

Ensham Mine Residual Void Study

Geomorphic Impact Assessment of Options

Stage 3

Ensham Resources Pty Ltd

1400-03-D10 FINAL DRAFT, 28 September 2018

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1 Executive summary

1.1 BACKGROUND

Ensham Resources Pty Ltd (Ensham) are preparing a residual void study for the Ensham Mine in compliance with their Environmental Authority. The residual voids are located on the Nogoia River floodplain and levees are used to prevent floodwater from entering the mine workings. The B Pit is located to the south of the river and the C Pit is located to the north. The study is being undertaken in five stages. An options assessment report prepared for Stage 1 identified two options:

- Option 1: Landform;
- Option 2: Beneficial Use.

DES required a third option, Backfill to Probable Maximum Flood level, be included in the study.

Stage 2 identified the Environmental Values (EVs) in the immediate and surrounding area of Ensham Mine and determined which EVs are likely to be affected by each Preferred Option. This report forms part of Stage 3 of the study to develop the feasibility level designs required to prevent or minimise the potential impacts to EVs from each Preferred Option. Feasibility designs for each of the Preferred Options will inform a risk assessment on each Preferred Option and include, as a minimum:

- the long-term stability of the final landform;
- safety of access to the site; and
- the short, medium and long-term risks associated with each Preferred Option.

The purpose of this document is to assess the potential impacts of the Preferred Options on the morphological behaviour of the Nogoia River and adjacent floodplain and in particular the environmental values of the river. The Preferred Options have the potential to change the flood behaviour which could potentially affect erosive forces on the channel bed and banks or lead to the loss or deposition of soils or sediment on the adjacent floodplain. A baseline geomorphic study and hydraulic analysis of the three Preferred Options have been used to assess the geomorphic impacts and in particular address the long-term stability and risk requirements for the feasibility level risk assessment.

For this study, the 10% annual exceedance probability (AEP) flood event has been used to define the short-term risks of each Preferred option. A flood of this magnitude would be expected once every 10 years on average. The 1% AEP event has been used to define the medium-term risks. A flood of this magnitude would be expected once every 100 years on average. The morphological behaviour of the floodplain during recent historical floods, which had comparable AEP's to these design events, have been used to assist in the risk assessment. The event that is 1.5 times greater than the 0.1% AEP, which is an extreme and very rare event (occurring around once every 5,000 years on average), has been used to define the long-term risks. This event has been used as it represents an event that just exceeds the Option 1 and Option 2 landforms.

1.2 GEOMORPHIC SETTING

Ensham Mine is located adjacent to the Nogoia River, an anabranching river system that is a major tributary of the Fitzroy River. The Nogoia River consists of a well-defined 10 m deep channel that is carved through a relatively flat floodplain. The flood slopes vary from 0.03% to 0.05%. The floodplain varies in width from about 4 km at the location of the mine (currently narrowed to 1.5 km by the mine levees) to about 13 km near the Crinum Creek confluence. The floodplain consists of quaternary alluvium and lacustrine deposits of a mix of sand, silt, clay and gravel. Hansen Consulting (2006) characterised the alluvium as a

strongly structured alkaline heavy (cracking) clay soil classified as a grey or brown vertosol soil. The soils are non-sodic but are moderately dispersive.

A number of anabranching flood channels cross the floodplain, the most prominent is the Anabranch located adjacent to the C Pit. The Anabranch receives flow every year on average and conveys 36% of the 10% AEP event. Other flood channels receive Nogoa River floodwater only for larger floods but convey a greater proportion of the flow during these large flood events. These channels may be parts of decaying or developing anabranch channels, varying through time. The B Pit has been constructed across one of the flood channels called Old Winton Creek. Prior to mining, Old Winton Creek conveyed 6% of the 10% AEP flow and 34% of the 1% AEP flow.

Flood modelling of pre-mining conditions shows flood velocities are generally low with median channel velocities between 1.1 m/s and 1.3 m/s. Overbank velocities in the flood channels are much lower with median values between 0.2 m/s and 0.8 m/s.

Observations of the Nogoa River channel and floodplain taken after the January 2008 and January 2010 floods, which were both very large events, found that the soils and vegetation characteristics at the time were capable of resisting channel bank and overbank sheet erosion, although some minor localised erosion was encountered. On the basis of these observations, minimal erosion or channel movement is expected for the range of modelled pre-mine velocities and shear stresses for events up to at least the 1% AEP event. Whilst acknowledging that anabranching systems are inherently not stable in the long term, this suggests that the pre-mining Nogoa River channel and floodplain are stable in the short term and medium term.

1.3 ASSESSMENT OF OPTION 1

Option 1 involves constructing a landform along the existing levee alignment that provides flood immunity for the 0.1% (1 in 1,000) AEP flood. Although the landform is slightly higher than the existing levee, it would have the same flooding characteristics as the existing conditions up to the overtopping level, and therefore would have the same morphological impacts as existing conditions up to this event. Compared to pre-mine conditions, the modelling shows that:

- there would be no change in peak velocities and shear stresses from pre-mine conditions for the 10% AEP flood;
- the differences between pre-mine and Option 1 flood velocities and shear stresses for the 1% AEP event are minor;
- where increases from pre-mine conditions occur for the 1% AEP event, the predicted velocities and shear stresses are no greater than pre-mine velocities and shear stress along the upstream reach of the river for the same event; and
- the extreme event (adopted as 1.5 x the 0.1% AEP event) would increase velocities and shear stresses along the Nogoa River channel and the adjacent floodplain for a distance of about 7 km. Again, the increased velocities and shear stresses are no greater than pre-mine velocities and shear stress along the upstream reach of the river for the same event.

Given that the assessment of the pre-mine conditions found that the Nogoa River channel and floodplain would be stable in the short term and medium term, the short and medium-term risks to the Nogoa River for Option 1 landform are low.

There remains a long-term risk of morphological change to the Nogoa River for Option 1 for extreme and rare events that overtop the landform. Along the C Pit, an overtopping event would erode the proposed landform embankment potentially to bed level. The potential of this occurring for the landform along the B Pit is lower given the highwall of the void is located much further from the river channel. If the C Pit or B Pit landforms were overtopped and the embankment eroded to bed level, their configuration away from the main flow path would suggest that both would act like connected off-stream storages. The pits would fill with water and once full they would have zero velocity allowing flows to continue downstream along the main Nogoa River channel and the Anabranch. If such an

extreme event occurred, it would appear unlikely that the course of the Nogoa River or Anabranch would be altered to drain through the voids although they would potentially reduce downstream bed sediment loads. Repairing the embankments, as done in 2008, would mean that it is unlikely there would any long-term impacts on the Nogoa River or its floodplain.

Option 1 moderately reduces the long-term risk of morphological change from existing conditions because the final landform levels are marginally higher and wider than the levees that are being replaced.

If Option 1 was to be preferred, the very low morphological risks could be reduced further by providing a designated overflow point in the proposed landform along the C Pit highwall to allow an overtopping event to fill the C Pit void in a controlled manner. A potential location to allow overtopping would be near the proposed Option 2 intake channel. Filling the void from this location would reduce the likelihood of an overtopping event eroding the embankment to bed level, in the unlikely event that an overtopping event occurred. The assessment of impacts in this investigation has been undertaken on the basis that a designated overflow point will be incorporated into the detailed design of the landform if this option is preferred.

1.4 ASSESSMENT OF OPTION 2

Option 2, which utilises the post-mining voids to form water storages to capture a proportion of high flow flood water and store this water for potential beneficial use, maintains the existing levees to protect the voids from flooding. As a result, there would be no material difference in velocities and shear stresses along the river channels or the floodplain between Option 1 and Option 2. Therefore, the results described for Option 1 are relevant for Option 2.

On the basis that the changes in hydraulic behaviour for events up to the 1% AEP event are minor, the short and medium-term risks to the Nogoa River for Option 2 landform are low.

The modelling of the extreme event suggests that there remains a very low long-term risk of morphological change to the Nogoa River for Option 2 because an overtopping event would scour the levee/embankment. However, there is little chance of the levee and embankment eroding to bed level because of the equalising effect of the water stored in the voids. On this basis, the long-term risk to the Nogoa River of Option 2 would be lower than the very low long-term risk for Option 1.

1.5 ASSESSMENT OF OPTION 3

Option 3 involves backfilling the residual mining voids located within the pre-mining floodplain up to the elevation of the original floodplain within the lateral extent of the pre-mining Probable Maximum Flood level. Modelling of the Option 3 conditions shows the following:

- There would be no material change in peak velocities and shear stresses from pre-mine conditions within the river channels and adjacent floodplains for all events.
- Velocities and shear stresses across the infilled C Pit are generally low for all events, suggesting that it will remain stable in the long term.
- Velocities and shear stresses are generally low across the infilled B Pit and are very low behind the elevated landform for the 10% and 1% AEP events suggesting some sediment deposition may occur for these events.
- Higher velocities and shear stresses occur along the constructed B Pit channel and across the top of the elevated landform sections of the B Pit for the extreme events suggesting that there is a higher erosion potential in these areas for the extreme events. Depending upon the success of maintaining the rehabilitated landform across the B Pit, downstream properties could be adversely affected by sediment eroded from the landform. Long-term erosion and sedimentation would also occur from any exposed subsoils on the landform.

The results demonstrate that there would be no short, medium or long-term term risks of accelerated morphological change to the Nogoia River and its floodplain for the Option 3 landform.

The expected low velocity zones across the surface of the infilled voids suggest these landforms will be stable in the short to medium term with potentially some sediment deposition occurring during moderate flood events.

The stability of the constructed B Pit channel and the elevated landform across the infilled B Pit surface will depend upon the success of achieving the final surface levels after subsidence and being able to maintain the surface rehabilitation. If the rehabilitation of the surface of the infilled voids is not maintained and bare earth soils remain post mining, then some erosion of the surface would be expected during flood events, potentially leading to adverse impacts on downstream environmental values. The extent of erosion would depend upon the erodibility of the soil. However, the low flood gradients and floodplain geometry would suggest that the erosion would not have a significant impact on the long-term floodplain morphology.

1.6 ASSESSMENT OF ENVIRONMENTAL VALUES

Table 1.1 shows the assessment of the potential impacts of each of the three preferred options on relevant environmental values (EVs) based on the outcomes of this report. The EV impact ranking of the three Preferred Options was assessed by comparing the potential for each option to have a positive or negative impact on the long-term morphological behaviour of the floodplain compared to existing conditions using the adopted ranking criteria ranging from -3 (significant negative impact) to +3 (significant benefit).

- Option 1 was ranked 1 because there are no short or medium-term risks of accelerated morphological change and there would be a minor reduction in the residual long-term risks from an increase in the levee height, which would reduce the frequency of an overtopping event. An overtopping event during a very rare and extreme event would erode the river bank, potentially to bed level, to cause a morphological change. Given that there is a low probability that an overtopping event would occur, the benefit of this improvement compared to existing conditions is only minor.
- Option 2 was also ranked 1 because there are no short or medium-term risks of accelerated morphological change and there would be a minor reduction in the residual long-term risks associated with an overtopping event. Elevated pit water levels would reduce the likelihood of the bank eroding to bed level to cause a morphological change to the river during an extreme overtopping event. Given that there is a low probability of an overtopping event occurring, the benefit of this improvement is only minor.
- Option 3 was ranked 2 because there are no short or medium-term risks of accelerated morphological change and the very low long-term risks associated with an Option 1 and Option 2 overtopping event would effectively be eliminated, particularly for the C Pit. This ranking assumes that the proposed post mining surface rehabilitation and levels can be achieved.

Table 1.1 - Environmental Values ranking of the Preferred Options

Environment Aspect	Environmental Value	Criteria	Option 1 Landform Levee	Option 2 FMBU ¹	Option 3 Backfill to PMF
Flooding	Changes in flooding & runoff characteristics	Velocity / erosion potential	1	1	2

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2 Introduction

2.1 BACKGROUND

Ensham Mine, an open cut and underground bord and pillar coal mine located approximately 35km east of Emerald, is operated by Ensham Resources Pty Ltd (Ensham), a wholly owned subsidiary of Idemitsu Australia Resources Pty Ltd (Idemitsu), on behalf of the Ensham Mine joint venture (JV) partners. The JV partners, and holders of the Environmental Authority, are Bligh Coal Limited, Idemitsu and Bowen Investment (Australia) Pty Ltd. EA EPML00732813 (the EA), dated 26 May 2017, is the relevant environmental authority under which Ensham operates the mine. The layout of Ensham mine is shown in Figure 2.1.

Condition G16 of the EA states that a Residual Void Project (RVP) must be completed and submitted to the administering authority for review and comment by 31 March 2019. The minimum content of the RVP is specified within Condition G16 of the EA as:

- a) Terms of Reference;
- b) Residual Void Study;
- c) Progress Reports; and
- d) Rehabilitation success criteria for voids.

In compliance with Condition G19 of the EA, *“the Residual Void Project must be carried out in accordance with the approved Terms of Reference”*. A Terms of Reference (ToR) (Ensham Resources, 2017) was approved by Queensland’s Department of Environment and Science (DES, formerly Department of Environment and Heritage Protection, DEHP) on 21 July 2017.

Condition G20 of the EA identifies the minimum content of the RVP identified in Condition G16. In accordance with the ToR, the project has been divided into five stages:

- Stage 1 - Project Definition and Options Identification;
- Stage 2 - Preferred Options Technical Studies;
- Stage 3 - Preferred Options Detailed Design;
- Stage 4 - Most Preferred Option Identification; and
- Stage 5 - Regulatory Documentation.

Stage 1 - Project definition and options identification for the RVP have been completed. The Stage 1 Options Assessment report has been finalised and issued to the Department of Environment and Science (DES), the Department of Natural Resources Mines and Energy (DNRME) and the Community Reference Group (CRG). The report was independently peer reviewed and revised to address peer review comments. The final report has been delivered to DES, DNRME and the CRG.

The Options Analysis workshop held in Stage 1 of the RVP identified two options:

- Option 1: Landform Levee
- Option 2: Flood Mitigation and Beneficial Use.

DES required a third option, Backfill to Probable Maximum Flood level, be included in the study.

All three options have been advanced through Stage 2 and into Stage 3 of the RVP and are referred to as the ‘preferred options’. The preferred options are discussed in Section 1.3 to Section 1.6 of this report.

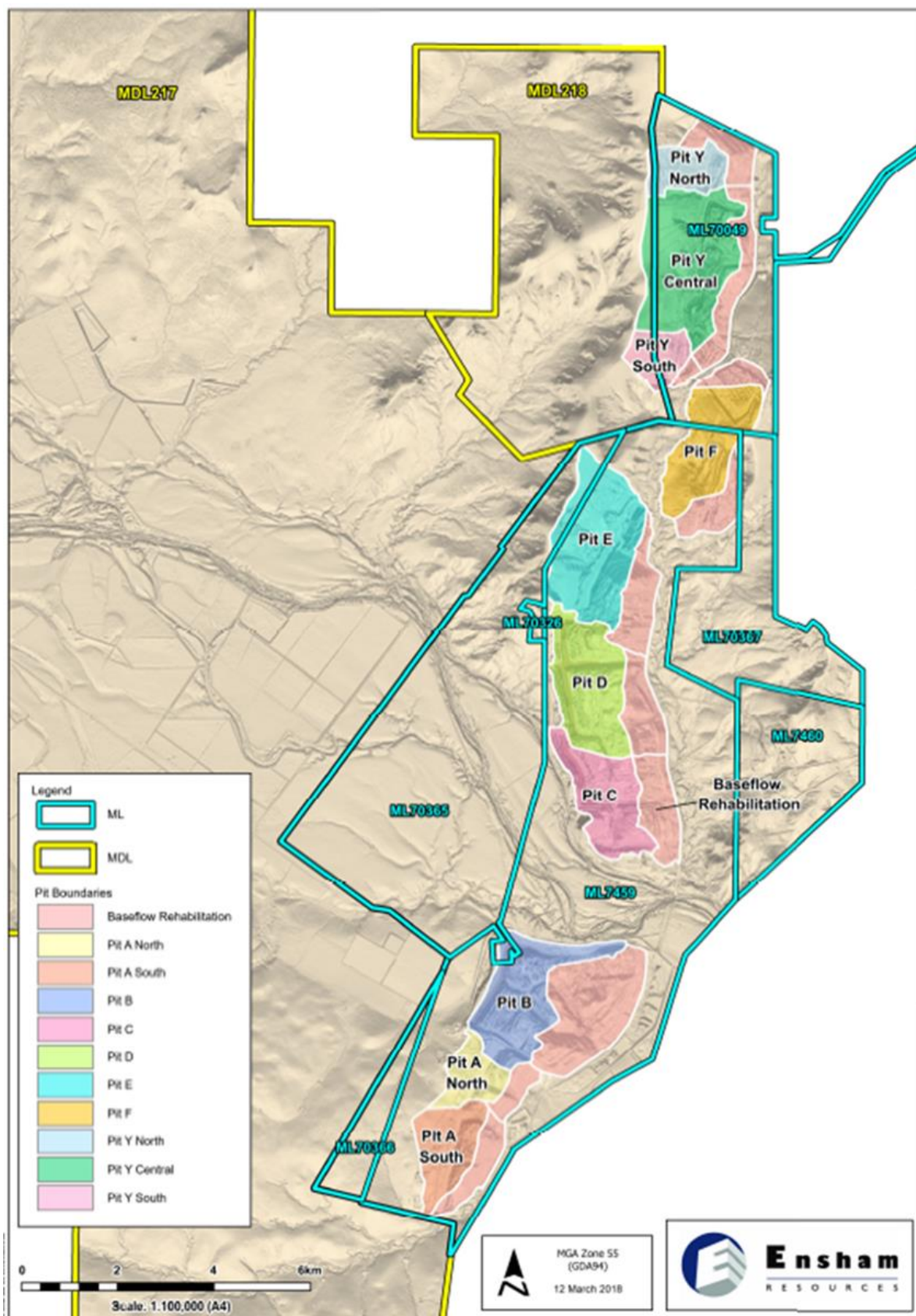


Figure 2.1 - Ensham Mine pit layout

Stage 2 identified the Environmental Values (EVs) in the immediate and surrounding area of Ensham Coal Mine and determined which EVs are likely to be affected by each preferred option. Similar to Stage 1, the Stage 2 EV report and technical studies have been Independently Peer Reviewed and issued in final to DES, DNRME and the CRG.

Stage 3 builds on the technical studies completed in Stage 2 to develop feasibility level designs required to prevent or minimise the potential impacts to EVs for each preferred option. Detailed designs for each of the preferred options will inform a risk assessment of each option and includes as a minimum:

- the long-term stability of the final landform;
- safety of access to the site; and
- the short, medium and long-term risks associated with each preferred option.

The output of Stage 3, in addition to the associated technical reports, will be an Environmental Assessment report for each preferred option which identifies the design and management practices to be implemented to minimise impacts on the identified EVs.

On completion, each preferred option report will be peer reviewed by an independent suitably qualified third party before submission to the administering authority for review and comment.

2.2 PURPOSE

The purpose of this document is to assess the potential impacts of the Preferred Options on the morphological behaviour of the Nogoia River and adjacent floodplain and in particular the environmental values of the river. The Preferred Options have the potential to change the flood behaviour which could potentially affect erosive forces on the channel bed and banks or lead to the loss or deposition of soils or sediment on the adjacent floodplain.

2.3 SCOPE OF WORK

The scope of work for the geomorphic assessment will address the long-term stability and short, medium and long-term risks associated with each Preferred Option and includes:

- a baseline geomorphic study to characterise the potential for landform changes including determining the dominant erosion mechanisms of the Nogoia River and its floodplain of relevance to the RVP under pre-mine conditions;
- presenting the results of hydraulic modelling undertaken by HEC (2018a) for the RVP to define and locate the changes in hydraulic characteristics (velocity and shear stress) of the river and floodplain; and
- analysing the results of the baseline study and hydraulic analysis to assess the geomorphic impacts of the three Preferred Options and in particular address the minimum requirements for the feasibility level risk assessment.

For this study, the 10% annual exceedance probability (AEP) flood event has been used to define the short-term risks of each Preferred option. A flood of this magnitude would be expected once every 10 years on average. The 1% AEP event has been used to define the medium-term risks. A flood of this magnitude would be expected once every 100 years on average. The morphological behaviour of the floodplain during recent historical floods, which had comparable AEP's to these design events, have been used to assist in the risk assessment. The event that is 1.5 times greater than the 0.1% AEP, which is an extreme and very rare event (occurring around once every 5,000 years on average), has been used to define the long-term risks. This event has been used as it represents an event that just exceeds the Option 1 and Option 2 landforms.

2.4 REPORT STRUCTURE

The report is structured as follows:

- Section 3 describes the Preferred Options;

- Section 4 outlines the geomorphic settings of the Nogoia River floodplain in the vicinity of Ensham Mine;
- Section 5 provides an assessment of the geomorphic impacts of the Preferred Options from the hydraulic modelling results;
- Section 6 outlines the conclusions of the study and recommendations for Stage 4.
- Section 7 provides a list of references.
- Section 8 lists a glossary of terms.
- Appendix A provides flood mapping for the Preferred Options.

3 Preferred Option descriptions

The following description of and commentary on the Preferred Options has been provided by Ensham.

3.1 PREFERRED OPTION 1: LANDFORM LEVEE

Having conceptually evolved since Stage 1, proposed Option 1 will develop permanent landforms along the existing levee alignment to provide flood immunity for the 0.1% (1 in 1,000) Annual Exceedance Probability (AEP) flood event having had consideration of the risk of a PMF level event (as proposed in the Stage 2 assessment). Figure 3.1 illustrates the current placement of the landform.



Figure 3.1 - Option 1 Landform levee

When compared to the landform levee designed at a PMF level (as considered in Stage 2) the proposed 0.1% AEP landform along the existing levee alignment:

- eliminates afflux impacts for upstream landholders in a greater than 0.1% AEP event;
- eliminates any potential increased impacts on downstream landholders associated with widening the river floodplain; and
- eliminates the need to realign the Nogoia anabranch

It is proposed to incorporate the existing levees into the landform design with overburden emplacement areas behind the levee being reshaped in a manner that achieves the minimum stable landform slope requirements.

In addition to any impacts associated with the existing farm levees and mining pit levees, flood levels in the vicinity of Ensham Mine are significantly affected by the confluence of flood flows from the Comet River and Nogoia River, which occurs immediately downstream of the mine. Pits would be subject to rehabilitation in accordance with the approved Ensham site Rehabilitation Management Plan and the landform design criteria.

A biodiversity corridor will be developed along the western (highwall) side of the rehabilitated A and B pits to provide connectivity between Corkscrew Creek and the Nogoa River floodplain as seen in Figure 3.1.

3.2 PREFERRED OPTION 2: FLOOD MITIGATION AND BENEFICIAL USE

Option 2 proposes to utilise the post-mining voids to form water storages to capture a proportion of high flow flood water and store this water for potential beneficial use as shown in Figure 3.2. Flood water harvesting is able to quickly fill the post-mining voids with minimal downstream impact, achieving improved water quality to support a range of reuse options, and/or environmental, and social values.



Figure 3.2 - Option 2 Flood mitigation and beneficial use

This option is founded on the concept of capturing a small fraction of larger magnitude flood event flows in the Nogoa River, storing this water in residual voids and releasing it back to irrigation and industrial users via a series of pipes to the Weemah Channel and Yamala Inland Port. There will be no discharge to the Nogoa River by this option.

The design of rehabilitation should comply with the current site Rehabilitation Management Plan and landform design criteria to optimise water storage capacity. Overburden emplacement areas located adjacent to the water storage voids are to be reshaped in a manner that achieves stable landform slopes without resulting in significant void backfilling. Low wall areas are to be reshaped in-pit to achieve minimum stable slope requirements to ensure safe access and stability of exposed slope surfaces.

Option 2 would utilise storage afforded by residual voids remaining in A Pit and B Pit south of the Nogoa River, and C Pit and D Pit north of the river. The quantity of water likely to be required to operate the system - or put another way, the headroom storage in the pits - is likely to be negligible when compared to overall discharges during flood events from the Nogoa River catchment into the Mackenzie River located downstream of the Ensham Coal Mine. However, in the context of irrigation usage, the headroom storage represents a significant volume and a potential economic asset.

Future assessment and optimisation of Option 2 will consider the potential for interactive operation of the voids with Fairbairn Dam to improve water use efficiency across the water supply system.

Currently Fairbairn Dam's southern irrigation channel, known as the Weemah Channel, extends eastward to within approximately 10 km of Ensham Coal Mine. Water captured from the upper Nogoa River catchment and retained in Queensland's second largest but relatively shallow Fairbairn Dam, is subject to significant evaporative losses. Furthermore, allocated water releases from the dam into the Weemah Channel (and the corresponding northern channel, the Selma Channel) experience significant seepage and seasonal evaporative losses before reaching their intended customers, particularly where these customers are close to the end of the Weemah Channel. This option includes linking the residual voids located to the south of the Nogoa River to the existing Weemah Channel with large diameter pipes and pumps to transfer water to and from the voids.

Water captured in Fairbairn Dam would be released into the Weemah Channel when hydrologic conditions are likely to result in minimal evaporative and seepage losses (ie. at times when the catchment is receiving rainfall, the ground is saturated and evaporation is minimal). Whilst the water may not be required by customers at these times, the water would be transferred to the residual voids via the proposed Weemah Channel(s) (refer red red line on Figure 3.3) and stored in the more evaporatively-efficient residual voids at Ensham. In times of irrigation water demand at the lower reaches of the Weemah Channel (ie where the evaporative and seepage distribution losses are likely to be greatest), water would be returned to the Weemah Channel from the residual voids via the Weemah channel.



Figure 3.3 - Conceptual drawing of the Weemah Virtual Channel to irrigation and Yamala Inland Port (red) and the mine internal pump system (blue)

Because the Weemah Channel and proposed channel(s) lie on the southern side of the Nogoa River floodplain, it would be necessary to maintain a hydraulic connection between the residual voids on the northern flanks of the floodplain and those on the southern flanks. It is proposed that an upgrade of the existing water distribution main, that runs parallel with the main haulage route between B Pit and C Pit, be undertaken early in the project to provide the required hydraulic connection (refer blue line on Figure 3.3).

Option 2 proposes that pontoon-based pumping stations would be sited at each pit to transfer water as required. The Weemah channel coming into the mining lease would be

configured to deliver water initially to A pit. Similarly, pumping from the mine to the Weemah Channel would be done from A Pit.

An offtake from the pipe to Weemah Channel would be used to meet water demand for the prospective Yamala Inland Port located to the south west of Ensham Mine.

The intakes from the Nogoa River to B and C Pits would allow temporary storage of peak flood flows during flood events. As the river rises during a flood event, it would reach the overflow level of the inlet structures constructed in the levee (the intakes) and flow into the residual voids. The water would rise in the voids to reflect the height of the flood. As flood levels recede, water would ebb back into the river floodplain through the intakes to the base level of the intakes leaving the voids at full level. The intake level for B and C Pits has been considered as part of Stage 3.

A further key aspect of Option 2 is the depth of the residual voids. Shallow expansive voids experience greater evaporative water losses and hence potential salt concentration. Hence improved water quality outcomes are likely to be delivered with deeper inundated pits.

There remain several opportunities to manage power demands of the scheme including solar-power to generate an income to cover some or all of the overall annual operating cost of this option.

Residual voids that are not within the floodplain, for example E, F and Y pits, would be rehabilitated to achieve minimum stable slope requirements and comply with currently approved site Rehabilitation Management Plan and landform design criteria.

A biodiversity corridor will be developed along the western (highwall) side of the rehabilitated A and B pits to provide connectivity between Corkscrew Creek and the Nogoa River flood plain as seen in Figure 3.2.

3.3 PREFERRED OPTION 3: BACKFILL TO PMF

Preferred Option 3 comprises backfilling residual mining voids located within the pre-mining floodplain up to the elevation of the original floodplain within the lateral extent of the pre-mining Probable Maximum Flood (PMF) level.

Conceptually, the residual voids lying within this PMF extent would be backfilled up to the approximate original (pre-mining) topography with an additional surcharging to accommodate settlement of the backfill. In practice, it may be necessary to extend the backfilling beyond the modelled extent of the PMF to ensure stability of the backfilled areas within the PMF extent and protect against collapse into the adjacent residual voids. Excess mining spoil that is currently present in the floodplain and that is not required for backfilling of residual mining voids, would be retained as seen in Figure 3.4.

The existing levees constructed to protect the voids from flooding would be removed, with the material re-used for backfilling voids. Material required to backfill residual voids would be drawn from the nearest cost-effective source eg. low wall spoil. Any negative material balance will need to be met from adjacent low wall and high wall spoils.

Virgin rock typically exhibits an increase in volume when excavated - this is referred to as 'bulking'. The degree of bulking will vary with the geo-mechanical properties and size distribution of the excavated rocks and the methods used in excavation and transport. Furthermore, it is likely to vary both along the linear extent of the open cut mine and within different parts of spoil tips created through the extraction of rock dominated by lithologies characterising the local stratigraphy. Re-excavation of spoil and re-emplacement within voids within the modelled PMF will again exhibit bulking. Whether subjected to dynamic compaction or allowed to settle with subsequent loading by overlying backfill, the spoil within the voids will inevitably exhibit uncontrolled settlement. This will lead to the development of low areas within the PMF extent which, though shallow, lie below the original level of the floodplain. These low areas will not necessarily be connected and are likely to collect surface water runoff but be subject to intense evaporation and surface accumulation of evaporative salts which would be flushed clean by fluvial flood events.



Figure 3.4 - Option 3 - Backfill to PMF

Static surcharging of the replaced spoil material may reduce the risk of long-term settlement below original floodplain. However, this will require material to be placed above the original floodplain elevation in direct contradiction of the intent of this option.

Beyond the modelled extent of the PMF, residual voids would be rehabilitated in accordance with a combination of Option 1 and Option 2 landform criteria requirements.

Replaced spoil, however comprehensively compacted, is unlikely to provide durability equal to the original virgin rock and hence during times of fluvial flood, of magnitudes such that the current floodplain pinch point between B Pit and C Pit begins to develop afflux, it is likely that the Nogoia River would scour spoil within the adjacent backfilled pits. This has the potential over time to result in sink holes and ultimately a repeat of the 2008/2010 inundation events with the Nogoia River cutting a channel into one or more backfilled pits and flooding the remaining un-backfilled parts of each pit. Additionally, impacts on turbidity downstream of the backfilled areas would need to be considered.

As part of the rehabilitation process, the establishment of a biodiversity corridor along the western (highwall) side of the rehabilitated A and B pits is proposed to link Corkscrew Creek and the Nogoia River flood plain as seen in Figure 3.4.

4 Geomorphic setting

4.1 GEOLOGY

The majority of the Fitzroy catchment is underlain by the Permo-Triassic sedimentary and volcanic deposits of the Bowen Basin. These are overlain by younger Triassic and Jurassic sedimentary rocks from upland erosion during the Palaeogene (Jones, 2006). Later in the Palaeogene, the landscape became predominantly erosional, and small coastal streams captured inland drainage basins, so the drainage divide migrated further west until it reached its current position (Jones, 2006). This net balance of erosion continued to present, re-exposing parts of earlier Palaeogene and Mesozoic surfaces (Jones, 2006), and resulting in incision of the stream network and the creation of dissected tablelands, extensive areas of subdued relief and the formation of floodplains along the major rivers. Across central areas of the catchment, the older rocks are overlain by Tertiary and Cretaceous basalts.

During the early Tertiary period, the eastern highlands of Central Queensland was dominated by a southerly flowing river system (Shu, 2002). The Burdekin, Cape and Campaspe Rivers drained through the Suttor River to the Mackenzie River via Sandy Creek and Theresa Creek. Around the early Tertiary, an eruption of a large volume of basalt disturbed this southerly drainage around Clermont. Tertiary basalts, extruded from fissures and circular vents over a large area, filled in valleys and blanketed sub-basaltic topography. As a consequence, the southerly flow Burdekin River system was choked, and a large lake was subsequently formed to the north of Clermont. With ongoing deposition in the Tertiary lake, floodwaters in the Burdekin River rose to a level high enough to find a new course along a gap through the Eastern Highlands and the river was diverted to the east.

Over the geological time scale since this period, the Theresa Creek and Mackenzie River systems, including in the Nogoa River in the vicinity of Ensham Mine, have been adjusting to this major reduction in catchment and flow regime.

4.2 REGIONAL DRAINAGE CHARACTERISTICS

Figure 4.1 shows the drainage network of the Nogoa River and Comet River catchments that drain to the Ensham Mine. The main drainage feature is the Nogoa River, which drains in a northeasterly direction from the Great Dividing Range towards Emerald before turning eastward towards the mine. There are several significant tributaries of the Nogoa River with the two of relevance to the project being Theresa Creek and Crinum Creek, which drain into the Nogoa River about 29 km and 21 km upstream of the Mine respectively.

The Comet River drains into the Nogoa River about 8 km downstream of the Ensham Mine. Flows from the Comet River may increase flood levels in the Nogoa at Ensham Mine during flood events. The Nogoa River and the Comet River combine to form the Mackenzie River, which then becomes the Fitzroy River.

The catchment areas of the major watercourses are as follows:

- Nogoa River - 28,550 km² (of which 8,610 km² is contributed by Theresa Creek and 1,750 km² by Crinum Creek), and
- Comet River - 16,510 km².

Outside of the towns of Clermont, Emerald, Springsure and Blackwater, the catchment is sparsely populated. Land use is typically rural with substantial areas cleared for grazing.

Fairbairn Dam was constructed on the Nogoa River 40 km upstream of the Theresa Creek confluence in 1973 (upstream of Emerald) and supplies water to various industrial, agricultural and residential users. The dam stores 1,300 gigalitres (GL) when full and has a catchment area of 16,500 km². It has significantly changed the flow regime in the downstream reaches of the Nogoa and Mackenzie Rivers.

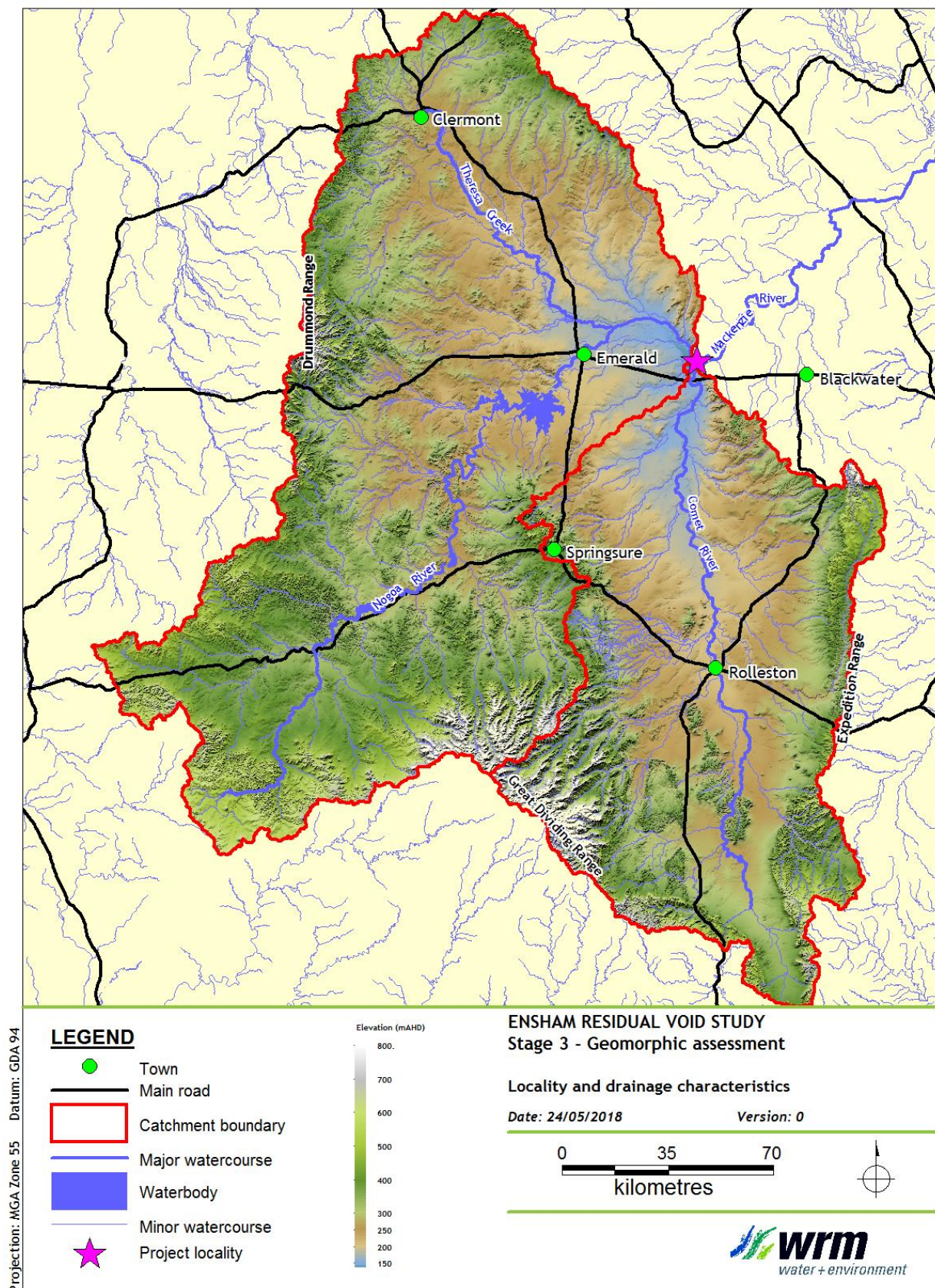


Figure 4.1 - Locality and regional drainage characteristics

Releases are made from the dam to deliver supplies to downstream riparian water users and to maintain supplies from Bedford and Bingegang weirs to various towns, mines and irrigators.

4.3 LOCAL DRAINAGE CHARACTERISTICS

Figure 4.2 shows the local drainage characteristics of the Nogoia River floodplain from the Theresa Creek confluence to the Comet River confluence. The main drainage feature is the Nogoia River, which drains through the floodplain from west to east. There are also a number of inactive palaeo-channels and active flood channels across the floodplain the most notable active channel is called the Anabranh, which is located immediately to the west of the mine. Two flood channels drain across the southern floodplain, one of which drains into Winton Creek. These flood channels have been called Flood Channel 1 and 2 in this report. Another flood channel called Mosquito Creek drains along the northern floodplain downstream of the Crinum Creek confluence. A cross section of the floodplain (at the location shown in Figure 4.2) is given in Figure 4.3.

The characteristics of these channels and the Nogoia River floodplain are given below.

4.3.1 Nogoia River

The Nogoia River within the reach shown in Figure 4.2 consists of a well-defined 10 m deep channel that is carved through a relatively flat floodplain channel. It is generally about 500 m wide from crest to crest except adjacent to the Anabranh, where it narrows to about 300 m.

The river channel contains a low flow channel and a series of active channels that dissect a lower bench. These channels are separated by well vegetated islands that are laterally stable. The low flow channel consists of a series of pools and riffles with water retained in the pools most of the time, likely by regulated releases from Fairbairn Dam. The riffles between the pools comprise gravelly cobbles that appear to form an armoured layer over the heavy clay. Recent sand deposits are evident but not dominant.

The lower bench channels become active during relatively small flood events and have bed levels that are generally not much above than the standing water levels in the adjacent pools.

