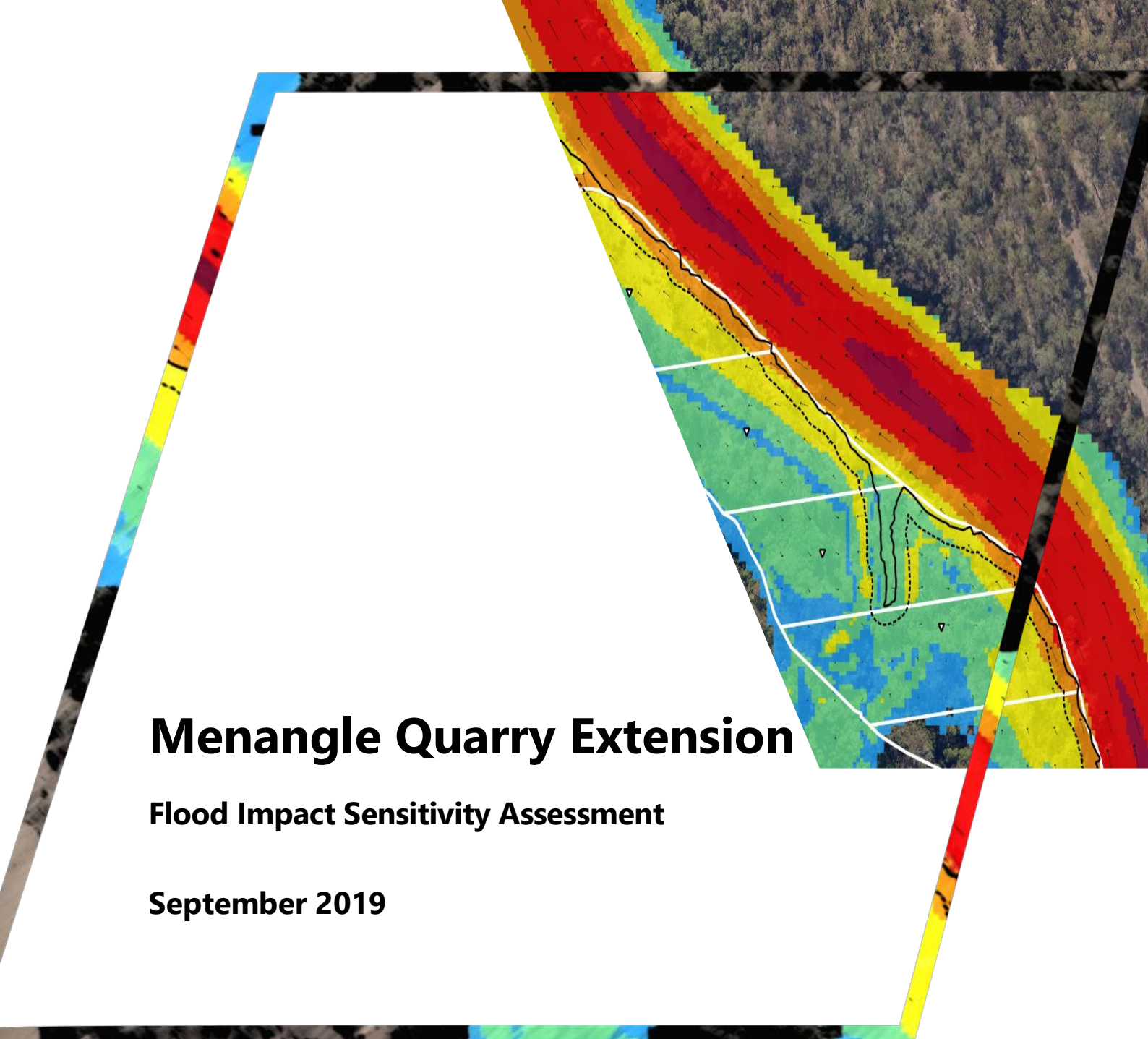


An aerial photograph of a quarry extension area, overlaid with a color-coded flood impact sensitivity map. The map uses a rainbow color scale from blue (low sensitivity) to red (high sensitivity). The quarry extension is outlined in white, and the surrounding area is colored in shades of blue, green, yellow, and red. The map is framed by a large, stylized 'A' shape.

# **Menangle Quarry Extension**

## **Flood Impact Sensitivity Assessment**

**September 2019**

Level 17, 141 Walker St  
North Sydney NSW 2060  
Australia

rp301015-04089lc\_crt190904-Menangle Quarry Extension FIA.docx

Revision A

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## Project: Menangle Quarry Extension – Stage 8 Flood Impact Sensitivity Assessment

| Rev | Description                               | Author              | Review              | Advisian Approval                                                                     | Date       |
|-----|-------------------------------------------|---------------------|---------------------|---------------------------------------------------------------------------------------|------------|
| 0   | Draft Report<br>Issue for Internal Review | LC<br>Leon Collins  | CRT<br>Chris Thomas |  | 04/09/2019 |
| A   | Final Report                              | CRT<br>Chris Thomas | LC<br>Leon Collins  | Chris Thomas                                                                          | 13/09/2019 |
|     |                                           |                     |                     |                                                                                       |            |

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# 1 Introduction

---

Menangle Sand & Soil Pty Ltd (MSS) currently operates the Menangle Sand and Soil Quarry located at 15 Menangle Road, Menangle. The quarry is located on the banks of the Nepean River within the Wollondilly Shire local government area. Sand and gravel extraction has occurred over decades with product extracted from specific areas of the floodplain as part of approved stages. Stages 1 to 6 have either already been rehabilitated or were never mined. Current operations at the quarry are ongoing within Stage 7.

Benedict Industries plans to extend the quarry upstream of the existing operations. The extension, known as Stage 8, is situated on the western bank of the Nepean River extending about 2.8 km upstream from the Hume Motorway crossing. The location of the proposed works is shown in **Figure 1-1**.

Stage 8 is proposed to be divided into thirteen (13) one-hectare sub-stages (refer **Figure 1-1**). The quarry will continually progress upstream from Sub-stage A to Sub-stage M. It is estimated that extraction of sand and soil from each sub-stage will take one year to complete. Within each substage, the area upstream of the advancing quarry face will be undisturbed. The active extraction area will move progressively upstream and will be about 33% of the substage; that is, about 0.33 ha.

Once extraction in each part of the sub-stage is complete, the area will be progressively rehabilitated. Therefore, when sand is being extracted from a sub-stage, about 33% of the sub-stage will be bare sand and soil and about 66% will be a combination of existing vegetation and the area being rehabilitated.

The pit is proposed to be set back at least 10 m from the 64 m Australian Height Datum (AHD) height contour. The existing river bank below the 64 m AHD contour will be left intact. Where there are no trees in the set back area, the sand and soil above the 64 m AHD contour will be removed and the area will be graded to 1(V):50(H) sloping towards the pit. Where there are trees in the set back area, the existing bank will be left in situ for at least 7.5 m inland from the base of the tree (*measured horizontally*). Therefore, the bank will be a mixture of graded and ungraded areas of varying height.

The vegetation community in parcels of land adjacent to Stage 8 extraction area will be restored through weed removal and vegetation management.

As the works will be in close proximity to the Nepean River, there is potential for the proposed operations to have an impact on flood flow velocities in the vicinity of the site. There is also potential for erosion of rehabilitated areas depending on the timing of a future flood relative to the date of rehabilitation of particular sub-stages. Therefore, there is a need to assess the potential impact of the proposed extension on flood characteristics related to bank stability.

In May 2018, Advisian undertook investigations including flood modelling to assess flood conditions in the vicinity of the proposed extension to the quarry. The investigations focussed on the 2.8 km extension of the quarry upstream from the Hume Motorway and involved the modelling of mid-works conditions to determine the impact of extraction operations on flood flow velocities and the associated potential for any impact on bed scour and bank stability. The findings are documented in a report titled, '*Menangle Quarry Extension – Flood Impact Assessment*' (May 2018), which was issued to the NSW Department of Planning following submission of the Environmental Impact Statement (EIS) for the Stage 8 Extension.

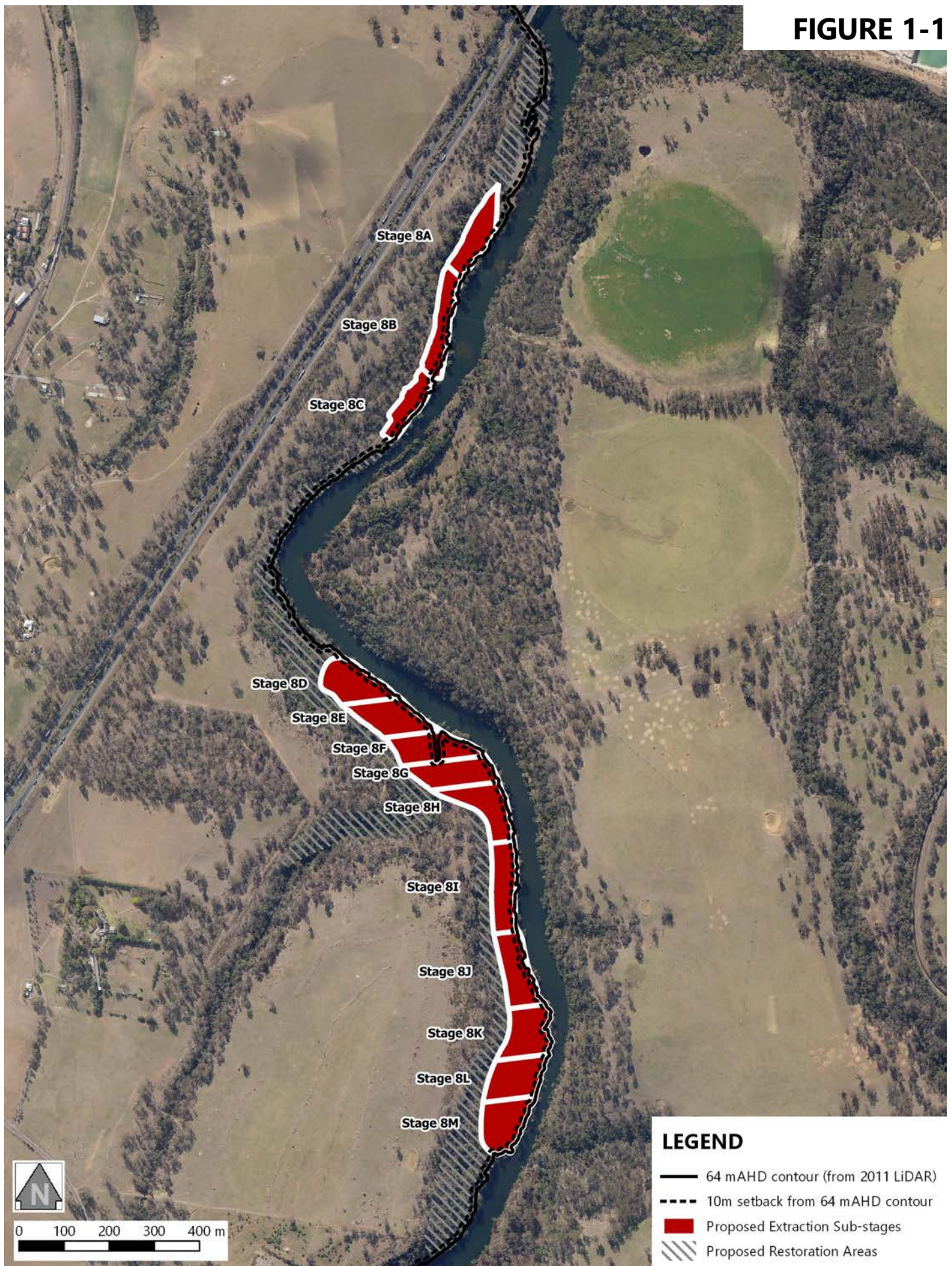
Following review of the EIS and further information provided by MSS, the quarry extension application was refused by the Department of Planning & Environment on 25<sup>th</sup> October 2018. MSS appealed this decision in the NSW Land & Environment Court and a Section 34 (s34) conference was convened for 14<sup>th</sup> June 2019.

During the s34 conference, experts acting on behalf of the Department provided comment on the Flood Impact Assessment. The comments included a request for additional sensitivity testing aimed at resolving issues in contention. It was argued that the Applicant should attend to these requests to allow the Department to fully assess the environmental impact of the proposal.

This report documents the findings from the additional flood related investigations that have been completed to address the issues in contention. It includes the results of additional sensitivity analysis to assess a range of scenarios identified by the Department, and documents predicted changes in flood flow velocities and bed shear stress as a consequence of the works.



**FIGURE 1-1**



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**PROPOSED STAGE 8 WORKS**



## 2 Hydraulic Modelling Approach

### 2.1 Previous Investigations

#### 2.1.1 Nepean River Flood Study (2015)

The extent of flooding along the Nepean River has been previously investigated in detail as part of the '*Nepean River Flood Study*' (2015) which was completed by WorleyParsons for Camden Council. As part of the study WorleyParsons developed a two-dimensional (2D) flood model for the Nepean River floodplain within the Camden Local Government Area (LGA). The Flood Study describes the flood characteristics of the river system for existing topographic and development conditions at the time of the study.

The hydraulic flood model was developed from hydrographic survey data (*river cross-sections*) and detailed topographic data. It covers a 45 km stretch of the Nepean River, extending from approximately the Hume Motorway at the upstream extent to the confluence of the Nepean River and the Warragamba River at the downstream extent. The TUFLOW software was used, in which the terrain surface and creek bathymetry is represented by a regular grid of square elements. Flow inputs to the TUFLOW model were determined using the XP-RAFTS hydrologic software.

The computer models were used to simulate a range of historical and design floods such as the 1% Annual Exceedance Probability (AEP) flood. The results from the modelling were used to define flood characteristics along the Nepean River and the lower reaches of its tributaries in the Camden LGA, and specifically to establish peak flood levels, flow velocities and flood hazard.

#### 2.1.2 Menangle Quarry Extension Flood Impact Assessment (May 2018)

In May 2018, Advisian modified and refined the TUFLOW model that was developed for the *Nepean River Flood Study* and used the modified model to assess flood conditions in the vicinity of the proposed Menangle Quarry Stage 8 Extension – that is, along the Nepean River from the Hume Motorway to a distance of about 3.4 km upstream.

Modification of the existing TUFLOW model involved the following:

- The upstream boundary was extended to a location approximately 5.2 km upstream of the Hume Motorway, thereby covering a distance of about 1.8 km beyond the full extent of the Stage 8 operations. River bed levels upstream of the Hume Motorway were based on a 1985 bathymetric survey as presented in Figure 5 of *Menangle Quarry Modification to Development Consent 85/2865 - Review of Fluvial Geomorphology (Fluvial Systems, 2018)*.
- The design flood hydrographs that were applied as inflows to the original TUFLOW model at the Hume Highway were instead applied at the new upstream boundary of the extended model.
- The downstream extent of the original TUFLOW model was truncated such that the downstream boundary is located about 50 m upstream of Argyle Street, Camden (*about 12.4 km downstream of the Hume Motorway*). A static water level boundary condition was applied at this location to ensure model stability.
- The TUFLOW model grid size was refined from 8 m to 5 m in order to properly resolve topographic changes to the areas where expansion of the quarry works is proposed.

To check that the modified TUFLOW model reliably represents flood behaviour near the site and in downstream areas, the model results were verified against those generated by the original 2015 Flood Study TUFLOW model. While small differences were observed between the modified TUFLOW model results and the original 2015 Flood Study results in areas downstream of the Hume Motorway (*i.e., generally less than +/- 0.10 m in the 1% AEP flood*), the primary area of interest to this study lies upstream of the Hume Motorway where no previous model results were available for comparison. Results from the modified TUFLOW model were considered to provide a suitable basis for assessing expected local flood behaviour under “existing condition” and “mid-works condition” scenarios and undertaking a direct like-for-like comparison.

## 2.2 Updated Hydraulic Modelling

The current flood assessment adopted the modified TUFLOW model described in **Section 2.1.2** of this report as its basis. Some additional minor modifications were made as described in the following.

- The “TUFLOW Heavily Parallelised Compute (HPC)” GPU based software was adopted in place of the previously used “TUFLOW Classic” CPU based software
  - TUFLOW HPC was adopted to enable simulation of the multiple flood events and extraction scenarios in a more practical timeframe, with total model run time approximately halved as a result
  - While TUFLOW HPC uses the same model schematisation as TUFLOW Classic, a different solution scheme is used and results therefore differ slightly.
- Representation of the Southern Highlands Railway Bridge and Menangle Road Bridge were updated from ‘flow constrictions’ to ‘layered flow constrictions’
  - The ‘flow constriction’ approach used to represent these bridges in the original TUFLOW model is out-dated and is not supported by the new TUFLOW HPC software. This is a simplified approach whereby Manning’s roughness is increased at the bridge location once water levels reach the bridge deck soffit.
  - The ‘layered flow constriction’ approach adopted applies blockages and energy losses for up to three layers that can be used to represent the hydraulic effects of the bridge piers, bridge deck and handrails respectively. Energy losses (*or more specifically ‘form loss coefficients’*) are determined from bridge geometry using methods described in *Waterway Design (AustRoads, 1994)*. This provides a more realistic hydraulic representation of the two bridges.
- The change to the TUFLOW HPC software and associated update of model bridge representation resulted in minor changes in peak flood level results in comparison to the previous study
  - TUFLOW HPC peak flood level results in the vicinity of the proposed quarry works for the 1% AEP design event were found to be between 0.05 and 0.15 m lower than those determined in the previous study.

It is noted that no calibrated model results are available for comparison in the primary area of interest to this study which lies upstream of the Hume Motorway. However, it is considered that the updated TUFLOW HPC model continues to provide a suitable basis for assessing expected local flood behaviour under “existing condition” and “mid-works condition” scenarios and undertaking a direct like-for-like comparison.

The updated TUFLOW HPC model has been used in this study to establish “existing condition” flood behaviour in the location of the proposed quarry extension, and to assess expected flood conditions under a number of potential “mid-works condition” scenarios (*refer Section 3*).

Flood events investigated include the 50%, 5% and 1% Annual Exceedance Probability (AEP) events, and historic floods which occurred in March 1978 and August 1990. Flow hydrographs for each of these floods were taken from the ‘*Nepean River Flood Study*’ (WorleyParsons, 2015) as determined using the associated XP-RAFS hydrologic model.

## 3 Extraction Scenarios

### 3.1 General

In its letter dated 19<sup>th</sup> June 2019, the Department of Planning listed a range of additional investigations and analyses that it required to allow the environmental impacts of the Stage 8 works to be fully assessed. Item 2 of that list involves additional sensitivity analysis using the flood model to assess the impacts of flooding on the mid-works condition recognising the likely schedule for extraction.

The Department requested that modelling be undertaken on the basis of the following status of the various sub-stages:

- Sub-stages A to F modelled as 'extracted' based on the proposed post-extraction topography;
- Sub-stage G modelled as if in 'active' operation; and,
- all other sub-stages modelled as untouched.

This represents 50% of extraction over the 13 sub-stages; ie., six extracted, one active and six intact.

### 3.2 Mid-Works Extraction Scenario

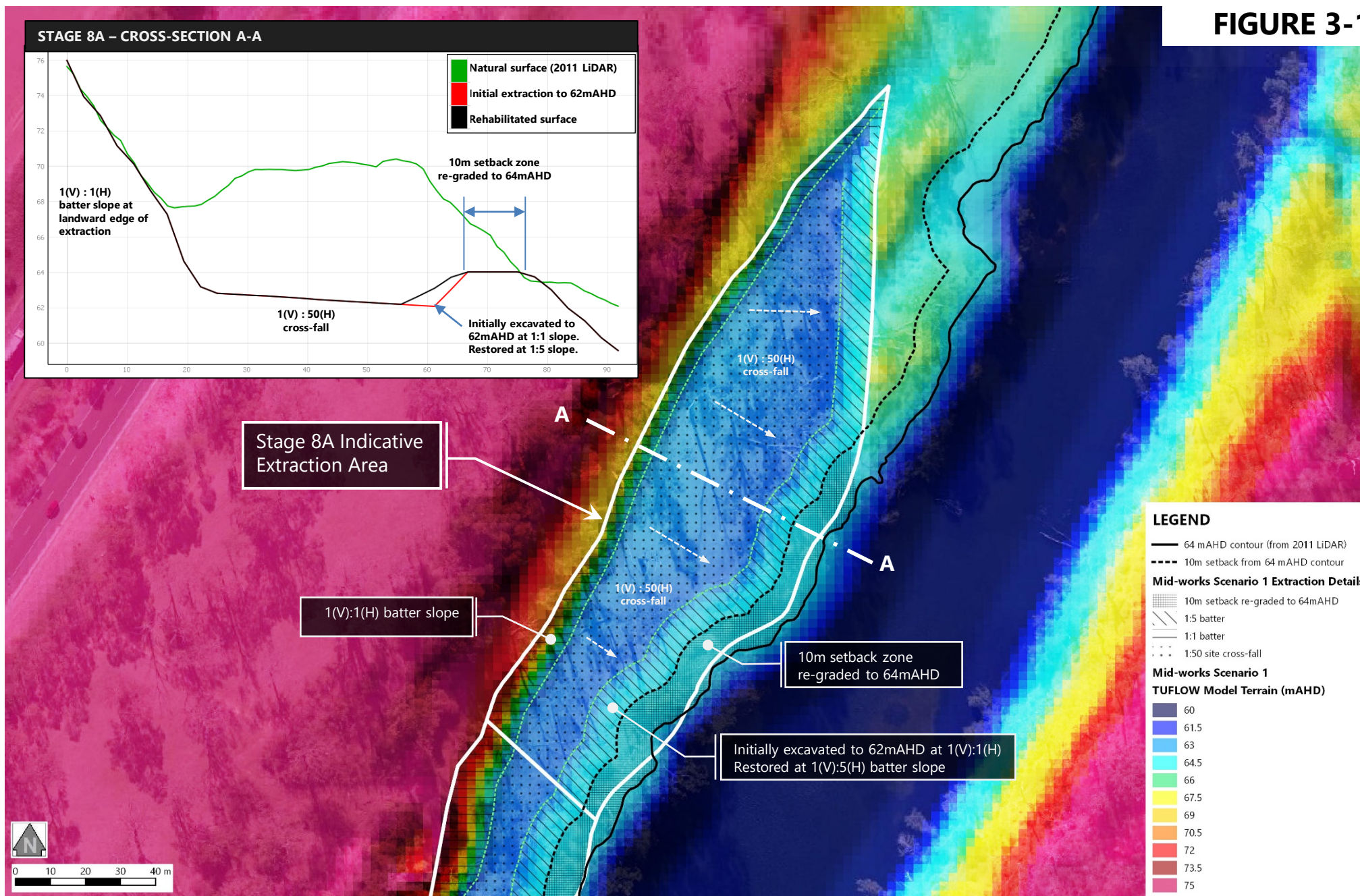
The adopted configuration of the model extraction area for assessment of the Mid-Works extraction condition (Scenario 1) is as follows:

- Stages 8A to 8F fully extracted.
- Stage 8G assumed to be 50% extracted with extraction assumed to progress from downstream to upstream.
- A 1(V):1(H) batter slope down from natural surface at landward edge of the extraction area.
- Minimum grade of 1(V):50(H) (i.e., 2%) toward the river across the base of the excavation area.
- Re-grading of the 10 metre wide river bank setback area to a minimum elevation of 64 mAHD. It is noted that this has been assumed for the purpose of modelling, but that re-grading would not occur along sections of the set back where there are trees.
- Initial excavation at 1(V):1(H) batter slope down from edge of setback area to maximum extraction depth of 62 mAHD, noting that:
  - this batter slope will be less than 30 metres long and will be restored to a finished graded of 1(V):5(H); and,
  - Stage 8G is modelled as 'active' with the initial 1(V):1(H) batter slope still in place.

The resulting TUFLOW "mid-works" scenario model terrain for Stages 8A to 8G are presented in **Figure 3-1 to Figure 3-7**. The plans show the extent of extraction within each sub-stage based on the extraction criteria listed above and LiDAR gathered in 2011. The alignment of the 64 mAHD contour (*based in interpretation of the LiDAR data*) and the alignment of the 10 m setback are superimposed. A cross-section profile is also provided on each figure which shows the typical profiles for the existing natural surface, the initial extraction to 62 mAHD and the rehabilitated surface.



**FIGURE 3-1**



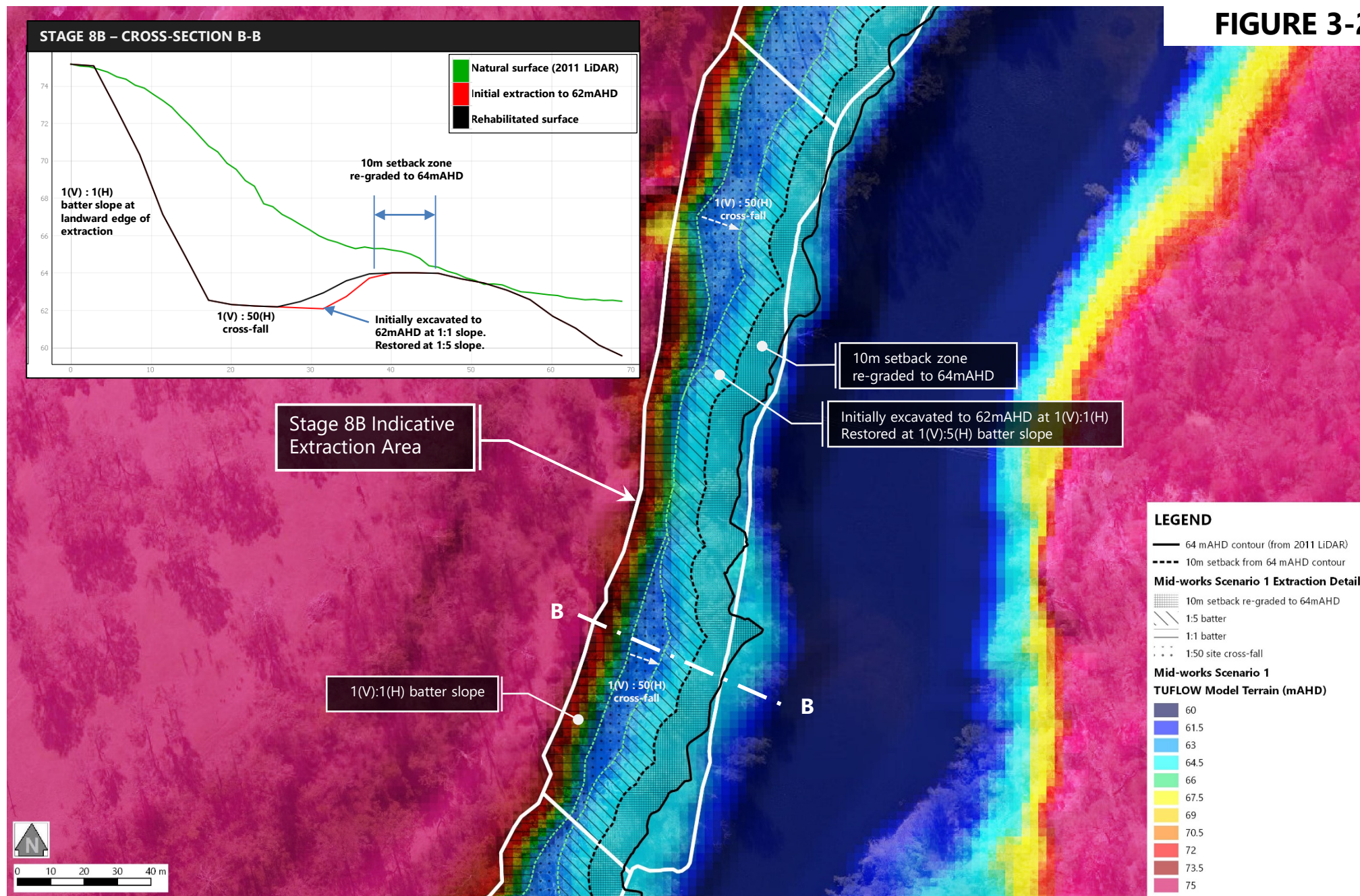
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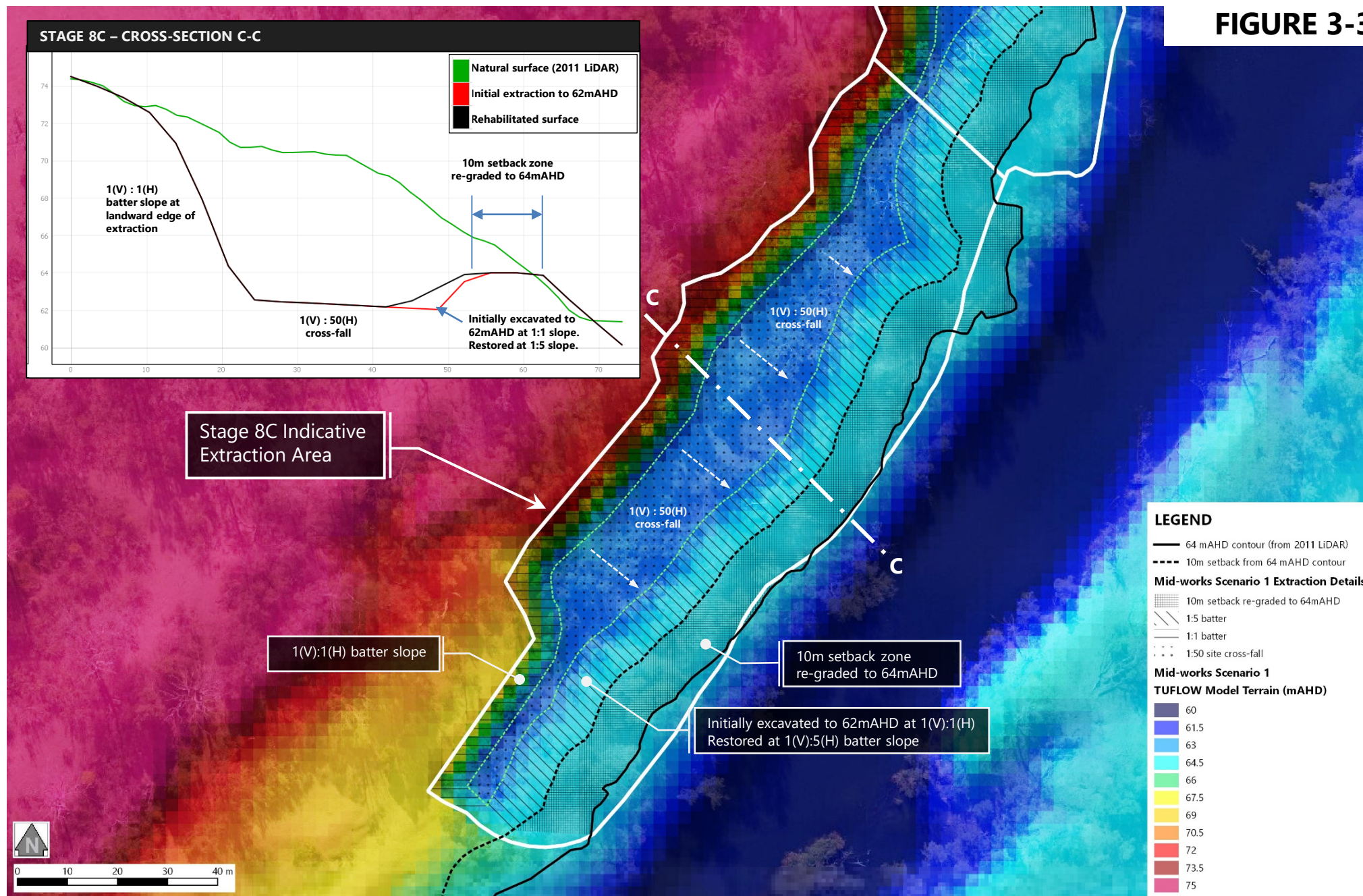
## MID-WORKS SCENARIO 1 TUFLOW TERRAIN STAGE 8A







**FIGURE 3-3**



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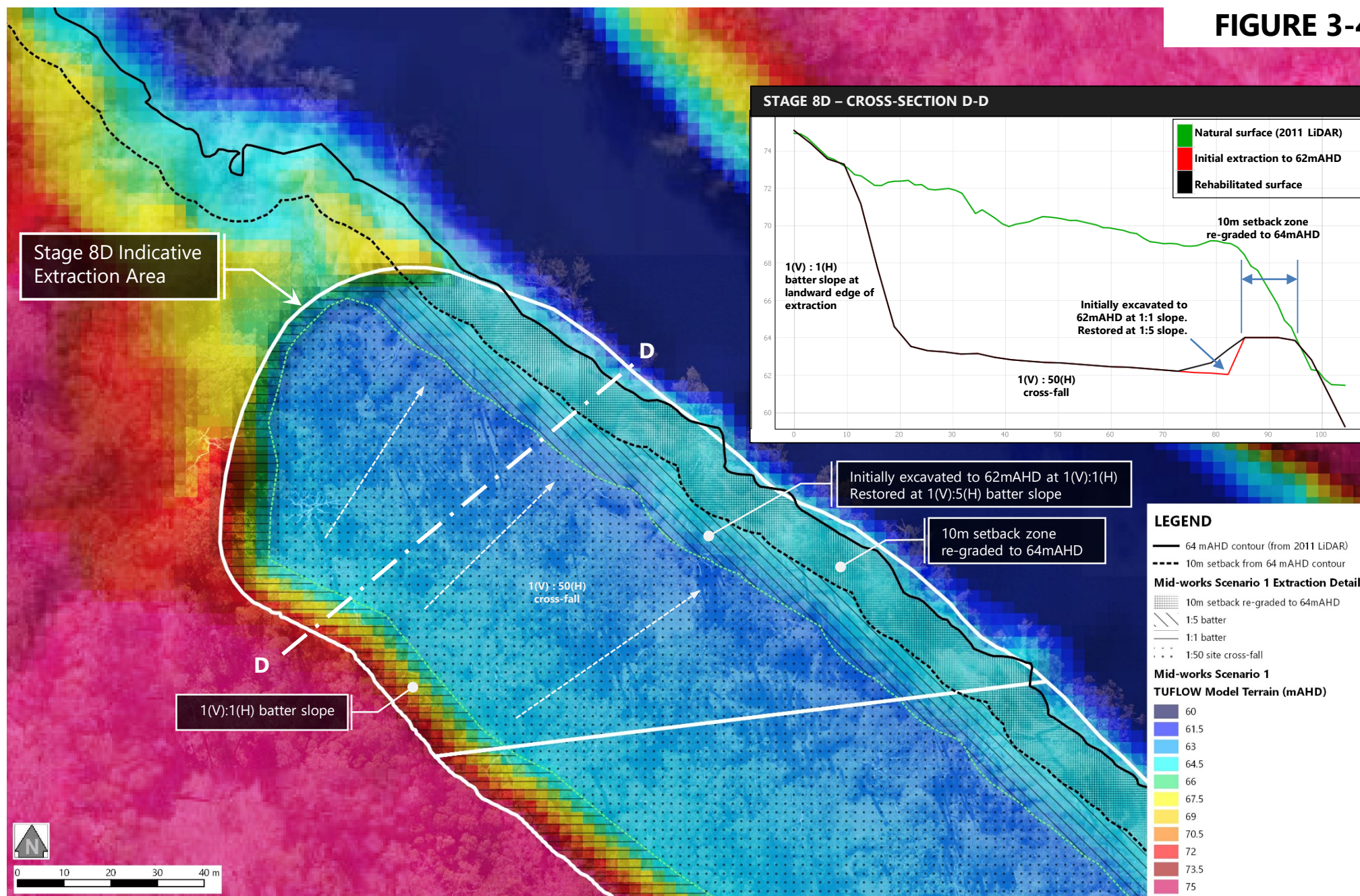
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## MID-WORKS SCENARIO 1 TUFLOW TERRAIN STAGE 8C



