Fortescue River, Weelamurra Creek and Caves Creek Waterways Summary Report

Manuwarra Red Dog Highway Stage 4

CW1128800

Prepared for

Main Roads Western Australia

22 April 2022

Cardno®

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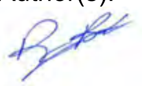

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A	17 September	Issued for Review	S Lambert	L Parsons
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1 Background and Purpose

KBR+CCS have been commissioned by MRWA to undertake a preliminary hydrologic and hydraulic assessment ("Study") of the Weelamurra Creek, Fortescue River, and Caves Creek watersheds located in the Pilbara region of Western Australia as part of the proposed Manuwarra Red Dog Highway (MRDH) Stage 4 design (refer Figure 1 below). This work is being undertaken in support of Alignment Definition activities with the primary outcome being a Preferred Project Development Corridor and concept design based on a thorough understanding of waterways management requirements.

Stream flows and roadway crossings (such as floodways, bridges and culverts) within these three watersheds will have a significant impact on the selection of an appropriate Preferred Development Corridor and the associated road concept design. As waterways management is a primary design consideration for MRDH Stage 4, it is important to have a thorough understanding of risks and opportunities related to these major waterways.

This summary report is intended to provide an understanding of the surface water regime throughout the study area, describe the identified hydrological risk factors and present the resulting proposed design criteria for adoption in managing major waterways. The report presents a clear way forward for design development that supports a regionally-considered and site-appropriate solution for management of the major waterways based on the outcomes of the following detailed investigations:

1. The **Fortescue River, Weelamurra Creek and Caves Creek Flood Study** ("Flood Study", Cardno, 2021a) which presents the data used, methodology implemented and factual results of the hydrology and modelling processes undertaken for the abovementioned major waterways and their confluence within the project area for the 'pre-development' scenario. This flood study covers over 40,000sqkm of terrain to model ad validate the statistical events driving design flows.
2. The **Fortescue River, Weelamurra Creek and Caves Creek Waterways Risks Report** ("Waterways Risks Report", Cardno, 2021b) which considers waterways risk, regional characteristics of the hydrological conditions and the development of 'Pilbara Proof' design serviceability and resilience. Climate change impacts, as they relate to the hydrologic modelling and waterways design, have been investigated with appropriate design criteria developed to manage these risks.

This Summary Report contains a high-level synopsis of the hydrologic and hydraulic analyses performed for the pre-development and post-development scenarios, a discussion of the associated risks and implications for roadway design, as well as recommendations for further waterways design development.

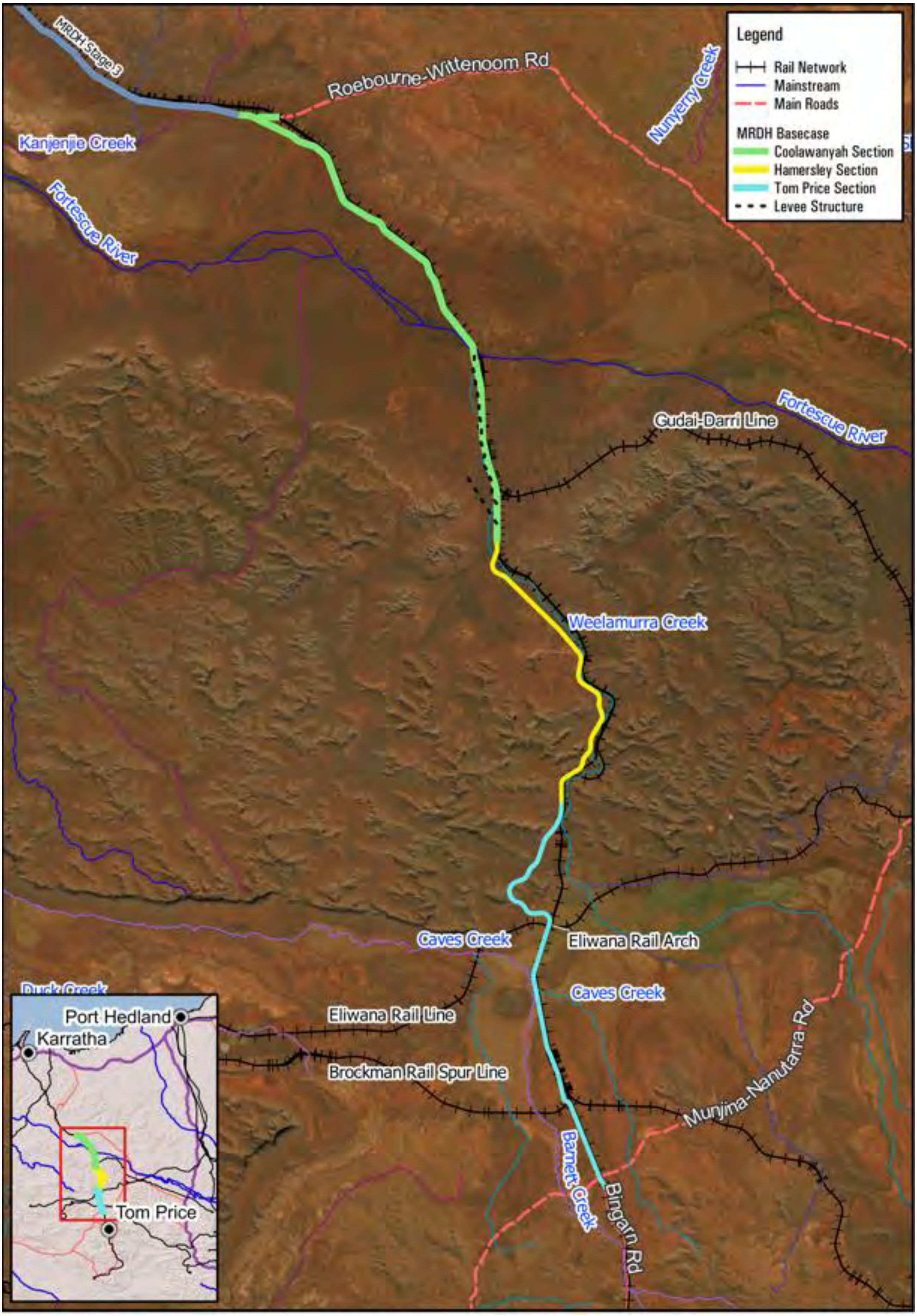


Figure 1 - Study Area and Major Waterways

2 Summary of Hydrologic and Hydraulic Analysis

2.1 Model Area

The model area for the hydraulic & hydraulic analysis includes the following large and complex catchments interacting with the MRDH Stage 4 Preliminary Project Development Corridor:

- The Coolawanyah Hydraulic model extends from the northern tie-in (to Stage 3) at Roebourne – Wittenoom Road to the Fortescue river crossing
  - The relatively small catchments in this model grade towards the Fortescue River (downstream of the project development corridor) and do not interact with the Weelamurra Creek
- The Fortescue River was considered separate to all other watercourses due to its size and complexity however the confluence with Weelamurra Creek was assessed for its impacts on the preliminary project development corridor.
- South of the Fortescue River crossing, Weelamurra Creek is modelled and includes for:
  - RTIO levee controls
  - Parallel flows to the RTIO railway (and the MRDH Preliminary Project Development Corridor)
  - Multiple sub-catchments throughout the Hamersley Ranges that flow both west to east and east to west across the RTIO rail infrastructure and MRDH Preliminary Project Development Corridor.
- South of the Hamersley Ranges, the Eliwana floodplain, Caves Creek, and Barnett Creek interact and eventually flow into the Ashburton River.

The above catchments and model extents are provided in Figure 2.

