WAMBO COAL PTY LIMITED

SOUTH BATES EXTENSION UNDERGROUND MINE

EXTRACTION PLAN
LONGWALLS 21 TO 24

REPORT 3
SURFACE WATER ASSESSMENT REVIEW

Peabody

REPORT:

Surface Water Technical Report for South Bates Extension Underground Mine (Longwalls 21- 24)

Wambo Coal Mine

February 2020

Document history

Revision:

Revision no.	01
Author/s	Jacob Dearlove Chris Power Rohan Lucas Alex Sen
Checked	Rohan Lucas
Approved	Rohan Lucas

Distribution:

Revision no.	01
Issue date	07/02/2020
Issued to	Nicole Dobbins
Description:	Draft

Ref:

C:\Projects_RL\Mines\Peabody\Wambo\0219055 South Bates Mine Extraction Plan LW21-24.docx

Contents

Figures

Tables

1 Introduction

Wambo Coal Mine (Wambo) is an open cut and underground mining operation in the Hunter Valley mining region of New South Wales operated by Wambo Coal Pty Limited (WCPL). WCPL is currently seeking approval of an Extraction Plan for its longwall mining operations at South Bates Extension underground mine. The proposed Extraction Plan will cover the mining of Longwalls (LWs) 21 to 24, extracting coal from the Whybrow Seam.

WCPL has previously developed three separate Extraction Plans for underground mining at the South Bates Extension and South Bates underground mines at Wambo. The first (for South Bates underground mine) covered LWs 11 to 13 and was approved in February 2015. A consolidated Extraction Plan for LWs 11 to 16 was then completed and approved in December 2016. The most recent covered LWs 17 to 20 (for South Bates Extension underground mine) and was approved in February 2019 following an amendment to the longwall layout. This report documents the surface water technical assessment for LWs 21 to 24 that informs the development of the overall Extraction Plan for LWs 21 to 24.

One of the effects of underground longwall mining is that after coal is mined, the roof strata falls into the void (goaf) causing the natural ground surface to subside. The environments of North Wambo Creek and the North Wambo Creek Diversion (NWCD), their adjacent floodplains and hill slopes that exist over the area of the South Bates Extension underground mine plan that will be affected by subsidence are the subject of this report.

This technical report outlines the pre (pre LW21-24) and post subsidence environment for the mine plan area (as shown in Figure 1-1 and Figure 1-2), addresses potential impacts on surface water caused by subsidence, and proposes mitigation, monitoring and reporting.

To effectively manage the impacts of subsidence this technical report consists of the following aspects:

- Measurement of pre-subsidence baseline data
- Predictive subsidence modelling and impact assessment
- Ongoing subsidence monitoring
- Pre-subsidence and post subsidence mitigation, reporting and maintenance

1.1 Scope

This technical report covers surface water aspects that interface with the South Bates Extension and South Bates underground mine plan. This includes North Wambo Creek, its diversion (NWCD), its tributaries and surrounding landscape.

The impact assessment of subsidence upon waterways and surface water generally is undertaken in the structure developed during the *Isaac River Cumulative Impact Assessment of Mine Developments* (Alluvium, 2008), a project jointly funded by Anglo American and BHP Billiton undertaken in collaboration with Queensland Government. Although not directly applicable to NSW regulation, the findings assisted the development of the *Watercourse Subsidence – Central Queensland Mining Industry* guideline (DERM, 2011). The framework for assessing impacts on watercourses by subsidence was developed into the following hierarchy, which has been adopted for this study:

- 1st order – direct physical effects of subsidence
- 2nd order – geomorphic response to subsidence
- 3rd order – changes to water quantity and quality
- 4th order – biological response

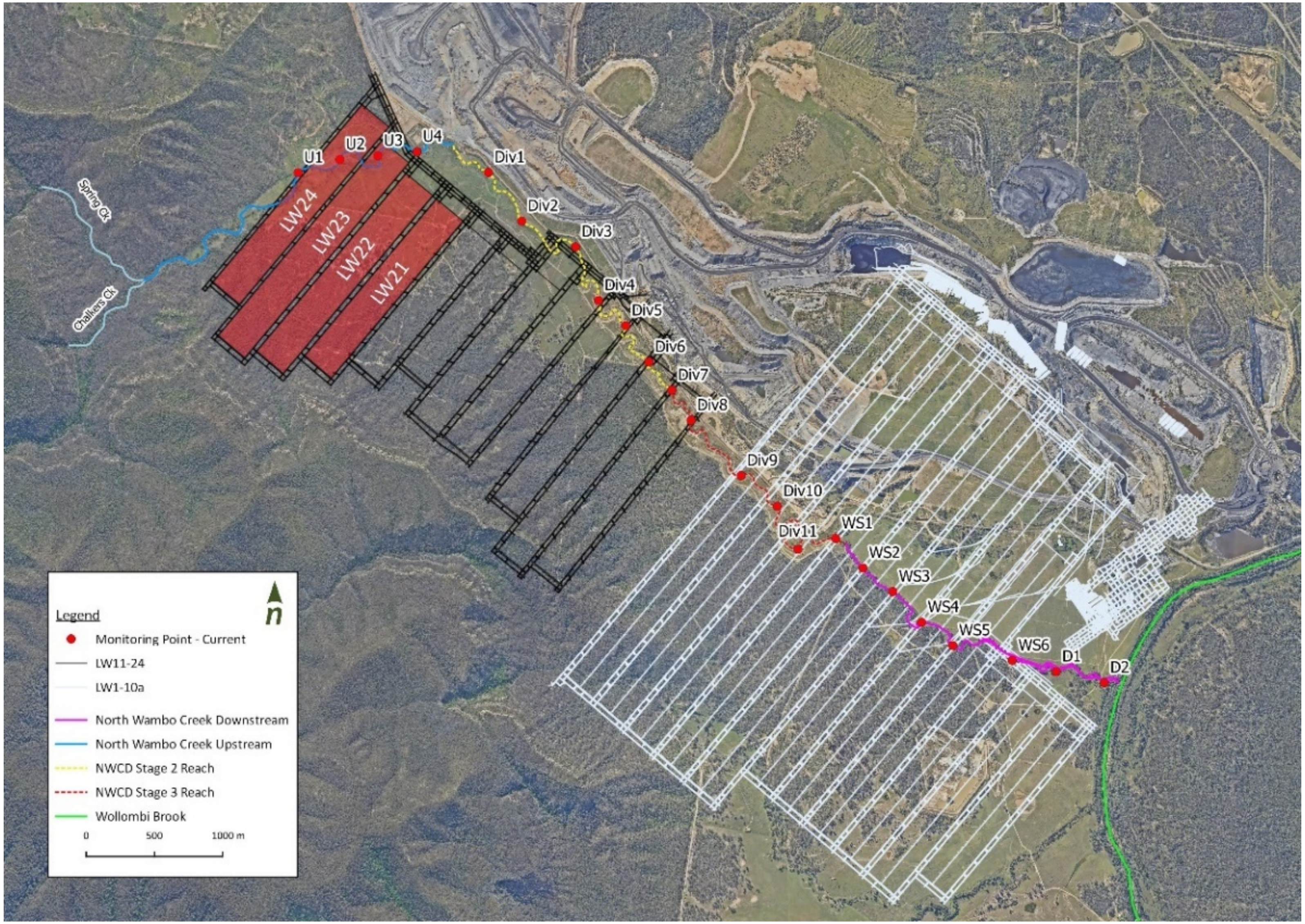


Figure 1-1. *Overview of underground mining at Wambo Coal Mine and location of NWCD monitoring points*

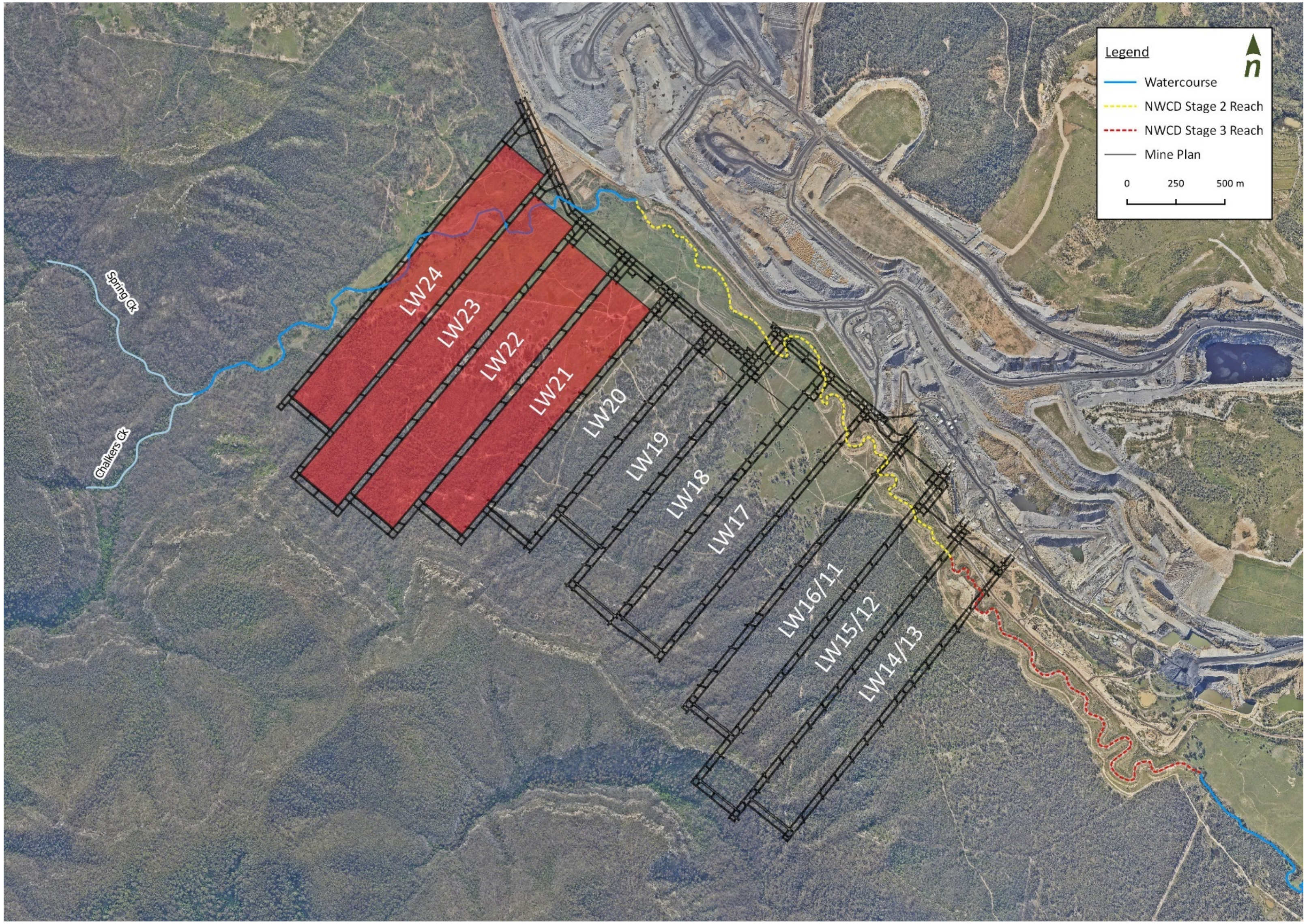


Figure 1-2. *Overview of South Bates Extension underground mine plan at Wambo Coal Mine*

2 Existing condition assessment

A snapshot of the condition of the landscape and surface water environments interacting with the South Bates Extension underground mine plan is provided to inform the impact assessment and any mitigation strategies that may be required. This snapshot is the existing condition based on several previous point in time condition assessments (2015-2018) and the 2019 NWCD monitoring. These assessments and monitoring were all undertaken pre-LW21-24 but without the full extents of LW17-LW20 mined (the 2019 NWCD monitoring was undertaken after LW17 was completed in 2019, but before LW18 was completed).

A monitoring program for NWCD was established in November 2017 in response to recommendations in the extraction plan for LW11 to LW16 (Alluvium, 2016) (see Figure 1-1). The monitoring results are detailed in Alluvium's report; *North Wambo Creek Diversion operations monitoring*. Further baseline assessment of the upstream reaches of North Wambo Creek and its tributaries Spring and Chalkers Creeks was completed in February 2018. The results of that assessment are detailed in Alluvium's report; *North Wambo Creek – Baseline assessment geomorphic context statement*. The latest operations monitoring of NWCD and North Wambo Creek was completed in November 2019, the details of which are found in *North Wambo Creek Diversion Operations Monitoring 2019*.

As well as the 2017 - 2019 monitoring, information from the 2015 performance review of NWCD (Alluvium, 2015) and other historical information were used to inform this condition assessment.

LW11 to LW17 had been fully mined at the time of the 2019 monitoring. LW18 to LW20 and LW21 to LW24, as currently planned, do not intercept the NWCD, while LW23 and LW24 directly undermine North Wambo Creek (Figure 1-2).

The downstream extent of NWCD was subsided prior to construction. Downstream of NWCD, North Wambo Creek has also been subsided in recent years.

2.1 Character, behaviour and condition of waterways

Upstream reach
The 2018 baseline assessment of the upstream reach of North Wambo Creek extended to include its upstream tributaries, Spring and Chalkers Creeks (Alluvium, 2018).

Spring and Chalkers Creek tributaries originate from the sandstone capped ranges to the west of the mine. These ranges have massive sandstone beds that form plateau on the crest with angle of repose slopes beneath. Consequently, these ranges can generate substantial quantities of sand as input to North Wambo Creek. Near the confluence, which forms North Wambo Creek, much of the sedimentary bedrock is conglomerate, providing cobbles and gravels as bedload to the waterway. Both these waterways have a steep gradient and are horizontally confined by bedrock in hillslopes with only minor floodplain pockets.

Downstream of the confluence of the confined Spring and Chalkers Creeks, North Wambo Creek becomes progressively less confined before becoming completely alluvial prior to the NWCD. The extents of North Wambo Creek assessed have been subject to a long period of adjustment in response to land clearing and domestic livestock grazing. The settlement of the valley appears to have comprised several smaller allotments and land use is likely to have been intensive. Grazing still occurs in the valley and along the subject reaches, however the intensity of land use may have decreased as the land is now part of broader mining tenements with lease back to graziers.

Prior to development of the mining operation, North Wambo Creek has undergone a number of adjustments. It is probable that the watercourse was a discontinuous alluvial channel with swamp like features, potentially a chain of ponds. With complete clearing of the valley floor it is possible that a channel incised, widened and meandered in the sandy alluvials. There is no longer an active channel present for much of North Wambo Creek immediately upstream of the diversion, it has infilled and exhibits very little fluvial bed form activity. This section appears to be returning to a discontinuous alluvial form, inset below the former surface.

It is likely in this setting that much of the flow generated in the range to the west in lower intensity and magnitude rainfall events was as base flow in the alluvial sediments. The current open cut operation adjacent to the offtake of NWCD influences the flow regime locally, in NWCD and downstream.

Riparian vegetation in the reach immediately upstream of NWCD is largely limited to ground cover, which has been dense at the times of inspection 2015-2019. The reasons for limited regeneration of woody species in this reach are not known. The reach is no longer subject to cattle grazing however kangaroo numbers in the area are significant. Changes in the saturation of alluvials due to a steeper hydraulic gradient to the open cut may also be a factor.

	
Typical Spring Creek reach (2018 baseline)	*Typical Chalkers Creek reach (2018 baseline)*
	
Partly confined North Wambo Creek, downstream of confluence of Spring and Chalkers Creeks (2018)	*Partly confined North Wambo Creek, downstream of confluence of Spring and Chalkers Creeks (2018)*
	

Upstream view in fully alluvial reach (2019)	Downstream view in fully alluvial reach, just upstream of NWCD (2019)

Figure 2-1. *North Wambo Creek Upstream reach photographs*

NWCD Stage 2

The upstream half (approx.) of NWCD is known as Stage 2. This was constructed prior to Stage 3 which replaces the mined-out Stage 1. Stage 2 of the diversion is constructed initially in the floodplain of North Wambo Creek then gradually into foot slopes of the range to the west (transitioning from an alluvial setting to fully bedrock controlled). A low capacity low flow channel, typically 2-3m deep and up to 10m top width has been cut into a constructed floodplain that decreases from around 80m wide to 30m wide moving downstream as depth of cut increases (to about 8m below natural ground surface at the interface with Stage 3).

At the upstream end of Stage 2, overland flow entry has been managed adequately and with a lower gradient and broader cross section the diversion is in similar condition to the upstream reach. Hydraulic energy conditions increase with the depth of cut and the narrower floodplain, moving downstream. This has resulted in deepening and widening of the low flow channel that is likely to continue in the alluvial/colluvial sediments present. This process is occurring in the zone over LW 11 and LW 12 and immediately upstream.

Overland flow entry to the diversion from the west has not been managed in the vicinity of LW 11. This already requires management response to limit further gully erosion. LW 11-LW16 subsidence has altered the location of where this gully erosion is likely to occur over these panels. Management of the overland flow to suit the post subsidence conditions has been designed for these panels.

Stage 2 of the diversion is known to have had substantial rehabilitation effort in the form of revegetation largely with a pasture seed mix and some tube stock patches and other remedial works in 2011 and again in 2013. This work has had limited success. A program of shallow ripping (including treatment of subsidence cracks) and seeding has progressed since early 2019 which has also had limited success, largely due to prolonged below average rainfall.

	
Upstream extents of Stage 2 NWCD at Div2 (2019)	*Minor overland flow and bank erosion in dispersive soils, mid stage 2 NWCD near Div3 (2019)*

<table>
<tr><td></td><td></td></tr>
<tr><td>Section of NWCD Stage 2 near Div 5 in 2018 undergoing erosional adjustment prior to being subject to increased erosion risk from LW 11-16 subsidence</td><td>Cracking in inset floodplain over LW 11 in dispersive soils may lead to new tunnel and gully erosion (2018)</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Gully development along the bank of NWCD Stage 2 near Div 6 (2019)</td><td>Upstream view from Div6, dry conditions in lower Stage 2 NWCD (2019)</td></tr>
</table>

Figure 2-2. *NWCD stage 2 photographs*

NWCD Stage 3

Stage 3 is largely constructed in foot slopes with much of the channel boundaries being weathered sandstone and conglomerate bedrock. Where not bedrock, the weathered sediments are generally highly dispersive and prone to erosion on the surface and sub-surface.