**FIGURE 3-4**



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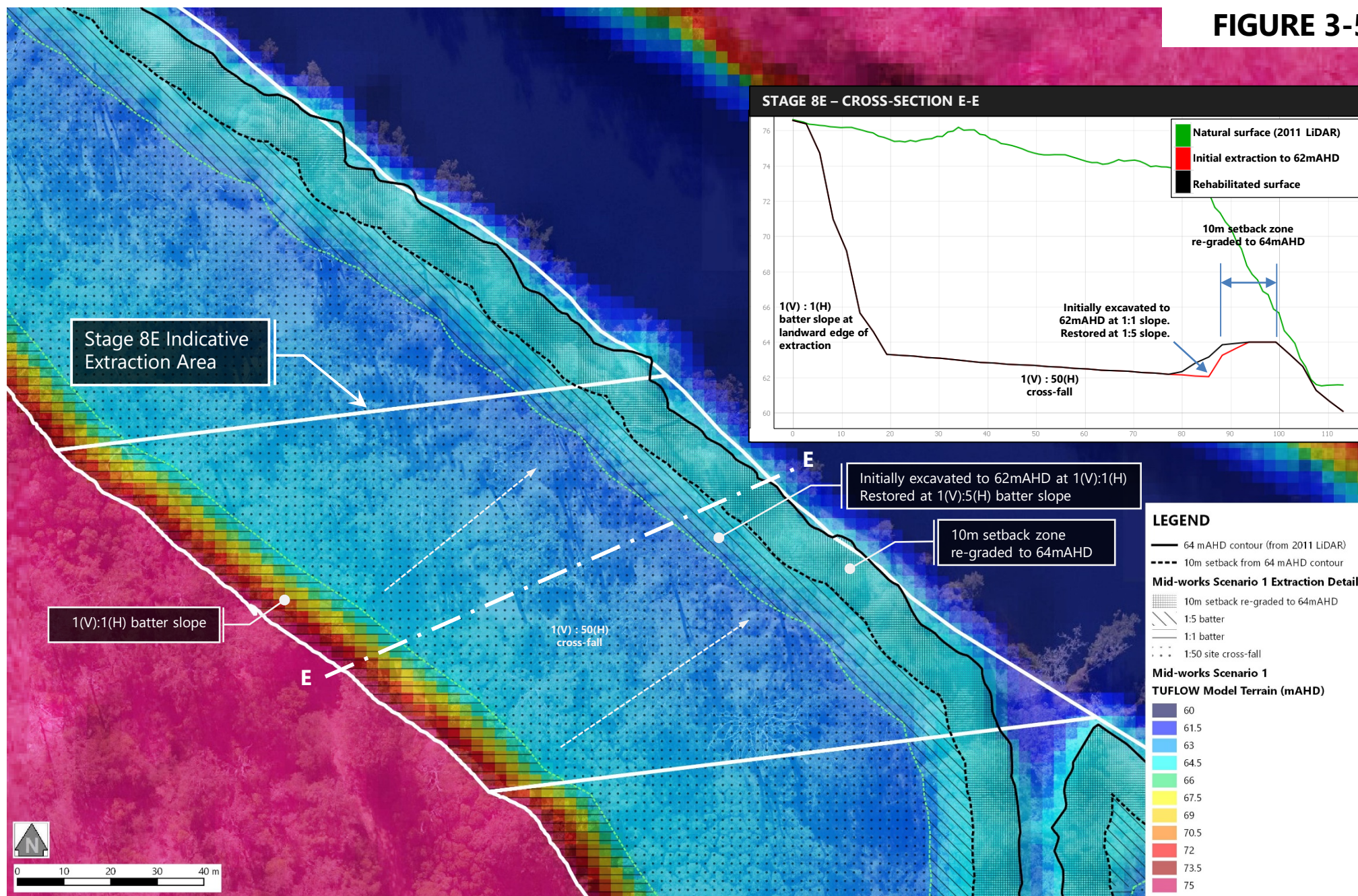
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## MID-WORKS SCENARIO 1 TUFLOW TERRAIN STAGE 8D



**FIGURE 3-5**



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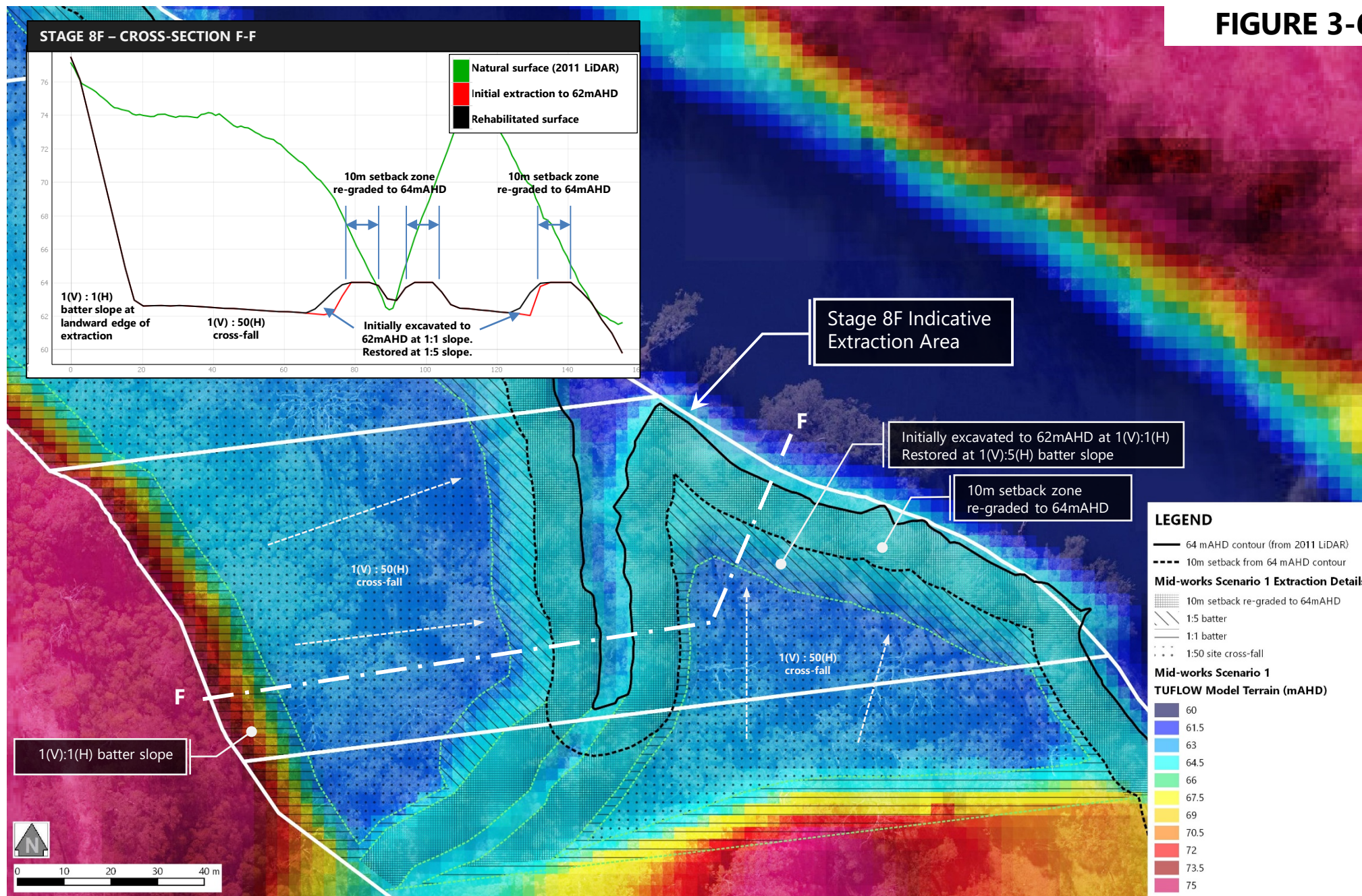
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## MID-WORKS SCENARIO 1 TUFLOW TERRAIN STAGE 8E



**FIGURE 3-6**



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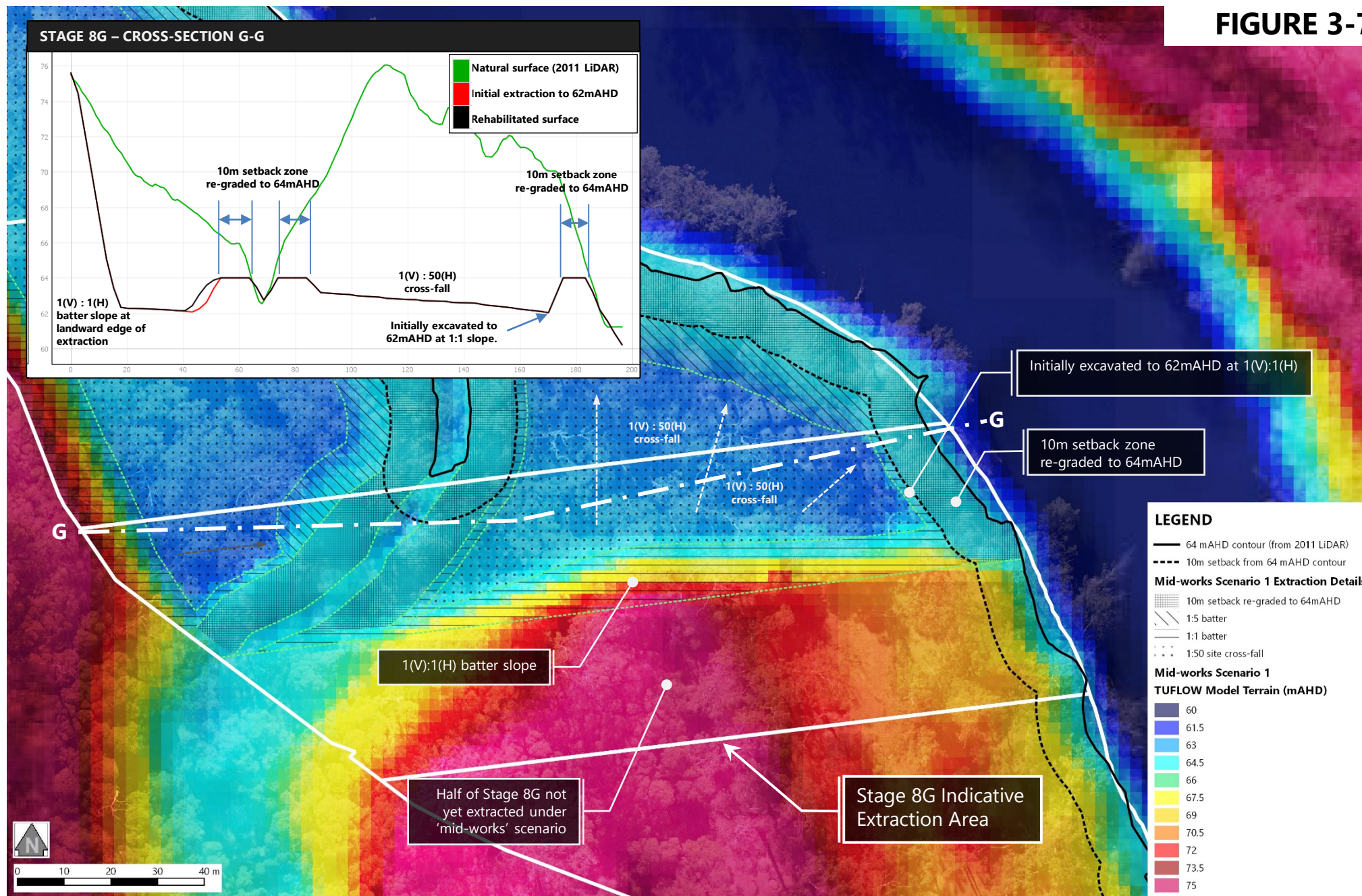
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## MID-WORKS SCENARIO 1 TUFLOW TERRAIN STAGE 8F



**FIGURE 3-7**



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## MID-WORKS SCENARIO 1 TUFLOW TERRAIN STAGE 8G



A sensitivity analysis was undertaken based on modelling the two floodplain roughness scenarios identified by the Department of Planning in its letter dated 19<sup>th</sup> June 2019. These hydraulic roughness scenarios are as follows.

**Hydraulic Roughness Scenario A** – “Rougher” rehabilitated and active areas

- Manning’s ‘n’ for rehabilitated areas = 0.08  
*This is considered to be representative of full re-growth of vegetation across the rehabilitated extraction areas*
- Manning’s ‘n’ for active areas (Stage 8G) = 0.06

**Hydraulic Roughness Scenario B** – “Less rough” rehabilitated and active areas

- Manning’s ‘n’ for rehabilitated areas = 0.05  
*This is considered to be representative of limited re-growth of vegetation across the rehabilitated extraction area*
- Manning’s ‘n’ for active areas (Stage 8G) = 0.03

Scenario A can be considered to be the ideal scenario where vegetation regrowth has occurred according to schedule to deliver the desired vegetation density as soon as possible after rehabilitation of the extraction areas. Scenario B might be considered to correspond to a circumstance where flooding of the overbank areas occurs relatively soon after rehabilitation; ie., typically within the first year after rehabilitation.

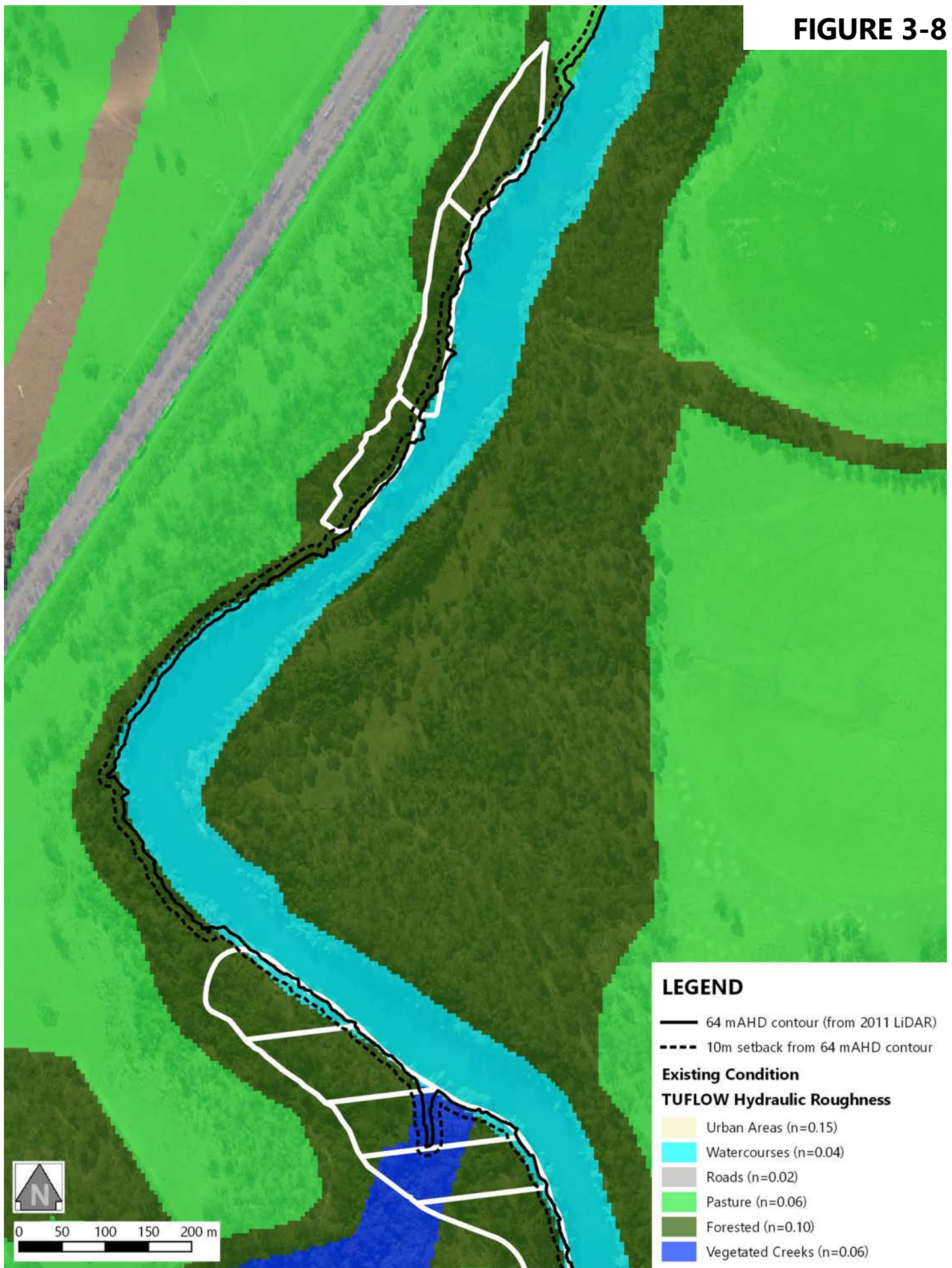
The TUFLOW hydraulic roughness delineation for the existing condition, mid-works hydraulic roughness Scenario A and mid-works hydraulic roughness Scenario B are presented in **Figure 3-8** to **Figure 3-10**, respectively.

### 3.3 Modelled Scenarios

Separate versions of the TUFLOW model were developed for each of Scenarios 1A and 1B and the models were applied to simulate the design 50%, 5% and 1% AEP floods and the March 1978 and August 1990 floods. The results were interrogated and used to plot:

- predicted peak velocity distributions under Scenarios 1A and 1B;
- predicted peak bed shear stress distributions under Scenarios 1A and 1B; and,
- time series velocity distributions at the centroid for each sub-stage for the 50%, 5% and 1% AEP floods and the March 1978 and August 1990 floods for both Scenarios 1A and 1B.

**FIGURE 3-8**



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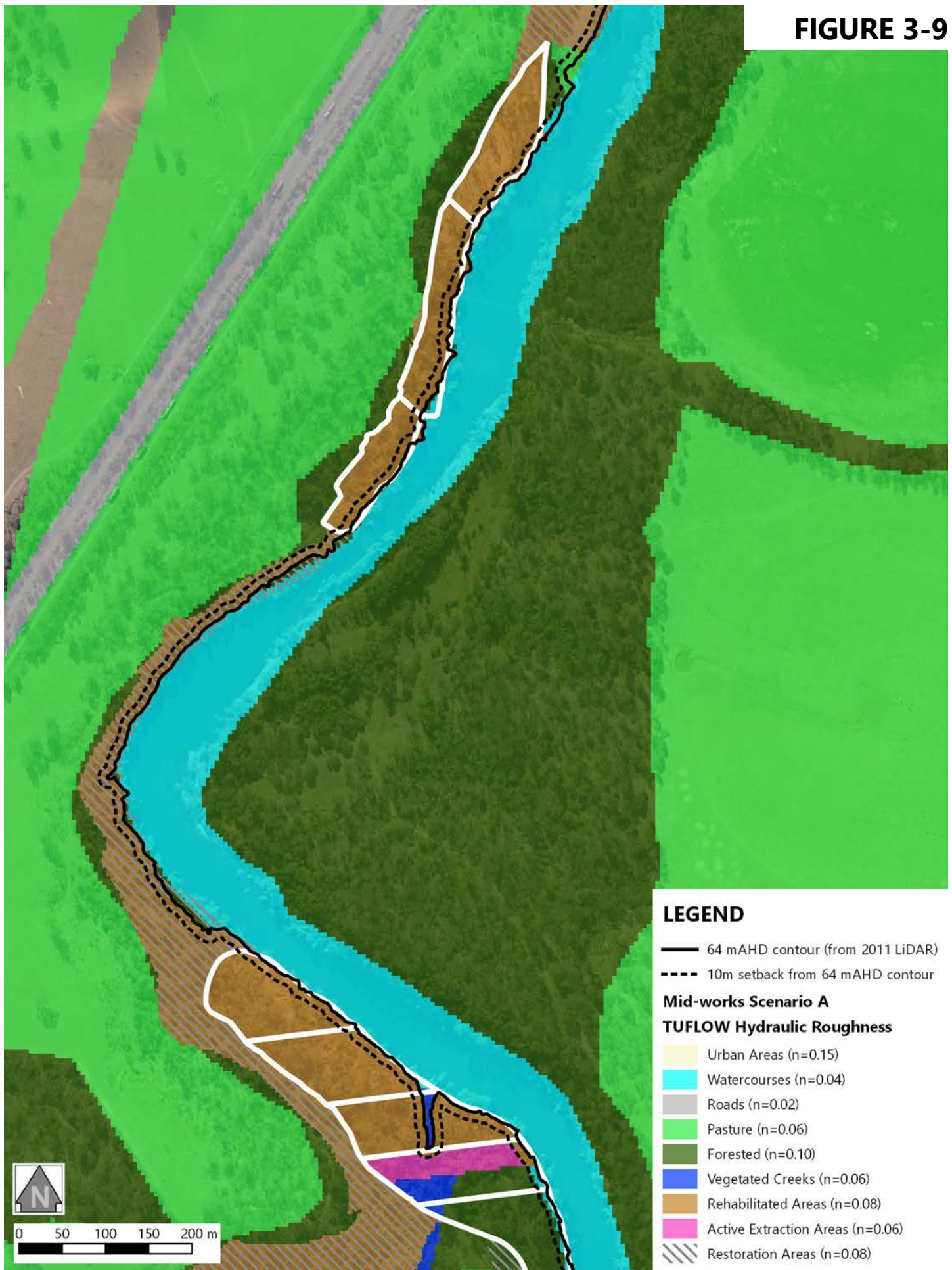
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## TUFLOW HYDRAULIC ROUGHNESS DELINEATION EXISTING CONDITION



**FIGURE 3-9**



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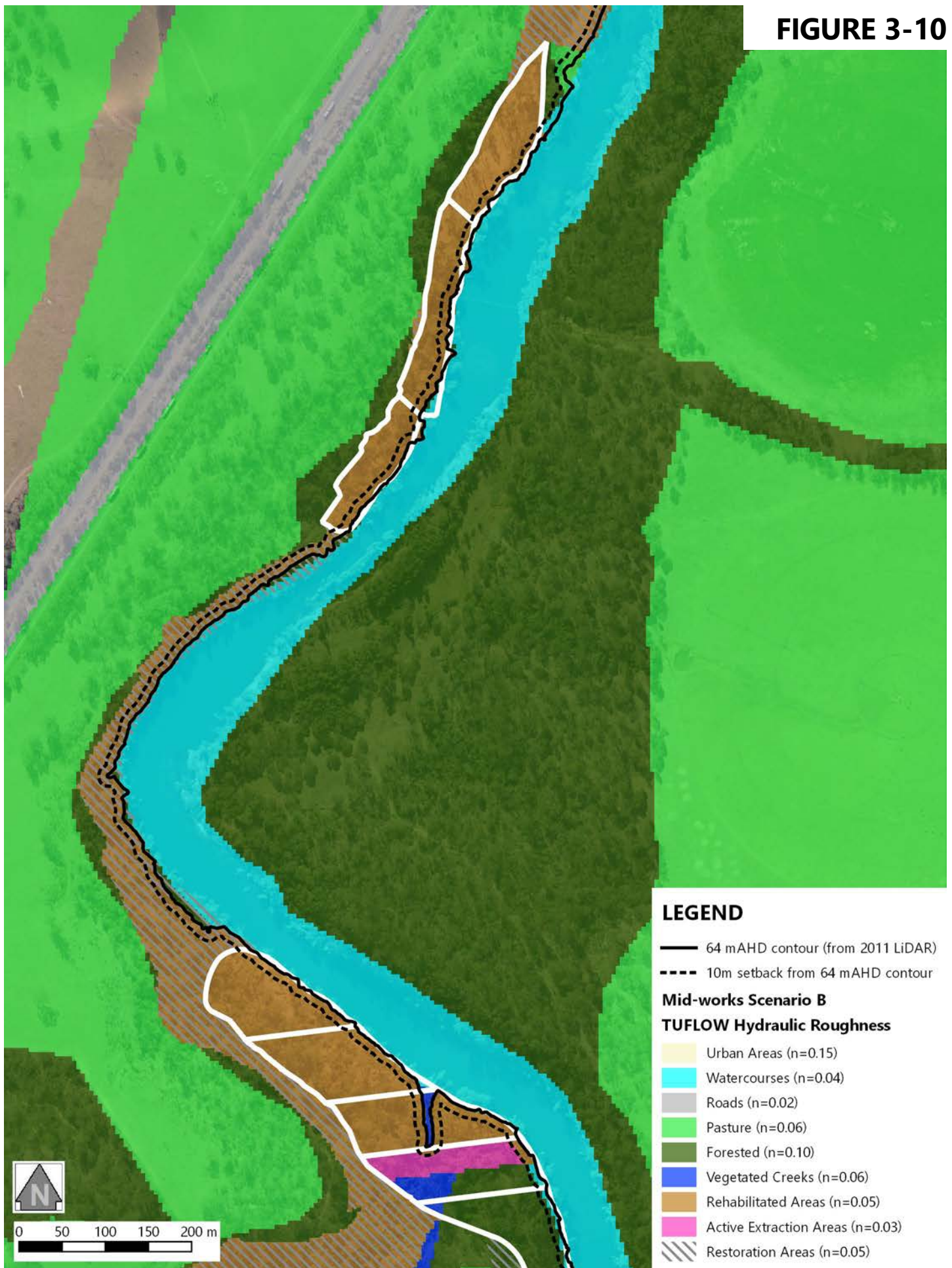
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## TUFLOW HYDRAULIC ROUGHNESS DELINEATION MID-WORKS SCENARIO A



**FIGURE 3-10**



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## TUFLOW HYDRAULIC ROUGHNESS DELINEATION MID-WORKS SCENARIO B



## 4 Hydraulic Modelling Results

### 4.1 Peak Velocity and Bed Shear Stress Mapping

Simulated peak section averaged flow velocities and peak bed shear stress results are presented in **Maps 1 to 36 of Appendix A**. The peak section averaged flow velocity is the maximum vertically averaged velocity that will occur at a location during the course of the flood that is simulated. It is the maximum velocity at each location across the floodplain based on the average of the variation in velocity through the depth of the water column at that location.

The velocity distributions included in **Appendix A** were derived from simulation of the 1978, 5% AEP and 1% AEP flood events under existing conditions and for Mid-works Scenarios 1A and 1B.

Peak velocity and shear stress distributions for the 50% AEP event are not included in this report due to the limited overbank inundation predicted in an event of this magnitude. Similarly, only the results for the March 1978 event are included as simulations for the August 1990 event typically generated similar or lower peak velocities for all sub-stages. This is evident by comparison of the time series plots for these events as shown in **Figures 4-1 to 4-7**.

### 4.2 Simulated Velocities at Sub-Stage Centroids

In addition to peak section averaged velocity, the modelling results were interrogated, and data extracted to produce time-series plots of velocity at the centroid of Stages 8A to 8G. These plots are presented in **Figure 4-1 to Figure 4-7** and show the variation in section averaged velocity at the centroid of each sub-stage over the duration of the flood.

Time series plots were generated from the modelling results for all five simulated flood events under existing conditions and for Mid-works Scenarios 1A and 1B.

#### 4.2.1 Overview of Impacts on Overbank Flood Flow Velocity

Summaries of velocity results for each stage are presented in the following pages. The key findings are summarised as follows.

##### ▪ Mid-Works Scenario 1A

- In general, relative to existing conditions, changes in peak simulated velocity are minor or result in peak velocities that remain 'low' in the context of scour potential, particularly during the smaller 50% AEP, 1978 and 1990 floods
- More significant increases in peak simulated velocity in the context of scour potential are as follows:
  - At Stage 8B during the 1% AEP flood – peak velocity increases from 0.9 m/s to about 1.8 m/s
  - At Stage 8B during the 5% AEP flood – peak velocity increases from 0.4 m/s to about 1.2 m/s
- Relative to existing conditions, the duration of low velocity inundation (less than about 1 m/s) is increased for most flood events and locations

▪ **Mid-Works Scenario 1B**

- Changes in peak simulated velocity are generally greater than for Mid-works Scenario 1A
- In general, relative to existing conditions, changes in peak simulated velocity are still minor or result in peak velocities that remain 'low' in the context of scour potential, particularly during the smaller 50% AEP, 1978 and 1990 floods
- More significant increases in peak simulated velocity in the context of scour potential are as follows:
  - At Stage 8A during the 1% AEP flood - peak velocity increases from 1.8 m/s to about 2.2 m/s
  - At Stage 8B during the 1% AEP flood – peak velocity increases from 0.9 m/s to about 1.9 m/s
  - At Stage 8B during the 5% AEP flood - peak velocity increases from 0.4 m/s to about 1.4 m/s
  - At Stage 8C during the 1% AEP flood - peak velocity increases from 3 m/s to about 3.5 m/s
  - At Stage 8C during the 5% AEP flood - peak velocity increases from 1.9 m/s to about 2.25 m/s
- Relative to existing conditions, the duration of low velocity inundation (*less than about 1 m/s*) is increased for most flood events and locations.

#### **4.2.2 Impacts on Overbank Flood Flow Velocity at Sub-Stage Level**

An assessment of the impact of the proposed works relative to existing conditions and based on consideration of the physical changes to the overbank area defined by Scenarios 1A and 1B is provided at a sub-stage level in the following.