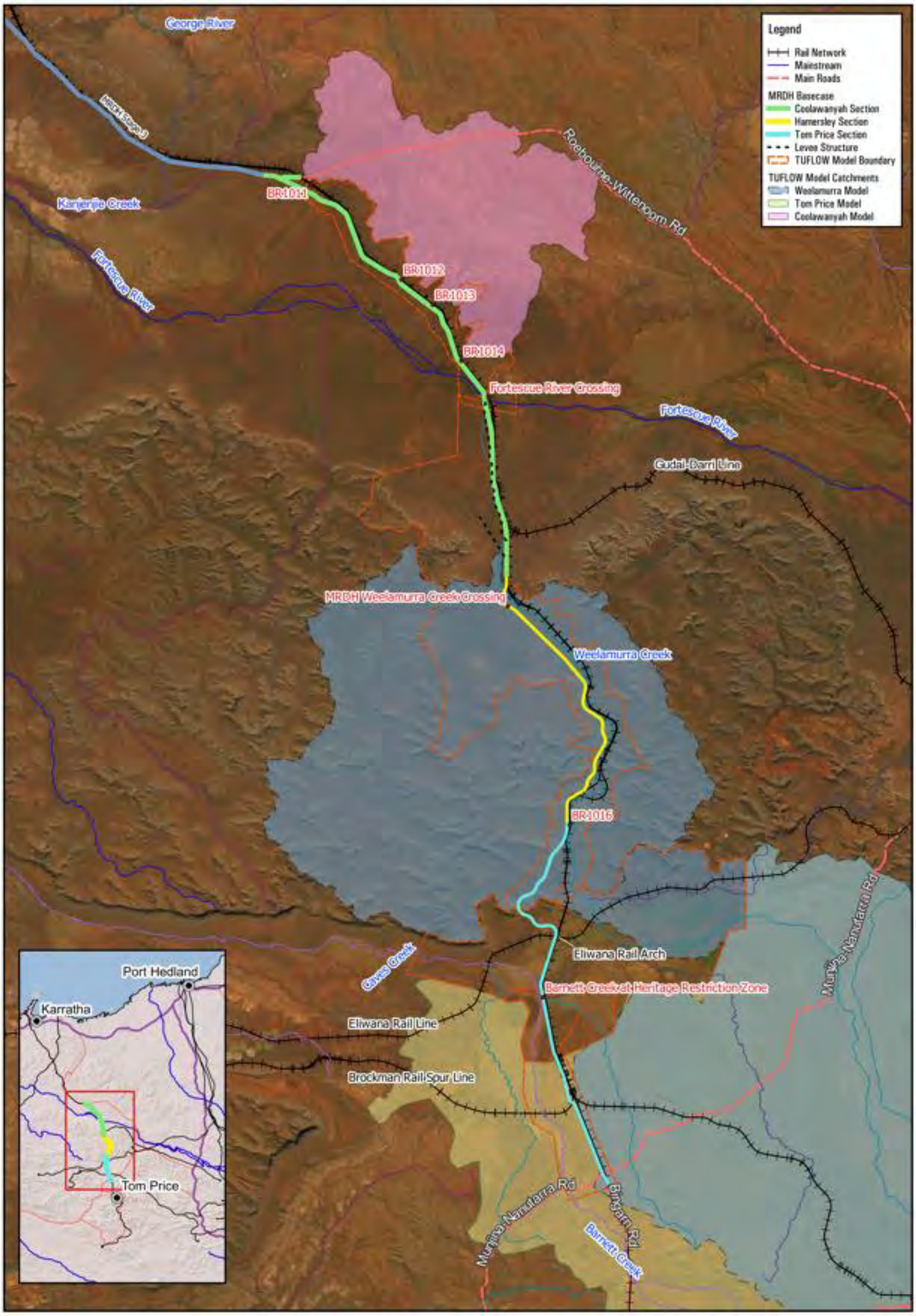


Figure 2 - Catchment Area and Model Extent

2.2 Pre-Development Analysis

To achieve the Flood Study objective, hydrologic and hydraulic models of the study area were developed using RORB Runoff Routing software and TUFLOW Hydraulic Modelling software. The design rainfalls for the 50%, 20%, 5%, 2% and 1% AEP events were applied to the runoff routing models using coarse elevation data. The output from these models were hydrographs which provide information about the critical rainfall durations in the Study area. The hydrographs were then used as inputs for more detailed TUFLOW 2D hydraulic models which showed how the runoff performs on the existing topography, including flow velocities and depths.

Existing infrastructure developed by mining companies are included in the ‘pre-development’ model as these attenuate and control the watersheds, significantly altering the ‘natural’ flows. In particular, the RTIO main rail alignment and Brockman spur line, associated culverts and bridge structures control east to west flow on the eastern side of the MRDH corridor. The RTIO levee system at Weelamurra Creek controls the watershed to the west of the road corridor as seen in Figure 2. The FMG Eliwana rail line bisects the road corridor and crosses the RTIO main alignment in the Caves Creek floodplain. This data was sourced from the asset owners, aerial imagery and LIDAR survey.

The adopted hydrological methodology is consistent with the latest industry and current best practice for hydrological modelling as defined by:

- Australian Rainfall and Runoff: A Guide to Flood Estimation, Commonwealth of Australia (2019).
- Design Flood Estimation in Western Australia, Australian Journal of Water Resources (2012).
- Estimation of RORB Kc parameter for ungauged catchments in the Pilbara Region of Western Australia, Proceedings of the 2014 Hydrology and Water Resources Symposium, 24 – 27 February, Perth (2014).

Throughout the model development, advice was sought from Jerome Goh, a waterways specialist with substantial experience in the Pilbara region. Jerome assisted with the development and validity assessment of the models using his extensive knowledge of local conditions.

The hydraulic model outputs were analysed, validated and used to create detailed maximum depth, velocity and hazard plans across the study area for the ‘pre-development’ scenario (refer Appendix A). These are also provided as layers in ‘ProjectMapper’ for full interrogation by the project team. From the model outputs and this mapping, it is apparent that the hydrologic risks of note are:

- High flow depths at major crossings in the Coolawanyah section and at Fortescue River.
- Interaction with existing Rio Tinto levees which direct Weelamurra Creek.
- Braided flows and narrow widths in Weelamurra Creek may cause difficulty for road crossings.
- Water levels in the flood plain at the Eliwana railway road under rail arch.
- Confluence of flows of Barnett Creek and Caves Creek near the proposed road alignment and the Rio Tinto railway.

The peak design flows at selected major tributaries are summarised in Table 2-1 below (locations are provided in Figure 2:

Table 2-1 Peak design flows at selected major tributaries (m^3/s)

Location / Landmark	20% AEP	5% AEP	2% AEP	1% AEP
Coolawanyah – Bridge 1011, Cowcumba Creek	63	461	792	1049
Coolawanyah – Bridge 1012	8	44	78	101
Coolawanyah – Bridge 1013, Ballyeerina Creek (north)	9	61	107	139
Coolawanyah – Bridge 1014, Ballyeerina Creek (south)	8	52	91	119
Coolawanyah – Fortescue River crossing	656	1525	2070	2371
Hamersley - MRDH Weelamurra Creek crossing		700	1200	
Tom Price - Upstream of Bridge 1016	13	39	60	77
Tom Price - Barnett Creek at heritage restriction zone	149	406	685	969

2.3 Post-Development Analysis

Hydrologic and hydraulic models of the study area were further developed from the 'pre-development' model with the inclusion of the Base Case Concept Design (the 'post-development' scenario). RORB Runoff Routing software and TUFLOW Hydraulic Modelling software evaluated the design rainfalls for the 50%, 20%, 5%, 2% and 1% AEP events.

Throughout the 'post-development' model development, advice was sought from Jerome Goh, a waterways specialist with substantial experience in the Pilbara region. Jerome assisted with the development and validity assessment of the models using his extensive knowledge of local conditions. Mr Goh also provided input to options at waterways crossings or suggested alternatives for consideration that are discussed within this report.

The hydraulic model outputs were analysed, validated and used to create detailed maximum depth, velocity and hazard plans across the study area for the 'pre-development' and 'post-development' scenarios, as well as comparative mapping comparing between the two scenarios. From the model outputs and this mapping, the hydrologic locations of note are:

> High flow depths at major crossings in the Coolawanyah Section and at the Fortescue River crossing.

> Interaction with existing Rio Tinto levees which direct the Weelamurra Creek parallel flow away from the RTIO rail alignment.

> Braided flows and narrow widths in Weelamurra Creek may cause difficulty for road crossings.

> Water levels in the floodplain in the vicinity of the FMG Eliwana railway crossing both the Preferred Project Development Corridor and the RTIO main rail alignment.

> Confluence of flows of Barnett Creek and Caves Creek near the proposed road alignment and the Rio Tinto railway.

Key risks associated with the hydrology within, and influencing, the project area that have an immediate impact on design outcomes include:

> Backwater impacts on third party infrastructure (Rio Tinto or FMG rail and access track embankments)

> Serviceability – road closure frequency and duration during storm events

> Resilience – ability of the road embankment to withstand storm events with minimal remediation or maintenance activities to resume normal operations

> Complexity and variability of channel flows (confluence areas impacting road design, main channel variability in different events, parallel creek flows)

> Complexity of the likely waterways design solution(s) to manage the above risks

These hydrological risks are further detailed in the table below and were assessed using the approved project risk tables.

Table 2-2 Identified high waterways risk locations

Hazard	Consequence	Severity	Likelihood	Risk
Backwater impacts from MRDH on third party infrastructure	Closure of railway Embankment and track reconstruction	Catastrophic	Possible	Extreme
Reduced serviceability due to high flows	Closure of road for long periods during events while the upstream catchment is draining	Major	Possible	High
Insufficient resilience of MRDH to high flows	Failure of road pavement, embankment or other component due to high flow velocities or inundation Failure of levees, bridge abutments, scour protection	Major	Possible	High
Insufficient design appreciation of complex channel flow	Changing upstream main channel flows	Major	Possible	High

	Embankment scour – reduced resilience Overtopping of road – reduced serviceability			
Insufficient design appreciation of complex waterways design requirements	Embankment scour – reduced resilience Overtopping of road – reduced serviceability Under / over design of drainage controls Longer periods of inundation adjacent to the road in floodplains – reduced resilience of the road embankment & pavement	Major	Possible	High

2.3.1 Consideration of risks during Alignment Definition

Upon completion of the base case design, the hydrologic & hydraulic models were updated to understand the resulting changes to watershed within the Preliminary Project Development Corridor. Alignment Definition activities have aimed to address the above risks, in the first instance, through the investigation of alternative horizontal and vertical road geometries. In particular, the proximity of the road alignment to the existing Rio Tinto railway requires that the design of the road appropriately considers how the change in flow conditions caused by the road could impact Rio Tinto assets. This involves issues such as increased water levels due to flow constrictions that could cause overtopping, or scour to embankments or other structures. The post-development model provided design teams with outputs to evaluate the impact of different design solutions across all the above identified risks, determined which alignment resulted in fatally flawed outcomes and provided guidance on the final offsets and/or treatments at major waterways crossings (refer "Waterways Risks Report", Cardno, 2021b).

This refinement will continue throughout final Concept Design, with the 'Post-Development' hydraulic & hydrologic models being updated to include the final concept alignment and resulting watershed impacts.

2.3.2 RTIO Levees

Two sets of levees constructed by Rio Tinto are present within the Coolawanyah Section of the MRDH4 project. The levee banks are constructed to provide protection to the Rio Tinto railway line and provide protection against flood waters which occur during large rainfall events in the region. Should these levee banks fail, there is the potential for washout of infrastructure to the east of the levees. A review of historical imagery suggests the second levee was built in the 1960s at the same time as the original railway, while the upstream levee was built separately in the 1970s.

Modelling indicates that some 50-year flood events could cause overtopping at the upstream levee, which would be generally managed by the second levee (modelling indicates this would not be overtopped in this scenario). Failure of both levees is likely to result in damage to the Rio Tinto railway and the proposed MRDH4 road. Figures presenting these situations are provided in Appendix C.

A site inspection at the second levee indicated substantial deterioration to the structure from apparent parallel flow. A failure of only the second levee, at a location in the vicinity of the observed deterioration is unlikely to substantially impact infrastructure (refer "Waterways Risks Report", Cardno, 2021b).