This section of the diversion presently has limited vegetation establishment and overland flow entry management issues that require attention. Works have been designed to manage these issues. The sandstone boundaries of the channel remain relatively sound in the majority, with only a few instances of bedrock weathering to the extent of it breaking down to constituent sediments.

Elevated energy conditions in Stage 3 and the limited finer sediment supplied to the reach under current sediment supply conditions means there is little prospect of deposition and that any fine sediment topsoil in the channel is likely to be stripped in larger flow events. Combined, these conditions constrain longer term vegetation establishment potential from regeneration/self-seeding processes. With the shallow bedrock in the reach, vegetation is at further risk of removal due to potential barriers to root penetration where sandstone beds are massive.

As part of Wambo Coal's response to the condition issues in NWCD, a soil treatment and revegetation program has been gradually implemented from the downstream end of the diversion, working upstream over the last few years. These works are showing early signs of success with improved ground cover (despite dry conditions) and improved woody species cover.

The downstream extents of Stage 3 were constructed over terrain that was already subsided by earlier longwall mining.

Figure 2-3. *Steep, bedrock-controlled transition zone from Stage 2 to Stage 3 showing the subsided drop into LW12/15 (2019)*

	
Compression buckle cracks at 1-2m spacing through the sandstone in NWCD near Div8 over LW 13/14 (2018)	*Compression buckle cracks at 1 to 2 m spacing through erodible soil near Div7 over LW 13/14 (2019)*

Improving woody vegetation establishment following light ripping of diversion batters (2018)

Typical conditions in mid Stage 3 of NWCD

Tunnel erosion associated with overland flow management in Stage 3 NWCD is the subject of a management program by Wambo Coal

Tunnel erosion undermining one of the overland flow entry structures that requires management (2018)

Example of good recent revegetation efforts at Div9

Improving vegetation cover downstream of Div10

Figure 2-4. *NWCD stage 3 photographs*

Downstream reach
Downstream of NWCD through to the confluence with Wollombi Brook, the remaining alignment of North Wambo Creek has been subsided by five longwalls over the last decade. This reach of North Wambo Creek is relatively low sinuosity and is increasingly incised as it cuts down to the level of Wollombi Brook. Channel migration is limited by consolidated Wollombi Brook terrace sediments. Bedrock controls are occasionally present in the channel bed.

Riparian vegetation remains minimally cleared for much of the reach, however clearing has occurred to the top of bank along the north eastern side for much of the reach. What remains, exhibited clear signs of water stress during the most recent monitoring period likely due, at least in part, to the dry climatic conditions in this area of NSW in the last 2 years, but also due to the reduction in flows from upstream reaches.

Subsidence pools are present in the reach, providing pool habitat that is otherwise not presently common in North Wambo Creek, although these were all found to be dry in Nov 2019. There has been limited erosion response in the reach, such as incision through pillars, to date.

A notable threat to the condition of the downstream reach exists in the form of a significant drop through culverts of a track crossing shortly upstream of the Wollombi Brook confluence. Sediment has accumulated upstream of the culverts and has been colonised by vegetation. Should the culverts fail through undermining or outflanking it is likely a considerable amount of deepening would occur through the accumulated sediments.

Figure 2-5. *Fully bedrock-controlled invert at WS2*

	
Deposition in subsided panel between WS2 and WS3 at risk of re-incision (2018)	*Erosion head cut migrating upstream through sediments over subsided panel (2018)*
	
Dry subsidence pool between WS3 and WS4 (2019)	*Subsidence pool where channel abuts a terrace scarp (2018)*
	
Terrestrial vegetation colonisation of the channel bed downstream of subsidence	*A significant step in bed profile through culverts near downstream extent of North Wambo Creek*

Figure 2-6. *North Wambo Creek Downstream reach photographs*

Western tributaries
Several tributaries flow from the sandstone escarpment of the range to the west into North Wambo Creek and NWCD, those over LW21 to LW24 are shown in Figure 2-7. These tributaries transition from steep deeply incised bedrock-controlled gullies to broad alluvial flood-outs with no defined channel progressing downstream before entry to North Wambo Creek and NWCD. These systems are all presently in dynamic equilibrium with relative stability. Riparian vegetation is near intact throughout the steeper upper reaches then cleared for grazing where they flood out onto the flatter valley base. There are small fam dams on some of these tributaries and the nature of their inflow to NWCD has been altered by works implemented with the diversion.

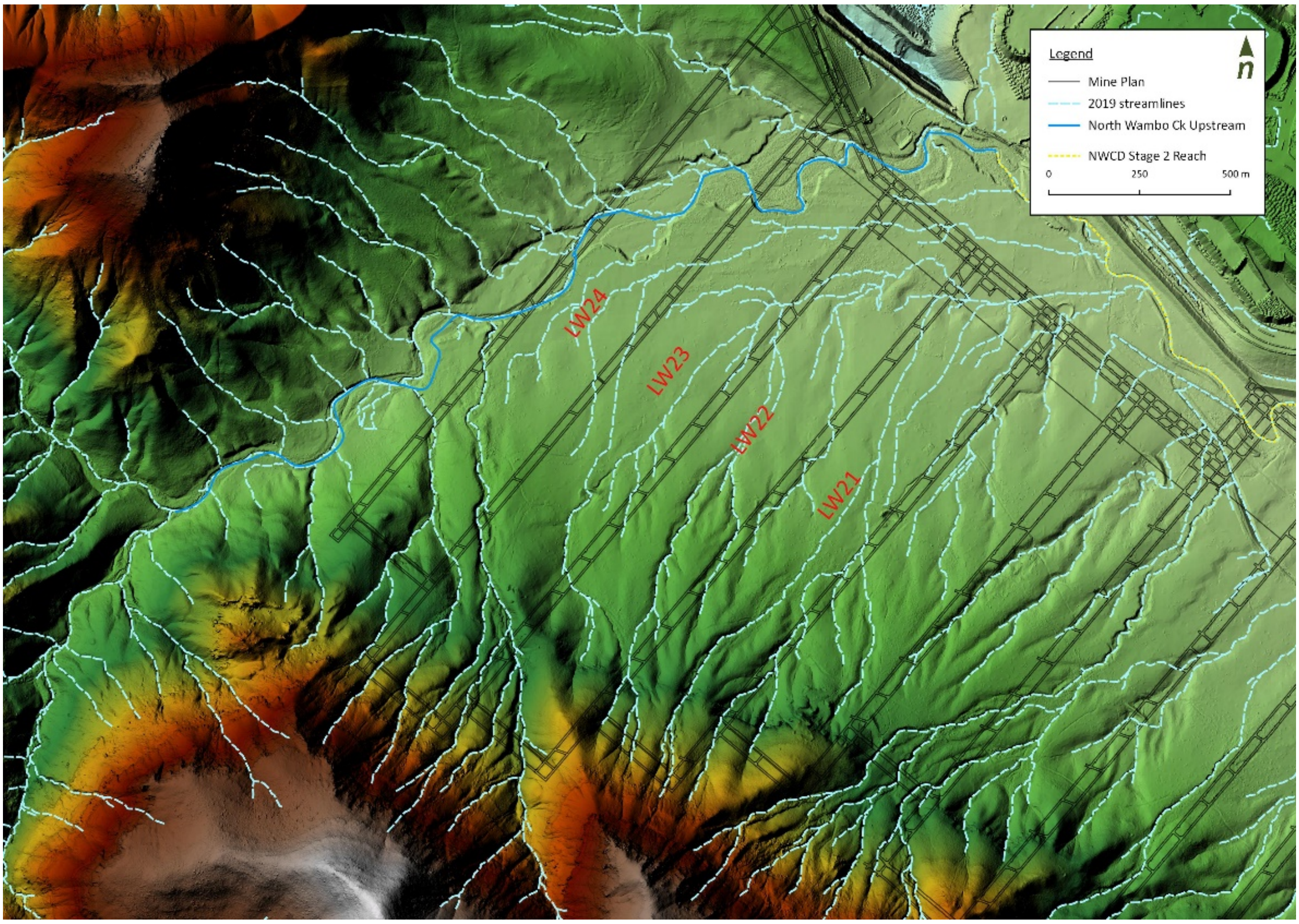


Figure 2-7. *Western tributaries overlying LW21 to LW24*

3 Impact assessment

3.1 1st order – direct effects of subsidence

Subsidence modelling
Mine Subsidence Engineering Consultants (MSEC) have provided subsidence predictions for the extraction of the South Bates Extension Whybrow Seam LW18 to LW24 (Figure 3-1). Note that there is low-level subsidence predicted above the recently subsided LW17 due to reactivation and long-term residual movements after the completion of that longwall.

A brief summary of the modelling results is presented below, however, for detailed information regarding the methodology please refer to the report prepared by MSEC, titled *South Bates Extension Subsidence Assessment – Subsidence Predictions and Impact Assessments for the Natural and Built Features in Support of the Extraction Plan Application for WYLW21 to WYLW24 at the South Bates Extension Underground Mine* (MSEC1080)[1]. The subsidence predictions are as follows:

- The maximum subsidence expressed at the surface for mining of the Whybrow seam is 1.95m.
- The chain pillar subsidence ranges from 0.2m to 0.3m for the mining of the Whybrow seam.

A plan view of the predicted subsidence depth output from the modelling for LW21 to LW24 (including subsidence due to LWs 17 to 20) is shown in Figure 3-2. A representation of the post subsidence digital terrain is presented in Figure 3-3. Shown is the 1m and 5m terrain contours derived from the LiDAR captured in May 2019 (which included the LW17 subsidence) modified to include the predicted subsidence modelled by MSEC. As LiDAR had already captured the LW17 subsidence, MSEC prepared contours for LW18 to LW24.

Modelling of the predicted subsidence is regularly updated as new monitoring data of actual subsidence at the Wambo Coal Mine becomes available. The predicted subsidence is compared to the actual subsidence for each subsided panel which allows the model to be re-calibrated if variances reach a certain threshold. In the most recent model update monitoring data measuring the recent subsidence of LW17 was compared to predicted subsidence. The maximum predicted vertical subsidence, maximum measured tilt and curvatures are similar to the maximum predicted values. It was considered, therefore, that it was not necessary to re-calibrate the model based on the monitoring data for the Whybrow Seam (MSEC, 2020).

[1] MSEC (2020) *South Bates Extension Subsidence Assessment – Subsidence Predictions and Impact Assessments for the Natural and Built Features in Support of the Extraction Plan Application for WYLW21 to WYLW24 at the South Bates Extension Underground Mine*

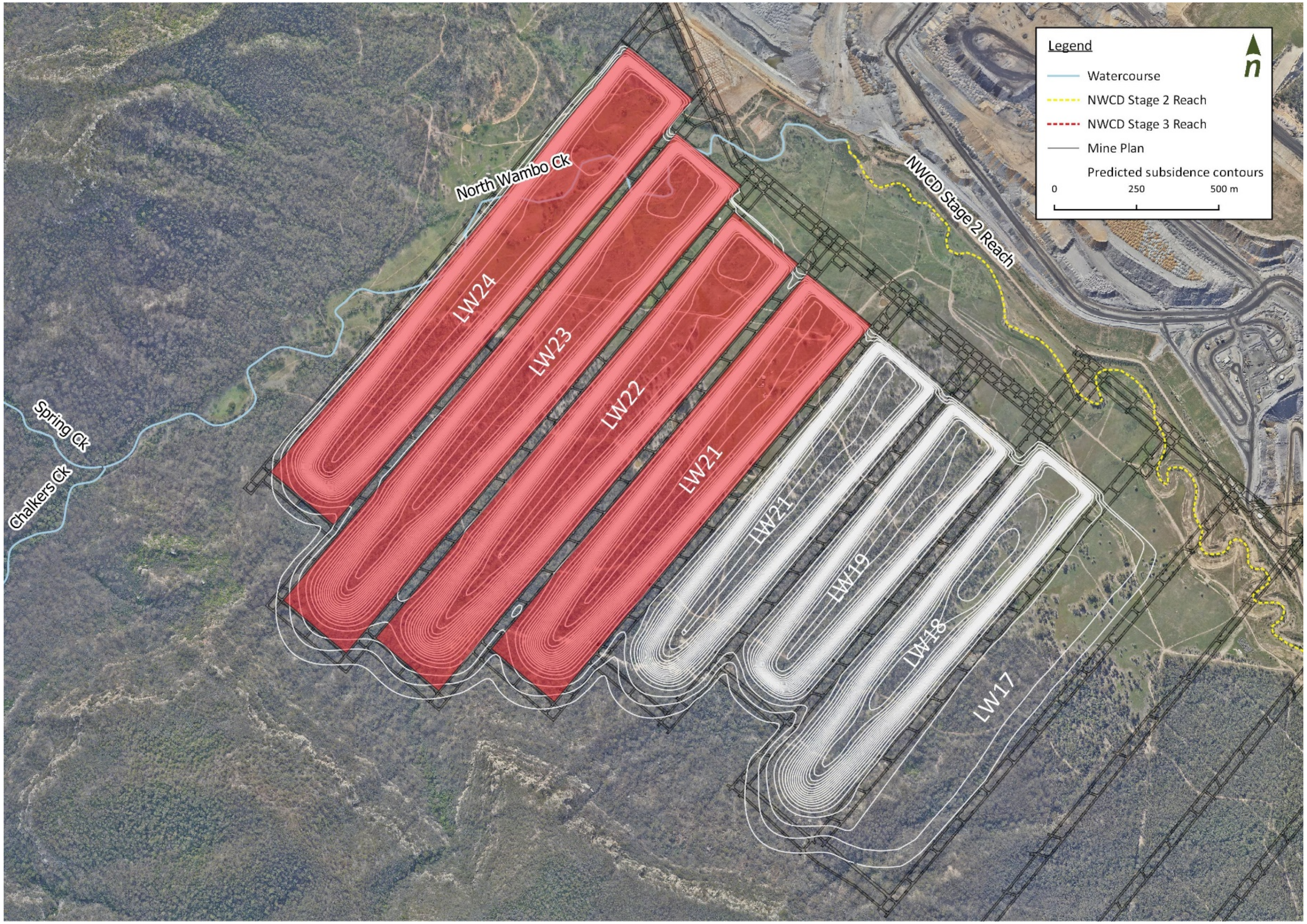


Figure 3-1. *Predicted subsidence contours for South Bates Extension underground mine LW21 to LW24, including LW17 to LW20 (MSEC, 2020)*

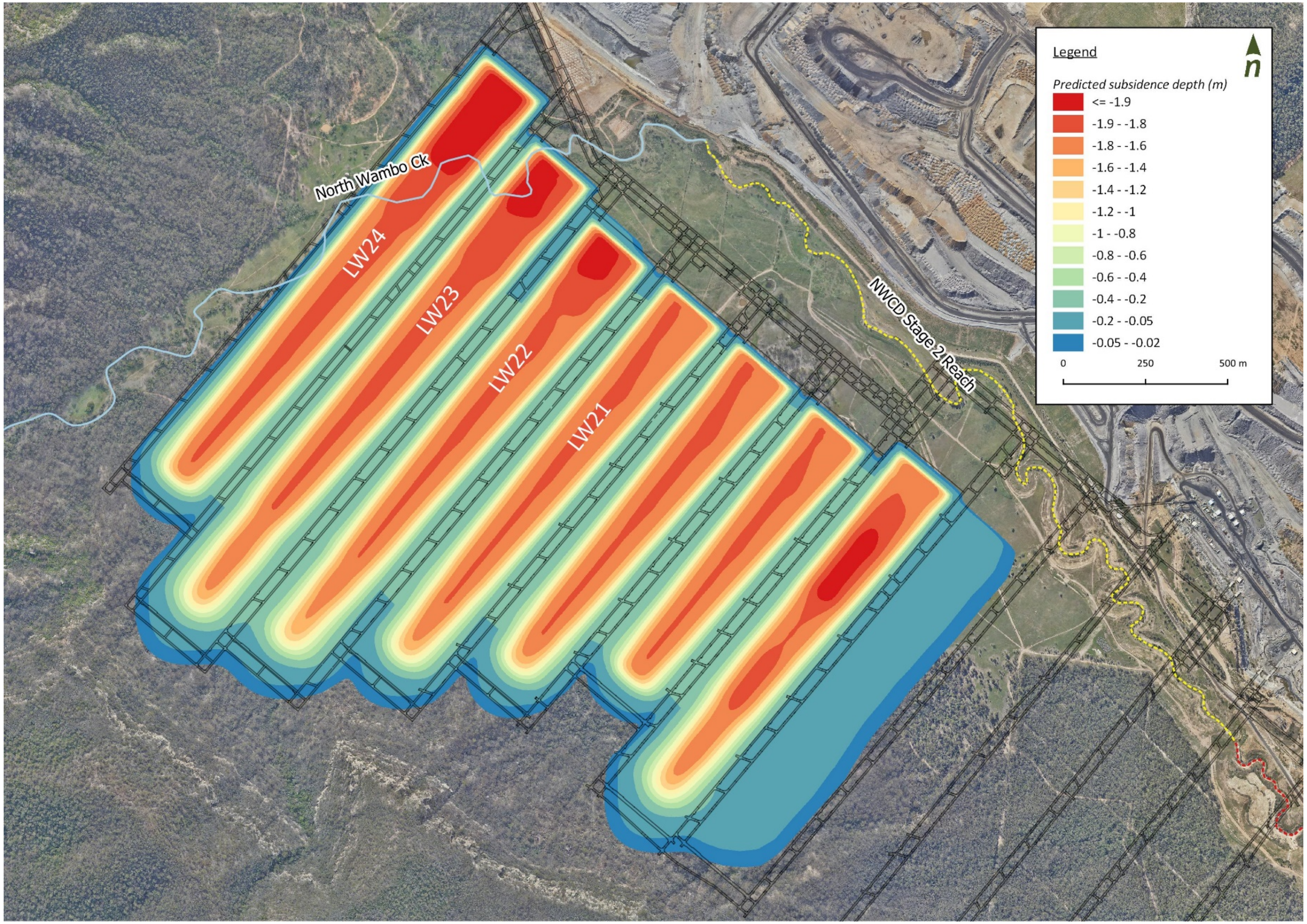


Figure 3-2. *Predicted subsidence depths for South Bates Extension underground mine LW21 to LW24, including LW17 to LW20*