**Stage 8A (refer Figure 4-1)**

- 1% AEP flood
  - Scenario 1A
    - results in negligible change in peak velocity of about 1.8 m/s
    - duration of low velocity inundation at the tail of the flood is increased
  - Scenario 1B
    - results in a 0.4 m/s increase in peak velocity to about 2.2 m/s
    - duration of low velocity inundation at the tail of the flood is increased
- 5% AEP
  - Scenario 1A
    - results in approximately 0.1 m/s decrease in peak velocity to about 1.2 m/s
    - duration of low velocity inundation at the tail of the flood is increased
  - Scenario 1B
    - results in approximately 0.3 m/s increase in peak velocity to about 1.5 m/s
    - duration of low velocity inundation at the tail of the flood is increased
- 50% AEP
  - Scenario 1A
    - not inundated under existing conditions, velocities reach a peak of about 0.5 m/s
    - duration of low velocity inundation is more than 24 hours
  - Scenario 1B
    - not inundated under existing conditions, velocities reach a peak of about 0.5 m/s
    - duration of low velocity inundation is more than 24 hours
- 1978 Flood
  - Scenario 1A
    - results in negligible change in peak velocity of about 0.9 m/s
    - duration of low velocity inundation is increased
  - Scenario 1B
    - results in approximately 0.3 m/s increase in peak velocity to about 1.2 m/s
    - duration of low velocity inundation is increased
- 1990 Flood
  - Scenario 1A
    - results in approximately 0.3 m/s increase in peak velocity to about 0.8 m/s
    - duration of low velocity inundation is increased
  - Scenario 1B
    - results in approximately 0.4 m/s increase in peak velocity to about 0.9 m/s
    - duration of low velocity inundation is increased

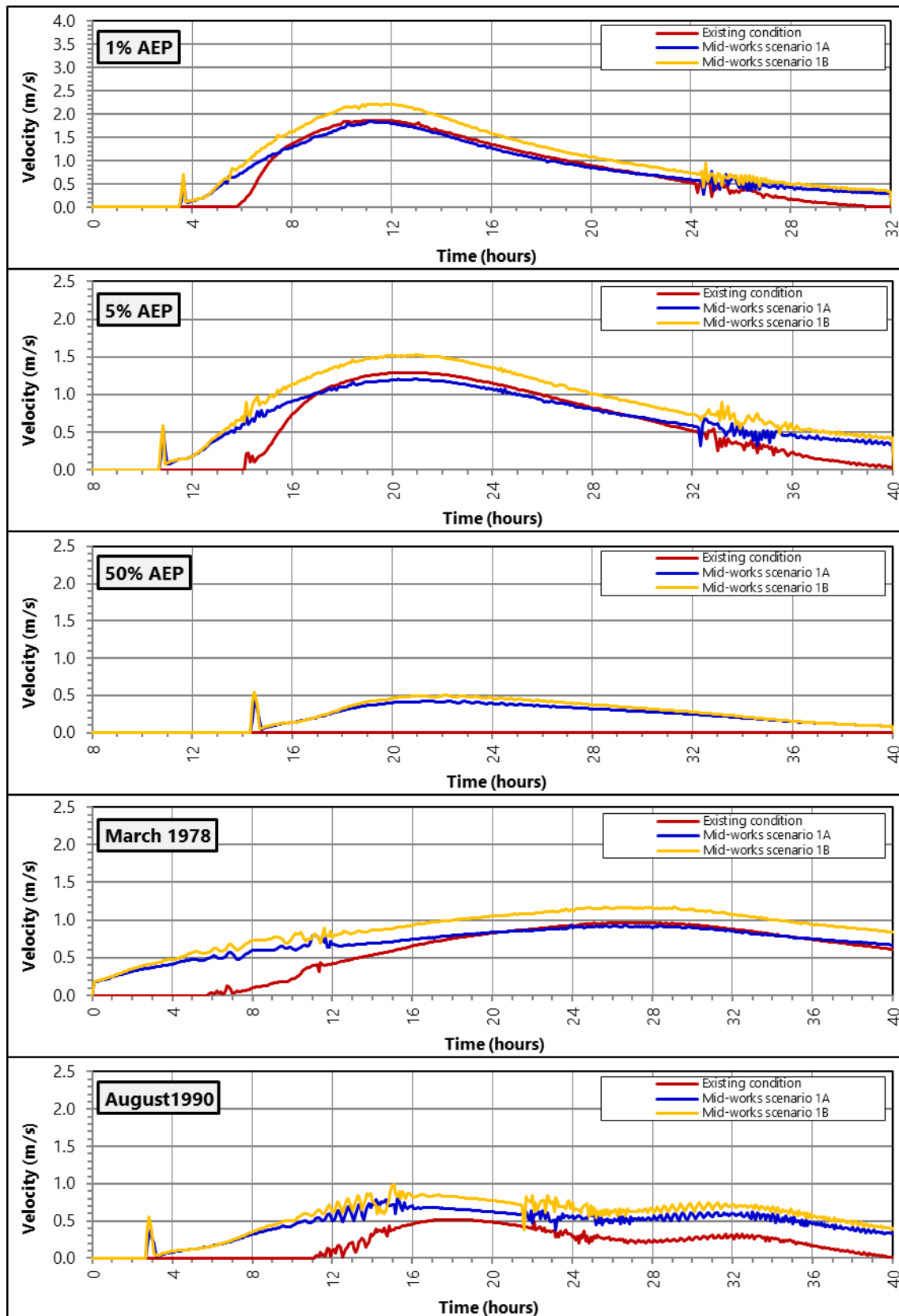


Figure 4-1 Simulated velocity plots at centroid of Stage 8A



**Stage 8B** (refer **Figure 4-2**)

- 1% AEP
  - Scenario 1A
    - results in approximately 0.95 m/s increase in peak velocity to about 1.8 m/s
    - duration of low velocity inundation at the tail of the flood is increased
  - Scenario 1B
    - results in approximately 1.05 m/s increase in peak velocity to about 1.9 m/s
    - duration of low velocity inundation at the tail of the flood is increased
- 5% AEP
  - Scenario 1A
    - results in approximately 0.8 m/s increase in peak velocity to about 1.2 m/s
    - duration of low velocity inundation at the tail of the flood is increased
  - Scenario 1B
    - results in approximately 1.0 m/s increase in peak velocity to about 1.4 m/s
    - duration of low velocity inundation at the tail of the flood is increased
- 50% AEP
  - Scenario 1A
    - not inundated under existing conditions, velocities reach a peak of about 0.25 m/s
    - duration of low velocity inundation is more than 24 hours
  - Scenario 1B
    - not inundated under existing conditions, velocities reach a peak of about 0.3 m/s
    - duration of low velocity inundation is more than 24 hours
- 1978 Flood
  - Scenario 1A
    - results in approximately 0.8 m/s increase in peak velocity to about 0.95 m/s
    - duration of low velocity inundation is increased
  - Scenario 1B
    - results in approximately 0.95 m/s increase in peak velocity to about 1.1 m/s
    - duration of low velocity inundation is increased
- 1990 Flood
  - Scenario 1A
    - results in approximately 0.6 m/s increase in peak velocity to about 0.75 m/s
    - duration of low velocity inundation is increased
  - Scenario 1B
    - results in approximately 0.7 m/s increase in peak velocity to about 0.85 m/s
    - duration of low velocity inundation is increased

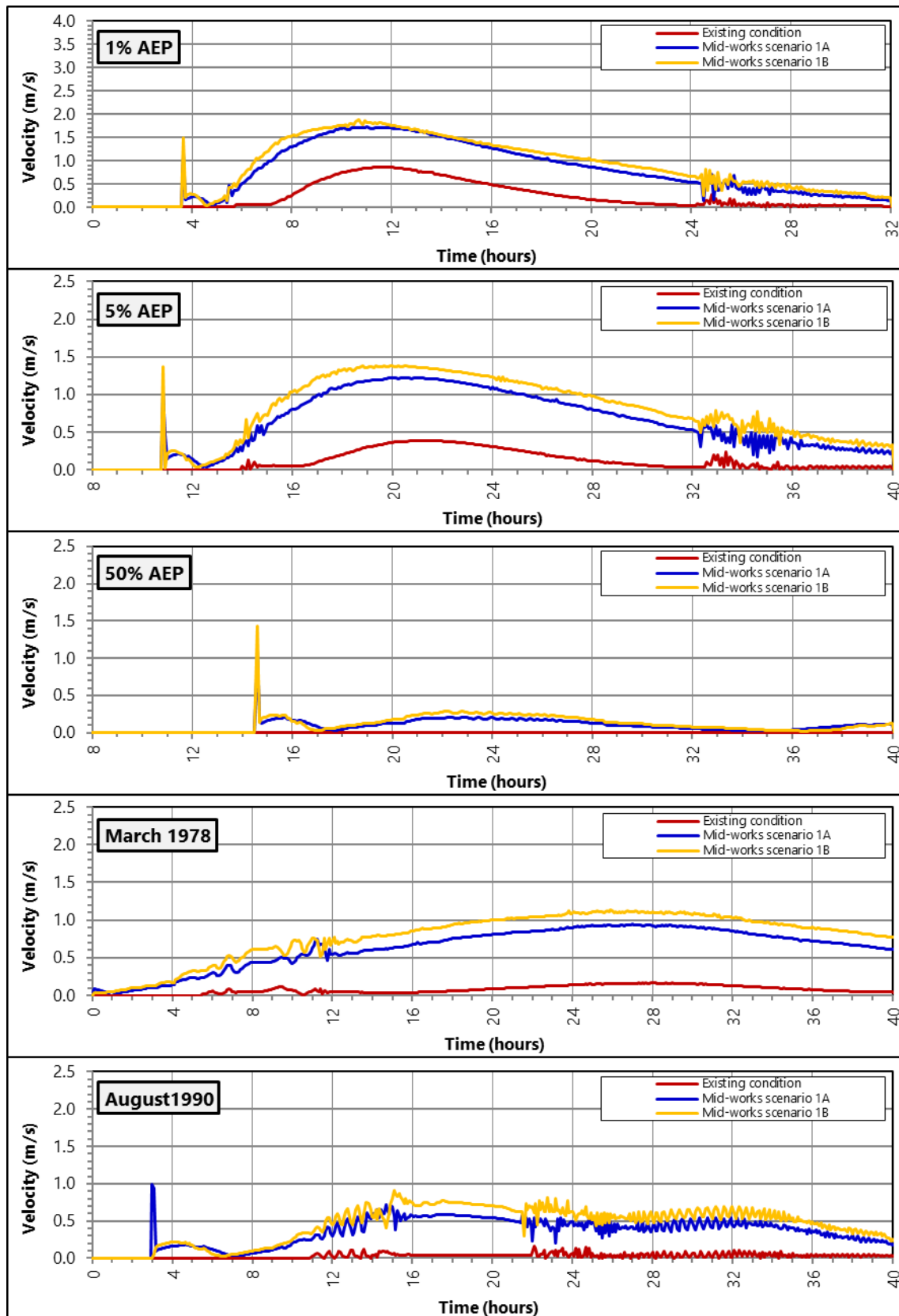


Figure 4-2 Simulated velocity plots at centroid of Stage 8B



**Stage 8C (refer Figure 4-3)**

- 1% AEP
  - Scenario 1A
    - results in negligible change in peak velocity of about 3.0 m/s
  - Scenario 1B
    - results in approximately 0.5 m/s increase in peak velocity to about 3.5 m/s
- 5% AEP
  - Scenario 1A
    - results in negligible change in peak velocity of about 1.9 m/s
  - Scenario 1B
    - results in approximately 0.35 m/s increase in peak velocity to about 2.25 m/s
- 50% AEP
  - Scenario 1A
    - results in negligible change in peak velocity of about 0.5 m/s
    - duration of low velocity inundation is significantly increased
  - Scenario 1B
    - results in approximately 0.2 m/s increase in peak velocity to about 0.7 m/s
    - duration of low velocity inundation is significantly increased
- 1978 Flood
  - Scenario 1A
    - results in negligible change in peak velocity of about 1.3 m/s
  - Scenario 1B
    - results in approximately 0.3 m/s increase in peak velocity to about 1.6 m/s
- 1990 Flood
  - Scenario 1A
    - results in negligible change in peak velocity of about 0.85 m/s
    - duration of low velocity inundation is increased
  - Scenario 1B
    - results in approximately 0.3 m/s increase in peak velocity to about 1.15 m/s
    - duration of low velocity inundation is increased.

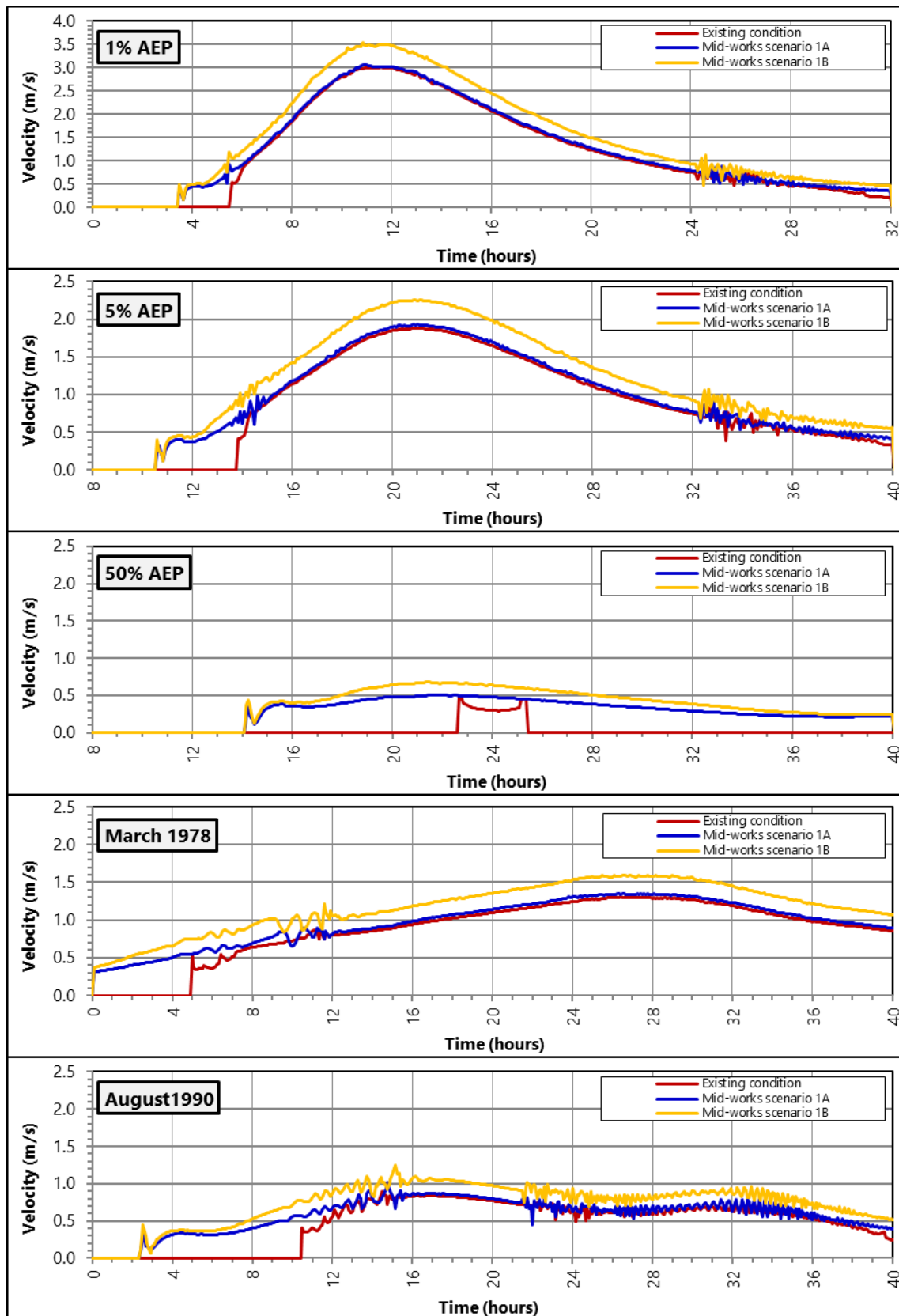


Figure 4-3 Simulated velocity plots at centroid of Stage 8C



**Stage 8D (refer Figure 4-4)**

- 1% AEP
  - Scenario 1A
    - results in approximately 0.2 m/s increase in peak velocity to about 1.1 m/s
    - duration of low velocity inundation is increased
  - Scenario 1B
    - results in approximately 0.3 m/s increase in peak velocity to about 1.2 m/s
    - duration of low velocity inundation is increased
- 5% AEP
  - Scenario 1A
    - results in approximately 0.3 m/s increase in peak velocity to about 0.8 m/s
    - duration of low velocity inundation is increased
  - Scenario 1B
    - results in approximately 0.3 m/s increase in peak velocity to about 0.8 m/s
    - duration of low velocity inundation is increased
- 50% AEP
  - Scenario 1A
    - not inundated under existing conditions, velocities reach a peak of about 0.35 m/s
    - duration of low velocity inundation is more than 24 hours
  - Scenario 1B
    - not inundated under existing conditions, velocities reach a peak of about 0.45 m/s
    - duration of low velocity inundation is more than 24 hours
- 1978 Flood
  - Scenario 1A
    - results in approximately 0.2 m/s increase in peak velocity to about 0.7 m/s
    - duration of low velocity inundation is increased
  - Scenario 1B
    - results in approximately 0.4 m/s increase in peak velocity to about 0.9 m/s
    - duration of low velocity inundation is increased
- 1990 Flood
  - Scenario 1A
    - results in approximately 0.3 m/s increase in peak velocity to about 0.75 m/s
    - duration of low velocity inundation is increased
  - Scenario 1B
    - results in approximately 0.55 m/s increase in peak velocity to about 1.0 m/s
    - duration of low velocity inundation is increased

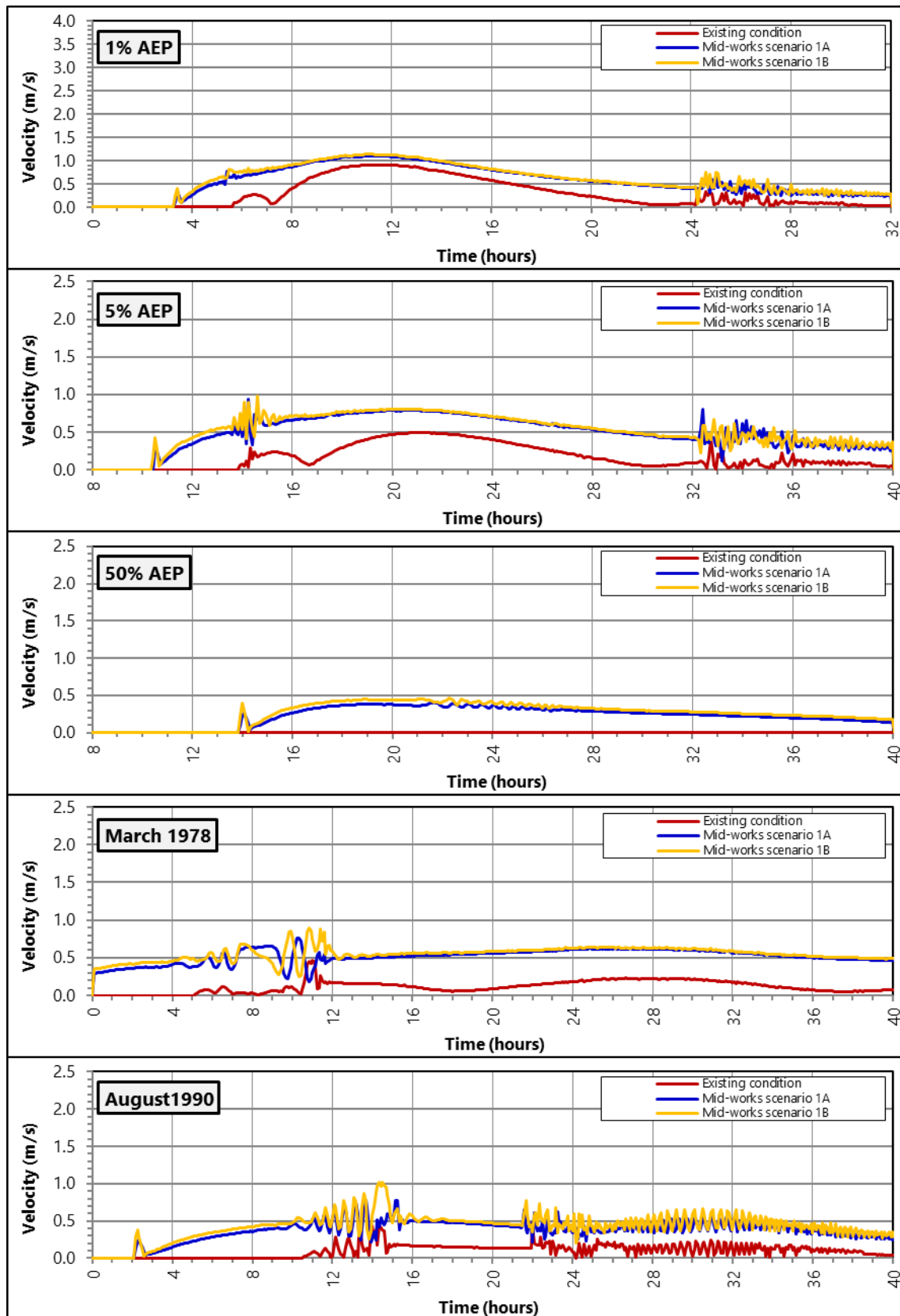


Figure 4-4 Simulated velocity plots at centroid of Stage 8D



**Stage 8E (refer Figure 4-5)**

- 1% AEP
  - Scenario 1A
    - results in approximately 0.6 m/s decrease in peak velocity to about 0.5 m/s
    - duration of low velocity inundation is increased
  - Scenario 1B
    - results in approximately 0.6 m/s decrease in peak velocity to about 0.5 m/s
    - duration of low velocity inundation is increased
- 5% AEP
  - Scenario 1A
    - results in approximately 0.6 m/s decrease in peak velocity to about 0.5 m/s
    - duration of low velocity inundation is increased
  - Scenario 1B
    - results in approximately 0.6 m/s decrease in peak velocity to about 0.5 m/s
    - duration of low velocity inundation is increased
- 50% AEP
  - Scenario 1A
    - not inundated under existing conditions, velocities reach a peak of about 0.3 m/s
    - duration of low velocity inundation is more than 24 hours
  - Scenario 1B
    - not inundated under existing conditions, velocities reach a peak of about 0.3 m/s
    - duration of low velocity inundation is more than 24 hours
- 1978 Flood
  - Scenario 1A
    - results in negligible change in peak velocity of about 0.4 m/s
    - duration of low velocity inundation is increased
  - Scenario 1B
    - results in negligible change in peak velocity of about 0.4 m/s
    - duration of low velocity inundation is increased
- 1990 Flood
  - Scenario 1A
    - not inundated under existing conditions, velocities reach a peak of about 0.4 m/s
    - duration of low velocity inundation is increased
  - Scenario 1B
    - not inundated under existing conditions, velocities reach a peak of about 0.4 m/s
    - duration of low velocity inundation is increased

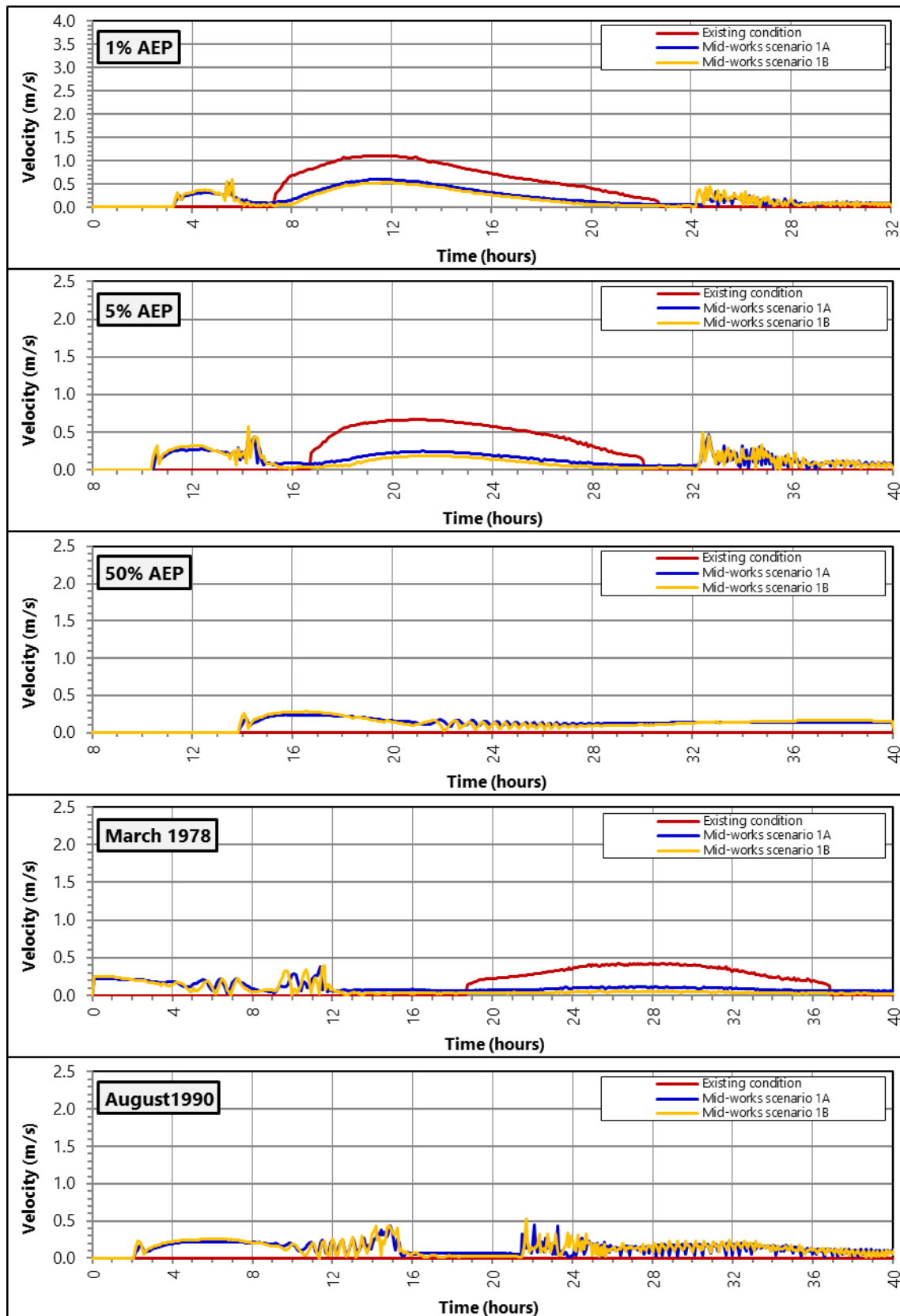


Figure 4-5 Simulated velocity plots at centroid of Stage 8E

**Stage 8F** (refer **Figure 4-6**)

- 1% AEP
  - Scenario 1A
    - results in negligible change in peak velocity of about 0.5 m/s
    - duration of low velocity inundation is increased
  - Scenario 1B
    - results in negligible change in peak velocity of about 0.5 m/s
    - duration of low velocity inundation is increased
- 5% AEP
  - Scenario 1A
    - results in approximately 0.3 m/s increase in peak velocity to about 0.5 m/s
    - duration of low velocity inundation is increased
  - Scenario 1B
    - results in approximately 0.6 m/s increase in peak velocity to about 0.8 m/s
    - duration of low velocity inundation is increased
- 50% AEP
  - Scenario 1A
    - not inundated under existing conditions, velocities reach a peak of about 0.2 m/s
    - duration of low velocity inundation is more than 24 hours
  - Scenario 1B
    - not inundated under existing conditions, velocities reach a peak of about 0.3 m/s
    - duration of low velocity inundation is more than 24 hours
- 1978 Flood
  - Scenario 1A
    - results in approximately 0.4 m/s increase in peak velocity to about 0.5 m/s
    - duration of low velocity inundation is increased
  - Scenario 1B
    - results in approximately 0.4 m/s increase in peak velocity to about 0.5 m/s
    - duration of low velocity inundation is increased
- 1990 Flood
  - Scenario 1A
    - not inundated under existing conditions, velocities reach a peak of about 0.5 m/s
    - duration of low velocity inundation is increased
  - Scenario 1B
    - not inundated under existing conditions, velocities reach a peak of about 0.7 m/s
    - duration of low velocity inundation is increased



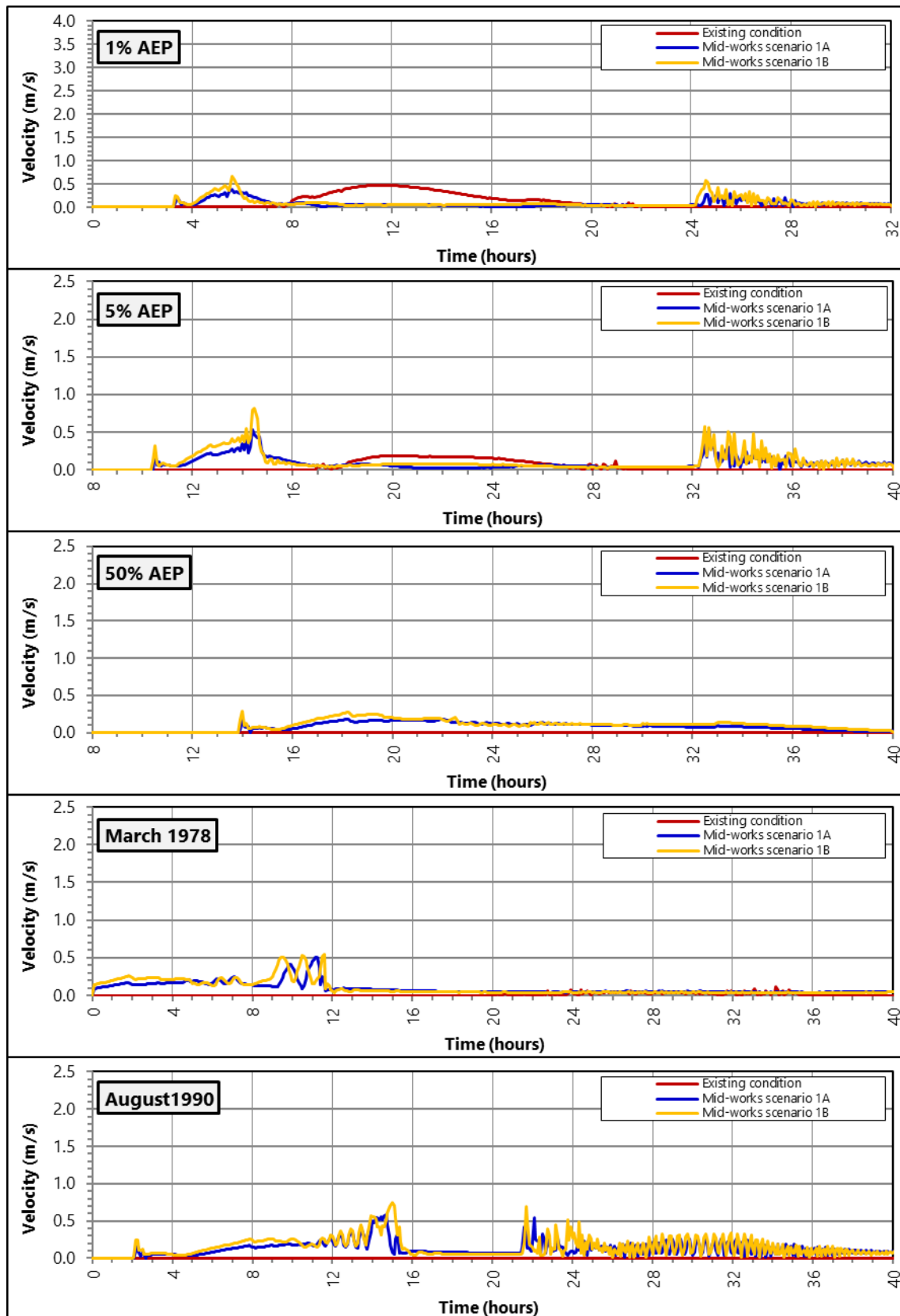


Figure 4-6 Simulated velocity plots at centroid of Stage 8F

**Stage 8G (refer Figure 4-7)**

- 1% AEP
  - Scenario 1A
    - results in approximately 1.0 m/s decrease in peak velocity to about 0.4 m/s
    - duration of low velocity inundation is increased
  - Scenario 1B
    - results in approximately 0.8 m/s decrease in peak velocity to about 0.6 m/s
    - duration of low velocity inundation is increased
- 5% AEP
  - Scenario 1A
    - results in approximately 0.2 m/s decrease in peak velocity to about 0.4 m/s
    - duration of low velocity inundation is increased
  - Scenario 1B
    - results in approximately 0.1 m/s increase in peak velocity to about 0.5 m/s
    - duration of low velocity inundation is increased
- 50% AEP
  - Scenario 1A
    - not inundated under existing conditions, velocities reach a peak of about 0.3 m/s
    - duration of low velocity inundation is more than 24 hours
  - Scenario 1B
    - not inundated under existing conditions, velocities reach a peak of about 0.4 m/s
    - duration of low velocity inundation is more than 24 hours
- 1978 Flood
  - Scenario 1A
    - not inundated under existing conditions, velocities reach a peak of about 0.4 m/s
    - duration of low velocity inundation is more than 24 hours
  - Scenario 1B
    - not inundated under existing conditions, velocities reach a peak of about 0.4 m/s
    - duration of low velocity inundation is more than 24 hours
- 1990 Flood
  - Scenario 1A
    - not inundated under existing conditions, velocities reach a peak of about 0.5 m/s
    - duration of low velocity inundation is more than 24 hours
  - Scenario 1B
    - not inundated under existing conditions, velocities reach a peak of about 0.5 m/s
    - duration of low velocity inundation is more than 24 hours.

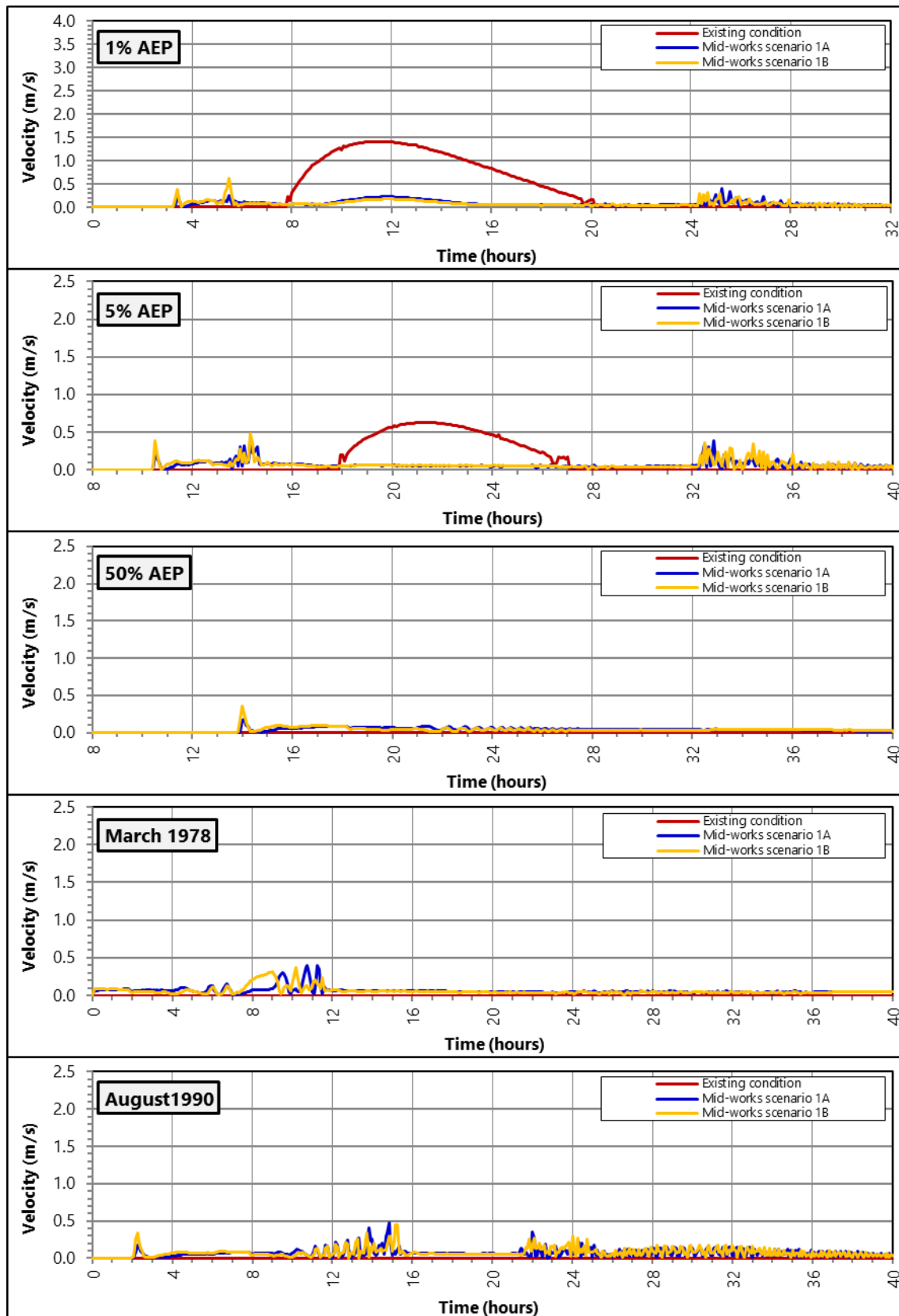


Figure 4-7 Simulated velocity plots at centroid of Stage 8G



### 4.3 Simulated Bed Shear Stress at Sub-Stage Centroids

Bed shear stress is the force per unit area with which flow pulls the bed downstream. Simulated time-series plots of bed shear stress at the centroids of Stages 8A to 8G are presented in **Figure 4-8** to **Figure 4-14**. These figures show the change in bed shear stress over the duration of the flood for all five simulated flood events under existing conditions and Mid-works Scenarios 1A and 1B.