2.4 Climate Change & Environmental Considerations

2.4.1 Climate Change

Future climate change impacts on hydrology and hydraulics were considered using current rainfall data with 2050 RCP4.5 and 2070 RCP8.5 interim climate change factors. It is recommended that 2070 RCP 8.5 rainfall data be adopted for design to ensure due consideration is given for whole-of-design-life road serviceability and resiliency.

Whole-of-life project costs (including the operations & maintenance implications of climate change) must be balanced with the associated climate change storm event risks when deciding the design criteria for waterways infrastructure. It is recommended that further investigation into balancing the costs and benefits of this 'whole of life' approach be undertaken to assess the value of early investment into the road design.

2.4.2 Environmental Risks

Identification of areas in which flow conditions may change following construction of the road were identified through the use of difference maps which compare pre- and post-development flow depths and were discussed when evaluating alignment options. These results should be communicated to stakeholders, such as pastoralists and Traditional Owners, as the change in flow conditions has the potential to adversely affect vegetation.

The extent of impact in an area will generally depend on terrain slopes in the area and the angle of the road compared to the terrain. In gently sloping areas the impact of the road could be substantial as it has the potential to obstruct considerable flow if it is perpendicular to the natural flow direction.

In particular, the Mulga communities present in the southern portion of the Tom Price Section (approx. cha 22,300 to 38,300) are susceptible to changes in flow conditions. The Base Case road alignment generally (and deliberately) matches the direction of fall in the area, resulting in a low risk of substantial changes in flow obstruction to the sensitive community.

2.5 “Pilbara Proof” Design

At the behest of the Regional Manager, Pilbara, a key philosophy driving waterways design is the understanding of local conditions and the undertaking of a ‘Pilbara-Proof’ design. In the context of waterways design, the development of ‘Pilbara-Proof’ design criteria is focussed on serviceability and resilience outcomes based on a comprehensive understanding of local hydrological conditions and Stakeholder expectations.

The project team undertook workshops and community consultation to better understand Stakeholder expectations for MRDH serviceability and continuity of access during severe weather events. The key finding from this process was that road closures are acceptable for short periods (less than a week) during (and directly after) major storm events, as there are alternative routes available between major centres serviced by MRDH. However; closures for remediation and maintenance are considered unacceptable, particularly for events considered ‘normal’ in this region (i.e. cyclones).

2.6 Anecdotal Considerations

Anecdotal evidence, or ground truthing of prior flood events, is of significant value in ungauged catchments like those considered for MRDH4. An example of information provided by local Stakeholders is provided in Appendix B, with photographs and discussion provided by Coolawanyah Station regarding a 2013 flood event.

Jerome Goh, who has substantial waterways experience in the Pilbara region, has assisted in development of the hydrologic and hydraulic models, as well as assisted in the identification of waterways risks and opportunities. His ongoing advice throughout model development and interpretation, based on over 40 years’ experience, has been instrumental in ensuring model outputs are valid for the level of detail they are being used.

Additional information on actual conditions during flood events will assist to calibrate and validate the hydrologic and hydraulic models on which the models and risk assessments are founded.

3 Waterways Design Recommendations

Through an informed understanding of key hydrologic risk areas, the implications of climate change, and the requirements for a 'Pilbara-Proof' design, the following design criteria are recommended for adoption in the waterways design going forward:

Table 3-1 Waterways Design Criteria

Element	Location	Criteria	Value	Unit
Serviceability / maximum road closure time due to flood water *i.e. normal crossings should be designed to be closed for no longer than 12 hours in a 5% AEP event.*	Normal crossings	10% AEP	0	hours
		5% AEP	12	hours
		2% AEP	72	hours
	Fortescue River floodway crossing	50% AEP	12	hours
		20% AEP	72	hours
		5% AEP	120	hours
	Bridges	1% AEP	12	hours
	Overall MRDH4 alignment	50% AEP	12	hours
		20% AEP	72	hours
		5% AEP	120	hours
Road closure in both directions for reconstruction following flooding	All crossings	2% AEP	0	hours
Floodway dry serviceability	Normal crossings	50% AEP		
Floodway wet serviceability	Normal crossings	20% AEP		
Culvert capacity	Non-floodway crossings	10% AEP		
Culvert scour treatments extents & sizing	All culverts	1% AEP		
Resistance to scour scenarios	All potential overtopping locations	1% AEP		
Pavement inundation duration without specialist treatment *i.e. all crossings & drains that are inundated for longer than 24 hours in a 10% AEP event will require specialist treatment in consideration of pavement resilience.*	All crossings and drains	10% AEP	24	hours
Roadside/formation drains	All locations	10% AEP		
Bridge dry serviceability	All locations (Weelamurra Creek Crossing)	2% AEP		
Levees – overtopping avoidance or scour protection	All locations	1% AEP		
Third party adverse backwater impacts	All locations	2% AEP	0	mm

3.2 Other Design Recommendations

Other design considerations when adopting the above design events and outcomes should be included in design calculations:

1. Design criteria adopted in each instance & location are to be 'worst-case' up to (and including) the proposed design event

2. Pavement inundation durations and impacts should be reviewed and adjusted if required by the project geotechnical consultant once detailed geotechnical data is available. This may result in greater embankment heights to accommodate capillary rise in locations of long duration inundation (i.e. floodplains)
3. Allowance for climate change has been included by adopting a rarer storm event using current (RCP 4.5) IFD data that is equivalent to worst case RCP 8.5 modelling.
4. All adverse impacts to third-party infrastructure (especially to assets within State Agreements) should be avoided as a general rule. Detailed investigation must be conducted at locations where this is likely to determine if an increase in backwater is acceptable to the asset owner. For example, a water level increase could be considered an acceptable risk when it occurs downstream of an existing culvert which is operating under inlet control conditions as it is likely to result in any adverse impact (i.e. changes to flow rate).
5. Impacts on sensitive environmental & heritage receptors to be evaluated for high probability events together with key stakeholders in all locations
6. Check to ensure the MRDH embankment is not impacted by downstream turbulence caused by flows controlled by the adjacent railway infrastructure i.e. high velocities and flows through rail culverts or bridges may result in dangerous velocities and flow depths across the road if not sufficiently controlled.
7. An important lesson learned from previous stages of MRDH development is the careful and comprehensive consideration of waterways risks. Ad hoc discussions with previous stage Site Superintendents, Jerome Goh and private asset owners directly impacted by Stage 4 have identified the following design suggestions to be adopted going forward:
    a. Roadside drains to be trapezoidal (not V-shaped) with a 1% min grade away from the road embankment
    b. Concrete floodways to be adopted for major floodway locations

3.3 Opportunities for Innovation and Sustainability

The following considerations identified within Alignment Definition Phase are not included in the above design criteria, but may provide opportunities for efficient management of waterways risks and are presented for consideration in delivery:

> Use of ITS for real-time floodway monitoring and road closures. There is an opportunity to install remote signage with a pre-warning system (ITS) that can warn road users of road closures and/or flooding during significant events well before they arrive at the crossing, allowing them to choose alternative and safer routes.
> Road furniture design – consideration of resilience during periods of significant inundation, or damage to other significant events (i.e. bushfires). This may necessitate a higher design standard but will minimise maintenance costs and extend the serviceable life of the asset.
> Fencing design – installation of fencing system in major waterways that will break back and/or blow over at a certain pressure and then reposition after the event to minimise maintenance and intrusion of livestock into the road reserve where it is fenced.
> Consideration of Rest Area locations between, or adjacent to, major waterways likely to be closed during severe events to provide safety & shelter until the road is safely traversable. Suggest that these locations also provide public facilities such as water tanks and toilets for hygiene.

3.4 Limitations and Recommendations for Future Design Stages

Key limitations of the current studies that are recommended to be rectified prior to further ‘Business as Usual’ model development beyond concept design include:

> Updating the topographical & survey data used to generate the hydrologic and hydraulic models to rectify the current varied levels of accuracy and resolution

> A ground survey of the existing waterways and infrastructure adjacent to the MRDH alignment including road & rail embankments, culverts, levees, and bridges. Adjacent infrastructure information used for the current study has not been received directly from the asset owners and can therefore not be relied upon.
> Discussions regarding waterways management with the Traditional Owner’s should continue and may result in additional design considerations
> Further modelling will be required to perform detailed design, including consideration of culvert crossing sizes, bridge scour analysis, roadway embankment stability, etc.

APPENDIX

A

‘PRE-DEVELOPMENT’ MODEL OUTPUTS

The following figures have been extracted from ProjectMapper for information purposes only. Detailed data for other events and at specific locations can be provided upon request.