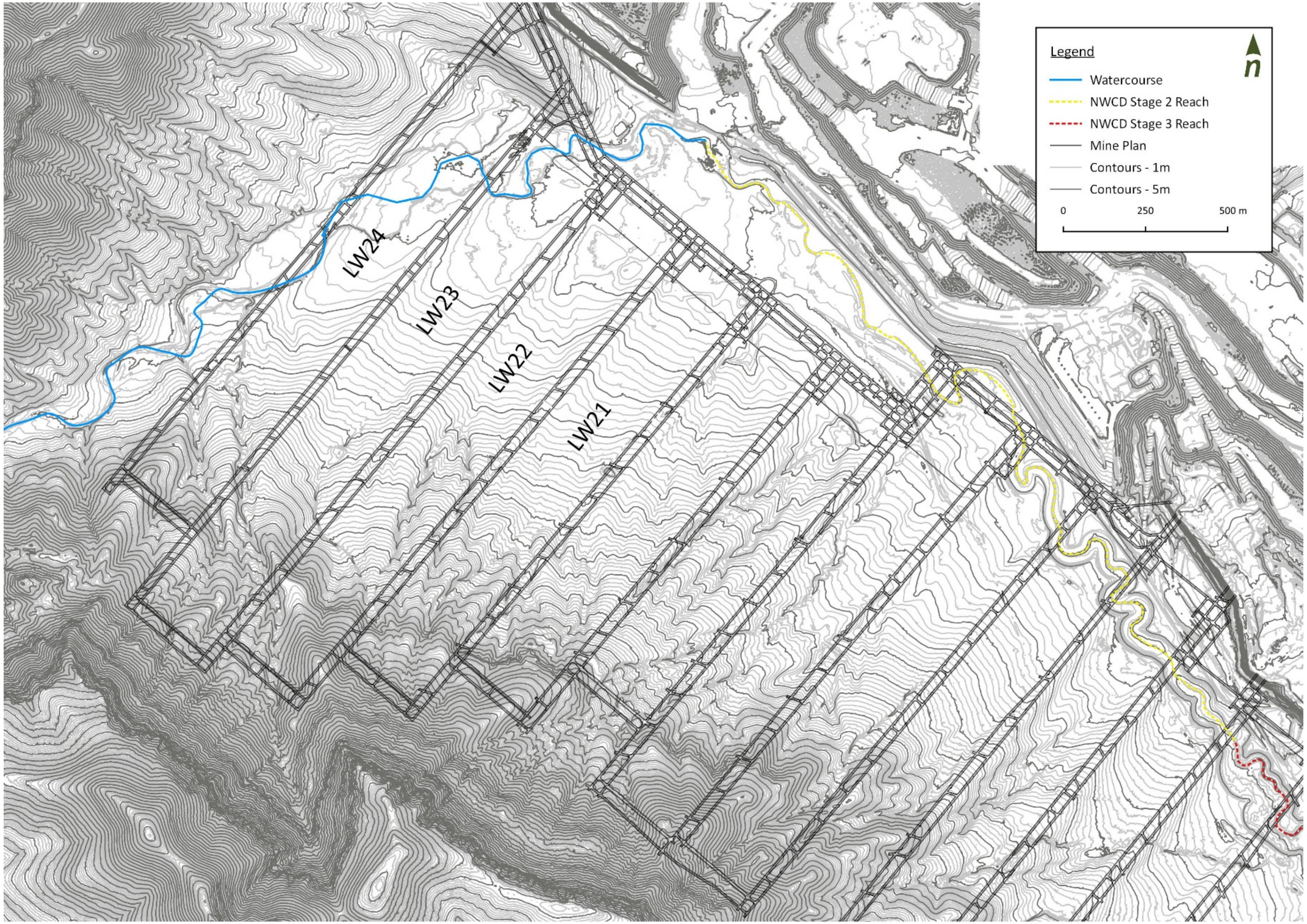


Figure 3-3. *Post subsidence digital terrain contours at 1m and 5m intervals LW17 to LW24*

Surface tensile cracking and compressional buckling
Cracking has been observed above LW11/16, LW12/15, LW13/14 (Figure 3-4) and 17 at the surface. As part of their subsidence assessment, MSEC have mapped the surface cracking across Wambo Mine for LW11-LW16 and LW17 (Figure 3-7). Where these cracks occur in colluvial and alluvial sediments, surficial and sub surface erosion response can be expected. The sediments across this terrain can be dispersive, which makes them prone to changes in rates of erosion with changes in landscape dynamics.

The areas of greatest risk will be where cracks open in erodible sediments with an orientation down slope or where flow entry may be concentrated, or ponding occurs. These may be prone to enlargement should the volume of the crack be sufficient that local inputs of sediment don't infill it nor do the clays swell sufficiently to seal it. In these instances, some rill/gully erosion may develop. This has not been observed to date as insufficient rainfall has occurred since mining. Cracks such as those shown in Figure 3-6 are likely to undergo substantial enlargement due to runoff.

Where local ponding occurs in the same location as cracking, dispersive sediments are likely to flow down cracks with water, enlarging the crack at surface, which may develop into considerable tunnel erosion. An example of tunnel erosion can be seen below in Figure 3-5.

Figure 3-4. *Cracking at surface over LW13/14*

Figure 3-5. *Tunnelling over LW12/15 on track adjacent NWCD associated with subsidence crack*

Figure 3-6. *Large crack development example over LW11-16 in woodland east of NWCD*

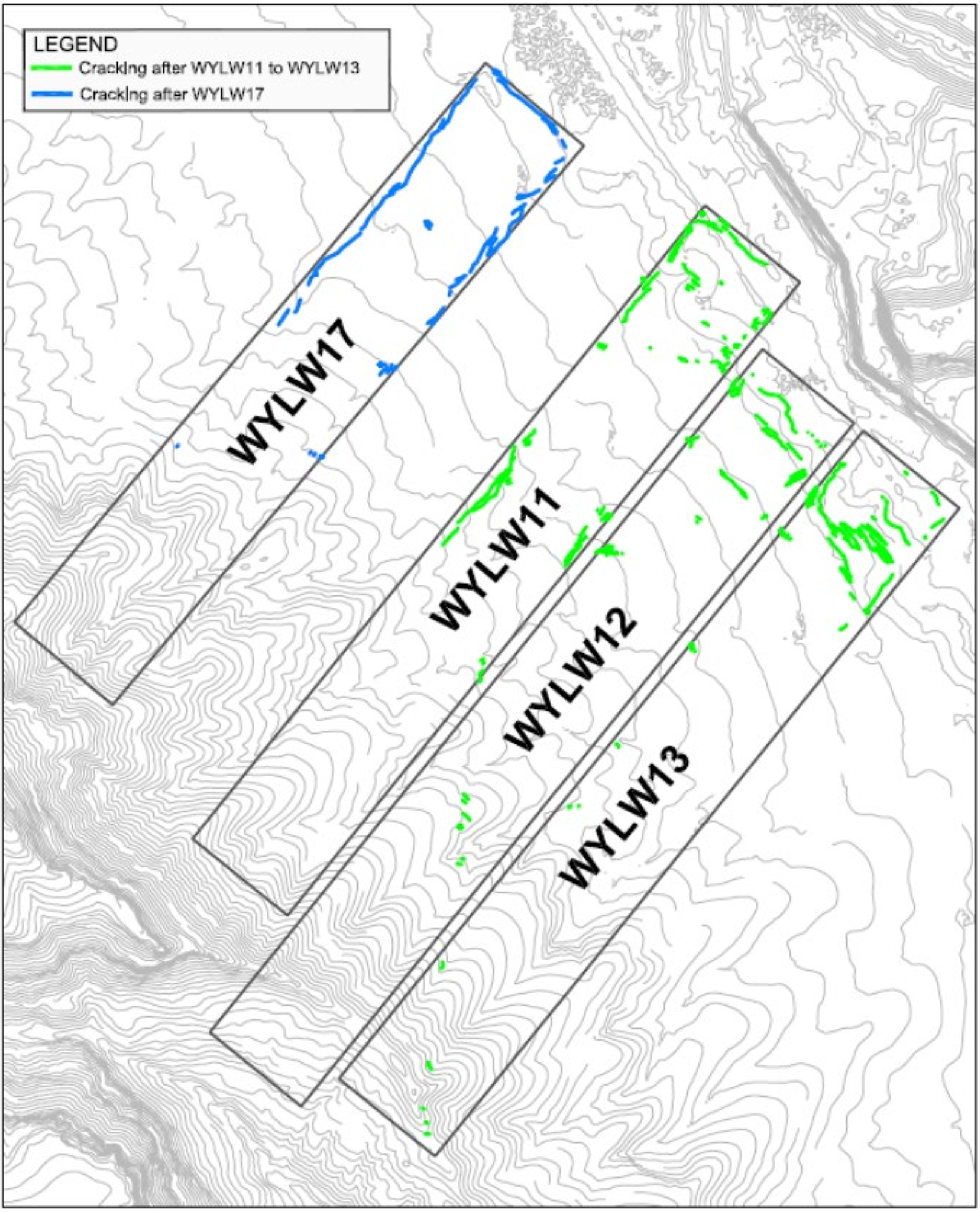


Figure 3-7. *Mapped surface cracking above LW11, LW12, LW13 and LW17 (MSEC, 2020)*

Subsurface cracking of overburden strata

An increase in hydraulic connectivity between the surface and the workings, particularly under waterways, is a considerable third order impact risk. Observations in the downstream extents of North Wambo Creek (downstream of where the panels LW1 to LW10 intercept the creek) indicate that flows reaching this part of the waterway are limited to high intensity rainfall events. Base flow conditions are likely to have altered because of underground mining, alluvial drawdown associated with open cut extraction, the removal of alluvium upstream for the construction of the NWCD and excision of catchment by the open cut. Observations of vegetation indicate that base flow conditions have been altered by a combination of the above factors, including death of aquatic plants and increasing colonisation by terrestrial vegetation. In the fully subsided sections of these longwalls, subsidence pools have developed over several panels. This may indicate that loss of base flow is most likely through tensile cracking along the boundaries of the pillars and not compression buckle cracks across the panel.

Predicted subsidence of panel catchments and waterways

Details of the predicted maximum subsidence within North Wambo Creek and its catchment are shown in Table 3-1 below. A visual representation of the maximum subsidence depth for each longwall panel is shown in Figure 3-9.

Table 3-1. Maximum predicted subsidence depth by longwall panel

Longwall Panel	Panel Length (km)	Maximum Depth of Subsidence (m)	
		Longwall Panel	North Wambo Creek channel
21	1.505	1.75	0
22	1.705	1.95	0
23	1.87	1.95	1.85
24	1.705	1.95	1.95

MSEC predicts that the maximum predicted total tilt for North Wambo Creek is 70 mm/m (i.e. 7.0 %, or 1 in 14). The maximum predicted total conventional curvature is greater than 3.0 km-1, which represents a minimum radius of curvature of less than 0.3 km. The maximum predicted conventional strains for North Wambo Creek, based on applying a factor of 10 to the maximum predicted curvatures, are greater than 30 mm/m tensile and compressive. The maximum predicted strains for the section of creek near the finishing (i.e. north-eastern) end of WYLW22 are 12 mm/m tensile and 17 mm/m compressive based on the 95 % confidence levels. Lesser strains are predicted further upstream as the depth of cover increases (MSEC, 2020).

The predicted subsidence void (or pool) volume estimates within the North Wambo Creek channel are summarised in Table 3-2. These assume static channel boundaries (no erosion or deposition or management intervention), which will not be the case when flows occur that are capable of eroding the channel boundaries (2nd order response). Such response will change the pool volumes over time. Volumes are calculated from toe of bank to toe of bank of the macro channel, which includes the inset floodplain/bench and the low flow channel. The predicted subsidence void volume for LW23 and LW24 is 113,030m^3 which is significantly higher than the predicted subsidence void volume of the previous panels (LW11 to LW16) subsiding NWCD which had a total subsidence void volume of 64,225m^3. This is because the section of creek being subsided by LW23 and LW24 is aligned almost in parallel with the panels unlike the previous panels which were perpendicular.

Table 3-2. Subsidence void volumes

Longwall Panel	Subsidence void volume (m^3)
23	23,490
24	89,540
Total	**113,030**

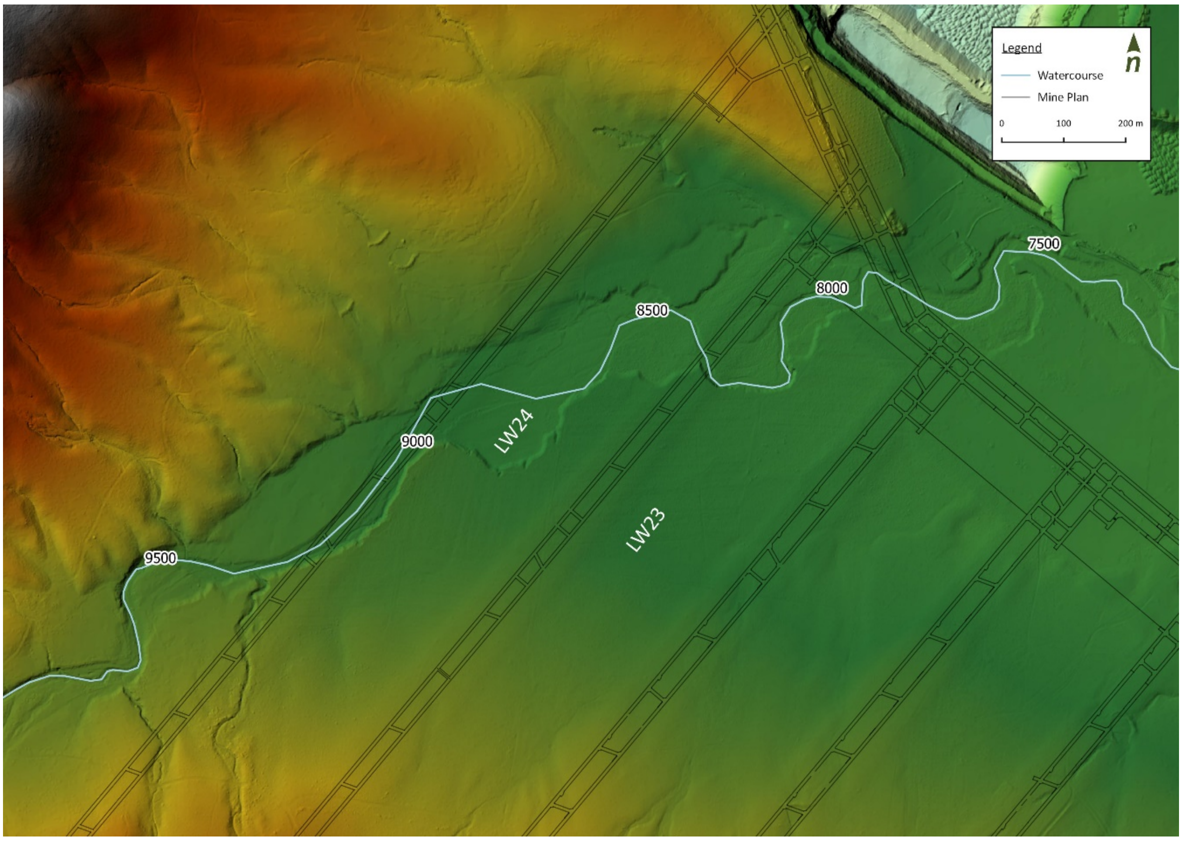


Figure 3-8. *Hillshade showing predicted post subsidence surface over LW23 and LW24. Note the extents of macro channel and orientation of the channel in relation to the LW23 and LW24 panel alignment*

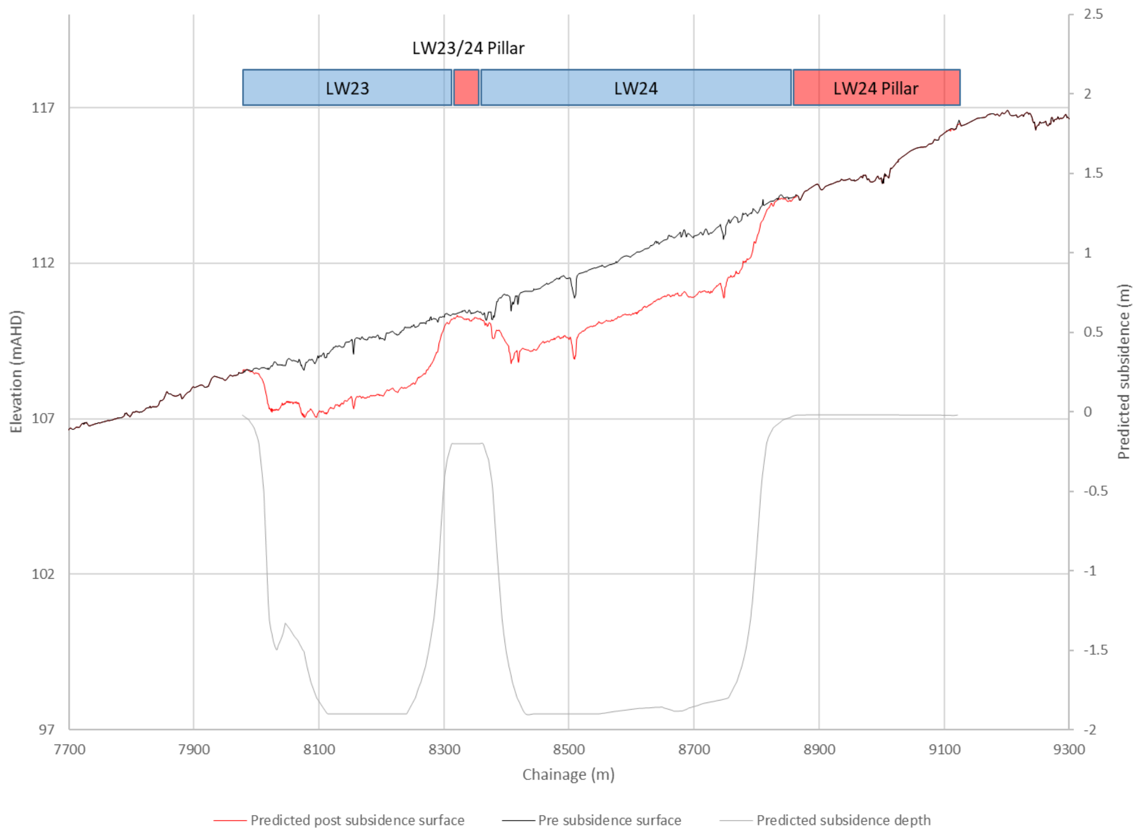


Figure 3-9. *Longitudinal profile of North Wambo Creek through LW23 and LW24 showing predicted post and pre subsidence surfaces (m AHD) as well as predicted subsidence depth (m)*

3.2 2nd order – predicted geomorphic response of surface water systems

North Wambo Creek

Upstream of LW24 is likely to experience erosion in response to the steepening of the channel longitudinal profile. Currently throughout this reach the previously active channel has infilled and exhibits very little fluvial bed form activity. This section appears to be returning to a discontinuous alluvial form, inset below the former surface. The response to subsidence is likely to initiate the propagation of a headcut, or series of headcuts, that could migrate upstream recreating the active channel throughout the alluvial layer. Any coarse bedload sediment generated by this process is likely to be deposited in the panels and only finer sediment transported downstream to NWCD.