For most locations and flood events bed shear stress is predicted to be reduced under the mid-works scenarios relative to bed shear stress under existing conditions. This is to be expected from the equation used to derive bed shear stress which includes Manning's 'n' in the numerator and water depth in the denominator. This equation is as follows:

$$\tau_{bed} = \frac{\rho g V^2 n^2}{y^3}$$

where:  $\tau_{bed}$  = bed shear stress in  $N/m^2$   
 $\rho$  = sediment submerged specific gravity  
 $g$  = acceleration due to gravity in  $m/s^2$   
 $v$  = velocity of flow in  $m/s$   
 $n$  = Manning's roughness parameter  
 $y$  = depth of flow in  $m$

Under the mid-works condition, Manning's 'n' was reduced and flood depth was generally increased. Both of these factors would act to reduce bed shear stress and will typically offset the impact of any potential increase in velocity.

### 4.4 Scour Potential

While bed shear stress is generally reduced, this does not necessarily mean that the potential for scour is reduced for the post-extraction landform. In addition to the change in the topography, the mid-works condition also results in a change in the surface condition of the extraction areas and the density of vegetation, which may serve to lower the threshold shear stress for erosion. Assessing the change in scour potential therefore requires an assumption about the mid-works surface condition and the density of the vegetation across the rehabilitated extraction areas.

In effect, the results of the analysis indicate that the potential for scour of the extraction areas during and post extraction operations is more significantly linked to the condition of the surface of the active and rehabilitated extraction areas than to the relatively minor changes in flow velocity that are predicted. That is, the potential for scour or erosion is not directly linked to an absolute velocity of overbank flow, but rather to the capacity for the active or rehabilitated surfaces to resist erosion as a consequence of that overland flow. If the surface is suitably compacted and revegetated at the time of flooding, then there will be less potential for scour.

The potential for scour post-extraction will also be less because the depth of overbank flooding across the extracted landform will be greater in the larger floods which generate the greater flow velocities across overbank areas.

Accordingly, it follows that the Stage 8A to 8G extraction areas will typically function as depositional areas, post extraction. The key to ensuring that they remain stable during the course of most floods rests with the operational activities undertaken to ensure that the active extraction area is kept to as small an area as possible and that areas where extraction has been completed are revegetated as quickly as possible.

This can most effectively be achieved via a site specific environmental management plan that incorporates the following:

- (i) A requirement that the active extraction area that has bare soil is kept to a minimum, with rehabilitation/revegetation of areas occurring progressively and as soon as possible after extraction in that part of the substage is complete
- (ii) Monitoring to ensure that revegetation occurs to deliver uniform coverage of vegetation across each rehabilitated extraction zone
- (iii) Management of the riverside batter in the active extraction zone according to the following protocols which are targeted at mitigating the risk of scour or bank erosion during flooding:
  - Excavation based on a short-term riverside batter with a maximum slope of 1(V):1(H) during sand and soil extraction
  - Ensuring that the riverside batter slope is never steeper than 1(V):1(H)
  - Backfilling of the riverside batter following extraction with acceptable backfill material to create a permanent riverside batter with a slope of 1(V):5(H)
  - Ensuring that there is never more than 30 m of riverside batter (*measured longitudinally along the river*) with a slope between 1(V):1(H) and 1(V):5(H)
  - Ensuring the maximum length of the riverside batter that has a slope between 1(V):1(H) and 1(V):5(H) will be limited so that it can be covered with a 1(V):5(H) batter within 12 hours if flooding is predicted

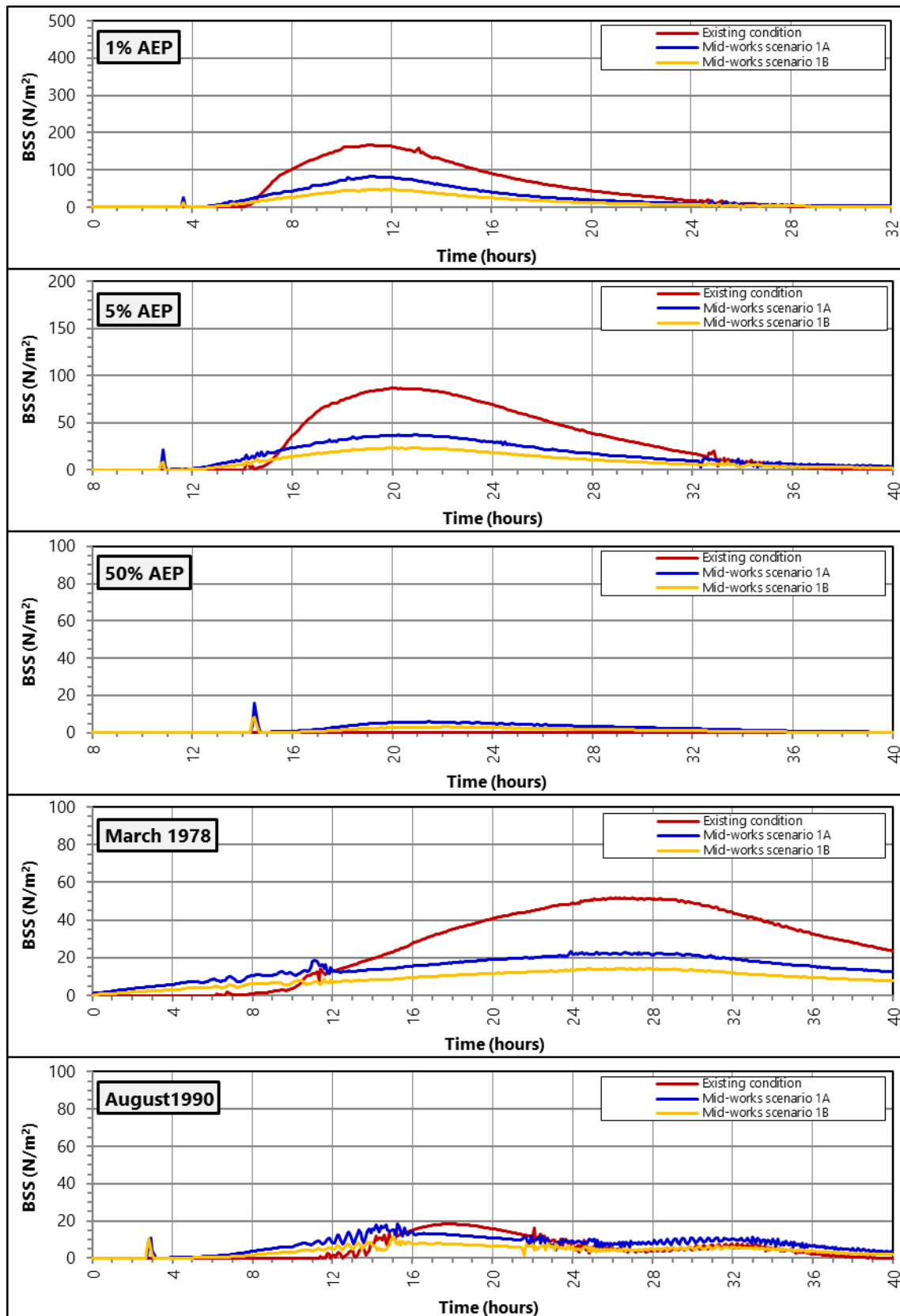


Figure 4-8 Simulated bed shear stress at Centroid of Stage 8A



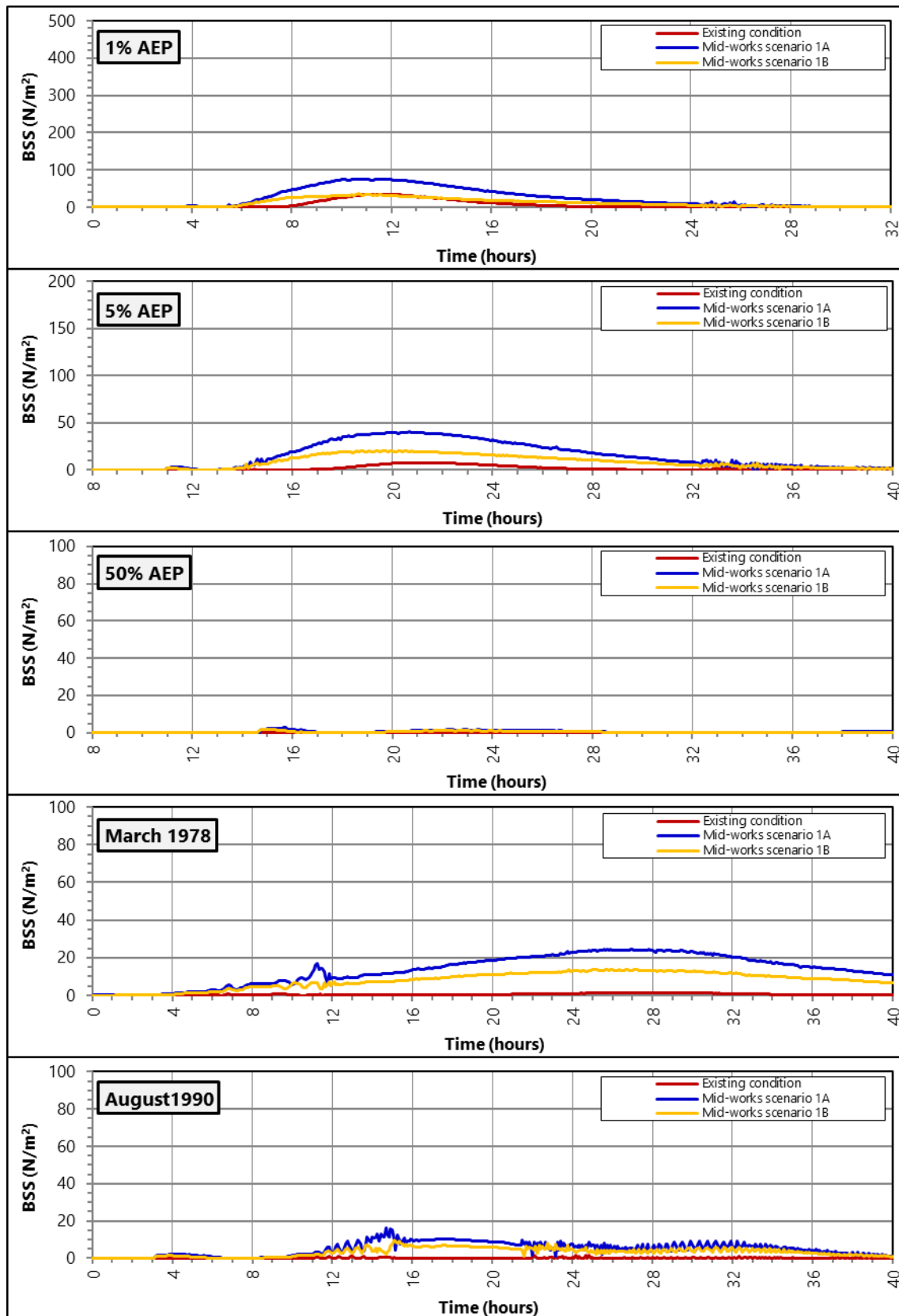


Figure 4-9 Simulated bed shear stress at Centroid of Stage 8B

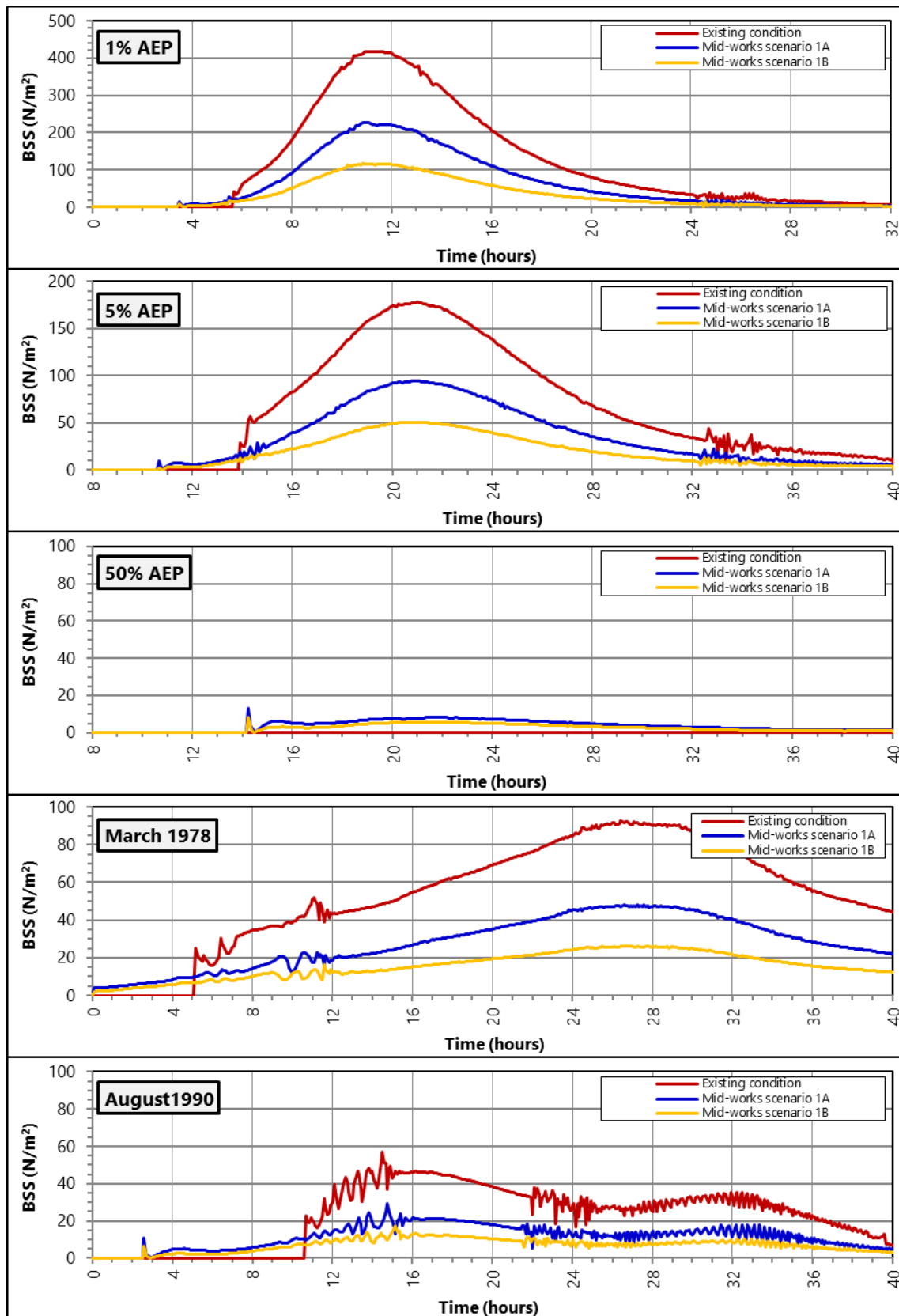


Figure 4-10 Simulated bed shear stress at Centroid of Stage 8C

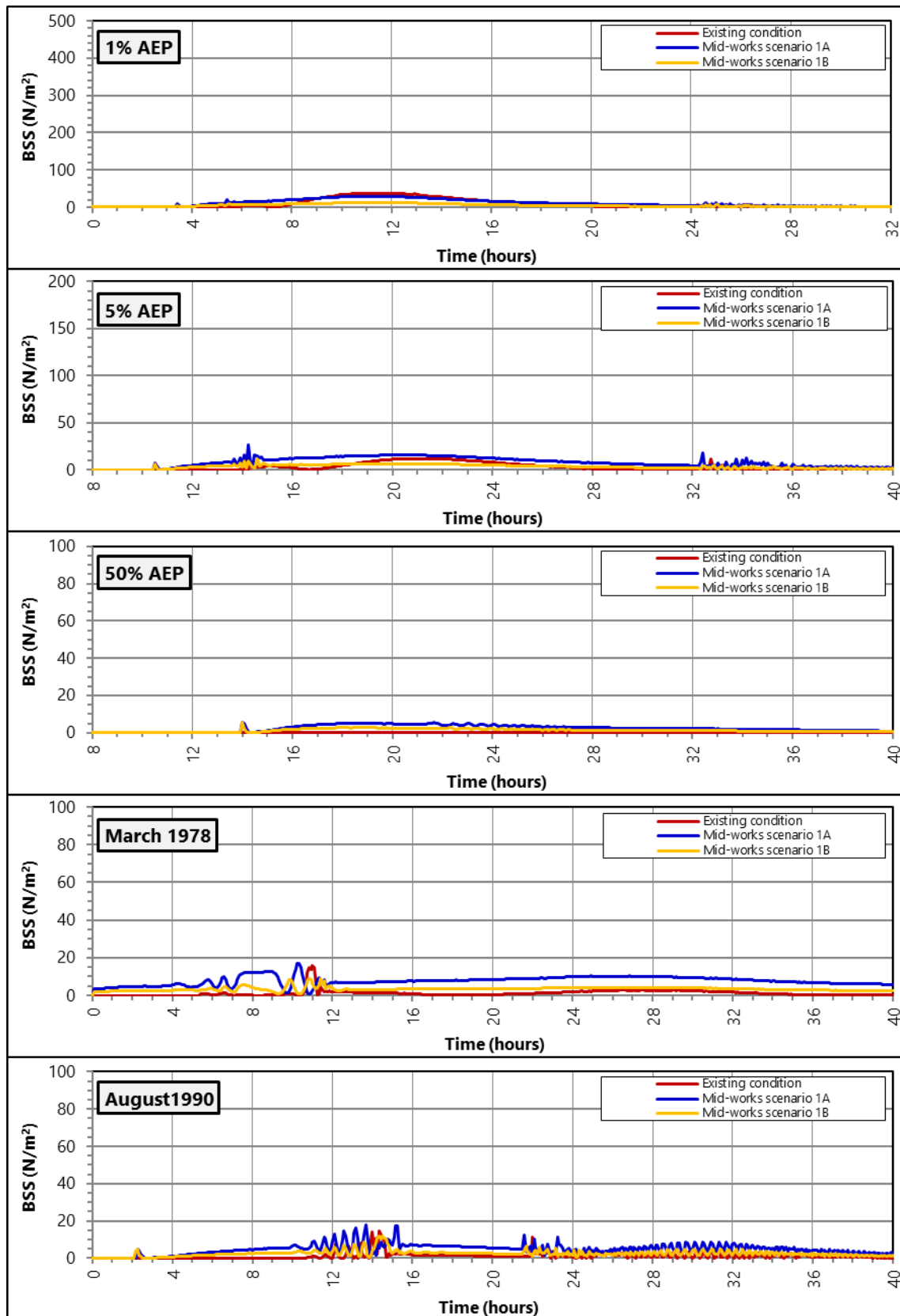


Figure 4-11 Simulated bed shear stress at Centroid of Stage 8D



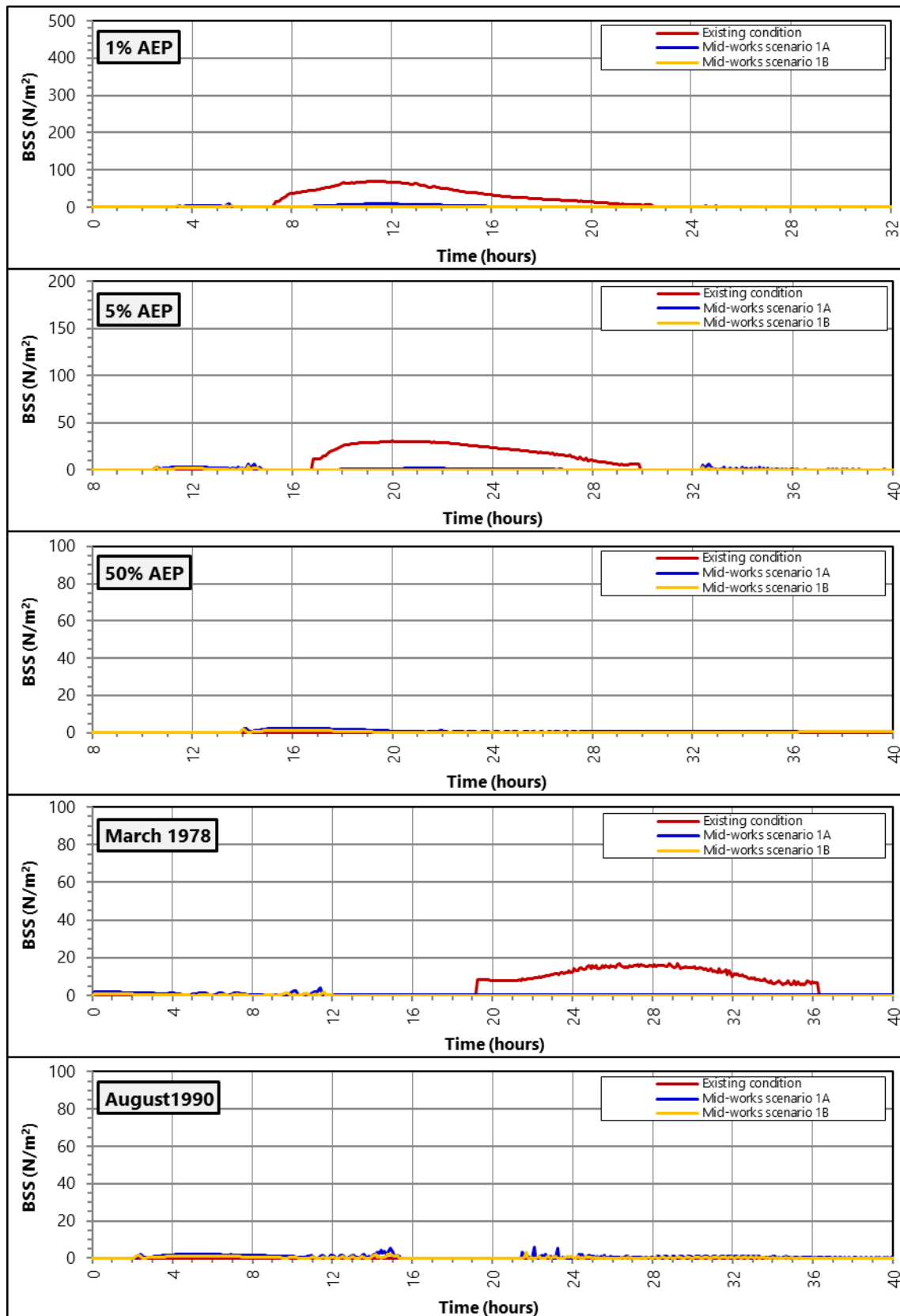


Figure 4-12 Simulated bed shear stress at Centroid of Stage 8E

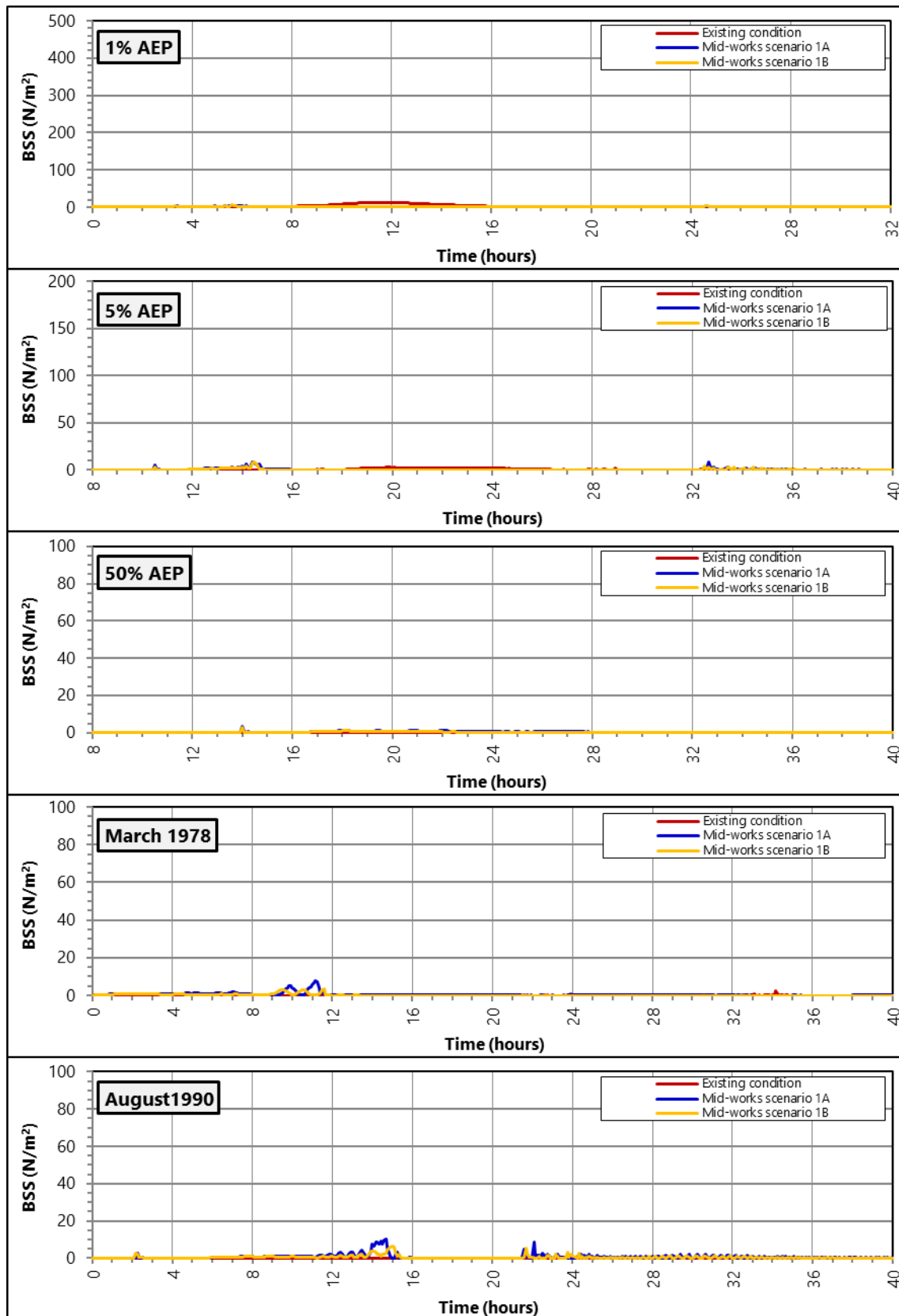


Figure 4-13 Simulated bed shear stress at Centroid of Stage 8F

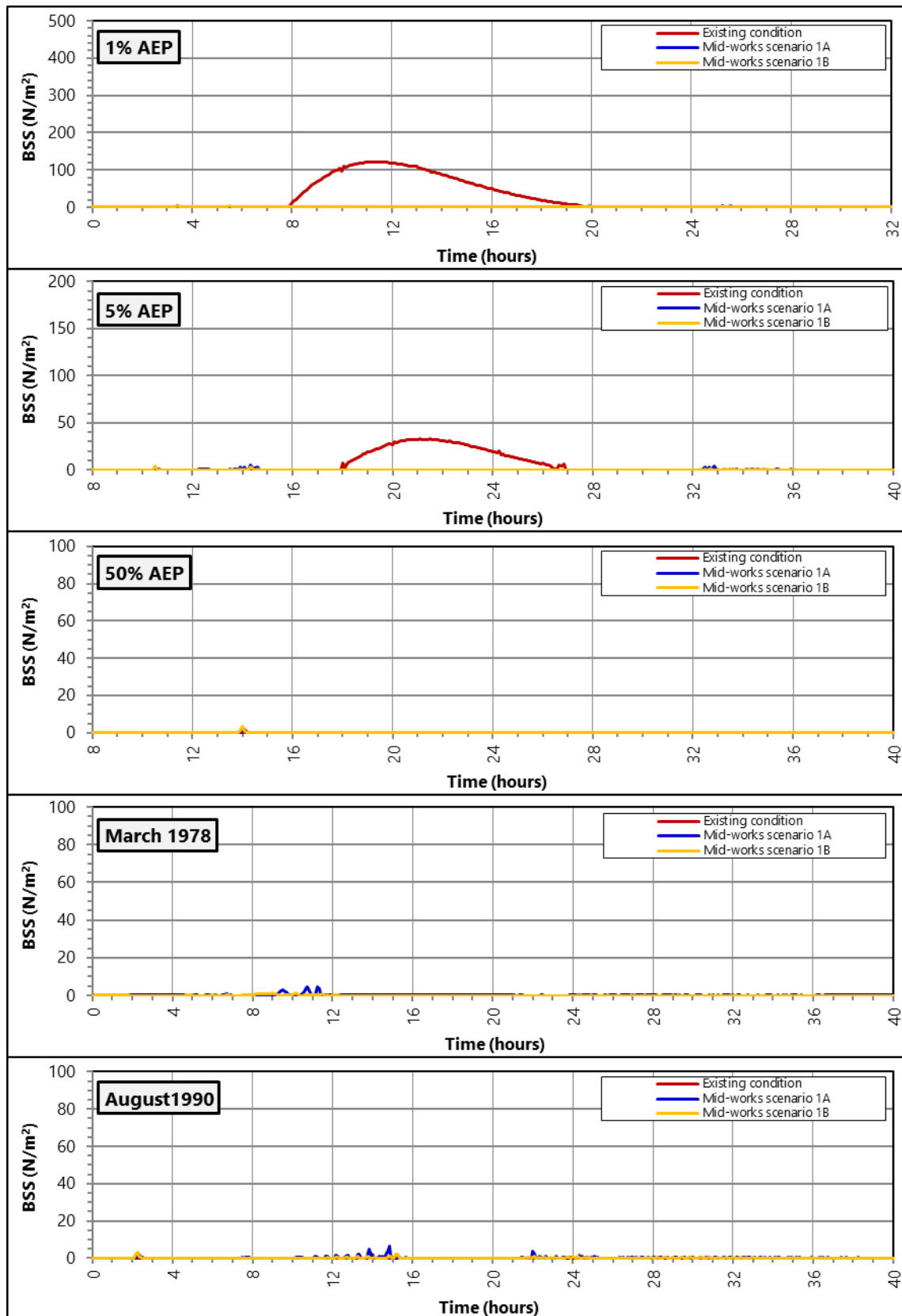


Figure 4-14 Simulated bed shear stress at Centroid of Stage 8G



## 5 Conclusions

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Additional flood impact sensitivity analyses have been undertaken to assess a range of scenarios which could exist during sand and soil extraction from Stage 8 of the Menangle Quarry prior to the onset of major flooding of the Nepean River. The scenarios were determined by the Department of Planning & Environment following conferencing between flooding and geomorphic assessment experts representing the Department and Menangle Sand & Soil during the s34 conference held on 14<sup>th</sup> June 2019.

The additional sensitivity analyses were undertaken to address issues in contention related to the potential impact of predicted changes in flood flow velocities and bed shear stress as a consequence of the proposed works. It was argued that the Applicant should attend to these requests to allow the Department to fully assess the environmental impact of the proposal.

The sensitivity analysis was based on adoption of a particular mid-works configuration for the extraction area (*Scenario 1*) which is described as follows:

- Stages 8A to 8F fully extracted.
- Stage 8G assumed to be 50% extracted with extraction assumed to progress from downstream to upstream.
- A 1(V):1(H) batter slope down from natural surface at the landward edge of the extraction area.
- Minimum grade of 1(V):50(H) (i.e., 2%) toward the river across the base of the excavation area.
- Re-grading of the 10 metre wide river bank setback area to a minimum elevation of 64 mAHD where there are no trees and leaving most or all of the bank in place where there are trees. It is noted that re-grading of the 10 metre wide river bank setback area to a minimum elevation of 64 mAHD has been assumed throughout for the purposes of modelling.
- Initial excavation at 1(V):1(H) batter slope down from edge of the setback area to a maximum extraction depth of 62 mAHD, noting that:
  - this batter slope will be less than 30 metres long and will be restored to a finished grade of 1(V):5(H); and,
  - Stage 8G is modelled as 'active' with the initial 1(V):1(H) riverside batter slope still in place.

The TUFLOW flood model that was developed for the '*Nepean River Flood Study*' (WorleyParsons, 2015) and extended for the '*Menangle Quarry Extension Flood Impact Assessment*' (Advisian, 2018), was modified to reflect this mid-works configuration. The modified model was then used to simulate a range of floods, including:

- 50% AEP flood;
- 5% AEP flood;
- 1% AEP flood;
- the March 1978 flood; and,
- the August 1990 flood.

The sensitivity analysis was undertaken based on modelling two floodplain roughness scenarios identified by the Department of Planning in its letter dated 19<sup>th</sup> June 2019. The hydraulic roughness scenarios are as follows:

- Hydraulic Roughness Scenario A – “Rougher” rehabilitated and active areas
  - Manning’s ‘n’ for rehabilitated areas = 0.08
  - Manning’s ‘n’ for active areas (Stage 8G) = 0.06
- Hydraulic Roughness Scenario B – “Less rough” rehabilitated and active areas
  - Manning’s ‘n’ for rehabilitated areas = 0.05
  - Manning’s ‘n’ for active areas (Stage 8G) = 0.03

The key impacts on flood flow velocities are summarised as follows.

#### **Mid-Works Scenario 1A**

- In general, relative to existing conditions, changes in peak simulated velocity are minor or result in peak velocities that remain ‘low’ in the context of scour potential, particularly during the smaller events such as the 50% AEP flood and the 1978 and 1990 floods.
- Relative to existing conditions, the duration of low velocity inundation (*less than about 1 m/s*) is increased for most flood events and locations.

#### **Mid-Works Scenario 1B**

- Changes in peak simulated velocity are generally greater than for Mid-works Scenario 1A
- In general, relative to existing conditions, changes in peak simulated velocity are still minor or result in peak velocities that remain ‘low’ in the context of scour potential, particularly during the smaller 50% AEP, 1978 and 1990 floods
- Relative to existing conditions, the duration of low velocity inundation (*less than about 1 m/s*) is increased for most flood events and locations

For most locations and flood events bed shear stress is predicted to be reduced under the mid-works scenarios relative to bed shear stress under existing conditions. This is to be expected because Manning’s ‘n’ roughness values across the extraction areas are reduced as part of the sensitivity analysis and floodwater depths across overbank areas will typically increase, post extraction. The changes to these two parameters serves to reduce bed shear stress across the extraction areas.