Figure A01 - 1:10 year 'Pre-Development' Maximum Flood Depths (m) – Coolawanyah Section

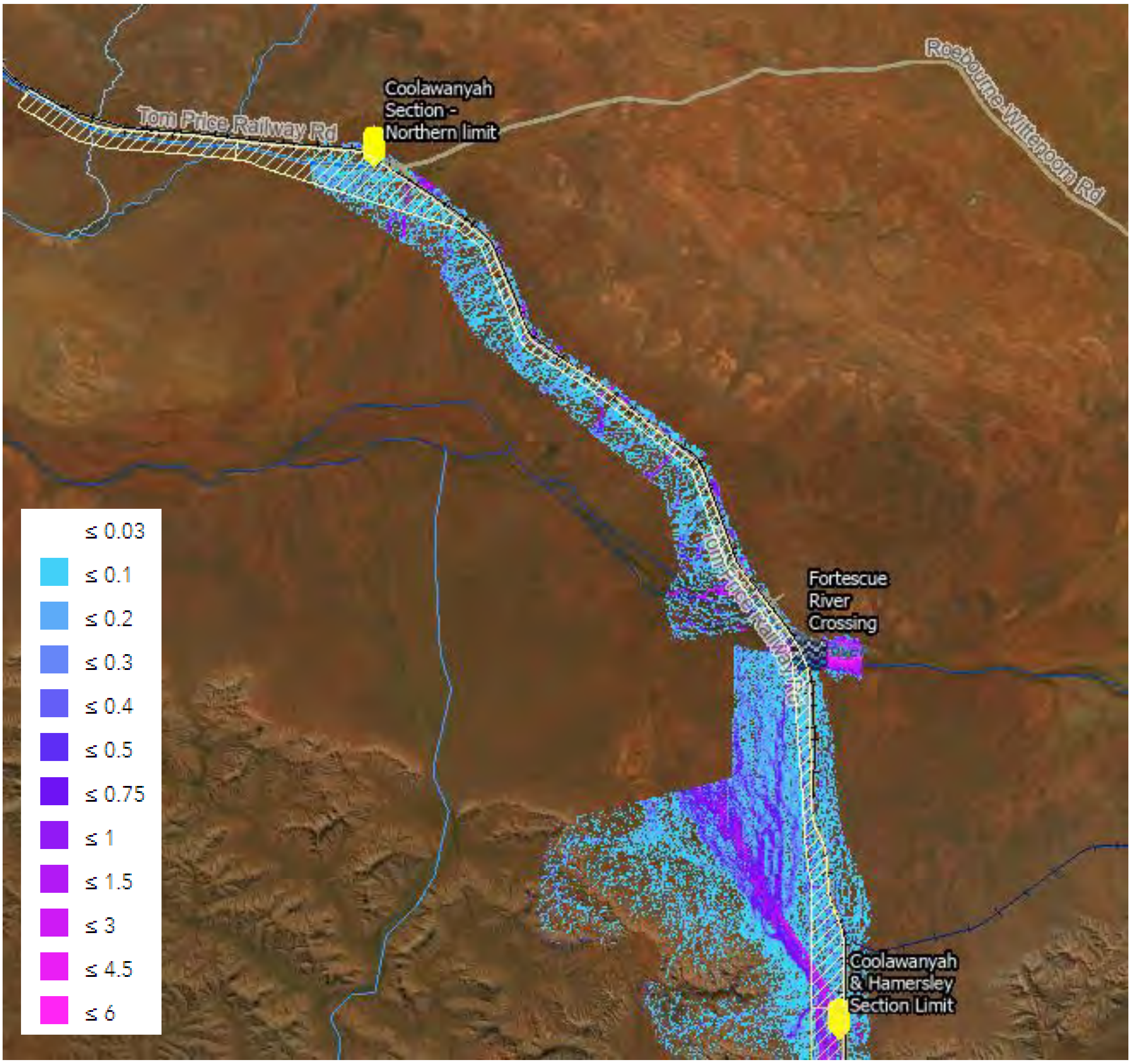


Figure A02 - 1:10 year 'Pre-Development' Maximum Flood Depths (m) – Hamersley Section

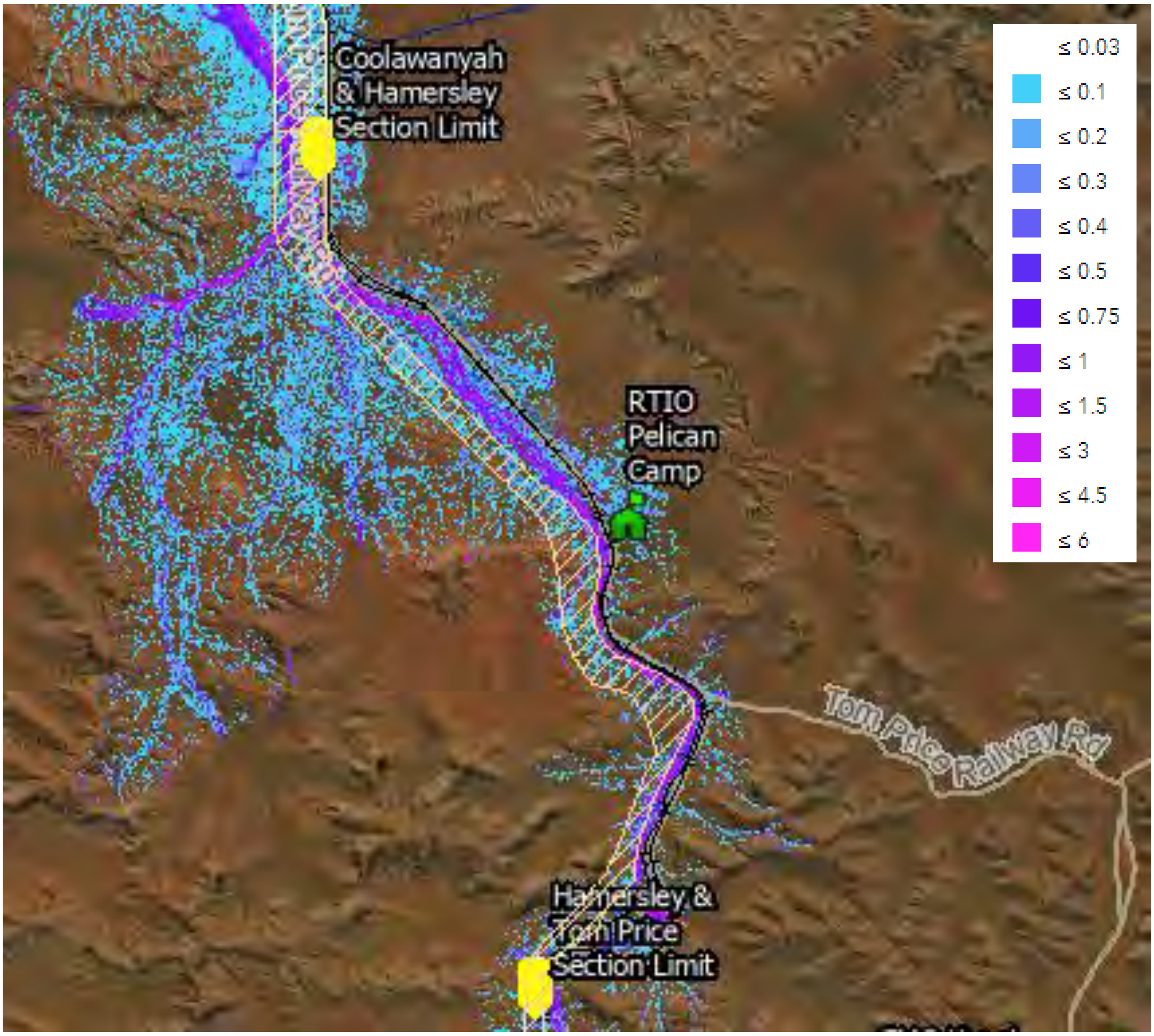


Figure A03 - 1:10 year 'Pre-Development' Maximum Flood Depths (m) – Tom Price Section

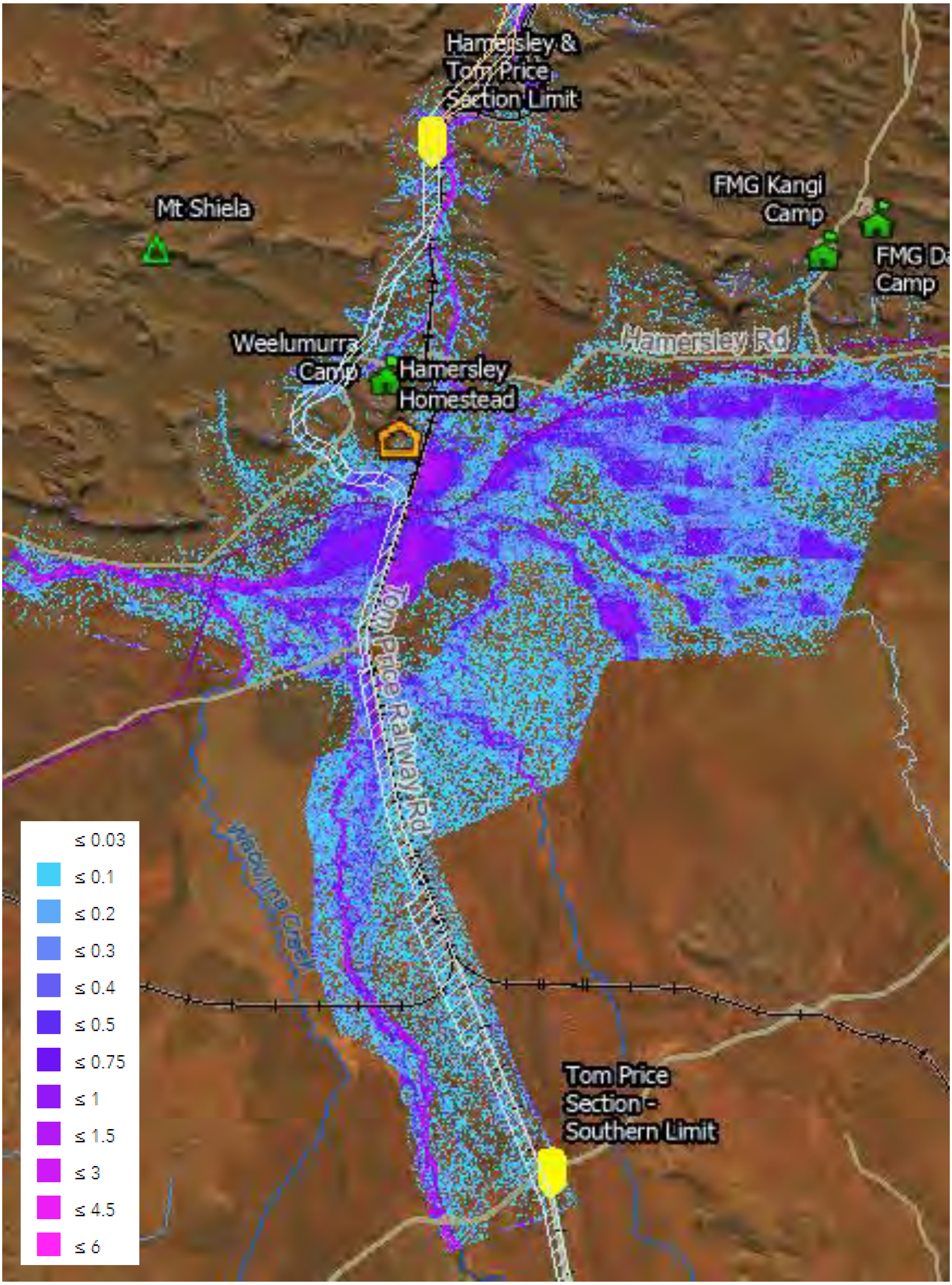


Figure A04 - 1:10 year 'Pre-Development' Maximum Flood Velocity (m/s) – Coolawanyah Section

