., 2016).

There were a number of models developed for the assessment of the proposed rail using the TUFLOW software package, including a series of models encompassing the Weelumurra Creek and Caves Creek catchments (Domain 1) to the South/South West of Solomon Mine and a smaller scale domain covering the Weelumurra tributary catchments (Domain 2 - adjacent to the existing Solomon Mine Aerodrome). The modelling undertaken for these domains is described below.

2. DOMAIN 1 – CAVES CREEK AND WEELUMURRA CREEK CATCHMENTS

Weelumurra Creek and Caves Creek are the largest catchments upstream of the proposed Eliwana Railway. In the vicinity of the railway, both catchments are characterised by a wide very flat floodplain with a series of small channels, many of which are discontinuous. There is interaction between the two catchments within this floodplain, as there is no distinct catchment divide. Further upstream, the eastern branch of Weelumurra Creek shares a floodplain with the Fortescue River South Branch. During flood events the two systems combine for a 14 km stretch of floodplain before splitting into separate branches.

Because of these complexities within this catchment, evaluating catchment hydrology is challenging, with traditional flood estimation techniques failing to properly account for these complex floodplain processes.

Consequently, a series of hydrologic and hydraulic models have been developed using RORB and TUFLOW for the purposes of hydrograph derivation. These include:

- Weelumurra Upper Catchment (RORB);
- Weelumurra Upper Catchment (TUFLOW); and
- Caves Catchment (TUFLOW).

The extents of the various models are shown in Figure 1. While the model extents overlap, the hydrographs from the upstream model are taken as inputs into the downstream model.

The hydraulic models used for more detailed assessment of hydraulics around the proposed rail are also shown on Figure 1, and include:

- Weelumurra Flats (TUFLOW model with 10m resolution); and
- Weelumurra Flats (TUFLOW model with 4m resolution).

These respective models are described in more detail below.

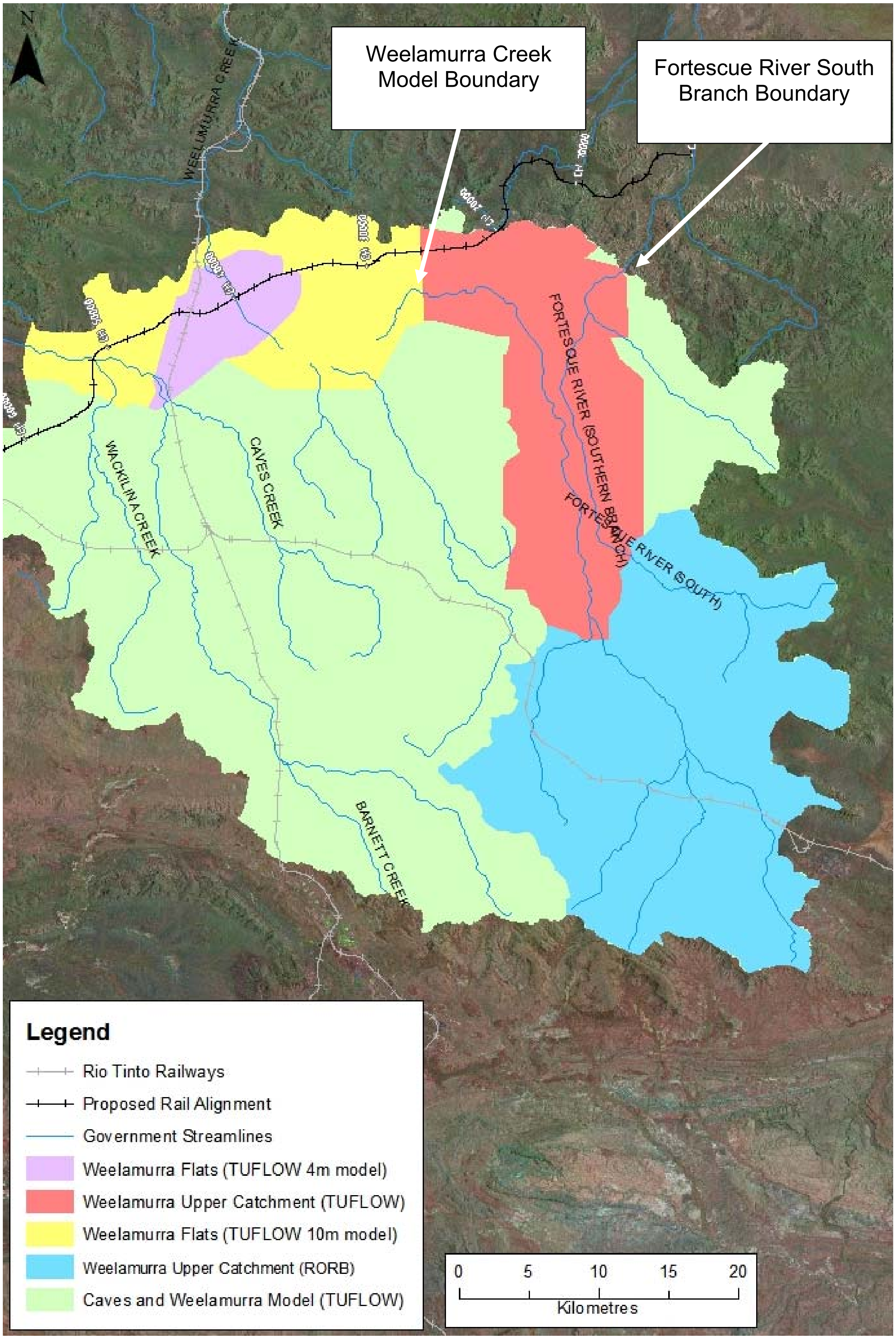

Figure 1: Caves and Weelumurra Model Domains

2.1 Weelumurra Upper Catchment (RORB) Modelling

A hydrologic model of the Weelumurra Creek catchment was developed to determine design flow hydrographs from the upper catchment as inflow inputs into the TUFLOW hydraulic model.

The adopted methodology described below is based on current guidelines described in ARR 2016. An ensemble approach was used where 10 different historical temporal patterns for each AEP and duration to simulate a range of different storms. The temporal pattern that produces the mean peak flow at the hydrograph output location is selected for design purposes.

2.1.1 Model Setup and Parameters

The RORB model had 33 sub-areas ranging in area from 6.4 – 68.2 km2, with a mean of 37.3 km2 and a total catchment area of 1,230 km2. The sub-catchment delineation and reach network is shown in Figure 2. Note that only the upper sections of the RORB model (as indicated in Figure 1) were used to estimate flows input into the Weelumurra Upper Catchment TUFLOW model.

Kc is the primary routing parameter in RORB, which is used to estimate the flow routing and attenuation characteristics within the catchment. The Weelumurra Creek catchment is ungauged, therefore other nearby calibrated gauged catchment parameters provide the best estimate for Kc. The Weelumurra Creek catchment has similar characteristics to the majority of catchments modelled in the previous study by Pearcey, et al. (Estimation of RORB Kc Parameter for Ungauged Catchments in the Pilbara Region of Western Australia, 2014). Therefore, the mean C value of 0.59 from that study was adopted, giving a Kc value of 26.7.

ARR 2016 areal reduction factors were applied to the catchment area and extracted from the ARR 2016 data hub. The catchment lies within the Northern Coastal Zone of aerial reduction factors and these were applied for all design modelling.

Temporal patterns from ARR 2016 were utilised in the analysis and extracted from the AR&R data hub. The Rangelands West Zone of temporal patterns was utilised. As the catchment is larger than 100 km^2, areal temporal patterns were used. The areal rainfall temporal patterns for 1,000 km^2 were applied, which contain durations from 12 hours to 7 days.

Design rainfall depths were determined using the 2016 Bureau of Meteorology online IFD tool. The rainfall Intensity Frequency Duration (IFD) parameters were generated for a location in the approximate centre of the Weelumurra Creek catchment. Design losses were estimated by using the new ARR 2016 datahub tool. The RORB model was run using the temporal pattern ensemble method.

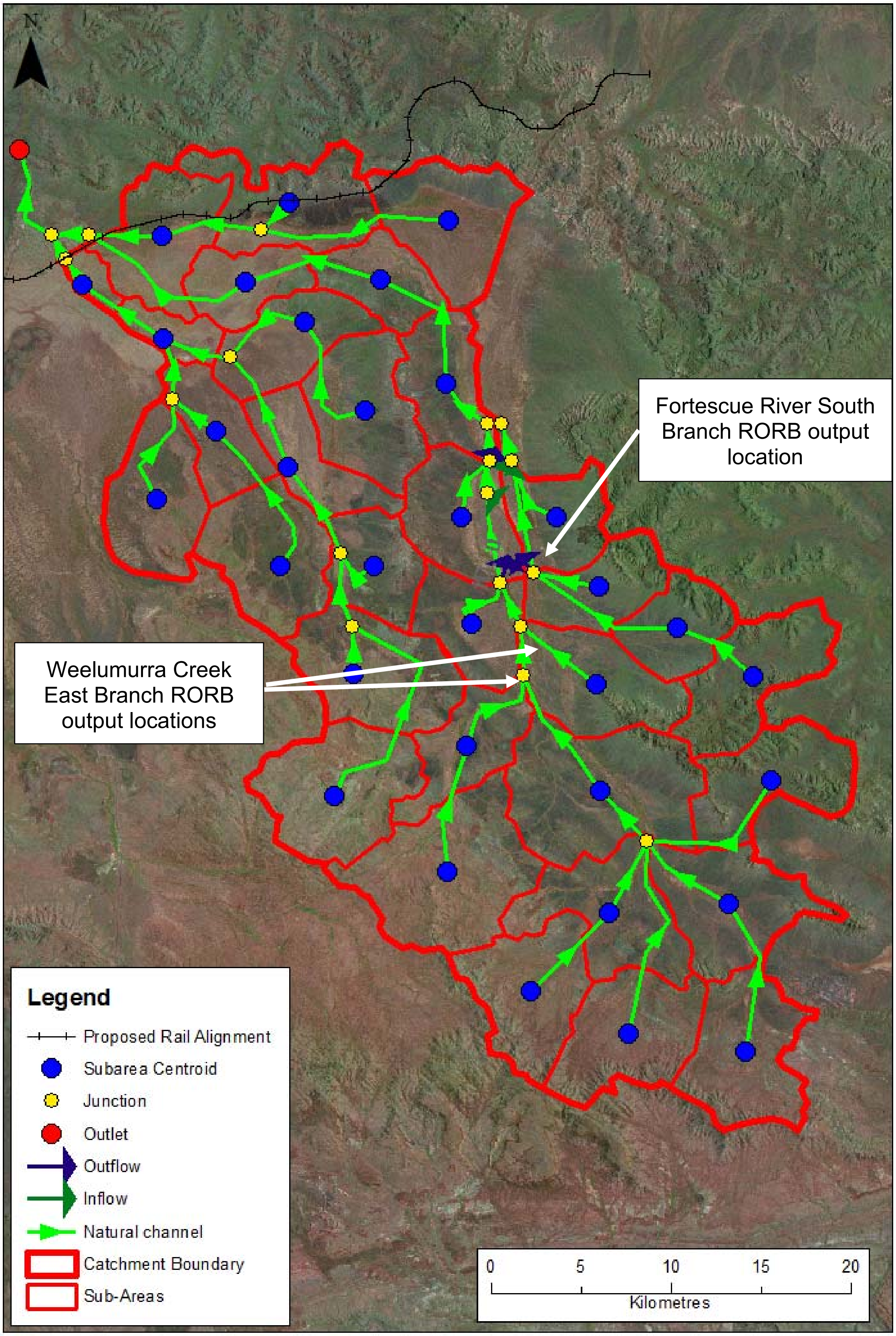

Figure 2: Weelumurra RORB Model Schematisation

2.1.2 Model Results

The RORB simulations produced ten hydrographs for each print location in the RORB model for each AEP and duration. This produces a variety of simulated storm events for the range of durations and probabilities. The critical duration for the Weelumurra Creek catchment was overwhelmingly the 24 hour event at all print locations. The temporal pattern that produced closest to the mean peak flow for the 24 hour event for each AEP was selected.