#### **Recommendations**

The analysis indicates that the potential for scour of the extraction areas during and post extraction operations is more significantly linked to the condition of the surface of the active and rehabilitated extraction areas than to the relatively minor changes in flow velocity that are predicted. That is, the potential for scour or erosion is not directly linked to an absolute velocity of overbank flow, but rather to the capacity for the active or rehabilitated surfaces to resist erosion as a consequence of that overland flow.

Therefore, the key to ensuring that the Stage 8A to 8G extraction areas remain stable during the course of most floods rests with the operational activities undertaken to ensure that the active extraction area is kept to as small an area as possible and that areas where extraction has been completed are revegetated as quickly as possible.

This can most effectively be achieved via implementation of a site specific environmental management plan that incorporates the following:

- (i) A requirement that the active extraction area that has bare soil is kept to a minimum, with rehabilitation/revegetation of areas occurring progressively and as soon as possible after extraction in that part of the substage is complete
- (ii) Monitoring to ensure that revegetation occurs to deliver uniform coverage of vegetation across each rehabilitated extraction zone
- (iii) Management of the riverside batter in the active extraction zone as follows:
  - Excavation based on a short-term riverside batter with a maximum slope of 1(V):1(H) during sand and soil extraction
  - Ensuring that the riverside batter slope is never steeper than 1(V):1(H)
  - Backfilling of the riverside batter following extraction with acceptable backfill material to create a permanent riverside batter with a slope of 1(V):5(H)
  - Ensuring that there is never more than 30 m of riverside batter with a slope between 1(V):1(H) and 1(V):5(H)
  - Ensuring the maximum length of the riverside batter that has a slope between 1(V):1(H) and 1(V):5(H) will be limited so that it can be covered with a 1(V):5(H) batter within 12 hours.

## 6 References

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- Advisian (May 2018), 'Menangle Quarry Extension – Flood Impact Assessment'; prepared for Benedict Industries Pty Ltd
- Austroads (1994), 'Waterway Design – A Guide to the Hydraulic Design of Bridges, Culverts and Floodways'; edited by David Flavell. ISBN 0 85588 440 1
- Camden Council (2015), 'Nepean River Flood Study'; prepared by WorleyParsons Services Pty Ltd.
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- EMM (2019), Letter to Minter Ellison titled 'NSW Land & Environment Court (2018/342158) Menangle Quarry – flood mitigation'; dated 9<sup>th</sup> September 2019.
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- Hewlett, H.W.M., Boorman, L.A. and Bramley, M.E. (1987), 'Design of Reinforced Grass Waterways'; CIRIA Report 116. CIRIA.
- NSW Department of Planning & Environment (2019), Letter to Minter Ellison dated 19<sup>th</sup> June 2019 detailing outcomes from s34 conference for LEC Proceedings 2018/342158.

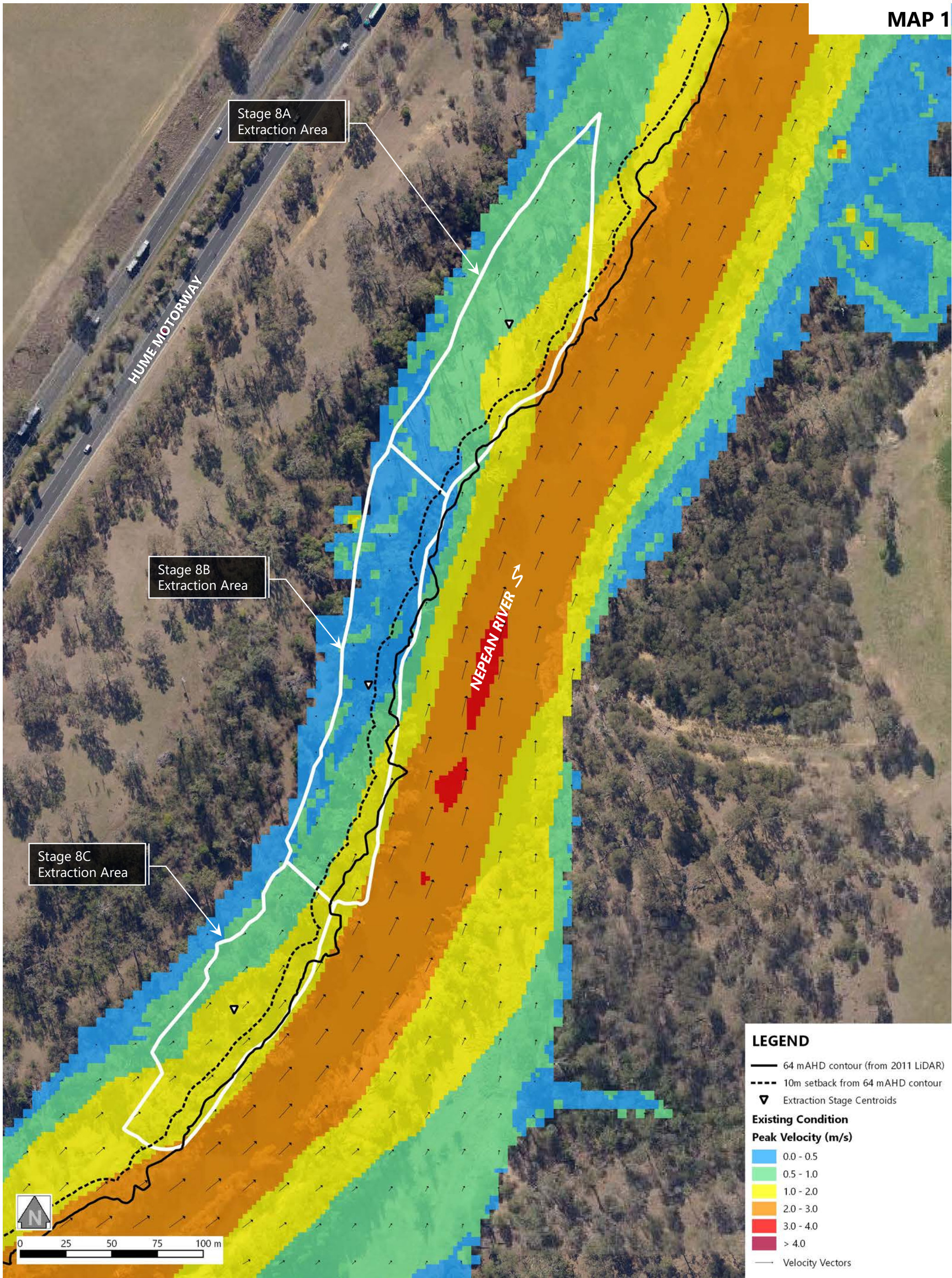


# Appendix A

## Peak Velocity and Bed Shear Stress Mapping

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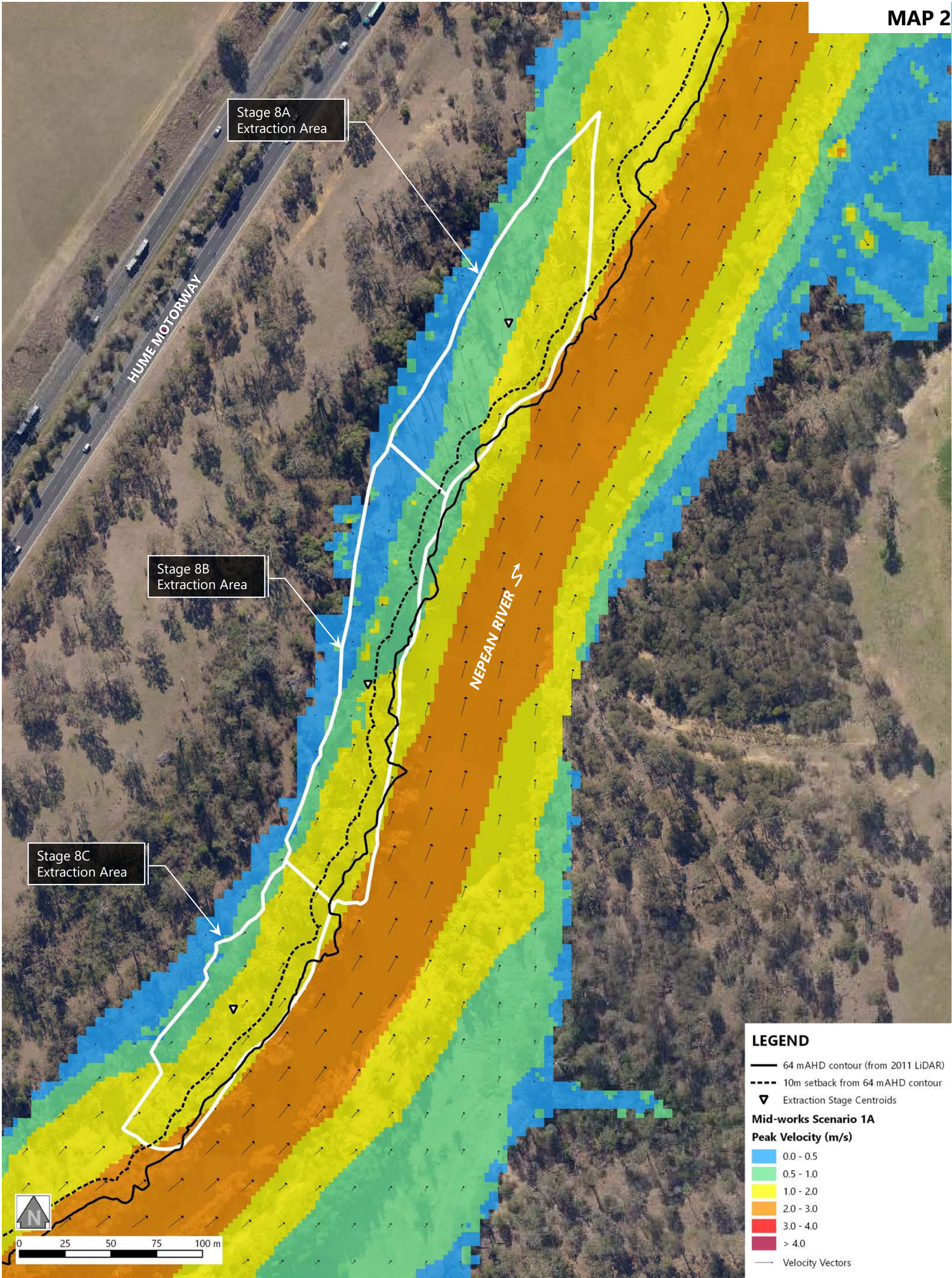
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**Advisian**  
Worley Group

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**STAGES 8A-8C EXISTING CONDITIONS**  
**MARCH 1978 EVENT SIMULATED PEAK FLOW VELOCITY**





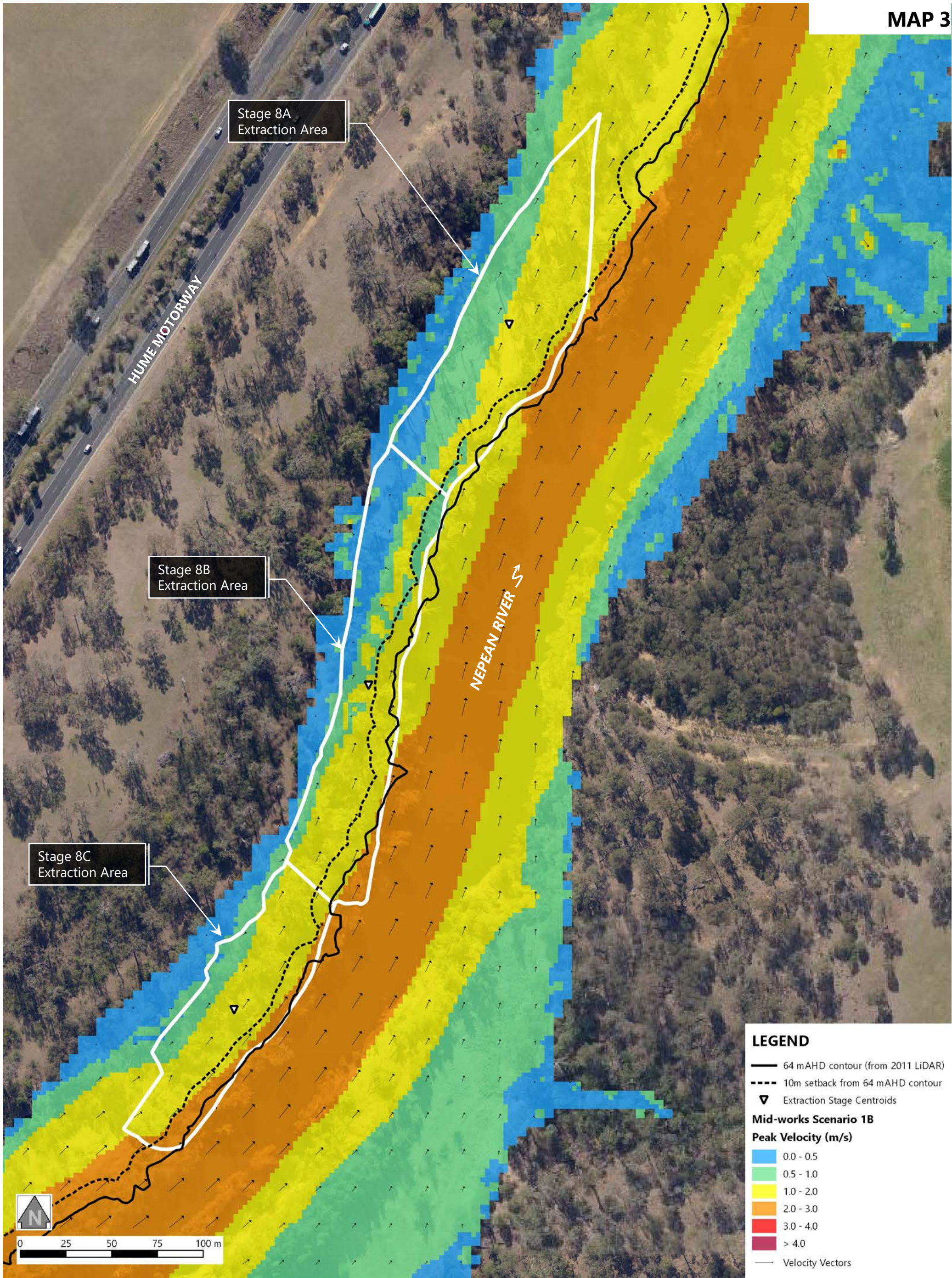
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**STAGES 8A-8C MID-WORKS SCENARIO 1A**  
**MARCH 1978 EVENT SIMULATED PEAK FLOW VELOCITY**





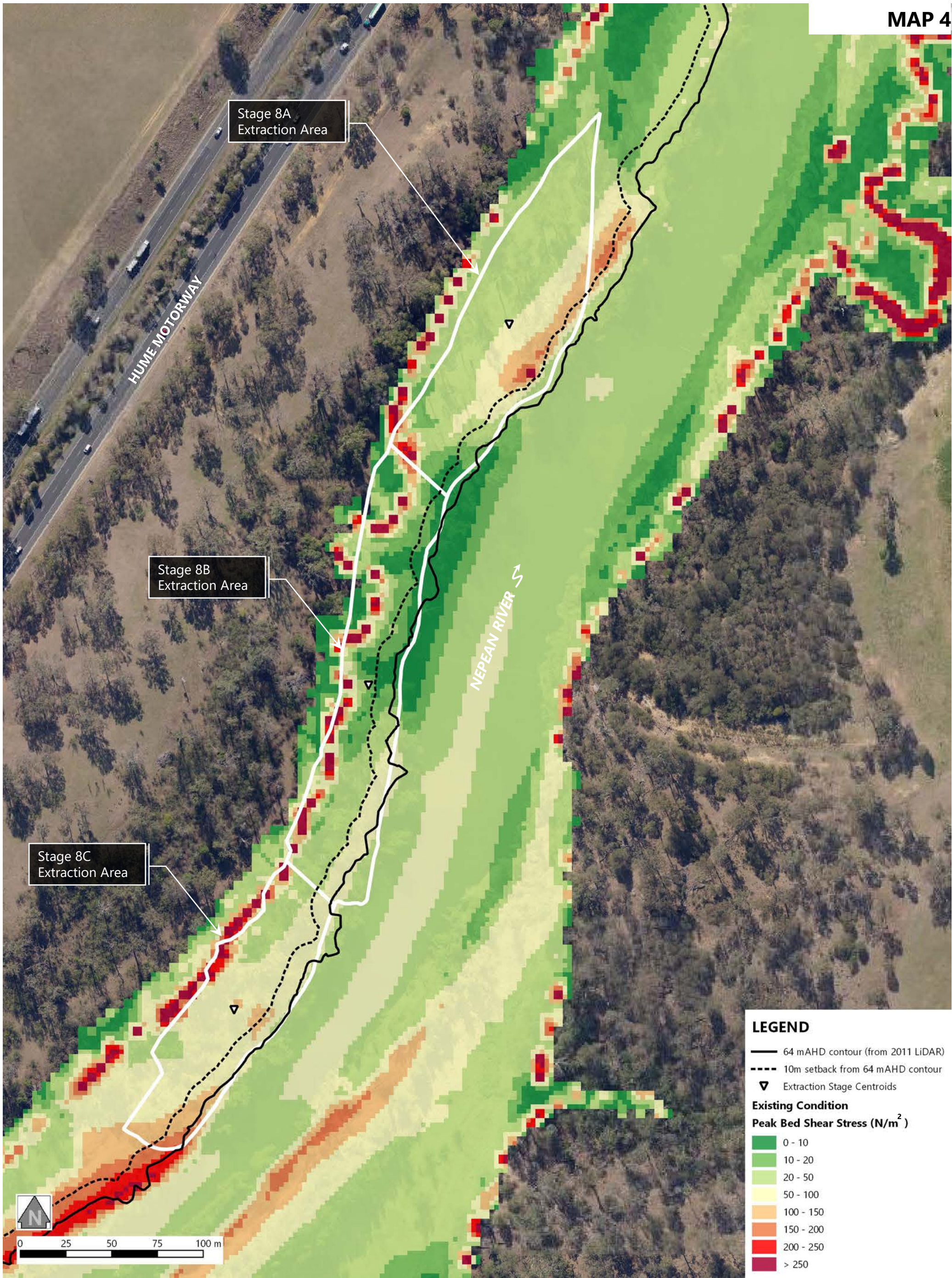
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**STAGES 8A-8C MID-WORKS SCENARIO 1B**  
**MARCH 1978 EVENT SIMULATED PEAK FLOW VELOCITY**





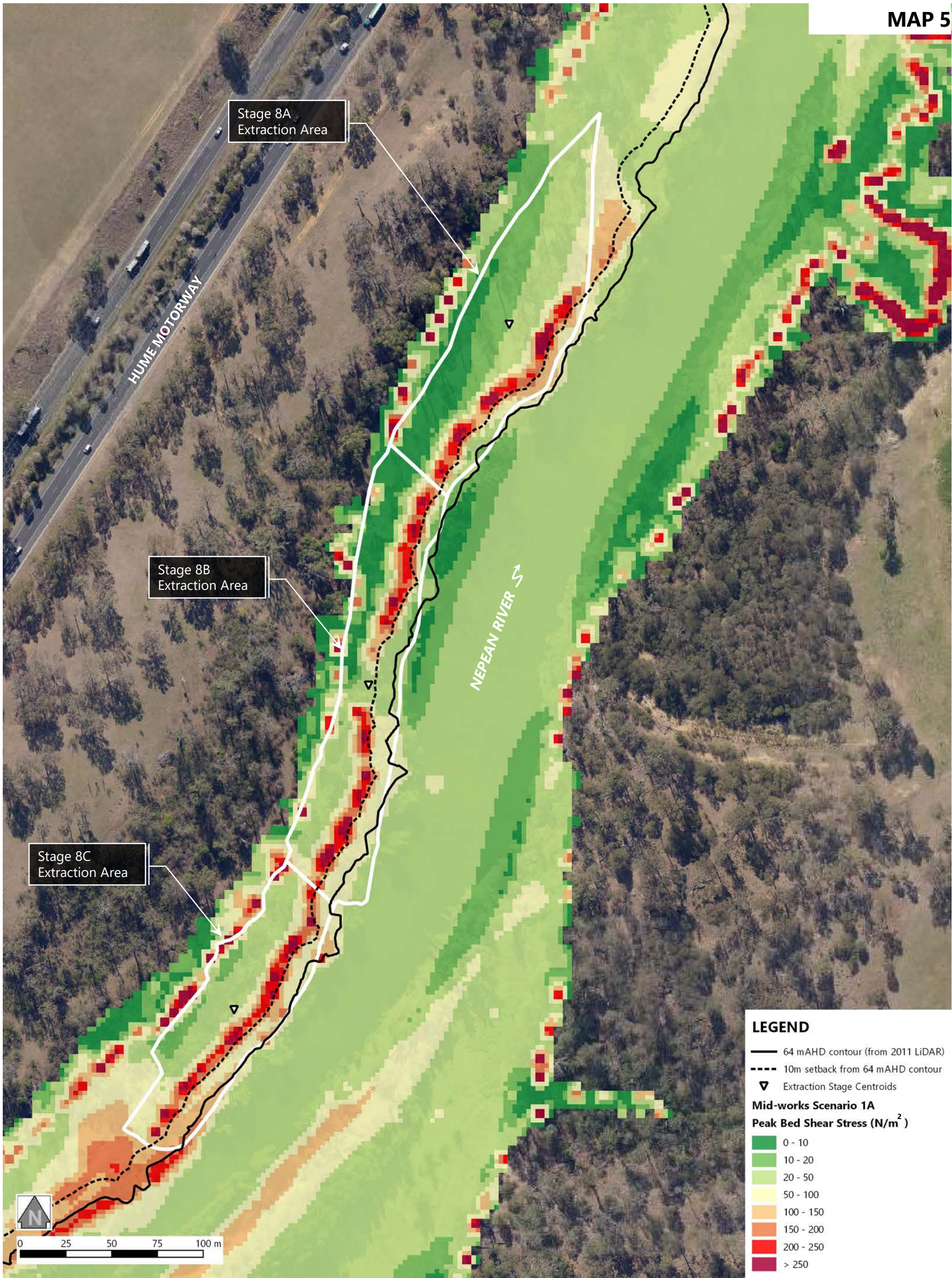
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Worley Group

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**STAGES 8A-8C EXISTING CONDITIONS**  
**MARCH 1978 EVENT SIMULATED PEAK BED SHEAR STRESS**





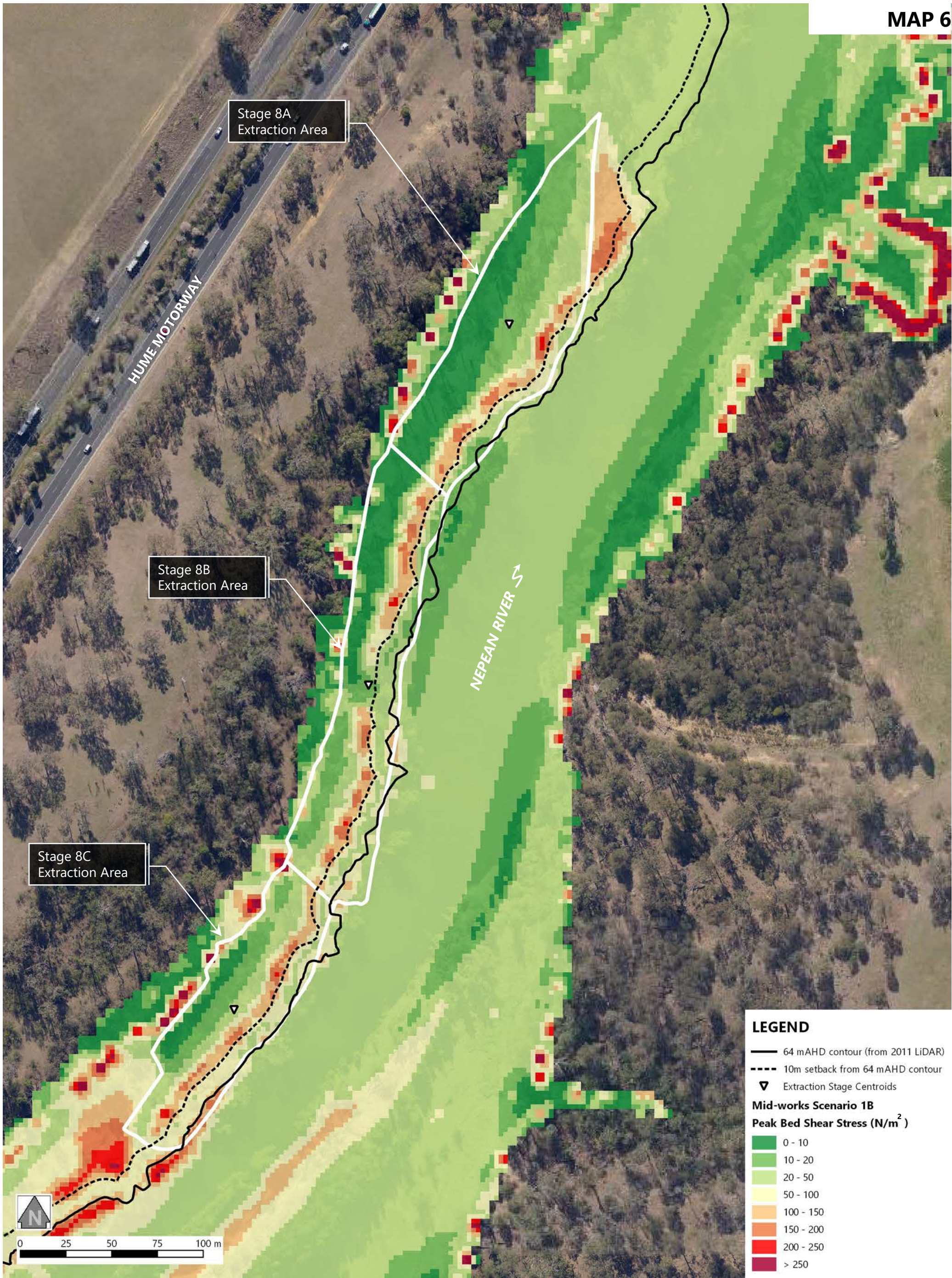
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**STAGES 8A-8C MID-WORKS SCENARIO 1A**  
**MARCH 1978 EVENT SIMULATED PEAK BED SHEAR STRESS**





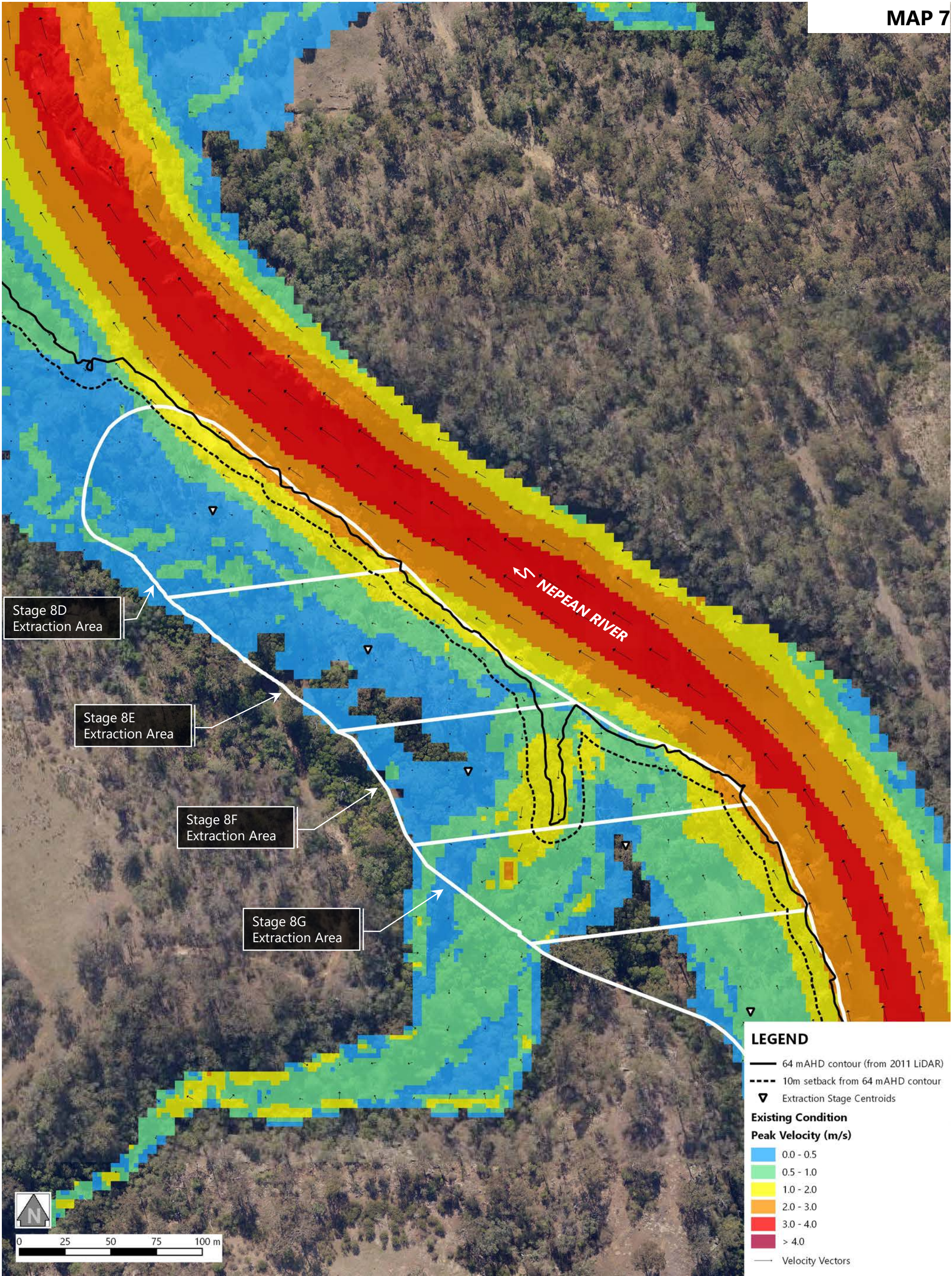
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**STAGES 8A-8C MID-WORKS SCENARIO 1B**  
**MARCH 1978 EVENT SIMULATED PEAK BED SHEAR STRESS**





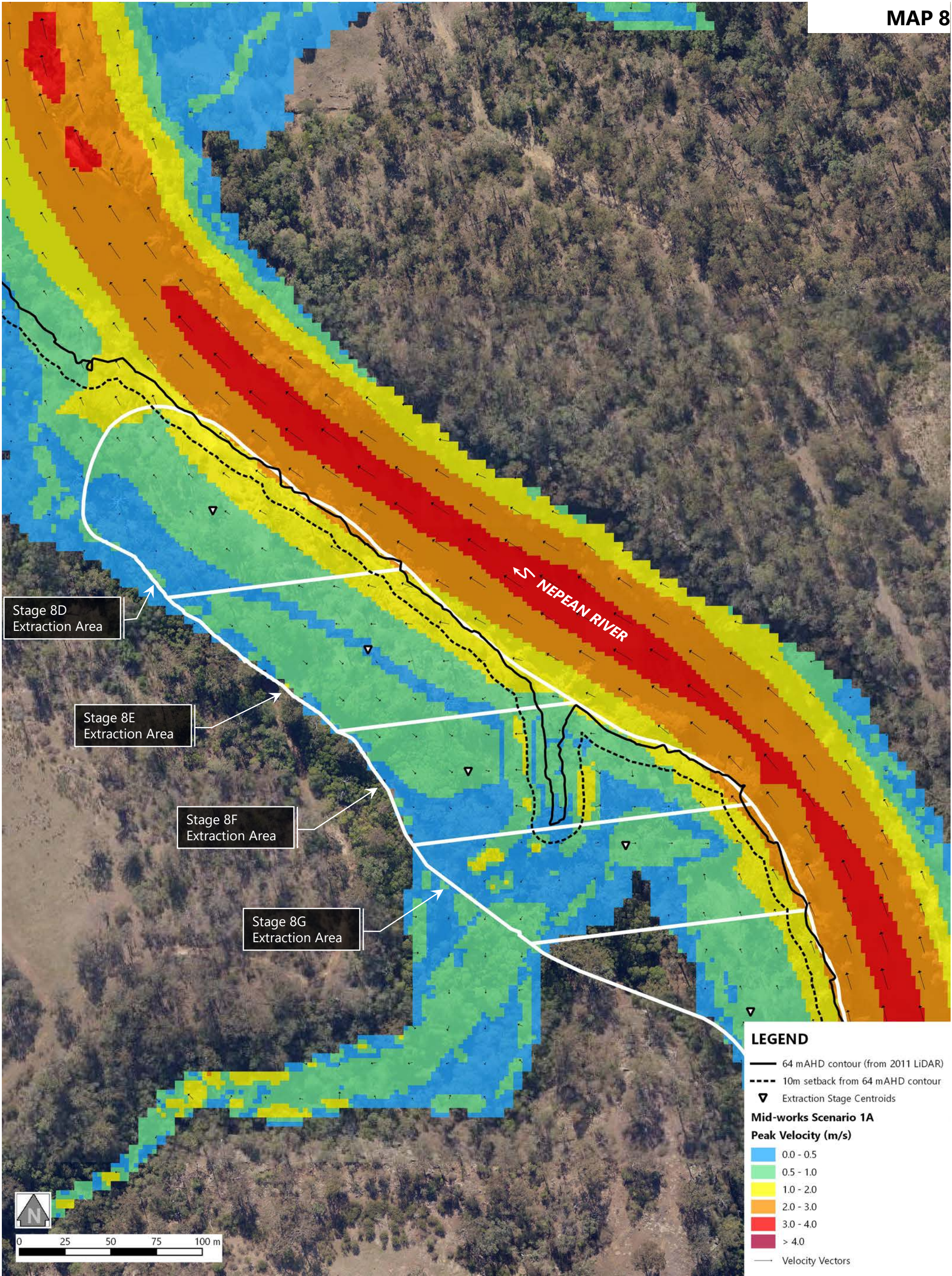
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**STAGES 8D-8G EXISTING CONDITIONS**  
**MARCH 1978 EVENT SIMULATED PEAK FLOW VELOCITY**