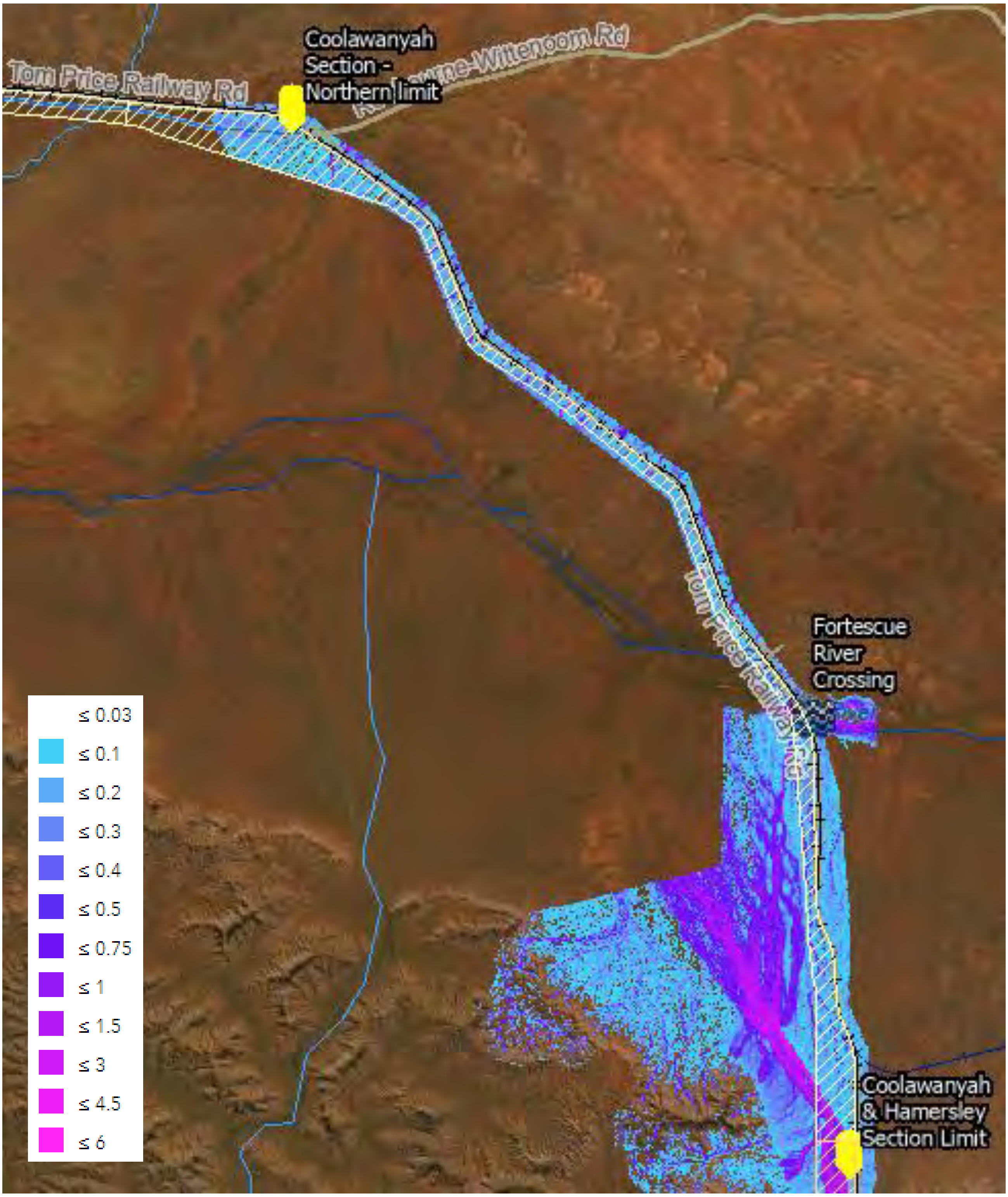


Figure A05 - 1:10 year 'Pre-Development' Maximum Flood Velocity (m/s) – Hamersley Section

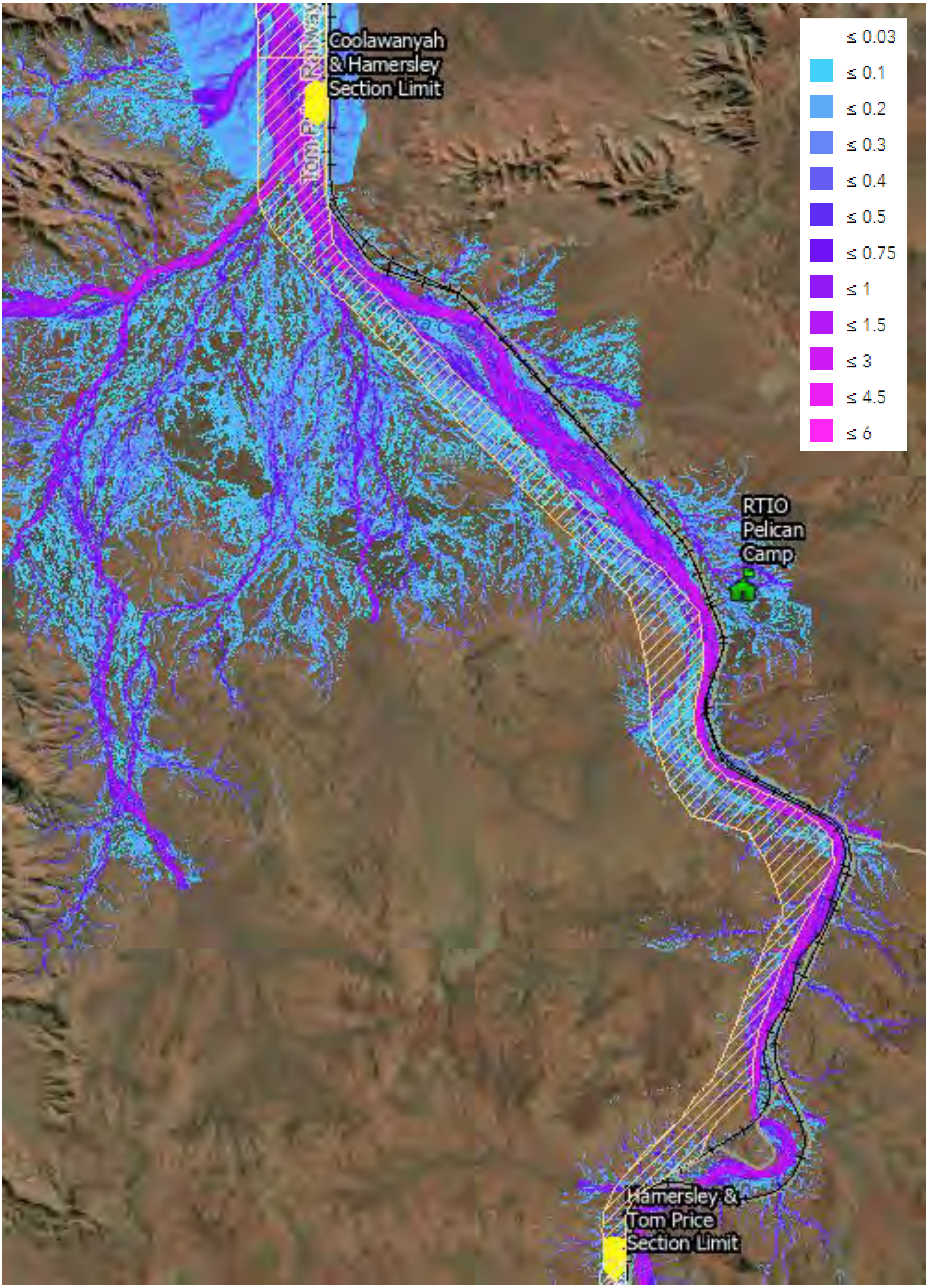
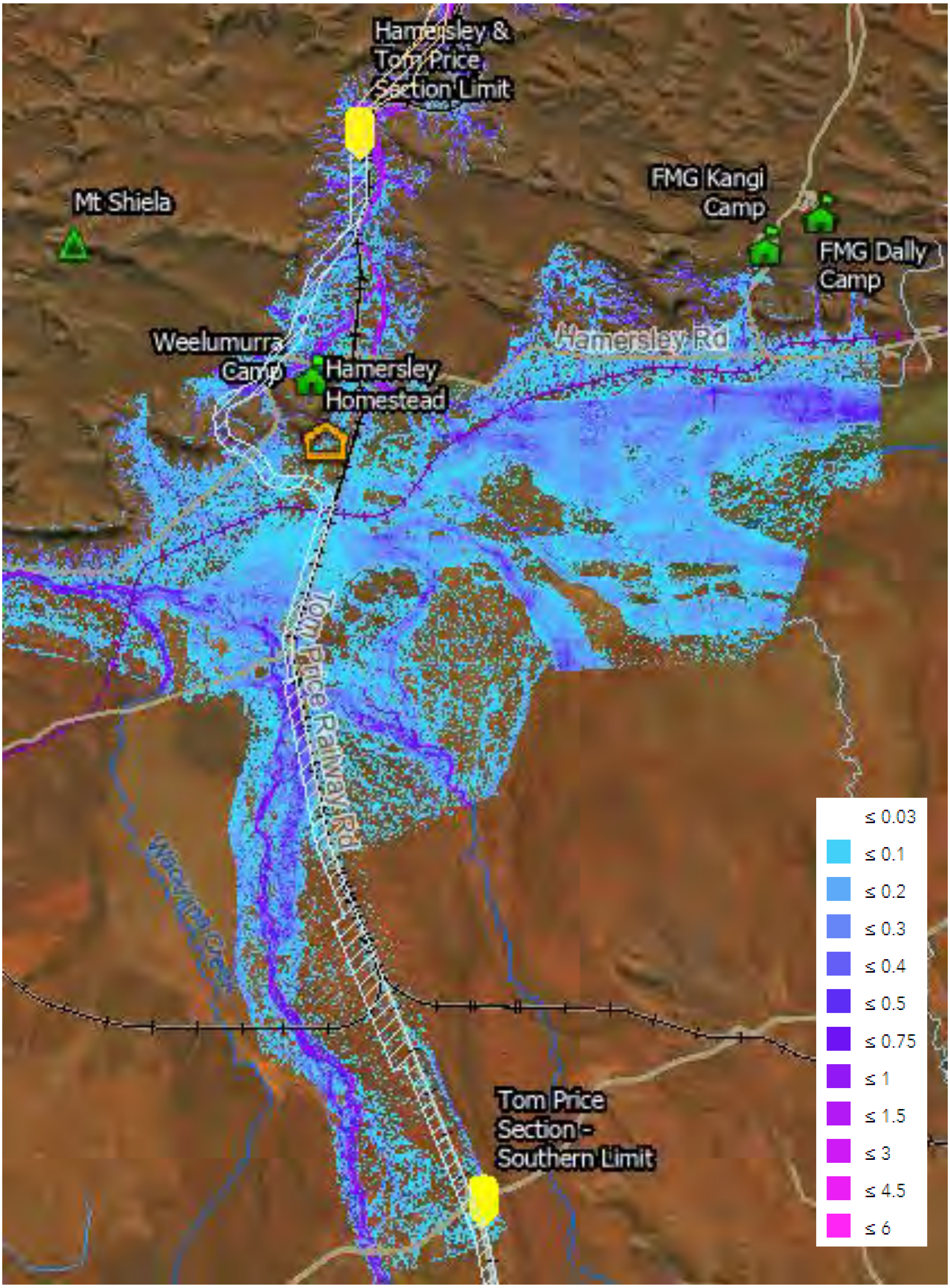