Flows from this RORB model were extracted at Weelumurra Creek and the Fortescue River South Branch to provide input hydrographs to the Weelumurra Upper Catchment TUFLOW model just upstream of where the two floodplains meet. Downstream of these locations, the floodplain becomes divergent and the RORB model can no longer accurately represent the complex floodplain behaviours as compared to detailed hydraulic modelling. Results are not presented as they are outside of locations of interest, but this model has been described to provide context for understanding how hydrology was developed through the catchment.

2.2 Weelumurra Upper Catchment Model (TUFLOW)

The complex flow paths in the upper Weelumurra Creek catchment, including the interaction with the Fortescue River South Branch, cannot be accurately accounted for using traditional flow estimation techniques such as RORB or regional methods. From the aerial imagery and site inspections, it's clear that there are significant areas of floodplain storage to the west of upper Weelumurra Creek on the floodplain south of Nanutarra Road. To account for these floodplain features, a TUFLOW hydraulic model was developed for the upper Weelumurra Creek catchment, with the intent of producing flow hydrograph inputs for the rail assessment TUFLOW model of the lower Weelumurra Creek floodplain (Weelumurra Flats model).

2.2.1 Model Setup

Topography for the upper Weelumurra Creek catchment was developed using a combination of LiDAR and Satellite SRTM data. A 5 m resolution grid was adopted for the model, covering approximately 291 km^2. At this grid size the width of the creek channels and overland flow paths were appropriately represented.

A constant manning's 'n' roughness coefficient of 0.05 was selected based on experience from nearby catchments. Model uncertainty due to potential variation in the parameter is considered to be significantly lower than rainfall and loss uncertainty, consequently the constant roughness is considered to be reasonable.

Rainfall hyetographs from the Weelumurra Creek RORB model as described above were constructed for a series of events. Rainfall was applied directly on to the grid, with the initial and continuing losses (using ARR 2016 datahub values) applied through the soils layer. Inflow hydrographs for the Weelumurra Creek and Fortescue River South Branch were extracted from the RORB model results. These boundaries were applied at the southern extent of the model (model boundary is shown in in Figure 1.)

The downstream boundaries used multiple normal flow boundaries at identified outflow locations calculated by TUFLOW from the topography. This type of boundary assumes a uniform flow based on the ground slope of adjoining cells. Outlet flow boundaries were placed across the Weelumurra Creek floodplain and at the entrance to Hamersley Gorge on the Fortescue River South Branch.

2.2.2 Model Results

The results of the Upper Weelumurra Creek TUFLOW model were used as inputs for the rail assessment model (Weelumurra Flats). Results are not presented as they are outside of locations of interest, but this mode setup has been described to provide context for understanding how hydrology was developed through the catchment.

2.3 Caves and Weelumurra Catchment Model (TUFLOW)

A catchment scale 2-dimensional hydraulic model was used to predict runoff and routing in the Caves Creek and Weelumurra catchments, to estimate design flow hydrographs reaching the Weelumurra Creek and Caves Creek Crossing. Due to discontinuities in available Landgate 10m DEM data, SRTM data was used to build the model grid, using a 30m grid, which was considered appropriate hydrograph estimation given the scale of the model.

The domain (shown in Figure 1) contained the entire Caves and Weelumurra Creek catchments (upstream of the proposed rail), extending downstream to slightly beyond the alignment crossings and the Fortescue South Branch to the start of the Hamersley Gorge, to avoid boundary effect.

The model used rainfall hyetographs developed from the Weelumurra Upper Catchment RORB model, which was applied directly on to the grid, with the initial and continuing losses (using ARR 2016 datahub values) applied through the soils layer.

A constant manning's 'n' roughness coefficient of 0.05 was selected based on experience from nearby catchments. Model uncertainty due to potential variation in the parameter is considered to be significantly lower than rainfall and loss uncertainty, consequently the constant roughness is considered to be reasonable.

The downstream boundaries used multiple normal flow boundaries at identified outflow locations calculated by TUFLOW from the topography. This type of boundary assumes a uniform flow based on the ground slope of adjoining cells. Outlet flow boundaries were placed across Weelumurra Creek and Caves Creek well downstream of our area of interest.

2.3.1 Model Results

The results of the Caves Creek and Weelumurra Catchment TUFLOW model were used as inputs for the rail assessment model (Weelumurra Flats). Results are not presented as they are outside of locations of interest, but this mode setup has been described to provide context for understanding how hydrology was developed through the catchment.

2.4 Weelumurra Flats Hydraulic Model

The Weelumurra Flats model was developed to provide an assessment of the proposed Eliwana Railway on the Weelumurra Creek and Caves Creek floodplains. Two model domains were used as indicated in Figure 1 including a 10m resolution domain covering the area between the proposed Caves Creek crossing and the downstream extent of the Weelumurra Upper Catchment TUFLOW model.

A finer resolution (4m) model developed to investigate finer scale hydraulic around a proposed bridge crossing for bridge design purposes. This model was not used for impact assessment and as such results are not included in this report.

2.4.1 Model Setup

The model grid was constructed from a LiDAR dataset covering the main rail corridor and photogrammetry data for extents outside of LiDAR coverage.

The model used rainfall hyetographs developed from the Weelumurra Upper Catchment RORB model, which was applied directly on to the grid, with the initial and continuing losses (using ARR 2016 datahub values) applied through the soils layer. Additional inflows derived from the upstream models including the Caves and Weelumurra Catchment Model and Weelumurra Upper Catchment TUFLOW models were introduced at locations shown in Figure 3.

A constant manning's 'n' roughness coefficient of 0.05 was selected based on experience from nearby catchments. Model uncertainty due to potential variation in the parameter is considered to be significantly lower than rainfall and loss uncertainty, consequently the constant roughness is considered to be reasonable.

The downstream boundary used normal flow boundaries at Caves Creek and Weelumurra Creek calculated by TUFLOW from the topography. This type of boundary assumes a uniform flow based on the ground slope of adjoining cells.

Development Scenario

Breaklines were used to ensure rail embankments were continuously represented in the model. With existing rail levels set based on LiDAR survey. Culvert crossings were represented 1D elements and linked to the 2D domain, including culverts under existing railways. The model domain is presented in Figure 3.

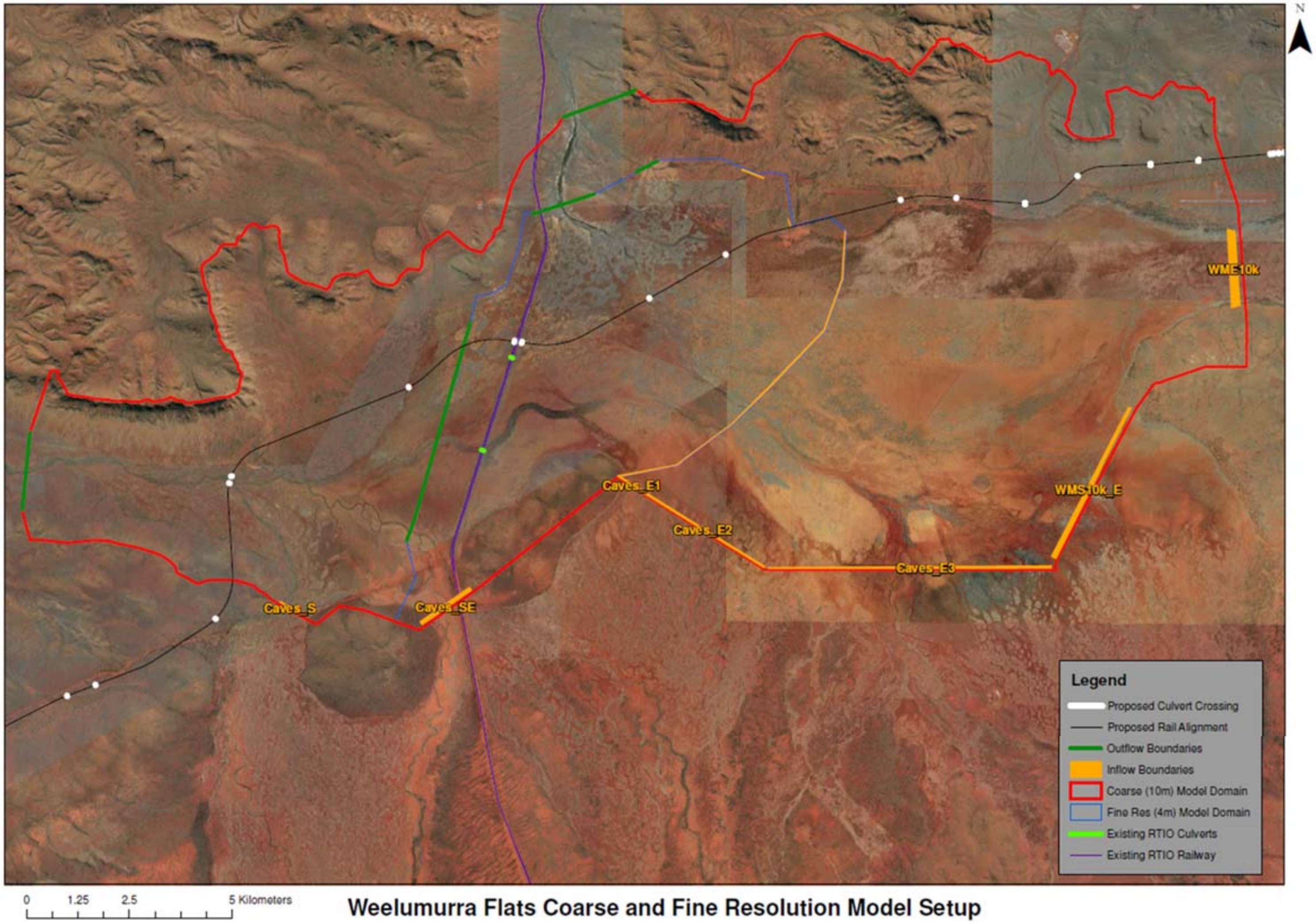

Figure 3: Weelumurra Flats TUFLOW Model Setup

2.4.2 Model Results

Hydraulic modelling of the Caves and Weelumurra Creek catchments has produced flood mapping for both existing conditions and with the propose rail alignment. Model results are presented in Appendix 2.

3. DOMAIN 2 - WEELUMURRA TRIBUTARY CATCHMENTS

The proposed rail alignment passes to the north of the Solomon Mine Aerodrome, which lies at the foothills of a set of hills that rise up to the north of the proposed rail alignment. The catchment runoff from these hills flows south until they intersect with the broad Weelumurra floodplain area. There is an existing unsealed road (Hamersley Road) servicing the airport also to the north.