Vegetation within the channel varies from very mature eucalypts (demonstrating low rates of lateral movement) on the islands to immature trees and pioneer species within the lower bench flood channels, which further suggests the lower bench flood channels are inundated frequently.

Figure 4.4 shows a longitudinal profile of the bed and the 10% AEP event flood levels along the Nogoia River between the Comet River and Theresa Creek confluences. The 10% AEP event was selected as all of the flood channels become active for this event (including the overbank flood channels) but the adjacent floodplain areas remain relatively dry. That is, the flows are relatively confined to the channels during this event.

The flood slope varies from 0.05% upstream of the Anabranh to about 0.03% downstream of the mine to the Comet River. It is possible that the lower downstream flood slope is due to backwater flooding from the Comet River.

4.3.2 Anabranh

The Anabranh is slightly narrower than the main Nogoia River channel and is about 150 m wide and is also slightly shorter and steeper (see Figure 4.4). The Anabranh is characterised by a low flow channel that has a pool and riffle sequence with a relatively defined lower bench and moderate bank slopes.

Figure 4.4 shows that there is a distinct change in bed and flood gradient about 2.5 km to 2.9 km upstream of the confluence, which results in an increase in bed gradient to 0.07% from 0.04% both upstream and downstream of this change. The bed of the Anabranh sits some 2 m to 3 m higher than the adjacent Nogoia River channel after this point, which continues to the upstream bifurcation.

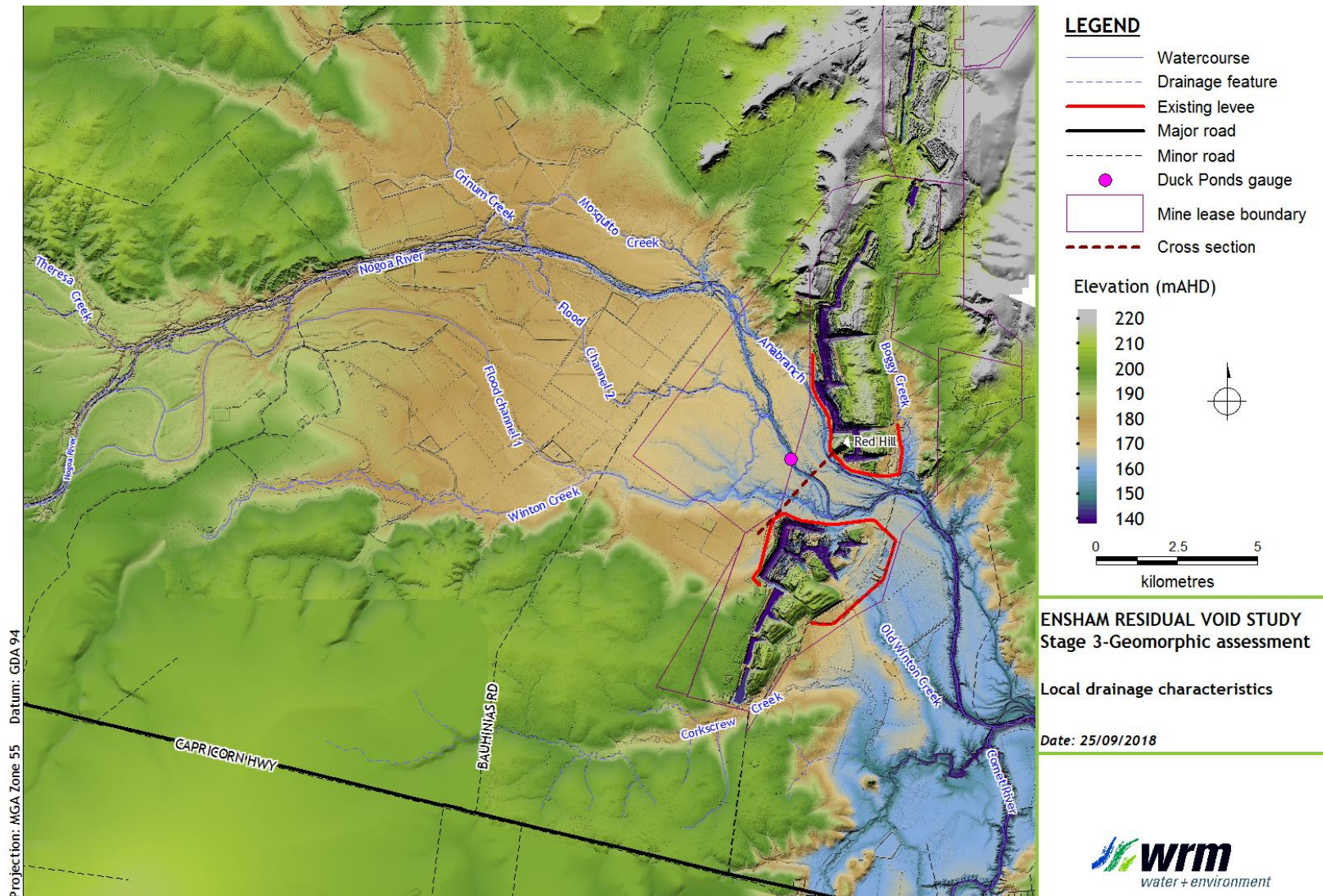


Figure 4.2 - Local drainage characteristics

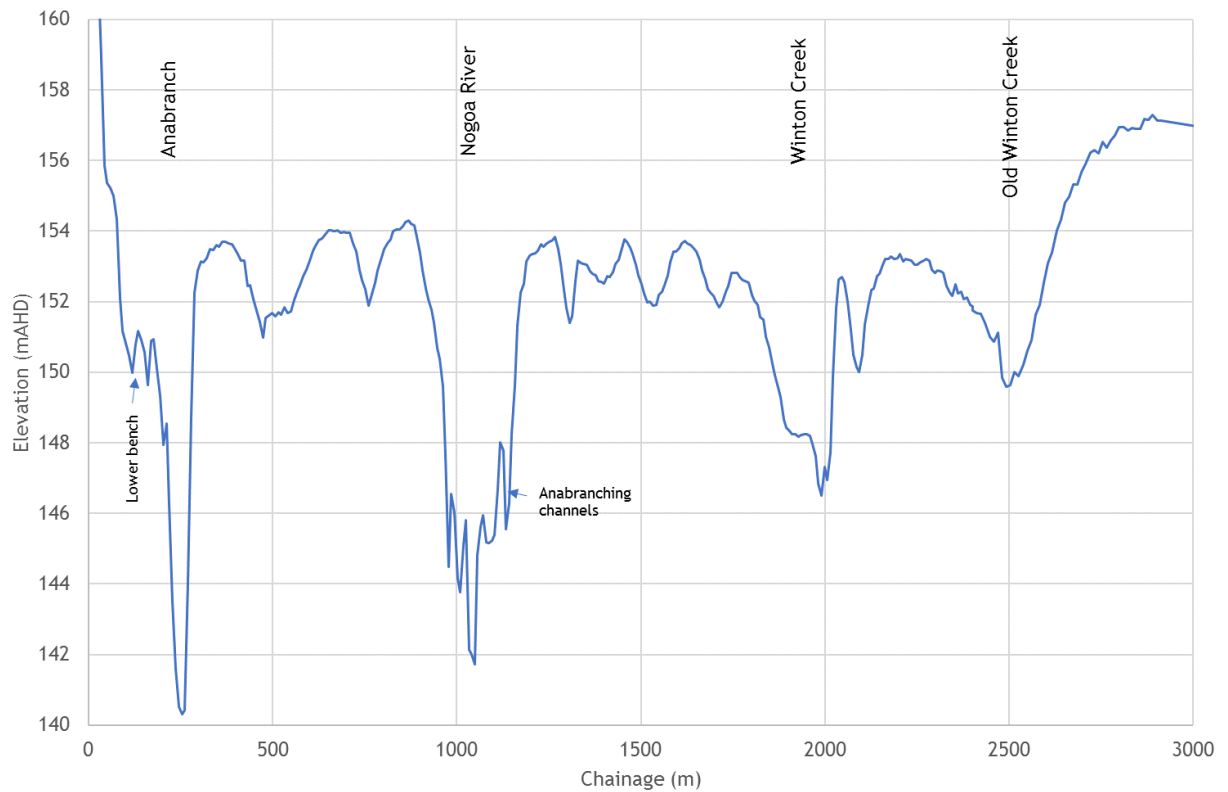


Figure 4.3 - Floodplain cross section

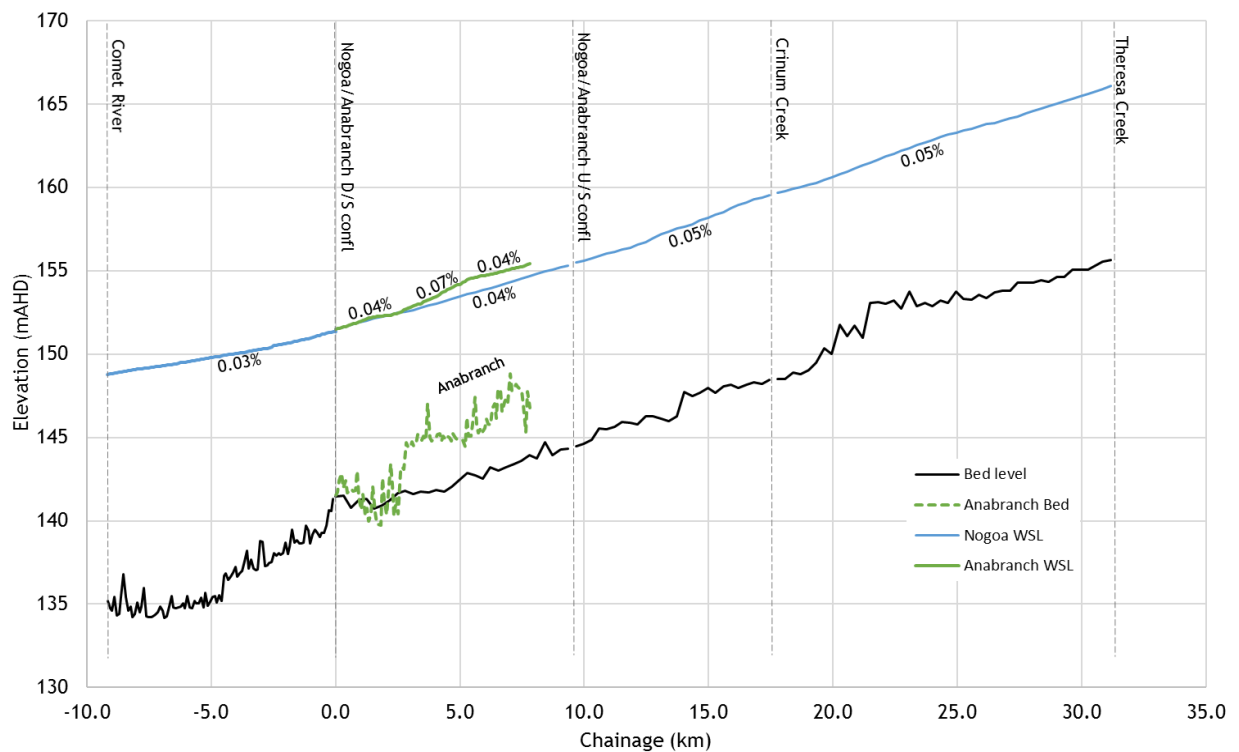


Figure 4.4 - Nogoa River channel longitudinal profile

This change is located adjacent to the natural sandstone outcrop identified as 'Red Hill' (see Figure 4.2) on the mining lease and as such the change may be geologically controlled. However, it could also indicate that headward erosion is occurring given that it is a shorter channel than the adjacent Nogoa River channel, although there was no evidence of headward erosion during the site inspection. A sandstone outcrop and cobble slug forming a long riffle in the anabranch may be the upstream limit of headward erosion in the anabranch at present.

The Anabranch has similar vegetation characteristics to the Nogoa River with mature eucalypts and casuarinas along the water line and immature species on the lower bench suggesting the channel bank is stable.

4.3.3 Flood channels

There are two flood channels that cross the southern floodplain (Flood Channel 1 and Flood Channel 2) and one on the northern floodplain (Mosquito Creek). These flood channels convey local catchment runoff from the floodplain as well as Nogoa River overflows. All of the flood channels are well vegetated.

- Flood channel 1 consists of a broad and ill-defined channel adjacent to the Nogoa River and becomes more defined as it drains into Winton Creek and has a bed slope of about 0.07%. The upper reaches are bound by floodplain infrastructure. The bed gradient in Winton Creek is 0.13%, almost twice as steep as the upstream Flood channel 1. However, water levels in Winton Creek are significantly impacted by backwater flows from Nogoa River.
- Flood channel 2 consists of a well-defined channel that is up to 5 m deep and 40 m wide. It is bound by floodplain infrastructure for much of its length and has a bed slope of around 0.05%, similar to the adjacent Nogoa River.
- Mosquito Creek, which bifurcates from Crinum Creek, drains along a relatively incised valley that is about 5 m deep and up to 200 m wide. It has a bed gradient of around 0.05%.

4.4 FLOODPLAIN CHARACTERISTICS

The Nogoa River floodplain varies in width from about 4 km at the location of the mine (currently narrowed to 1.5 km by the mine levees) to about 13 km near the Crinum Creek confluence. The floodplain consists of quaternary alluvium and lacustrine deposits of a mix of sand, silt, clay and gravel. Hansen Consulting (2006) characterised the alluvium as a strongly structured alkaline heavy (cracking) clay soil classified as a grey or brown vertosol soil. The soils are non-sodic but are moderately dispersive.

The alluvial soils are bound to the south by eroded sediments from the elevated Tertiary Emerald formation and to the northwest by late tertiary colluvium and late Permian sandstone and silty sandstone at the location of the mine.

Croke et al (2011) provide a reasonable characterisation of the Nogoa River floodplain from five cores bored to a depth of 10 to 11 m across the Nogoa floodplain upstream of the Theresa Creek confluence. It is expected that the floodplain in the study area would be similar to that recorded by Croke.

The core sample taken in the river recorded approximately 5 m of basal coarse sand, located on a contemporary mid-island ridge between anabranching channels. This is overlain by 3.75 m of fine grained sediments, which displays decreasing sand content with height, from sandy mud (heavy clay) at the base of the unit to mud at the top.

Three cores were located on the palaeo-floodplain surface at an average elevation of 4 to 6 m higher than the core taken within the river channel:

- One core was extracted from the centre of a palaeo-meander and contains an 8 m thick fine-mud (heavy clay) deposit overlying a gravelly and muddy very-coarse sand deposit. Gravel clasts of up to 2.5 cm were recorded in this unit. The upper facies consist of cohesive muds with some sand and gravel clasts in the basal 1.3 m of the unit.

- Two cores were taken from remnant scroll bars on the inside bend of the palaeo-meander and display upper units of very fine sand and silt overlying coarser deposits. In one of the cores, the basal deposit is comprised of slightly gravelly fine sand and in the other, the basal deposit is composed of medium-coarse sand and gravel.

The final core was collected from the scroll bar of another adjacent palaeo-meander. It comprises a similar sequence of mud overlying a sand deposit, although this core also penetrated an underlying fine-grained deposit, at 6 m depth. The sand deposit in this core contained thin muddy drapes between 1 and 4.5 m that were mostly between 10 and 50 mm thick, but with some up to 100 mm thick.

4.5 RECORDED STREAM FLOWS

Figure 4.5 shows a ranked plot of recorded stream flows in the Nogoia River (1993-2017) at the Duck Ponds gauge (GS130219A), located upstream of the mine (see Figure 4.2). The plot is derived by ranking all of the daily flows from highest to lowest and then dividing the ranking by the number of days over the period of recorded. The following is of note:

- Flows have been recorded almost every day of the period due to the regulated releases from Fairbairn Dam to supply downstream users;
- 50% of all flows are less than 2 m³/s;
- 95% of flows are less than 50 m³/s,
- The highest recorded water level occurred on 1 January 2011 at a gauge level of 15.152m (155.92 mAHD), which equates to a peak flow of 4,795 m³/s.

QLD DNRME WMDB - Production SQL

HYFLOW V180 Output 26/04/2018

Time Weighted Stream Discharge Duration Curve.

Stream Discharge in Cumecs, Instantaneous Values. Interval 1 Days

Site 130219A Nogoia_R Duck Ponds 03/04/1993..17/11/2017

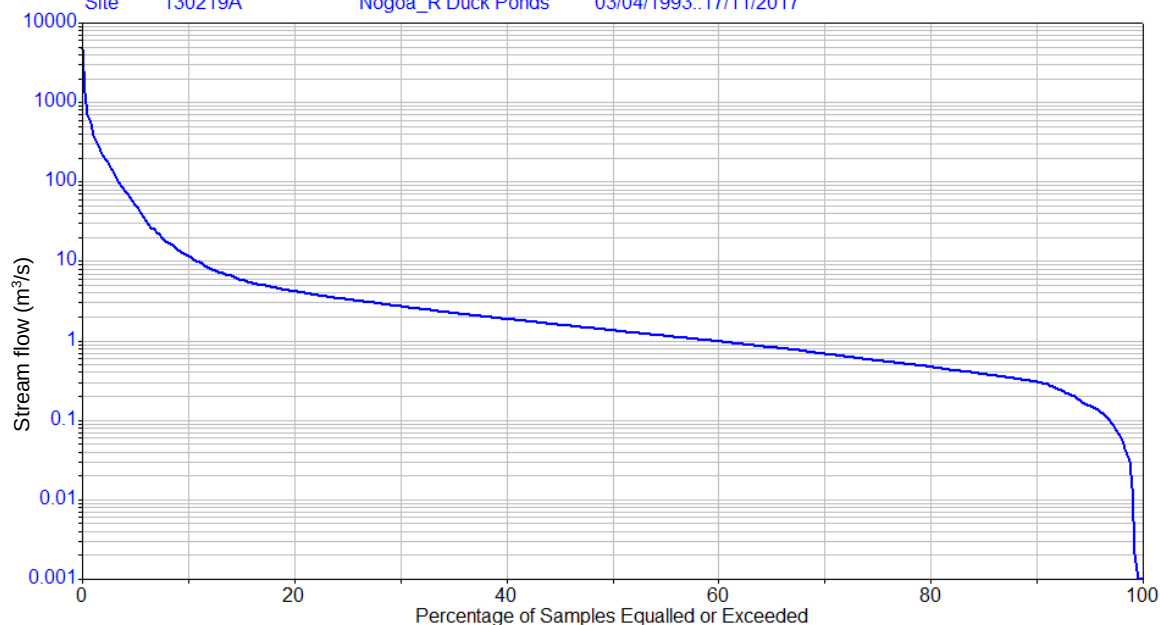


Figure 4.5 - Nogoia River at Duckponds discharge duration curve, 1993 - 2017

4.6 PRE-MINE FLOODING CHARACTERISTICS

Flood modelling has been undertaken of the Preferred Options by HEC (2018a). Details of the modelling methodology and flood results including the flood level impacts of the various options are given in the HEC (2018a) report. These models have been provided to WRM to assist in describing the flooding characteristics of relevance to assessing the

morphology of the Nogoia River floodplain. For this study, HEC's 'regional' model was modified by reducing the grid size from 30 m to 10 m to improve the model resolution and then rerun without altering the hydrology or other hydraulic model parameters. No other parameters in the model were reviewed or altered as part of this assessment.

The pre-mine conditions assume that there were no mine levees or open voids on the floodplain. The pre-mine landform was derived from previous flood modelling results prepared for the Stage 2 study by HEC (2018b) and therefore only approximates pre-mine conditions. The modelling has been used to define the capacity of the Nogoia River channel together with the frequency at which the various flood channels receive Nogoia River flows. The distribution of flow in the flood channels has also been determined. Velocity and shear stress have been used to define the hydraulic characteristics of relevance to the floodplain morphology:

- Stream velocity has been used as an indicator of stream impacts, where increases in velocities would suggest some change in the stream characteristics may occur. Note there is not a direct relationship between velocity and the force exerted on soil particles at the boundary and thus stream power and shear stress are used as more reliable indicators of erosion potential.
- Shear stress provides a measure of the tractive force acting on sediment particles at the boundary of the stream and is used to determine the threshold of motion for bed material. It provides an indication of the potential for erosion of cohesive sediments or movement of non-cohesive sediments at the channel boundary.

The modelling included:

- An assessment of the 10% AEP design flood to represent the behaviour of the river at bank full flow conditions. The bank full flow is the maximum flow that the channel can carry before it overflows onto the adjacent floodplain. In geomorphologic studies, the bank full flow is often considered to be the stream forming flow, because it often exerts the greatest influence on channel geometry.
- An assessment of the 1% AEP design flood to represent the behaviour of the river during large floods.
- An assessment of an event that is 50% greater than the 0.1% AEP flood to determine what would occur in the unlikely event that the levels of the final landform levees are exceeded.
- An assessment of the PMF to determine how Option 3 compares to pre-mine conditions.

Note that the PMF event has not been used for the geomorphic assessment, as required by the ToR. The event that is 50% greater than the 0.1% AEP flood provides a better assessment of the long-term geomorphological impacts as there is some potential, albeit very small, to occur. The impact assessment presented for the event that is 50% greater than the 0.1% AEP flood would be the same as that for the PMF. An assessment of the PMF is provided by HEC (2018).

4.6.1 Nogoia River channel breakout flows

Figure 4.6 shows the latest stream flow rating curve (relationship between stream water level and flow) at the Nogoia River at Duck Ponds gauge (GS130219a). The estimated flow at which the Nogoia River overflows into each of the flood channels is also shown.

The results show that the Anabranh would receive flows potentially multiple times per year whereas the flood channels would receive flows once every 5 to 10 years, on average.

These results suggest that the channel capacity, or the channel forming flow described in Section 5.1, potentially equates to an event between the 18% and 10% AEP events. The 10% AEP has been used in this analysis to be consistent with the HEC (2018a) flood modelling results.

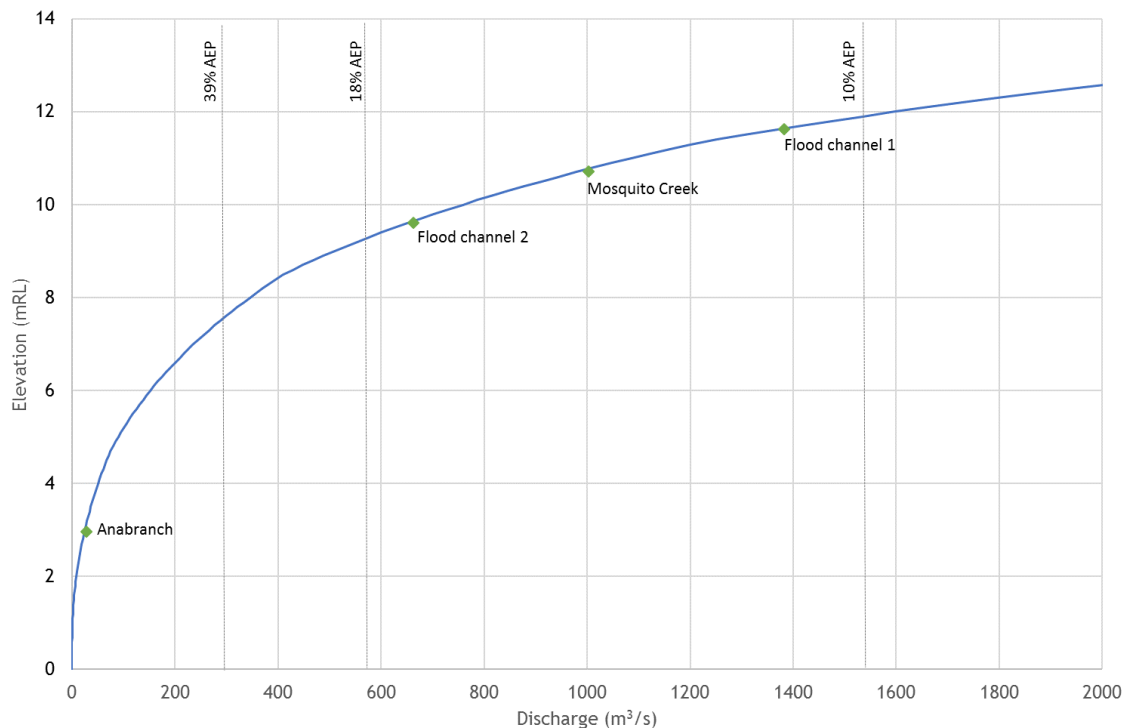


Figure 4.6 - Nogoia River at Duck Ponds rating curve and estimated flood channel breakout flows

4.6.2 Flood channel flow distribution

Figure 4.7 shows the estimated distribution of flow between the Nogoia River and each of the flood channels for the 10% and 1% AEP events. Again, these flows were determined using the modified HEC (2018a) model. The results show the following:

- For the 10% AEP event, the majority of flows are conveyed by the Nogoia River channel (54%) with the Anabranche conveying 36% and Flood Channel 2 10%. Very little flow is conveyed by Flood Channel 1.
- For the 1% AEP event, Flood Channel 1 and 2 convey the majority of the flow (52%) followed by the main Nogoia River channel (26%).
- The Old Winton Creek channel, which has now been consumed by the B Pit void, would have flowed about 2 m deep at the location of the B Pit levee for the 10% AEP event. The Old Winton Creek channel carried 6% of the 10% AEP flow and 34% of the 1% AEP flow.

4.6.3 Velocity

Figure A1 to Figure A3 in Appendix A show peak flood velocities for the 10%, 1% and 1.5 x 0.1% AEP events for pre-mine conditions. The range of peak channel velocities along the Nogoia River channel between the Theresa Creek and Comet River confluences and along the two flood channels under pre-mine conditions is shown in Table 4.1.

These results have been derived from a point inspection of the velocity maps taken along the centre line of the channels. Results are shown for the 10 percentile, 50 percentile (median) and 90 percentile values (percentage of values are less than this).

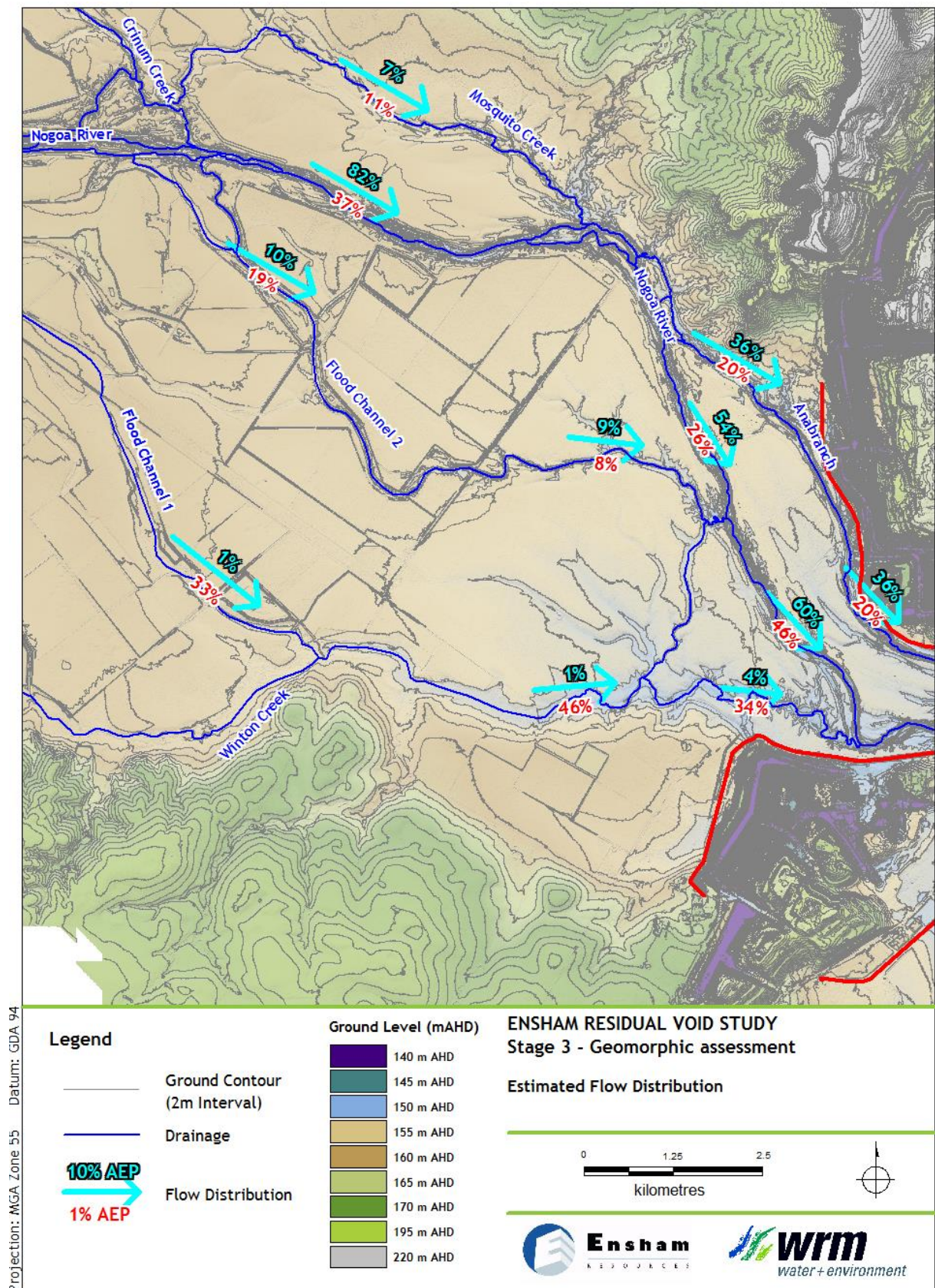


Figure 4.7 - Estimated flow distribution for each channel, 10% and 1% AEP events

Table 4.1 - Nogoa River and Flood Channel velocities, 10%, 1% and 1.5 x 0.1% AEP event

Event (AEP)	Nogoa River Velocity (m/s)			Flood channel 1 Velocity (m/s)			Flood channel 2 Velocity (m/s)		
	10%ile	50%ile	90%ile	10%ile	50%ile	90%ile	10%ile	50%ile	90%ile
10%	0.9	1.1	1.3	0.1	0.2	0.5	0.5	0.6	0.9
1%	1.0	1.2	1.4	0.4	0.6	0.8	0.6	0.8	1.1
1.5x0.1%	1.1	1.3	1.6	0.5	0.7	0.9	0.6	0.8	1.1

The following is of note:

- The Nogoa River channel velocities are similar for the three events with median values between 1.1 m/s and 1.3 m/s.
- Overbank velocities are much lower with median values between 0.2 m/s and 0.7 m/s along Flood Channel 1 and 0.6 m/s and 0.8 m/s along Flood channel 2 for the three events.

4.6.4 Shear stress

Figure A4 to Figure A6 in Appendix A show peak shear stress for the 10%, 1% and 1.5 x 0.1% AEP events for pre-mine conditions.

Table 4.2 shows the range of peak shear stress along the Nogoa River channel between the Theresa Creek and Comet River confluences and along the two flood channels under pre-mine conditions.

Table 4.2 - Nogoa River and Flood Channel Shear stress, 10%, 1% and 1.5 x 0.1% AEP event

Event (AEP)	Nogoa River Shear stress (Pa)			Flood channel 1 Shear stress (Pa)			Flood channel 2 Shear stress (Pa)		
	10%ile	50%ile	90%ile	10%ile	50%ile	90%ile	10%ile	50%ile	90%ile
10%	34.5	48.3	87.2	1.6	5.3	12.0	11.2	21.2	37.0
1%	42.5	60.9	97.1	9.1	19.1	32.3	16.4	27.4	57.2
1.5x0.1%	49.0	67.9	106.8	13.4	24.5	45.6	18.8	31.2	63.4

The following is of note:

- The Nogoa River shear stress generally increases with AEP roughly in proportion to the increase in flow depth.
- Higher shear stresses occur along the Nogoa River between the Theresa Creek and Crinum Creek confluences particularly for the 1% and 0.1% AEP events.
- The 90%ile shear stresses along the Nogoa River are sufficient to transport bed sediments through the reach that would limit deposition and the long term reduction in channel capacity.
- Along Flood Channel 1, the shear stresses are low for all three events. A review of the mapping suggests that Flood Channel 1 overflows and drains along a new flow path between Flood Channel 1 and Flood Channel 2 for the larger events.
- The Flood Channel 2 shear stresses are generally about half of those of the Nogoa River.

4.6.5 Fluvial erosion potential

The potential for the predicted velocities and shear stress values to cause erosion of the Nogoa River channels and floodplain is dependent upon the capacity of the soils to resist erosion as well as the vegetation characteristics at the time of the flood. Local issues, such as woody debris, can also impact erodibility. An assessment of the erosion that occurred as a result of the January 2008 flood by KBR (2009) provides some guidance as to what would occur during a large flood. KBR (2009) provides the following comments regarding the 2008 flood:

- Overbank flows showed typical channelising across floodplain areas. While these “channels” occasionally show signs of localised erosion, they are largely areas of deposition of flood sediments similar to the adjacent floodplains.
- While there were areas where some major morphologic impacts were observed, these were largely due to the levee breaches into B Pit and C Pit and are not representative of the general response to the flood. In fact, the main channel was not impacted to any significant extent in areas away from the locations of the levee breaches.
- Observations of a major overbank flow location near the breakout into C Pit showed the flattening of the natural grasses with little evidence of erosion. The grasses show little sign of removal, and it is apparent they acted more as a trap for sediment which was deposited some 10 cm thick.
- Based on site characteristics, it is considered that the appropriate velocity limits for the Ensham Mine area are 1.5 m/s (average ground cover) to 2.1 m/s (good ground cover). It appears that shear stress of up to 100 N/m² (Pa) would be acceptable for a good stand of grass cover with higher values for areas with well-established tree/scrub cover.

A Nogoa River flood occurred in January 2011 at Ensham, which was larger than the 2008 flood and the largest recorded. Detailed observations of the river and floodplain following this flood in the vicinity of Ensham Mine are not available. However, observations of the Nogoa River in and around Emerald by WRM staff after this flood identified no significant erosion. However, localised erosion associated with recently fallen trees and woody debris was evident in places. A review of aerial photographs of the river (from Google Earth) shows no signs of significant bank erosion or evidence of floodplain changes.

On the basis of these observations, minimal erosion or channel movement is expected for the range of modelled pre-mine velocities and shear stresses given in Table 4.1 and Table 4.2 for at least the 1% AEP flood. This suggests that the Nogoa River channel and floodplain are likely to be stable in the short term and medium term.

5 Assessment of Preferred Options

5.1 ASSESSMENT METHODOLOGY

The potential for the three Preferred Options to have a detrimental impact on the morphology of the Nogoa River and its floodplain has been assessed through both field observations and hydraulic model results. Models developed by HEC (2018a) for the Stage 3 study have been obtained and modified for the assessment, as described in Section 4.6.

The Preferred Options have been compared against pre-mine flooding conditions described in Section 4.6. Stream velocity and shear stress have been used as indicators of potential stream impacts, where changes between pre and post-mining conditions would suggest some change in the stream characteristics may occur. The maximum velocity and shear stress at the affected zones have then been compared to the maximum velocity and shear stress at other locations on the floodplain with similar characteristics to determine whether the changes could potentially cause a detrimental impact long term. Other parameters such as stream power, which are also useful assessing stream impacts, are not directly available from the hydraulic model.

5.2 PREFERRED OPTION 1

Figure A7 to Figure A12 in Appendix A show peak flood velocities and peak shear stresses for the 10%, 1% and 1.5 x 0.1% AEP events for Preferred Option 1 (Landform levee). Option 1 velocity and shear stress impacts compared to pre-mine conditions are shown in Figure 5.1 to Figure 5.6. The results are described below.

5.2.1 10% AEP event

For the 10% AEP event, the modelling shows that there would be no material change in peak velocities and shear stresses from pre-mine conditions as a result of the Option 1 landform within the channel or the overbank areas. Minor impacts associated with the road crossings are predicted, which could potentially be removed post mining.

This suggests that the morphology of the river channel and floodplain including the sediment transport characteristics and erosion potential will not be impacted by Option 1 during small to moderate sized flood events.

5.2.2 1% AEP event

The flood modelling of the 1% AEP event, which represents a large and infrequent flood event shows the following:

- Peak Nogoa River channel velocities increase by up to 0.25 m/s in the 5 km reach immediately downstream of the mine. However, the median velocity (1.2 m/s) and 90th percentile velocity (1.4 m/s) in this reach under Option 1 conditions are essentially the same as the pre-mining median and 90th percentile velocities along the entire reach (see Table 4.1).
- Similarly, peak Nogoa River shear stresses increase by up to 15 Pa along this reach. However, the median shear stress (56 Pa) and 90th percentile shear stress (87 Pa) are lower than the pre-mining median and 90th percentile shear stress along the entire reach (see Table 4.2).
- There is a minor reduction in peak velocities and shear stresses along the Winton Creek channel immediately upstream of the B Pit levees. Given that flood velocities and shear stresses generated from the Winton Creek catchment are likely to be higher than Nogoa River generated velocities and shear stresses in this area (without backwater flooding), this reduction in flood velocity and shear stress is not expected to significantly change the morphological response in this area.