Figure A06 - 1:10 year 'Pre-Development' Maximum Flood Velocity (m/s) – Tom Price Section



APPENDIX

B

ANECDOTAL INFORMATION FROM COOLAWANYAH STATION

Figure B01 - 12 Mile mill and tank – 25 January 2013

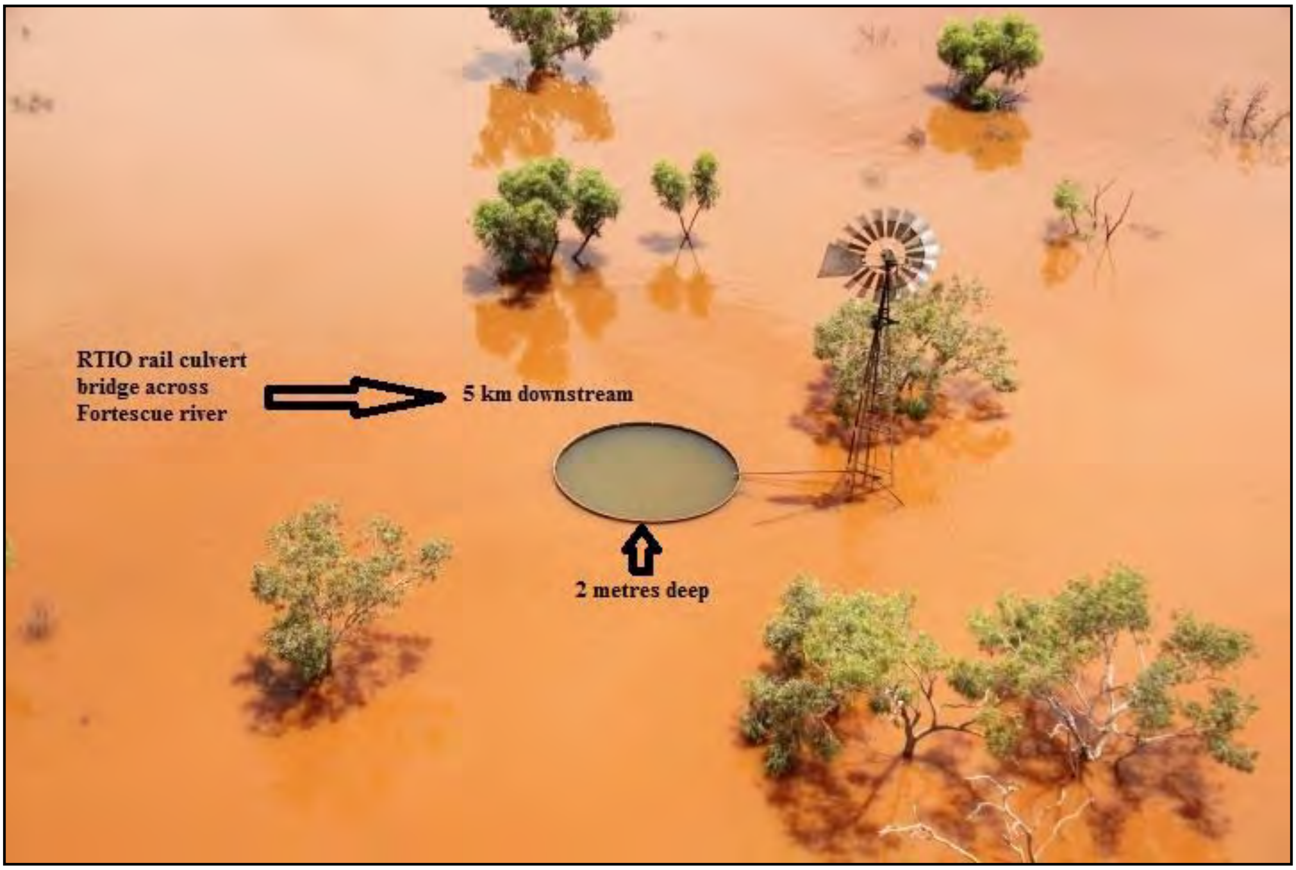


Figure B02 - Hoppy's Camp upstream of Rio Tinto Fortescue crossing – 25 January 2013