The hydraulic model was developed to assess the impacts of the proposed rail alignment on the tributaries to the Weelumurra floodplain. The model covers the catchments upstream of the proposed rail alignment through to their confluence with the Weelumurra floodplain.

3.1 Design Rainfall

Design rainfall depths were determined using the 2016 Bureau of Meteorology (BoM) online IFD tool. Areal reduction factors were used to convert point rainfall to areal estimates and are used to account for the variation of rainfall intensities over a large catchment. Australian Rainfall and Runoff (ARR) 2016 areal reduction factors were applied to the catchment area and extracted from the ARR 2016 data hub (Ball, et al., 2016). The catchment lies within the Northern Coastal Zone of aerial reduction factors and these were applied for all design modelling.

Temporal patterns from ARR 2016 were utilised in the analysis and extracted from the ARR 2016 data hub. The Rangelands West Zone of temporal patterns was utilised. ARR 2016 guidance suggests analysis with various temporal patterns allows for exhibited variability in rainfall events of similar magnitude. The new temporal patterns are based on historical storms using the extensive network of pluviograph data collected by the Bureau of Meteorology. Design temporal patterns were selected based on rigorous analysis and comparison with other modelling undertaken for adjacent areas.

Design losses were estimated by using the new ARR 2016 datahub tool, which has derived loss prediction equations for rural catchments using attributes from the Australian Water Resource Assessment – Landscape (AWRA-L) model developed by CSRIO and BoM.

3.2 Model Setup

Topography for the Weelumurra tributary catchments was based on LiDAR survey shown in Figure 4. The model extends from the top of the catchments to the north, to downstream of the proposed rail alignment to the south, the Solomon Airport and the northern part of the Weelumurra Creek floodplain. A 3 meter resolution grid was adopted for the model, covering approximately 64.5 km^2. At this grid size the width of the creek channels were appropriately represented. Features such as the Solomon Airport drains, roads and general floodplain features were well represented by the model. The selected grid size allowed representative modelling of the rail and creeks while maintaining manageable model run times.

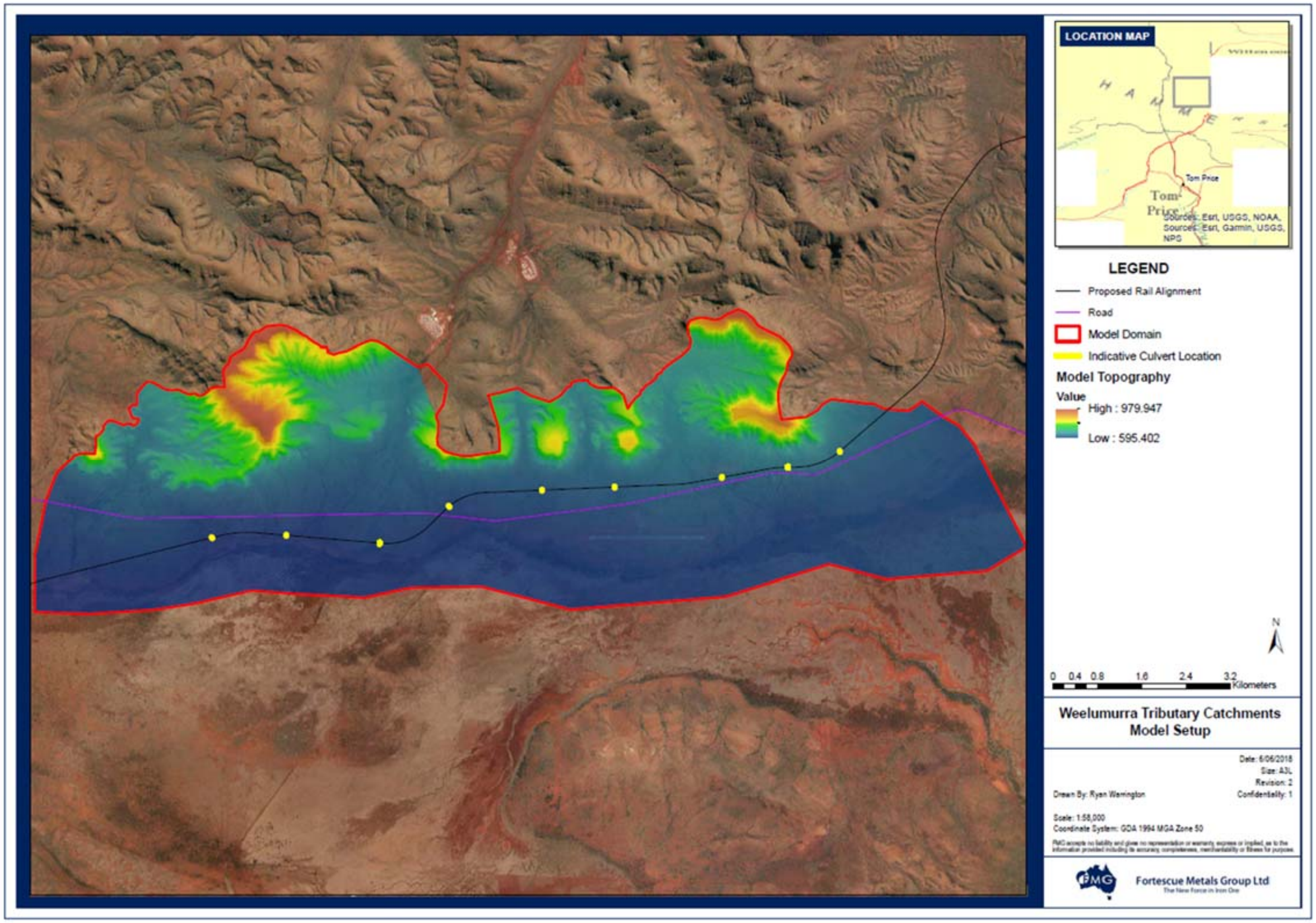

Figure 4: **Solomon Airport Catchments – Topography**

The Weelumurra tributary catchments are predominantly natural rural landscape, with the only unnatural features being an unsealed light vehicle road and the airport. The airport is relatively confined with internal drainage features that have not been included specifically in the model. For this reason, and from previous experience in nearby catchments, a constant manning's 'n' roughness coefficient of 0.05 was selected.

Rainfall was applied directly on to the grid, with the initial and continuing losses applied through the soils layer. An inflow boundary for the Weelumurra Creek northern floodplain was extracted from a regional hydraulic model for each annual exceedance probability (AEP) event. This boundary was applied at the eastern extent of the model.

The downstream boundary used multiple normal flow boundaries at identified outflow locations calculated by TUFLOW from the topography. This type of boundary assumes a uniform flow based on the ground slope of adjoining cells. Outlet flow boundaries along the Weelumurra Creek floodplain allows for reasonable representation of the broader floodplain behaviour without needing to model the entire floodplain extent, which would greatly impact on run times.

3.2.1 Development Scenario

The rail alignment was included as a break line in the hydraulic model, based on the assumption that the rail would be have engineered culverts and off-formation drainage works to prevent overtopping. To represent these proposed waterway structures, gaps in the rail break line were used in conjunction with cell width reduction factors to limit the modelled flow area to approximate the waterway structure. Proposed off-formation drainage was modelled with break lines.

3.3 Hydraulic Model Results

Hydraulic modelling of the Weelumurra tributary catchments has produced flood mapping for both existing conditions and with the propose rail alignment. Note that the adopted losses from the ARR 2016 datahub result in there being no runoff predicted from a 50% AEP rainfall event, so no results are presented for this event. These results are presented in Appendix 3

At the eastern extent of the model, a proposed drain upstream of the rail alignment directs flows to a set of culverts in the adjacent catchment, which are beyond the extent of the model. Hence the water flows out of the model at the proposed drain. Similarly, at the western extent of the model, a large proposed drain directs flows to the Weelumurra Creek north of the rail alignment. Again the water flows out of the model directly from the drain.

4. CONCLUSION

The results from both models show some changes to flood patterns downstream of the rail as a result of the current culvert and drain configuration. These changes are focused on the area above the Weelumurra floodplain and have very minimal impact on the Weelumurra floodplain itself. Areas that have predicted reductions in flooding will have potential for associated impacts mitigated somewhat by direct rainfall, which will vary proportionally with event magnitude.

The proposed rail waterway design will be refined as the design progresses towards construction minimise impacts through design as much as possible.