Given LW23 is planned to be mined prior to LW24, the same process could occur over the LW23-LW24 pillar should flow events of sufficient magnitude occur before LW24 subsides. Similarly, that pillar may also erode in time. There are several possible outcomes for the flow path of NWC following subsidence as shown in later figures. Management response is best timed after full subsidence based on the scenarios contemplated in this report.

In-channel one dimensional hydraulic assessment (Figure 3-11 and Figure 3-12) indicates that the reach impacted by LW21 to 24 is relatively low energy with stream power, shear stress and velocity being mostly within current best practice design criteria for diversions in Australian mining (Figure 3-11 and Figure 3-12). Following subsidence there are some areas (particularly across the panels) where hydraulic parameters decrease and some areas (particularly across the pillars) where they extend within the range where instability for alluvial channel boundaries is expected and may require management (Section 4).

The two panels are likely to capture any bedload sediment transported to this point in North Wambo Creek, which is presently negligible. This means that flows downstream of the panels are effectively clear and will look to mobilise material from the channel bed. Downstream within the NWCD where potential for deposition is already limited due to diversion configuration, surfaces are likely to remain as bare bedrock, limiting potential for vegetation establishment on lower channel boundaries.

Modelling of the post predicted subsidence streamlines indicates that a possible meander cutoff could develop across the LW23/LW24 pillar towards the north of the panels. The flowpath of North Wambo Creek is predicted to follow the north easterly direction of the panel and enter an existing tributary entering from the north west which, together with the formation of a raised section of creek over the LW23/24 pillar, could result in a meander cutoff forming. If the meander cutoff were to form the length of North Wambo Creek would be decreased by 150-200 m, therefore increasing the channel grade. However, as mentioned above, the erosion of the elevated section of bed over the LW23/24 pillar is likely to occur which will reinstate flows down the existing North Wambo Creek channel. This area should be monitored following subsidence of LW23/24 as stream bank and bed stabilisation measures may need to be implemented.

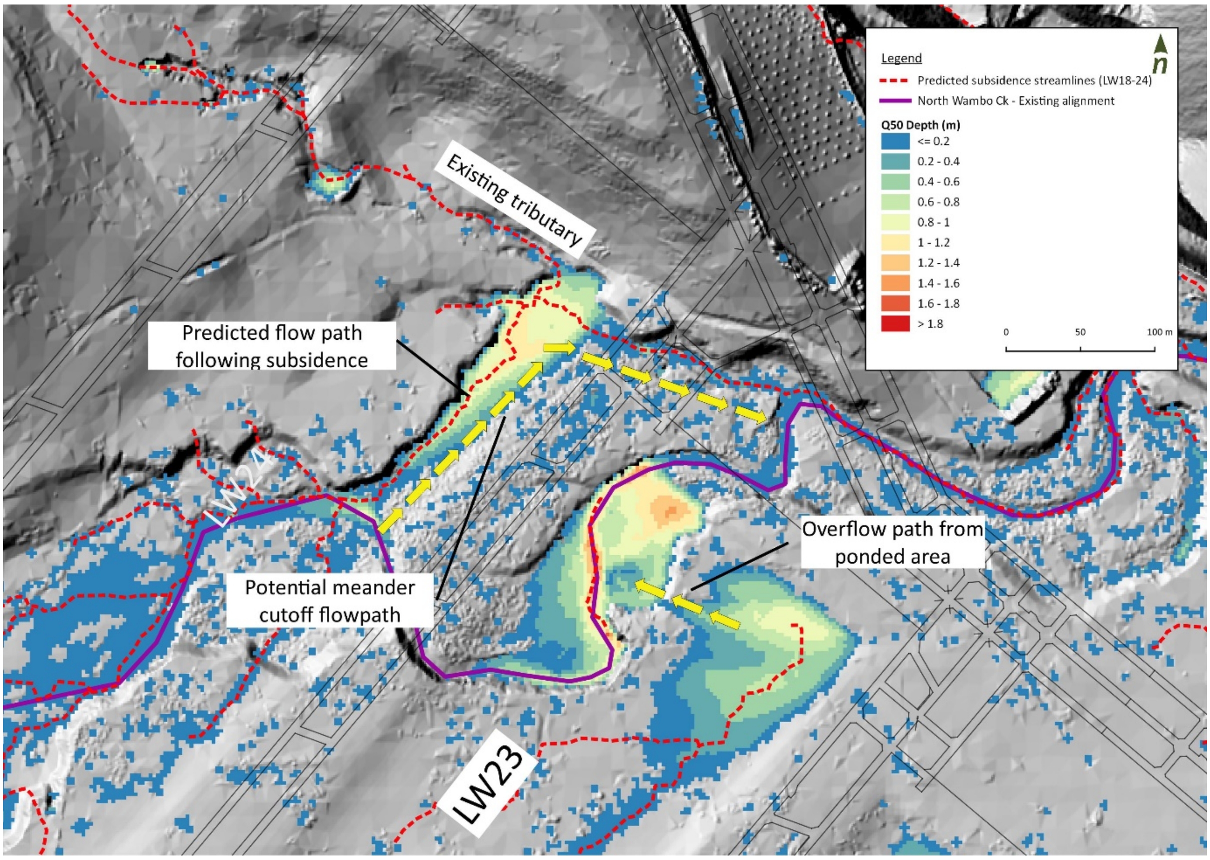


Figure 3-10. *Potential meander cutoff within North Wambo Creek over LW23 and LW24 including estimate of ponding following 50-year ARI event (subsided conditions)*

NWCD

There is no predicted subsidence within NWCD caused by the extraction of LW21 to LW24. Increased geomorphic impacts are likely due to further starvation of bedload sediment transport into NWCD, increasing erosion potential, should flow reach the diversion. The potential for flow to get to the diversion will be decreased by LW23 and LW24.

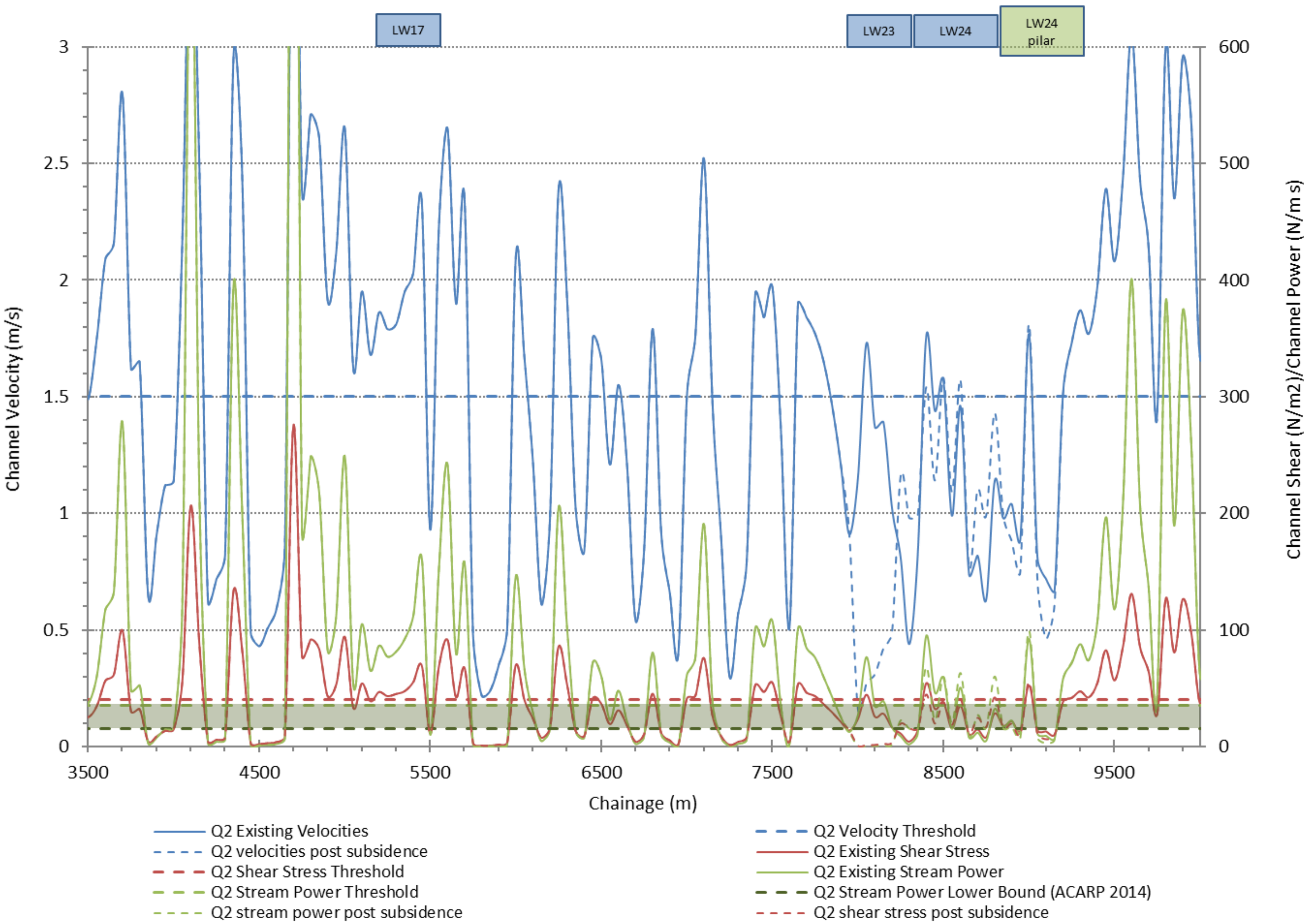


Figure 3-11. *Existing and post subsidence hydraulic conditions for 2-year ARI*

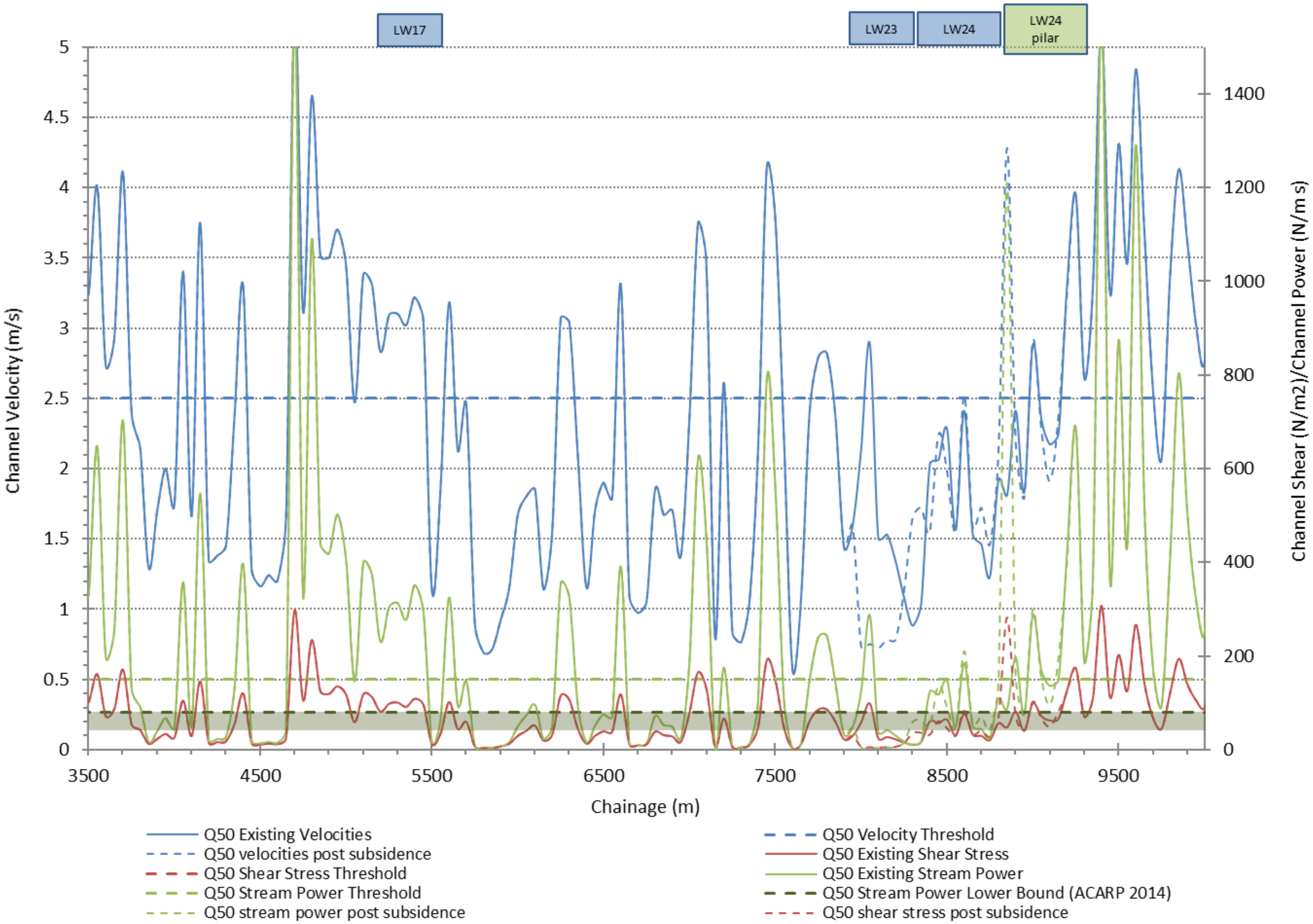


Figure 3-12. *Existing and post subsidence hydraulic conditions for 50-year ARI*

Western tributaries
The flow paths from the range to the west into North Wambo Creek are also likely to undergo substantial change following subsidence of LW21 to LW24. This is due to the geometry of these flow paths relative to magnitude of subsidence.

The predicted changes in flow paths are presented in Figure 3-14. The streamlines shown are those predicted by the software CatchmentSIM using the existing and predicted subsidence digital terrain models (DTM). It is important to note that the predicted flow path changes are completely reliant on the accuracy of the DTM and subsidence predictions, particularly as changes in flow paths occur with relatively small changes in elevation.

The existing streamlines are shown as light blue dashed lines with the predicted post subsidence streamlines shown as solid red sitting underneath them. Hence where a blue dashed streamline is shown on the map with no underlying red, that section of stream is abandoned post subsidence.

Over LW21 the major change for the existing streamlines following subsidence occur towards the north of the panel, near the LW21/22 pillar zone. The flow path is predicted to shift slightly further to the south, rather than over the pillar zone, and drain east. This will result in some slight shortening of this tributary which will increase the grade and therefore lead to possible instabilities.

The main tributary flowing down LW22 previously converged with the smaller tributaries from LW23 over what will become the LW22/23 pillar zone. The predicted flow path for this tributary is now down the centre of LW22 before again converging with the LW23 tributaries further downstream.

Following subsidence, LW23 will now capture one of the main western tributaries that currently flows north over the proposed LW22, LW23 and then LW24 locations. Previously this tributary would have flowed north before flowing east, back across LW23 and into the NWCD. Following subsidence, the flow path of this tributary, along with another main tributary will shift towards the centre of LW23 and flow down the panel to the north east. The modelling shows the streamlines becoming discontinuous at the northern extent of the panel with no defined entry point into North Wambo Creek. This indicates that ponding will occur in this area. Once the ponded area fills it will overflow into North Wambo Creek to the east as the elevation of the pillar zone will be higher than the right bank of North Wambo Creek following subsidence (Figure 3-10). This area should be monitored as the new flow entry point will potentially lead to erosion (headcut) where it enters North Wambo Creek.

There will be minor changes to the flow paths of the western tributaries flowing down LW24 which will shift towards the centre of the panel.

Northern tributaries
The flow paths from the range to the north into North Wambo Creek are also likely to undergo some change following subsidence of LW24. The location at which one of these minor tributaries enters North Wambo Creek will move upstream approximately 50m. This new entry point may cause some erosion and may initiate a headcut which should be monitored.