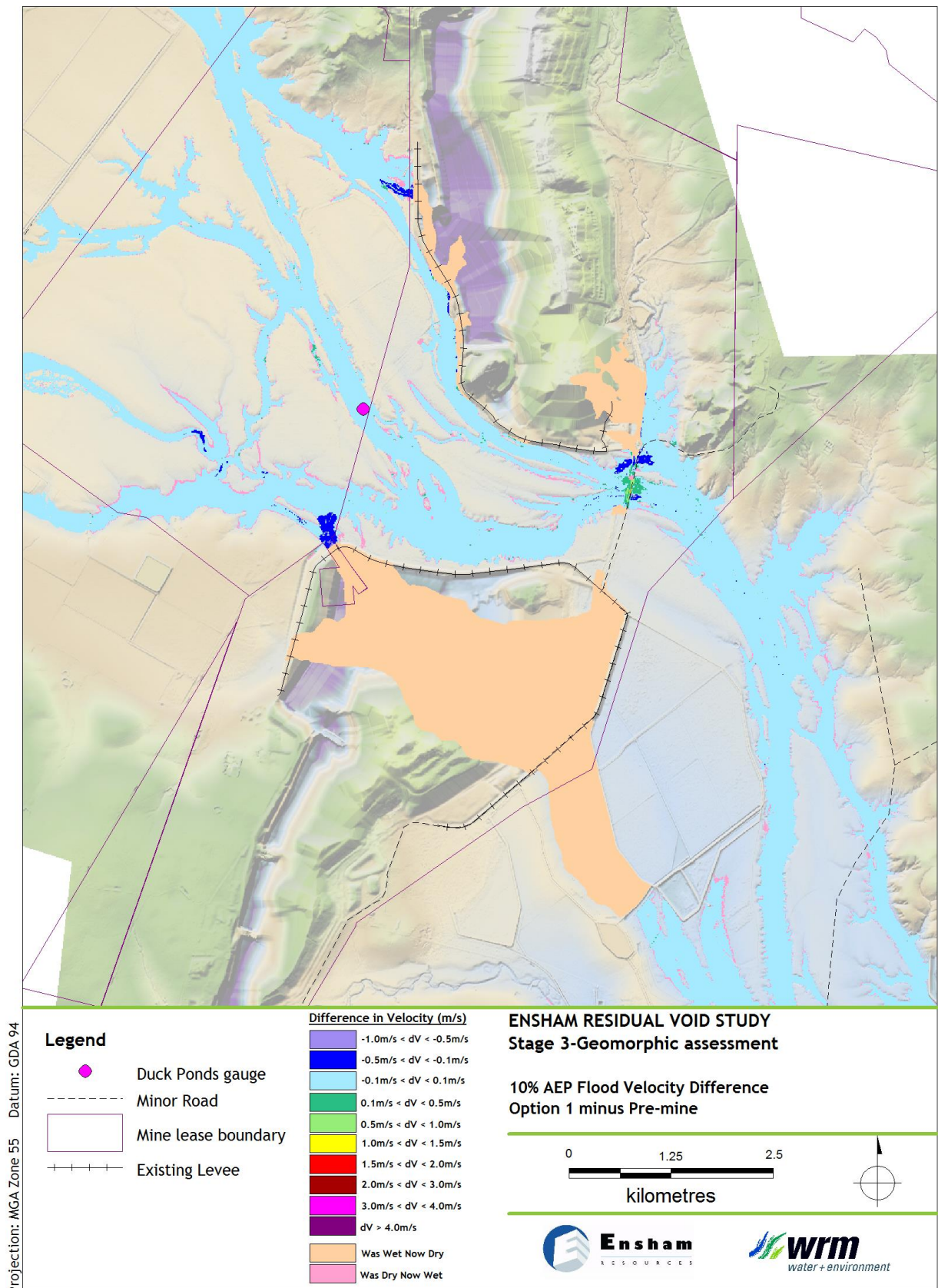


Figure 5.1 - Option 1 minus Pre-mine flood velocity difference, 10% AEP event

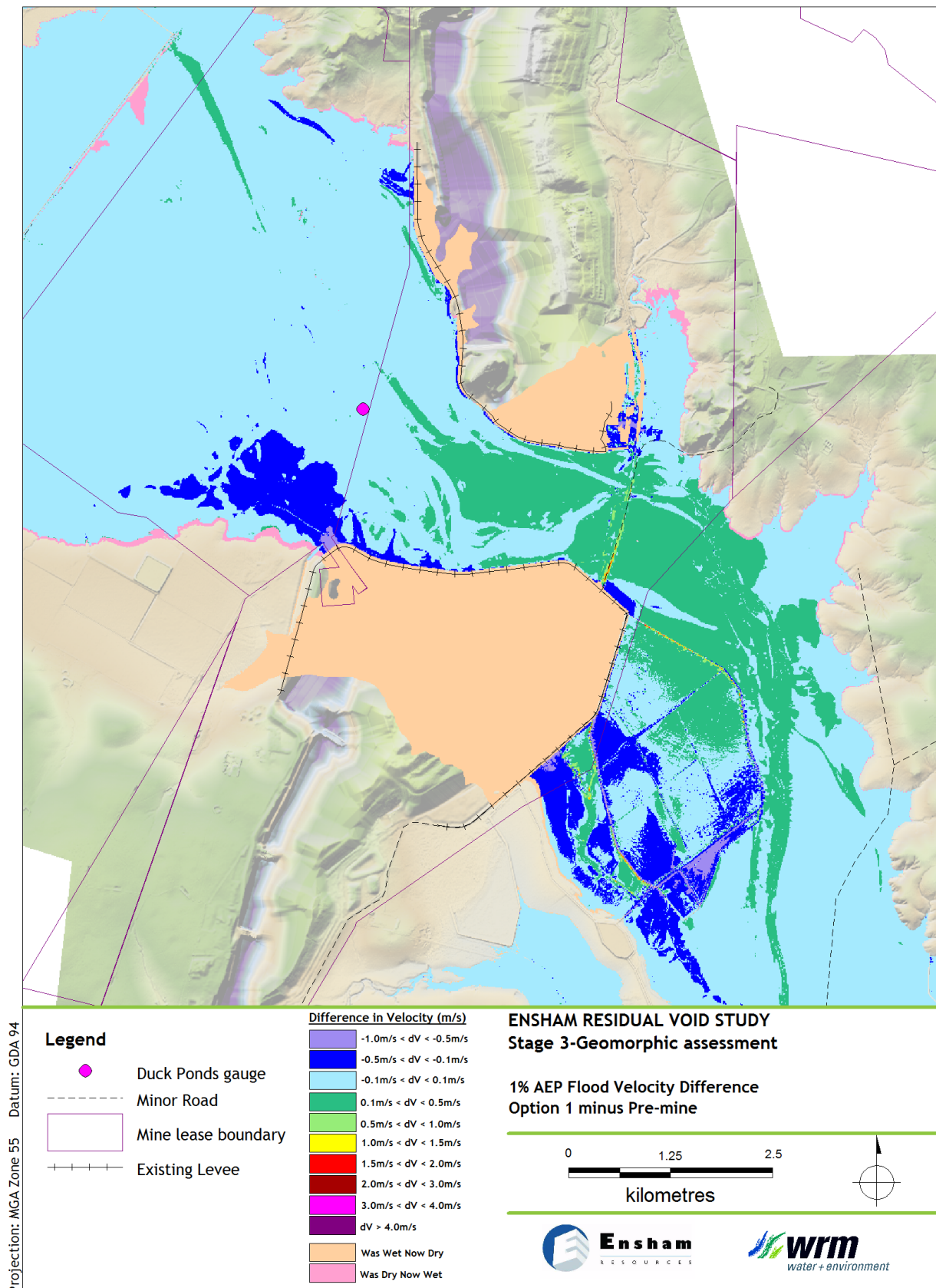


Figure 5.2 - Option 1 minus Pre-mine flood velocity difference, 1% AEP event

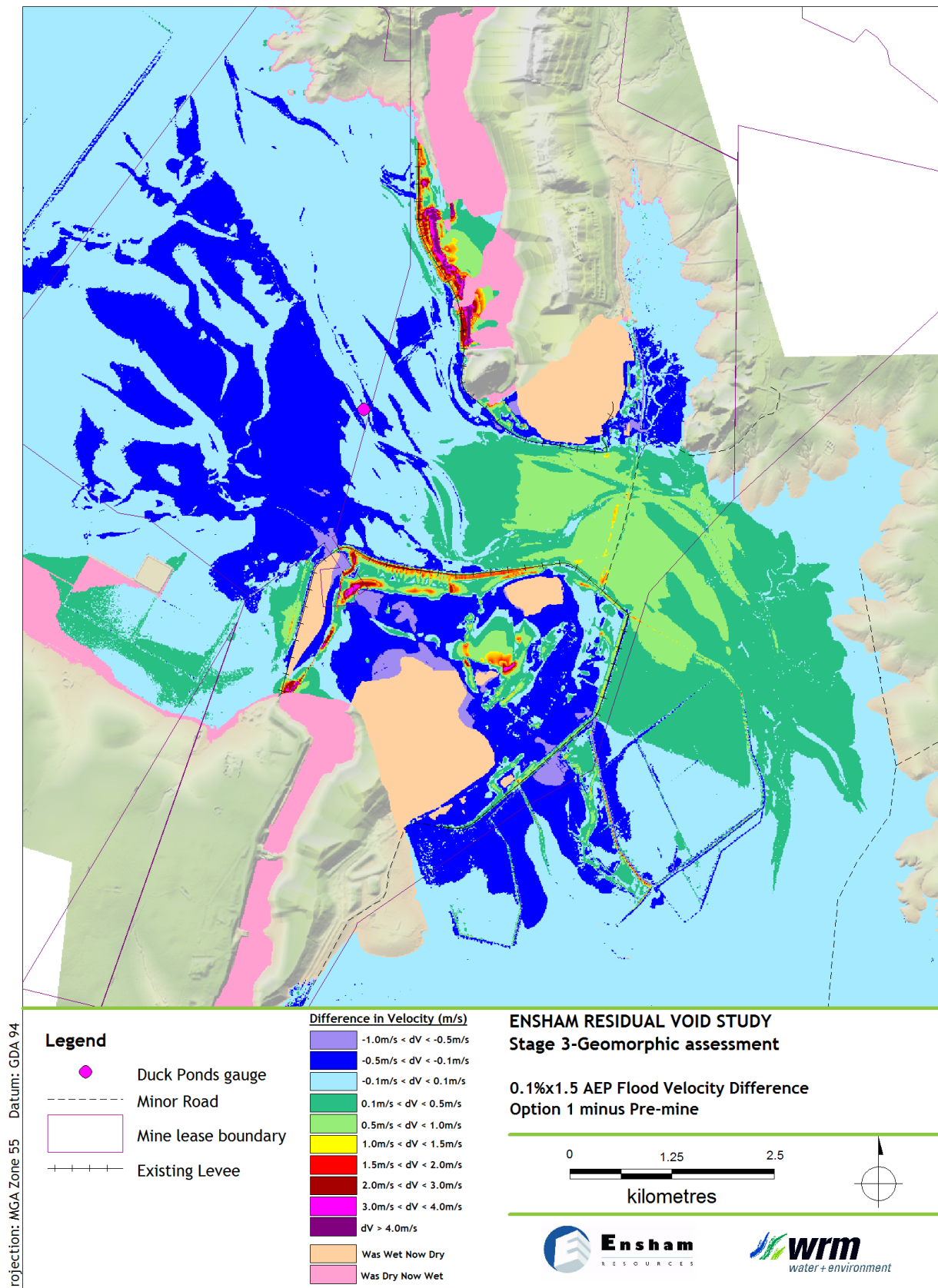


Figure 5.3 - Option 1 minus Pre-mine flood velocity difference, 1.5 x 0.1% AEP event

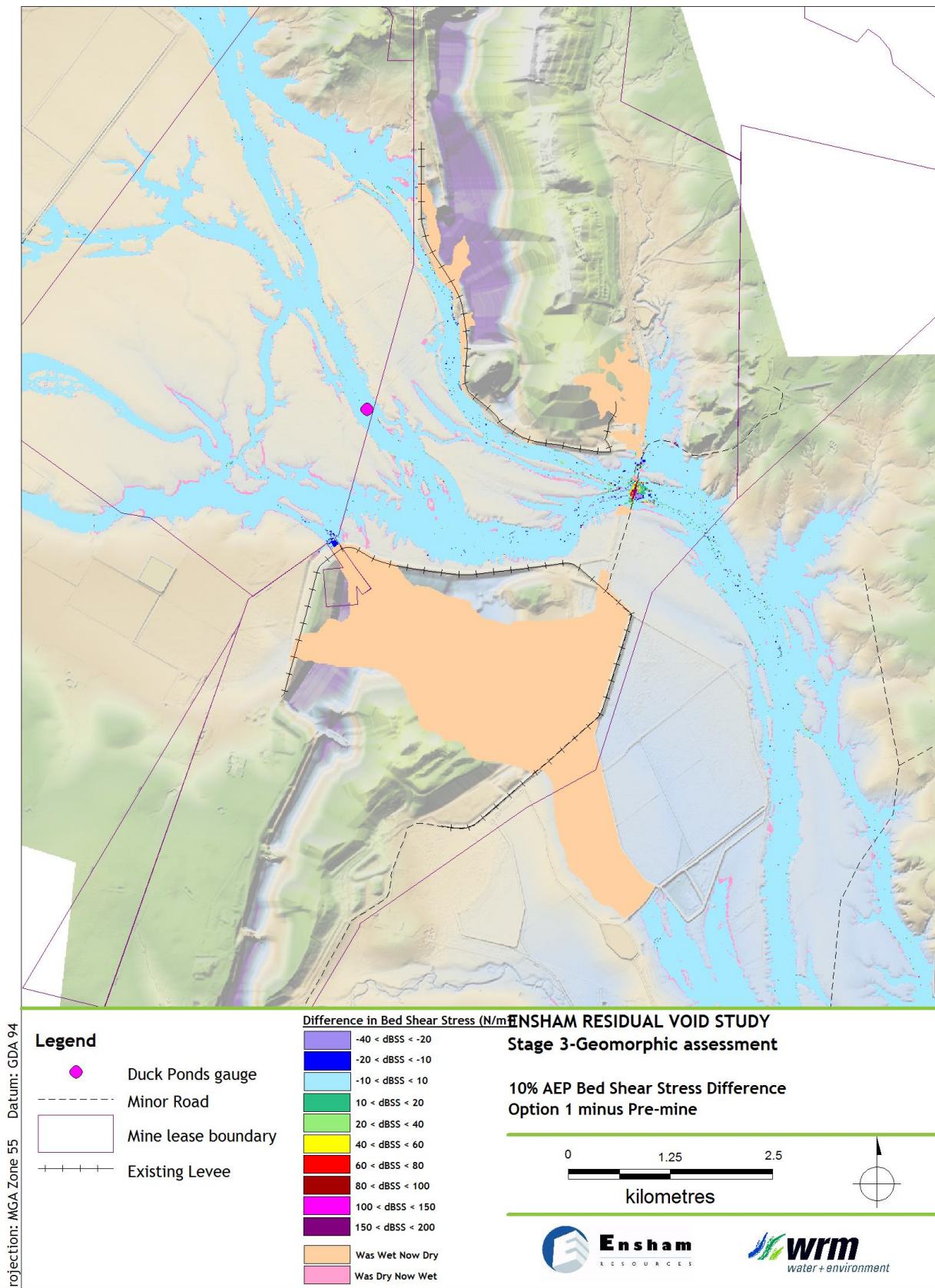


Figure 5.4 - Option 1 minus Pre-mine shear stress difference, 10% AEP event

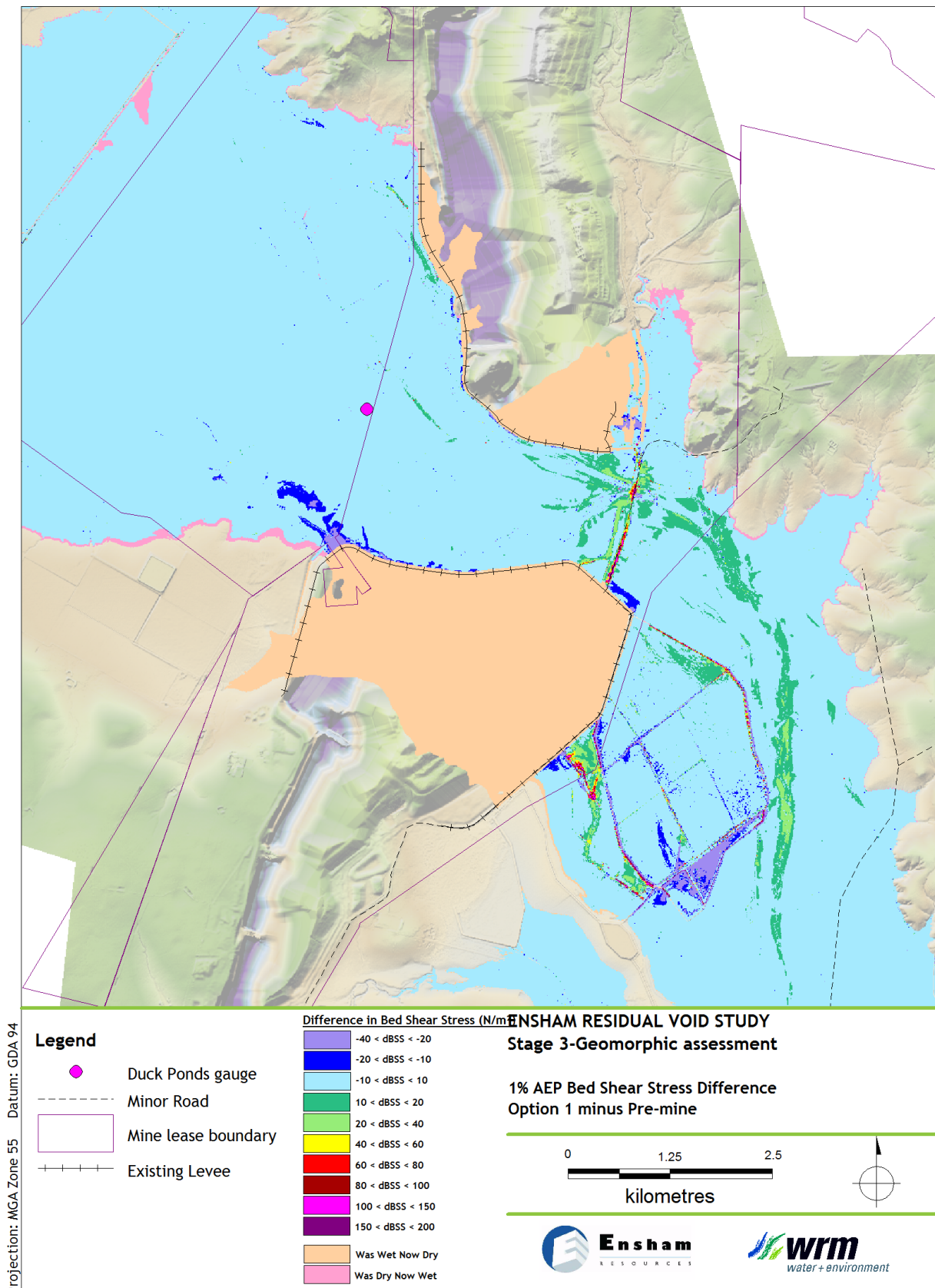


Figure 5.5 - Option 1 minus Pre-mine shear stress difference, 1% AEP event

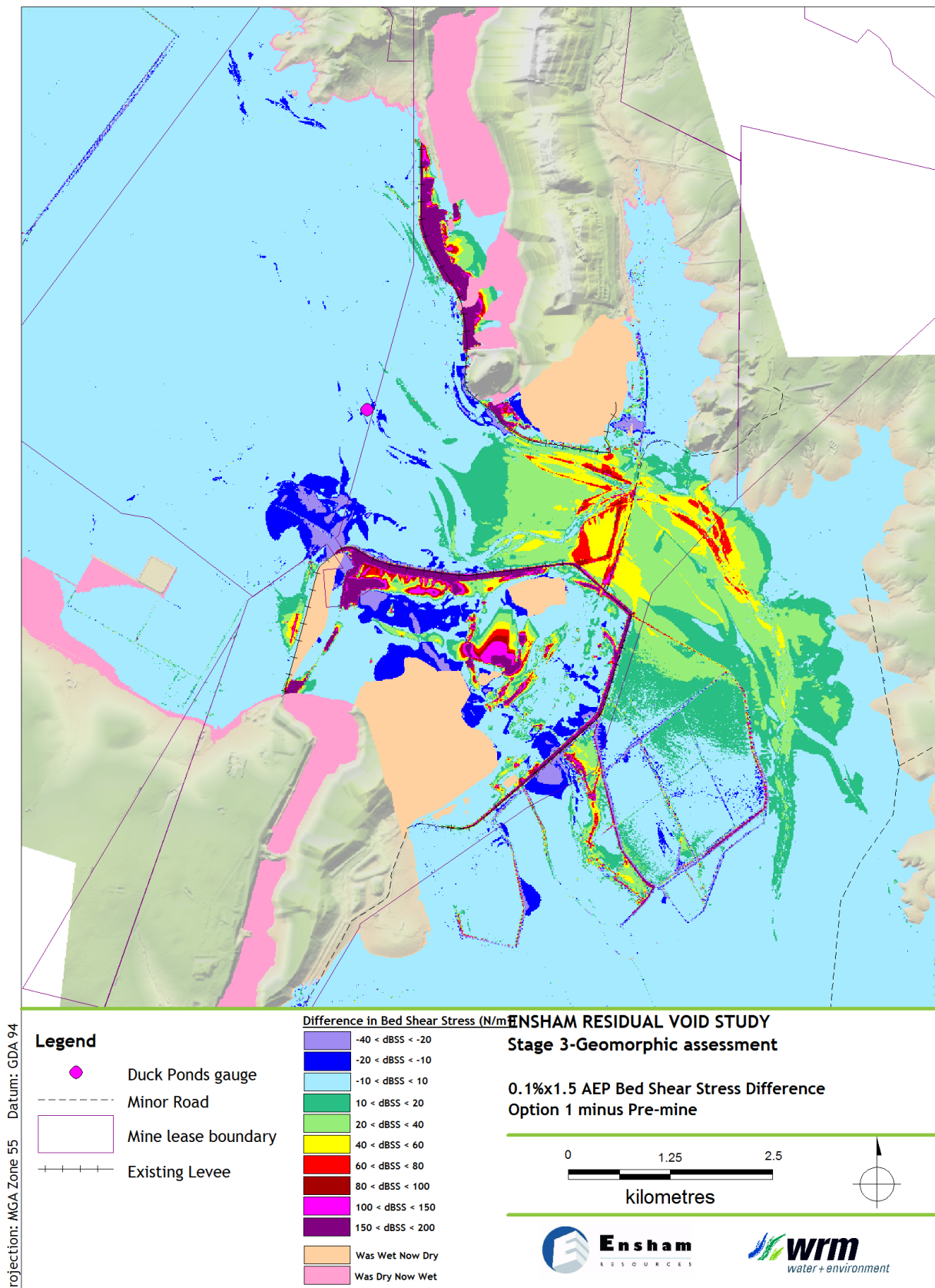


Figure 5.6 - Option 1 minus Pre-mine shear stress difference, 1.5 x 0.1% AEP event

- Peak floodplain velocities between the levees and in the 3 km reach immediately downstream of the mine increase by up to 0.25 m/s. However, the peak floodplain velocities in this reach are similar to peak velocities on the floodplain along Flood Channel 1. The change in shear stresses along the floodplain is not significant.

A further review of these results found that this reach is potentially impacted by backwater flooding from the Comet River (for both the 1% AEP event and the 1.5 times the 0.1% AEP event). Therefore, flood velocities would be lower when compared to the reach upstream of the mine that is not backwater affected. It is likely that the channel velocities and shear stresses would be higher when the Nogoia River peak does not coincide with a Comet River flood.

Notwithstanding, the differences between pre-mine and Option 1 flooding conditions are minor for this event and therefore Option 1 would not have a detrimental impact on channel morphology for events up to the 1% AEP event.

5.2.3 Extreme (overtopping) event

For the event that is 50% greater than the 0.1% AEP event:

- There would be significant increases in peak velocities and shear stresses in the reach adjacent to the levees extending for about 7 km downstream of the mine. The increases would appear to generally be on the overbank areas where pre-mine velocities and shear stress are generally lower than the adjacent channel velocities. The increase would suggest there is an increased erosion potential on the over bank areas for this extreme event.
- Along the Nogoia River channel, the predicted median and 90th percentile channel velocities and shear stresses in this reach are similar to the median and 90th percentile values along the entire reach.

The floodplain levees are overtopped for this extreme event (as it is larger than the design event). Although it is difficult to determine what would occur during an overtopping event, the results suggest that the integrity of the proposed Option 1 landform may be compromised by overtopping scour particularly if overtopping occurred for an extended period of time.

For the C Pit, the highwall is about 200 m away from the Anabranh and the crest of the landform is about 17 m above the channel bed and 80 m above the base of the void. The likelihood of the C Pit embankment eroding to bed level would depend upon the depth and duration of overtopping as well as the embankment material. However, given the enormous stream power of the overflowing water into the deep void, erosion of the embankment would likely continue until the void water level equalised with the river water level.

The B Pit landform is a similar distance and elevation from the Nogoia River at the location where the river is closest. However, the final landform ground levels behind the levee are about 9 m above the adjacent Nogoia River bed level at this location. For an overtopping event at this location, erosion would likely cease when the river level fell below the ground level, which would mean that the Nogoia River embankment would likely remain intact. The B Pit void that is below the bed level of the Nogoia River is located some 600 m to 700 m away from the Nogoia River and Winton Creek channels and therefore has less of a chance of eroding to bed level.

If the C Pit or B Pit landforms were overtopped and the embankment eroded to bed level, their configuration away from the main flow path would suggest that both would act like connected off-stream storages. The pits would fill with water and, once full, have zero velocity allowing flows to continue downstream along the main Nogoia River channel and the Anabranh. If such an event occurred, it would appear unlikely that the course of the Nogoia River or Anabranh would be altered to drain through the void. Repairing the embankments, as occurred in 2008, would mean that there would be no long-term impacts on the Nogoia River or its floodplain.

Note that the proposed overtopping levels of the Option 1 landform are higher than the existing levee crest heights and therefore Option 1 would reduce the chance of an overtopping event occurring. On this basis, Option 1 provides a marginal benefit when compared to existing conditions.

5.3 PREFERRED OPTION 2

Figure 5.7 and Figure 5.8 show the potential intake levels in relation to the river channel cross sections that have been adopted for the Preferred Option 2 (flood mitigation and beneficial use) conditions. Modelling has assumed that the voids were empty at the start of the event and filled through the proposed culvert intake structures. Figure A13 to Figure A18 in Appendix A show peak flood velocities and peak shear stresses for the 10%, 1% and 1.5 x 0.1% AEP events for Option 2. Option 2 velocity and shear stress impacts compared to pre-mine conditions are shown in Figure 5.9 to Figure 5.14.

5.3.1 10% and 1% AEP events

The results show that there is no material difference in velocities and shear stresses along the river channels or the floodplain between Option 1 and Option 2. Therefore, the commentary provided for Option 1 above would be the same for Option 2. The comparison flood maps between Option 2 and pre-mine conditions has not been provided as it would be the same as that presented for Option 1.

The modelling shows only a minor increase in velocity and shear stresses around the intake structures when compared to Option 1. Some additional eddying and localised velocities would be expected and appropriate erosion and scour protection measures should be installed at the inlet and along the channel.

In the vicinity of the B Pit intake channel, the Nogoia River low flow channel drains along the inside bend of the river and an 80 m wide lower terrace separates the low flow channel from the intake channel (see Figure 5.7) on the outside of the bend. The low flow channel embankment and lower terrace are well vegetated with a mix of mature and immature tree species suggesting the river channel and lower terrace are stable at the location of the intake channel. However, it is possible that the low flow channel may naturally move to drain along the outside bed of the river adjacent to the intake channel over time, given higher velocities tend to occur on the outside of bends (irrespective of Ensham Mine). The flood modelling demonstrates that the proposed Option 2 intake channel would not increase the potential for the low flow channel to move because there would be no (or minimal changes) in velocities or shear stresses.

The C Pit intake channel is separated from the Anabran low flow channel by only 30 m (see Figure 5.8). However, the channel is relatively straight and flood flows are naturally directed away from the C Pit intake channel, which suggests that the Anabran is unlikely to change location near the intake channel either naturally or due to the intake channel.

5.3.2 Extreme (Overtopping) event

For the extreme overtopping event, the modelling shows significant reductions in velocities and shear stresses across the levees when compared to Option 1. The modelling shows that the voids would fill with river water through the intake channels to reduce the water level difference across the levee and therefore reduce the scour potential at the time of overtopping. The duration of overtopping prior to the levees being drowned out is also substantially reduced.

Although the levee and embankment would be damaged during the overtopping event, the high void water levels would limit the overtopping damage to the levee such that the natural river channel embankment would unlikely be eroded, as it potentially could for Option 1.

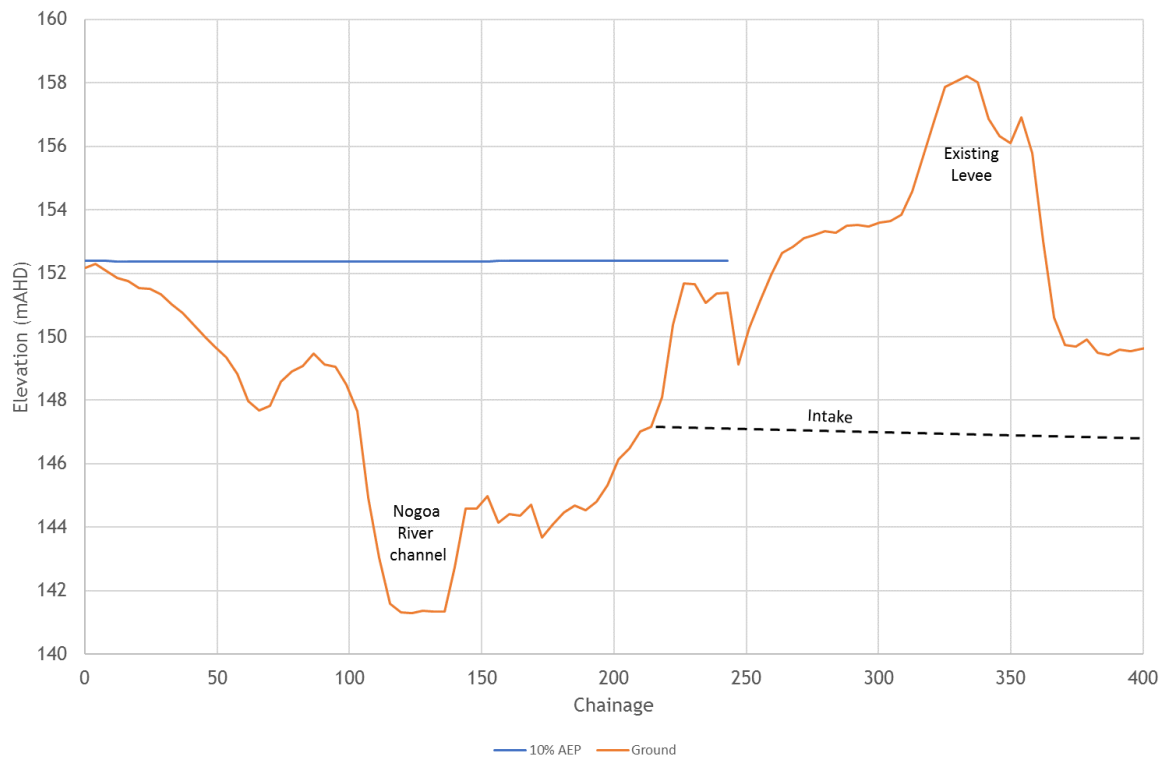


Figure 5.7 - Nogoa River cross section at the proposed B Pit intake channel

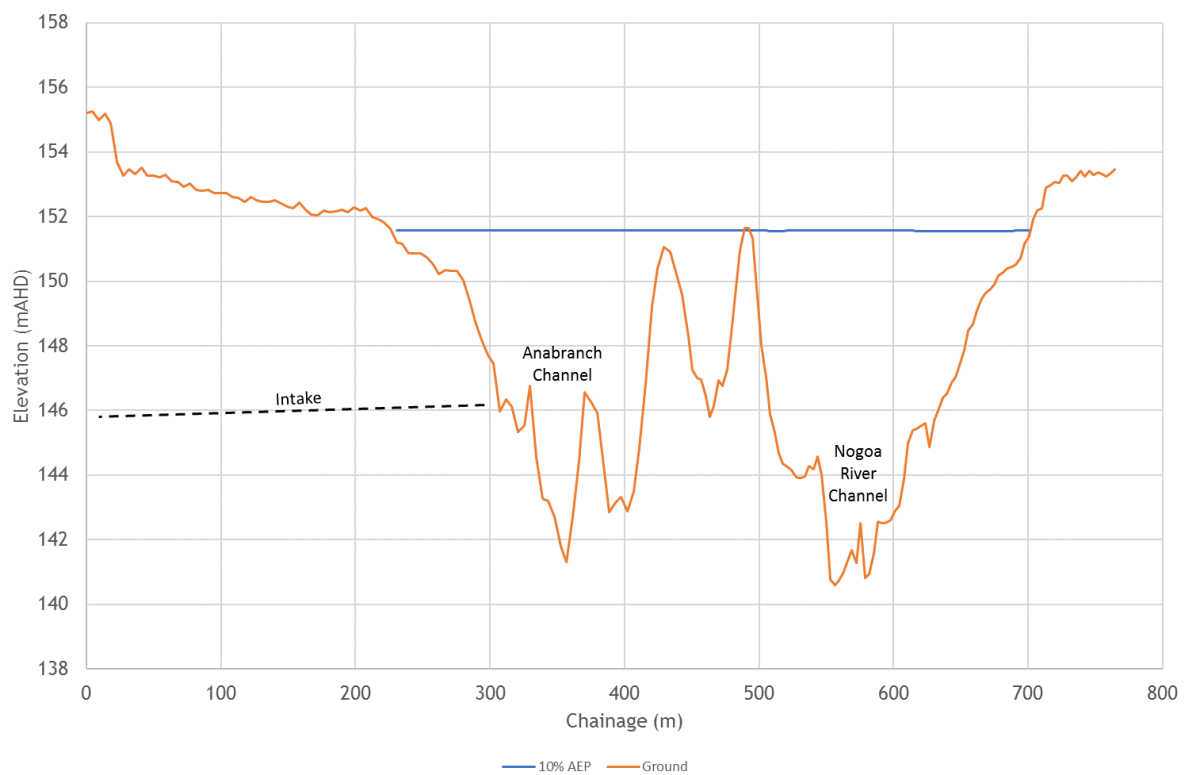


Figure 5.8 - Nogoa River cross section at the proposed C Pit intake channel

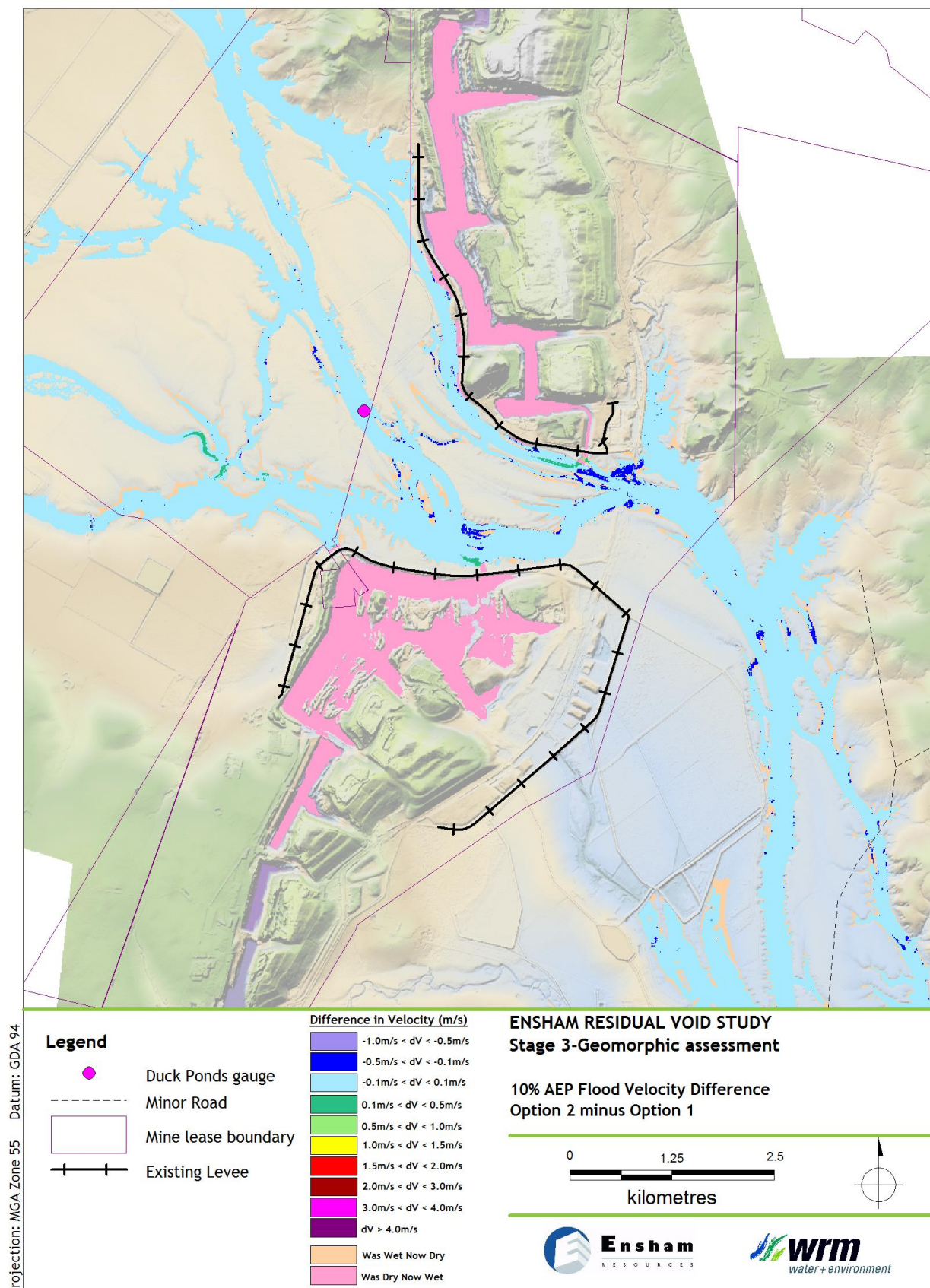


Figure 5.9 - Option 2 minus Option 1 flood velocity difference, 10% AEP event

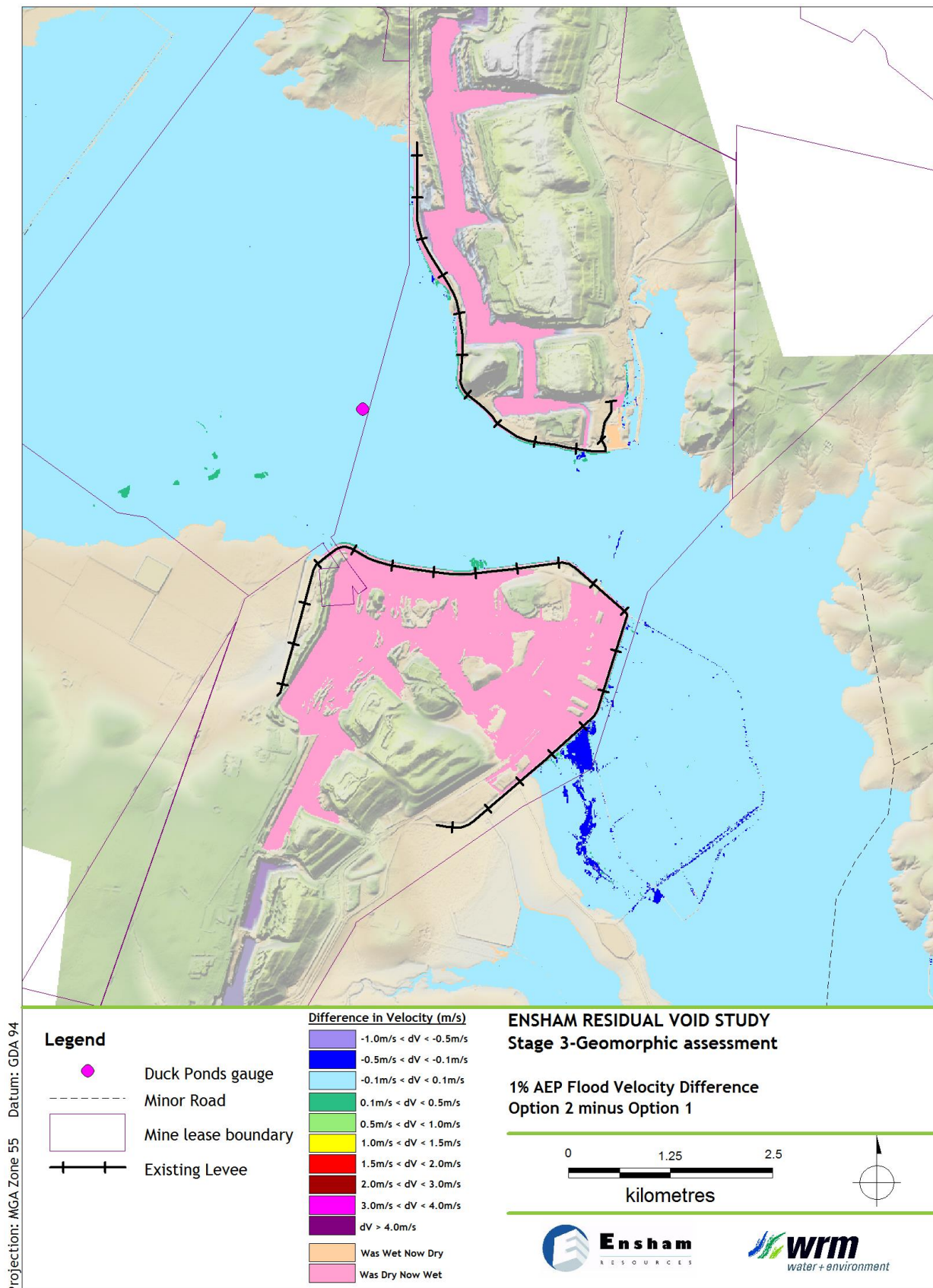


Figure 5.10 - Option 2 minus Option 1 flood velocity difference, 1% AEP event

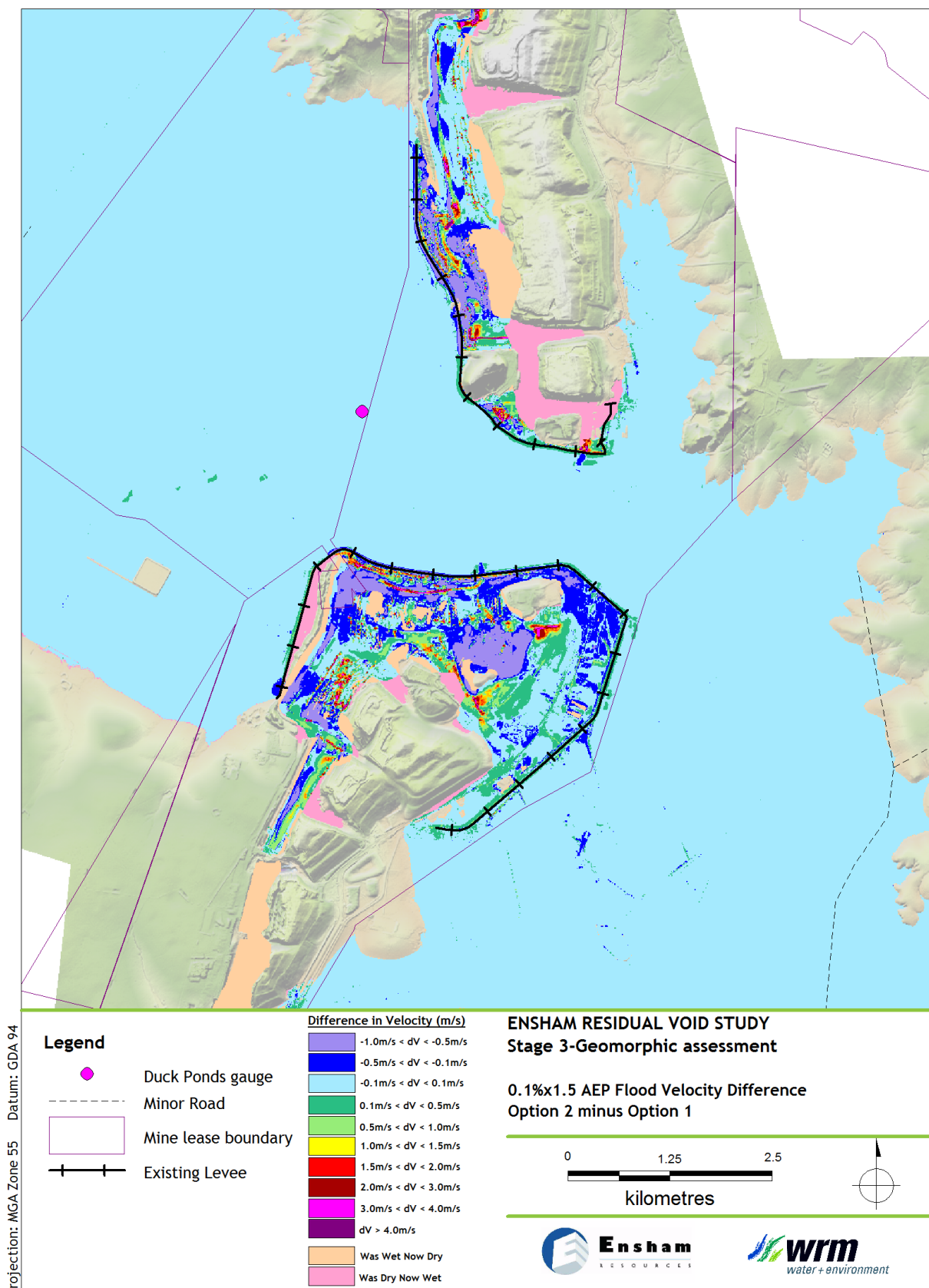


Figure 5.11 - Option 2 minus Option 1 flood velocity difference, 1.5 x 0.1% AEP event