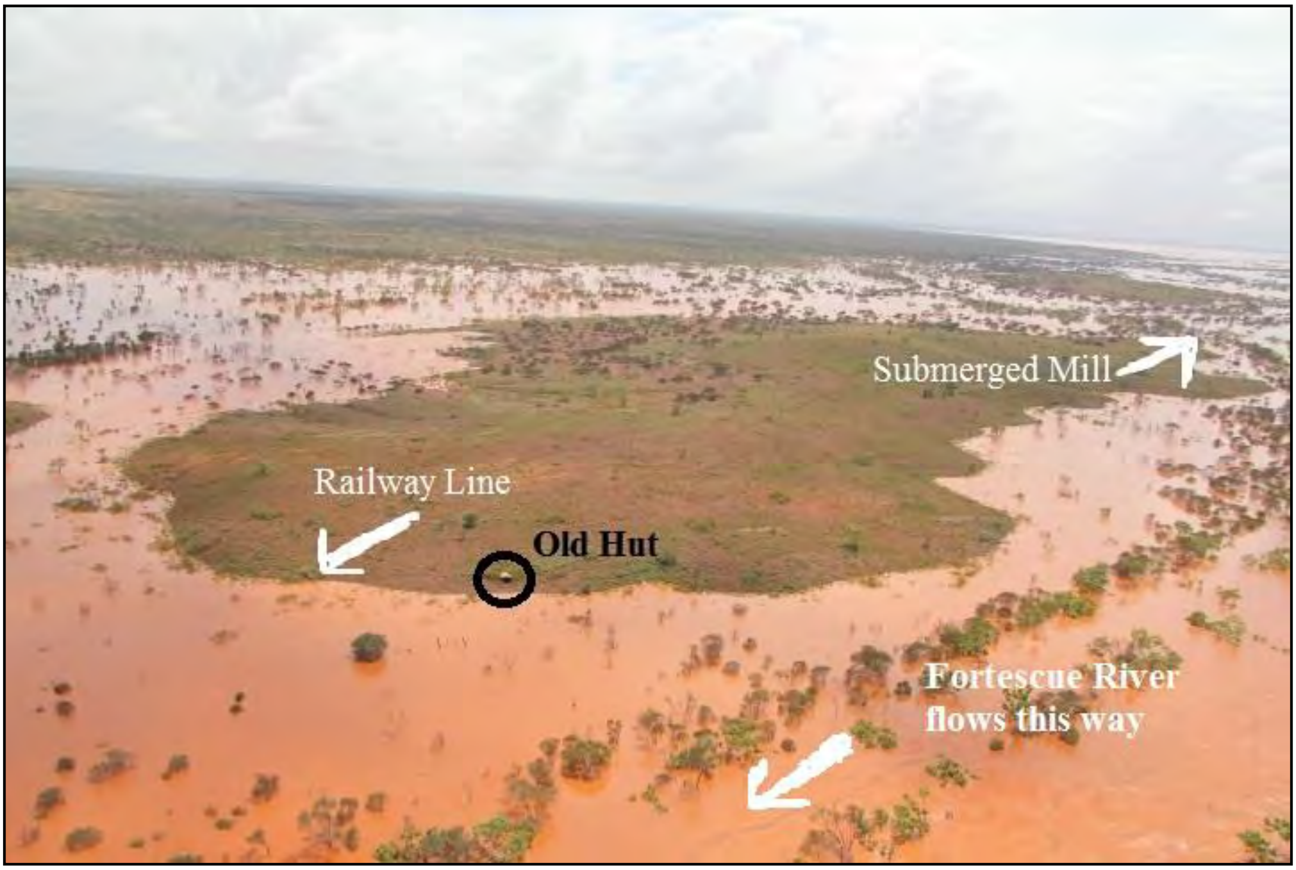


Figure B03 - Looking north at Rio Tinto Fortescue crossing – 25 January 2013

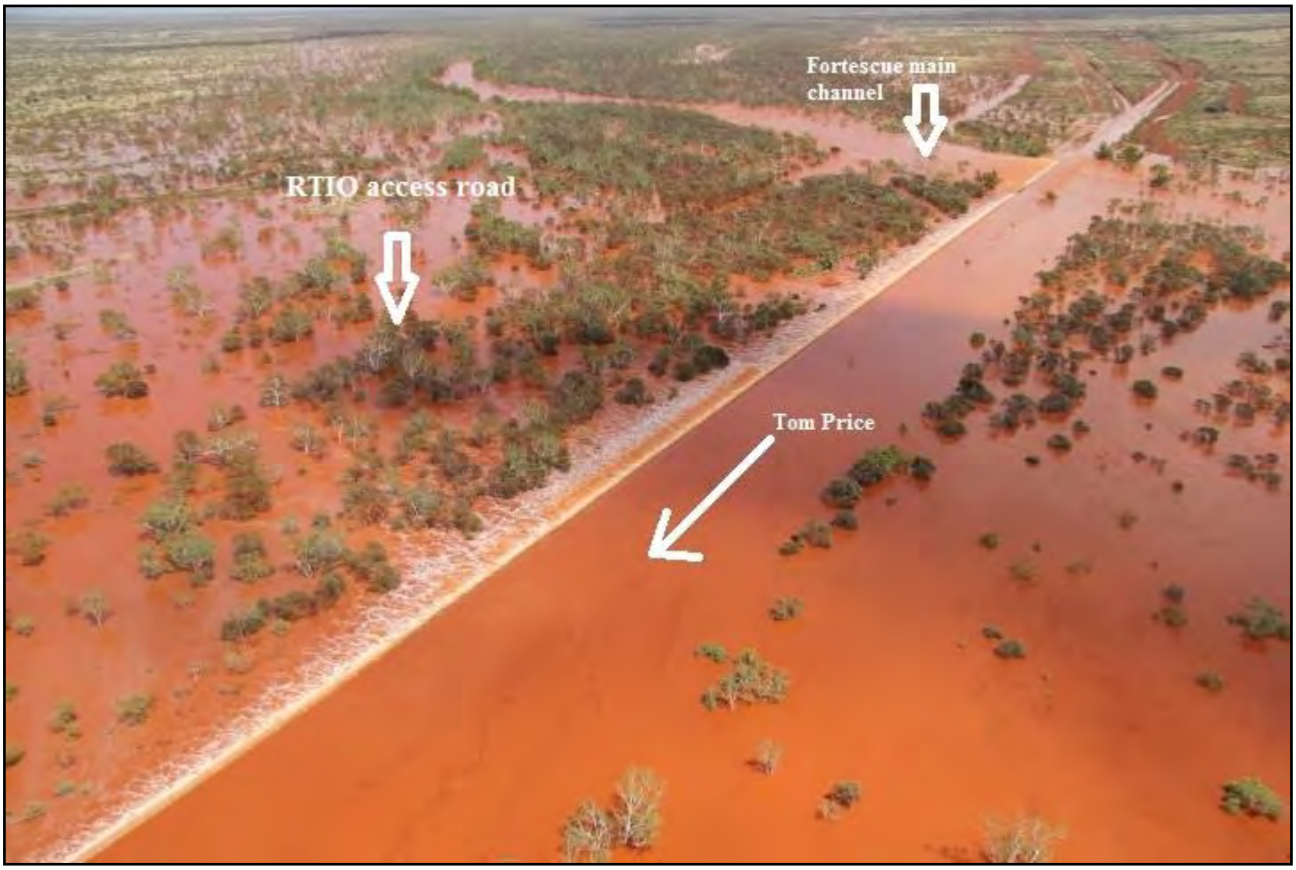


Figure B04 - Level difference across Rio Tinto Fortescue crossing railway floodway – 25 January 2013

Figure B05 - Looking south at Rio Tinto Fortescue crossing – 25 January 2013

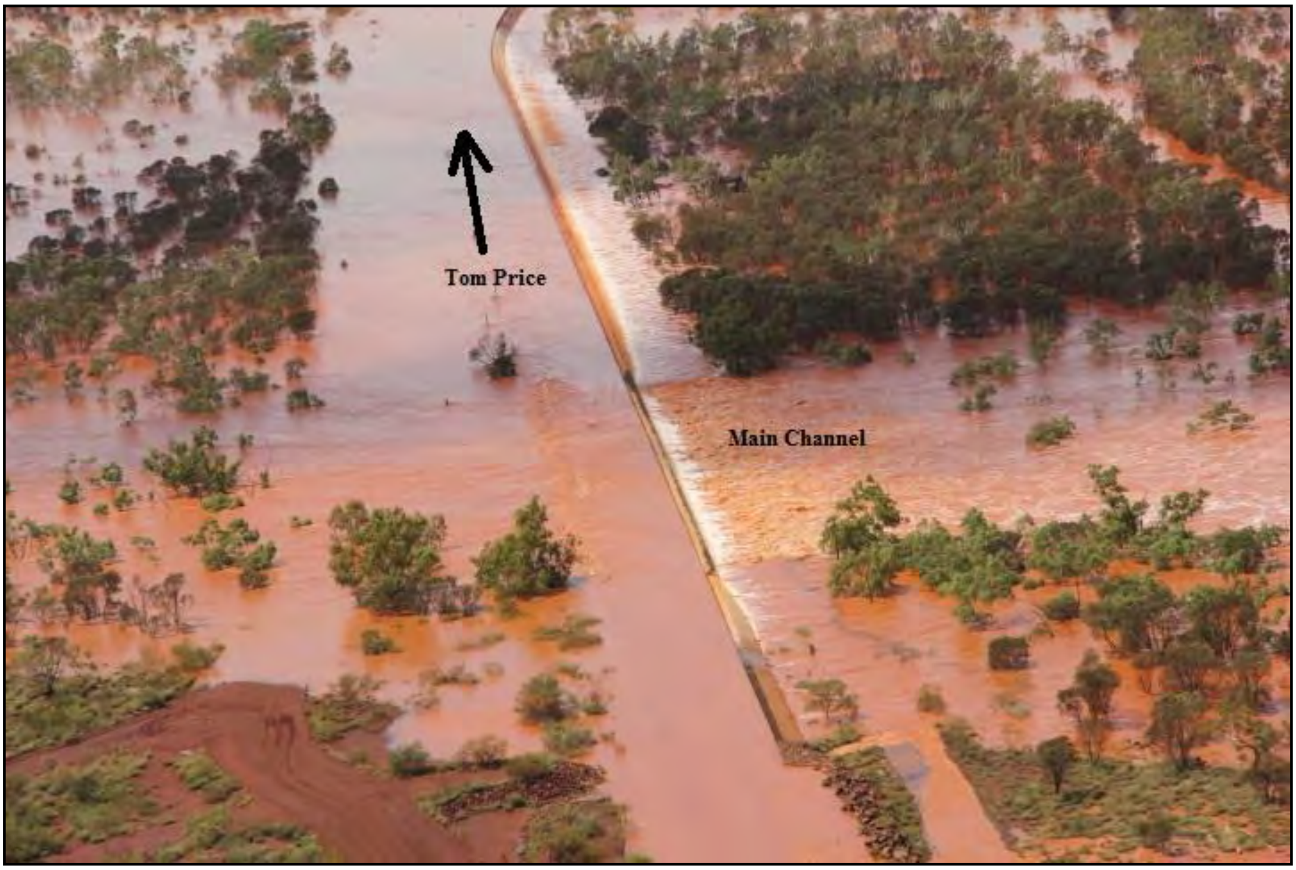
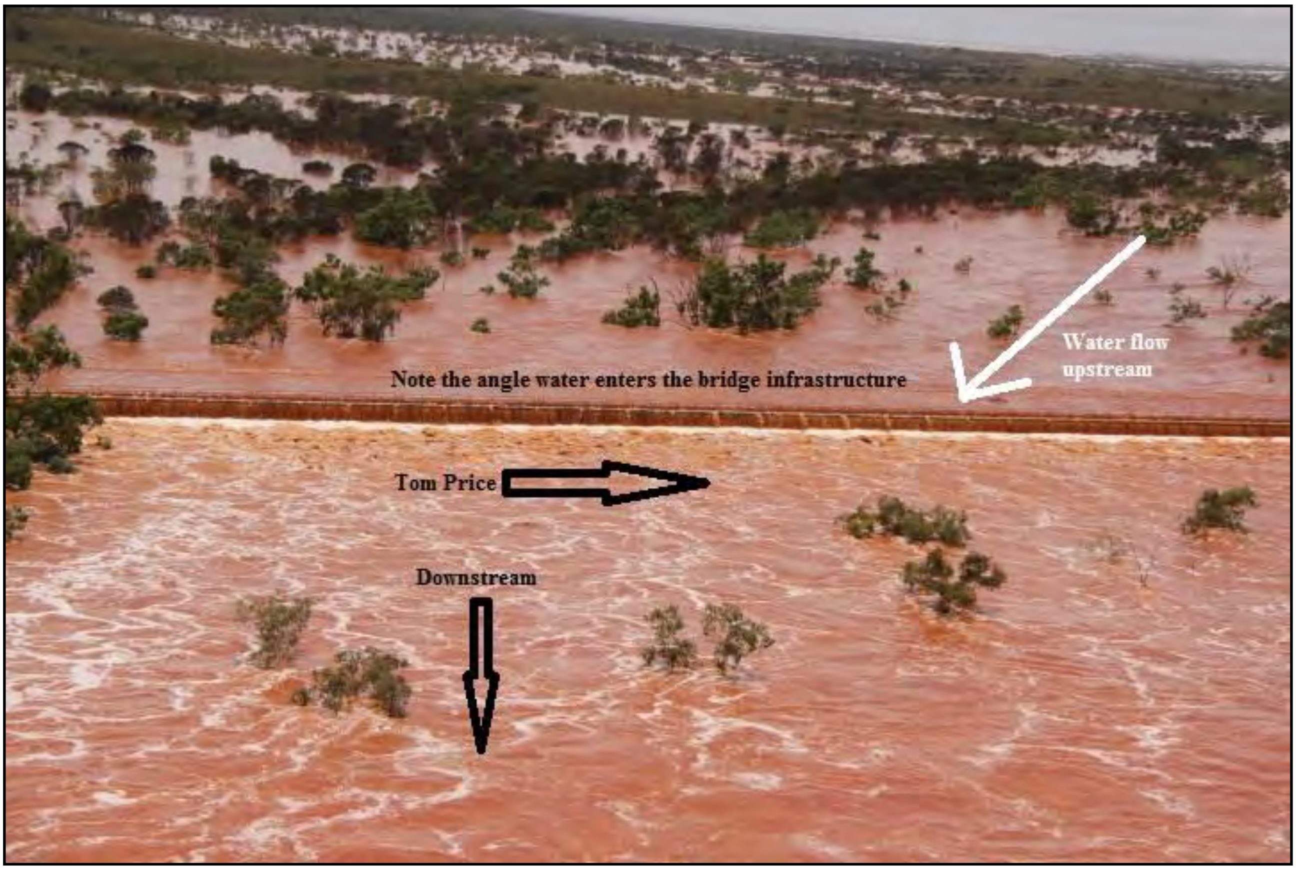