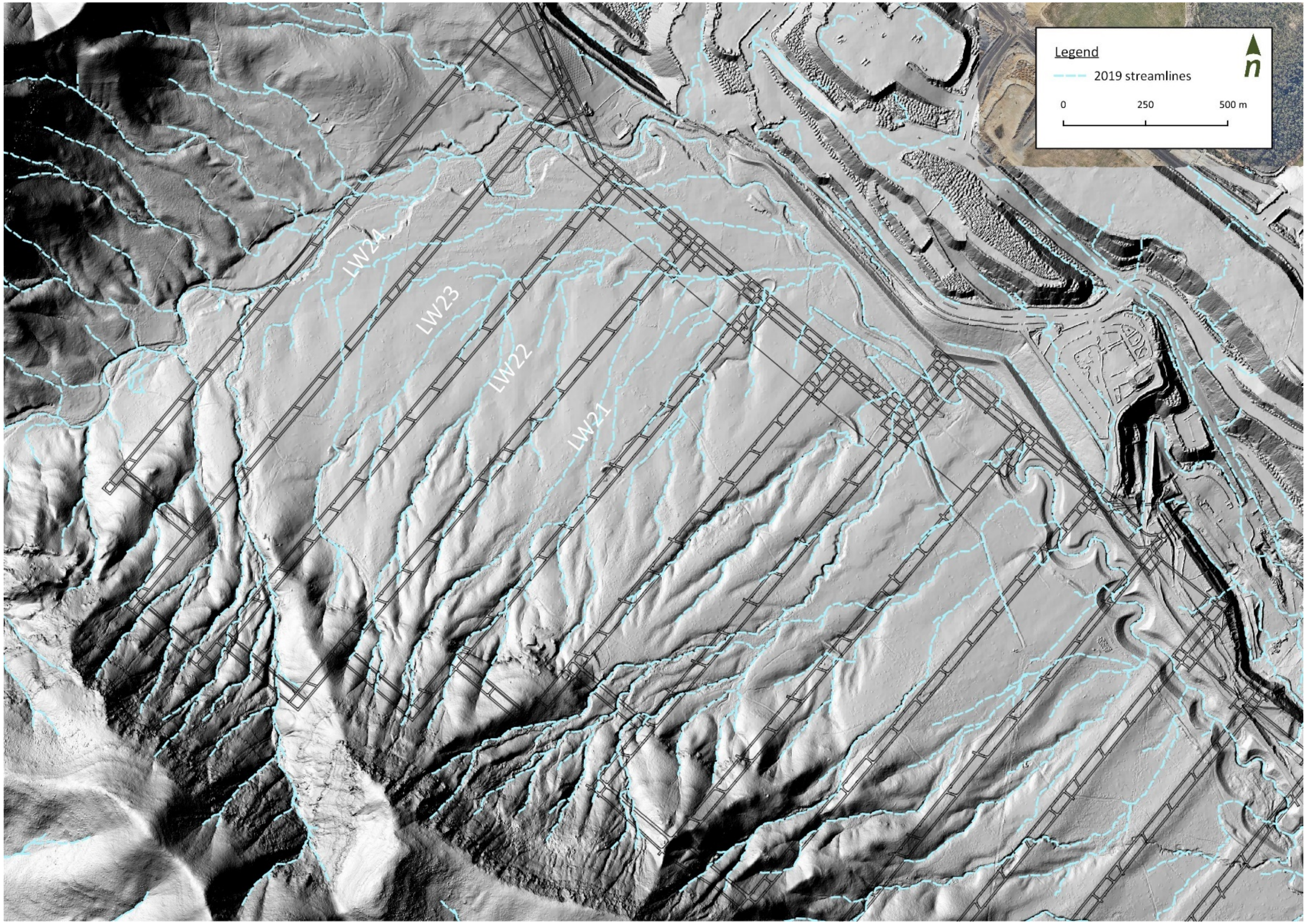


Figure 3-13. *Flow paths under existing (LIDAR collected 05/05/2019) conditions for western tributaries with existing surface hillshade*

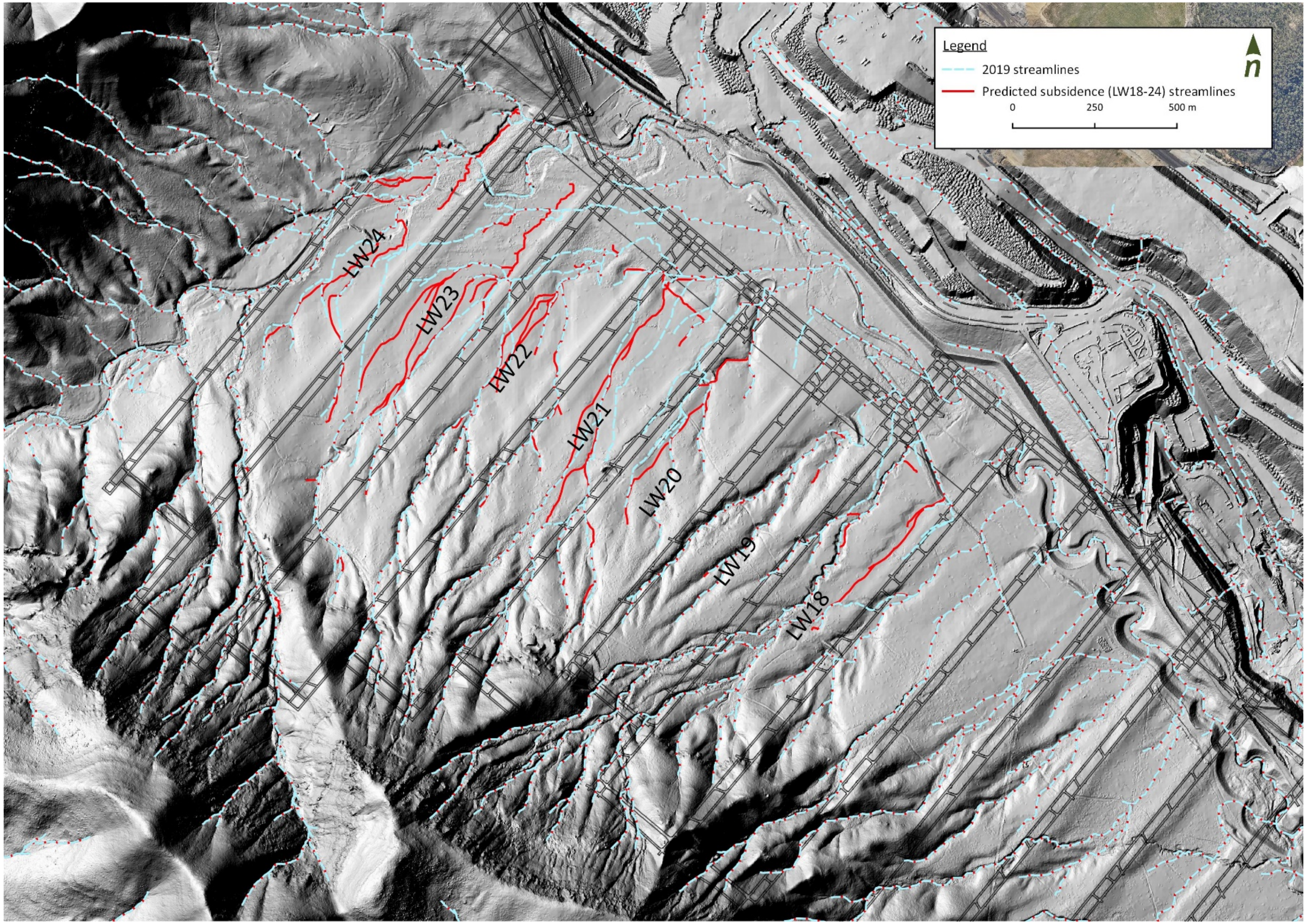


Figure 3-14. *Flow path changes for western tributaries with predicted subsidence surface hillshade*

3.3 3rd order – predicted impacts to water quantity and quality

Changes to water quantity

The impact of subsidence on flow and storage in the channel and western tributaries was assessed using 2D modelling. Using the existing and post subsided landforms, the 2D model was used to determine how the subsidence from LW21 to 24 (including LW17 to 20) would impact on the stream and surface water flow passing through the site. The models were run longer than the duration of the storm events to determine the volume of water remaining ponded across the site.

As part of this project, the North Wambo Creek hydrology has been updated to meet the recent update to the 2016 Australian Rainfall and Runoff (2016 ARR). Prior to release of 4th edition of the Australian Rainfall and Runoff national guideline document the 3rd edition was utilised in previous projects. The 2016 ARR provides a greater capture of the uncertainties inherent in hydrology than the previous ARR edition 1987 (3rd). The resulting updated hydrological outputs are incorporated into the 2D hydrodynamic model and will provide a more robust estimation of hydraulic conditions and flood levels.

Previous hydrological modelling built in 2016, utilised 25mm as the initial loss. Subsequent work in 2018 revised this with a higher loss of 65.9mm based on advice from 2017 and 2018 site visits. Following the 2016 ARR update the modelling for this report utilised the Australian Rainfall and Runoff Datahub's initial loss value of 50 mm and a continuing loss of 3.4. The continuing loss value was multiplied by a factor of 0.4 down to 1.36 mm/h on advice provided by the ARR Data Hub. This advice suggested that the data hub values are underpredicting design flows in NSW.

Table 3-3 illustrates the effect of these changes on the peak design values across the four AEP events.

Table 3-3. Design discharges generated from hydrologic modelling of existing conditions, 2016 estimates, 2018 estimates and 2020 estimates

	2016 estimates	2018 estimates	2020 estimates
Upstream catchment (km²)	34	34	34
ARI/AEP	**Peak Discharge (m³/s)**	**Peak Discharge (m³/s)**	**Peak Discharge (m³/s)**
2 year	43	10.5	21.6
50 year	154	57.6	102.3
100 year	180	75.4	119.6
1000 year	324	93	225.8

Subsidence of Longwalls 23 and 24 will increase in-channel storage by more than 9 times when compared to existing conditions (Table 3-4).

Table 3-4. Residual ponding estimates in North Wambo Creek after 2D model runs (50-year ARI)

Longwall	Existing (m³)	Subsided (m³)	Difference (m³)
23	250	7,000	6,750
24	600	950	350
Total	850	7,950	7,100

As well as increasing in-channel storage, the subsidence of LW21 to LW24 will result in ponding of water at the north eastern ends of all the panels . The predicted ponding following subsidence is depicted in greater detail in Figure 3-15 and Figure 3-16, using the 50 year ARI event as an example.

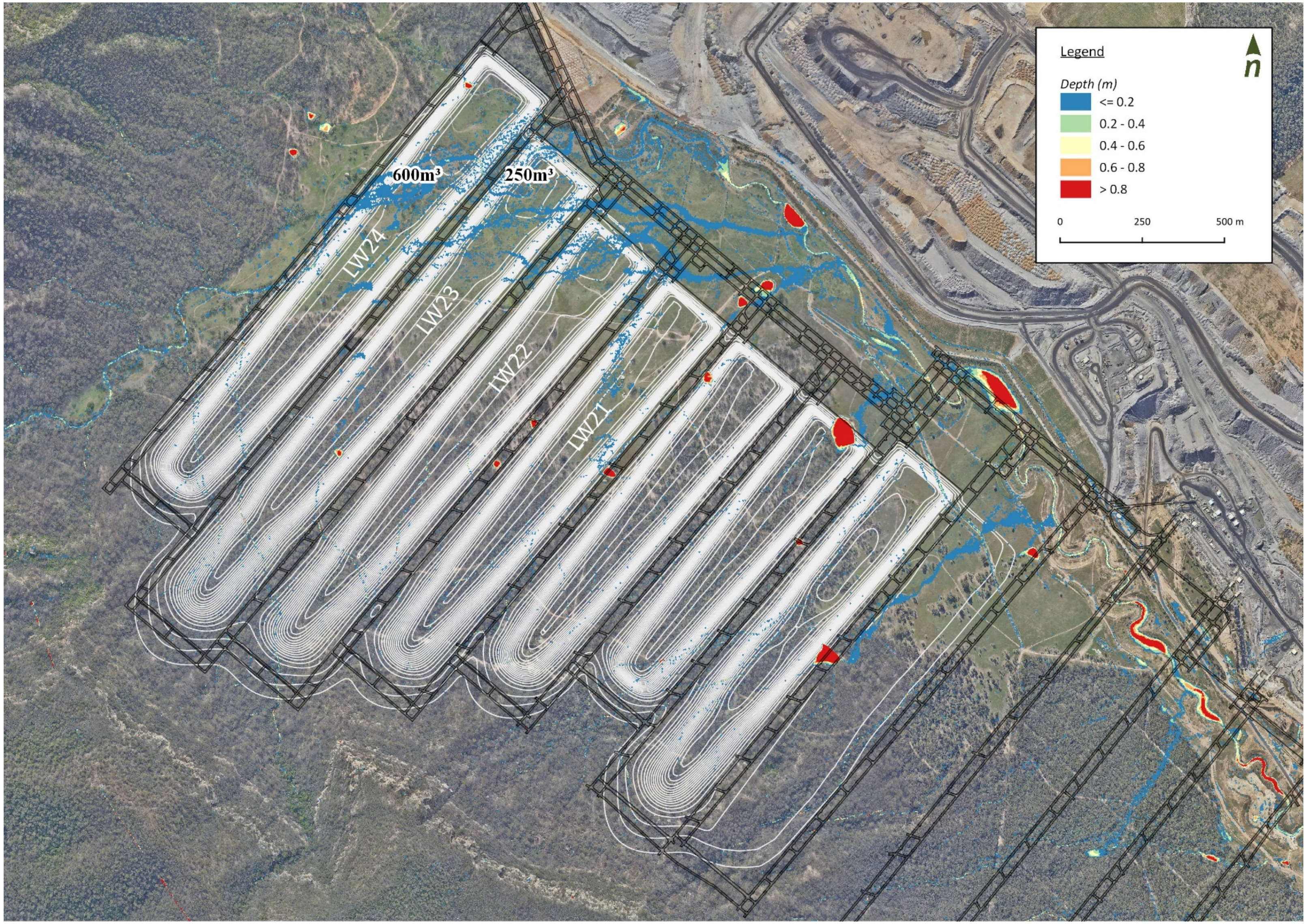


Figure 3-15. *Estimates of ponding following 50-year ARI event (existing conditions)*

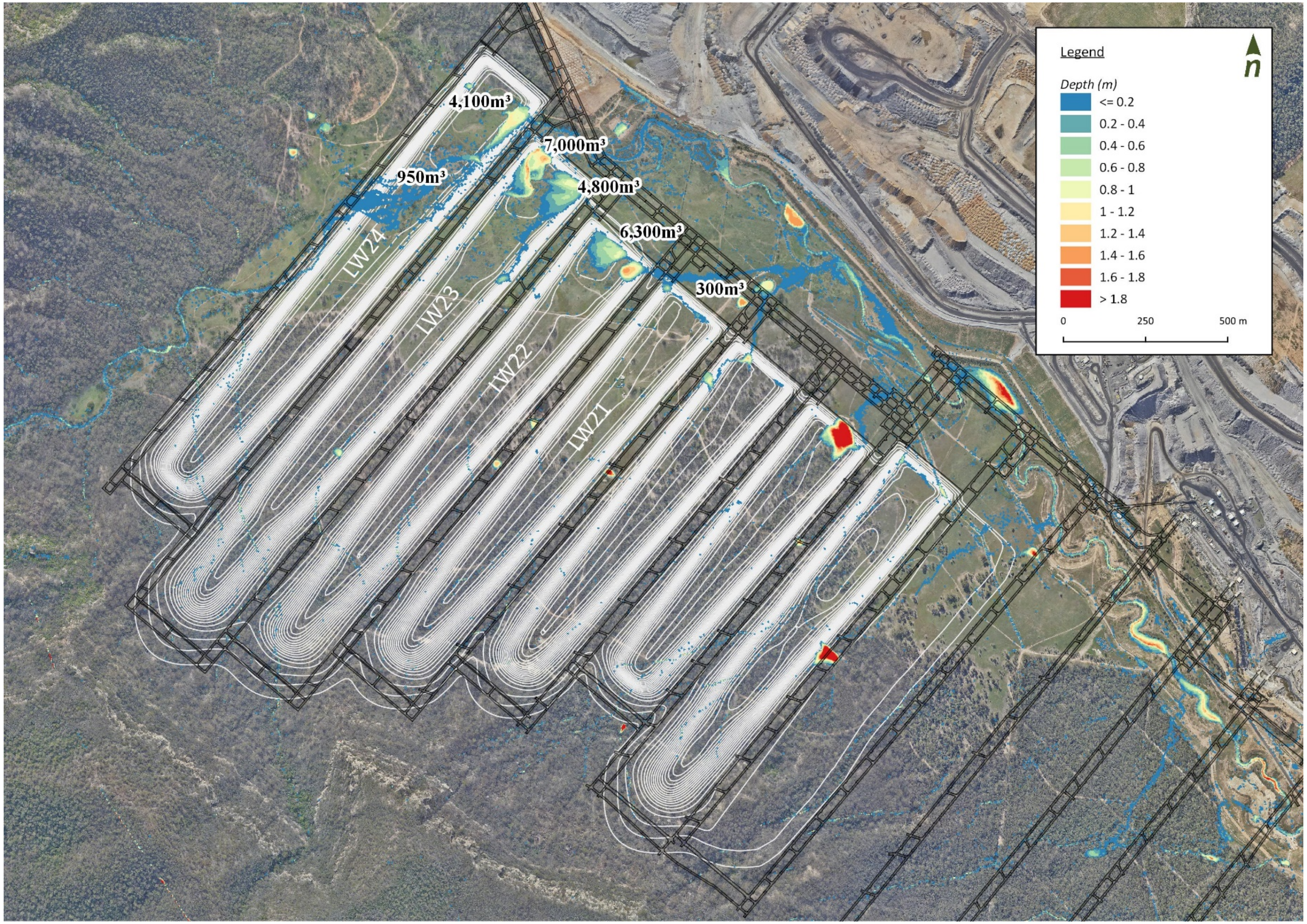


Figure 3-16. *Estimates of ponding following 50-year ARI event (post subsidence conditions)*

The impact of subsidence of Longwalls 21 to 24 (including LW17 to LW20) on flow from a pure surface water perspective in North Wambo Creek is relatively small. As demonstrated in Table 3-4, the greatest change is a reduction in flow volume of 8.7%. The impact on volume decreases as the magnitude of the design flood event increases (as the subsidence driven storage volume does not increase).