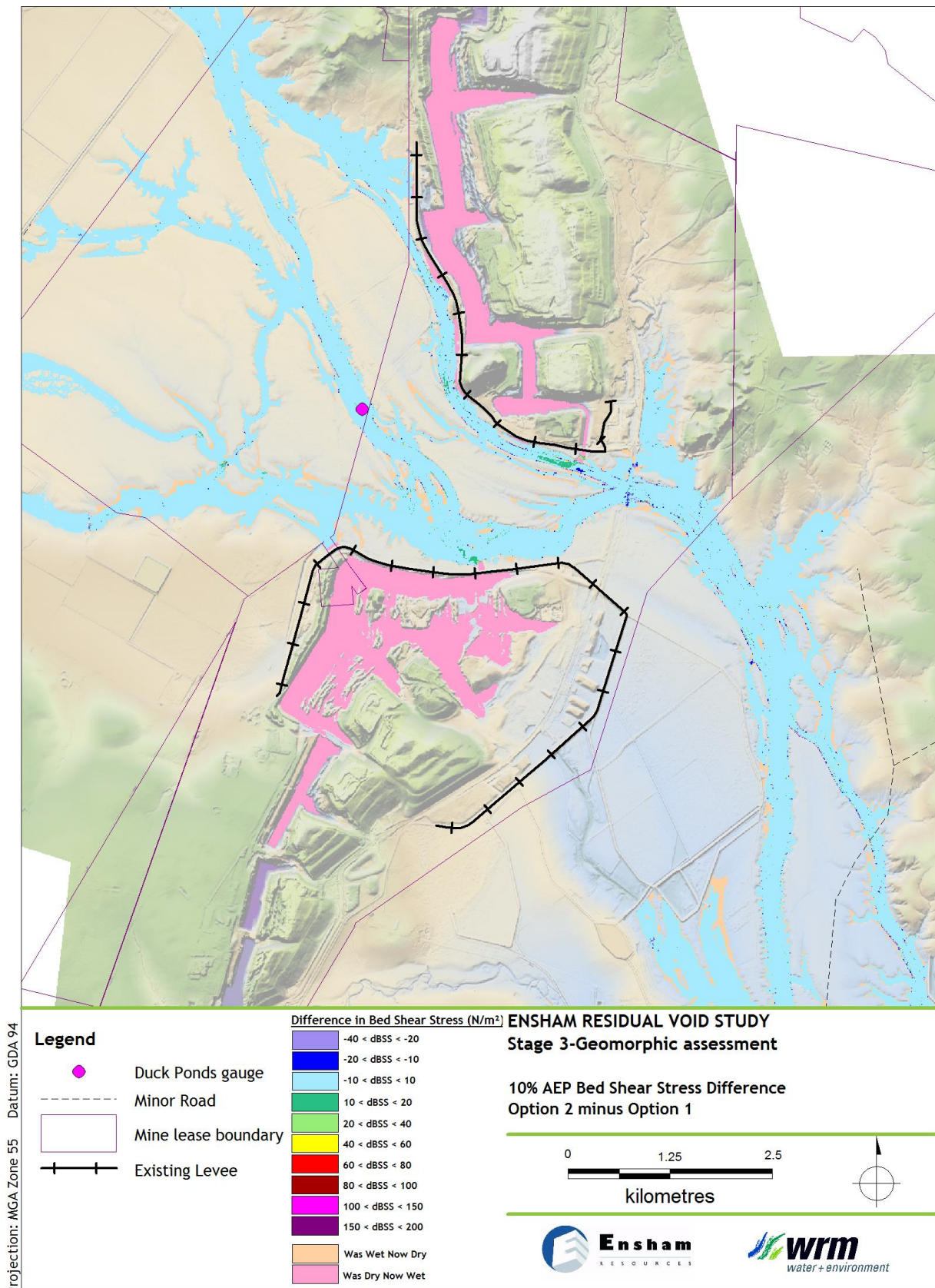


Figure 5.12 - Option 2 minus Option 1 shear stress difference, 10% AEP event

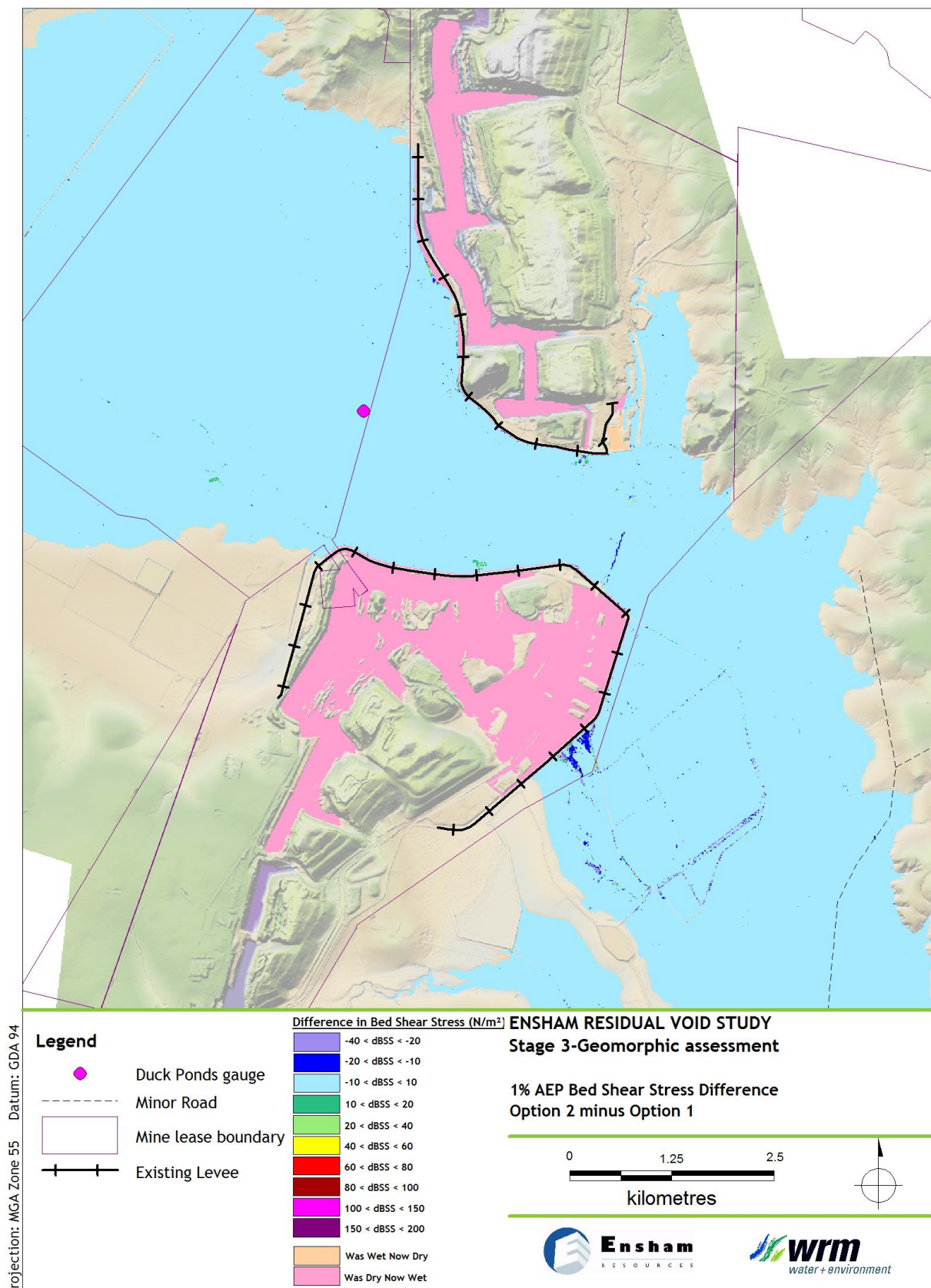


Figure 5.13 - Option 2 minus Option 1 shear stress difference, 1% AEP event

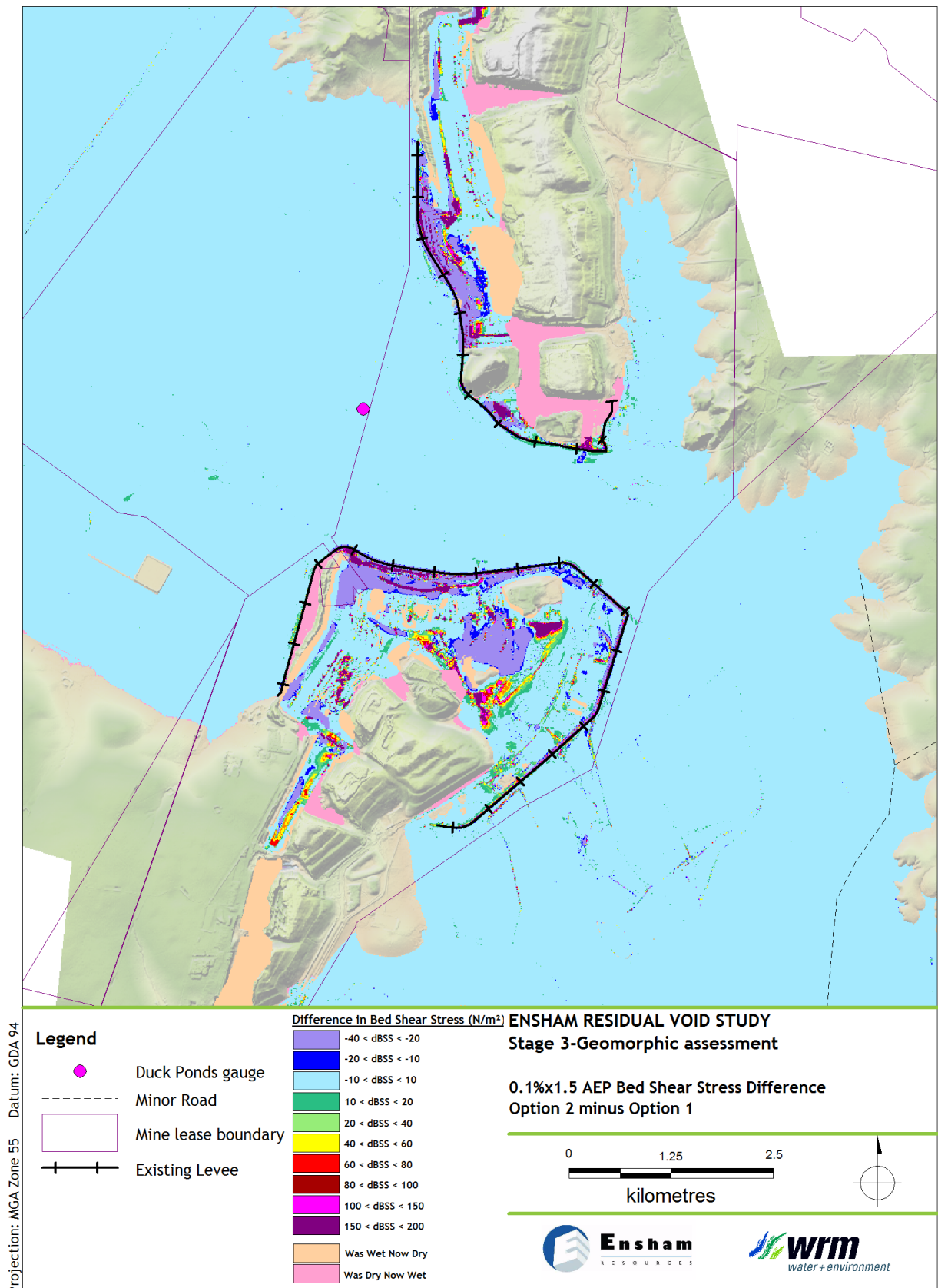


Figure 5.14 - Option 2 minus Option 1 shear stress difference, 1.5 x 0.1% AEP

5.4 PREFERRED OPTION 3

The Preferred Option 3 landform has, as much as practicable, attempted to replicate the pre-mining conditions landform across both the B Pit and C Pit. The B Pit landform includes a channel that replicates the Old Winton Creek channel along a slightly different alignment (Constructed B Pit channel) and removes the surrounding levees including the access road to the east (see Figure 5.15). Elevated areas of the existing B Pit overburden dump are proposed to remain. The C Pit landform attempts to replicate the pre-mining conditions flood channel that was located adjacent to the Anabranche as well as the pre-mining hillslope drainage lines from the adjacent rehabilitated overburden dump areas.

The success of this landform both from a local drainage and riverine flooding stability perspective will depend upon several factors including:

- the ability to achieve the proposed final landform levels after settlement;
- the performance of the established landform when subject to inundation;
- the post mine hydraulic characteristics; and
- the success at re-establishing a suitable growing medium to sustain a range of floodplain vegetation.

As described in Section 3.3, there is considerable uncertainty surrounding the ability to achieve the final landform levels after settlement. There is also uncertainty surrounding the success of the final landform surface rehabilitation. If the rehabilitated surfaces comprise of stiff clay alluvial soils that are indicative of the existing Nogoa River floodplain and the hydraulic characteristics are the same, then the erosion resistance potential and long-term sustainability is expected to be similar to the pre-mining conditions. Alternatively, an unvegetated 'bare earth' surface will have a much higher erosion potential than under pre-mining conditions with the same hydraulic characteristics.

It will not be possible to replicate the existing Nogoa River floodplain surface characteristics, which comprise of strongly structured alkaline heavy (cracking) clay alluvial soils up to 10 m deep, as these volumes of soil are not available. Rather, the finished landform will likely comprise of existing or manufactured topsoil to provide a growing medium over overburden subsoils. WSP (2018) have also advised that "the re-created landform will be subject to ongoing settlement for many years after placement has been completed, which may result in surface irregularity regarding desired final landform, impeded drainage and surface soil waterlogging issues associated with depressions. Soil piping may occur as the backfill settles."

Given the uncertainty surrounding the rehabilitated final landform surface and levels, the short and long-term stability of the Option 3 landform has been assessed by comparing the pre and post mining hydraulic characteristics only. The peak velocities and shear stresses across the post mining landform have been provided to assist in the design of the surface material at a later stage if this landform is adopted.

Figure A19 to Figure A24 in Appendix A show peak flood velocities and peak shear stress for the 10%, 1% and 1.5 x 0.1% AEP events for Option 3 (backfill to PMF) conditions. Figures A25 to A30 in Appendix A show PMF results for pre-mine and Option 3. The results are described below. Option 3 velocity and shear stress impacts compared to Pre-mine conditions for events up to PMF are shown in Figure 5.15 to Figure 5.22.

5.4.1 10% AEP event

For the 10% AEP event, the modelling shows that there would be no material change in peak velocities and shear stresses from pre-mine conditions within the channel and adjacent floodplains as a result of the Option 3 landform.

There would potentially be some impacts to the floodplain levees immediately downstream of the mine due to the removal of the access road. However, the levee could be upgraded to maintain its immunity level.

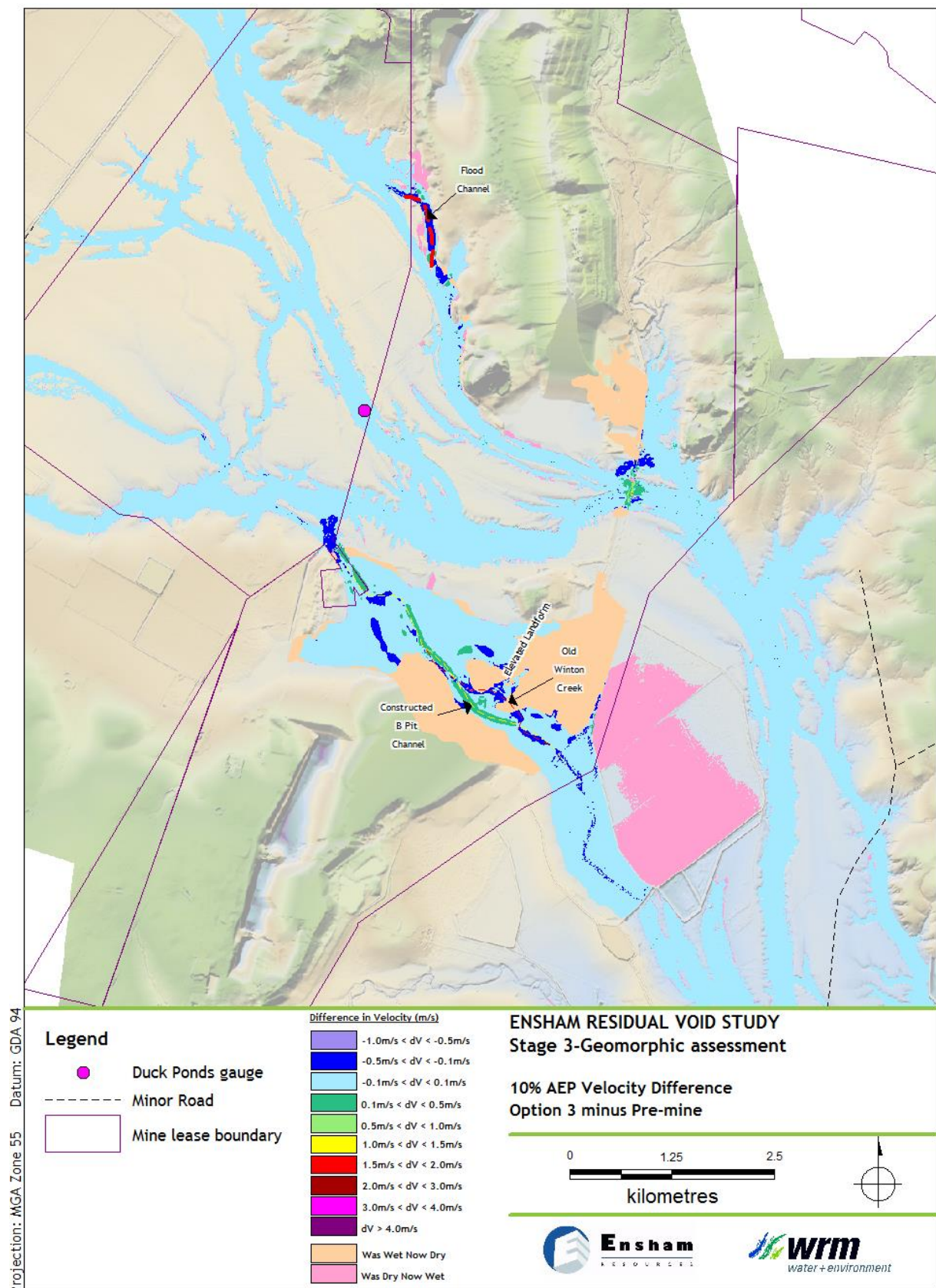


Figure 5.15 - Option 3 minus Pre-mine flood velocity difference, 10% AEP event

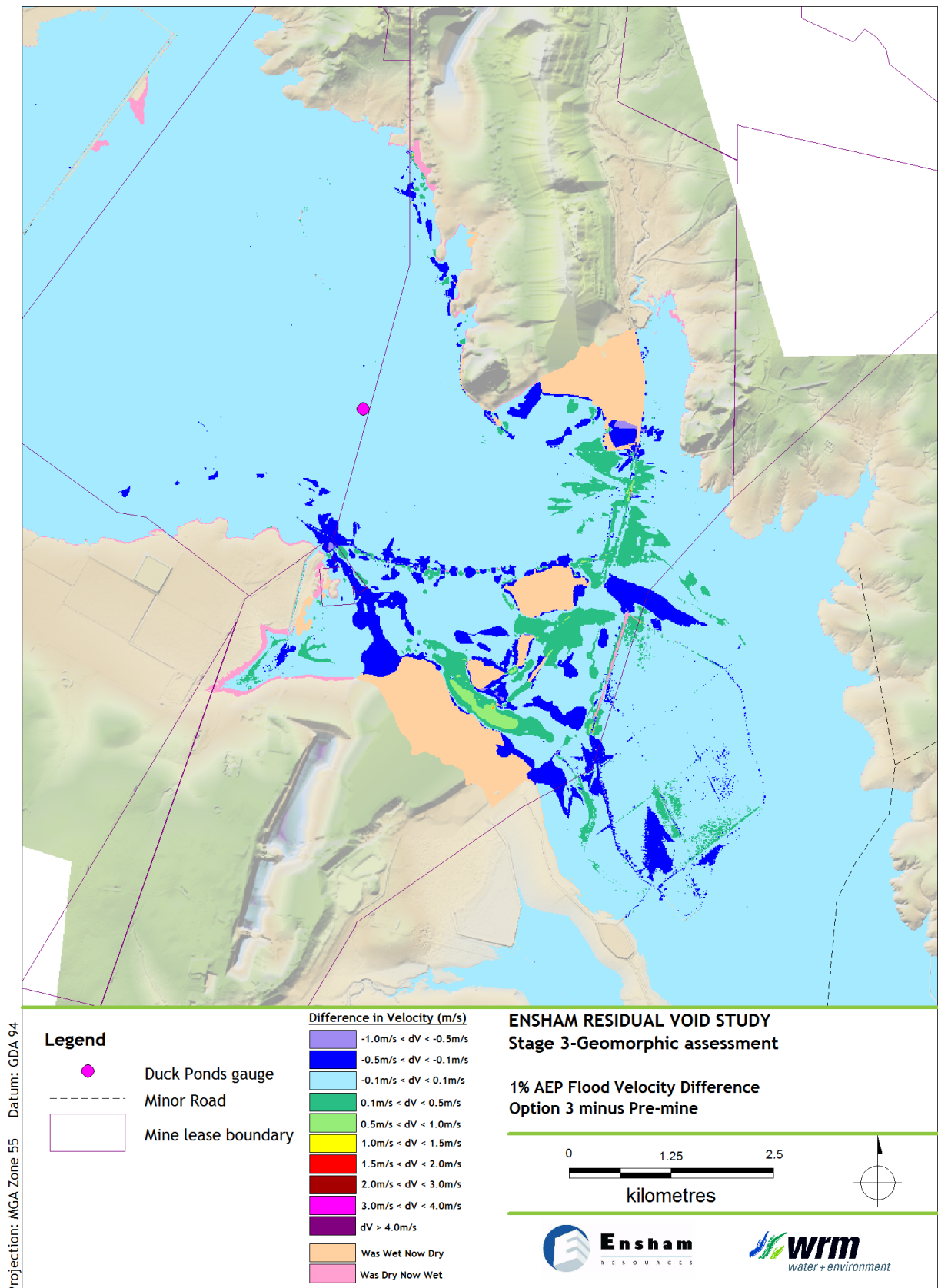


Figure 5.16 - Option 3 minus Pre-mine flood velocity difference, 1% AEP event

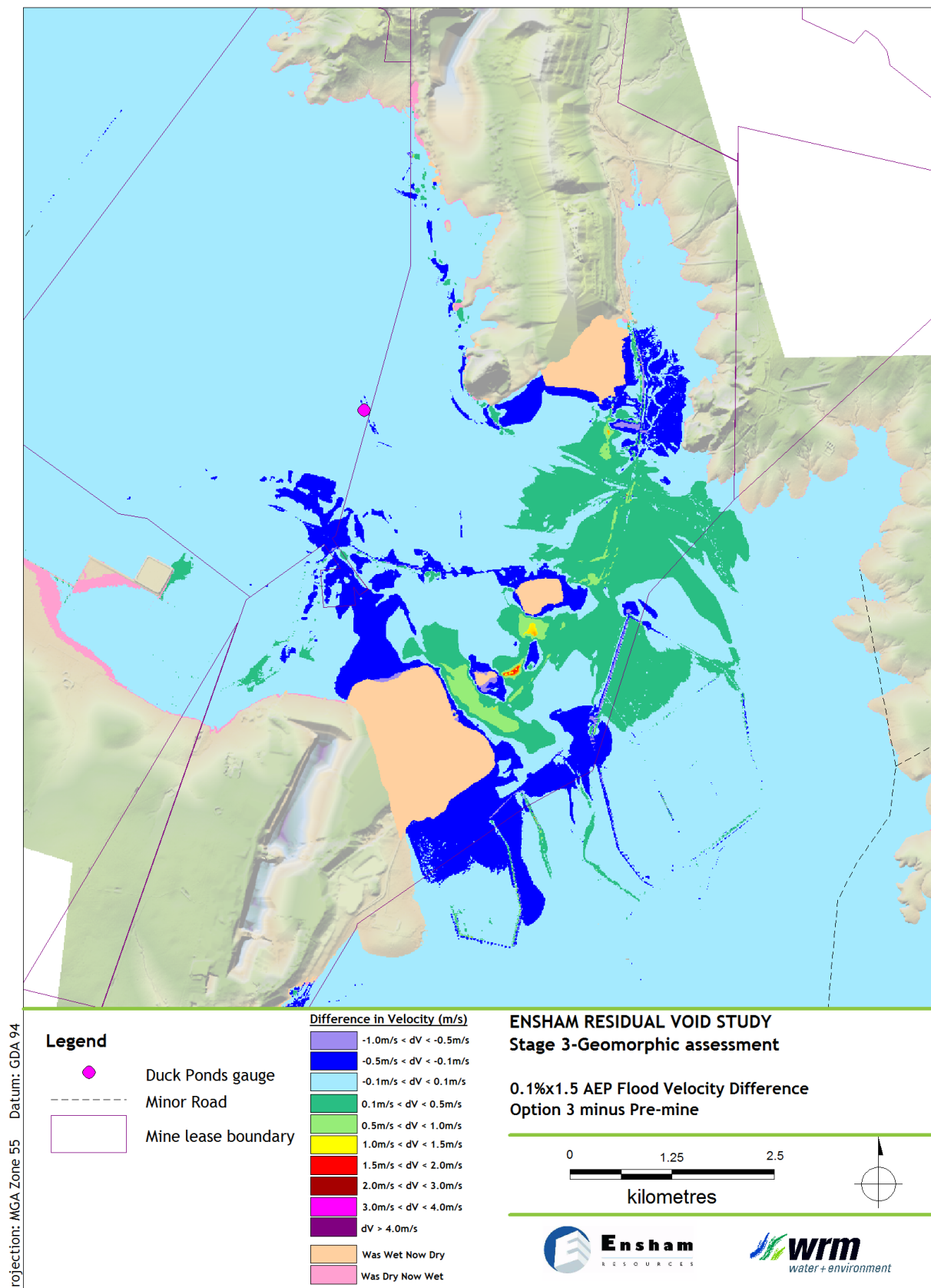


Figure 5.17 - Option 3 minus Pre-mine flood velocity difference, 1.5 x 0.1% AEP event