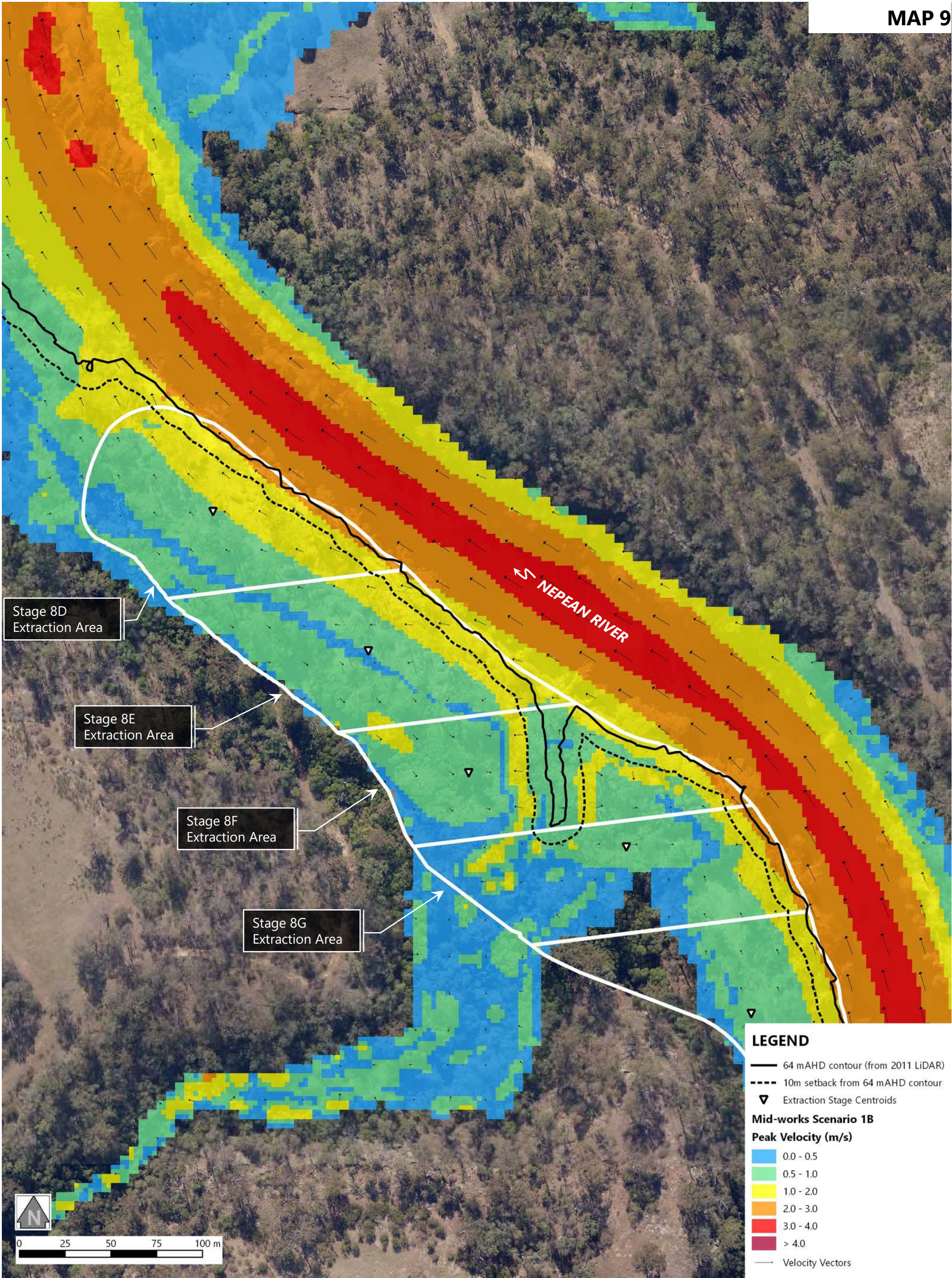
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**STAGES 8D-8G MID-WORKS SCENARIO 1A**  
**MARCH 1978 EVENT SIMULATED PEAK FLOW VELOCITY**





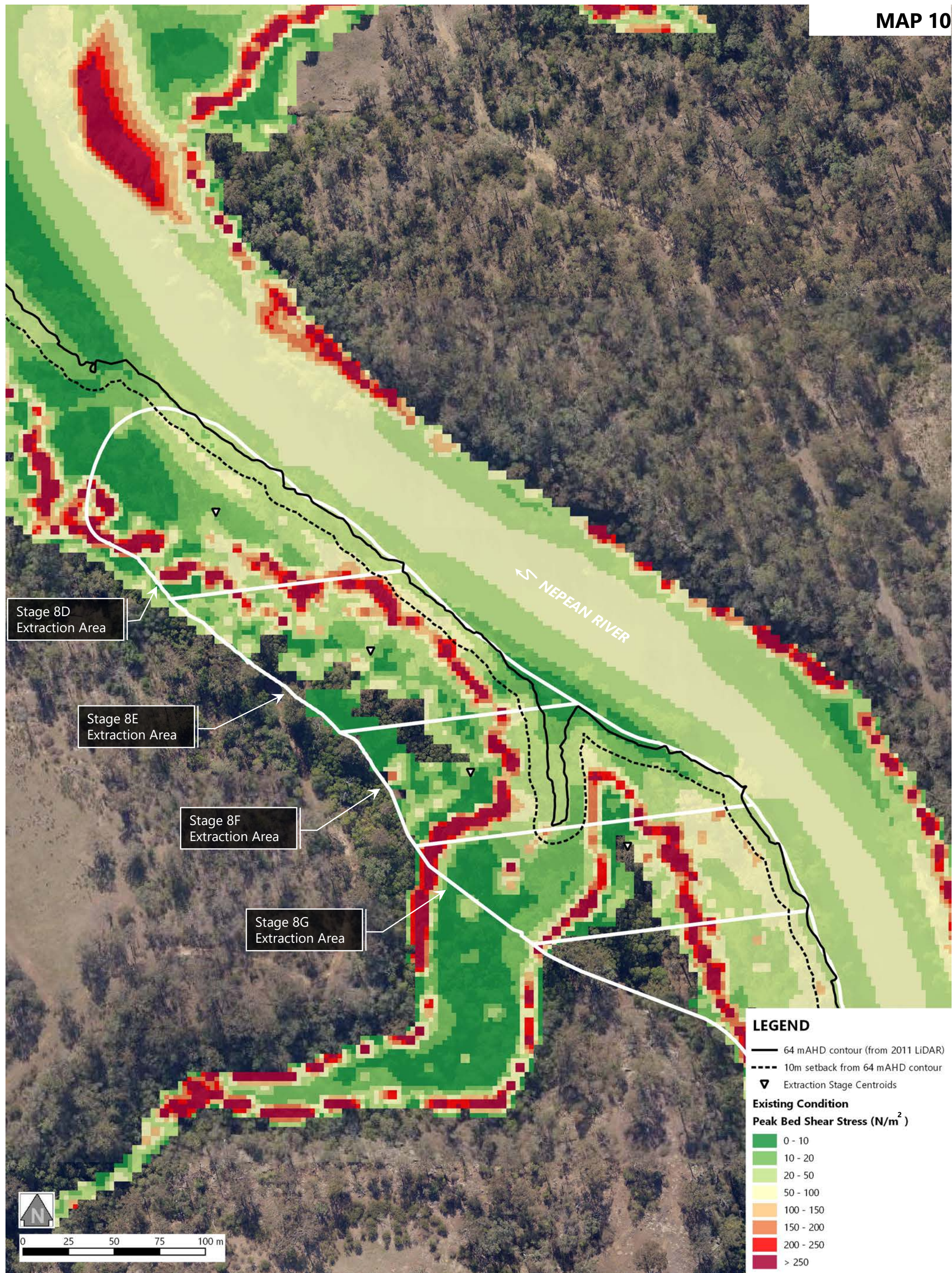
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**STAGES 8D-8G MID-WORKS SCENARIO 1B**  
**MARCH 1978 EVENT SIMULATED PEAK FLOW VELOCITY**





Prepared by:

**Advisian**  
Worley Group

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**STAGES 8D-8G EXISTING CONDITIONS**  
**MARCH 1978 EVENT SIMULATED PEAK BED SHEAR STRESS**





Prepared by:

**Advisian**  
Worley Group

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**STAGES 8D-8G MID-WORKS SCENARIO 1A**  
**MARCH 1978 EVENT SIMULATED PEAK BED SHEAR STRESS**





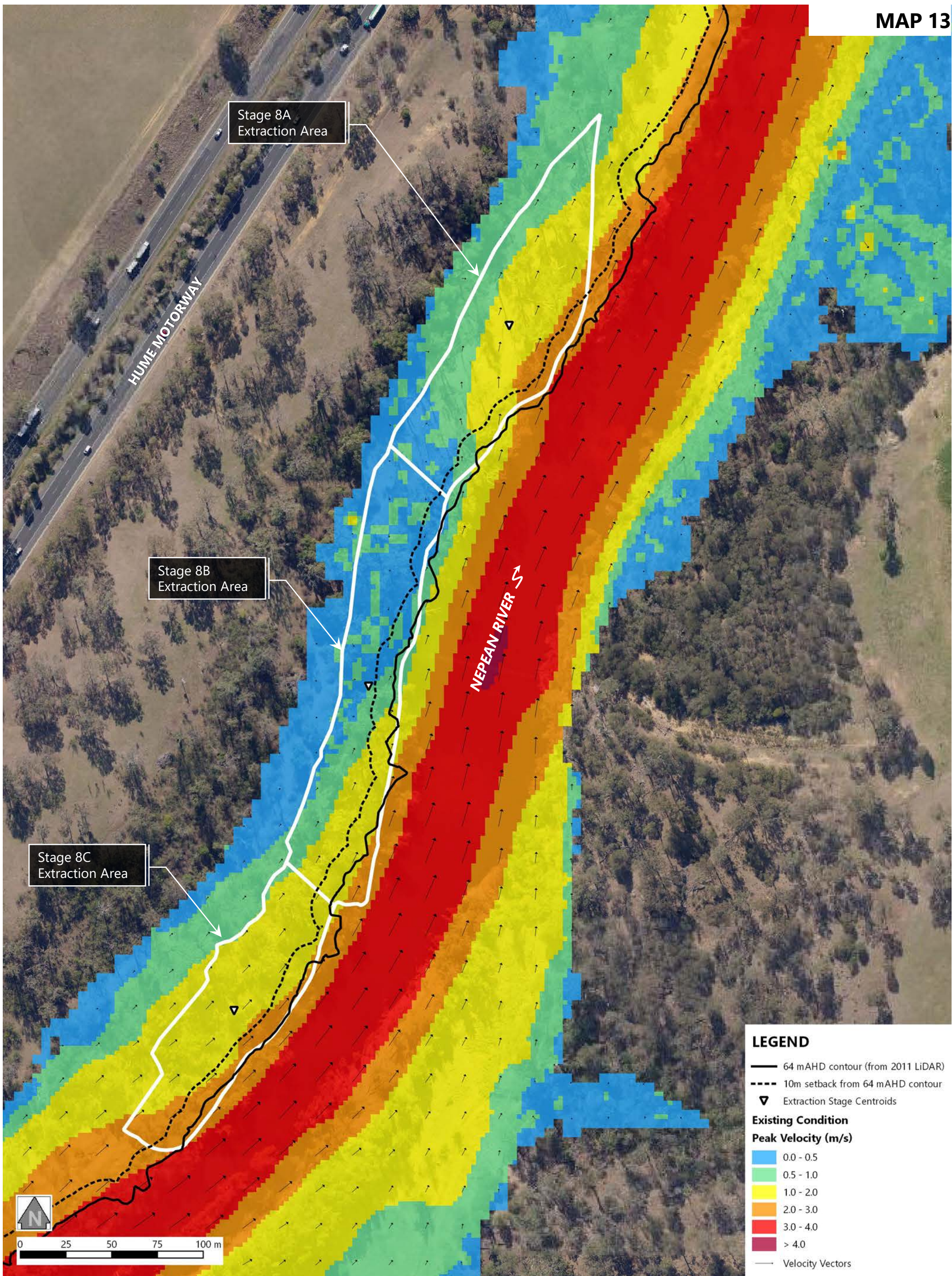
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**STAGES 8D-8G MID-WORKS SCENARIO 1B**  
**MARCH 1978 EVENT SIMULATED PEAK BED SHEAR STRESS**





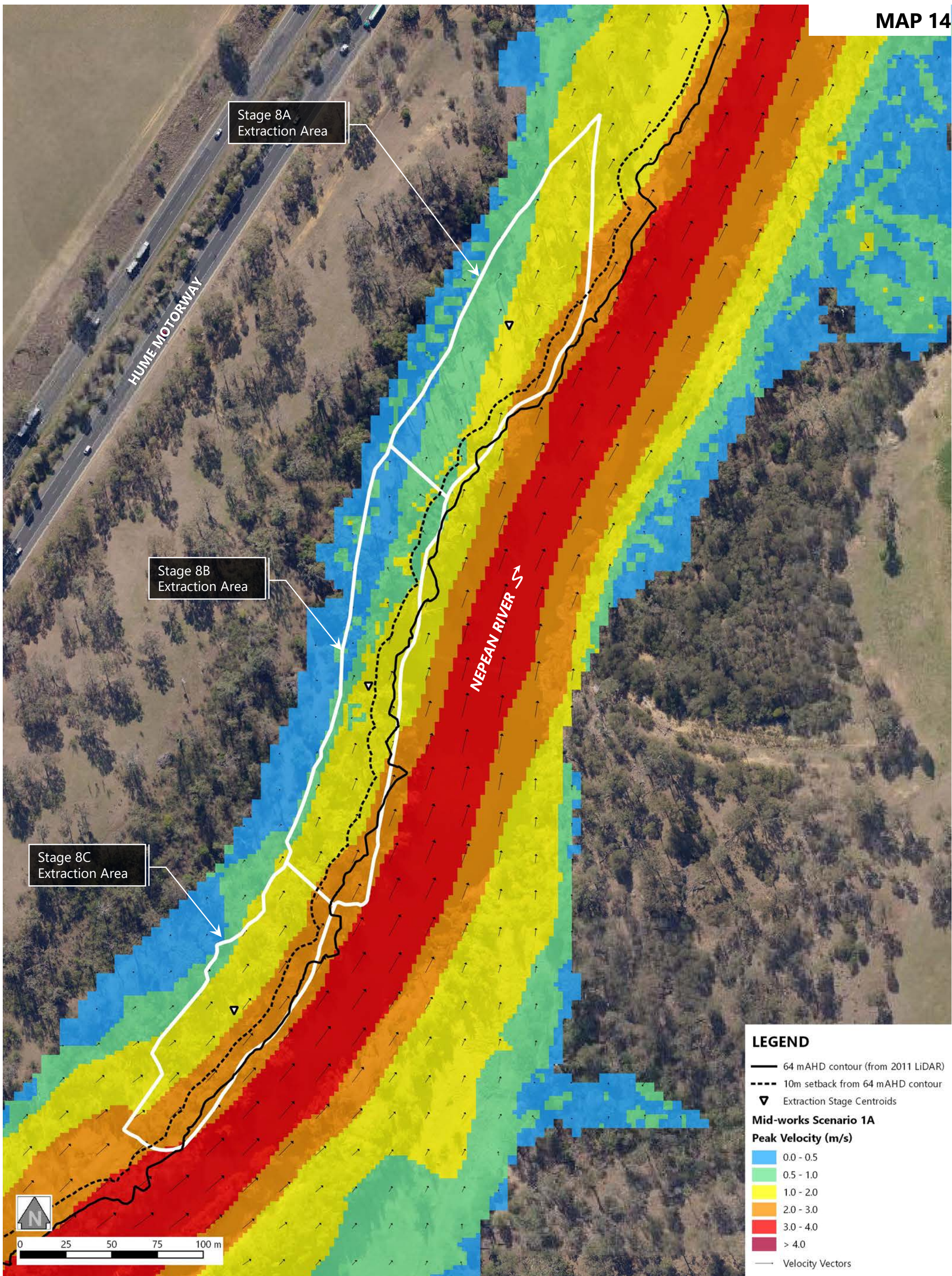
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**5% AEP SIMULATED PEAK FLOW VELOCITY**





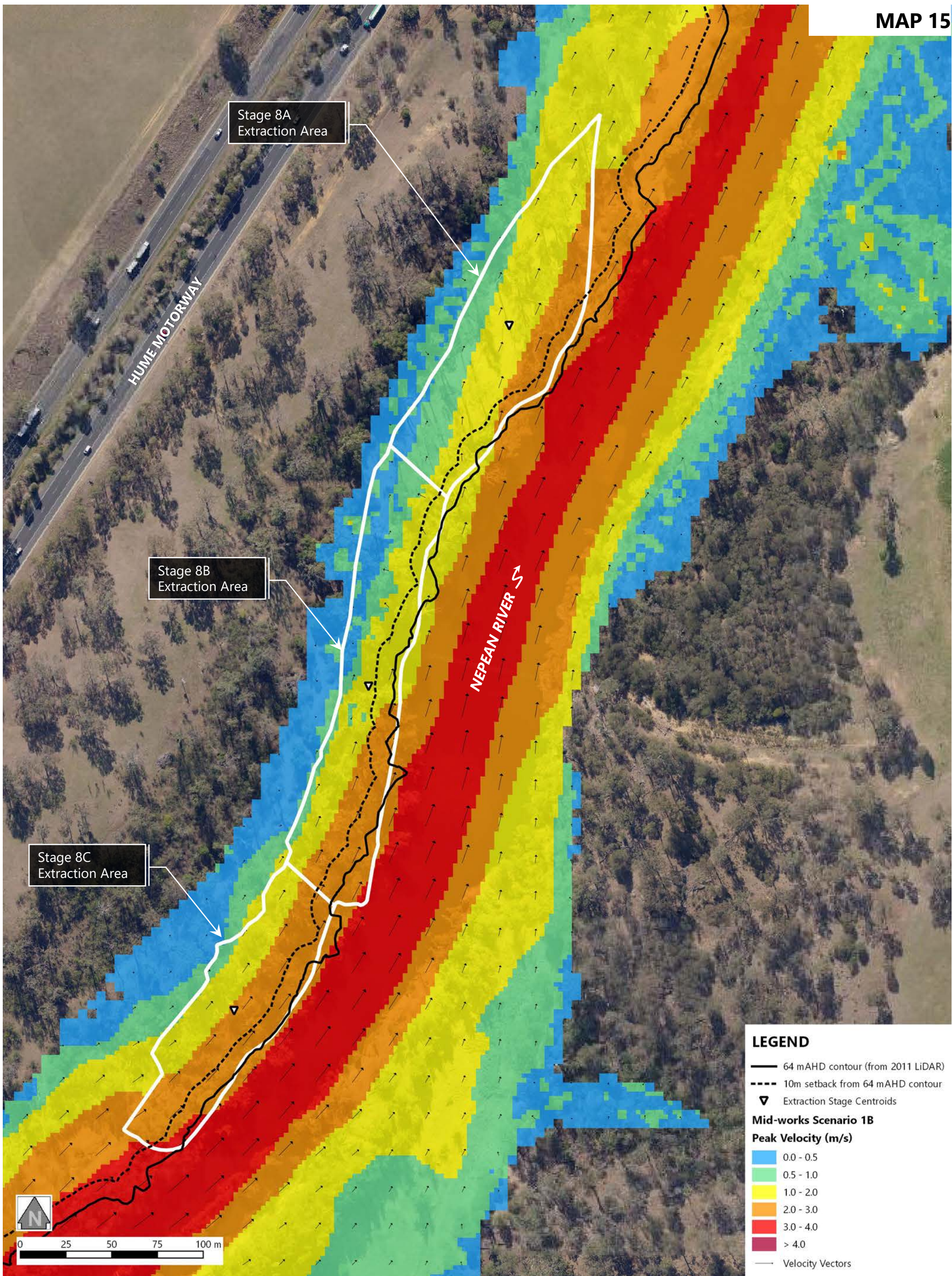
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**STAGES 8A-8C MID-WORKS SCENARIO 1A**  
**5% AEP SIMULATED PEAK FLOW VELOCITY**





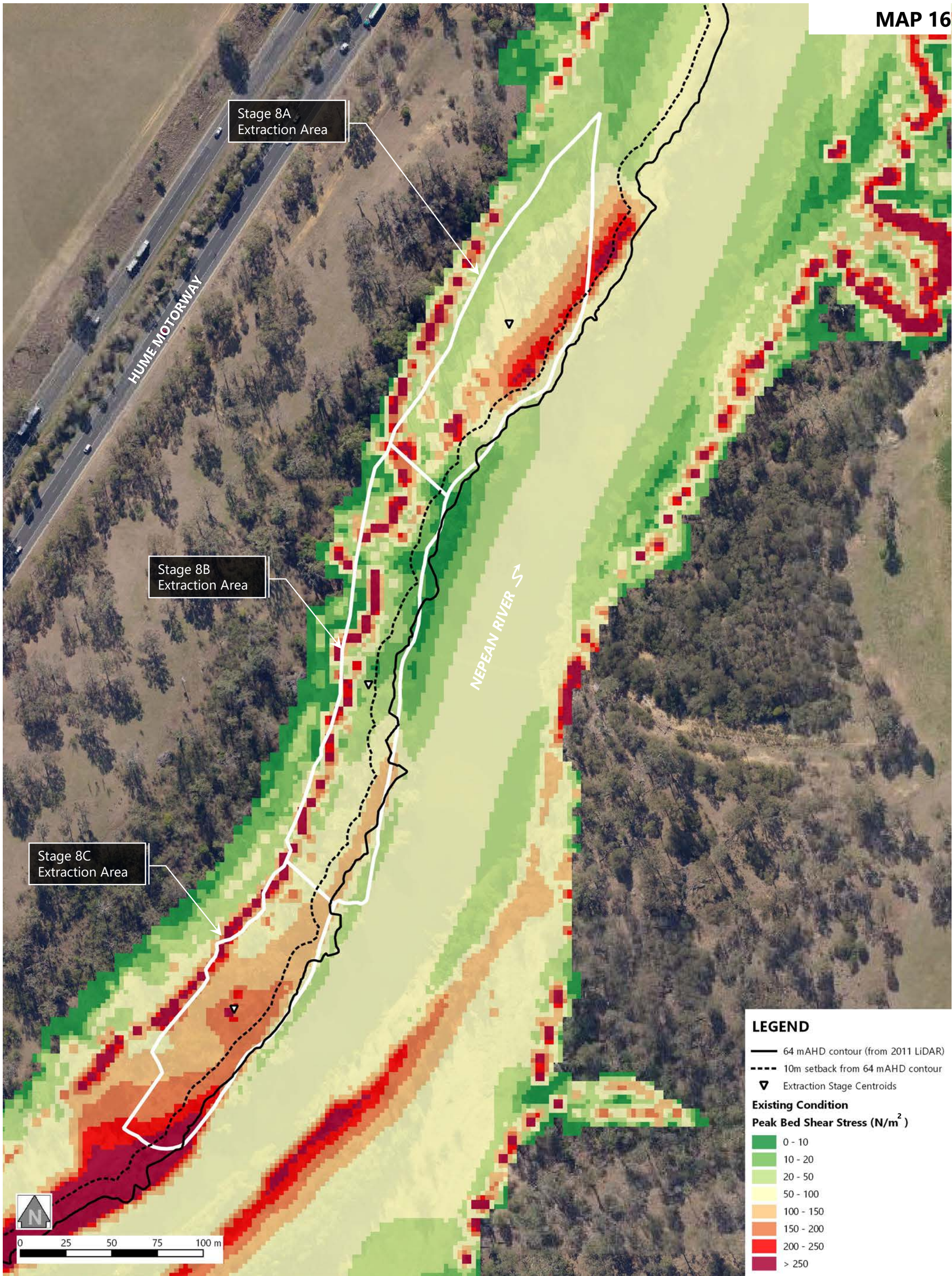
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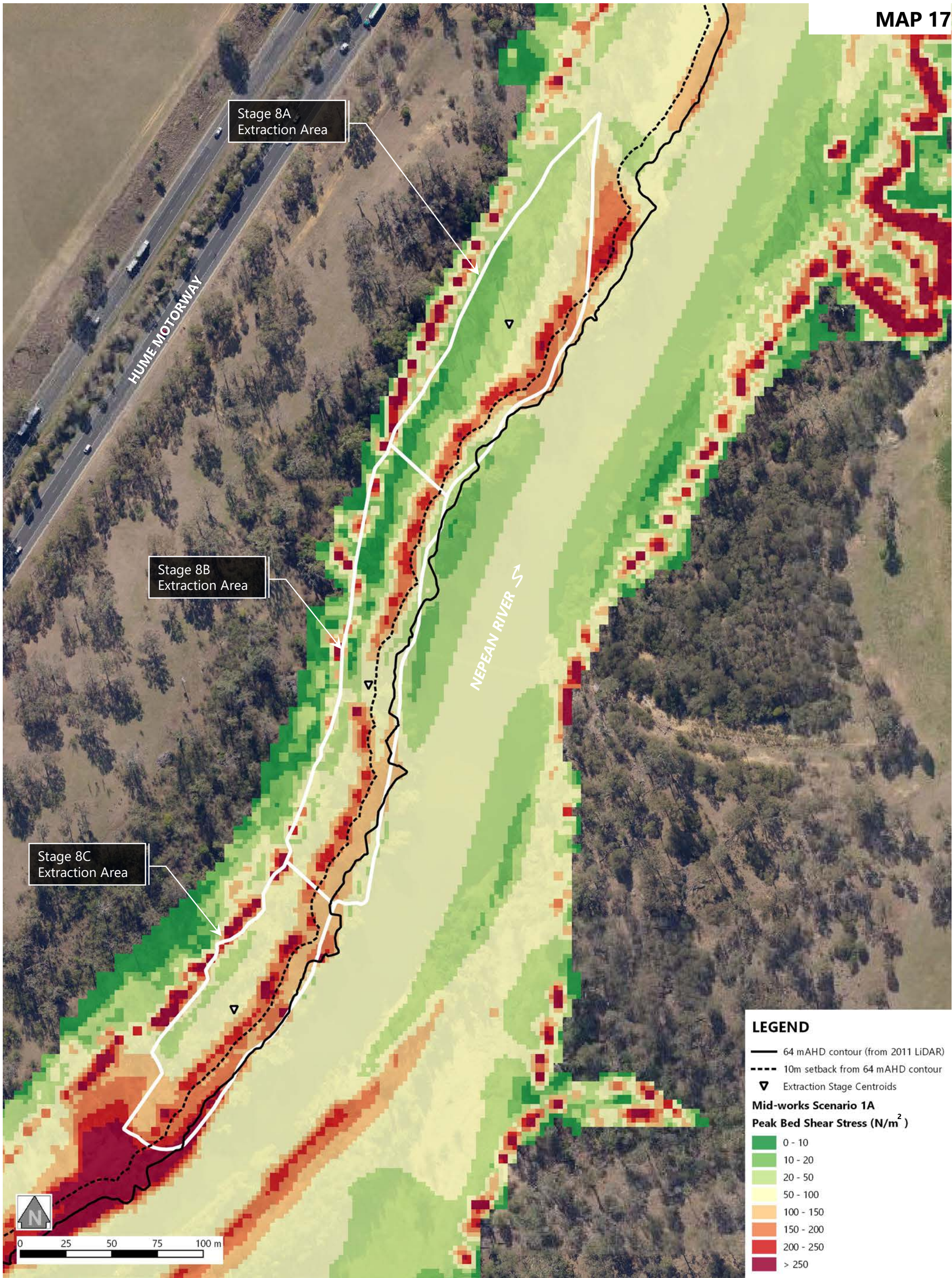
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**STAGES 8A-8C EXISTING CONDITIONS**  
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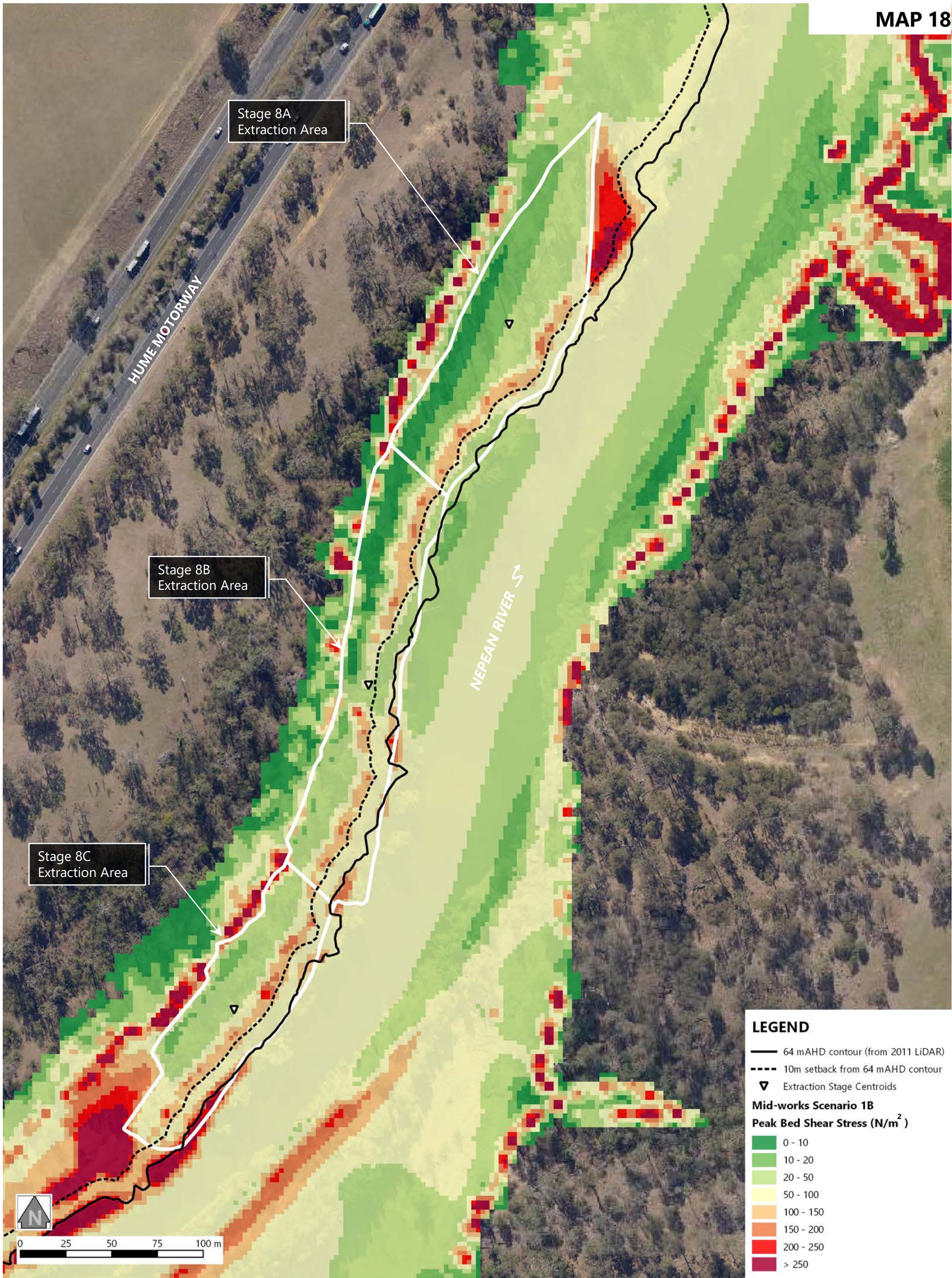
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**STAGES 8A-8C MID-WORKS SCENARIO 1A**  
**5% AEP SIMULATED PEAK BED SHEAR STRESS**