Table 3-5. Predicted volume changes to North Wambo Creek stream flow post subsidence

ARI	Existing (m^3)	Subsided (m^3) after LW21-24	Difference (%)
2 year	518,448	473,287	-8.7%
50 year	2,393,254	2,348,819	-1.9%
100 year	2,819,623	2,792,624	-1.0%
1000 year	5,515,367	5,495,113	-0.4%

The changes to the flow hydrograph resulting from subsidence are shown in Figure 3-17 (2 year ARI), Figure 3-18 (50 year ARI), Figure 3-19 (100 year ARI) and Figure 3-20 (1000 year ARI).

Please note that this assessment has focussed solely on the impact that the topographical changes resulting from subsidence have had on storage and flow in North Wambo Creek. The assessment does not consider the potential for losses to the alluvial aquifer, losses to the underground workings or changes to topography by erosion/deposition or management intervention. It is likely that such losses will increase with ponding in these areas unless fine sediment decreases the hydraulic conductivity of the base of the pools or there is management intervention.

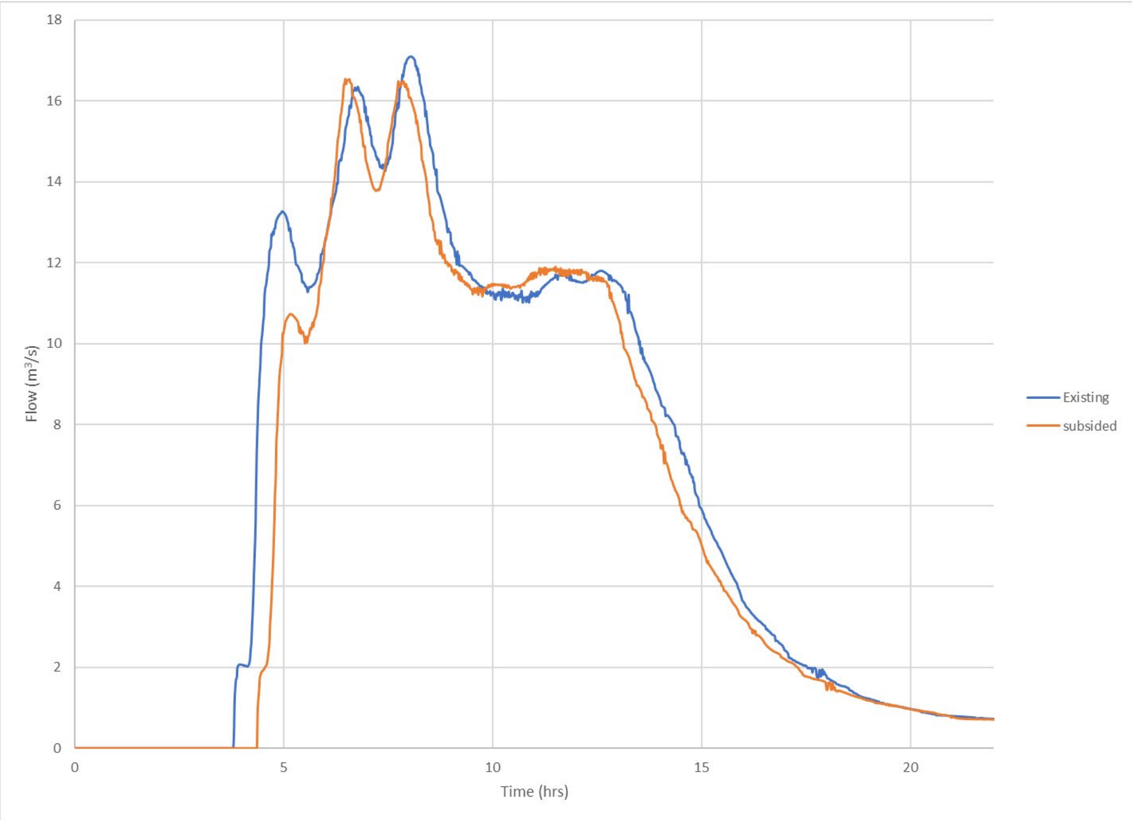


Figure 3-17. *Hydrographs for North Wambo Creek for existing and post subsidence conditions (2-year ARI)*

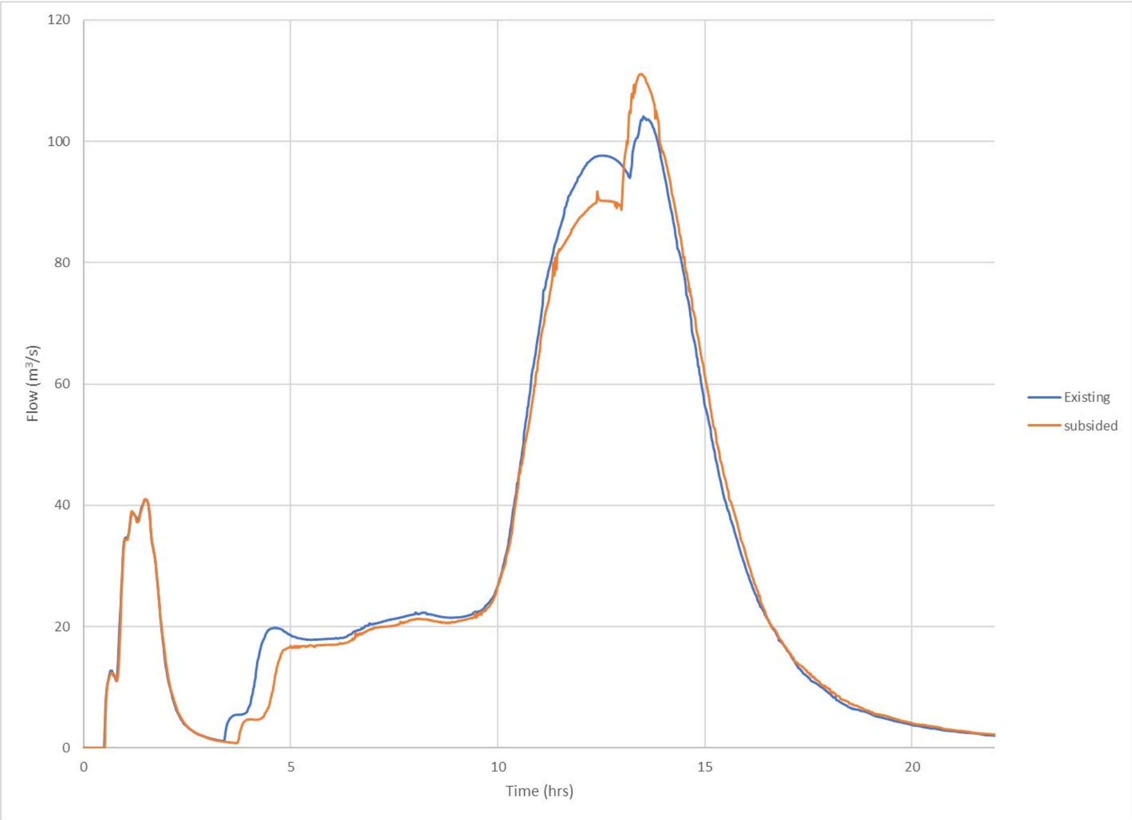


Figure 3-18. *Hydrographs for North Wambo Creek for existing and post subsidence conditions (50-year ARI)*

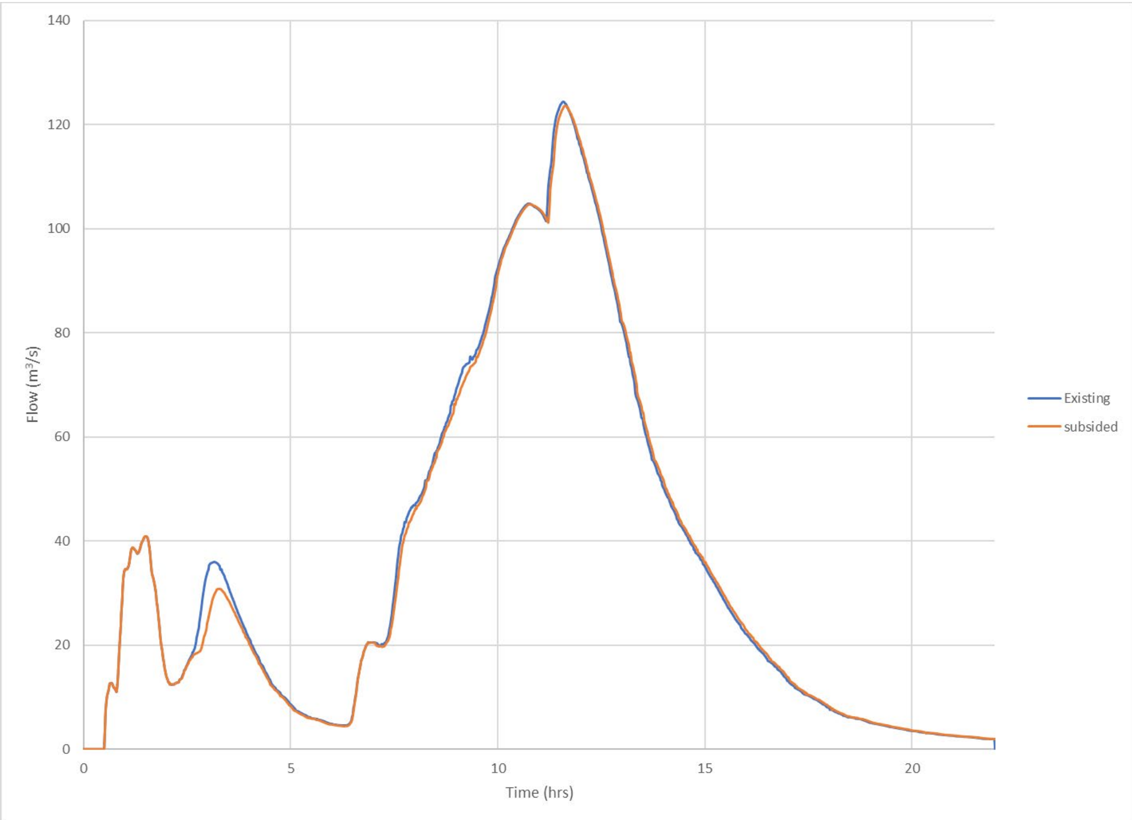


Figure 3-19. *Hydrographs for North Wambo Creek for existing and post subsidence conditions (100-year ARI)*

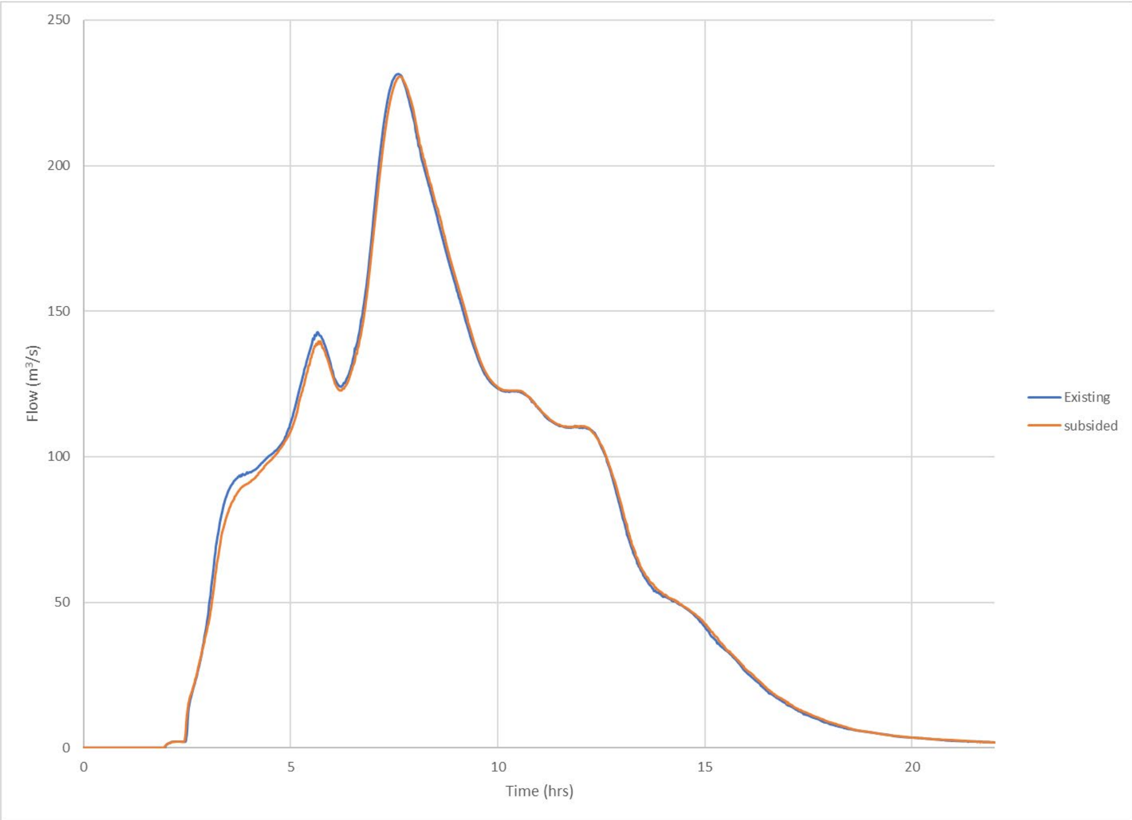


Figure 3-20. *Hydrographs for North Wambo Creek for existing and post subsidence conditions (1000-year ARI)*

Changes to water quality
An increase in suspended sediments in North Wambo Creek and NWCD is possible from increased erosion. Management measures can be put in place to reduce that risk to low.

Due to a predicted decrease in flows (water quantity) through the North Wambo Creek and NWCD as a result of losses to alluvial aquifer, subsidence cracks and voids it is possible that any negative impacts to water quality will be exacerbated as there will be less dilution occurring.

3.4 4th order – predicted impacts to flora and fauna

The consequences for ecology associated with impacts described above should be considered by WCPL's ecology specialists. The changes in behaviour of water in the landscape due to subsidence provide potential for both positive and negative impacts, depending on current ecological conditions and the extent of change. The primary change of note is alteration of flow paths in the western tributaries may alter the species composition along the zones that currently receive flows and similarly for those areas that will receive flows post subsidence. There is also the possibility of pools forming over LW23 and LW24 which may provide ecological habitat for some flora and fauna yet impact negatively on others.

4 Subsidence Management

Subsidence management involves monitoring the impacts of subsidence to identify issues or the need for mitigation activities. Monitoring involves establishing baseline data against which future monitoring can be compared. Monitoring of waterways intersected by the panels extends upstream and downstream of the mine footprint to determine if observed changes are the result of subsidence or other factors. The monitoring program implemented at Wambo is described below.

4.1 Monitoring and Evaluation

As part of the Extraction Plan for LW11 to 16 it was identified that up until 2016 the monitoring activities undertaken across NWCD, North Wambo Creek and South Bates underground mine subsidence area included:

- Streamflow monitoring
- Surface water quality monitoring
- Groundwater monitoring
- Riparian monitoring
- Freshwater Macroinvertebrate monitoring
- Bed and bank stability monitoring
- Landscape Function Analysis (LFA)
- Floristic and habitat monitoring sites

While the extent and complexity of the monitoring satisfied regulatory conditions regarding mining operations, the information was not synthesised to evaluate the impact of subsidence on waterways or the condition of NWCD in relation to reaches of North Wambo Creek, upstream and downstream.

It was recommended that existing monitoring be integrated into a diversion and subsidence monitoring program based upon the "Monitoring and Evaluation Program for Bowen Basin River Diversions" (ID&A, 2001, ACARP project C9068), which was undertaken for the Australian Coal Association Research Program (ACARP). This monitoring program is considered best practice for diversions in the Australian mining industry at present. Despite the methodology being developed for diversions it is readily applicable to monitoring subsidence of a watercourse and it has been successfully implemented at several longwall mines over the past decade (some of which also subside diversions).

Adopting a consistent monitoring methodology for the upstream and downstream reaches of North Wambo Creek, NWCD (Stages 2 and 3) and the subsided reach, meant the results were comparable and able to provide an overall perspective on the creek's response to subsidence and overall performance in relation to relinquishment in the longer term.

The current monitoring program implemented and developed as part of the Extraction Plans for LW11 to LW20 encompasses the entire diversion and all current and past longwalls, including the extents of the NWCD over LW17 to 20. Now that mining is extending to LW21 to LW24, it is recommended that two additional monitoring points be included on the pillar zones of LW23/24 (UA – upstream A) and LW24 (UB – upstream B) as well as four additional points upstream of mining extents (UC to UF). It is noted that the current U2 or U3 could be moved slightly to cover pillar zone LW23/24 instead of adding the extra point UA.

A summary of the monitoring program is provided below. A summary of the monitoring program findings (in relation to LW21 to 24) from the first round of monitoring (baseline monitoring) are provided in section 2.

A Baseflow Separation Analysis for NWC (Alluvium, 2020, in prep) identified a data gap in the existing surface flow measuring system. This could be enhanced by the installation of rainfall gauges at the flow monitoring stations in the upper catchment to provide detailed data on precipitation depth and intensity.

4.2 Typical monitoring program components

A typical monitoring package from baseline to approvals relinquishment comprises four components as shown in Table 4-1.