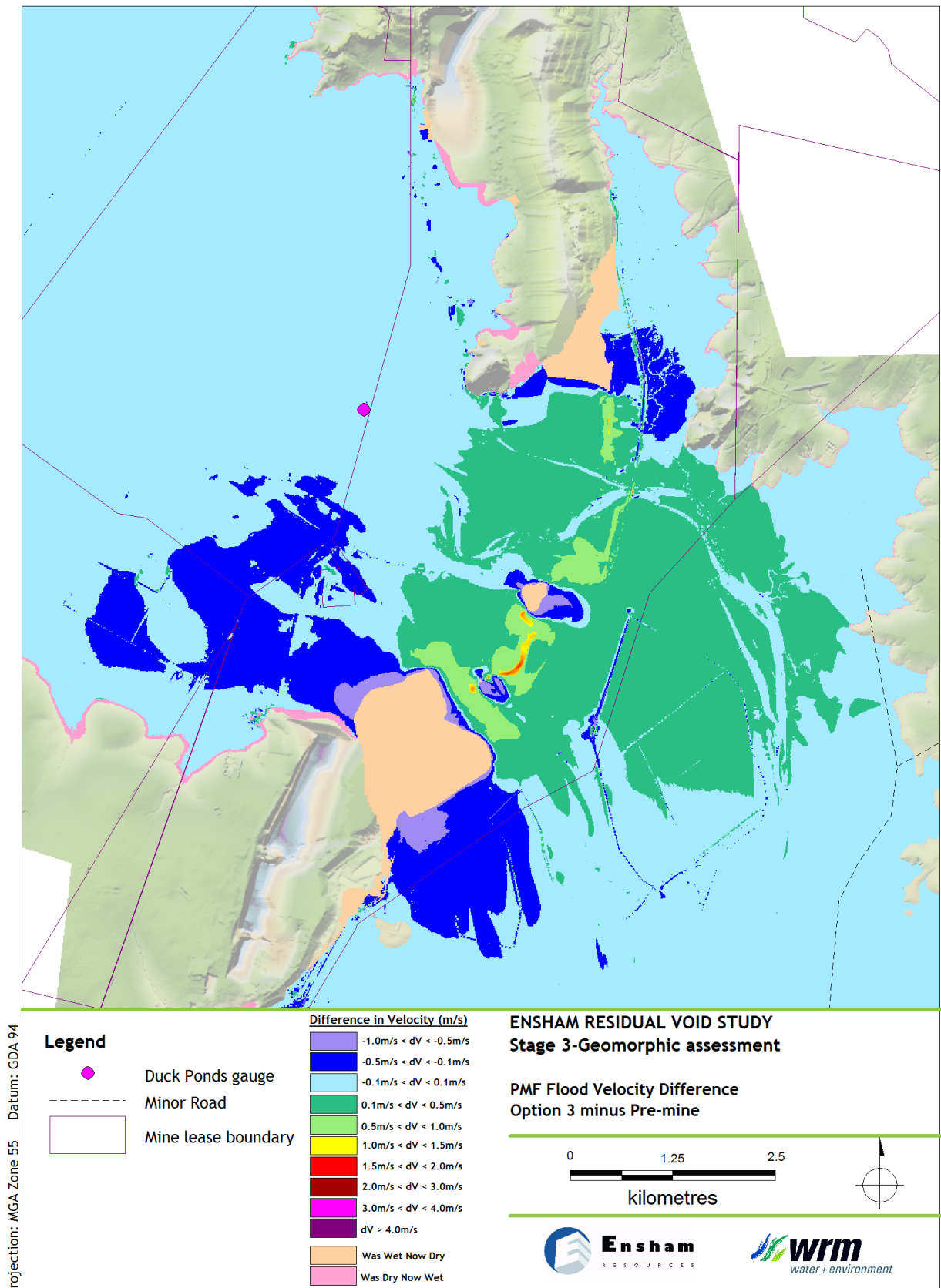


Figure 5.18 - Option 3 minus Pre-mine flood velocity difference, PMF

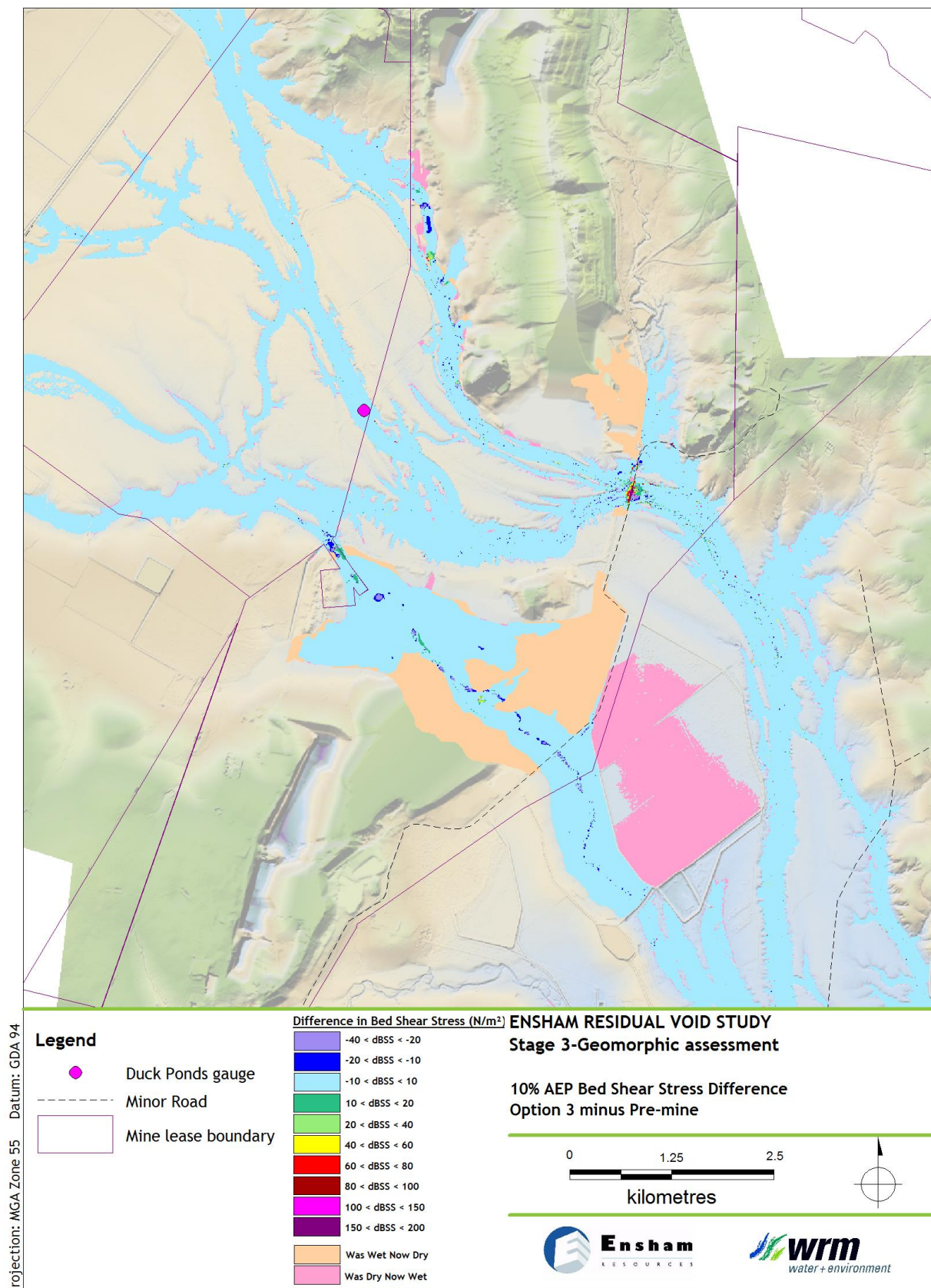


Figure 5.19 - Option 3 minus Pre-mine shear stress difference, 10% AEP event

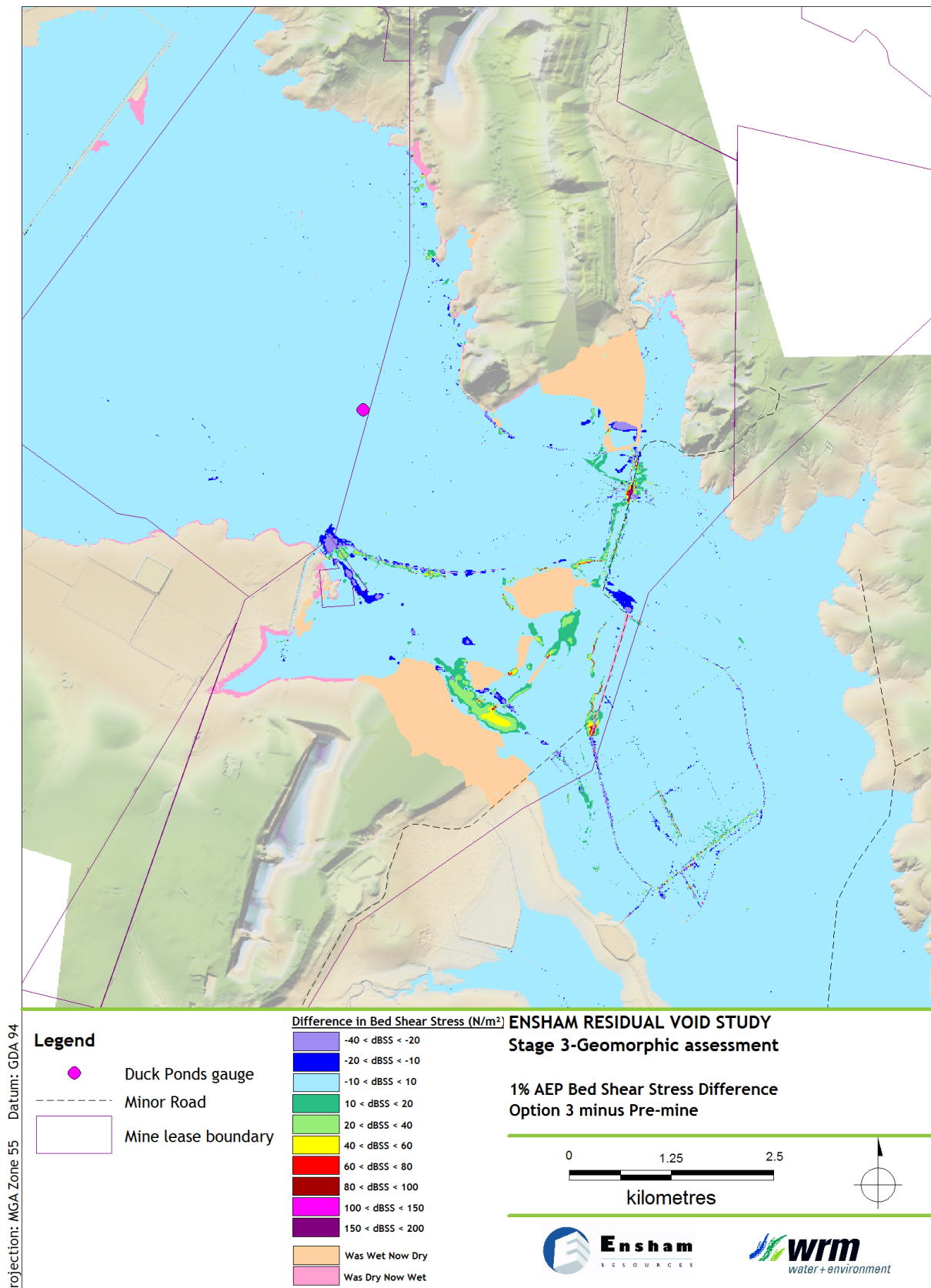


Figure 5.20 - Option 3 minus Pre-mine shear stress difference, 1% AEP event

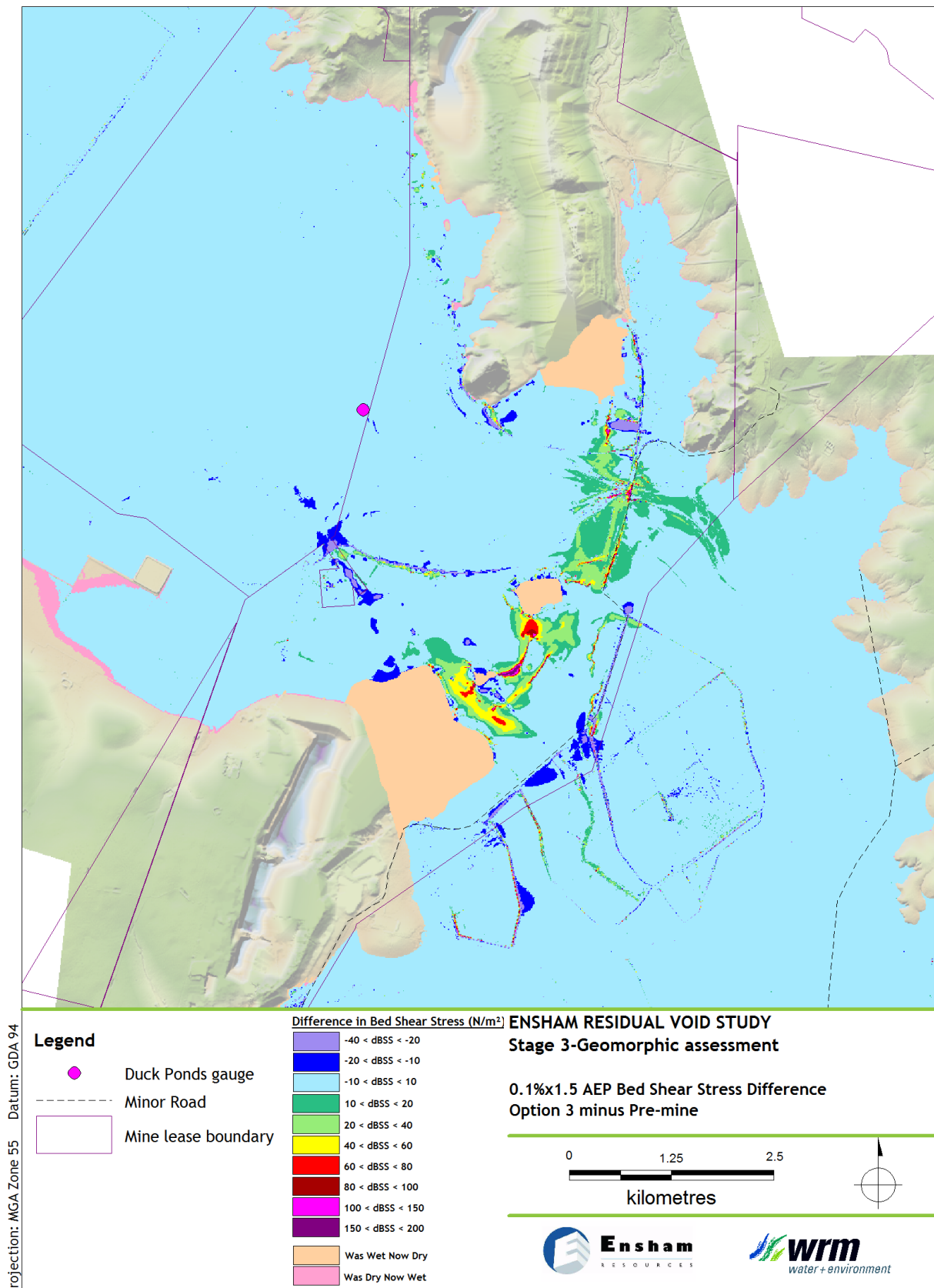


Figure 5.21 - Option 3 minus Pre-mine shear stress difference, 1.5 x 0.1% AEP event

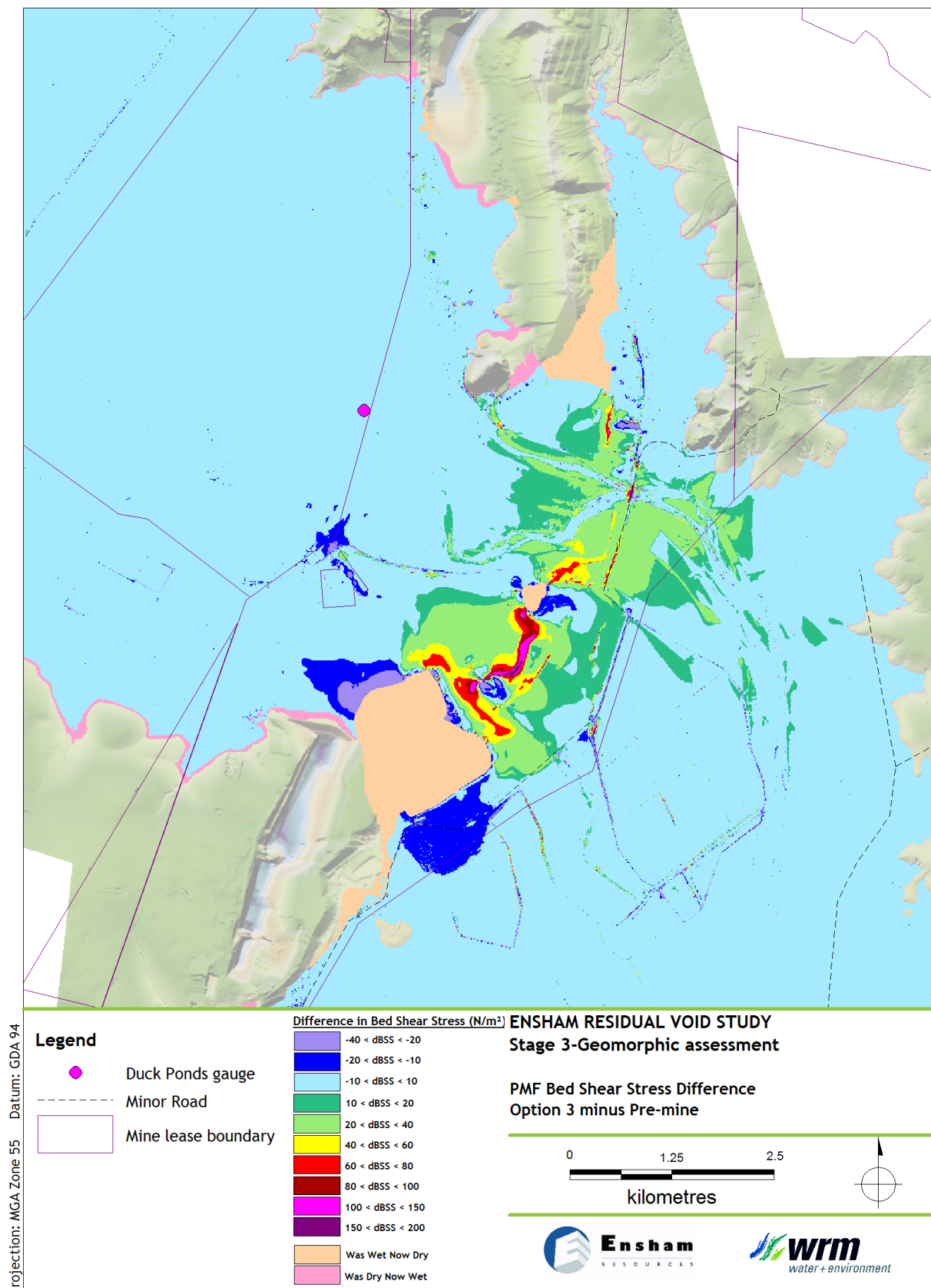


Figure 5.22 - Option 3 minus Pre-mine shear stress difference, PMF

Across the backfilled B Pit and C Pit, peak velocities generally do not exceed 0.25 m/s and peak shear stresses do not exceed 5 Pa, which are very low and indicate backwater flooding. Peak velocities and shear stresses increase to 0.5 m/s and 20 Pa along the constructed B Pit channel, which is similar to the Old Winton Creek channel. The minor changes in peak velocity (see Figure 5.15) and shear stress (see Figure 5.19) across the backfilled B Pit are due to the differences between the constructed B Pit channel and Old Winton Creek channel alignments.

The low velocities suggest that increased deposition of floodplain sediments may occur across the backfilled areas when compared to pre-mining conditions for this event. Investigations by Joo et.al. (2005) found that some 500,000 tonnes per day of suspended sediment would pass the Nogoia River at the Duckponds gauge at the peak of the 10% AEP event, which suggests that there is ample suspended sediment supply for deposition to occur.

Notwithstanding, the results suggest that these impacts would be minimal and there would be no detrimental impacts to the morphology of the river channel and floodplain including the sediment transport characteristics as a result of Option 3 during small to moderate sized flood events regardless of the finished rehabilitated surface characteristics. Further, given the limited topsoil supplies, rehabilitation efforts should focus on the constructed B Pit channel to maximise its erosion resistance potential.

5.4.2 1% AEP event

The flood modelling of the 1% AEP event shows the following:

- Peak Nogoia River and Anabran channel velocities and shear stresses do not change from pre-mining conditions.
- Peak floodplain velocities and shear stresses upstream and downstream of the mine do not change from pre-mining conditions.
- Across the B Pit:
 - peak velocities and shear stresses would increase along the constructed B Pit channel and conversely decrease along the Old Winton Creek channel alignment;
 - the median velocity (0.8 m/s) and median shear stress (28 Pa) along the constructed B Pit channel would be moderately higher than under pre-mining conditions (0.7 m/s and 22 Pa) but 90th percentile velocities and shear stresses (1.2 m/s and 50 Pa) would be similar;
 - the median and 90th percentile velocities and shear stresses along the constructed B Pit channel would be similar to Flood Channel 2 velocities and shear stresses (see Table 4.1 and Table 4.2); and
 - peak velocities and shear stresses across the remaining areas of the backfilled B Pit void (outside the constructed B Pit channel) are generally below 0.5 m/s and 10 Pa.
- Across the C Pit, the Option 3 landform reinstates a pre-mining flood channel, which carries flood flow during the 1% AEP flood (see Figure 5.15) and the remaining areas are located in backwater areas of the river. The peak velocities and shear stresses are generally:
 - below 0.75 m/s and 15 Pa and are lower than under pre-mining conditions within the reinstated flood channel; and
 - below 0.3 m/s and 5 Pa across other in-filled areas (outside of this flood channel) of the C Pit.

Overall, the flooding characteristics of the Option 3 landform generally replicates the flooding characteristics of the pre-mining conditions landform for the 1% AEP event. The low velocities and shear stresses across the backfilled voids would suggest that sediment deposition may occur for this event with the exception of along the constructed B Pit

channel and the reinstated flood channel across the C Pit. Again, the rehabilitation should focus on these channels to maximise its erosion resistance potential.

On this basis, Option 3 is not expected to have a detrimental impact on channel and floodplain morphology for events up to the 1% AEP event, provided no sink holes occur in the settled backfill and the surface of the constructed B Pit channel across the B Pit and the reinstated flood channel across the C Pit are suitably rehabilitated.

If the significant differential settlement occurs or the rehabilitation of these channels is not maintained and bare earth soils remain post mining, then some erosion of the channel surface would be expected during a 1% AEP flood. The extent of erosion would depend upon the erodibility of the soil. However, the low flood gradients and floodplain geometry would suggest that the erosion would not have a significant impact on the long-term floodplain morphology.

5.4.3 Extreme event

The flood modelling for the extreme event (1.5 x 0.1% AEP) shows the following:

- Peak Nogoia River and Anabran channel velocities and shear stresses do not change from pre-mining conditions.
- Peak floodplain velocities and shear stresses upstream and downstream of the mine do not change from pre-mining conditions.
- Across the backfilled C Pit, there are isolated areas of high peak velocities and shear stresses associated with the approximated final landform surface that has been provided for this assessment, which can be refined to mitigate these local peaks. Notwithstanding, peak velocities and shear stresses are generally:
 - below 0.75 m/s and 15 Pa within the reinstated flood channel;
 - below 0.5 m/s and 10 Pa across the infilled void to the south-east of Red Hill;
 - below 0.3 m/s and 5 Pa across other in-filled areas of the C Pit indicating that the area remains as a backwater area of the river.
- Across the backfilled B Pit, the elevated sections of landform that remain form a minor constriction to the floodplain flows. The elevated areas are overtopped by about 5 m for this event but cause an afflux of about 0.2 m to 0.3 m. The peak velocities and shear stresses:
 - increase on the adjacent Nogoia River floodplain but are no higher than other locations on the floodplain;
 - increase to a maximum of 1.55 m/s and 75 Pa within the constructed B Pit channel;
 - are no higher than 0.7 m/s and 20 Pa across the infilled void upstream of the elevated landform; and
 - increase to a maximum of 2 m/s and 100 Pa across the top of the elevated landform.

Overall, the flooding characteristics of the Option 3 landform generally replicates the flooding characteristics of the pre-mining conditions landform for the extreme flood event. As a result, there would be no long-term risk of accelerated morphological change to the Nogoia River channel, the Anabran or the adjacent floodplain for Option 3. This again depends upon the success in achieving the proposed post settlement landform levels and surface rehabilitation.

Velocities and shear stresses across the infilled C Pit are generally low for this event, suggesting that it will remain stable in the long term. Across the B Pit, elevated velocities and shear stresses along the constructed B Pit channel and across the top of the elevated landform sections are higher than at any other location of the floodplain, which suggest that higher erosion may occur at these locations for this extreme event. Depending upon the ability to maintain the rehabilitation across the B Pit, downstream properties could be

adversely affected by sediment eroded from the landform, however this is likely to be insignificant compared to the sediment load of the river in such an event. Long term erosion and sedimentation would also occur from any exposed subsoils on the landform.

Given the low probability of this event occurring, and that any erosion will be localised and not near the Nogoa River channel, the Option 3 B Pit landform is expected to be sustainable for this event.

5.4.4 PMF event

The flood modelling shows that the final voids are not inundated by the PMF. As a result, the Option 3 landform would reduce the residual risk of extreme flooding overtopping events associated with Option 1 and Option 2. Further, there are no material changes in peak flood velocities and shear stresses along the river channels or the floodplain from pre-mining conditions for this event and therefore there is minimal risk of accelerated morphological change as a result of Option 3 for this extreme event.

Increased velocities and shear stresses occur along the constructed B Pit channel and across the top of the elevated landform for the infilled B Pit. As a result, the assessment findings described above for the 1.5 x 1% AEP event would be the same for the PMF. Again, the extreme nature of this event, and that any erosion will be localised and not near the Nogoa River channel, the Option 3 B Pit landform is expected to be sustainable in the long term.

5.5 ASSESSMENT OF POTENTIAL IMPACTS ON ENVIRONMENTAL VALUES

An assessment of the potential impacts of each of the three Preferred Options on relevant environmental values (EVs) has been undertaken based on the outcomes of this study. The EVs are described in the Ensham Residual Void Project Stage 2 Environmental Values Workshop Report (March, 2018) and the EVs relevant to each of the Stage 3 studies have been determined by Ensham.

The assessment of impacts on EVs has been undertaken by assigning a ranking for each of the Preferred Options to each EV. The adopted scoring criteria is given in Table 5.1 using the following definitions:

- **Significant impact/benefit** - results in a change which is important, notable or of consequence to the EV having regard to its intensity/frequency. For an impact the change will result in not being able to meet published standards (if there are any). For a benefit the change should meet best practice standards (if there are any published)
- **Medium impact/benefit** - results in a change which is potentially important, notable or of consequence to the EV having regard to its intensity/frequency. For an impact, the change will result in occasions where the criterion will not meet published standards (if there are any). For a benefit the change should meet good practice standards (if there are any published)
- **Minor impact/benefit** - results in a change which is identifiable but is not important, notable or of consequence to the EV having regard to its intensity

Note that the definition of significant impact has been based on the Federal Government's definition of significant impact contained within its "Matters of National Environmental Significance, Significant Impact Guidelines 1.1, *Environment Protection and Biodiversity Conservation Act 1999*".

The EV impact ranking of the three Preferred Options was assessed by comparing the potential for each option to have a positive or negative impact on the long-term morphological behaviour floodplain compared to existing conditions. The ranking for the erosion assessment is given in Table 5.2.

Table 5.1 - Environmental Value impact scoring criteria

Scoring Criteria	Ranking
Significant negative impact for this criterion	-3
Medium negative impact for this criterion	-2
Minor negative impact for this criterion	-1
No impact for this criterion	0
Minor benefit for this criterion	1
Medium benefit for this criterion	2
Significant benefit for this criterion	3

Table 5.2 - Environmental values ranking of the Preferred Options

Criteria	Option 1 Landform Levee	Option 1 Evidence	Option 2 FMBU	Option 2 Evidence (short description/reference to section in technical report)	Option 3 Backfill to PMF	Option 3 Evidence (short description/reference to section in technical report)
Velocity / erosion potential	1	There are no short or medium-term risks of accelerated morphological change and there would be a minor reduction in the residual long-term risks from an increase in the levee height, which would reduce the frequency of an overtopping event. An overtopping event during a very rare and extreme event would erode the river bank, potentially to bed level, to cause a morphological change. Given that there is a low probability that an overtopping event would occur, the benefit of this improvement compared to existing conditions is only minor.	1	There are no short or medium-term risks of accelerated morphological change and there would be a minor reduction in the residual long-term risks associated with an overtopping event. Elevated pit water levels would reduce the likelihood of the bank eroding to bed level to cause a morphological change to the river during an extreme overtopping event. Given that there is a low probability of an overtopping event occurring, the benefit of this improvement is only minor.	2	There are no short or medium-term risks of accelerated morphological change and the very low long-term risks associated with an Option 1 and Option 2 overtopping event would effectively be eliminated, particularly for the C Pit. This ranking assumes that the proposed post mining surface rehabilitation and levels can be achieved.

6 Conclusions and recommendations

6.1 CONCLUSIONS

The flooding and geomorphological behaviour of the Nogoia River and adjacent floodplain have been reviewed to assess the long-term stability of the final landform and the short, medium and long-term risks associated with each Preferred Option.

6.1.1 Preferred Option 1

Option 1, which involves constructing a landform along the existing levee alignment that provides flood immunity for the 0.1% (1 in 1,000) AEP flood, has the same flooding characteristics as the existing conditions and therefore would have the same morphological impacts as existing conditions.

Modelling of the Option 1 conditions compared to pre-mine conditions shows that:

- there would be no change in peak velocities and shear stresses from pre-mine conditions for the 10% AEP flood;
- the differences between pre-mine and Option 1 flood velocities and shear stresses for the 1% AEP event are minor;
- where increases from pre-mine conditions occur for the 1% AEP event, the predicted velocities and shear stresses are no greater than pre-mine velocities and shear stress along the upstream reach of the river for the same event; and
- the extreme event would increase velocities and shear stresses along the Nogoia River channel and the adjacent floodplain for a distance of about 7 km. Again, the increased velocities and shear stresses are no greater than pre-mine velocities and shear stress along the upstream reach of the river for the same event.

An assessment of the pre-mine conditions found that the Nogoia River channel and floodplain would be stable in the short term and medium term. On the basis that the changes in hydraulic behaviour for events up to the 1% AEP event are minor, the short and medium-term risks of accelerated morphological change in the Nogoia River for Option 1 landform are low.

The modelling of the extreme event suggests that there remains a long-term risk (albeit with very low probability) of morphological change to the Nogoia River for Option 1. Along the C Pit, an extreme overtopping event would erode the proposed landform embankment potentially to bed level. The likelihood of this occurring for the landform along the B Pit is even lower given the highwall of the void is located much further from the river channel. If the C Pit or B Pit landforms were overtopped and the embankment eroded to bed level, their configuration away from the main flow path would suggest that both would act like connected off-stream storages. The pits would fill with water and once full have zero velocity allowing flows to continue downstream along the main Nogoia River channel and the Anabranche, however they would potentially reduce downstream bed sediment loads. If such an extreme event occurred, it would appear unlikely that the course of the Nogoia River or Anabranche would be altered to drain through the voids. Repairing the embankments, as done in 2008, would mean that there would be no long-term impacts on the Nogoia River or its floodplain other than localised impacts, which may be considerable.

6.1.2 Preferred Option 2

Option 2, which utilises the post-mining voids to form water storages to capture a proportion of high flow flood water and store this water for potential beneficial use, maintains the existing levees to protect the voids from flooding. As a result, the modelling results for Option 2 show no material difference in velocities and shear stresses along the

river channels or the floodplain between Option 1 and Option 2. Therefore, the results described for Option 1 are relevant for Option 2.

On the basis that the changes in hydraulic behaviour for events up to the 1% AEP event are minor, the short and medium-term risks of accelerated morphological change in the Nogoia River for Option 2 are low.

The modelling of the extreme event suggests that there remains a very low probability long-term risk of morphological change to the Nogoia River for Option 2 because an overtopping event would scour the levee/embankment. However, there is little chance of the levee and embankment eroding to bed level because of the equalising effect of the water stored in the voids. On this basis, the long-term risk to the Nogoia River of Option 2 would be lower than for Option 1.

6.1.3 Preferred Option 3

Option 3 involves backfilling the residual mining voids located within the pre-mining floodplain up to the elevation of the original floodplain within the lateral extent of the pre-mining Probable Maximum Flood level.

Modelling of the Option 3 conditions shows the following:

- There would be no material change in peak velocities and shear stresses from pre-mine conditions within the river channels and adjacent floodplains for all events.
- Velocities and shear stresses across the infilled C Pit are generally low for all events, suggesting that it will remain stable in the long term.
- Velocities and shear stresses are generally low across the infilled B Pit and are very low behind the elevated landform for the 10% and 1% AEP events suggesting some sediment deposition may occur for these events.
- Higher velocities and shear stresses occur along the constructed B Pit channel and across the top of the elevated landform sections for the extreme events suggesting that there is a higher erosion potential in these areas for the extreme events. Depending upon the success of the rehabilitation across the B Pit, downstream properties could be adversely affected by sediment eroded from the landform. Long term erosion and sedimentation would also occur from any exposed subsoils on the landform.
- Extreme event velocities and shear stresses across the infilled C Pit are generally low indicating that the area remains as a backwater area of the river and therefore has a relatively low erosion potential.
- The Option 3 landform would reduce the residual risk of extreme flooding overtopping events associated with Option 1 and Option 2.

The results demonstrate that there would be no short, medium or long-term term risks of accelerated morphological change to the Nogoia River and its floodplain for the Option 3 landform.

The expected low velocity zones across the surface of the infilled voids suggest these landforms will be stable in the short to medium term with potentially some sediment deposition occurring during moderate flood events.

The stability of the constructed B Pit channel and the elevated landform across the infilled B Pit surface will depend upon the success of the surface rehabilitation and achieving the proposed finish surface levels. If the rehabilitation of the surface of the infilled voids is not maintained and bare earth soils remain post mining, then some erosion of the surface would be expected during flood events, potentially leading to adverse impacts on downstream environmental values. The extent of erosion would depend upon the erodibility of the soil. However, the low flood gradients and floodplain geometry would suggest that the erosion would not have a significant impact on the long-term floodplain morphology.

6.2 RECOMMENDATIONS

For Option 1, the already very low probability geomorphological risks could be reduced by providing a designated overflow point in the proposed landform along the C Pit highwall to allow an overtopping event to fill the C Pit void in a controlled manner. A potential location to allow overtopping would be near the proposed Option 2 intake channel. Filling the void from this location would reduce the likelihood of an overtopping event eroding the embankment to bed level, in the unlikely event that an overtopping event occurred. It is recommended that a designated overflow point be incorporated into the detailed design of the landform if this option is preferred.

For Option 2, some scour protection is recommended around the intake channels.

For Option 3, it is recommended to focus the rehabilitation along the high velocity areas of constructed B Pit channel and the flood channel across the C Pit to assist with resisting erosion.

7 References

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8 Glossary

alluvium	material deposited by running water, typically rivers. It displays characteristics such as stratification and size sorting. The term is usually restricted to relatively young sediment and does not include lithified material such as sedimentary rock
anabranch	a section of a river or stream that diverts from the main channel or stem of the watercourse and rejoins the main stem downstream.
Annual exceedance probability (AEP)	the chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. (see ARI)
Australian Height Datum (AHD)	a common national surface level datum approximately corresponding to mean sea level.
Average recurrence interval (ARI)	the long-term average number of years between the occurrence of a flood as big as or larger than the selected event.
Bank full flow	The discharge that fills a river discharge channel to the bank full level without spilling over to the floodplain.
Catchment	the land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
Discharge	the rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m ³ /s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
flood	relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunamis.
Flood mitigation standard	the average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.
Floodplain	area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.
Floodplain risk management options	the measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.
Flood prone land	land susceptible to flooding by the PMF event. Flood prone land is synonymous with flood liable land.
Flood risk	potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk

in this manual is divided into 3 types, existing, future and continuing risks. They are described below.

Existing flood risk: the risk a community is exposed to as a result of its location on the floodplain.

Future flood risk: the risk a community may be exposed to as a result of new development on the floodplain.

Continuing flood risk: the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.

Flood storage areas	those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.
Floodway areas	those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels.
Freeboard	provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
Geomorphology	the study of landforms, their processes, form and sediments at the surface of the Earth. Study includes looking at landscapes to work out how the earth surface processes, such as air, water and ice, can mould the landscape.
Hazard	a source of potential harm or a situation with a potential to cause loss.
Historical flood	a flood which has actually occurred.
Hydraulics	term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
Hydrograph	a graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.
Hydrology	term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
Lacustrine	of, relating to, formed in, living in, or growing in lakes
Mathematical / computer models	the mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity

	of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.
Palaeo channel	A remnant of an inactive river or stream channel that has been filled or buried by younger sediment. The sediments that the ancient channel is cut into or buried by can be unconsolidated, semi-consolidated, consolidated or lithified.
Peak discharge	the maximum discharge occurring during a flood event.
Probable maximum flood (PMF)	the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event.
Probable maximum precipitation (PMP)	the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.
Probability	a statistical measure of the expected chance of flooding (see annual exceedance probability).
River terrace	Fragment of a former valley floor that now stands above the level of the present floodplain. It is caused by stream incision, which may be due to uplift of the land, to a fall in sea level, or to a change in climate.
River morphology	Describes the changes of river planform and cross-section shape due to sedimentation and erosion processes over time. In this field the dynamics of flow and sediment transport are principal elements.
risk	chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	the amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
shear stress	is a measure of the force of friction from a fluid acting on a body in the path of that fluid. In the case of open channel flow, it is the force of moving water against the bed of the channel.
stage	equivalent to water level (both measured with reference to a specified datum).
stage hydrograph	a graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
TUFLOW	a 1-dimensional and 2-dimensional flood simulation software. It simulates the complex movement of floodwaters across a particular area of interest using mathematical approximations to derive information on floodwater depths, velocities and levels.



velocity

the speed or rate of motion (distance per unit of time, e.g., metres per second) in a specific direction at which the flood waters are moving

water surface profile

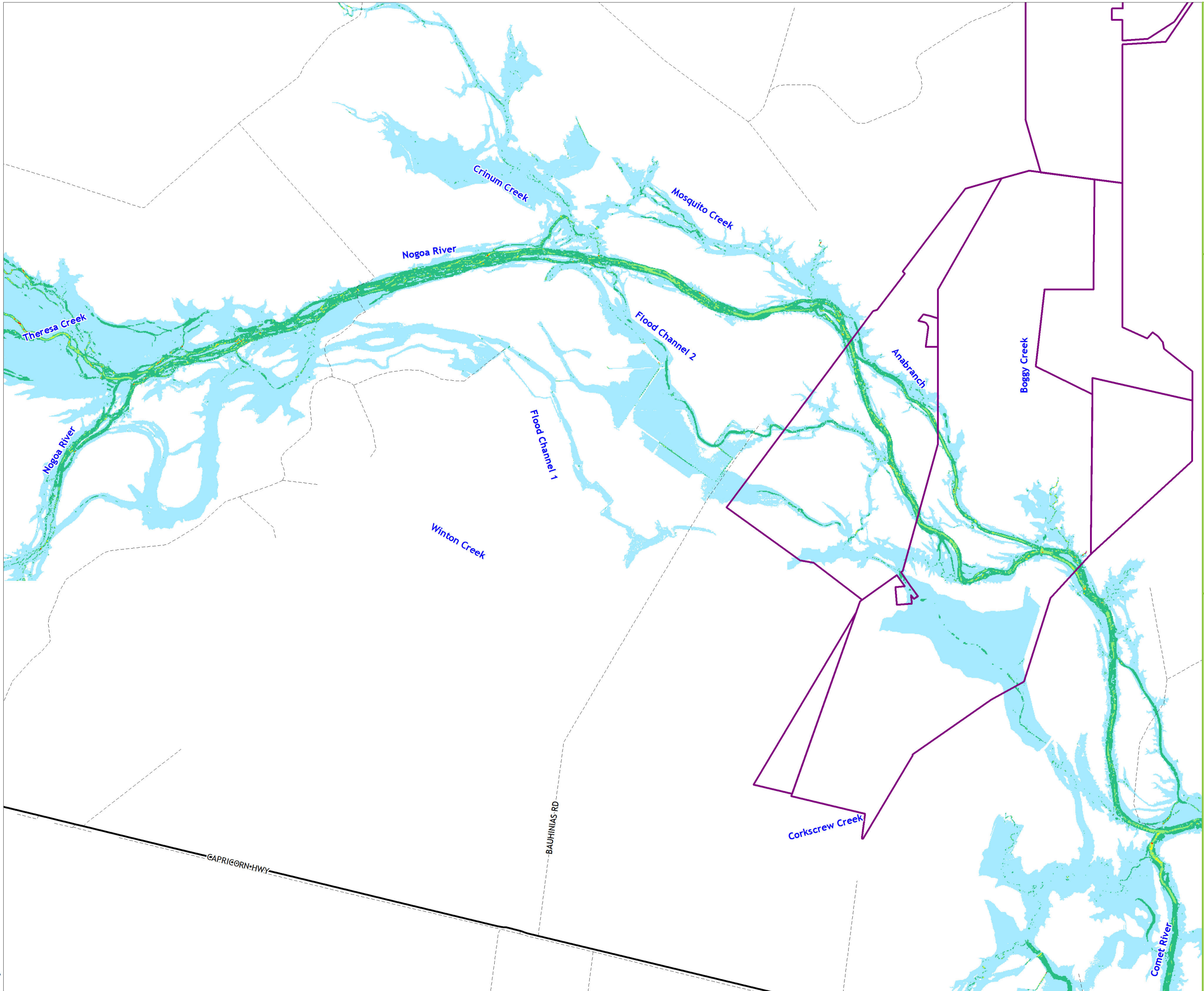
a graph showing the flood stage at any given location along a watercourse at a particular time

Appendix A - Flood modelling results

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Projection: MGA Zone 55 Datum: GDA 94

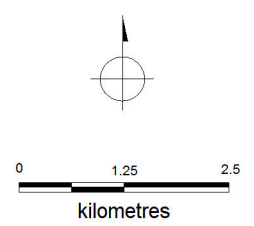


Legend

- Minor road
- Major road
- Mine lease boundary

Flood Velocity (m/s)

0.0m/s - 0.5m/s
0.5m/s - 1.0m/s
1.0m/s - 1.5m/s
1.5m/s - 2.0m/s
2.0m/s - 2.5m/s
2.5m/s - 3.0m/s
3.0m/s - 4.0m/s
>4.0m/s

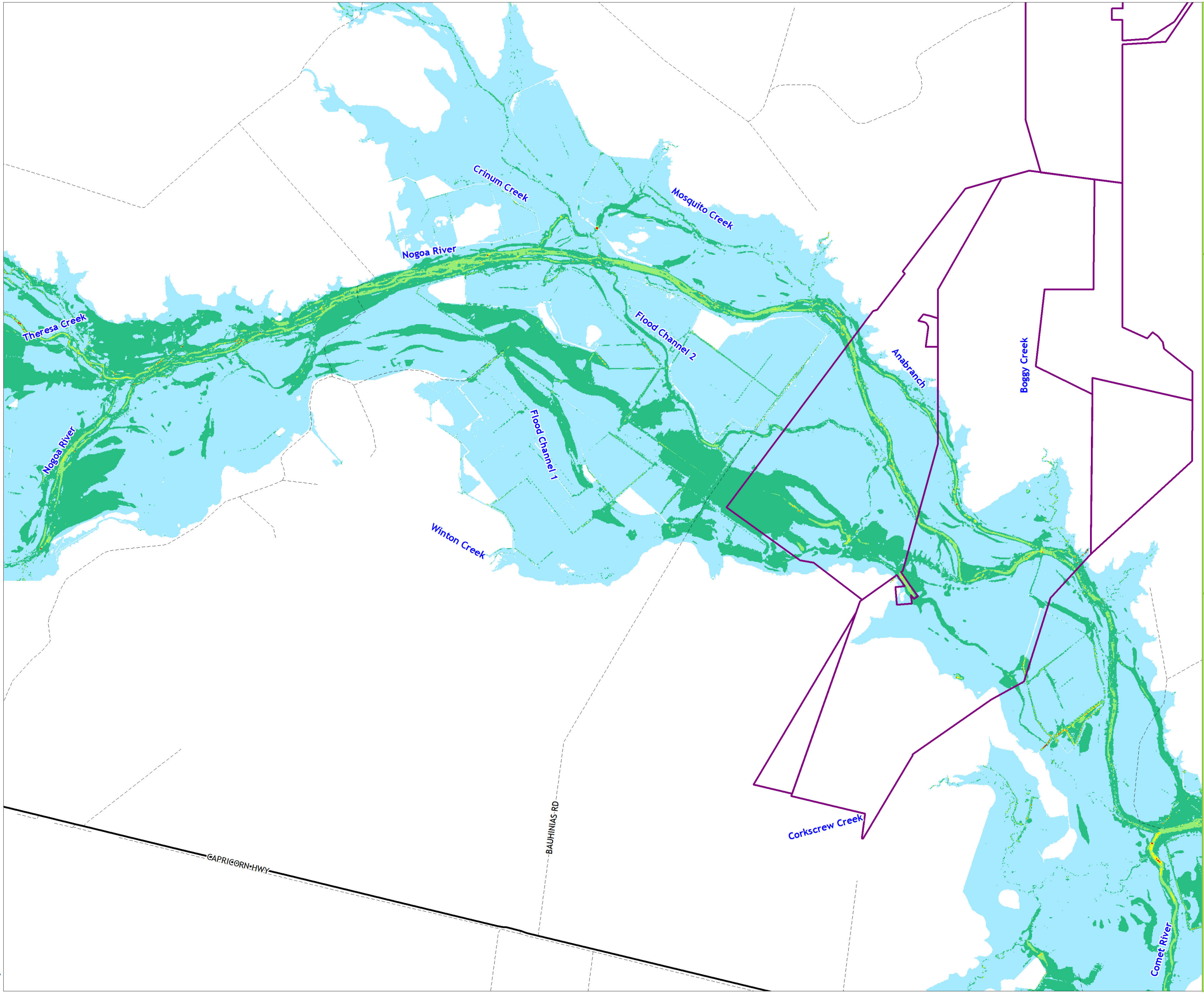


**ENSHAM RESIDUAL VOID STUDY
STAGE 3-GEOMORPHIC ASSESSMENT**

Figure A.1 -
Pre-mine conditions peak flood
velocities, 10% AEP event



Projection: MGA Zone 55 Datum: GDA 94

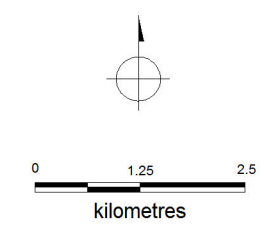


Legend

- Minor road
- Major road
- Mine lease boundary

Flood Velocity (m/s)