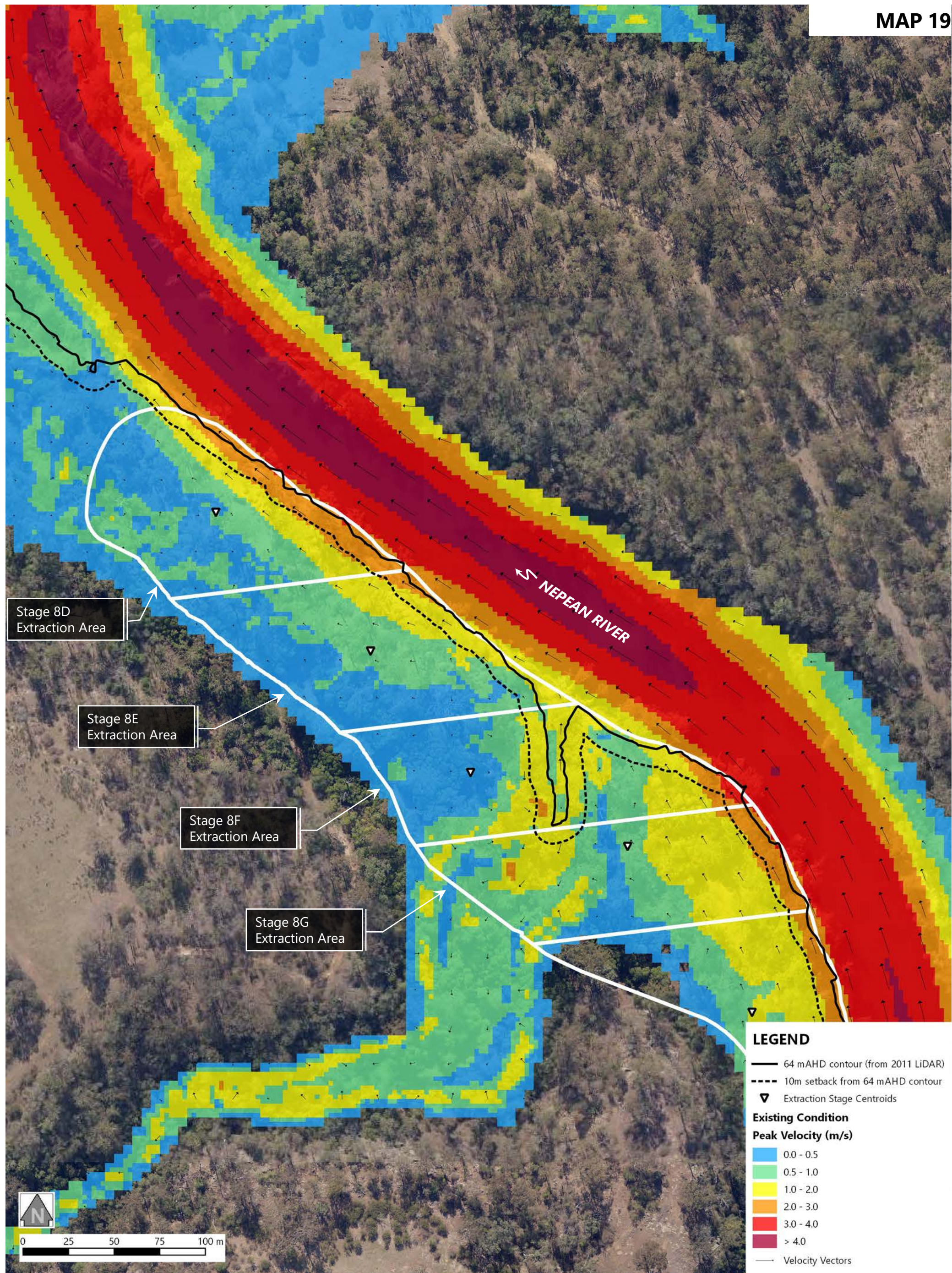
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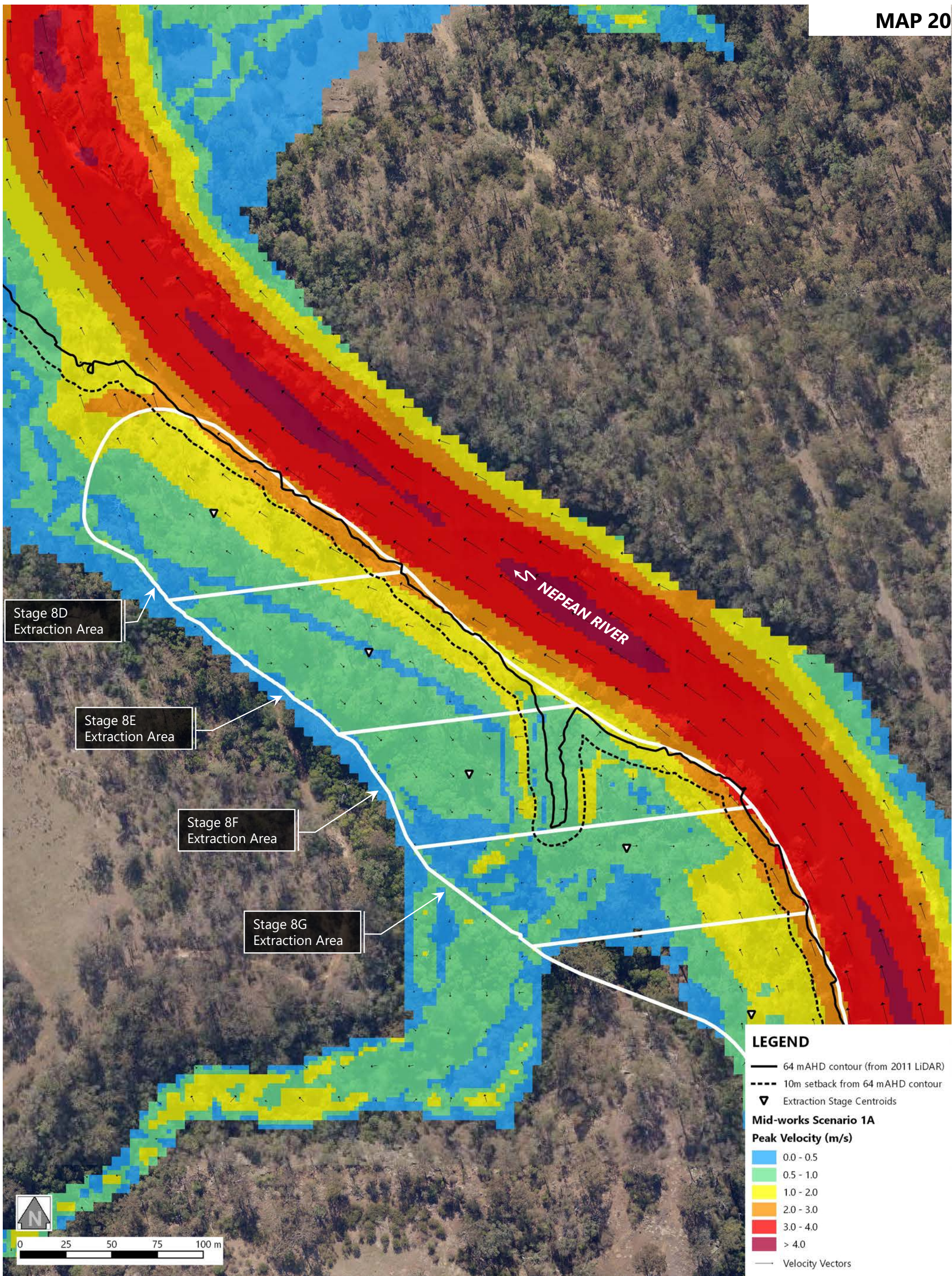
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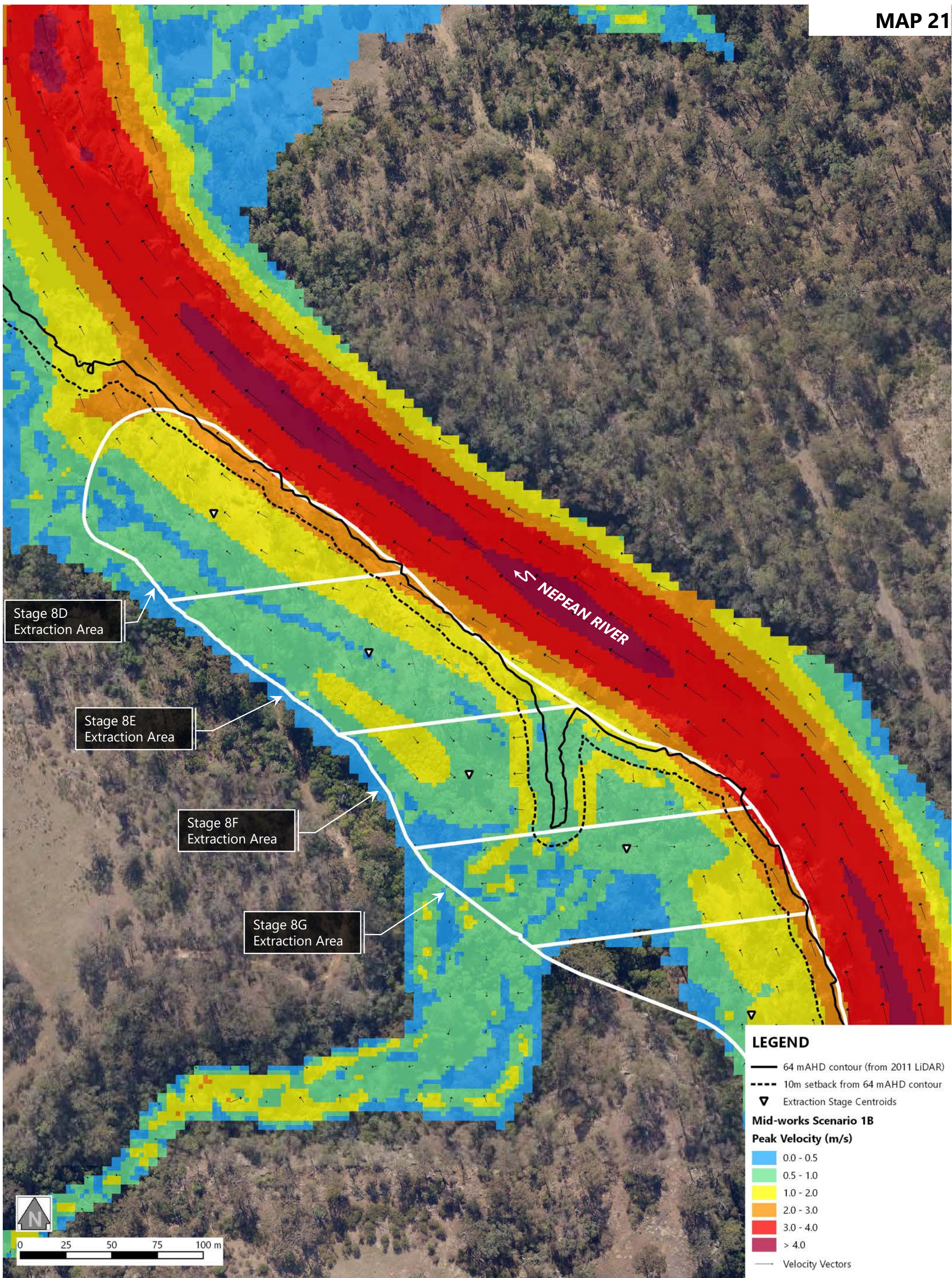
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**STAGES 8D-8G MID-WORKS SCENARIO 1A**  
**5% AEP SIMULATED PEAK FLOW VELOCITY**





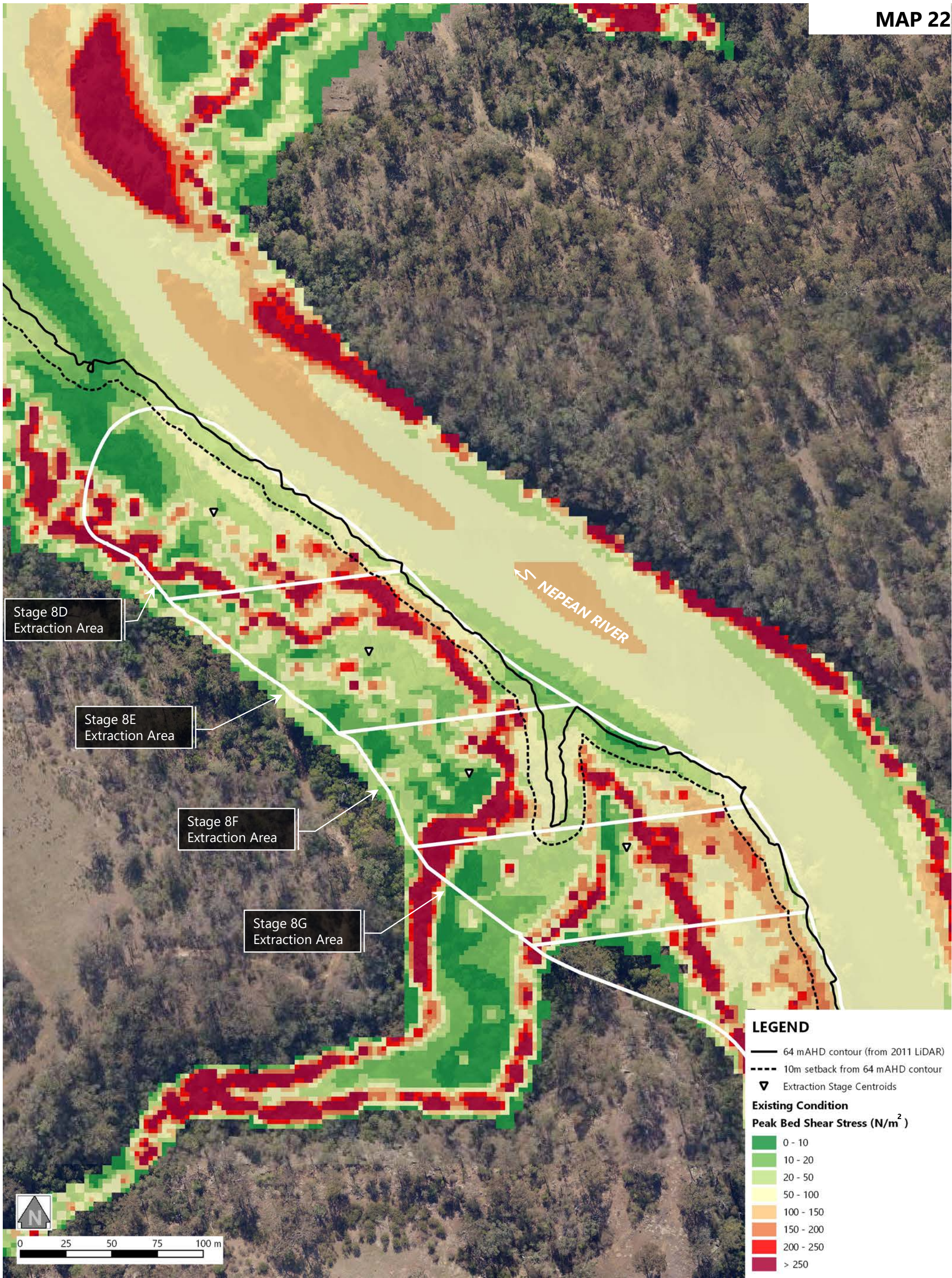
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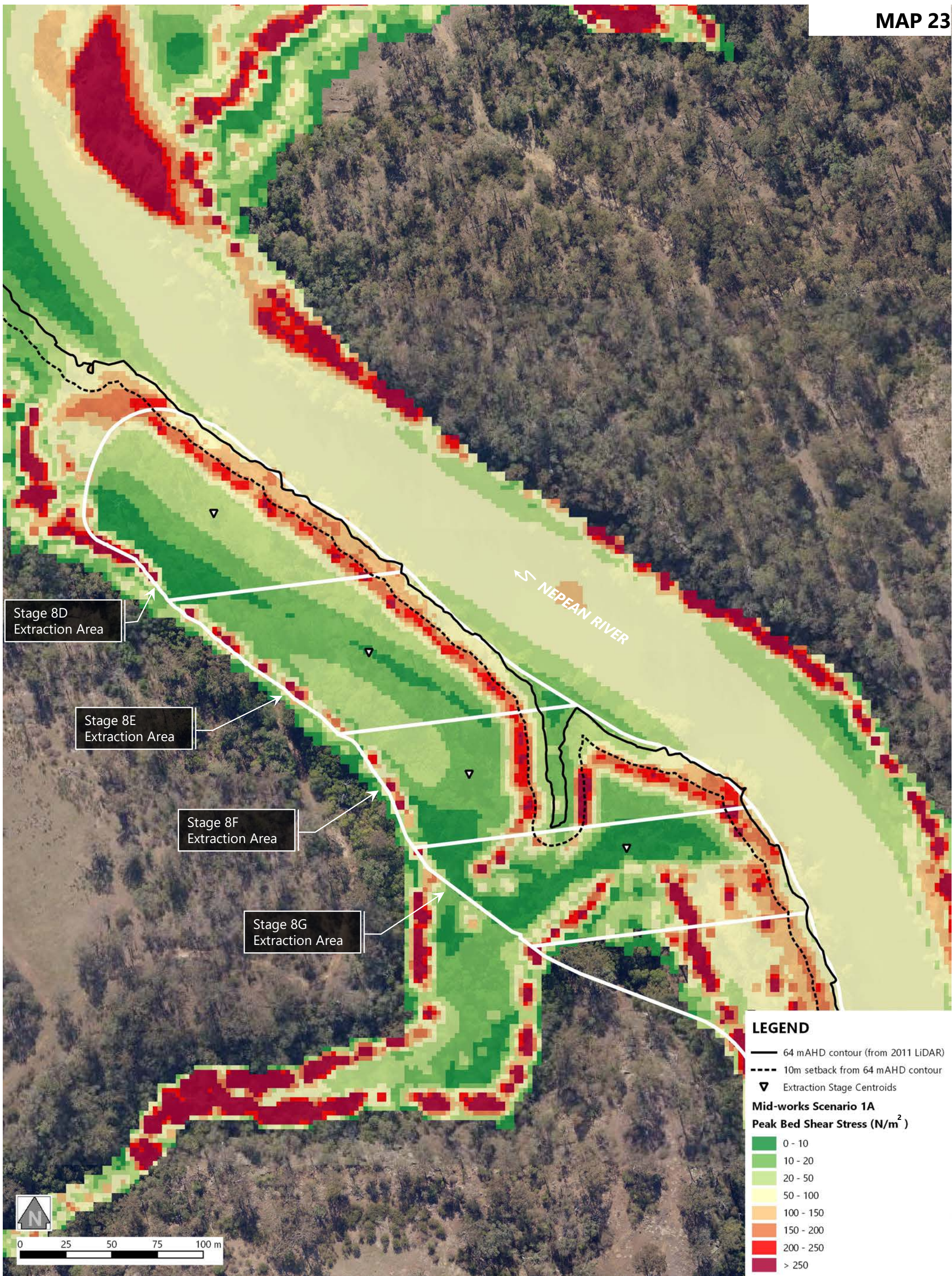
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**STAGES 8D-8G EXISTING CONDITIONS**  
**5% AEP SIMULATED PEAK BED SHEAR STRESS**





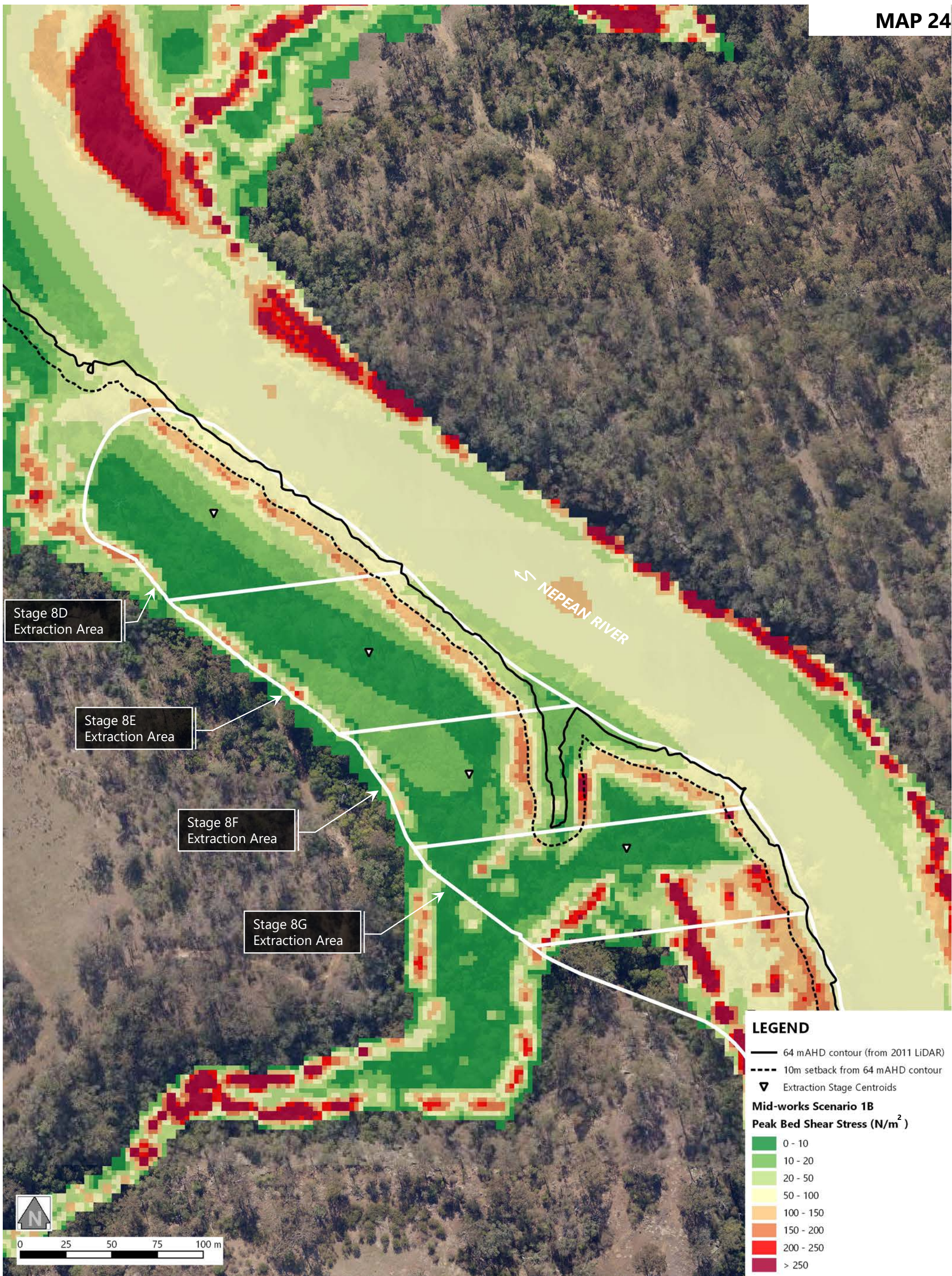
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**STAGES 8D-8G MID-WORKS SCENARIO 1A**  
**5% AEP SIMULATED PEAK BED SHEAR STRESS**





**LEGEND**

- 64 mAHd contour (from 2011 LiDAR)
  - - - 10m setback from 64 mAHd contour
  - ▼ Extraction Stage Centroids
- Mid-works Scenario 1B**  
**Peak Bed Shear Stress ( $\text{N/m}^2$ )**
- |           |
|-----------|
| 0 - 10    |
| 10 - 20   |
| 20 - 50   |
| 50 - 100  |
| 100 - 150 |
| 150 - 200 |
| 200 - 250 |
| > 250     |

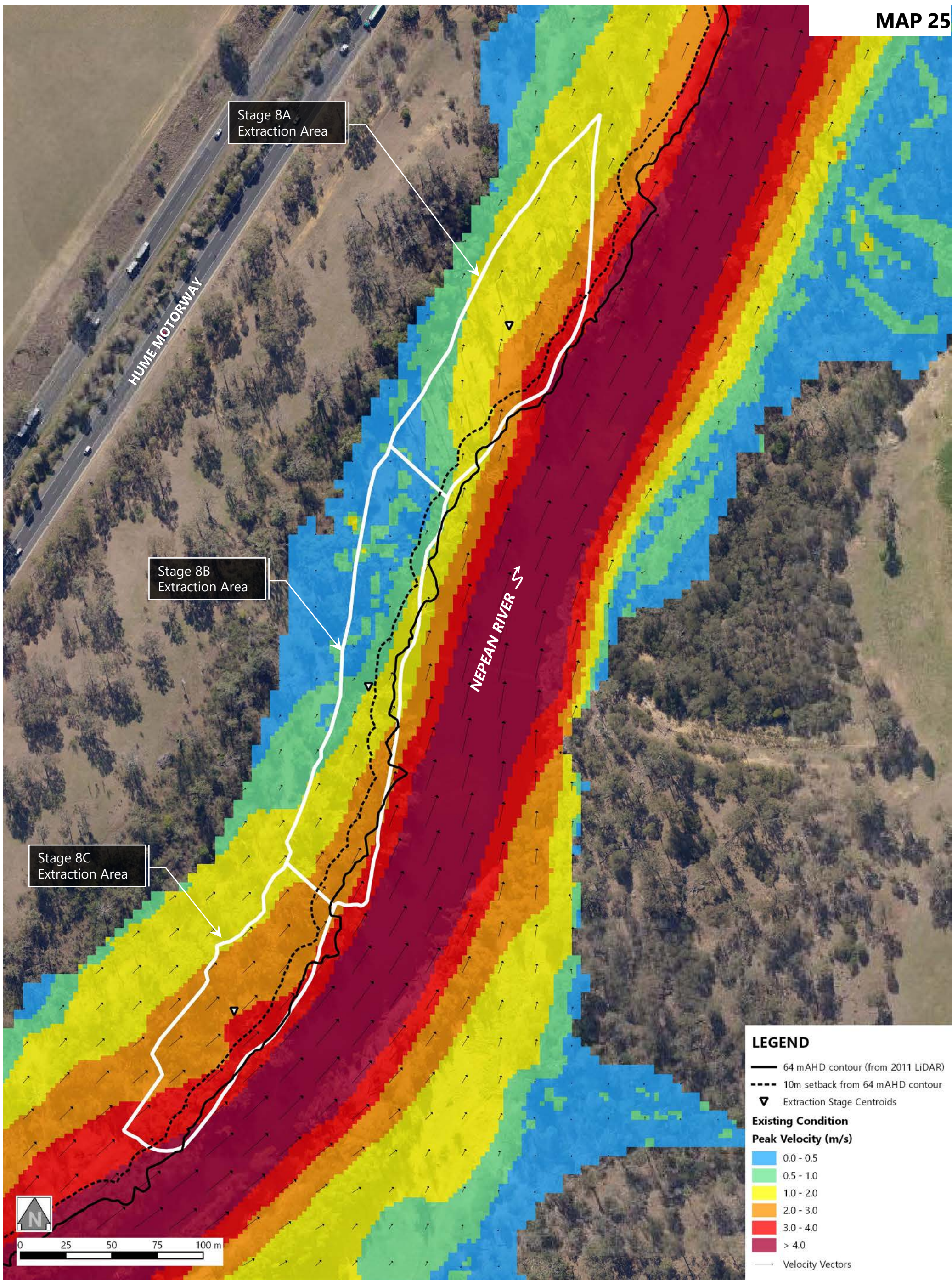
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**STAGES 8D-8G MID-WORKS SCENARIO 1B**  
**5% AEP SIMULATED PEAK BED SHEAR STRESS**





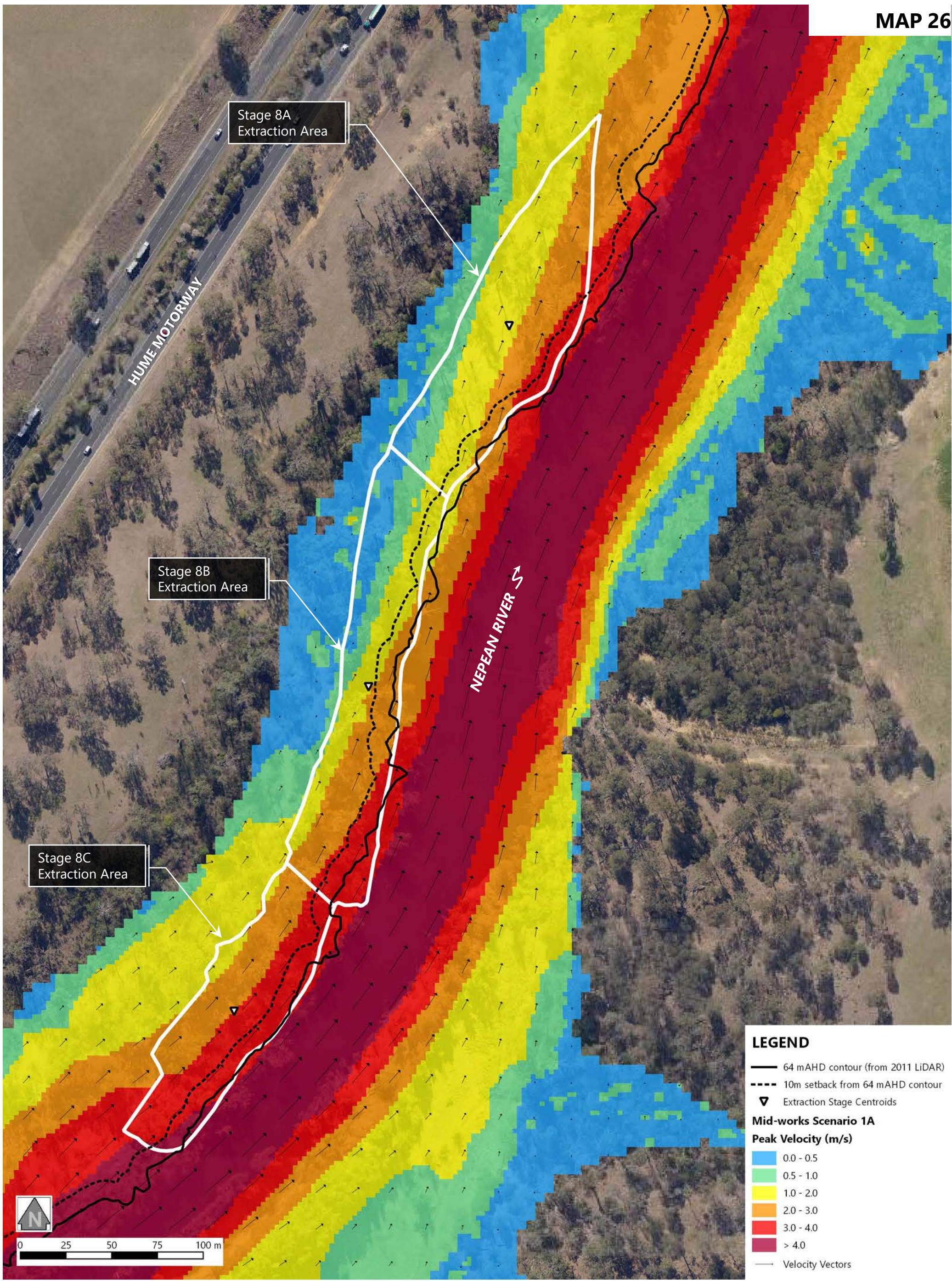
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**STAGES 8A-8C EXISTING CONDITIONS**  
**1% AEP SIMULATED PEAK FLOW VELOCITY**





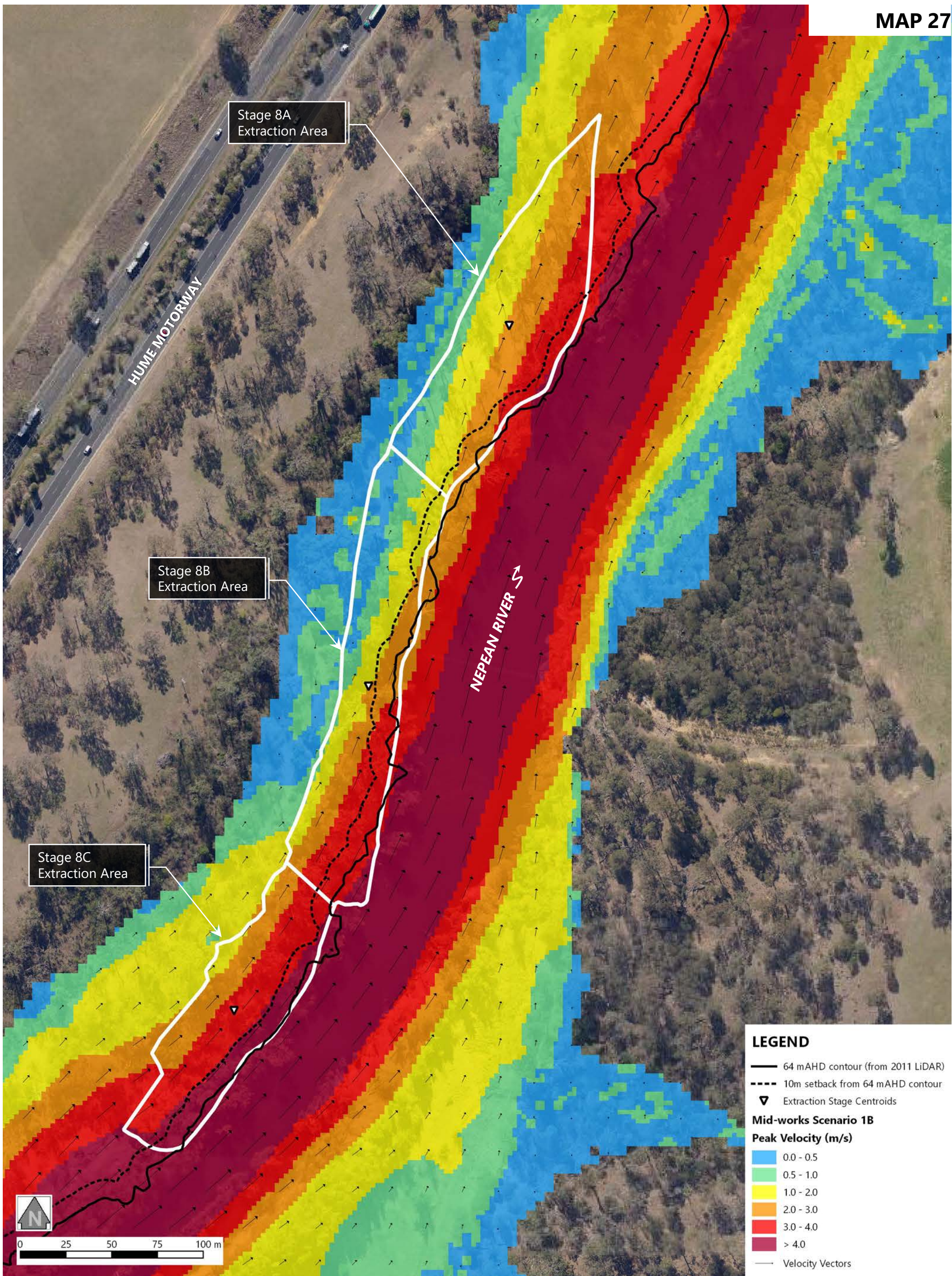
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**STAGES 8A-8C MID-WORKS SCENARIO 1A**  
**1% AEP SIMULATED PEAK FLOW VELOCITY**