Table 4-1. Subsidence and diversion monitoring package components

Monitoring components	Objective	Status
1: Baseline monitoring	To establish a baseline data set that can be used for tracking condition trajectory.	The diversion is already constructed, as such the first-round operations monitoring (stage 3 below) would establish the baseline. Baseline monitoring will be extended upstream of LW21-LW24 prior to mining of those panels.
2: Construction / rehabilitation monitoring	Technical overview of construction and documentation of as constructed works including any amendments from design (new or rehabilitation).	The diversion is already constructed, as such the first-round operations monitoring (stage 3 below) would establish the baseline.
3: Operations monitoring	To assess the performance of the NWCD and North Wambo Creek following subsidence to maintain or improve channel condition and reduce risk to mining infrastructure and the environment.	First round completed by Alluvium in November 2017. Most recent round completed by Alluvium in November 2019.
4: Relinquishment monitoring	To demonstrate North Wambo Creek through the area of subsidence and the NWCD is operating as a waterway in equilibrium with and not adversely impacting on adjoining reaches.	To be completed following relinquishment of mine.

4.3 The monitoring program

In 2017 Alluvium began implementation of the monitoring program that was recommended as part of the previous extraction plan for LW11 to 16 by completing baseline monitoring.

Baseline monitoring

The baseline data provides a reference to evaluate the condition of all reaches of North Wambo Creek over time.

As the NWCD is already constructed, the first round of operations monitoring completed in 2017 established the baseline and considered:

- Index of Diversion Condition (IDC) (including establishment of reaches and monitoring points) collected in the first round of operational monitoring
- Assessment of performance against risks identified in the Extraction Plan by expert fluvial geomorphic assessment
- Aerial photography analysis of changes relative to subsidence in the monitoring period
- Vegetation of geomorphic features in the monitoring area (referencing previous LFA monitoring)
- Analysis of flow event information for frequency and duration
- Analysis of long and cross-section survey for future comparison
- Summary of baseline condition and recommendations for mitigation of risks

A series of upstream, diversion and downstream monitoring transects were completed for North Wambo Creek and NWCD. The current monitoring sites for subsidence are shown in Figure 4-1.

Operations monitoring - Index of Diversion Condition transects

The Index of Diversion Condition (IDC) provides a rapid assessment of the diversion and adjoining reaches of interest along the watercourse(s) and is designed to flag potential management issues rather than provide a detailed scientific assessment of the waterway. It is an integrated suite of indicators that measures the geomorphic and riparian condition of a diversion (Geomorphic Index and Riparian Index, respectively) and its upstream and downstream reaches. Observations are recorded at monitoring points, spaced at regular intervals, within each reach to determine an average score for the reach. To provide a consistent approach at each monitoring point, observations are recorded within a limited area known as a transect. IDC monitoring locations are established in Wambo's Surface Water Monitoring Program.

For details on the most recent round of monitoring at Wambo refer *North Wambo Creek Diversion Operations Monitoring 2019 (Alluvium, 2019)*.

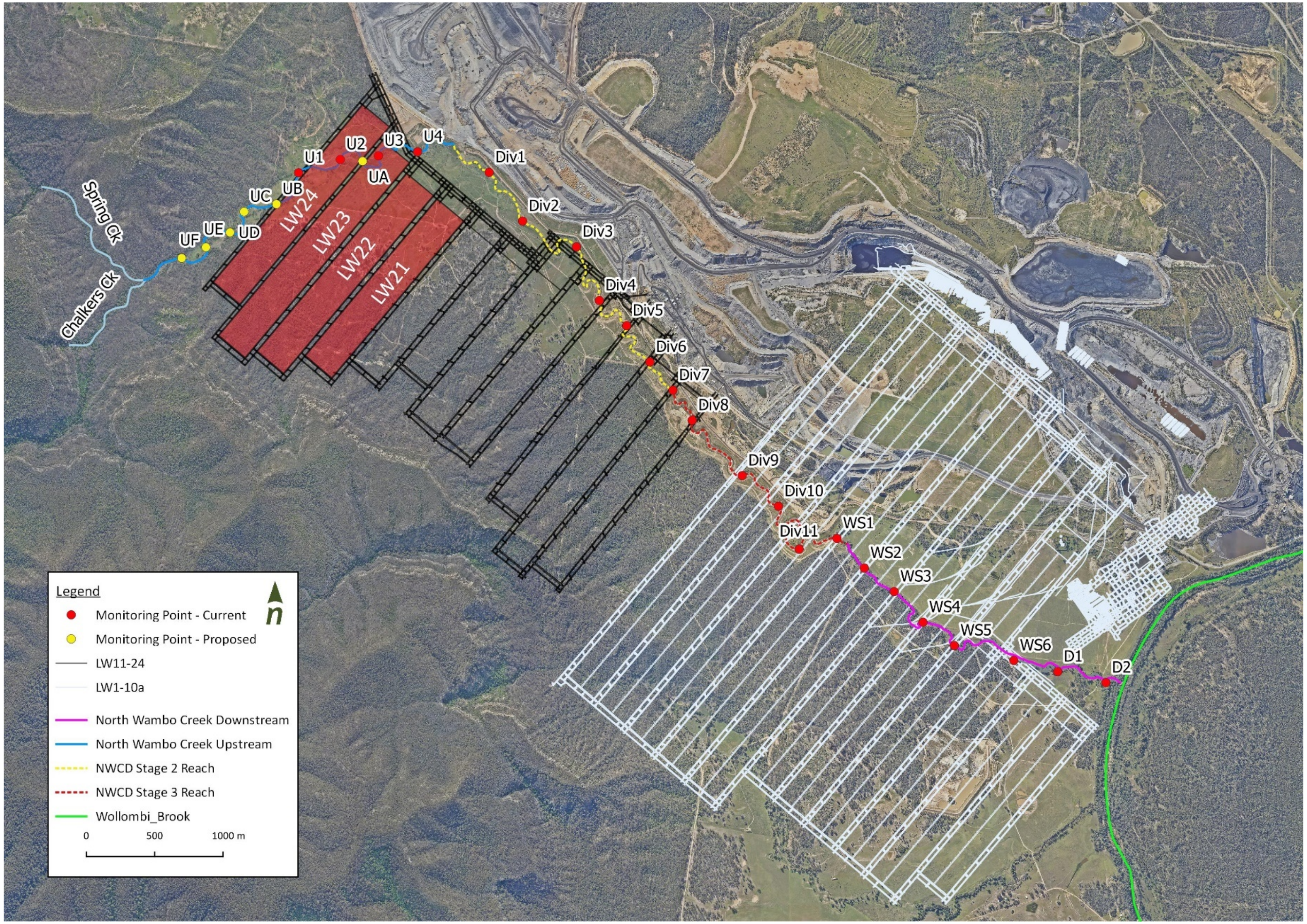


Figure 4-1. *Monitoring locations for Diversion and Subsidence Monitoring Program including proposed monitoring points*

4.4 Recommendations for mitigation works

The zone where works are recommended for North Wambo Creek and the western tributaries associated with the subsidence of LW21 to LW24 are shown on Figure 4-2. Based on the predicted subsidence and landscape response, a number of mitigation measures are proposed. These measures are indicative only and purely relate to potential geomorphic response associated with surface water flows. Any mitigation works will need to be coordinated with any works associated with alluvial groundwater management that may be proposed as part of meeting rehabilitation targets for NWCD and NWC through to its confluence with Wollombi Brook.

It is important to note that all the mitigation works mentioned are based on predicted subsidence modelling and final mitigation works will be dependent on actual subsidence.

North Wambo Creek

Instabilities are likely to develop at the drop into LW24 (and upstream), the LW23-24 pillar, the potential re-alignment (meander cut off) of NWC and potential bedload sediment starvation downstream of LW23 in response to stream flows. Based on stream flow gauging over the last decade, the magnitude of stream flows being gauged are less than the 2-year ARI design flow estimated through the 2016 ARR. This may be simply related to an extended dry period, technical issues associated with gauging or changes in alluvial aquifer saturation associated with losses to the open cut. NWC currently exhibits limited fluvial activity in channel bed forms over LW23-24. The combination of these observations may mean that the potential for instabilities is limited, however the observation period on stream flows is too short to draw that conclusion.

On the assumption that stream flows of sufficient magnitude will occur, indicative mitigation measures for the predicted geomorphic responses will involve a combination of vegetation management and channel stabilisation through measures such as timber pile field alignment training, armouring and/or channel reconfiguration.

Western Tributaries

It is recommended that the western tributaries be monitored as subsidence occurs. Comparison of modelled streamlines for existing and post subsidence conditions (Figure 3-13) indicate that the length of some of the western tributaries could decrease which could initiate incision that will propagate upstream as headcuts.

Erosion mitigation measures such as revegetation in combination with channel realignment (to increase length and reduce grade) or structural bed works such as rock chutes may be required.

The modelling indicates that the overland flow entry location of at least one of the western tributaries will now be further upstream within North Wambo Creek over LW23 rather than downstream in the NWCD (Figure 3-10). Some form of mitigation measure would be required to manage this new overland flow entry point in order to prevent a headcut forming at this location. Mitigation measures will depend on the actual location and severity of the erosion and could range from revegetation to channel realignment and lengthening or the construction of a rock chute.

Review of LW17 to 20 mitigation works

As part of the previous extraction plan for LW17 to 20 (*Surface Water Technical Report for South Bates Underground Mine (Longwalls 17-20) – Amendment, Alluvium 2019)* a series of mitigation measures were recommended. Since this report was submitted, LW17 has almost fully subsided allowing for a review of the recommended mitigation measures based on modelling of predicted subsidence modelling to be compared with modelling based on actual subsidence (Figure 4-3).

Review of the predicted streamlines, which dictated the positioning of the LW17 rock chute, against the actual post subsidence streamlines indicates that the positioning of the rock chute does not need adjusting.

The chute has not yet been constructed. Note that there is still some low-level subsidence predicted above the recently subsided LW17 due to reactivation and long-term residual movements after the completion of that longwall however this should not impact the design of the LW17 rock chute.

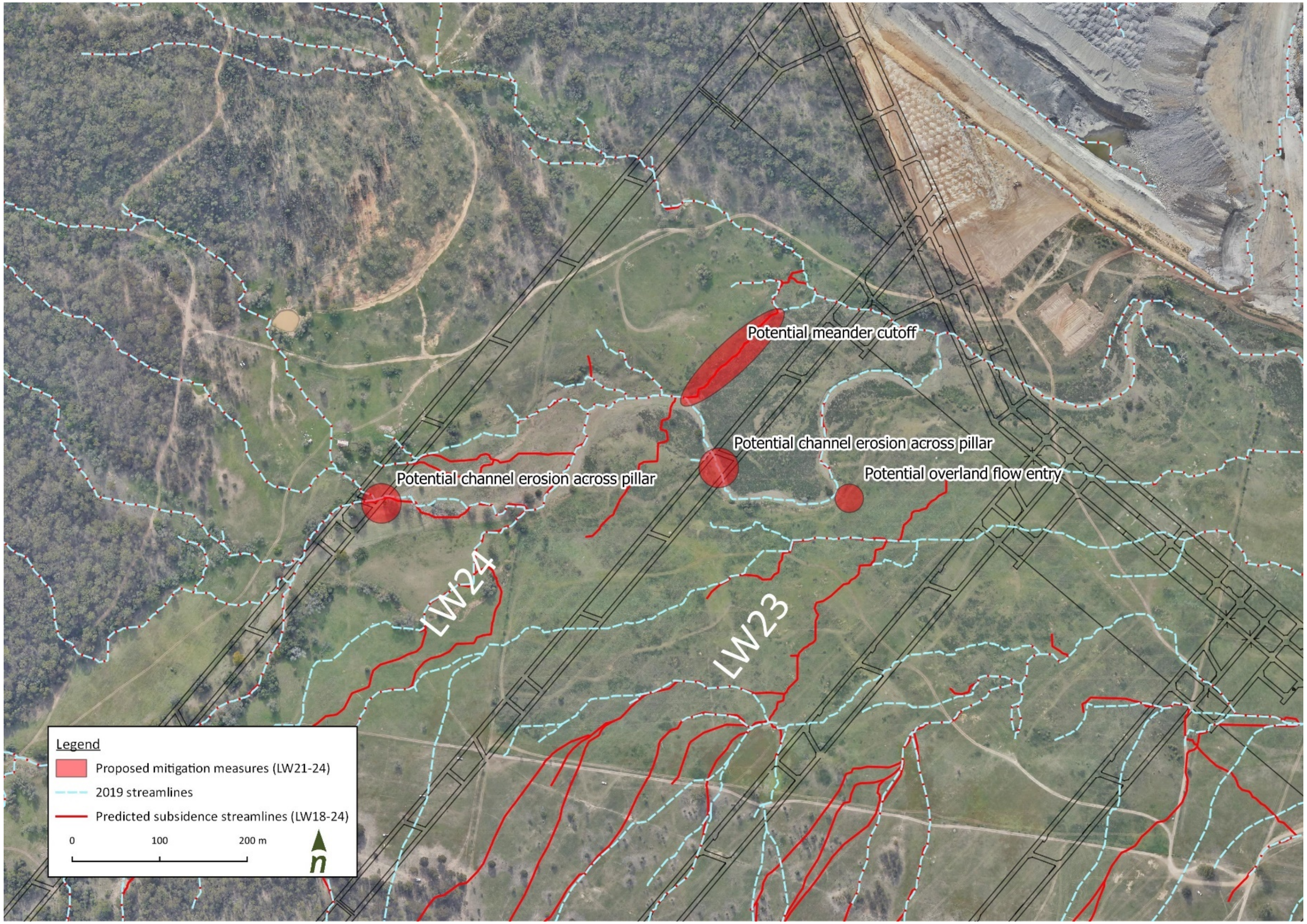
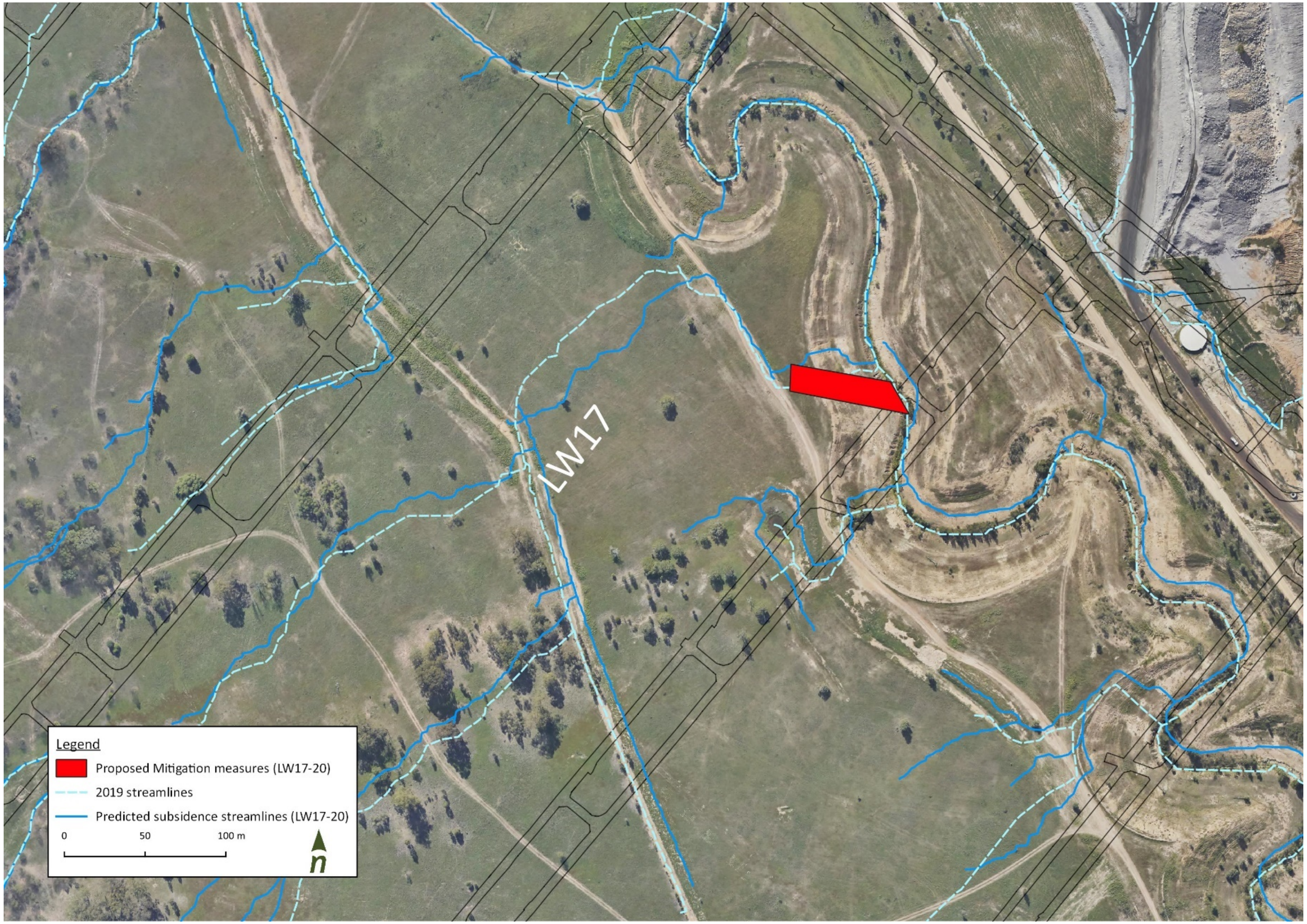


Figure 4-2. *Location where mitigation measures are likely required following subsidence*



- **Figure 4-3.** *Previous predicted streamlines post LW17 subsidence, including proposed batter chute location, compared to 2019 streamlines*

5 References

Alluvium (2016). *Surface Water Technical Report for South Bates Underground Mine (Longwalls 11-16).*

Alluvium (2018). *North Wambo Creek Diversion Operations Monitoring 2017.*

Alluvium (2019). *Surface Water Technical Report for South Bates Underground Mine (Longwalls 17-20).*

Alluvium (2019). *Surface Water Technical Report for South Bates Underground Mine (Longwalls 17-20) – Amendment.*

Alluvium (2019). *North Wambo Creek Diversion Operations Monitoring 2019*.