0.0m/s - 0.5m/s
0.5m/s - 1.0m/s
1.0m/s - 1.5m/s
1.5m/s - 2.0m/s
2.0m/s - 2.5m/s
2.5m/s - 3.0m/s
3.0m/s - 4.0m/s
>4.0m/s

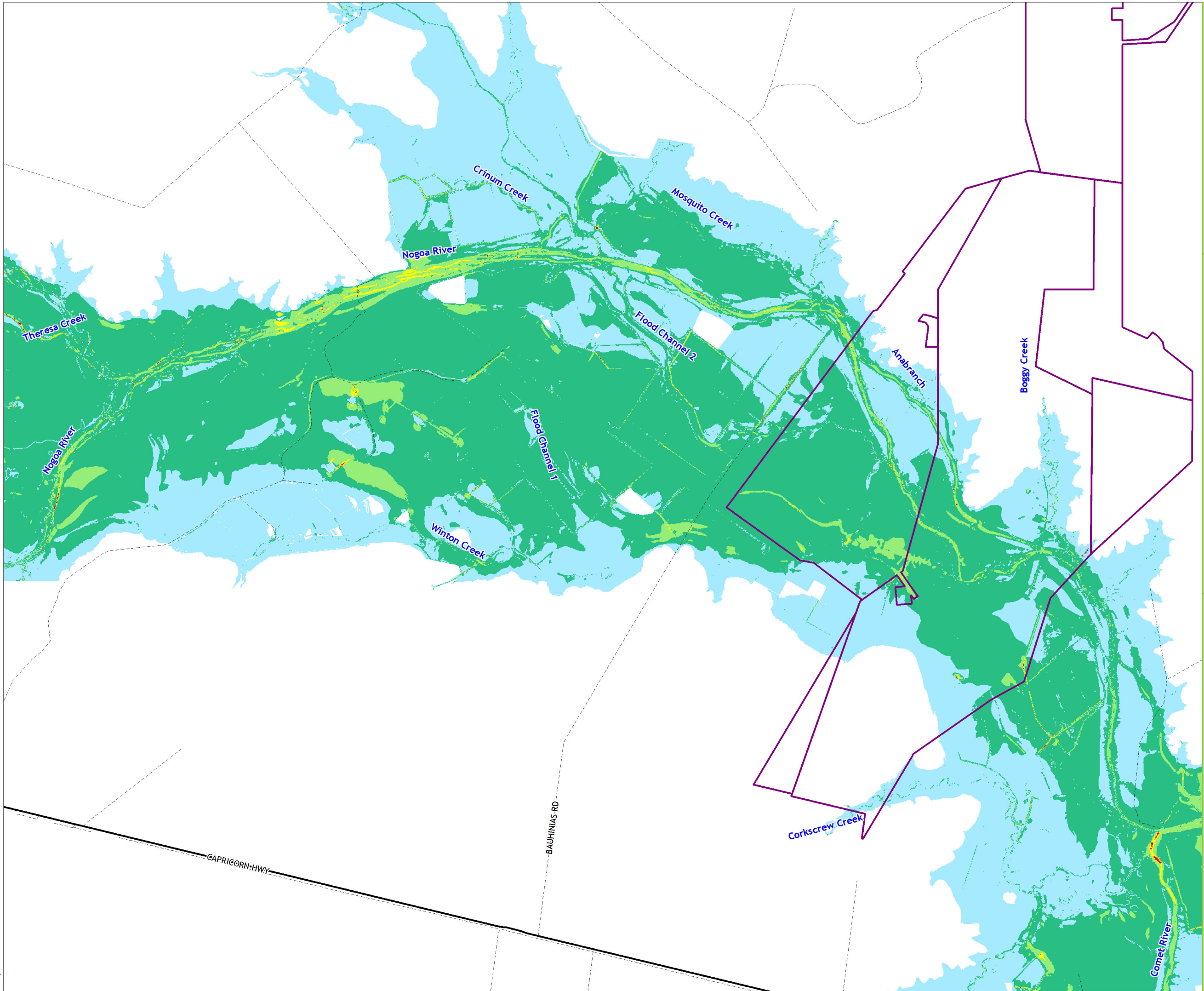


**ENSHAM RESIDUAL VOID STUDY
STAGE 3-GEOMORPHIC ASSESSMENT**

Figure A.2 -
Pre-mine conditions peak flood
velocities, 1% AEP event



Projection: MGA Zone 55 Datum: GDA 94



Legend

- Minor road
- Major road
- Mine lease boundary

Flood Velocity (m/s)

0.0m/s - 0.5m/s
0.5m/s - 1.0m/s
1.0m/s - 1.5m/s
1.5m/s - 2.0m/s
2.0m/s - 2.5m/s
2.5m/s - 3.0m/s
3.0m/s - 4.0m/s
>4.0m/s

**ENSHAM RESIDUAL VOID STUDY
STAGE 3-GEOMORPHIC ASSESSMENT**

Figure A.3 -
Pre-mine conditions peak flood
velocities, 0.1% x 1.5 AEP event

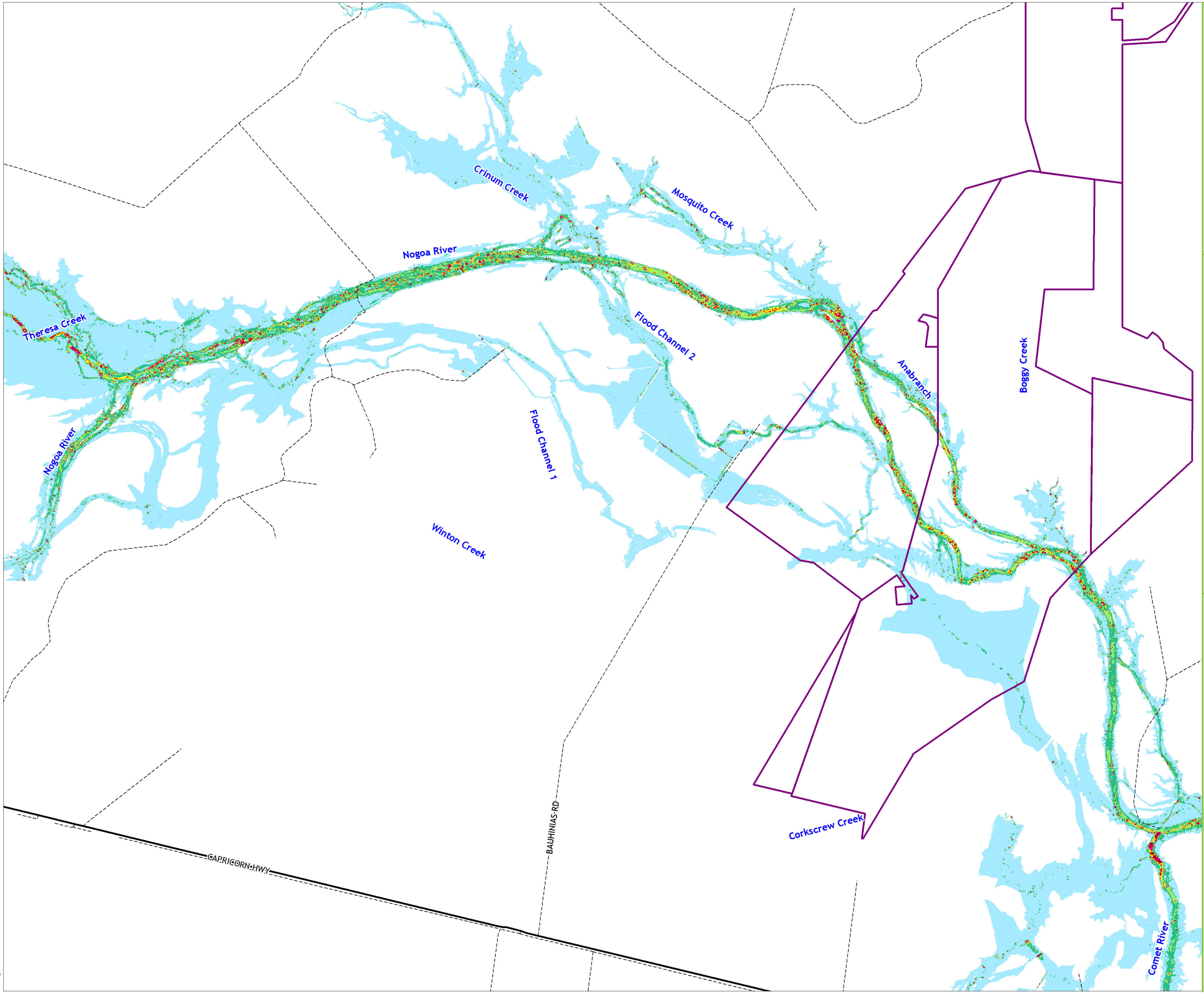


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Projection: MGA Zone 55 Datum: GDA 94



Legend

- Minor Road
- Major Road
- Mine lease boundary

Bed Shear Stress (N/m²)

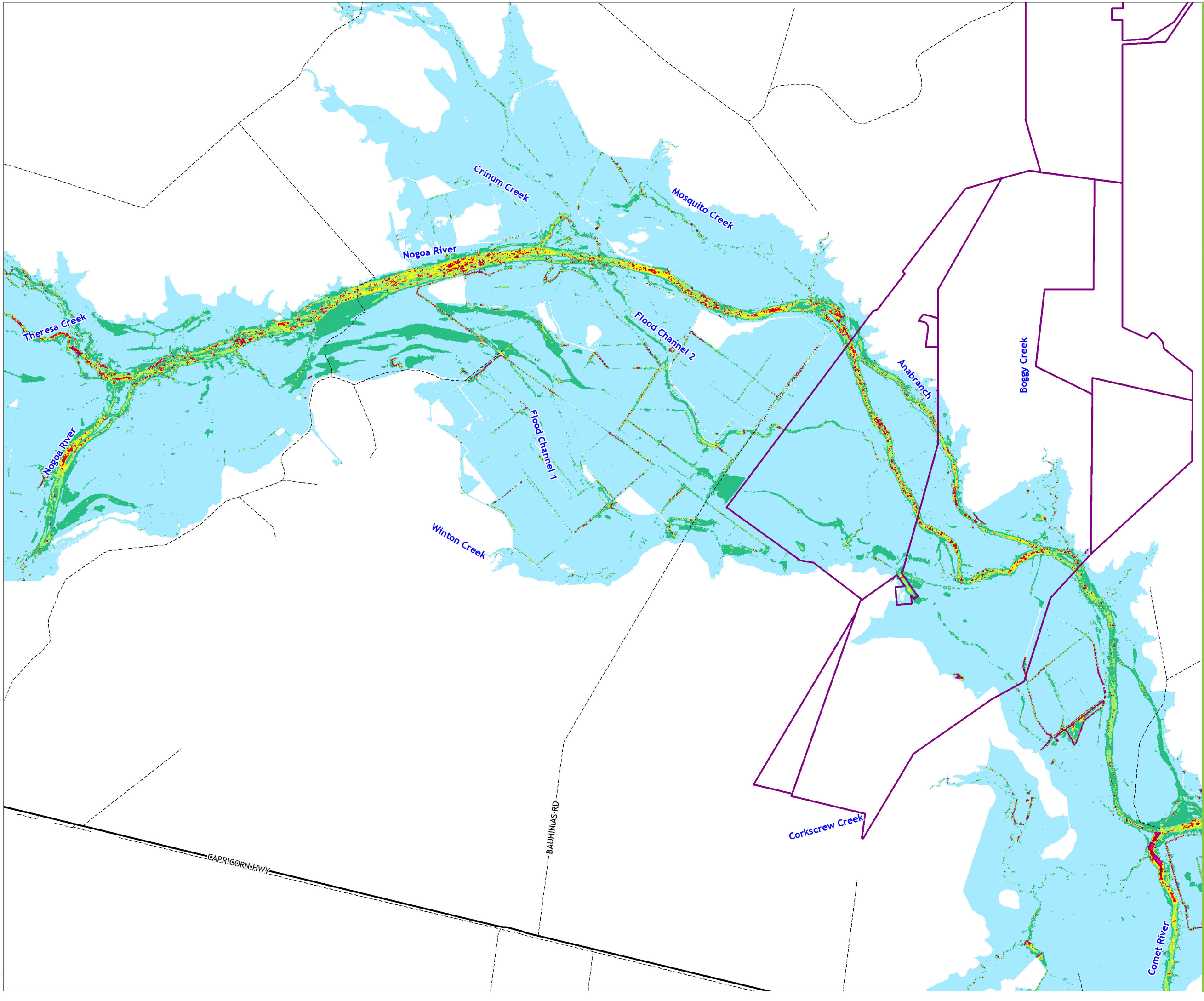
0 - 20
20 - 40
40 - 60
60 - 80
80 - 100
100 - 150
150 - 200
>200

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STAGE 3-GEOMORPHIC ASSESSMENT**

Figure A.4 -
Pre-mine conditions peak bed shear stress, 10% AEP event



Projection: MGA Zone 55 Datum: GDA 94

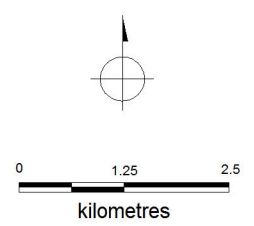


Legend

- Minor Road
- Major Road
- Mine lease boundary

Bed Shear Stress (N/m²)

0 - 20
20 - 40
40 - 60
60 - 80
80 - 100
100 - 150
150 - 200
>200



**ENSHAM RESIDUAL VOID STUDY
STAGE 3-GEOMORPHIC ASSESSMENT**

Figure A.5 -
Pre-mine conditions peak bed shear stress, 1% AEP event

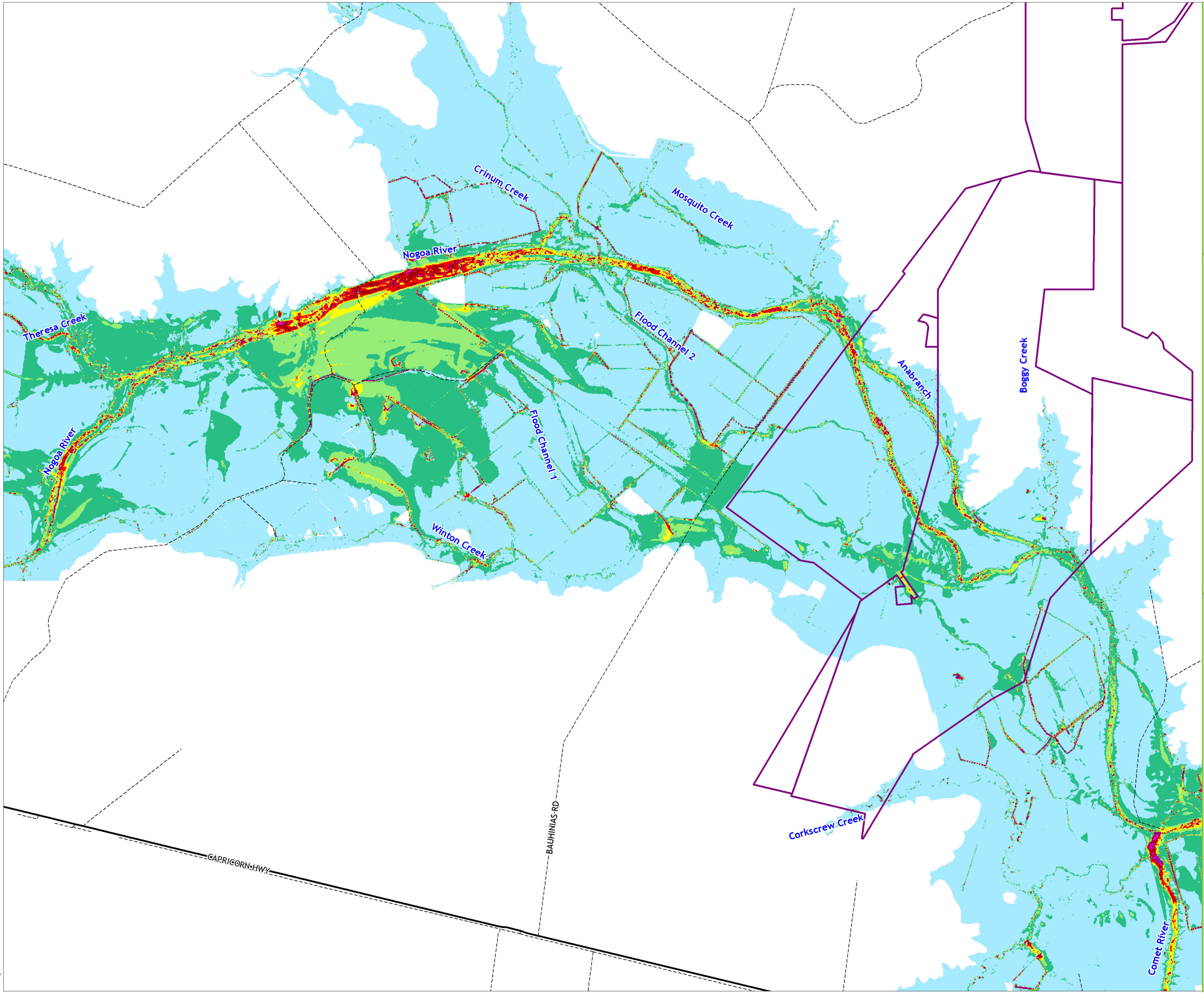


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Projection: MGA Zone 55 Datum: GDA 94

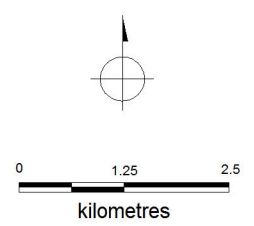


Legend

- Minor Road
- Major Road
- Mine lease boundary

Bed Shear Stress (N/m²)

0 - 20
20 - 40
40 - 60
60 - 80
80 - 100
100 - 150
150 - 200
>200



**ENSHAM RESIDUAL VOID STUDY
STAGE 3-GEOMORPHIC ASSESSMENT**

Figure A.6 -
Pre-mine conditions peak bed shear stress, 0.1%x1.5 AEP event

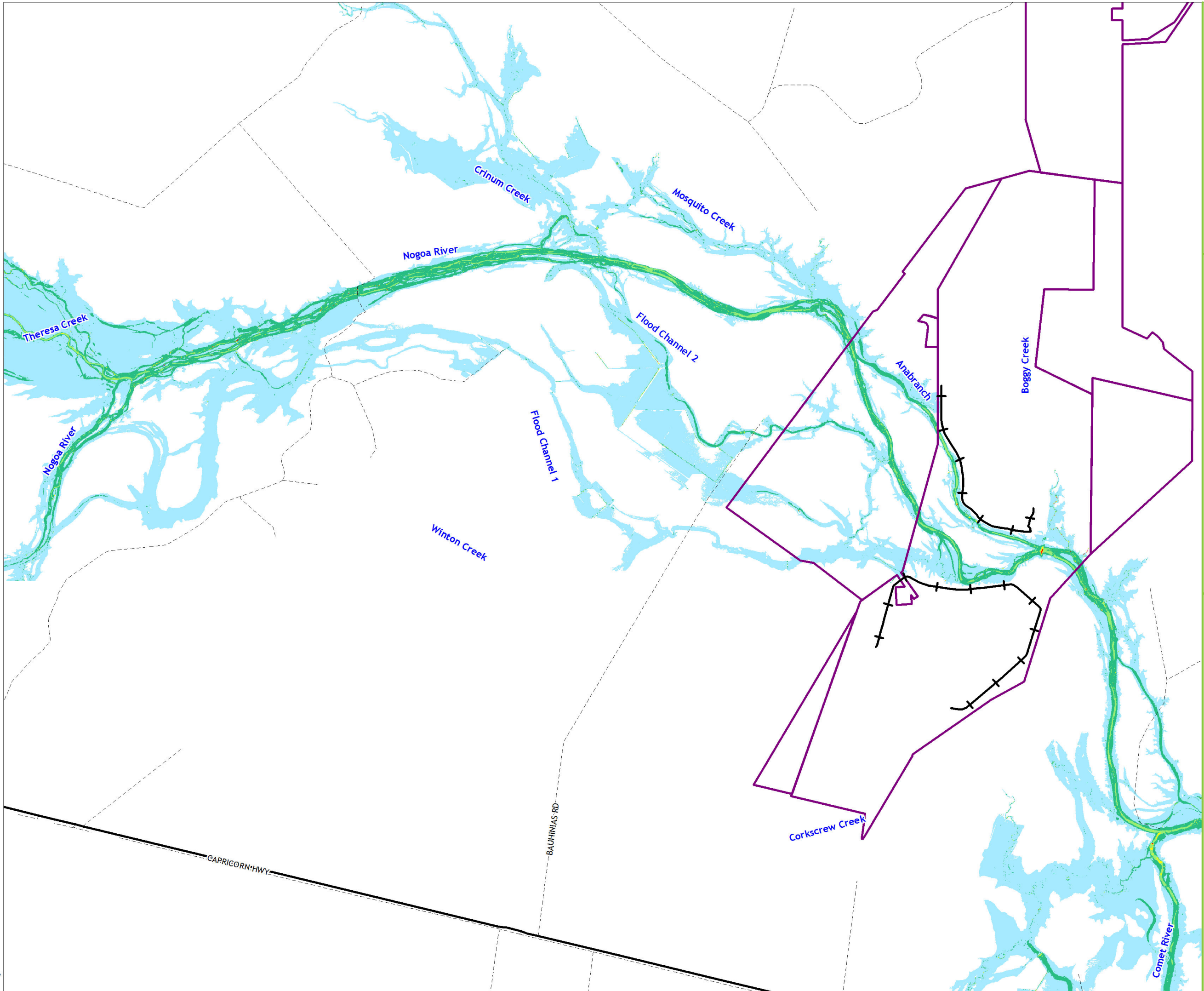


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Projection: MGA Zone 55 Datum: GDA 94

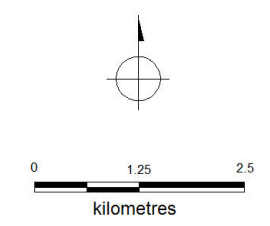


Legend

- Minor road
- Major road
- Mine lease boundary
- Existing Levee

Flood Velocity (m/s)

0.0m/s - 0.5m/s
0.5m/s - 1.0m/s
1.0m/s - 1.5m/s
1.5m/s - 2.0m/s
2.0m/s - 2.5m/s
2.5m/s - 3.0m/s
3.0m/s - 4.0m/s
>4.0m/s



**ENSHAM RESIDUAL VOID STUDY
STAGE 3-GEOMORPHIC ASSESSMENT**

Figure A.7 -
Option 1 conditions peak flood
velocities, 10% AEP event

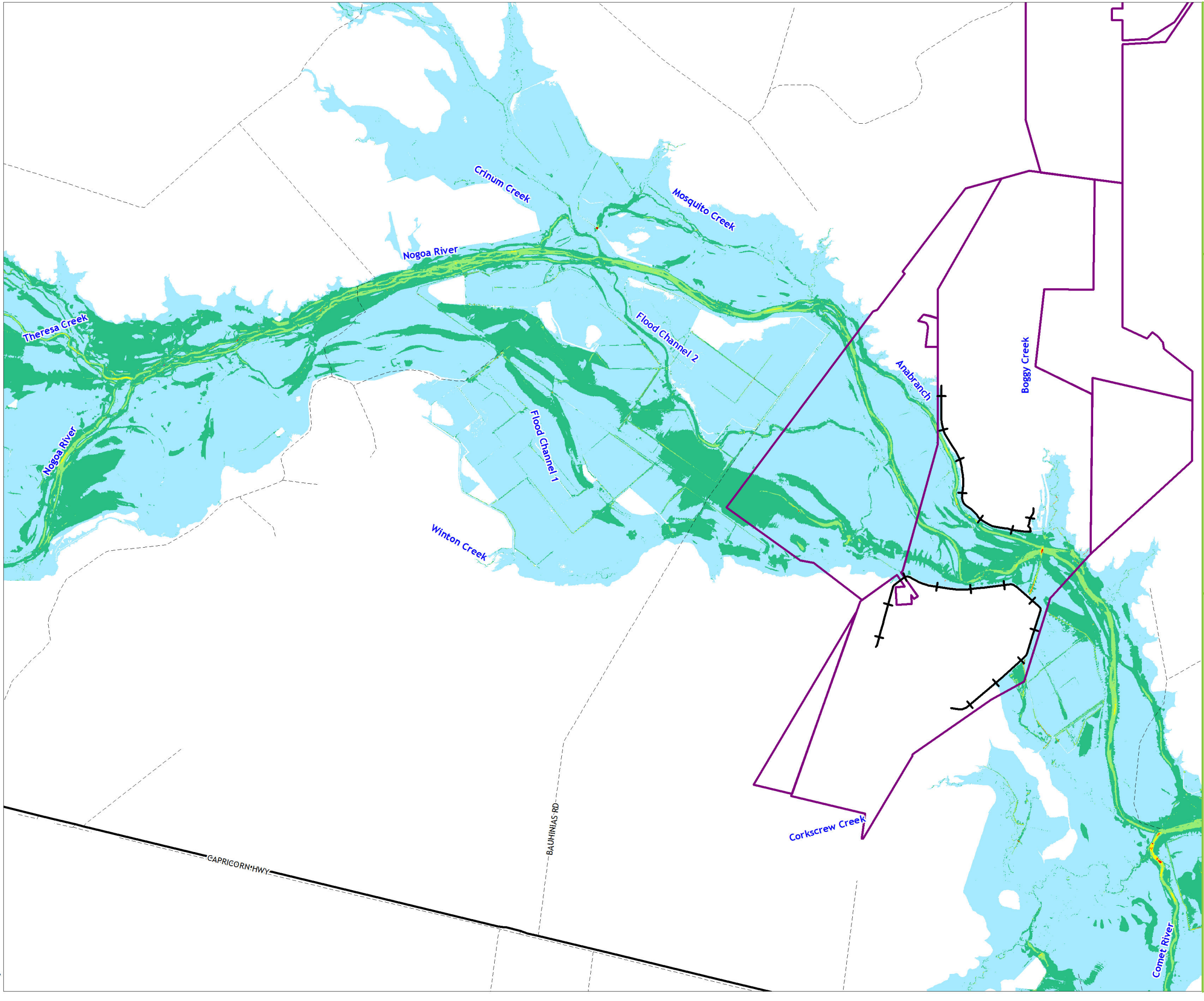


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Projection: MGA Zone 55 Datum: GDA 94

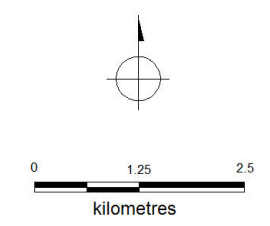


Legend

- Minor road
- Major road
- Mine lease boundary
- Existing Levee

Flood Velocity (m/s)

0.0m/s - 0.5m/s
0.5m/s - 1.0m/s
1.0m/s - 1.5m/s
1.5m/s - 2.0m/s
2.0m/s - 2.5m/s
2.5m/s - 3.0m/s
3.0m/s - 4.0m/s
>4.0m/s



**ENSHAM RESIDUAL VOID STUDY
STAGE 3-GEOMORPHIC ASSESSMENT**

Figure A.8 -
Option 1 conditions peak flood
velocities, 1% AEP event

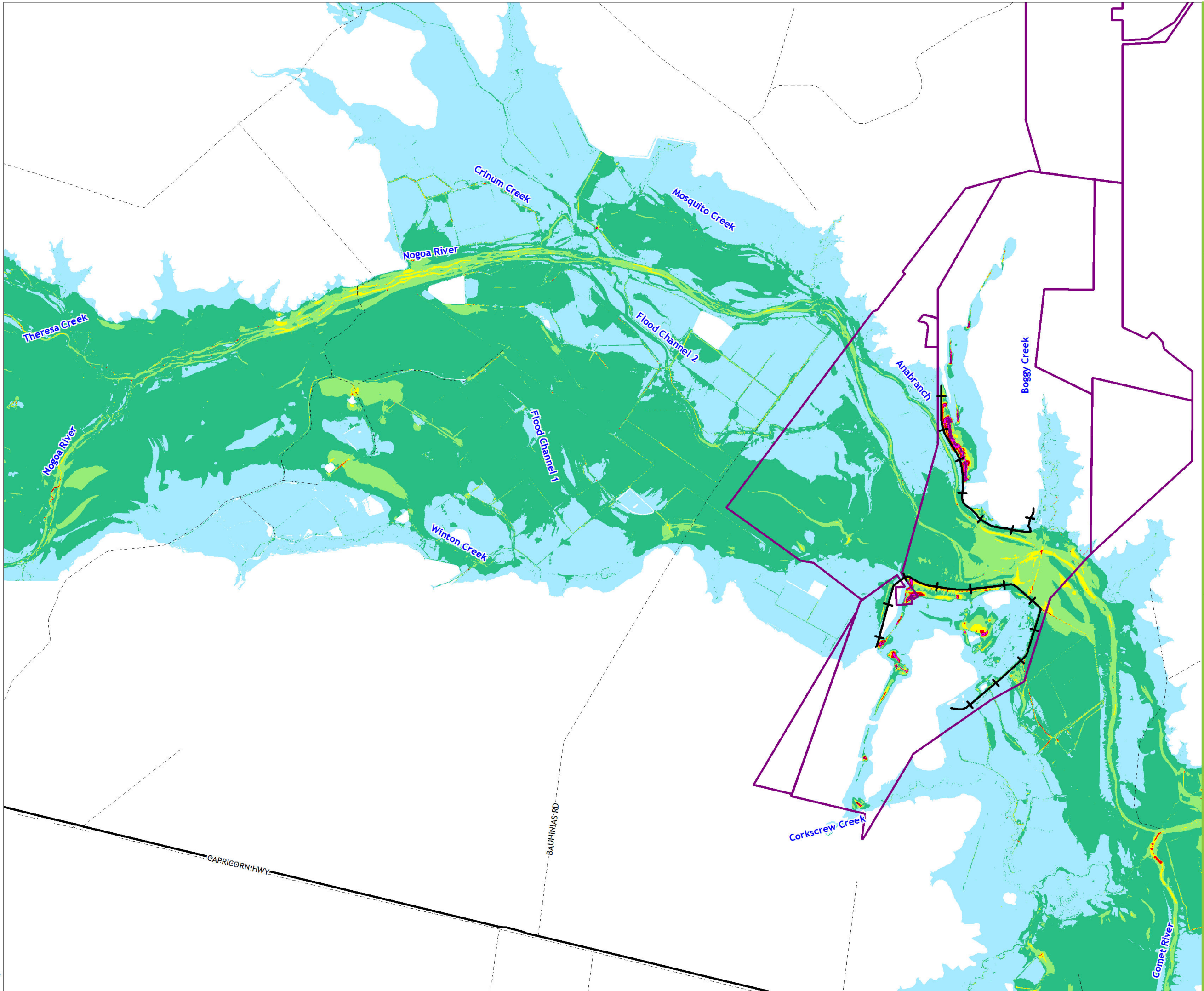


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RESOURCES



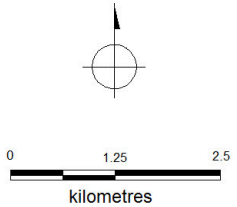
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Projection: MGA Zone 55 Datum: GDA 94



- Legend**
- Minor road
 - Major road
 - Mine lease boundary
 - Existing Levee

- Flood Velocity (m/s)**
- 0.0m/s - 0.5m/s
 - 0.5m/s - 1.0m/s
 - 1.0m/s - 1.5m/s
 - 1.5m/s - 2.0m/s
 - 2.0m/s - 2.5m/s
 - 2.5m/s - 3.0m/s
 - 3.0m/s - 4.0m/s
 - >4.0m/s

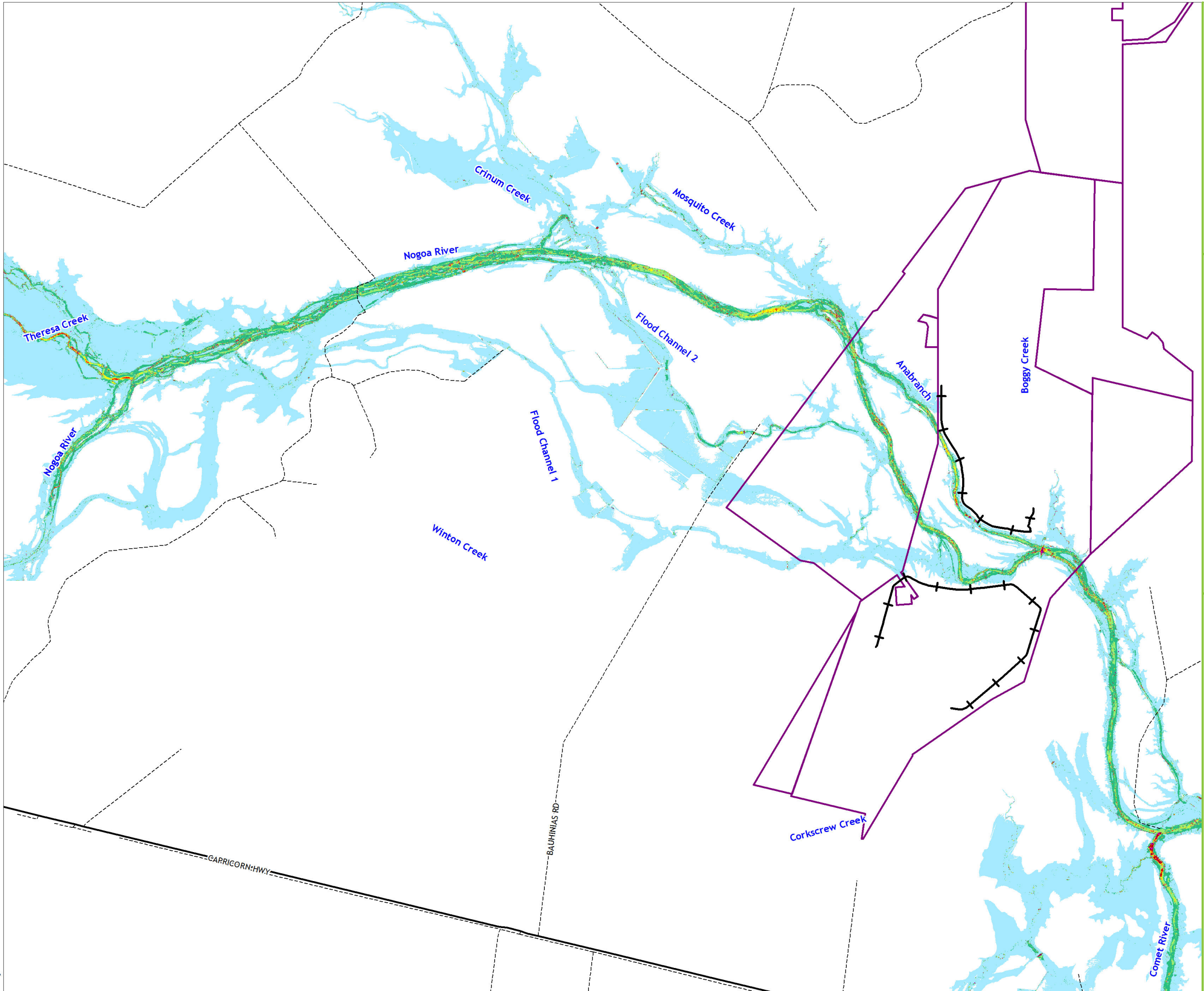


**ENSHAM RESIDUAL VOID STUDY
STAGE 3-GEOMORPHIC ASSESSMENT**

Figure A.9 -
Option 1 conditions peak flood
velocities, 0.1%x1.5 AEP event



Projection: MGA Zone 55 Datum: GDA 94



Legend

- Minor Road
- Major Road
- Mine lease boundary
- Existing Levee

Bed Shear Stress (N/m²)

0 - 20
20 - 40
40 - 60
60 - 80
80 - 100
100 - 150
150 - 200
>200

0 1.25 2.5
kilometres

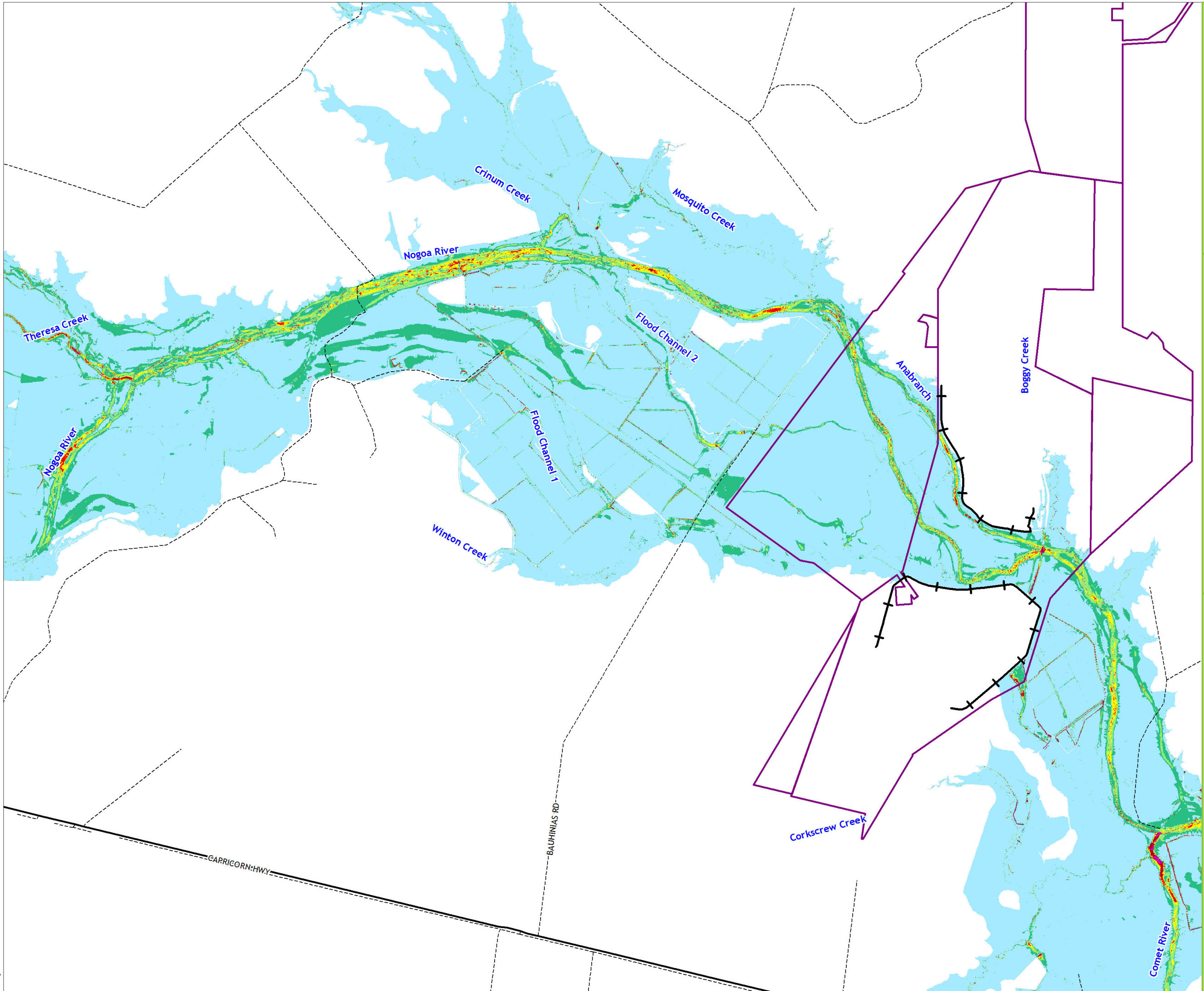
**ENSHAM RESIDUAL VOID STUDY
STAGE 3-GEOMORPHIC ASSESSMENT**

Figure A.10 -
Option 1 conditions peak bed shear
stress, 10% AEP event

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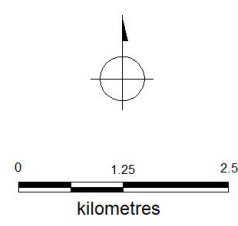
Projection: MGA Zone 55 Datum: GDA 94