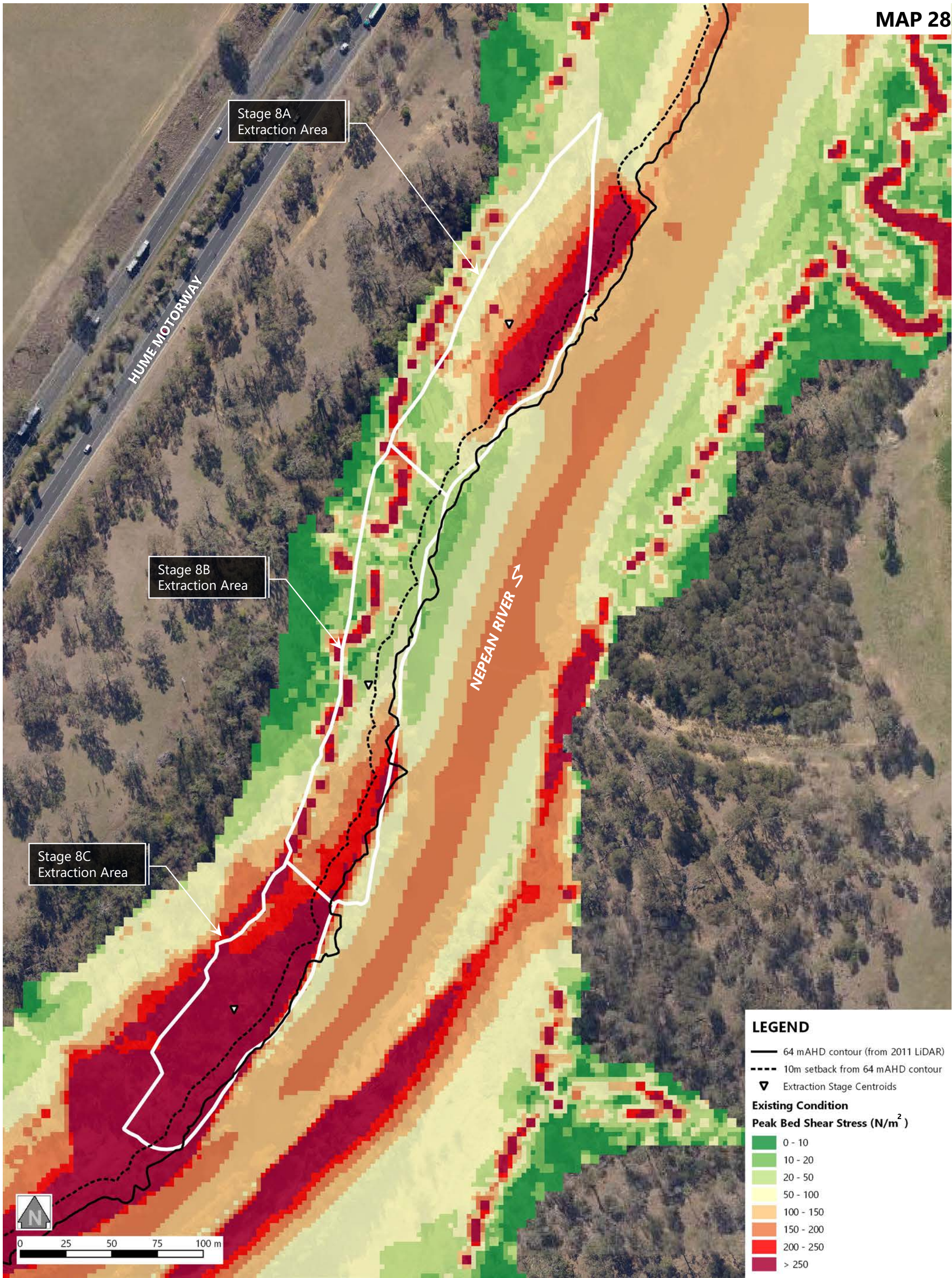
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**STAGES 8A-8C MID-WORKS SCENARIO 1B**  
**1% AEP SIMULATED PEAK FLOW VELOCITY**





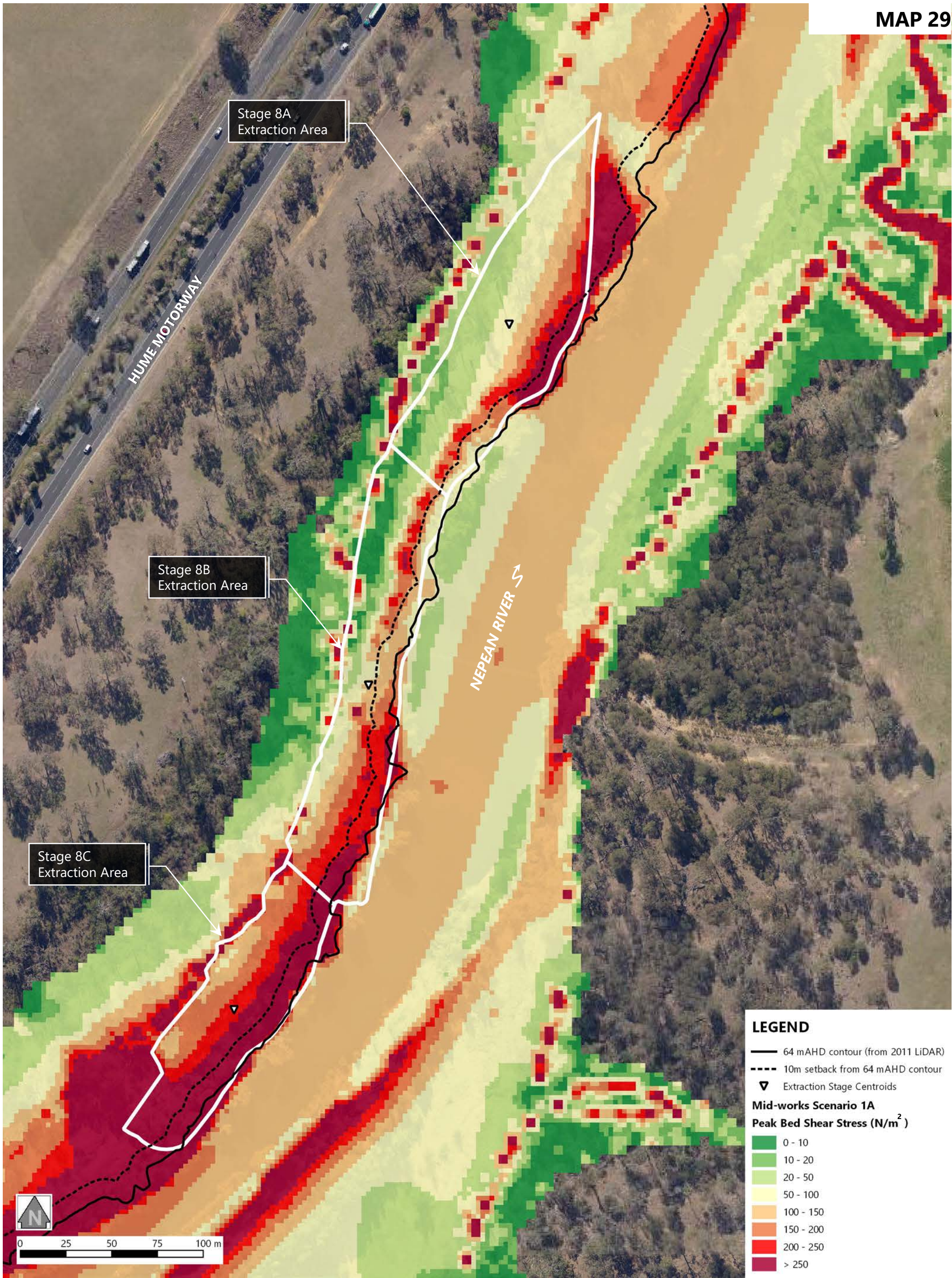
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**STAGES 8A-8C EXISTING CONDITIONS**  
**1% AEP SIMULATED PEAK BED SHEAR STRESS**





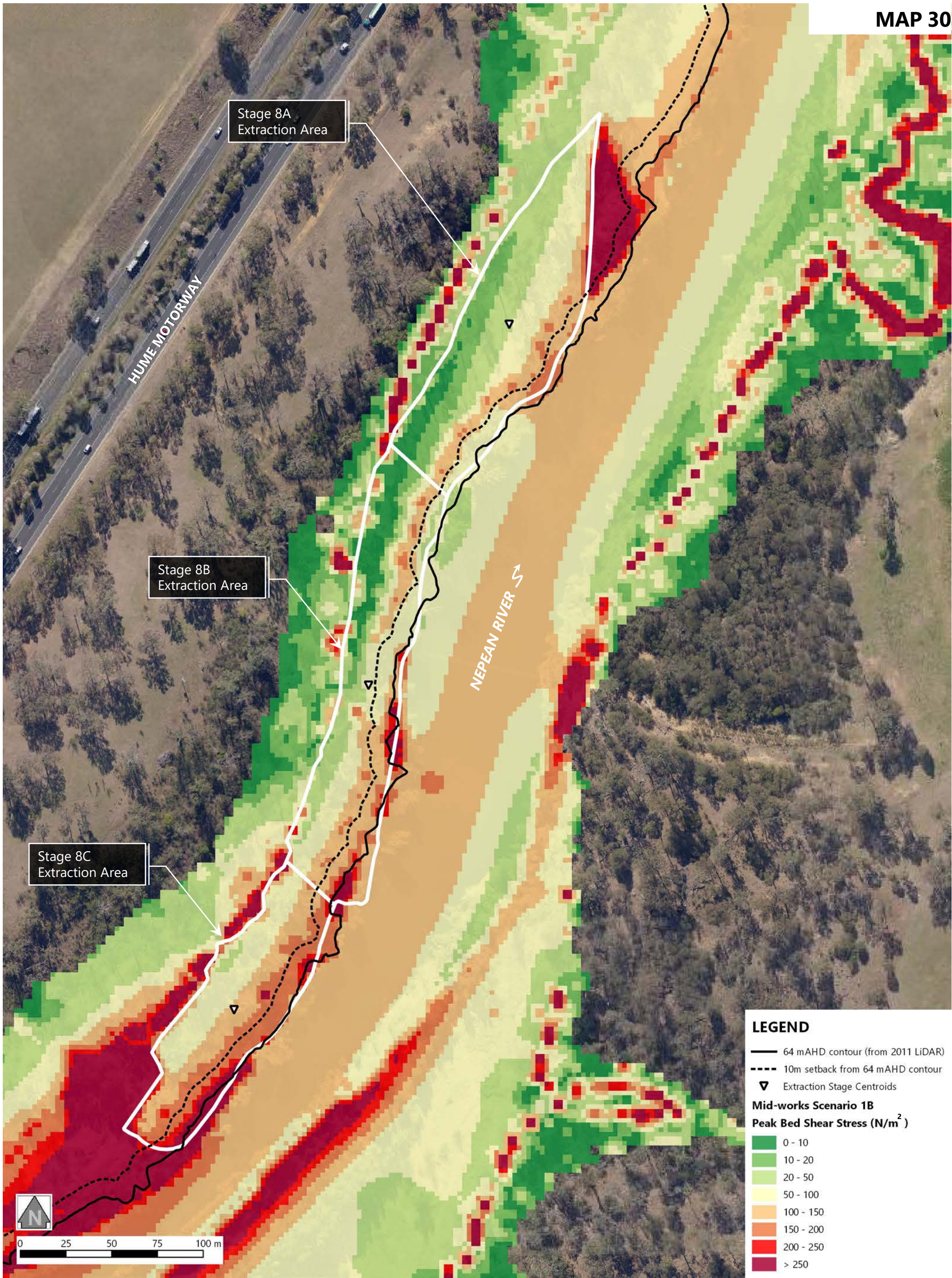
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**STAGES 8A-8C MID-WORKS SCENARIO 1A**  
**1% AEP SIMULATED PEAK BED SHEAR STRESS**





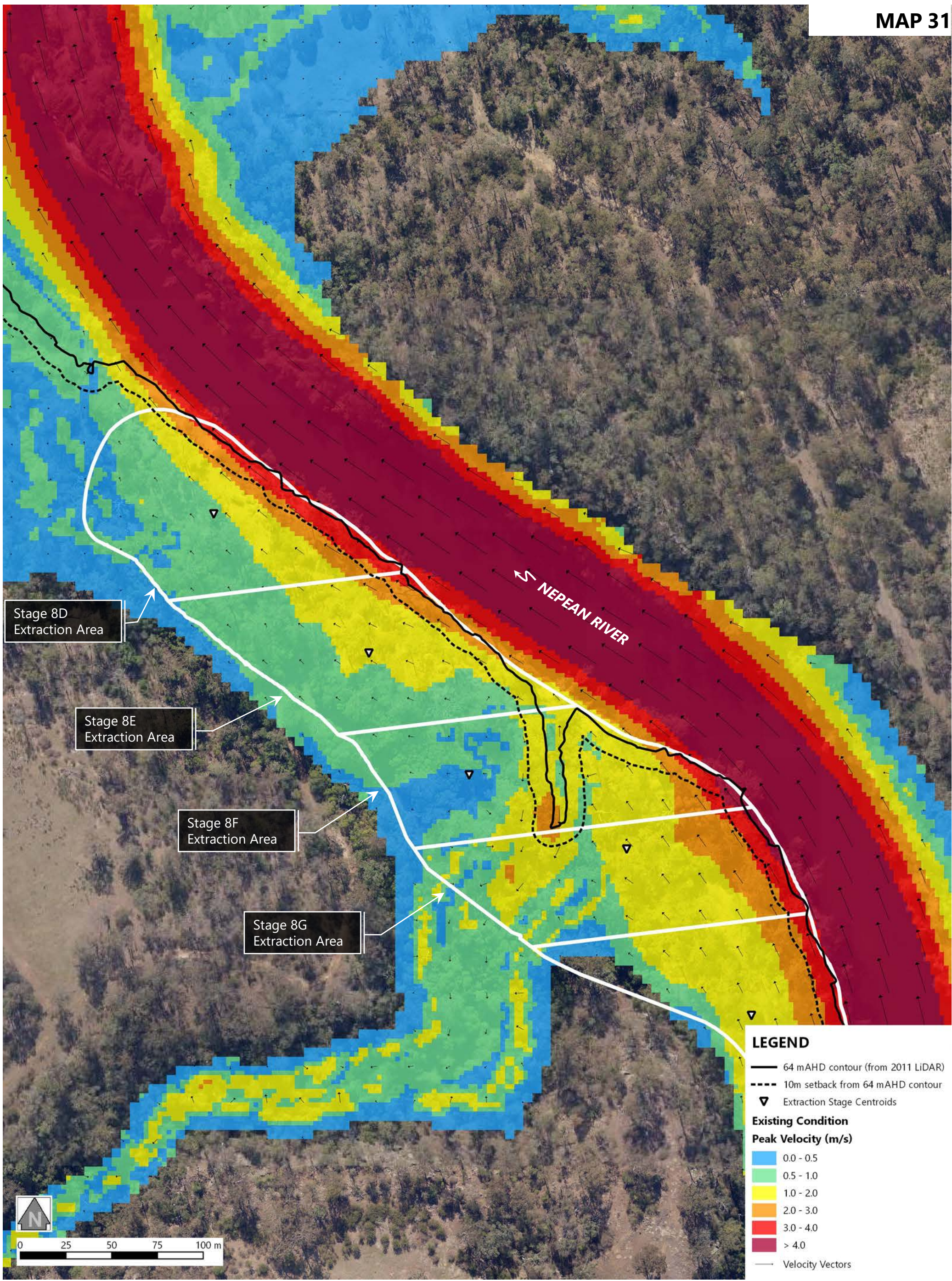
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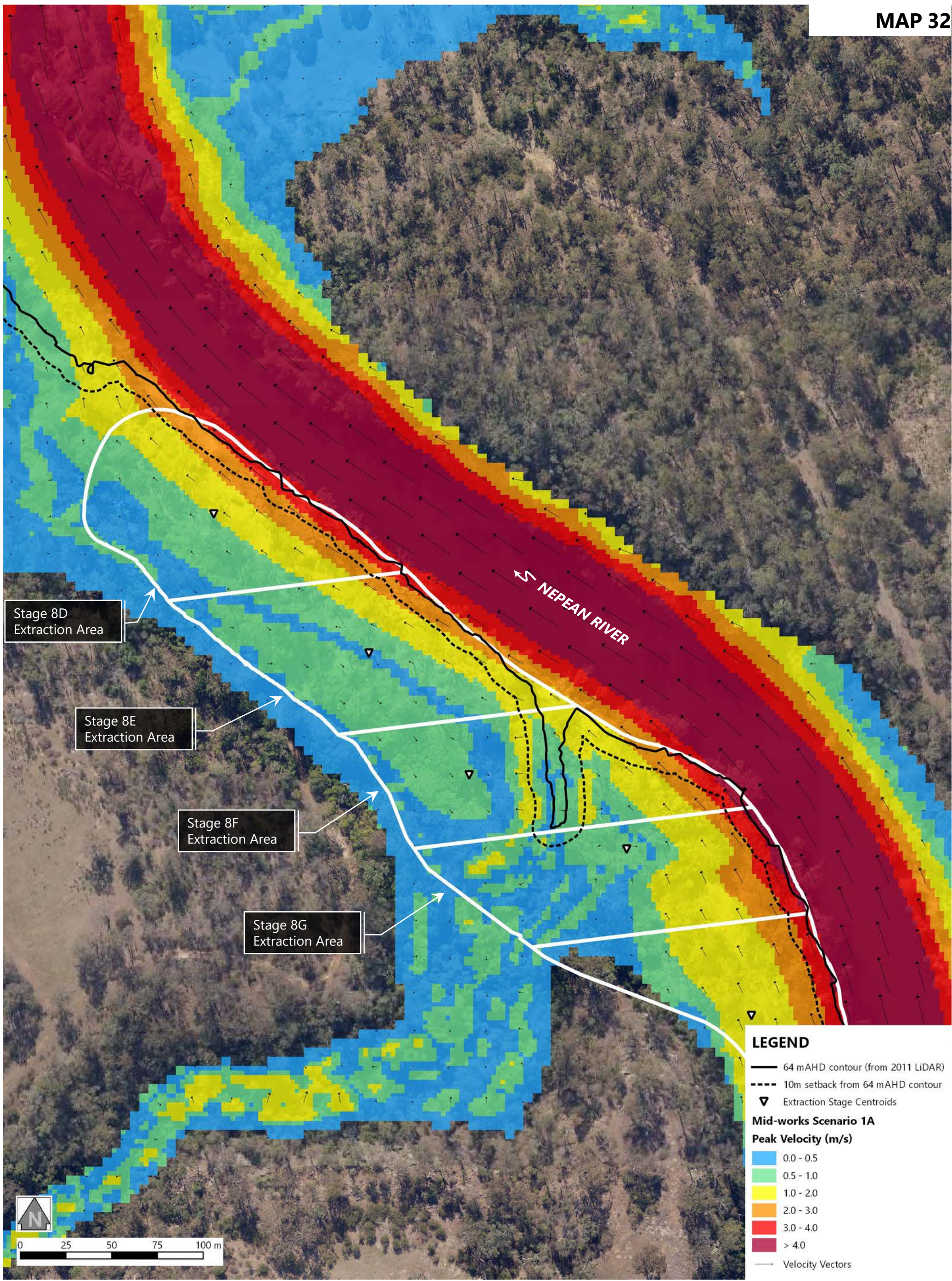
**STAGES 8A-8C MID-WORKS SCENARIO 1B**  
**1% AEP SIMULATED PEAK BED SHEAR STRESS**





**STAGES 8D-8G EXISTING CONDITIONS**  
**1% AEP SIMULATED PEAK FLOW VELOCITY**





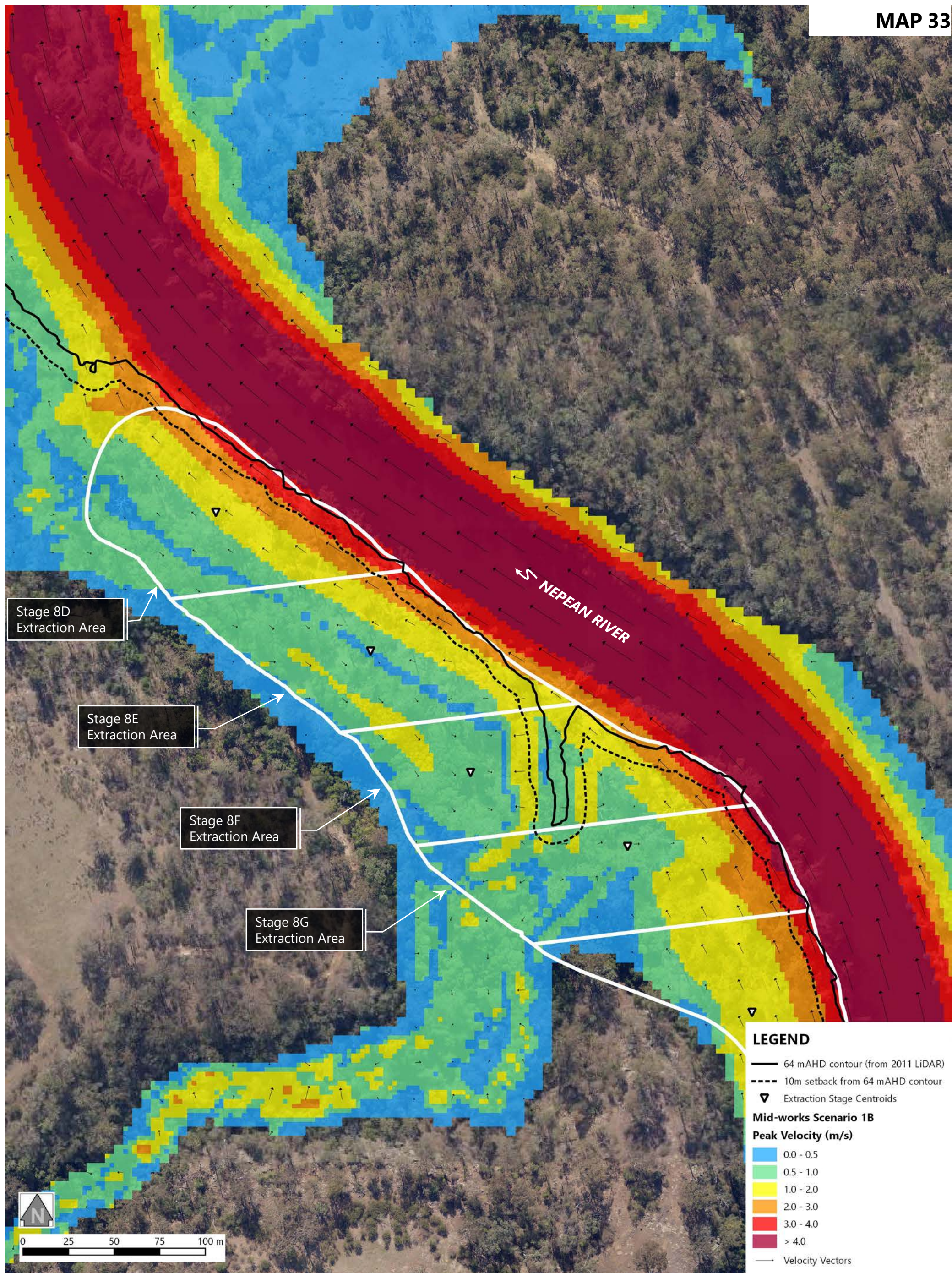
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**STAGES 8D-8G MID-WORKS SCENARIO 1A**  
**1% AEP SIMULATED PEAK FLOW VELOCITY**





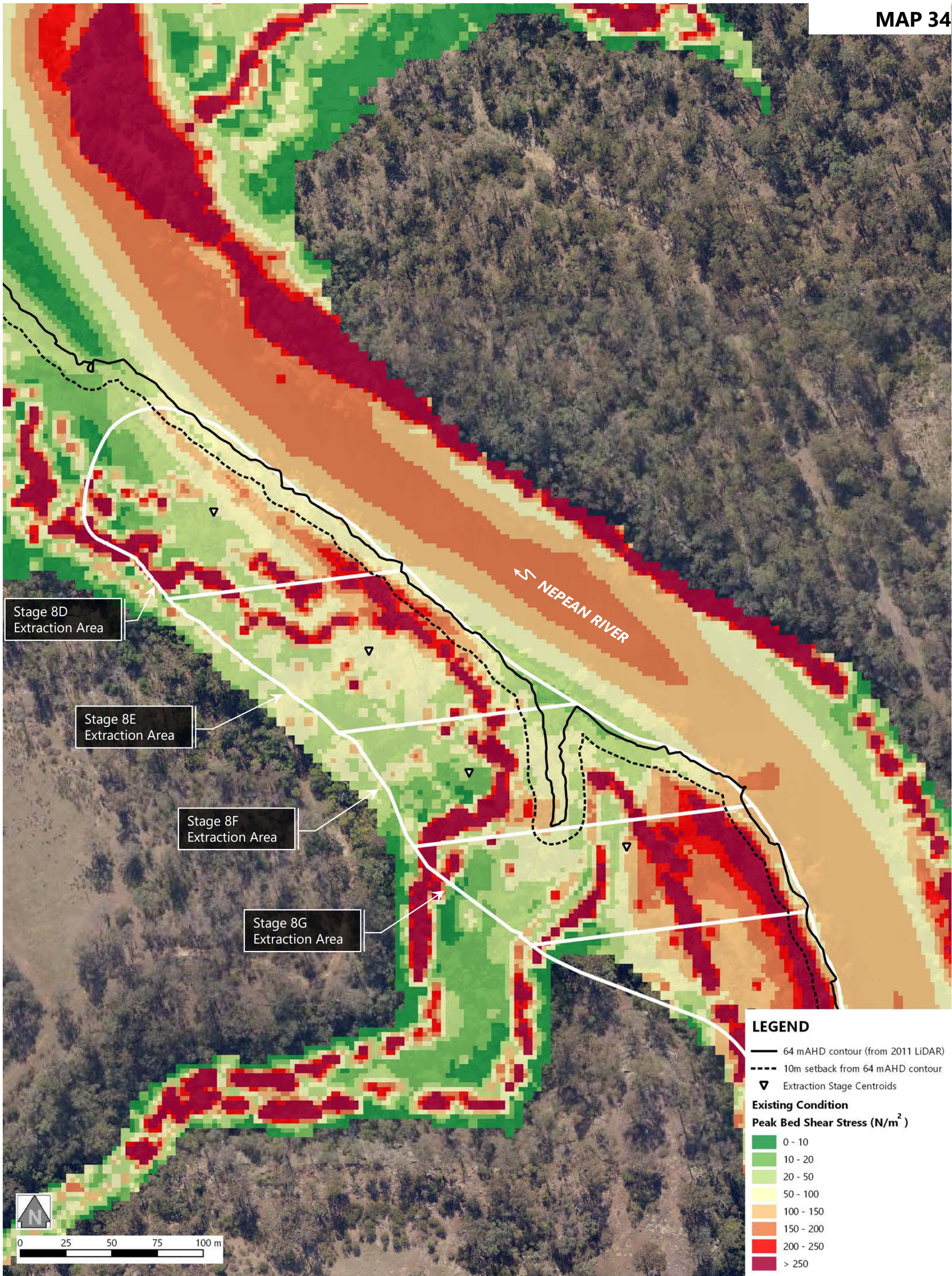
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**STAGES 8D-8G MID-WORKS SCENARIO 1B**  
**1% AEP SIMULATED PEAK FLOW VELOCITY**





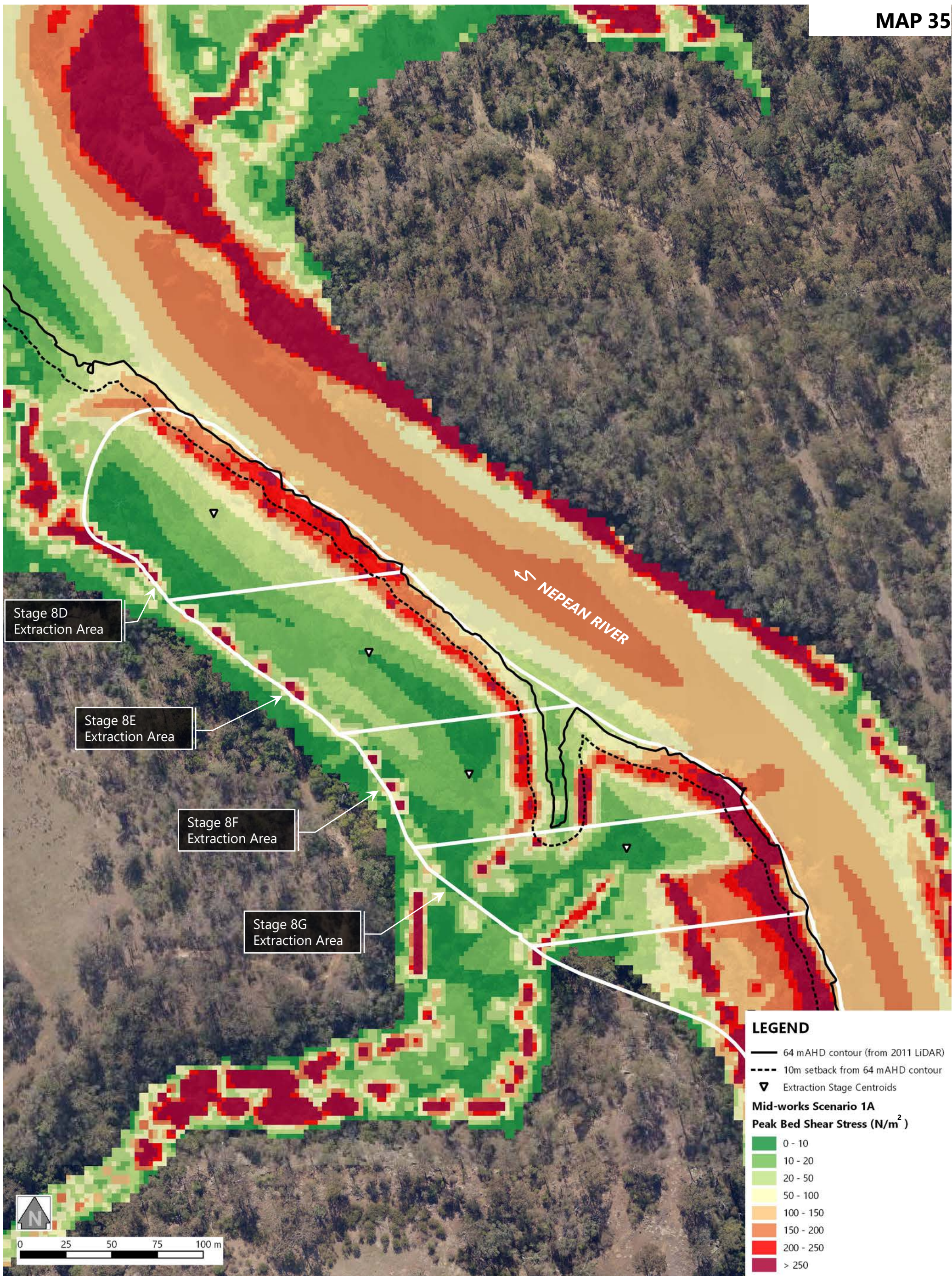
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**STAGES 8D-8G EXISTING CONDITIONS**  
**1% AEP SIMULATED PEAK BED SHEAR STRESS**





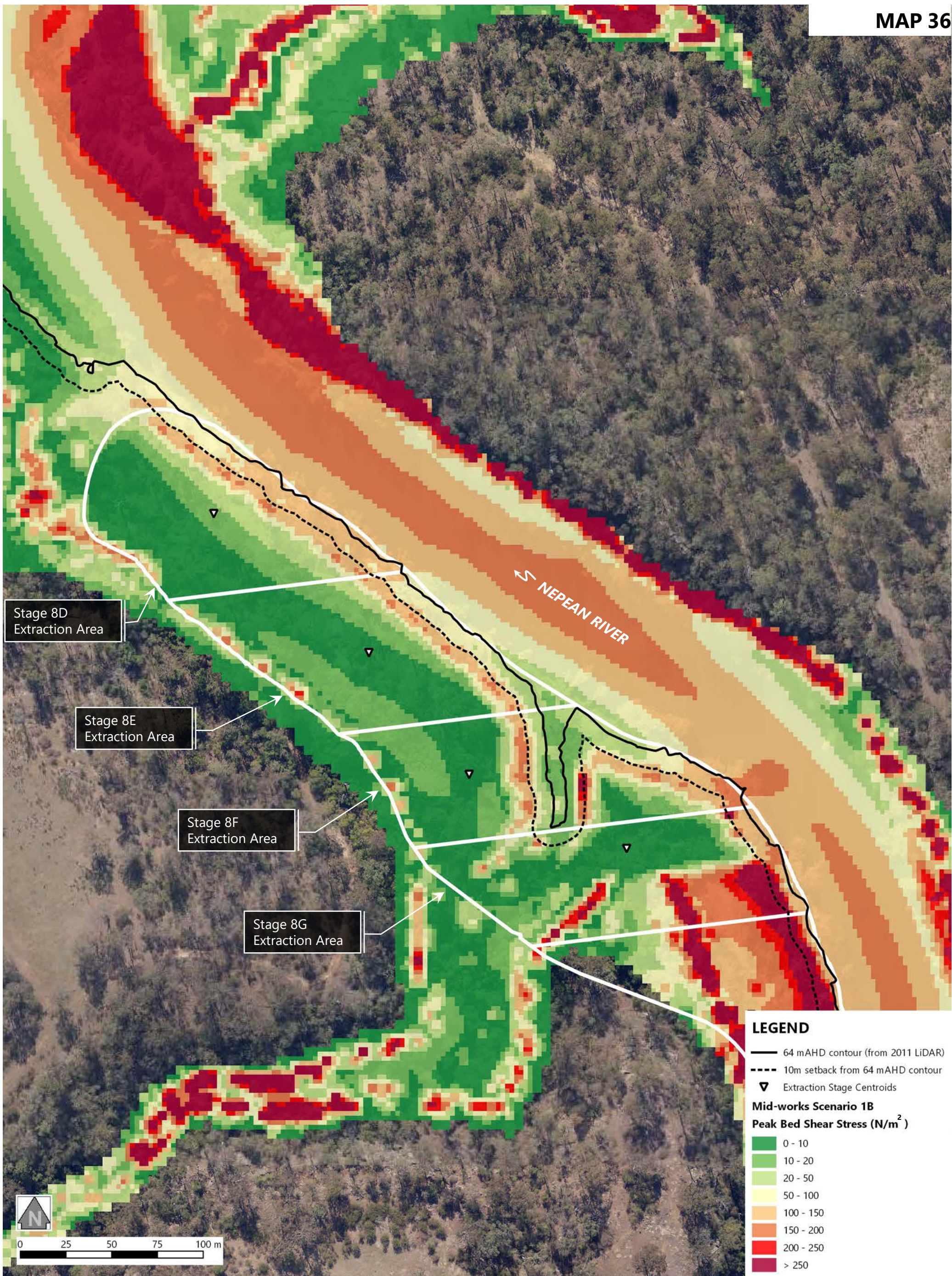
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**STAGES 8D-8G MID-WORKS SCENARIO 1A**  
**1% AEP SIMULATED PEAK BED SHEAR STRESS**





**LEGEND**

- 64 mAH contour (from 2011 LiDAR)
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- ▽ Extraction Stage Centroids
- Mid-works Scenario 1B**
- Peak Bed Shear Stress ( $\text{N/m}^2$ )**
- 0 - 10
- 10 - 20
- 20 - 50
- 50 - 100
- 100 - 150
- 150 - 200
- 200 - 250
- > 250

Prepared by:



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**STAGES 8D-8G MID-WORKS SCENARIO 1B**  
**1% AEP SIMULATED PEAK BED SHEAR STRESS**