Figure B06 - Looking east at Rio Tinto Fortescue crossing – 25 January 2013



APPENDIX

C

RTIO LEVEE FAILURE SCENARIO

Figure C01 - First Coolawanyah levee failure – 2% AEP

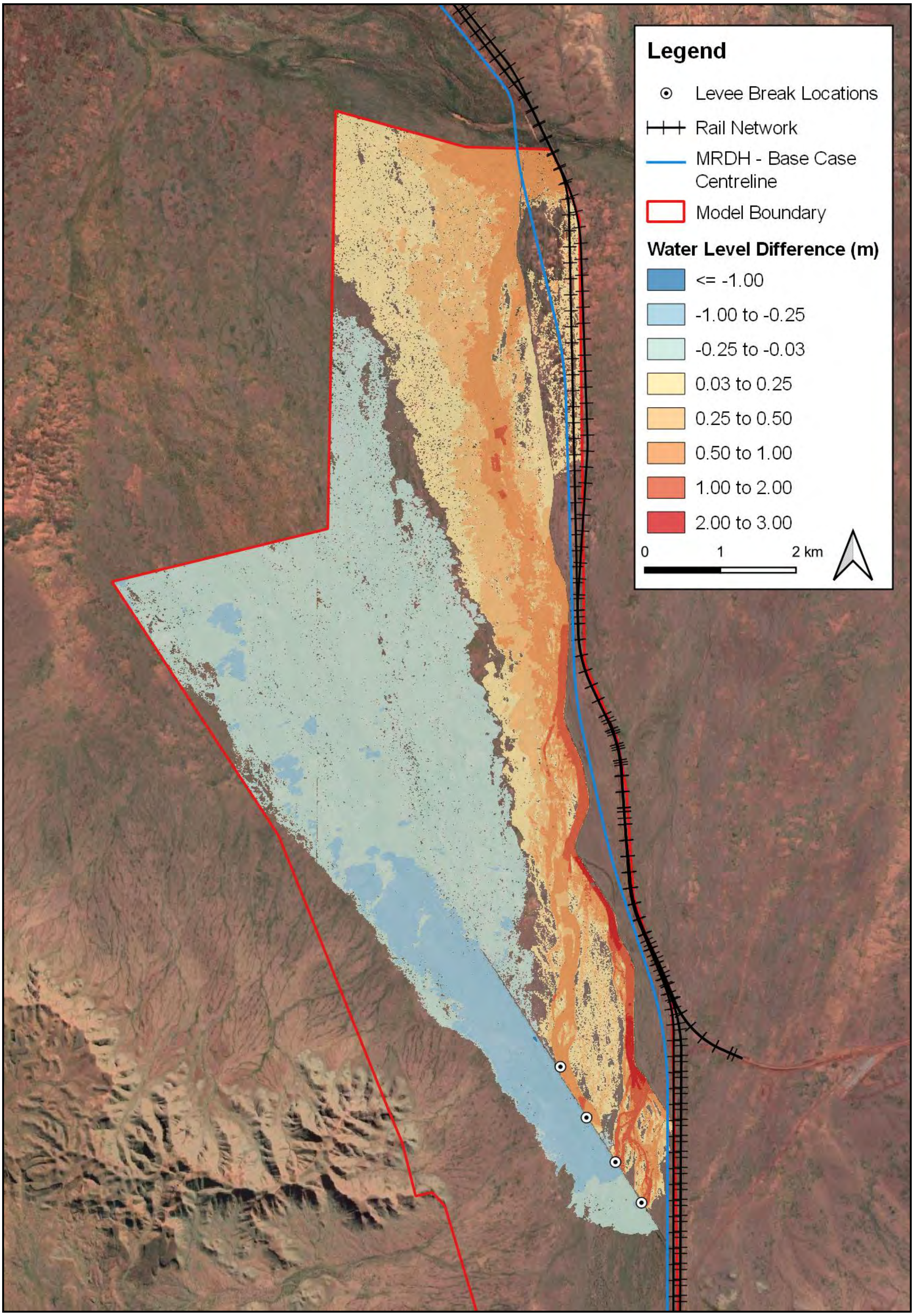


Figure C02 - First and second Coolawanyah levee failure – 2% AEP

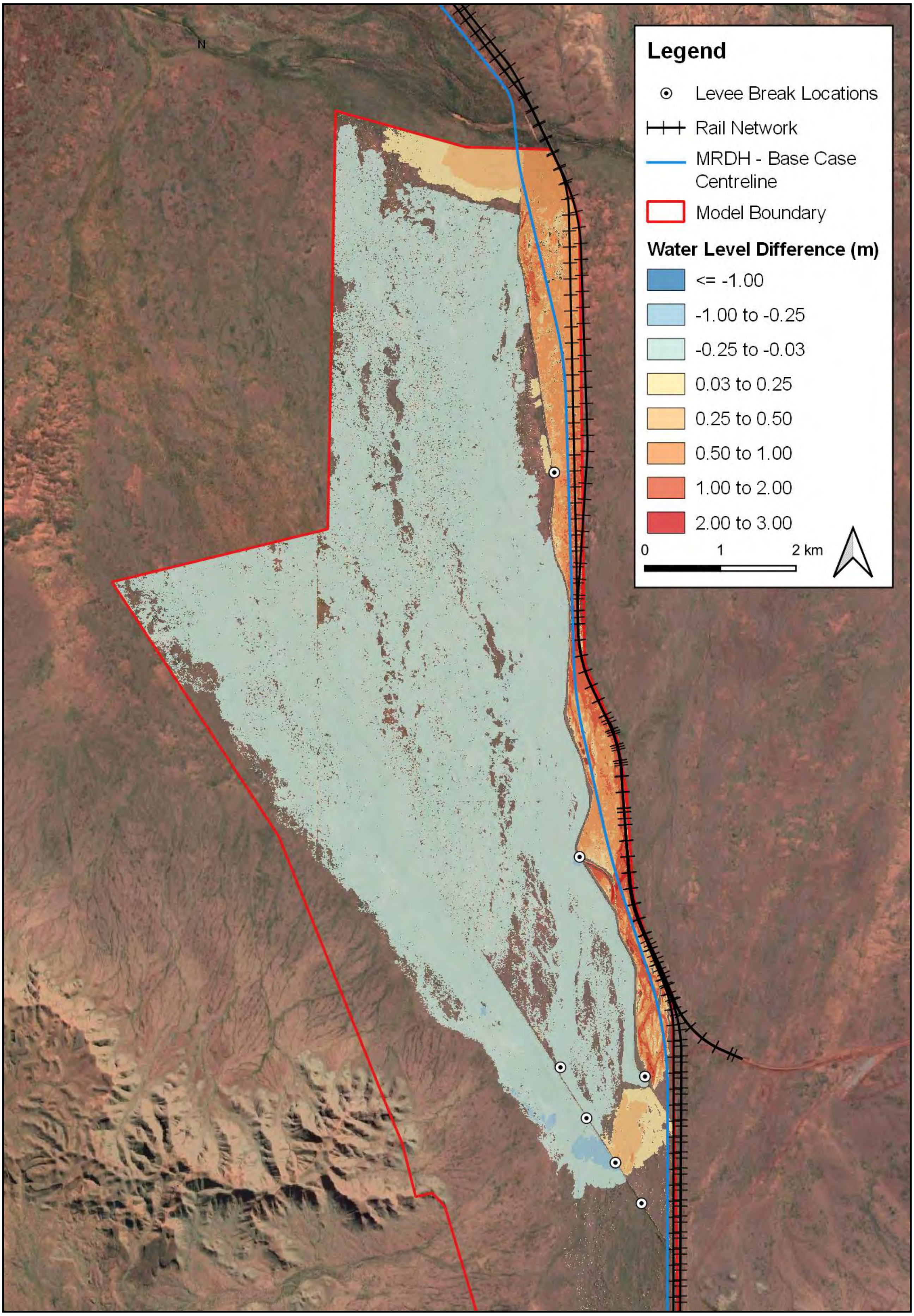


Figure C03 - Second Coolawanyah levee failure (First levee intact) – 2% AEP