5. REFERENCES

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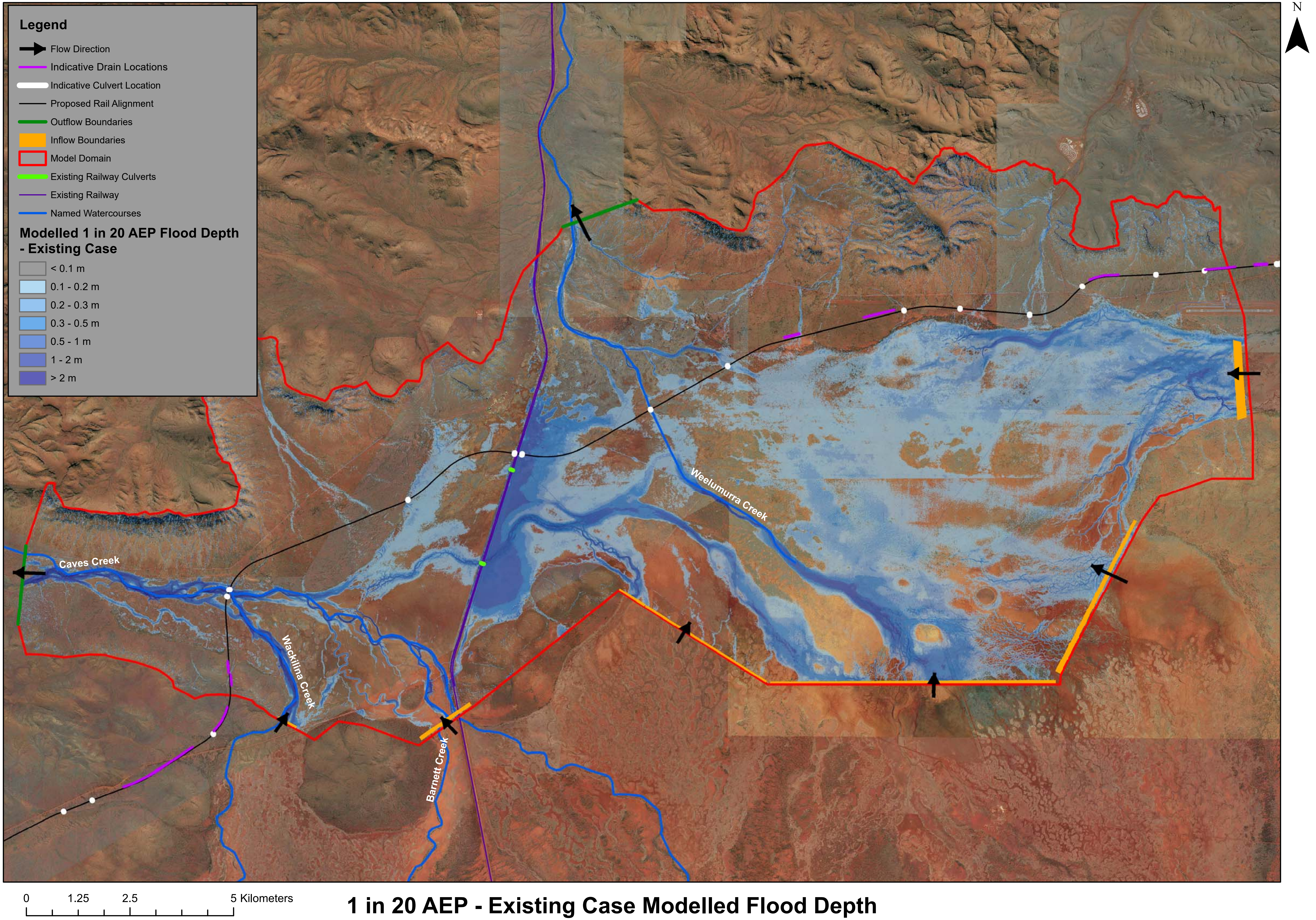
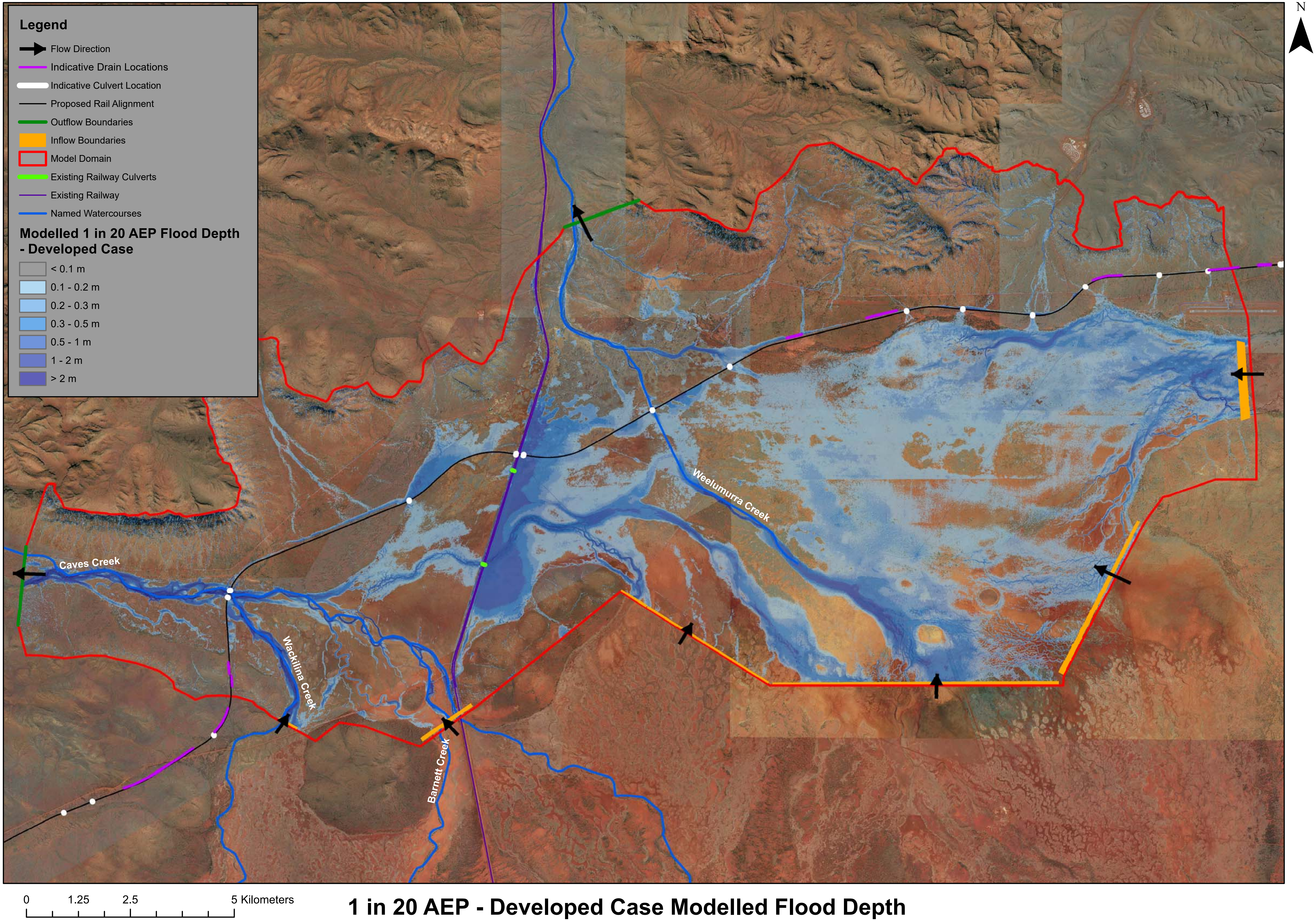
Pearcey, M., Pettett, S., Cheng, S., & Knoesen, D. (2014). Estimation of RORB Kc Parameter for Ungauged Catchments in the Pilbara Region of Western Australia. *Hydrology & Water Resources Symposium 2014* (pp. 206-214). Perth: Engineers Australia.

Yu, B., & Ford, B. R. (1989). Regional Relationships for the Runoff Routing Model (RORB) Revisited. *Transactions of the Institution of Engineers: Civil Engineering, 31*(4), 186-191.

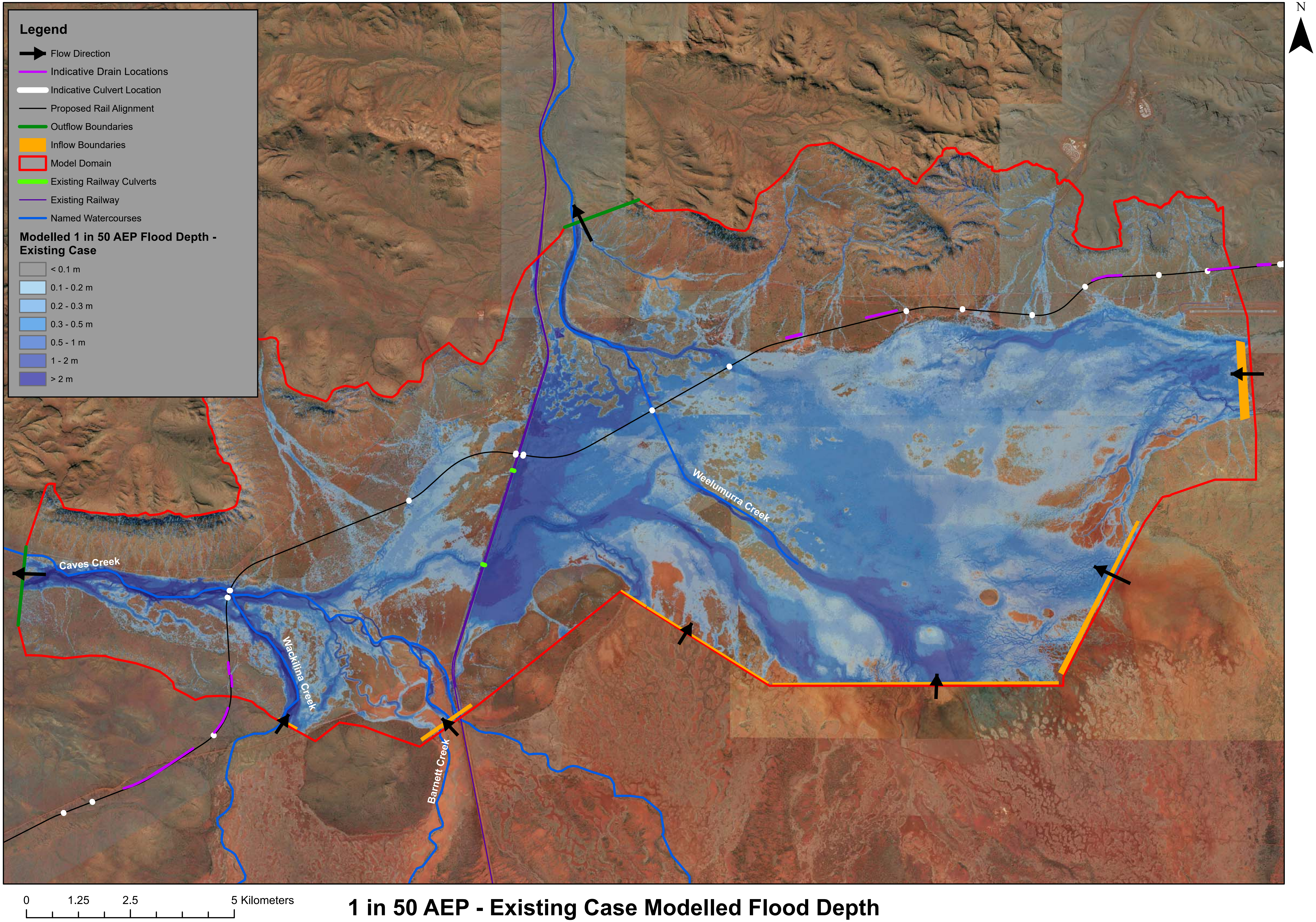
Appendix 2: Domain 1 Hydraulic Modelling Results



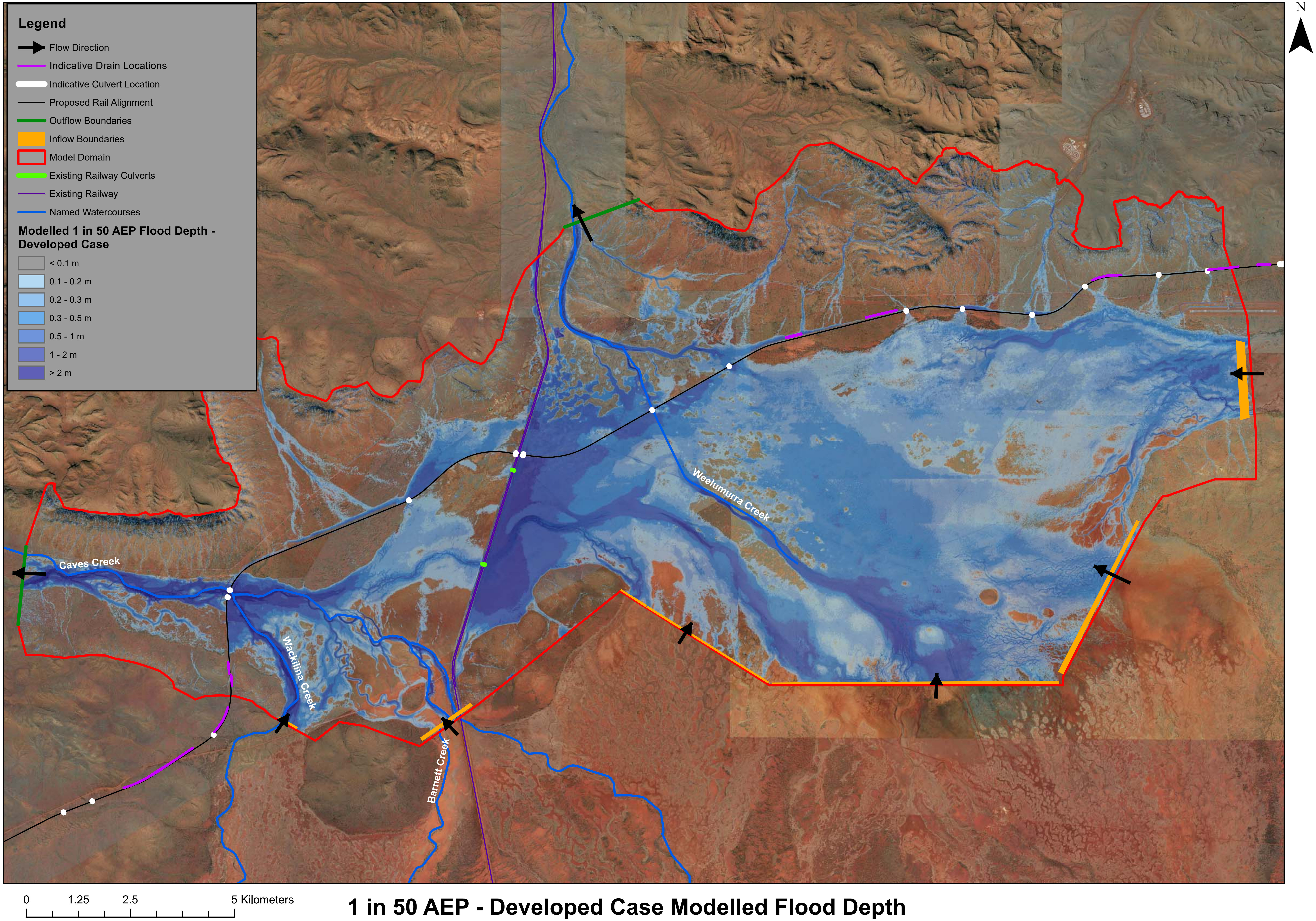
1 in 20 AEP - Existing Case Modelled Flood Depth