- Legend**
- Minor Road
 - Major Road
 - Mine lease boundary
 - Existing Levee

Bed Shear Stress (N/m²)

0 - 20
20 - 40
40 - 60
60 - 80
80 - 100
100 - 150
150 - 200
>200

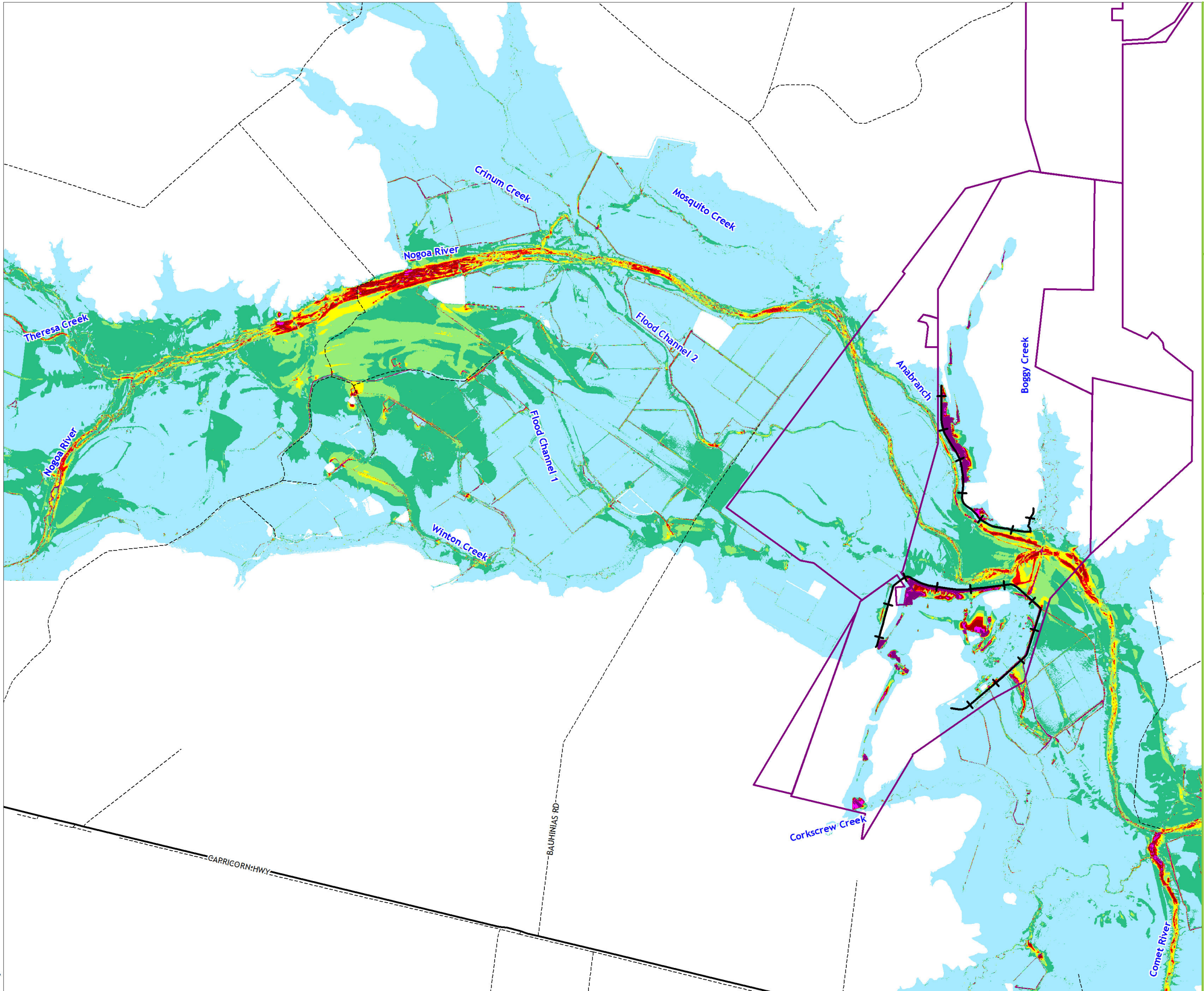


**ENSHAM RESIDUAL VOID STUDY
STAGE 3-GEOMORPHIC ASSESSMENT**

Figure A.11 -
Option 1 conditions peak bed shear stress, 1% AEP event



Projection: MGA Zone 55 Datum: GDA 94



Legend

- Minor Road
- Major Road
- Mine lease boundary
- Existing Levee

Bed Shear Stress (N/m²)

0 - 20
20 - 40
40 - 60
60 - 80
80 - 100
100 - 150
150 - 200
>200

0 1.25 2.5
kilometres

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STAGE 3-GEOMORPHIC ASSESSMENT**

Figure A.12 -
Option 1 conditions peak bed shear stress, 0.1%x1.5 AEP event

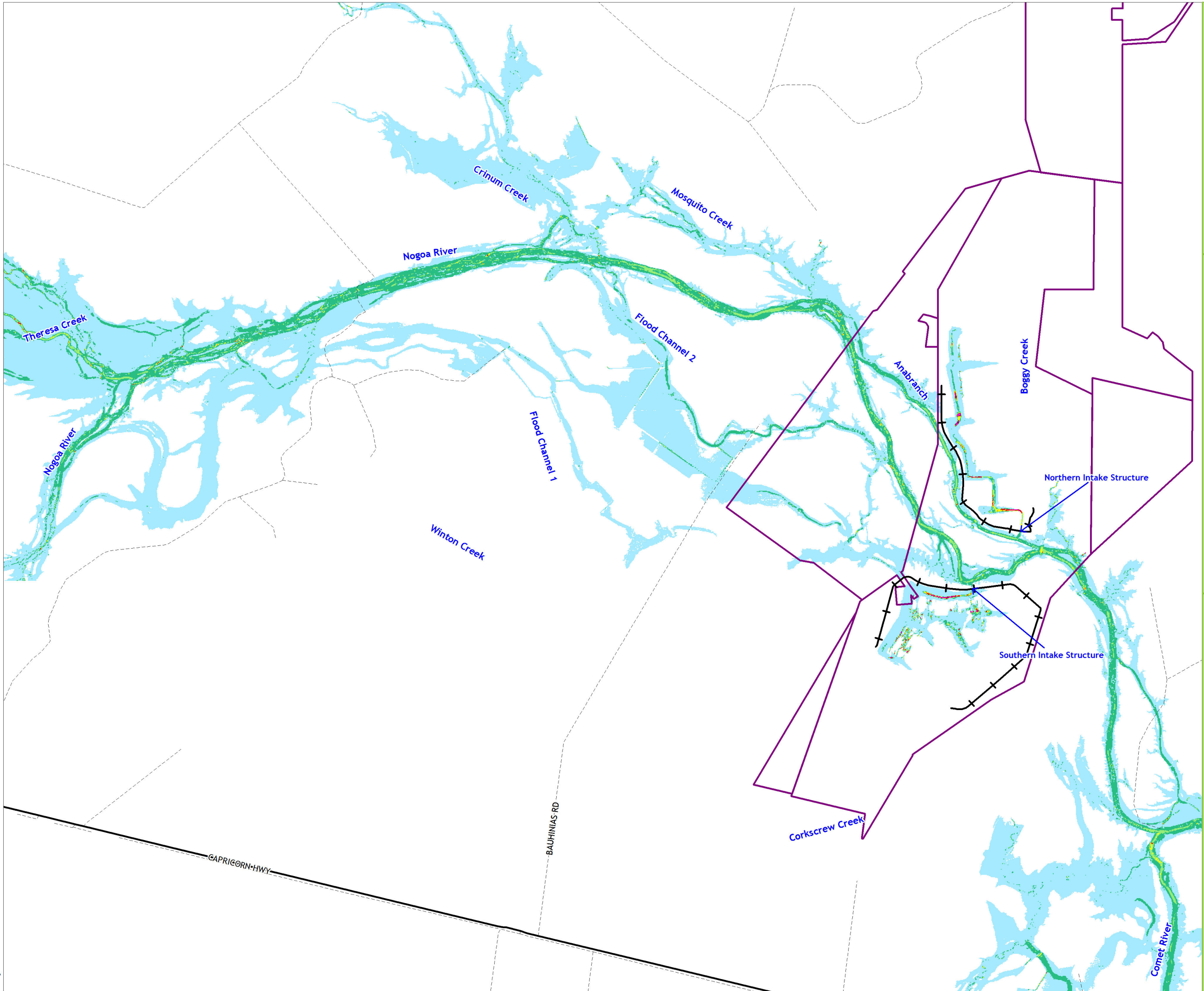


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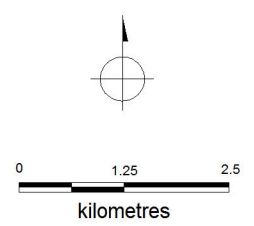
wrm
water+environment

Projection: MGA Zone 55 Datum: GDA 94



- Legend**
- Minor road
 - Major road
 - Mine lease boundary
 - Existing Levee

- Flood Velocity (m/s)**
- 0.0m/s - 0.5m/s
 - 0.5m/s - 1.0m/s
 - 1.0m/s - 1.5m/s
 - 1.5m/s - 2.0m/s
 - 2.0m/s - 2.5m/s
 - 2.5m/s - 3.0m/s
 - 3.0m/s - 4.0m/s
 - >4.0m/s

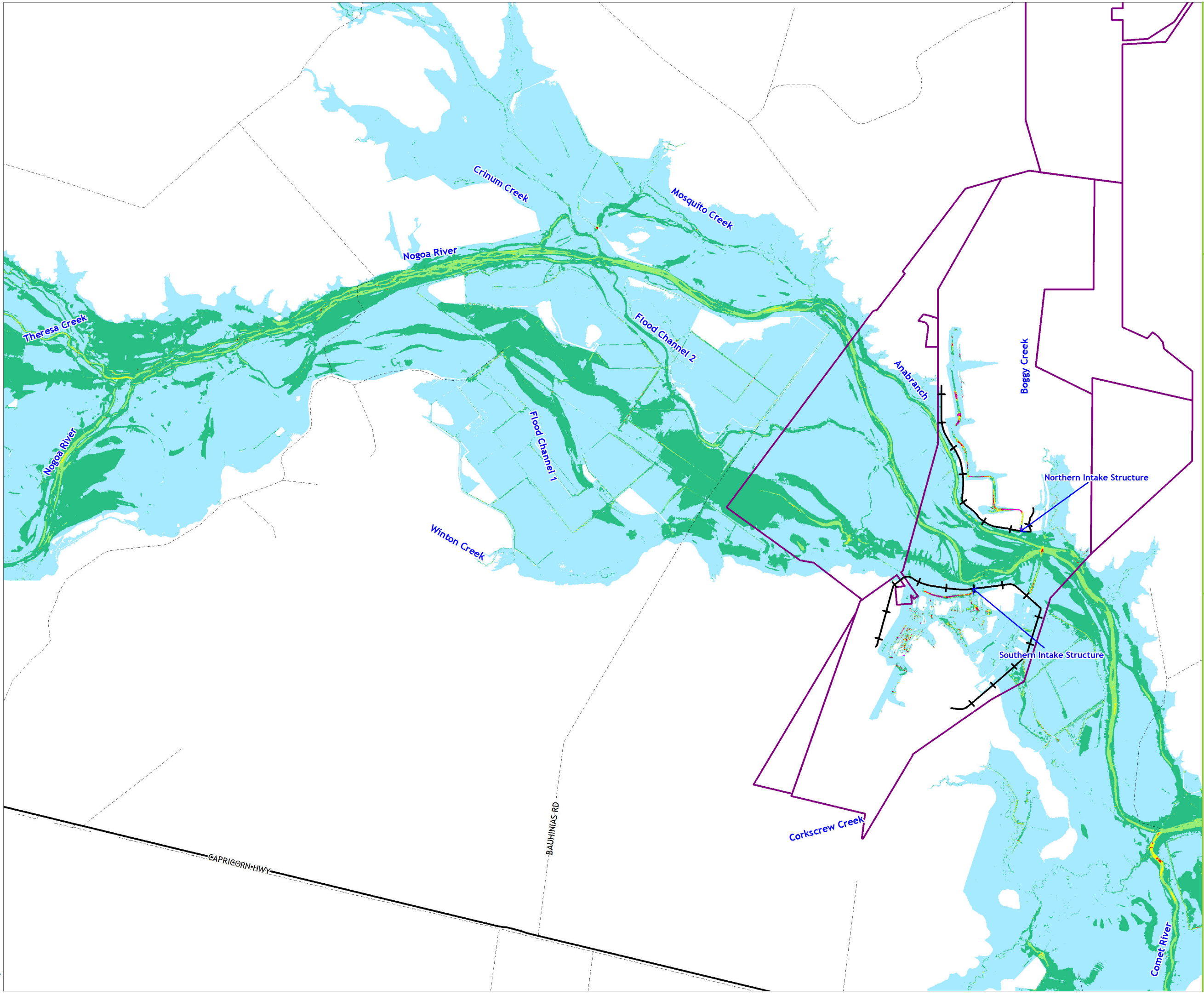


**ENSHAM RESIDUAL VOID STUDY
STAGE 3-GEOMORPHIC ASSESSMENT**

Figure A.13 -
Option 2 conditions peak flood
velocities, 10% AEP event



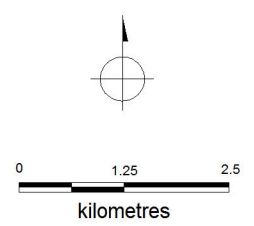
Projection: MGA Zone 55 Datum: GDA 94



- Legend**
- Minor road
 - Major road
 - Mine lease boundary
 - Existing Levee

Flood Velocity (m/s)

0.0m/s - 0.5m/s
0.5m/s - 1.0m/s
1.0m/s - 1.5m/s
1.5m/s - 2.0m/s
2.0m/s - 2.5m/s
2.5m/s - 3.0m/s
3.0m/s - 4.0m/s
>4.0m/s

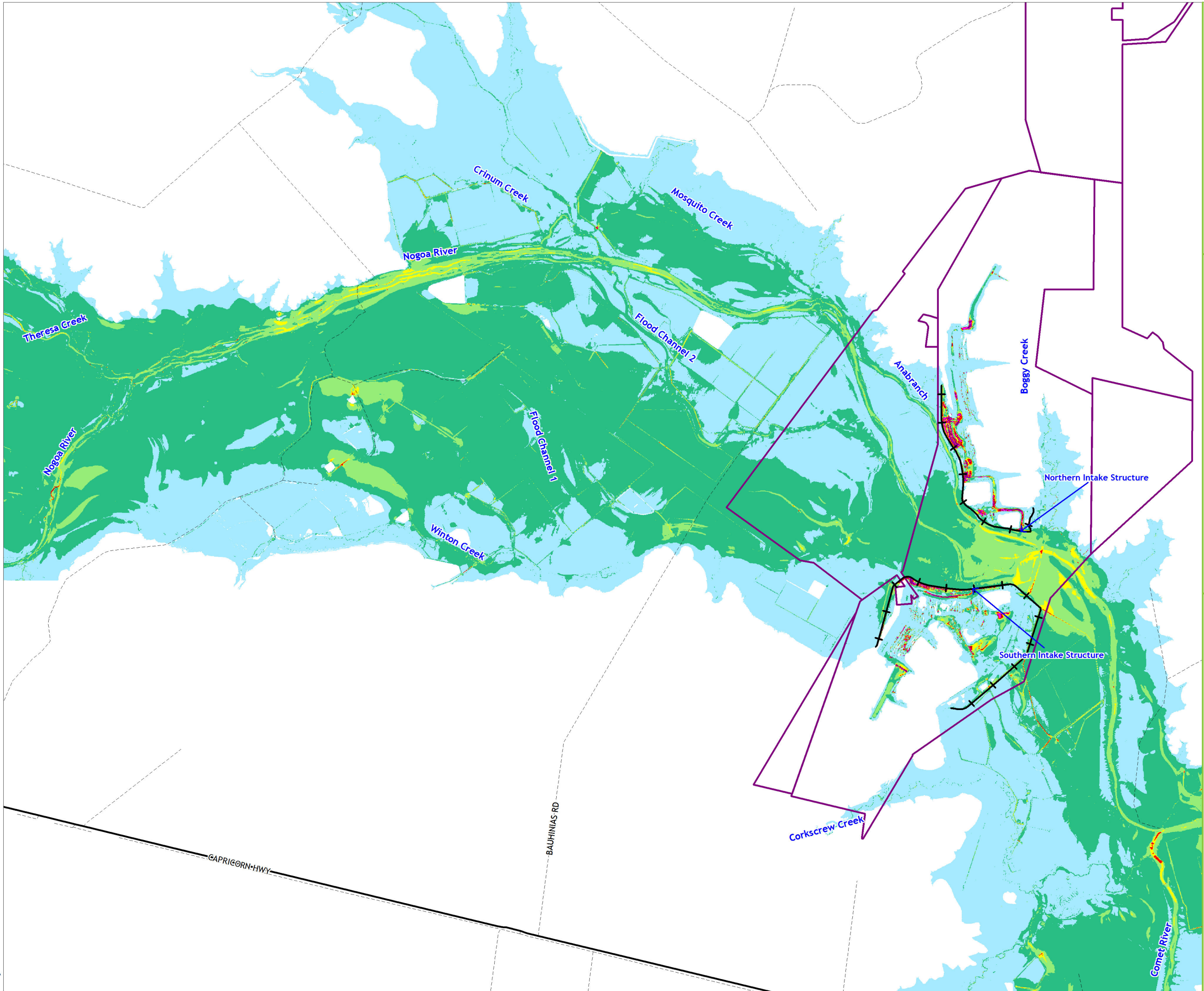


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STAGE 3-GEOMORPHIC ASSESSMENT**

Figure A.14 -
Option 2 conditions peak flood
velocities, 1% AEP event



Projection: MGA Zone 55 Datum: GDA 94



Legend

- Minor road
- Major road
- Mine lease boundary
- Existing Levee

Flood Velocity (m/s)

0.0m/s - 0.5m/s
0.5m/s - 1.0m/s
1.0m/s - 1.5m/s
1.5m/s - 2.0m/s
2.0m/s - 2.5m/s
2.5m/s - 3.0m/s
3.0m/s - 4.0m/s
>4.0m/s

0 1.25 2.5
kilometres

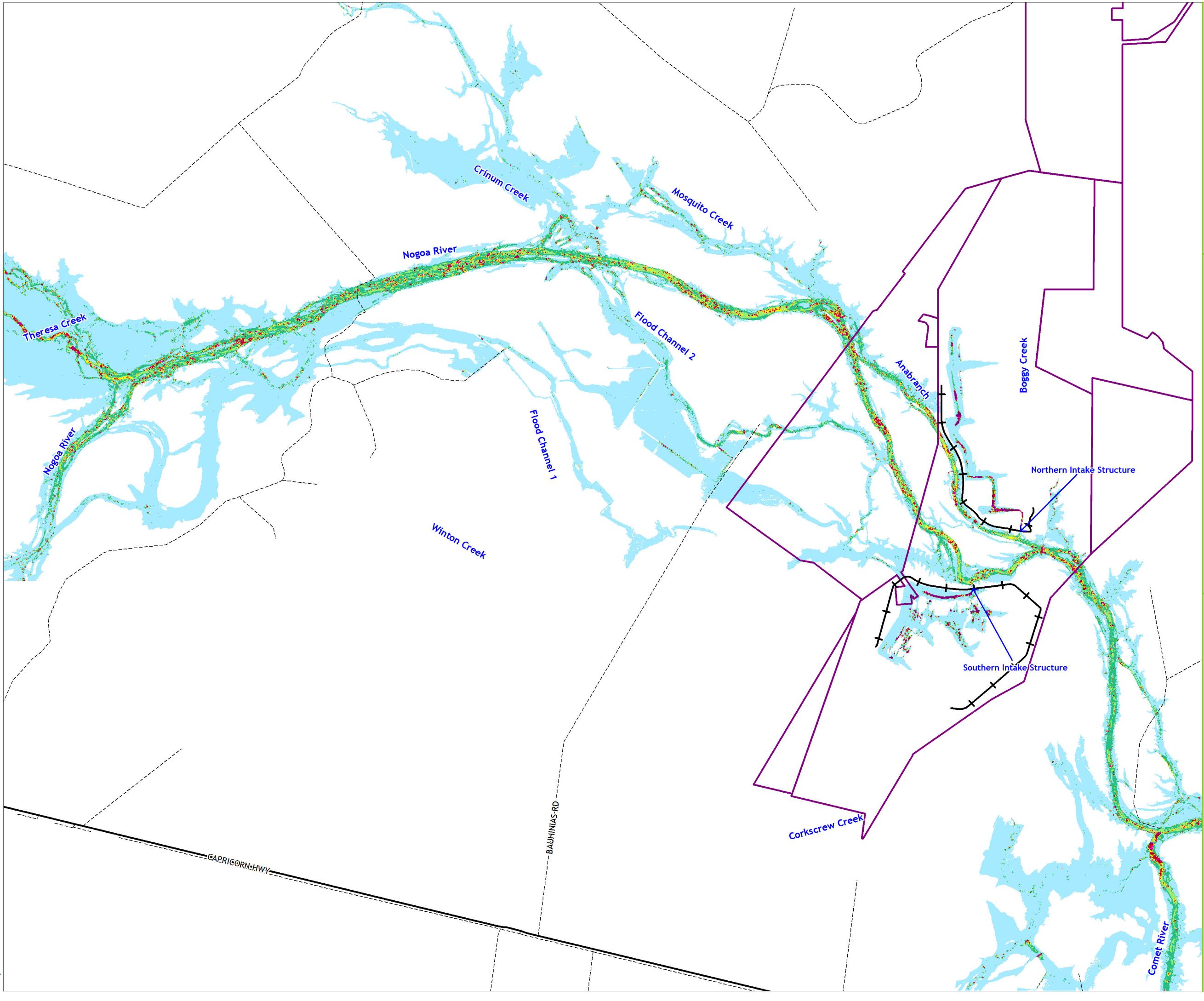
**ENSHAM RESIDUAL VOID STUDY
STAGE 3-GEOMORPHIC ASSESSMENT**

Figure A.15 -
Option 2 conditions peak flood
velocities, 0.1%x1.5 AEP event

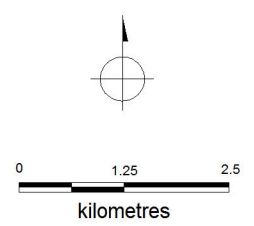
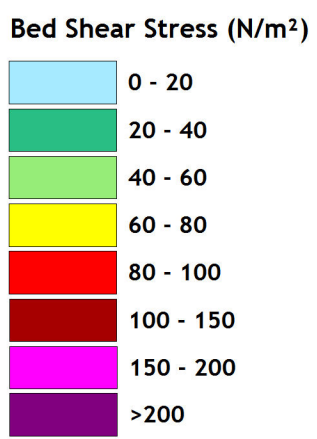
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Projection: MGA Zone 55 Datum: GDA 94



- Legend**
- Minor Road
 - Major Road
 - Mine lease boundary
 - Existing Levee

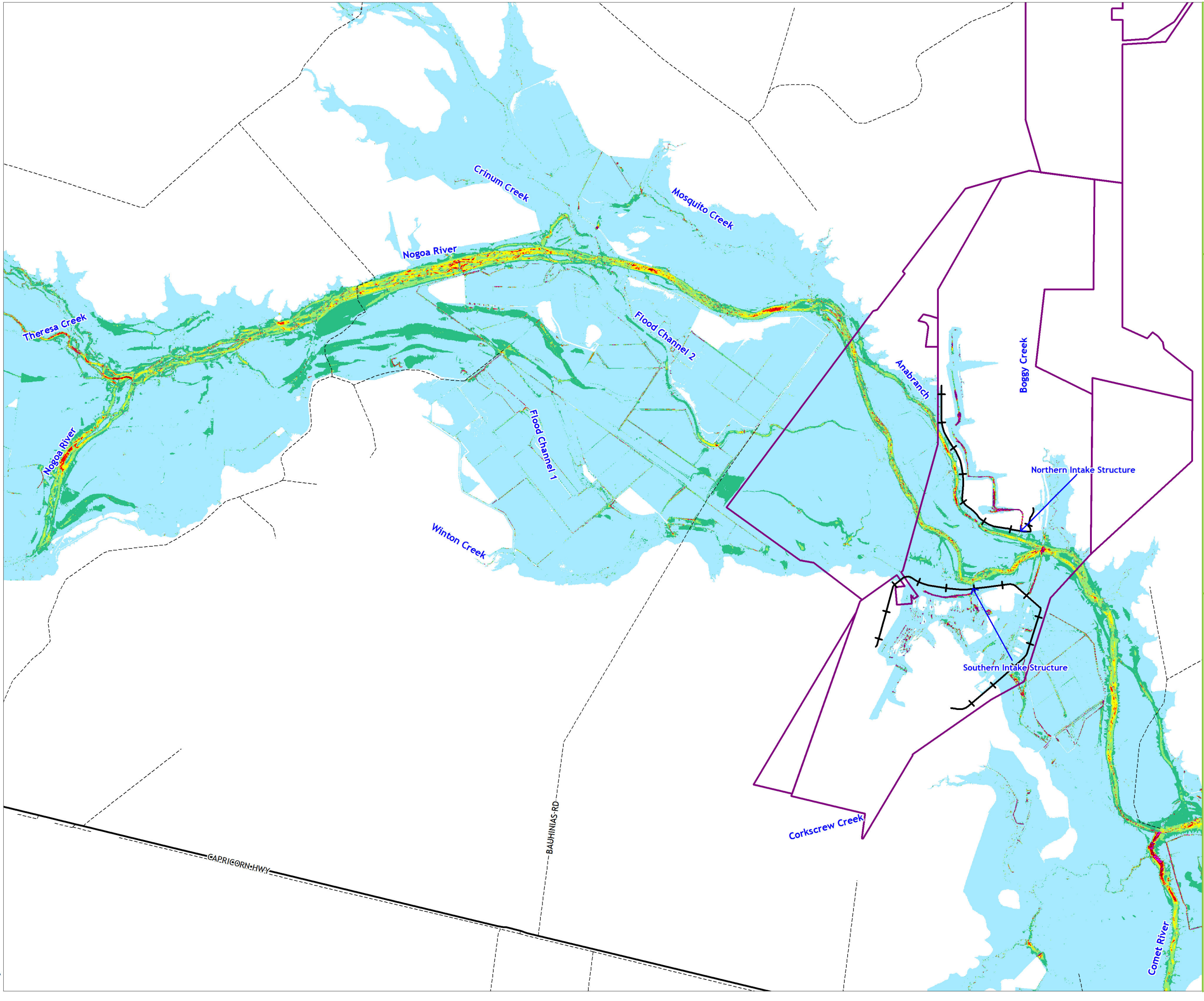


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STAGE 3-GEOMORPHIC ASSESSMENT**

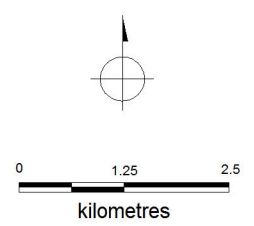
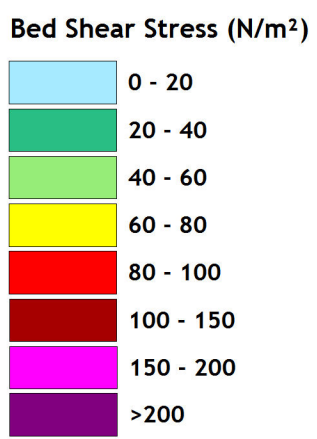
Figure A.16 -
Option 2 conditions peak bed shear stress, 10% AEP event



Projection: MGA Zone 55 Datum: GDA 94



- Legend**
- Minor Road
 - Major Road
 - Mine lease boundary
 - Existing Levee

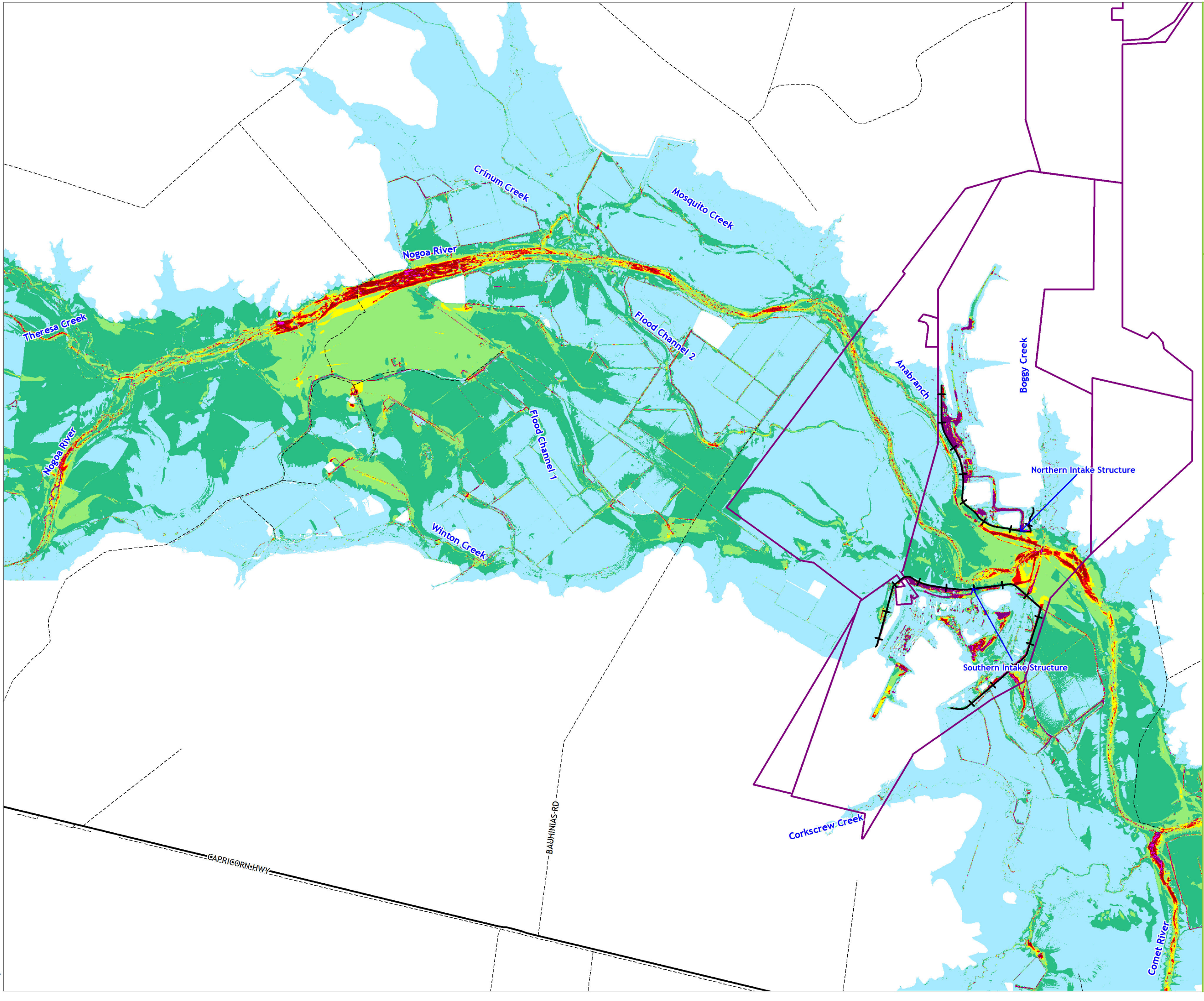


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STAGE 3-GEOMORPHIC ASSESSMENT**

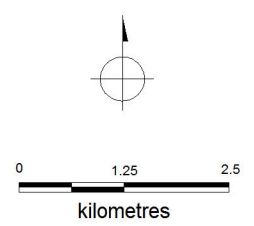
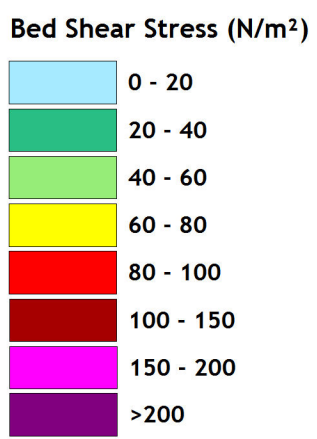
Figure A.17 -
Option 2 conditions peak bed shear stress, 1% AEP event



Projection: MGA Zone 55 Datum: GDA 94



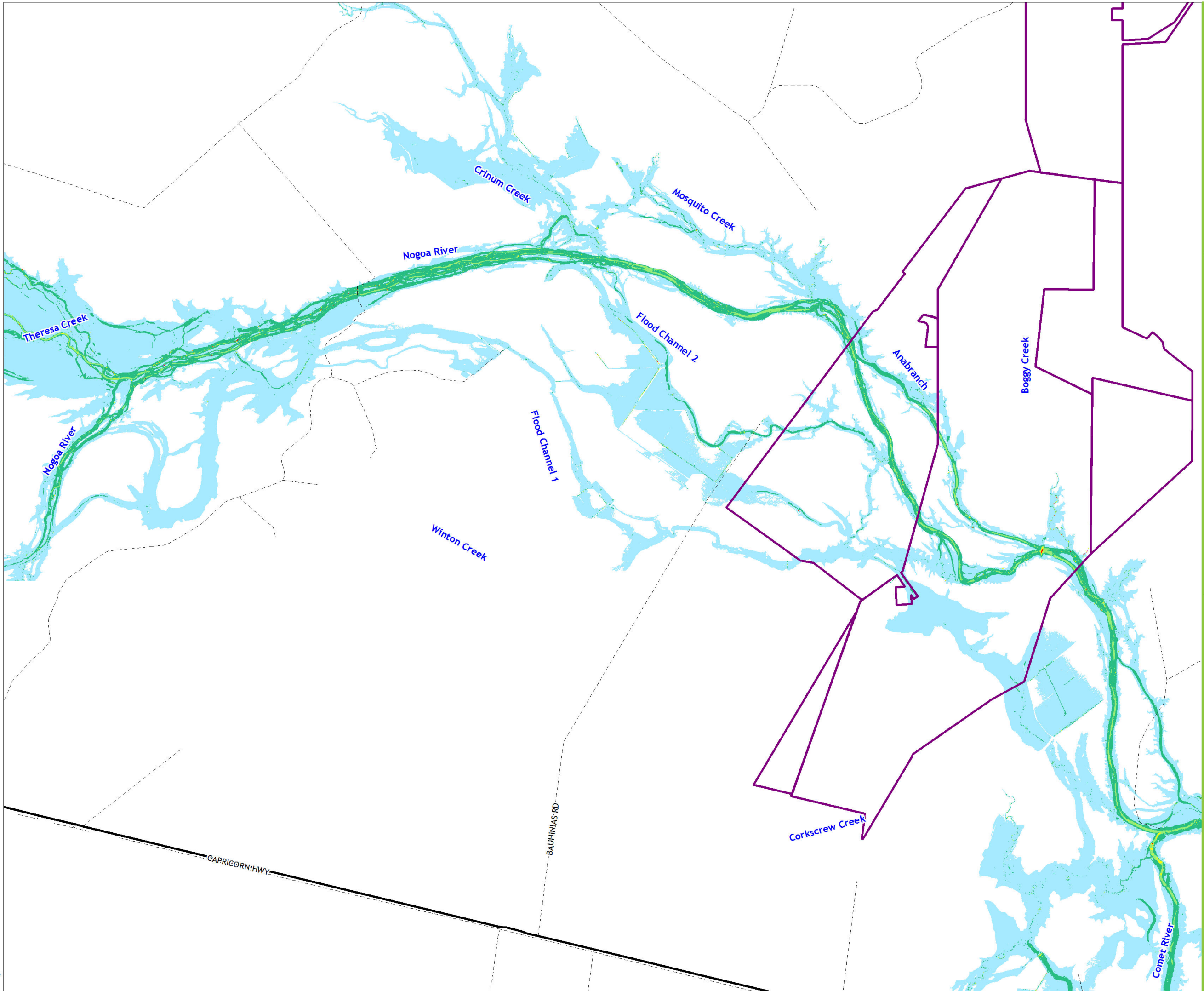
- Legend**
- Minor Road
 - Major Road
 - Mine lease boundary
 - Existing Levee



**ENSHAM RESIDUAL VOID STUDY
STAGE 3-GEOMORPHIC ASSESSMENT**

Figure A.18 -
Option 2 conditions peak bed shear stress, 0.1%x1.5 AEP event



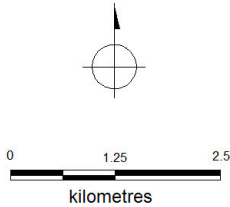


Legend

- Minor road
- Major road
- Mine lease boundary

Flood Velocity (m/s)

0.0m/s - 0.5m/s
0.5m/s - 1.0m/s
1.0m/s - 1.5m/s
1.5m/s - 2.0m/s
2.0m/s - 2.5m/s
2.5m/s - 3.0m/s
3.0m/s - 4.0m/s
>4.0m/s