1 in 20 AEP - Developed Case Modelled Flood Depth

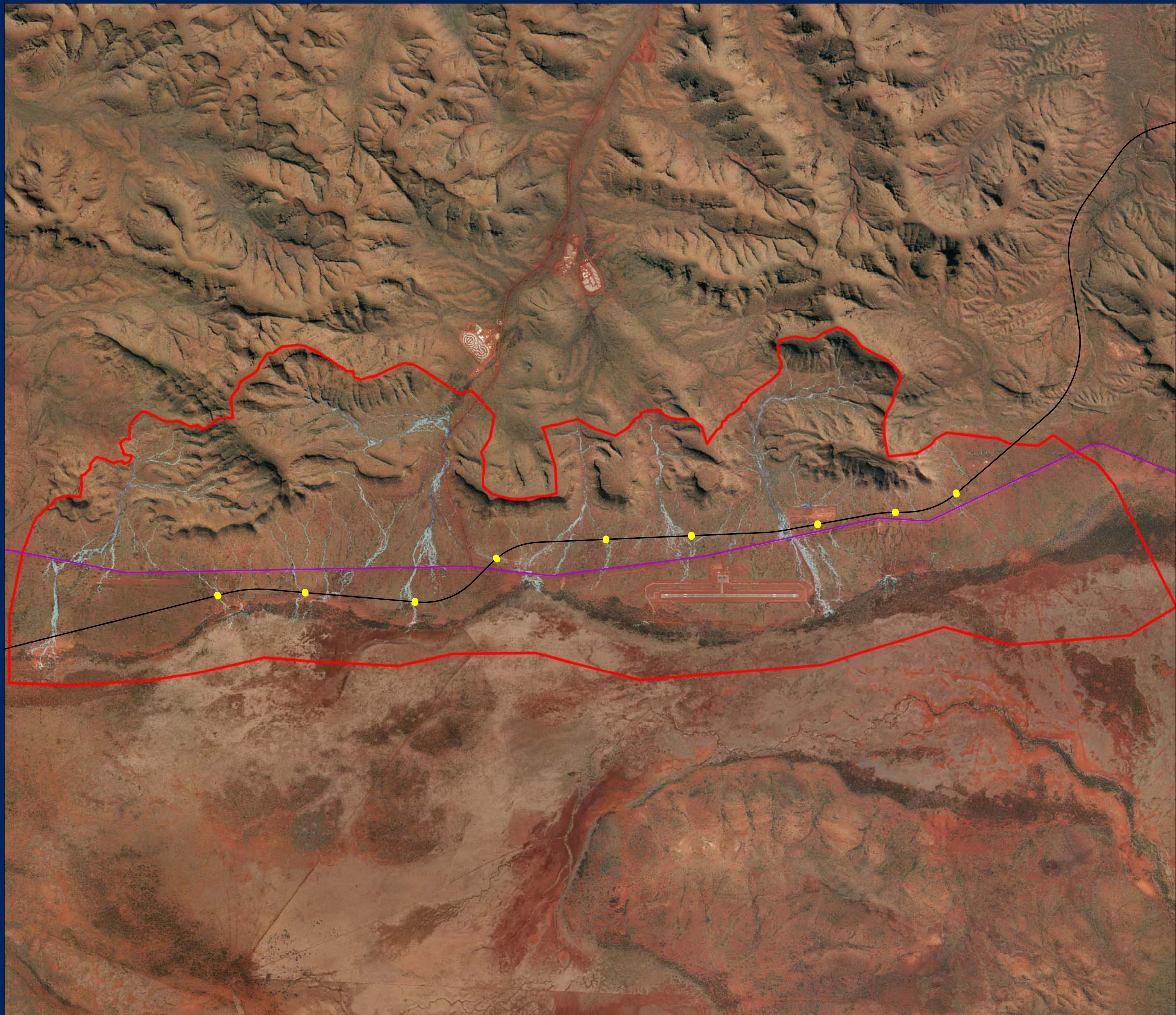


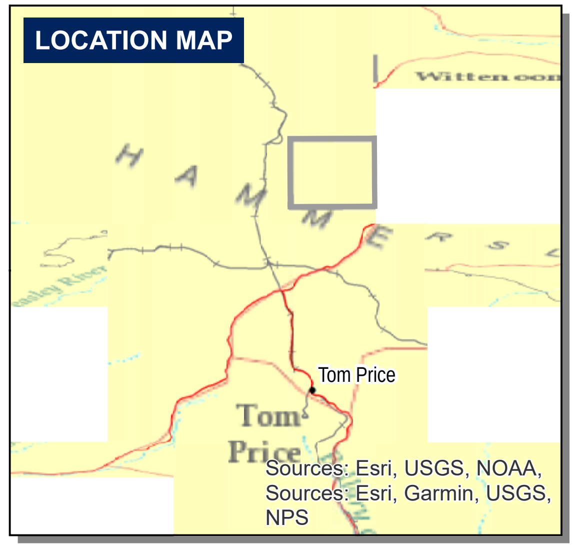
1 in 50 AEP - Existing Case Modelled Flood Depth



1 in 50 AEP - Developed Case Modelled Flood Depth

Appendix 3: Domain 2 Hydraulic Modelling Results





LEGEND

- Proposed Rail Alignment
- Road
- Model Domain
- Indicative Culvert Location

Modelled Flood Depth

- < 0.1 m
- 0.1 - 0.25 m
- 0.25 - 0.5 m
- 0.5 - 1 m
- > 1 m

N

0 0.4 0.8 1.6 2.4 3.2 Kilometers

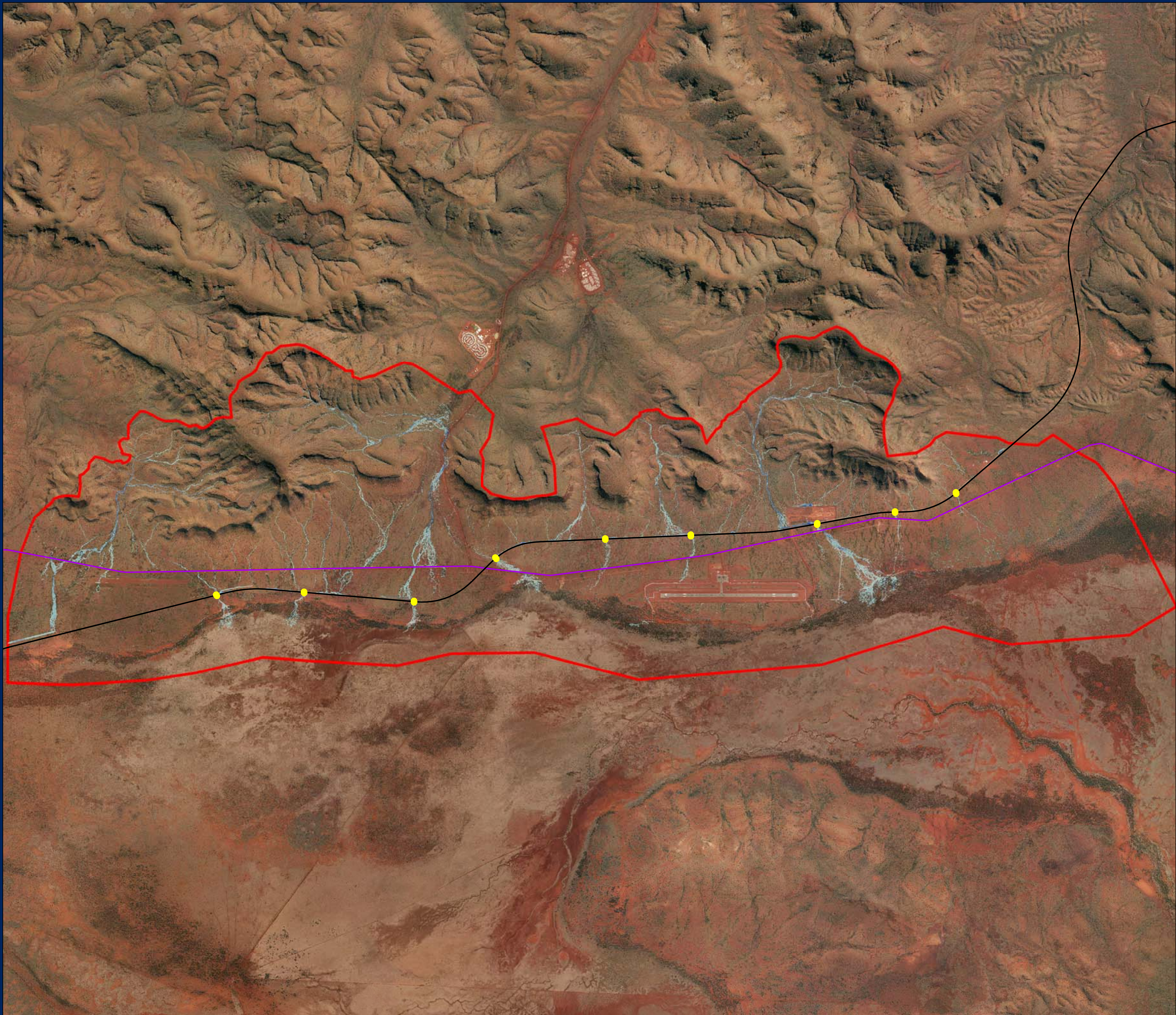
1 in 5 AEP - Existing Case Modelled Flood Depth

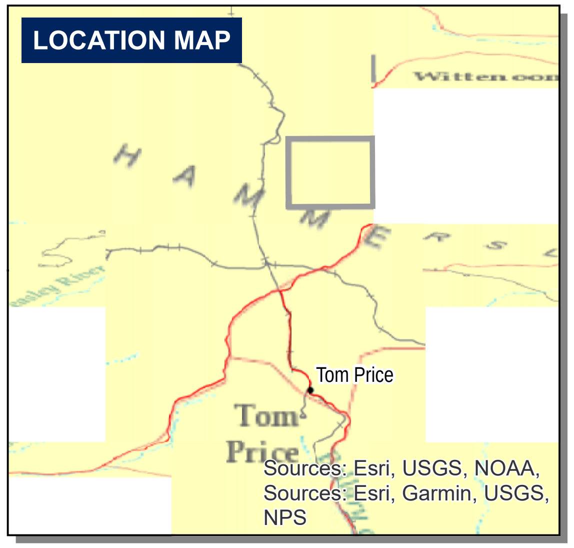
Date: 6/06/2018
Size: A3L
Revision: 2
Confidentiality: 1

Drawn By: Ryan Warrington

Scale: 1:58,000
Coordinate System: GDA 1994 MGA Zone 50

Fortescue Metals Group Ltd
The New Force in Iron Ore





LEGEND

- Proposed Rail Alignment
- Road
- Model Domain
- Indicative Culvert Location

Modelled Flood Depth

- < 0.1 m
- 0.1 - 0.25 m
- 0.25 - 0.5 m
- 0.5 - 1 m
- > 1 m

N

0 0.4 0.8 1.6 2.4 3.2 Kilometers

1 in 5 AEP - Developed Case Modelled Flood Depth

Date: 6/06/2018
Size: A3L
Revision: 2
Drawn By: Ryan Warrington
Confidentiality: 1

Scale: 1:58,000
Coordinate System: GDA 1994 MGA Zone 50

Fortescue Metals Group Ltd
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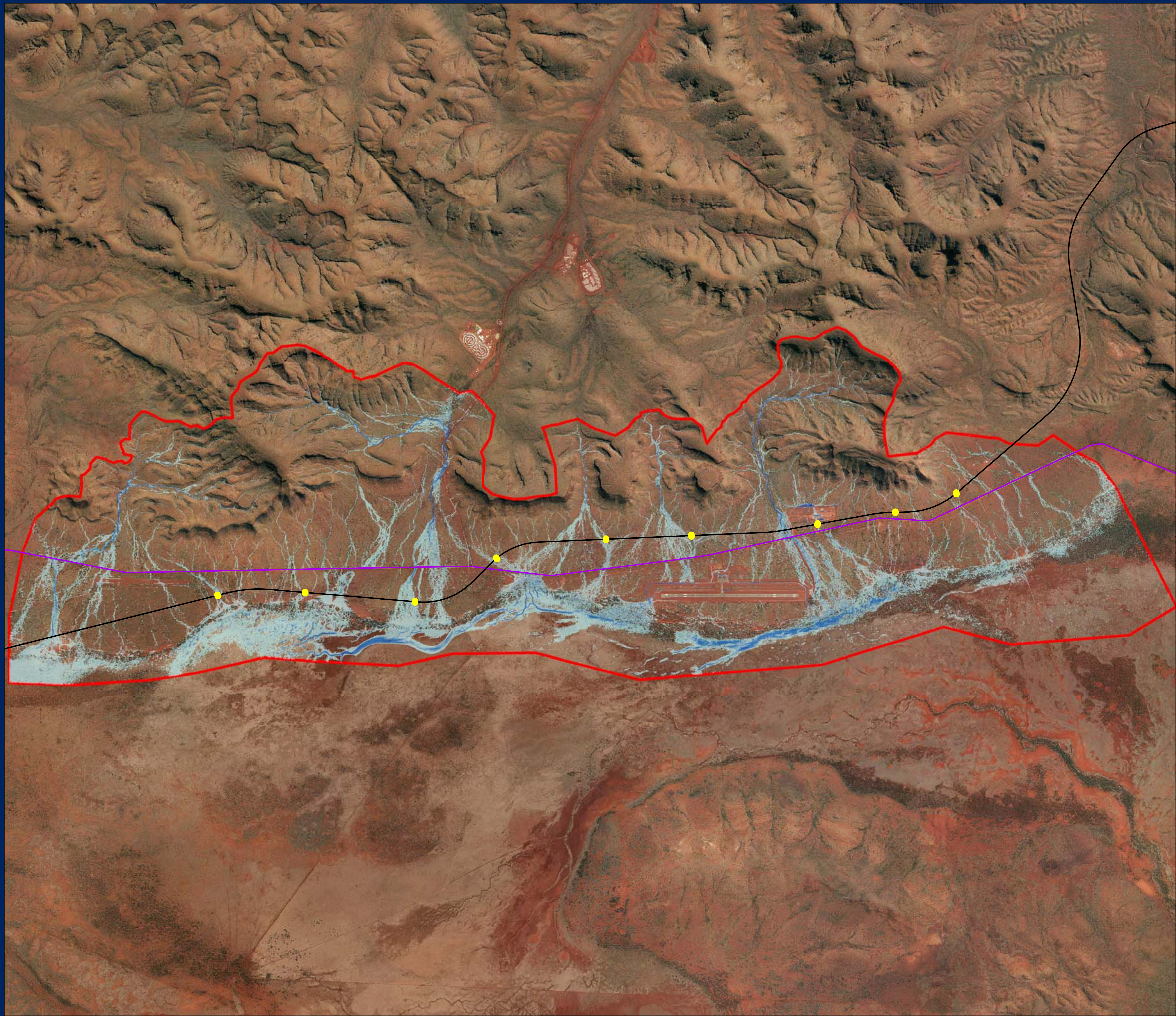

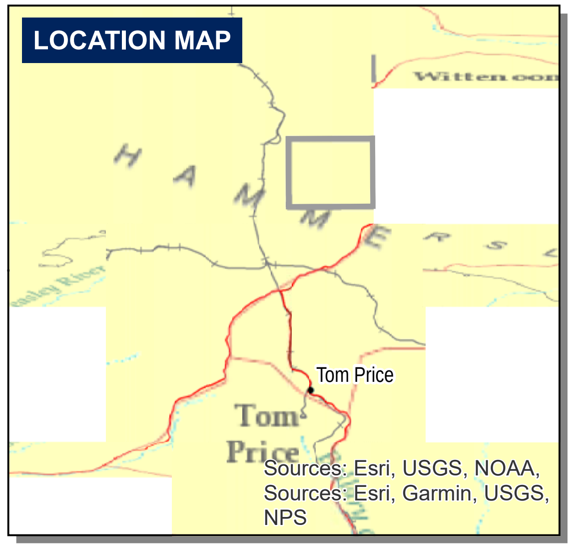

LEGEND

- Proposed Rail Alignment
- Road
- Model Domain
- Indicative Culvert Location

Modelled Flood Depth

- < 0.1 m
- 0.1 - 0.25 m
- 0.25 - 0.5 m
- 0.5 - 1 m
- > 1 m

N

0 0.4 0.8 1.6 2.4 3.2 Kilometers

1 in 10 AEP - Existing Case Modelled Flood Depth

Date: 5/06/2018
Size: A3L
Revision: 2
Confidentiality: 1

Drawn By: Ryan Warrington

Scale: 1:58,000
Coordinate System: GDA 1994 MGA Zone 50

Fortescue Metals Group Ltd
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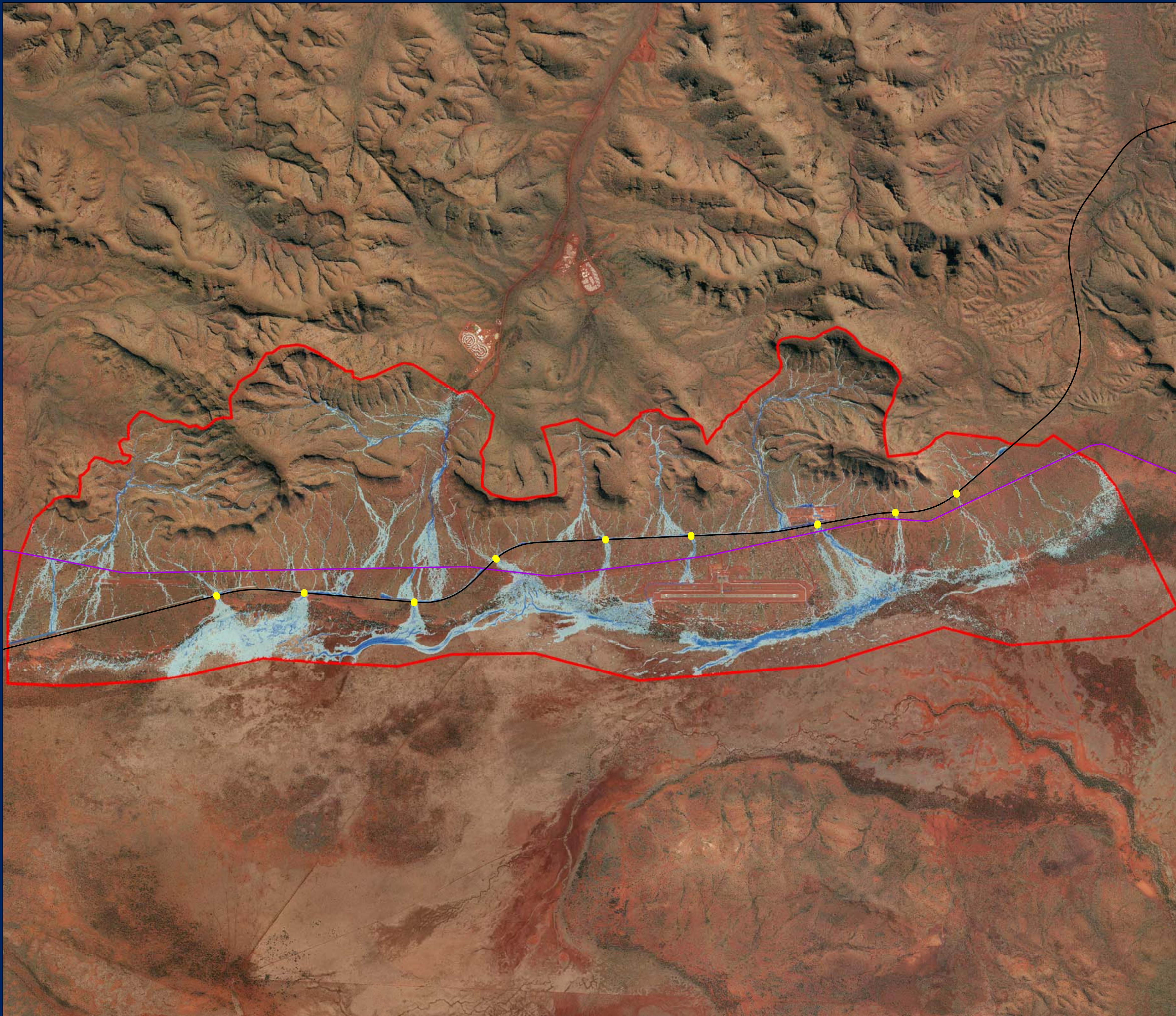