**ENSHAM RESIDUAL VOID STUDY
STAGE 3-GEOMORPHIC ASSESSMENT**

Figure A.19 -
Option 3 conditions peak flood
velocities, 10% AEP event

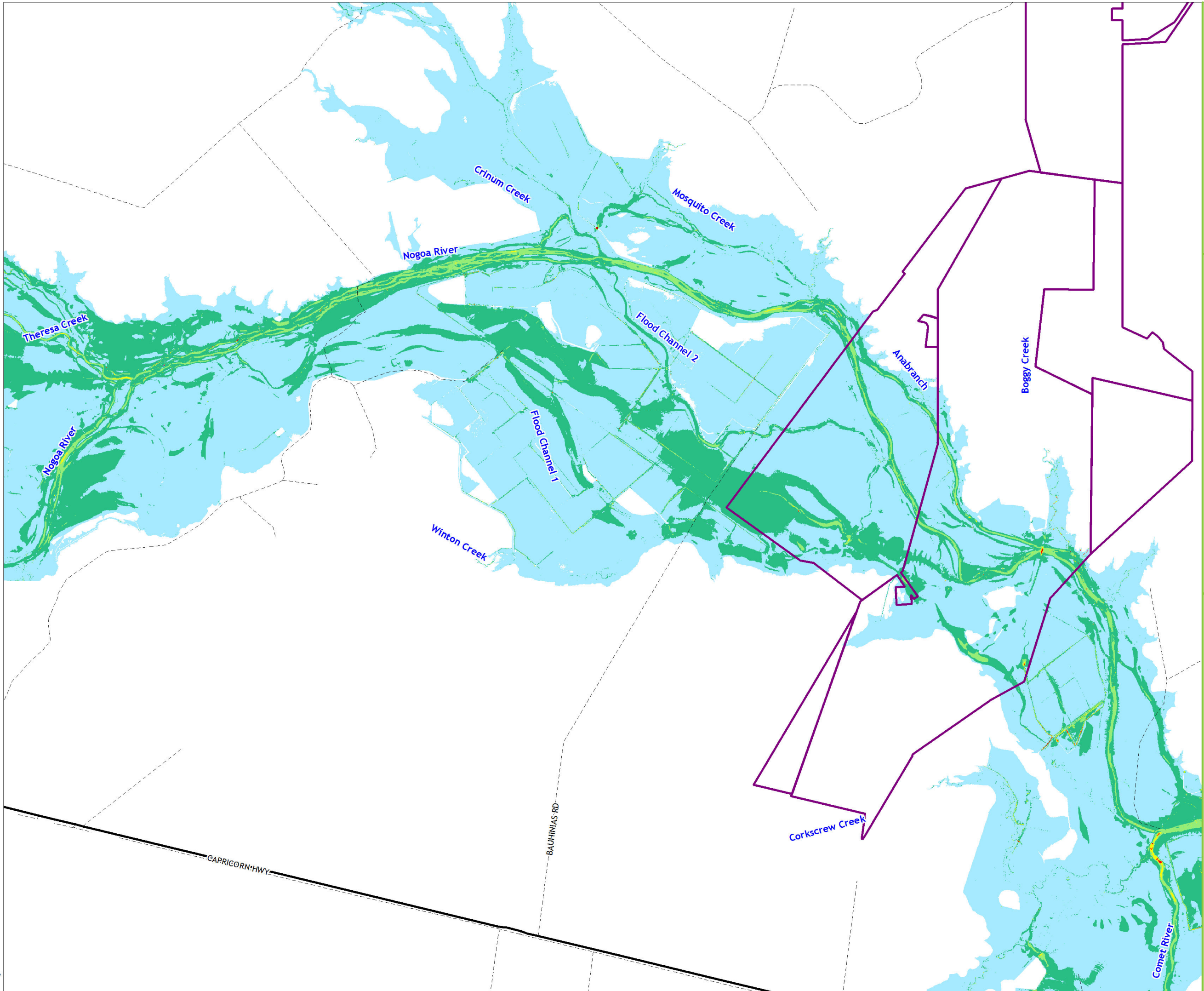


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Projection: MGA Zone 55 Datum: GDA 94

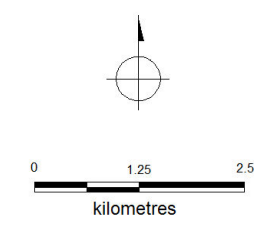


Legend

- Minor road
- Major road
- Mine lease boundary

Flood Velocity (m/s)

0.0m/s - 0.5m/s
0.5m/s - 1.0m/s
1.0m/s - 1.5m/s
1.5m/s - 2.0m/s
2.0m/s - 2.5m/s
2.5m/s - 3.0m/s
3.0m/s - 4.0m/s
>4.0m/s



**ENSHAM RESIDUAL VOID STUDY
STAGE 3-GEOMORPHIC ASSESSMENT**

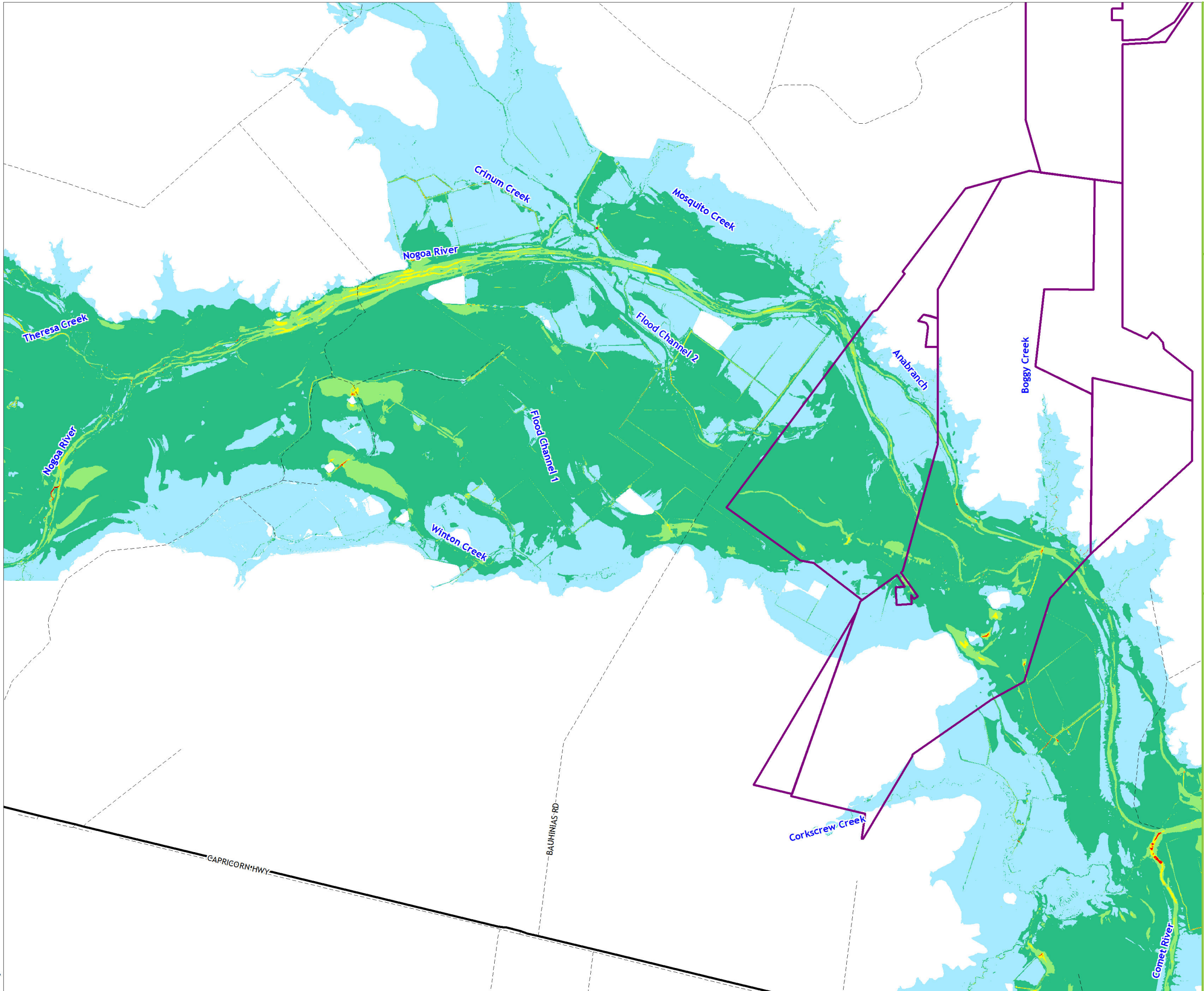
Figure A.20 -
Option 3 conditions peak flood
velocities, 1% AEP event



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RESOURCES



wrm
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Legend

- Minor road
- Major road
- Mine lease boundary

Flood Velocity (m/s)

0.0m/s - 0.5m/s
0.5m/s - 1.0m/s
1.0m/s - 1.5m/s
1.5m/s - 2.0m/s
2.0m/s - 2.5m/s
2.5m/s - 3.0m/s
3.0m/s - 4.0m/s
>4.0m/s

**ENSHAM RESIDUAL VOID STUDY
STAGE 3-GEOMORPHIC ASSESSMENT**

Figure A.21 -
Option 3 conditions peak flood
velocities, 0.1%x1.5 AEP event

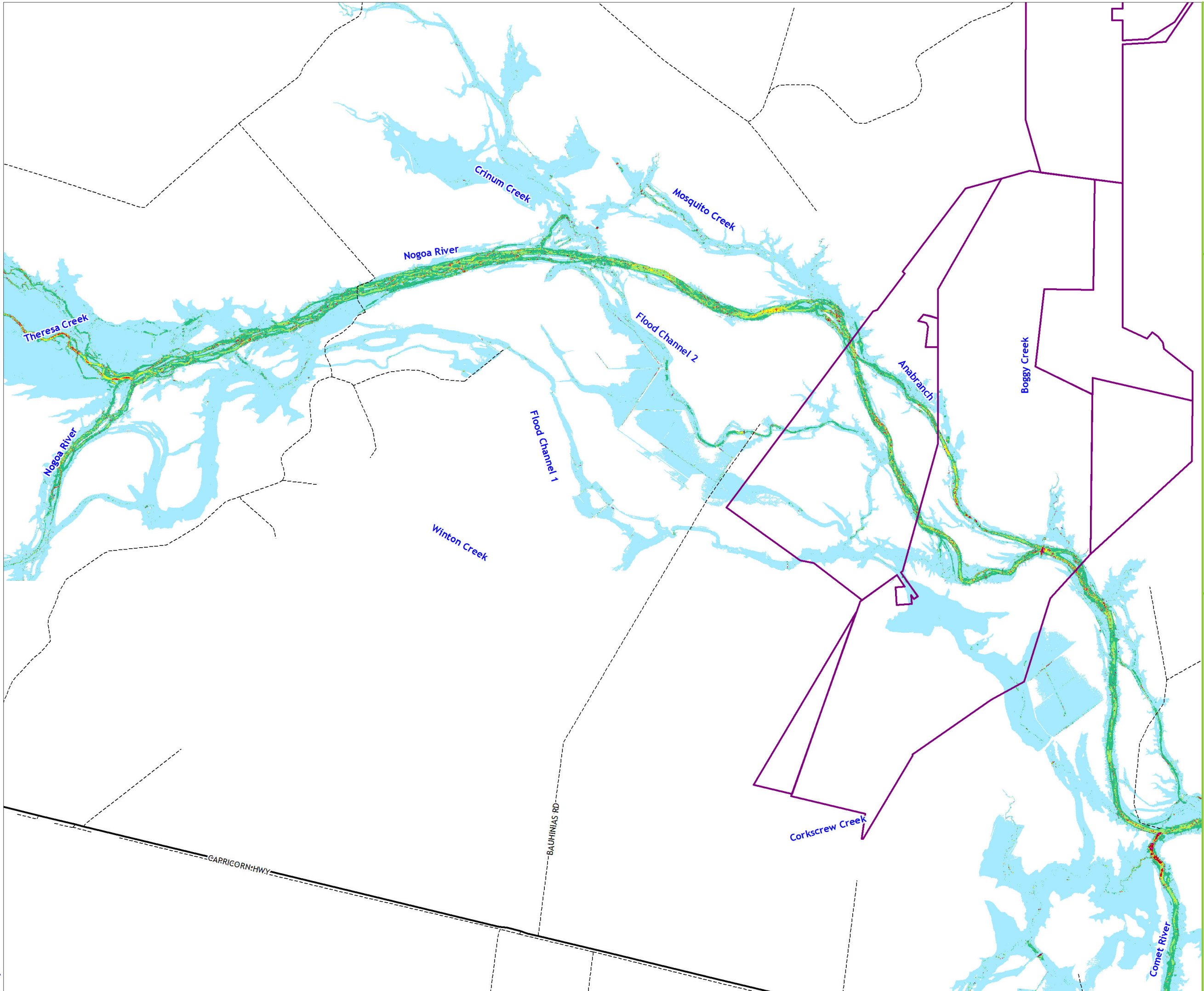


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Projection: MGA Zone 55 Datum: GDA 94



Legend

- Minor Road
- Major Road
- Mine lease boundary

Bed Shear Stress (N/m²)

0 - 20
20 - 40
40 - 60
60 - 80
80 - 100
100 - 150
150 - 200
>200

**ENSHAM RESIDUAL VOID STUDY
STAGE 3-GEOMORPHIC ASSESSMENT**

Figure A.22 -
Option 3 conditions peak bed shear stress, 10% AEP event

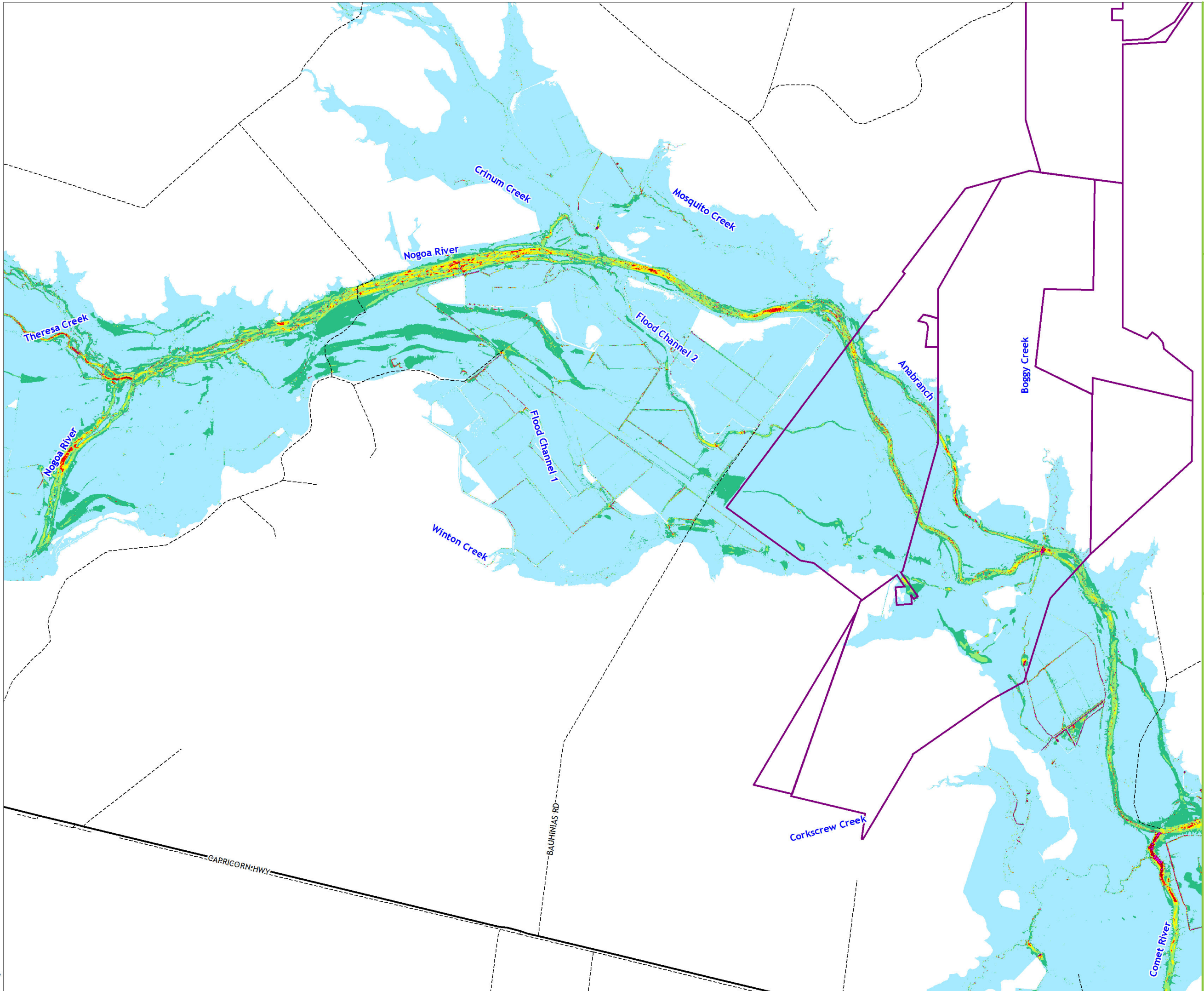


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RESOURCES



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Projection: MGA Zone 55 Datum: GDA 94

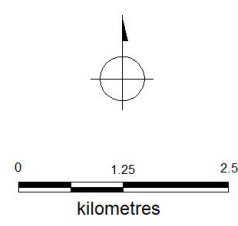


Legend

- Minor Road
- Major Road
- Mine lease boundary

Bed Shear Stress (N/m²)

0 - 20
20 - 40
40 - 60
60 - 80
80 - 100
100 - 150
150 - 200
>200



**ENSHAM RESIDUAL VOID STUDY
STAGE 3-GEOMORPHIC ASSESSMENT**

Figure A.23 -
Option 3 conditions peak bed shear stress, 1% AEP event

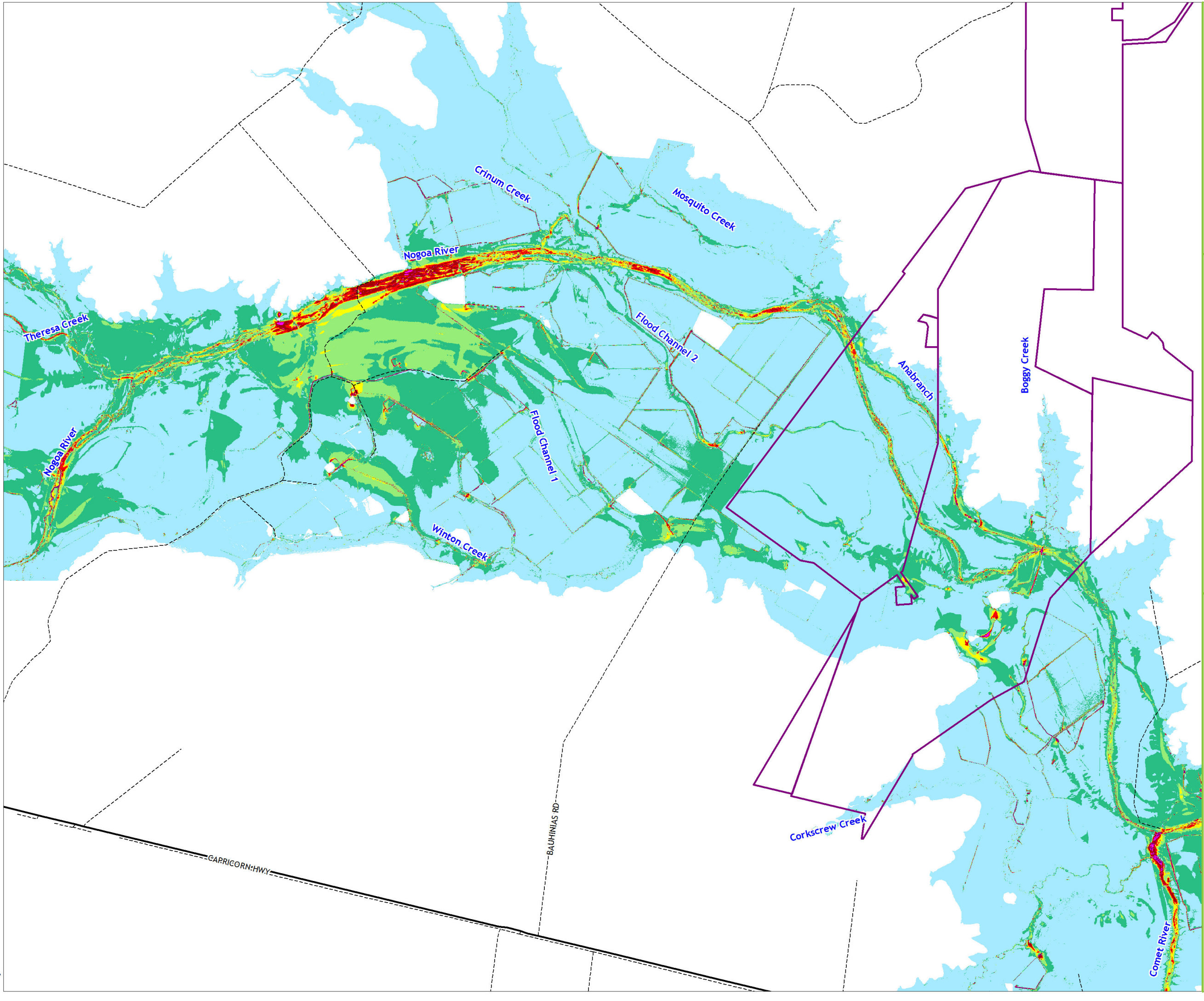


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Projection: MGA Zone 55 Datum: GDA 94

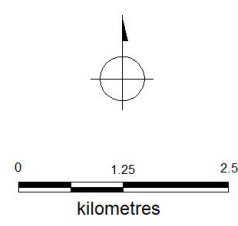


Legend

- Minor Road
- Major Road
- Mine lease boundary

Bed Shear Stress (N/m²)

0 - 20
20 - 40
40 - 60
60 - 80
80 - 100
100 - 150
150 - 200
>200



**ENSHAM RESIDUAL VOID STUDY
STAGE 3-GEOMORPHIC ASSESSMENT**

Figure A.24 -
Option 3 conditions peak bed shear stress, 0.1%x1.5 AEP event

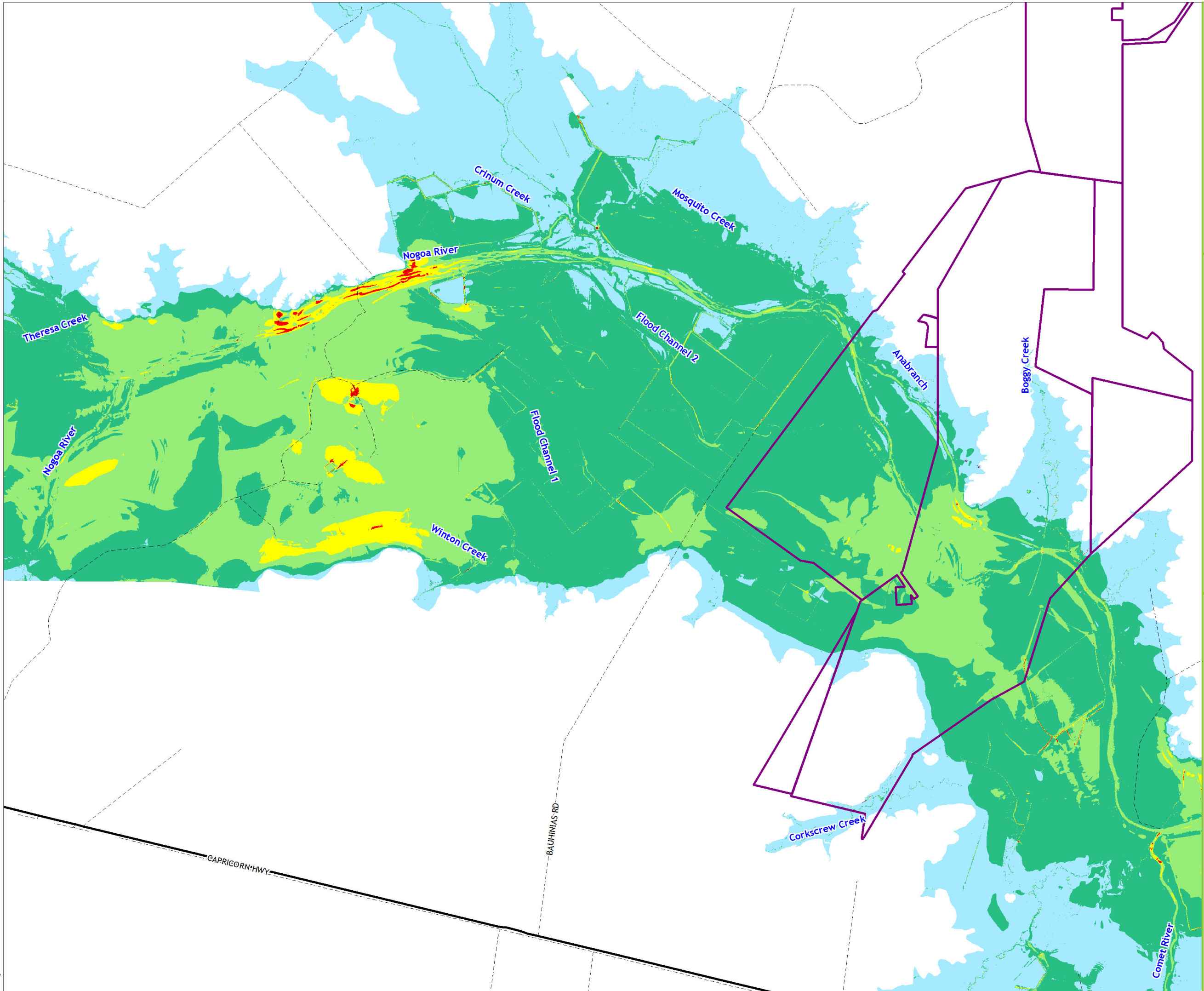


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Projection: MGA Zone 55 Datum: GDA 94



Legend

- Minor road
- Major road
- Mine lease boundary

Flood Velocity (m/s)

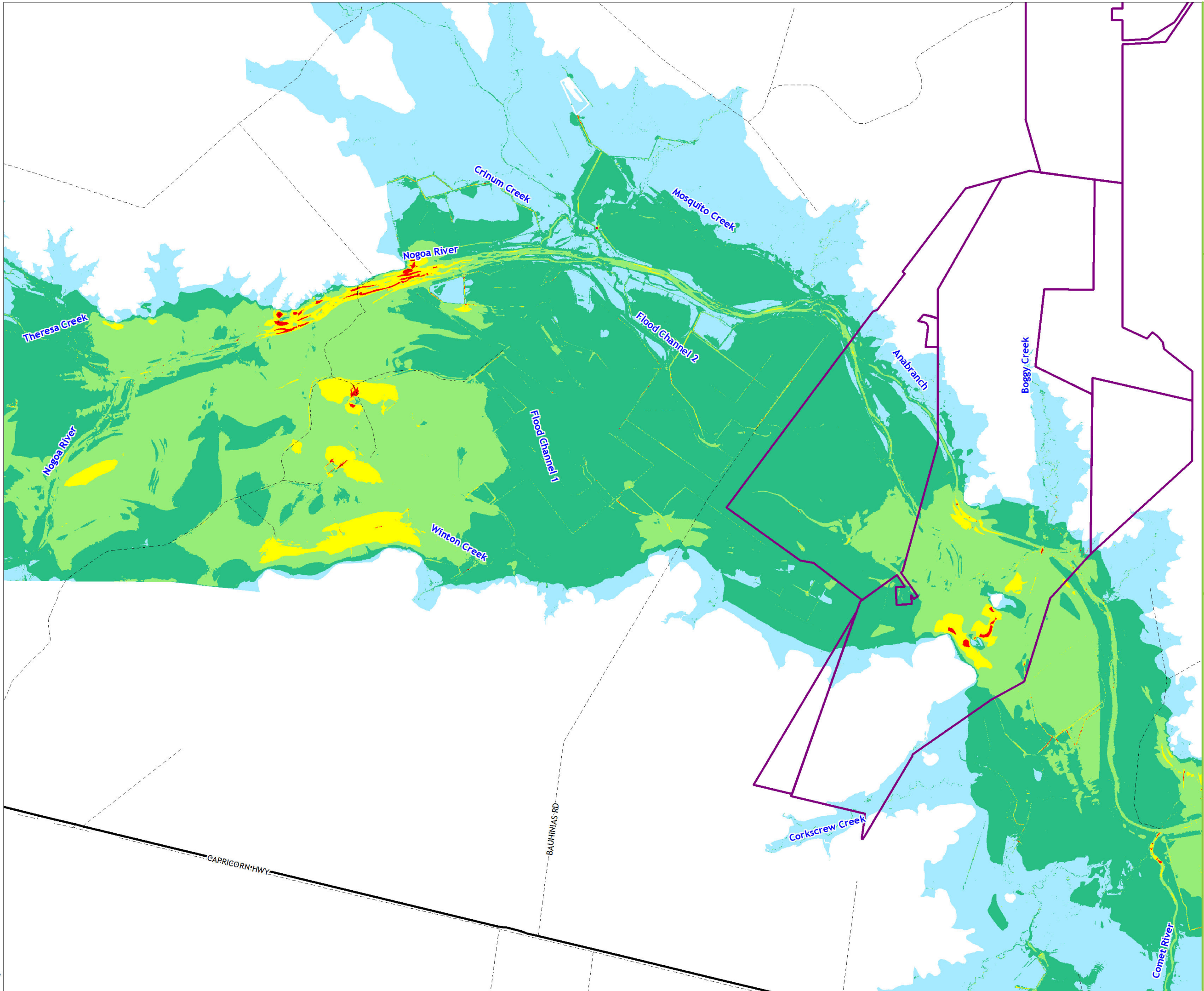
0.0m/s - 0.5m/s
0.5m/s - 1.0m/s
1.0m/s - 1.5m/s
1.5m/s - 2.0m/s
2.0m/s - 2.5m/s
2.5m/s - 3.0m/s
3.0m/s - 4.0m/s
>4.0m/s

**ENSHAM RESIDUAL VOID STUDY
STAGE 3-GEOMORPHIC ASSESSMENT**

Figure A.25 -
Pre-mine conditions peak flood
velocities, PMF



Projection: MGA Zone 55 Datum: GDA 94

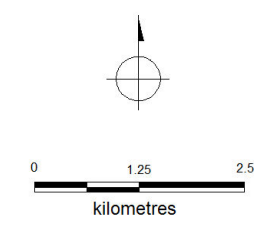


Legend

- Minor road
- Major road
- Mine lease boundary

Flood Velocity (m/s)

0.0m/s - 0.5m/s
0.5m/s - 1.0m/s
1.0m/s - 1.5m/s
1.5m/s - 2.0m/s
2.0m/s - 2.5m/s
2.5m/s - 3.0m/s
3.0m/s - 4.0m/s
>4.0m/s



**ENSHAM RESIDUAL VOID STUDY
STAGE 3-GEOMORPHIC ASSESSMENT**

Figure A.26 -
Option 3 conditions peak flood
velocities, PMF

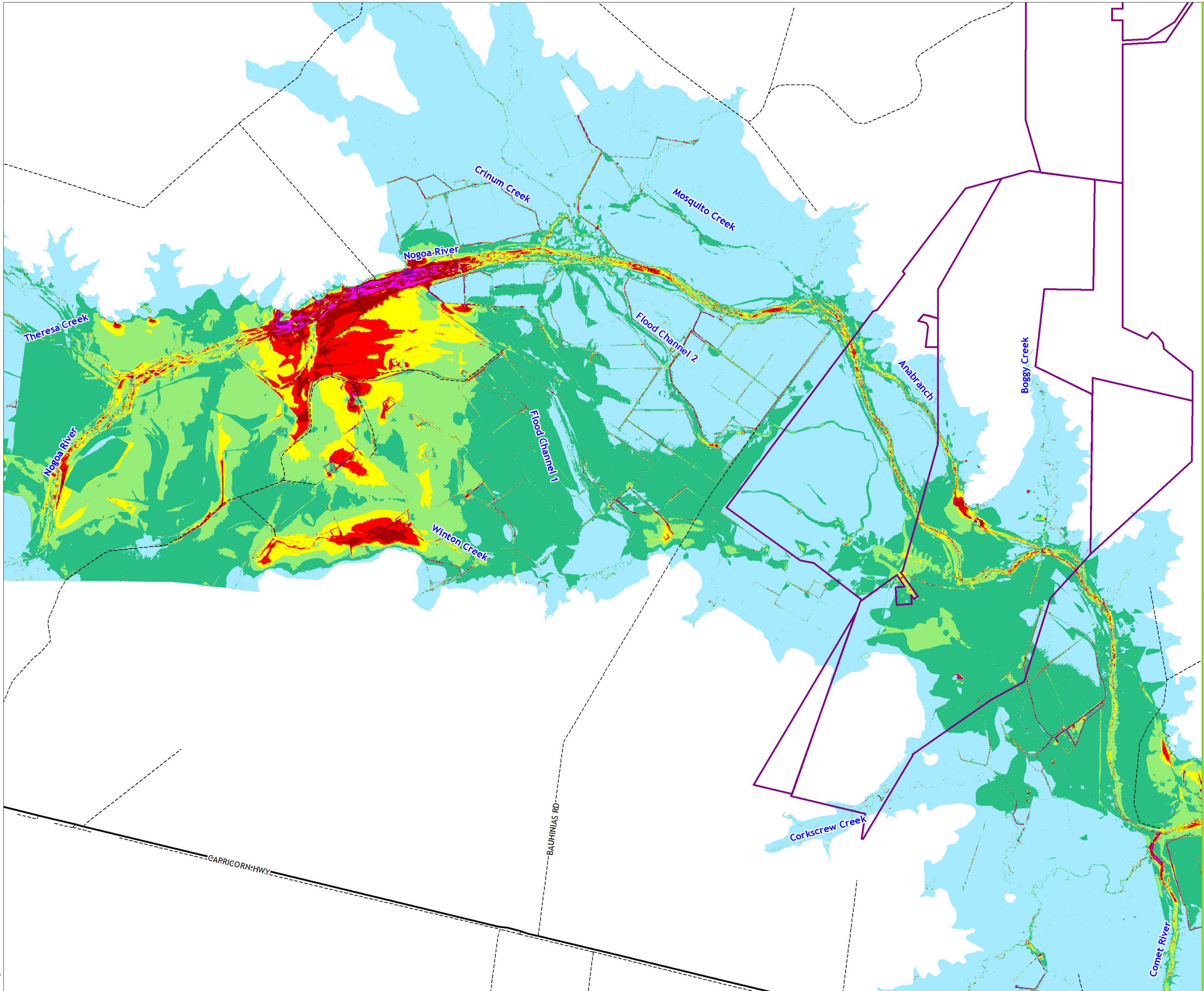


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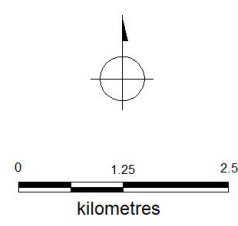
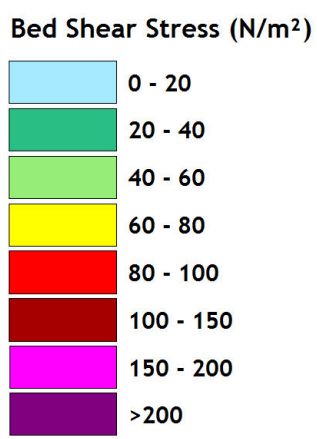


wrm
water+environment

Projection: MGA Zone 55 Datum: GDA 94



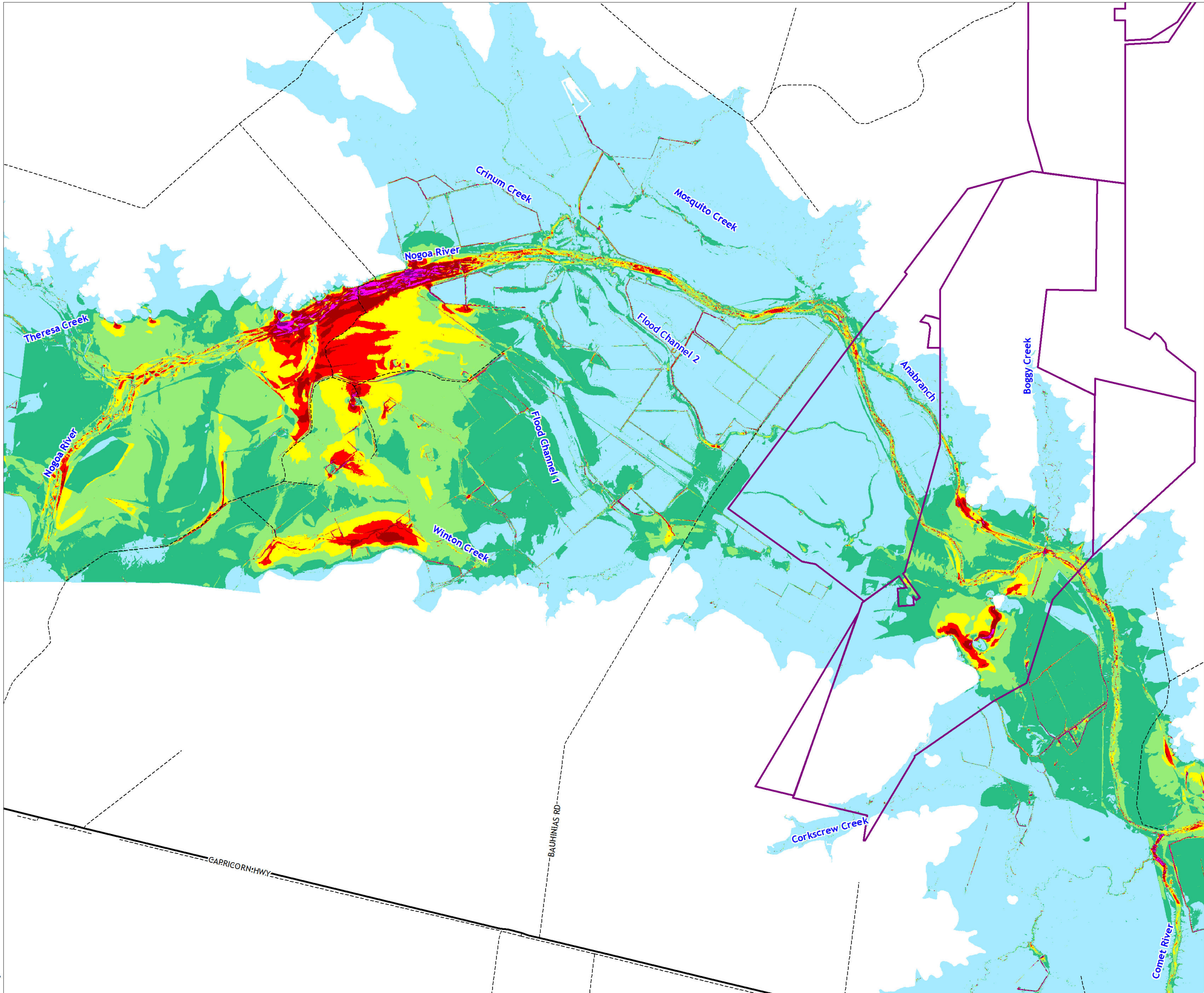
- Legend**
- Minor Road
 - Major Road
 - Mine lease boundary



**ENSHAM RESIDUAL VOID STUDY
STAGE 3-GEOMORPHIC ASSESSMENT**

Figure A.27 -
Pre-mine conditions peak bed shear
stress, PMF

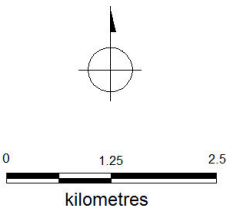




- Legend**
- Minor Road
 - Major Road
 - Mine lease boundary

Bed Shear Stress (N/m²)

- 0 - 20
- 20 - 40
- 40 - 60
- 60 - 80
- 80 - 100
- 100 - 150
- 150 - 200
- >200



**ENSHAM RESIDUAL VOID STUDY
STAGE 3-GEOMORPHIC ASSESSMENT**

Figure A.28 -
Option 3 conditions peak bed shear
stress, PMF