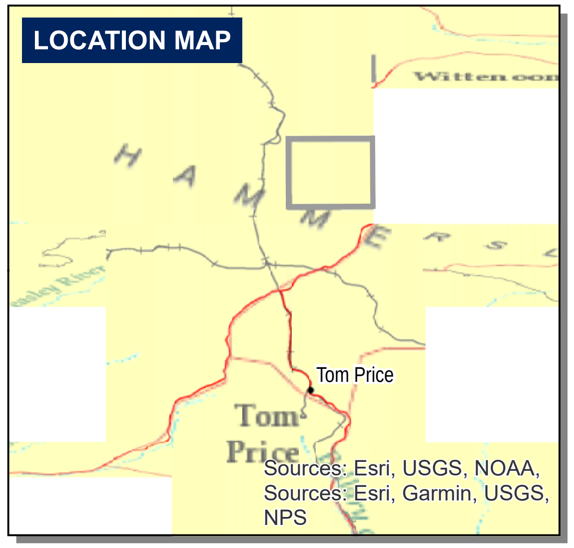

LEGEND

- Proposed Rail Alignment
- Road
- Model Domain
- Indicative Culvert Location

Modelled Flood Depth

- < 0.1 m
- 0.1 - 0.25 m
- 0.25 - 0.5 m
- 0.5 - 1 m
- > 1 m

N

0 0.4 0.8 1.6 2.4 3.2 Kilometers

1 in 10 AEP - Developed Case Modelled Flood Depth

Date: 5/06/2018
Size: A3L
Revision: 2
Confidentiality: 1

Drawn By: Ryan Warrington

Scale: 1:58,000
Coordinate System: GDA 1994 MGA Zone 50

Fortescue Metals Group Ltd
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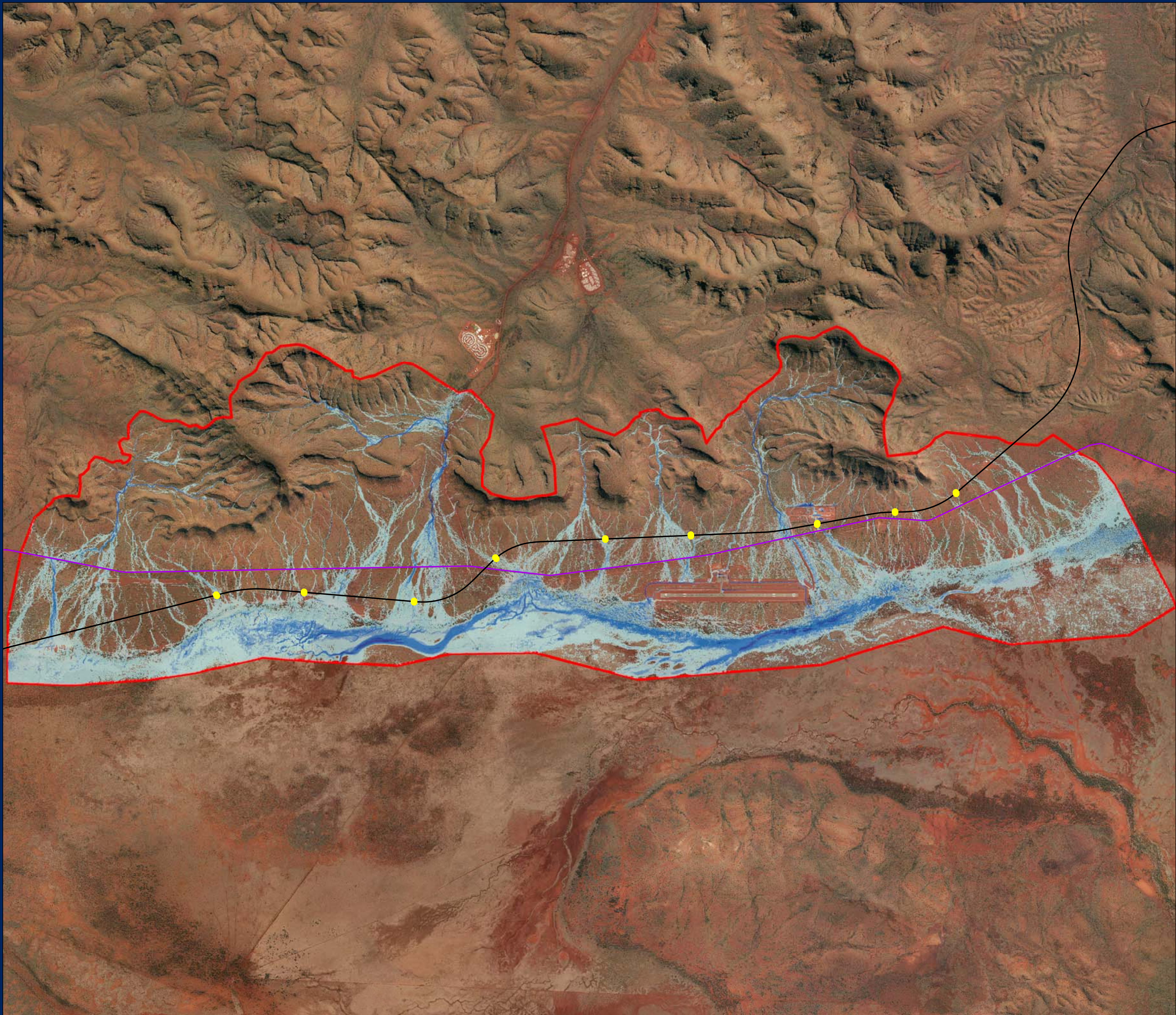

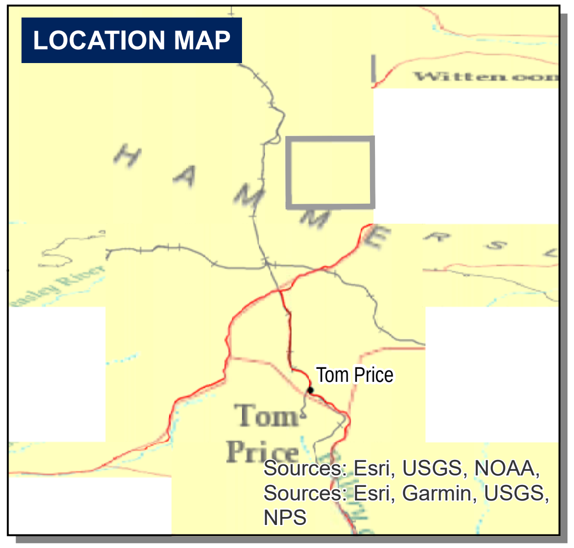

LEGEND

- Proposed Rail Alignment
- Road
- Model Domain
- Indicative Culvert Location

Modelled Flood Depth

- < 0.1 m
- 0.1 - 0.25 m
- 0.25 - 0.5 m
- 0.5 - 1 m
- > 1 m

N

0 0.4 0.8 1.6 2.4 3.2 Kilometers

1 in 20 AEP - Existing Case
Modelled Flood Depth

Date: 6/06/2018
Size: A3L
Revision: 2
Drawn By: Ryan Warrington
Confidentiality: 1

Scale: 1:58,000
Coordinate System: GDA 1994 MGA Zone 50

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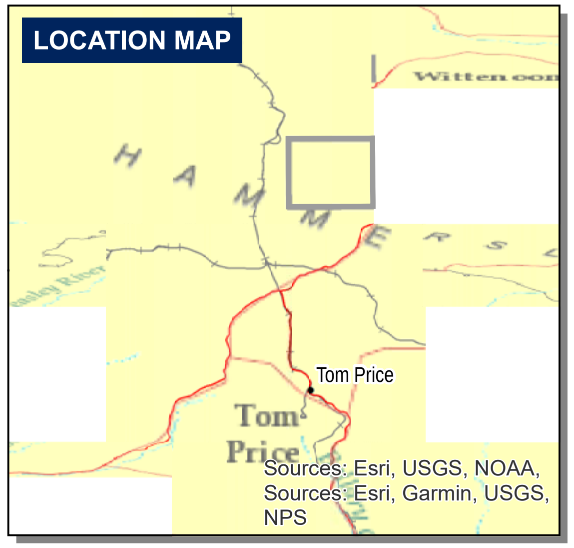

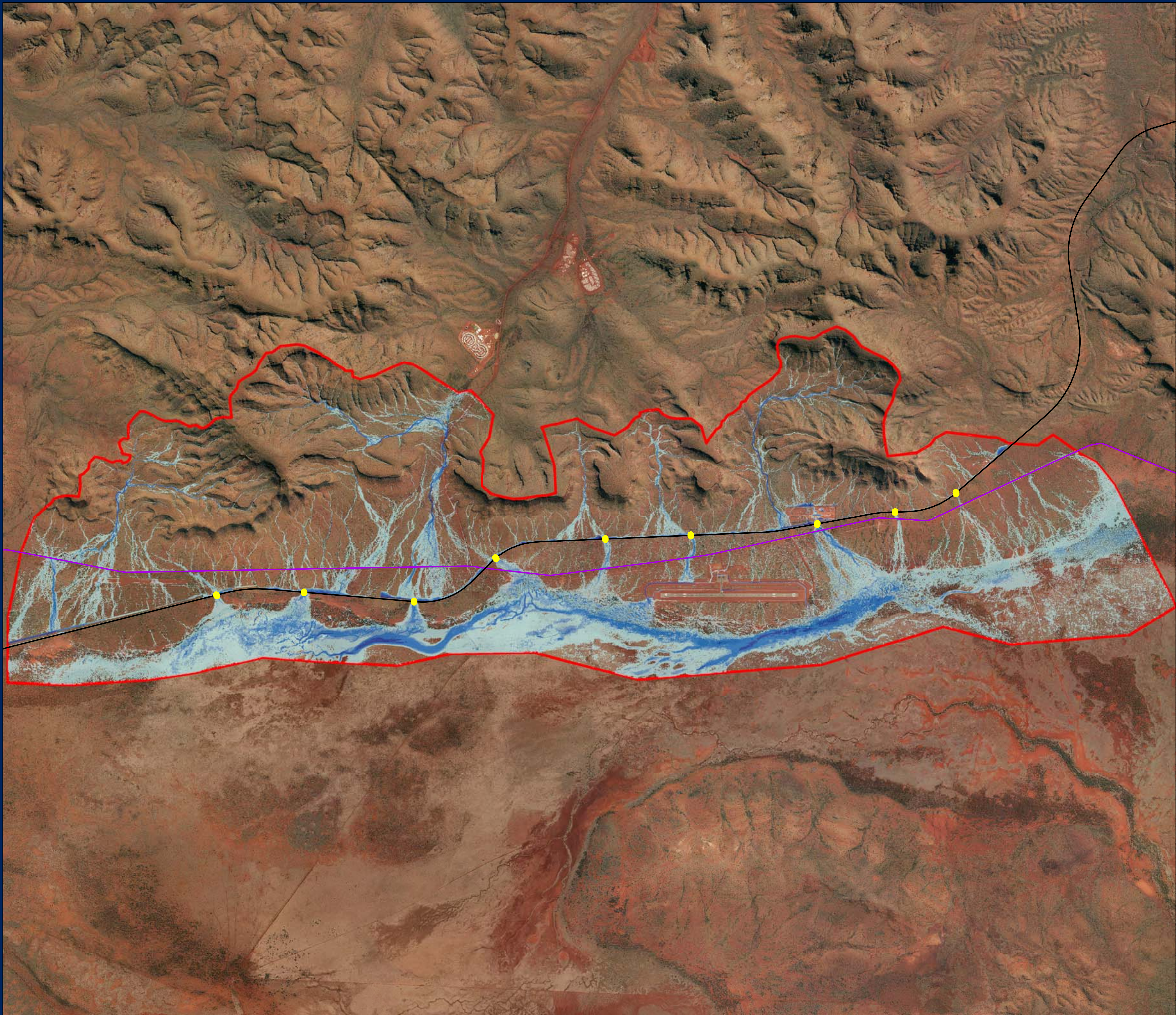

1 in 20 AEP - Developed Case
Modelled Flood Depth

Date: 6/06/2018
Size: A3L
Revision: 2
Confidentiality: 1

Drawn By: Ryan Warrington

Scale: 1:58,000
Coordinate System: GDA 1994 MGA Zone 50

Fortescue Metals Group Ltd
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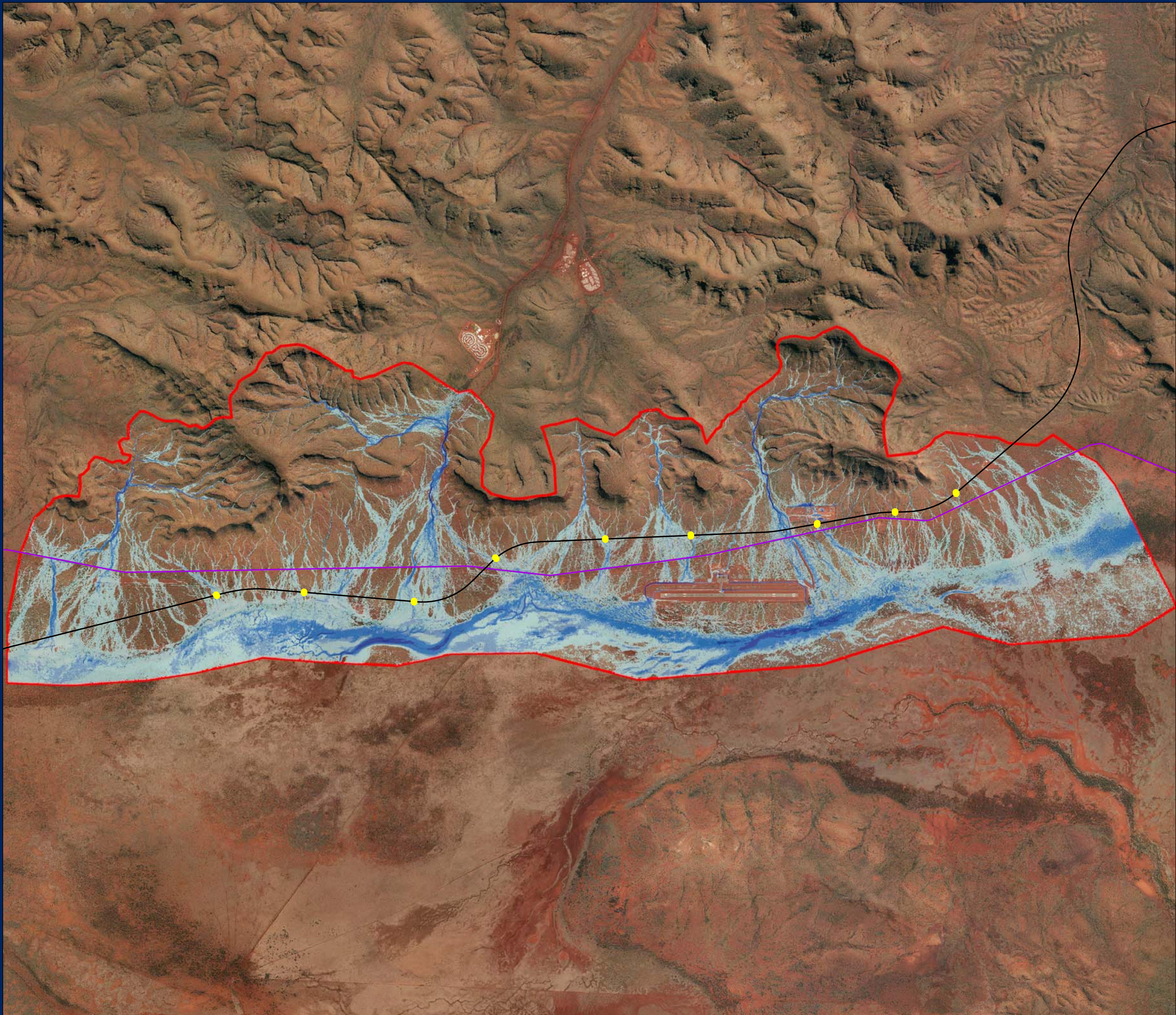
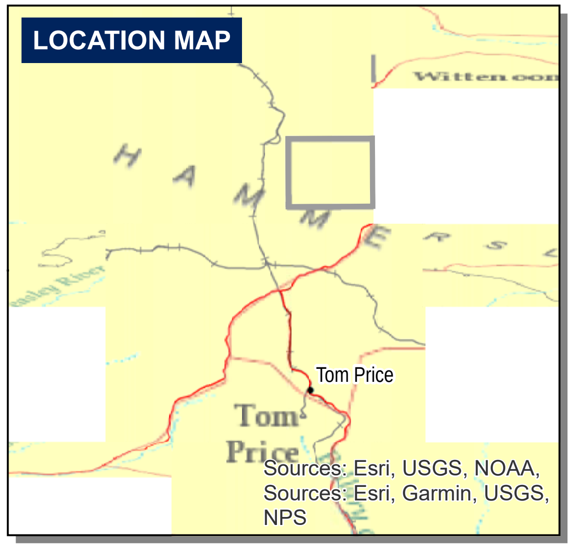




LEGEND

- Proposed Rail Alignment
- Road
- Model Domain
- Indicative Culvert Location

Modelled Flood Depth

- < 0.1 m
- 0.1 - 0.25 m
- 0.25 - 0.5 m
- 0.5 - 1 m
- > 1 m

N

0 0.4 0.8 1.6 2.4 3.2 Kilometers

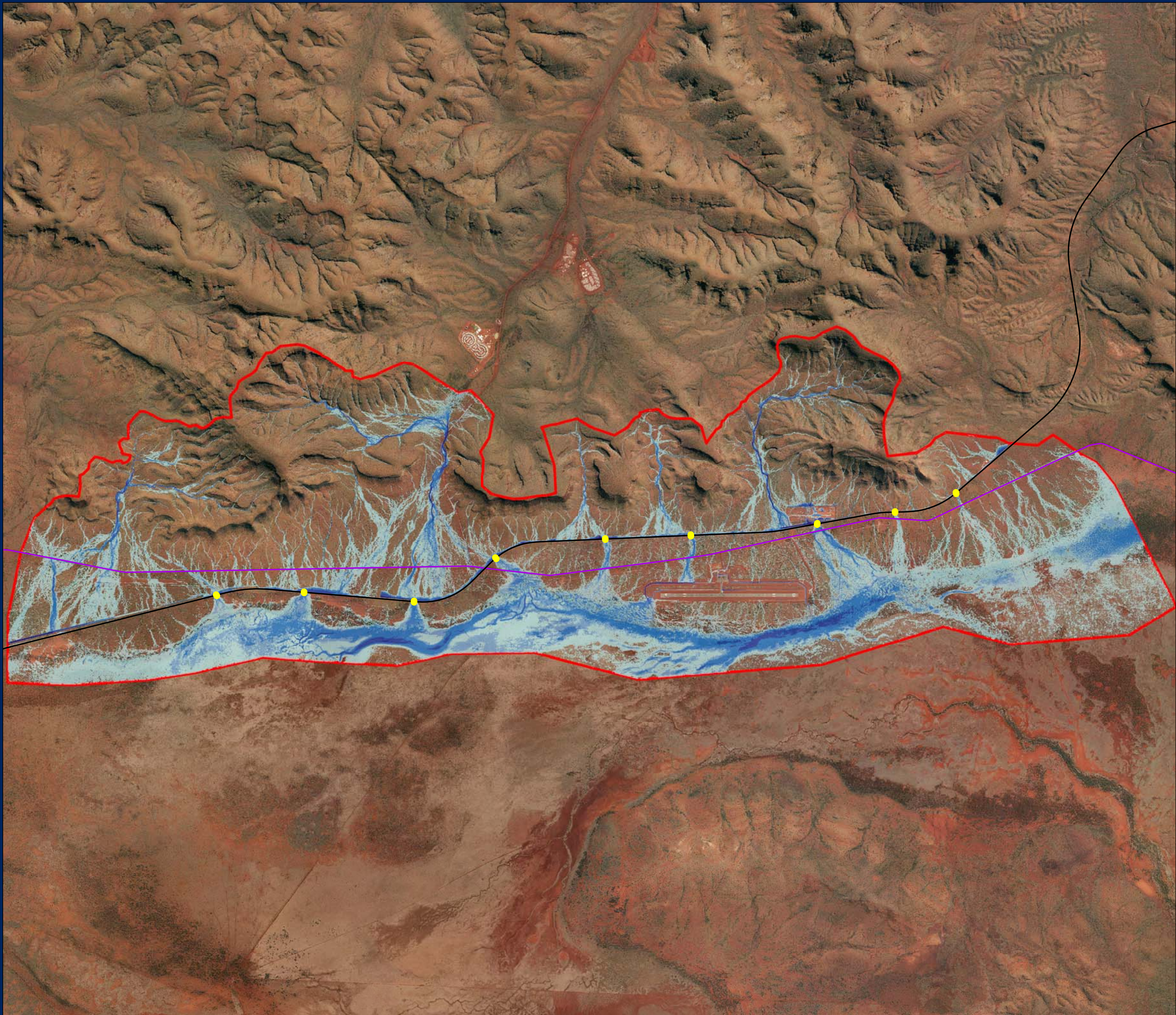
1 in 50 AEP - Existing Case Modelled Flood Depth

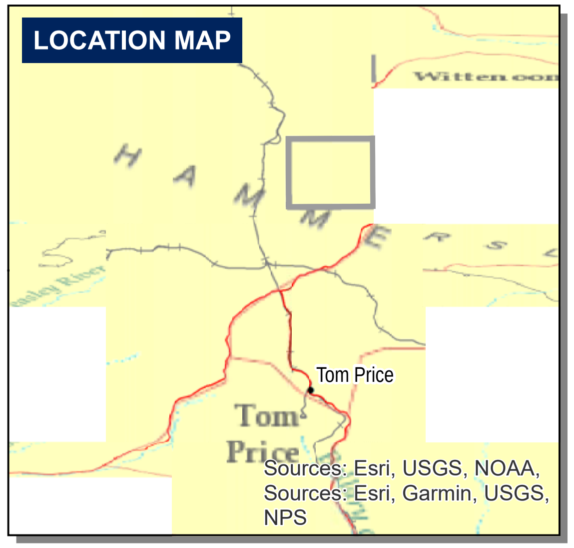
Date: 6/06/2018
Size: A3L
Revision: 2
Confidentiality: 1

Drawn By: Ryan Warrington

Scale: 1:58,000
Coordinate System: GDA 1994 MGA Zone 50

Fortescue Metals Group Ltd
The New Force in Iron Ore





LEGEND

- Proposed Rail Alignment
- Road
- Model Domain
- Indicative Culvert Location

Modelled Flood Depth

- < 0.1 m
- 0.1 - 0.25 m
- 0.25 - 0.5 m
- 0.5 - 1 m
- > 1 m

N

0 0.4 0.8 1.6 2.4 3.2
Kilometers

1 in 50 AEP - Developed Case
Modelled Flood Depth

Date: 6/06/2018
Size: A3L
Revision: 2
Confidentiality: 1

Drawn By: Ryan Warrington

Scale: 1:58,000
Coordinate System: GDA 1994 MGA Zone 50

Fortescue Metals Group Ltd
The New Force in Iron Ore