Bureau of Meteorology (2003). *The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method*. Bureau of Meteorology.

DERM (2011). Draft Central West Water Management and Use Regional Guideline 'Watercourse Subsidence – Central Qld Mining Industry V1'.

ID&A (2001). Monitoring and Evaluation Program for Bowen Basin Diversions, undertaken for the Australian Coal Association Research Program (ACARP), Program No. C9068.

Institute of Engineers, Australia (1987 and newer drafts). *Australian Rainfall and Runoff*. Institute of Engineers, Australia.

Jordan P, Nathan R, Mittiga L, Taylor B. (2005). *Growth curves and temporal patterns of short duration design storms for extreme events*. Sinclair Knight Mertz and Bureau of Meteorology.

Laurenson E.M, Mein R.G. and Nathan R.J. (2007). *RORB Version 6 Runoff Routing Program User Manual*, Monash University Department of Civil Engineering.

Mine Subsidence Engineering Consultants (2018). *South Bates Extension Subsidence Assessment – Subsidence Predictions and Impact Assessments for the Natural and Built Features in Support of the Extraction Plan Application for the South Bates Extension WYLW17 to WYLW20.* Report Number MSEC935.

Mine Subsidence Engineering Consultants (2019). *South Bates Extension Subsidence Assessment – The Effects of the Modified Finishing Ends of Whybrow Longwalls 17 to 20 on the Subsidence Predictions and Impact Assessments for the Natural and Built Features in Support of an Application to Amend the Extraction Plan.* Report Number MSEC1012.

Attachment A
1D hydraulic modelling graphs

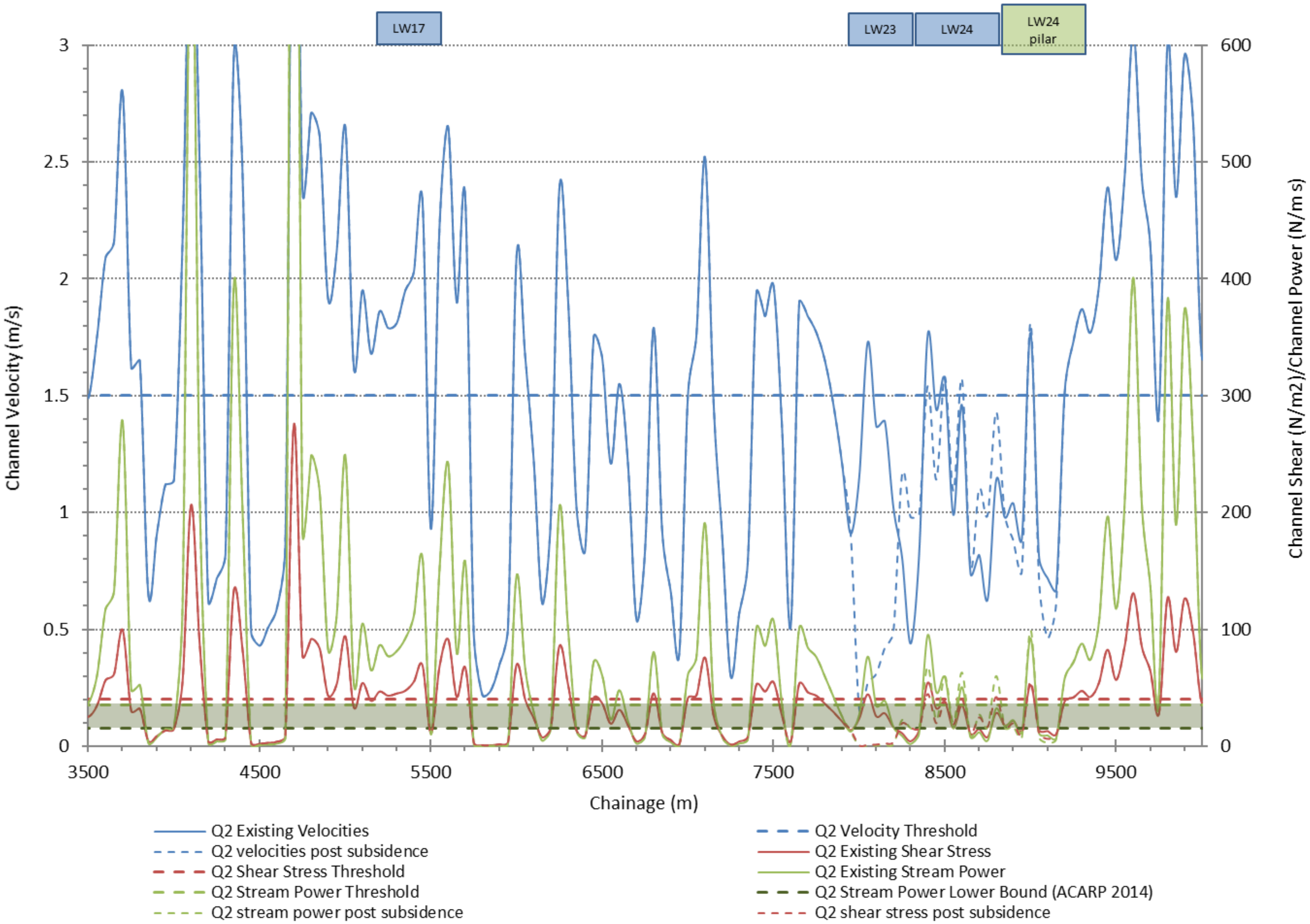


Figure A- 1. *Existing and subsided conditions 2-year ARI hydraulic performance*

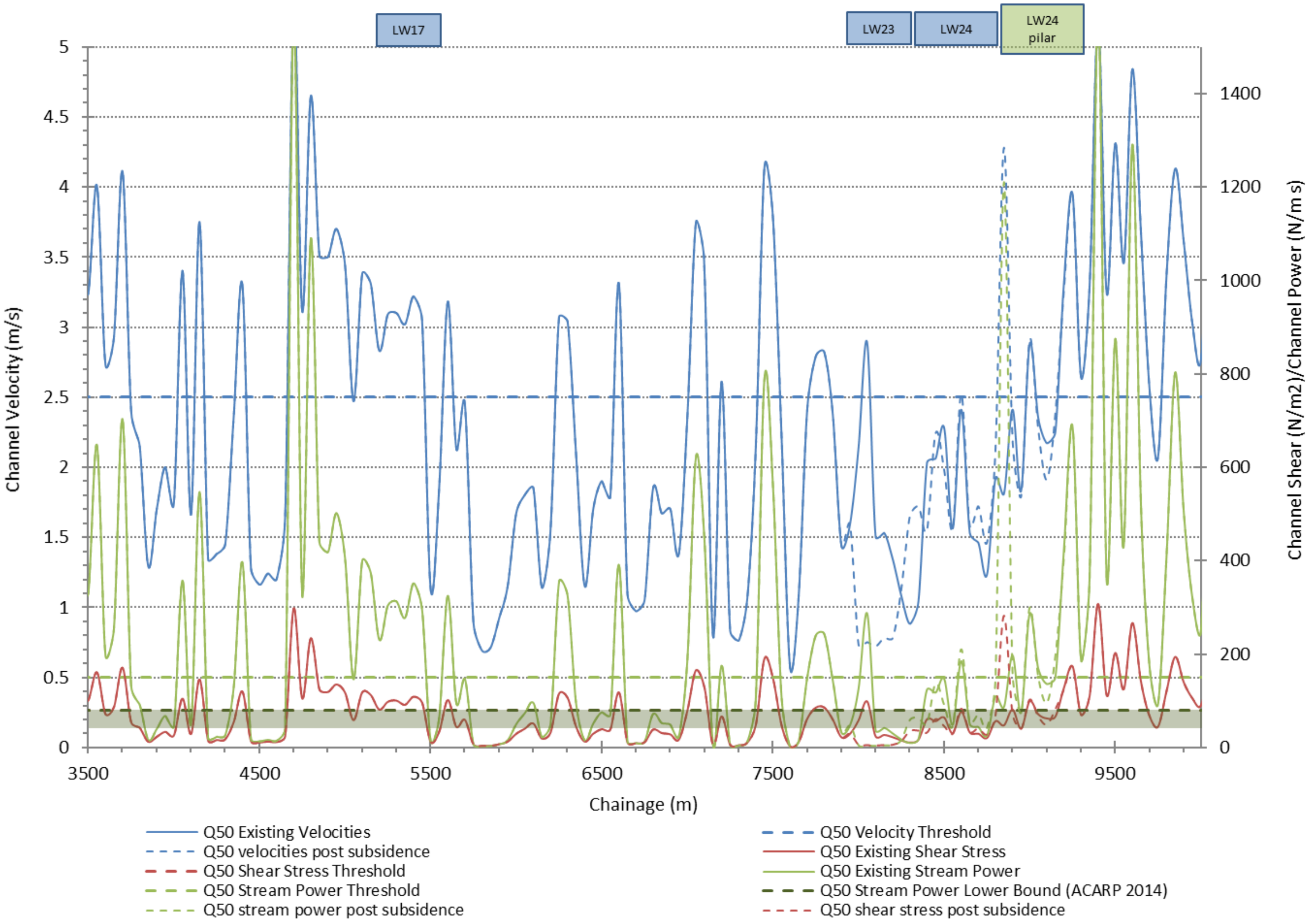


Figure A- 2. *Existing and subsided conditions 50-year ARI hydraulic performance*

Attachment B
Hydrology

Hydrologic modelling

The North Wambo Creek catchment passes by the Wambo Coal Mine open cut, initiating in the hills, to the west, and outfalling into Wollombi Brook on the east side of the mine. The catchment, as defined for the study, covers an area of approximately 39.5km^2. See Figure 4.

A hydrologic model was built for the entire catchment and flows were generated for 2, 50, 100 and 1000 year ARI for existing conditions. The hydrologic model has not been directly calibrated as no reliable long-term flow data was available for the catchment. Hydrologic outputs for the catchment have been derived at locations to facilitate flood modelling of existing mining operations.

RORB model description

The hydrologic modelling software used in this study is RORBWin version 6.45, a Windows version of the industry accepted RORB program (Laurenson et al 2007).

A RORB model represents the rainfall runoff process occurring in a catchment by:

- Conceptualising the catchment as a linked series of sub-catchments represented in the model by catchment storages and river reach storages;
- Applying rainfall excess (rainfall minus losses) to each sub-catchment (rainfalls are assumed to enter the sub-catchment at its centroid);
- Calculating the resulting runoff from each sub-catchment storage;
- Routing the runoff through the catchment system, combining flows at channel junctions; and
- Outputting flow hydrographs at points of interest in the catchment.

The model represents only the rapid flow or surface runoff component of stream flow, and the slow response or base flow component has not been included in the model.

Setting up the model comprises:

- Determining the catchment boundary and dividing the catchment into sub-catchments;
- Calculating the area of each sub-catchment;
- Placing model nodes at sub-catchment inflows and junctions;
- Placing reach storages between nodes; and
- Measuring the length of reach between adjacent nodes.

The RORB model requires four parameters to be specified which include k_c, m, initial loss (IL) and continuing loss (CL). The k_c and m parameters are factors in the storage discharge relationship.

The storage discharge relationship for the reach storages in the model has the general form:

$$S = 3600k\,Q^m$$

Where:

S is the volume of water in storage (m^3);
k is related to travel time of a particular reach and the characteristics of the whole catchment;
Q is outflow rate from the reach storage; and

m is a dimensionless exponent representing the non-linearity of catchment response. m varies in the range 0.6 to 1.0 with a value of 1 representing a linear response. Many studies adopt a value of 0.8.

The relationship between k and k_c is given by the equation:

$$k = k_{ri} k_c$$

Where:

k_{ri} is the relative delay time of reach i; and
k_c is an empirical coefficient applicable to the catchment and is a constant for the whole catchment.

The two rainfall loss parameters of initial loss and continuing loss are used in the generation of the rainfall excess hyetograph for the model. Initial loss is the rainfall at the start of a storm event which fills soil and groundwater storage, is intercepted by vegetation, or is lost by another process and does not contribute to runoff. Continuing loss is the ongoing portion of rainfall that falls after the initial loss that does not produce surface runoff. This could be due to deep soil storage, vegetation interception or evaporation. The loss parameters used in the model can be storm and catchment specific.

Catchment delineation

Catchment delineation and subdivision was undertaken using the CatchmentSIM software program which delineates sub-catchments from a Digital Terrain Model (DTM), calculates their properties and creates output files for a range of hydrologic models including RORB.

For this project, the 04/07/2016 LiDAR survey data obtained by WCPL covered the majority of the catchment. To fill the area beyond the mine, 3 arcsecond NASA SRTM 90m DEM grid data was used. This data was obtained by Alluvium from Geosciences Australia.

The catchment delineation and subdivision took account of all known diversions and watercourses within the project area. Following delineation of the sub-catchments, the CatchmentSIM model was exported as a RORB catchment file using a CatchmentSIM-RORB macro (6.0 v3). This automatically sets up the connections between sub-catchments and reaches and calculates and assigns the sub-catchment areas, reach lengths and slopes in the RORB catchment file. This file was then modified to specify the locations where hydrograph outputs were required.

The existing conditions model for the North Wambo Creek catchment has 35 subcatchments. The resulting layout of subcatchments and reaches is shown in Figure B- 1.

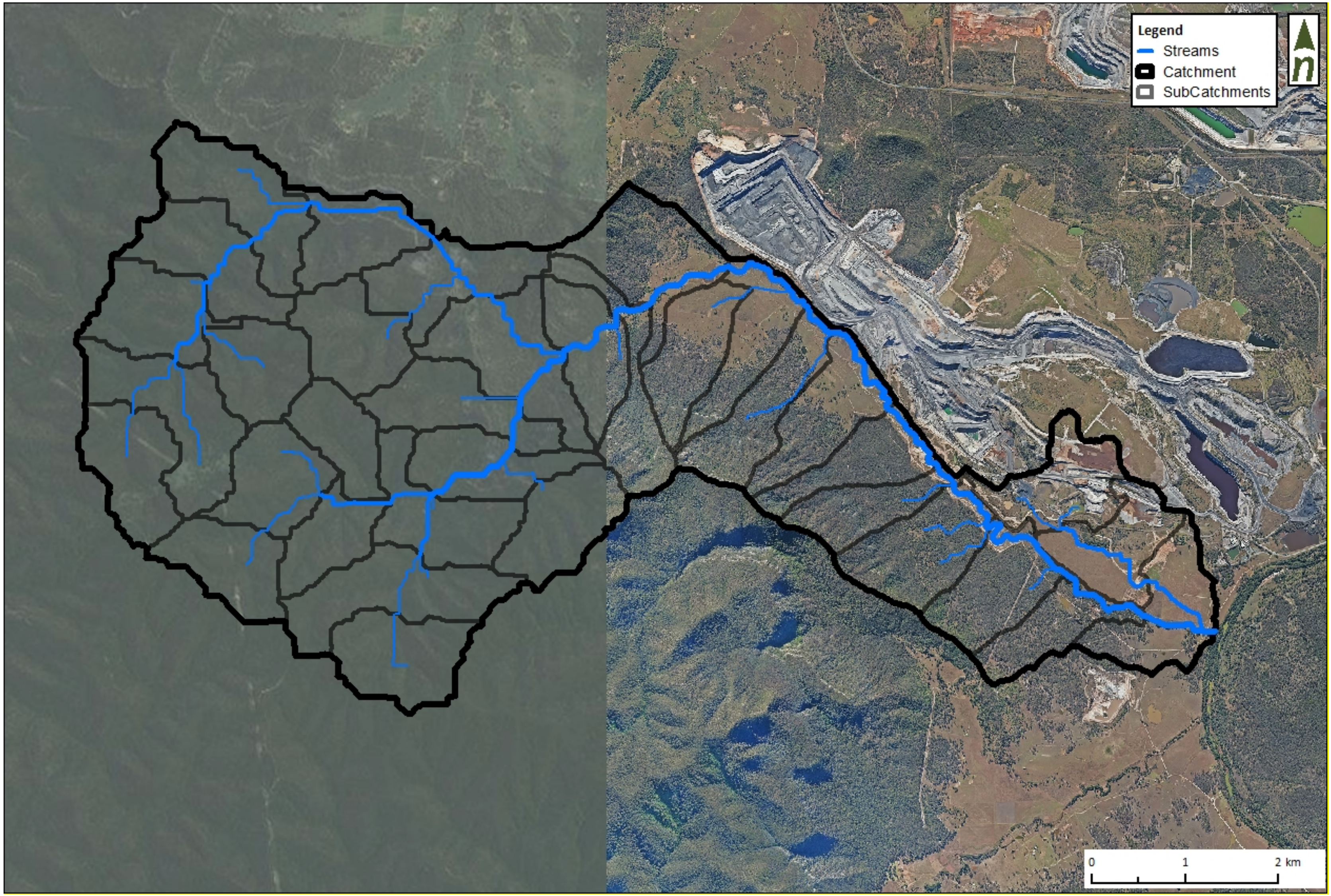


Figure B- 1. *North Wambo Creek catchment watercourse and features surrounding mine*

Model parameter derivation

Due to the lack of long-term stream flow data for the catchment, it was not possible to directly calibrate the hydrologic model. Therefore, it was necessary to investigate what options were available to develop the parameters required for modelling.

Weeks regional relationship method
Australian Rainfall and Runoff (ARR) outlines, in section 3.6.2, the regional relationships developed to calculate k_c for ungauged catchments. For eastern New South Wales, the relevant method was derived by Kleemola and takes the form:

$$k_c = 1.18*Area^{0.46}$$

Table B- 1, below, lists the Kleemola-derived k_c value.

Table B- 1. Calculated Kleemola value

Scenario	Catchment Area (km^2)	Kleemola k_c Value*
Existing Conditions	39.5	6.40

*Note, that the underlying assumption is that m = 0.8.

Other modelling parameters
The initial loss-continuing loss (IL/CL) model was used. ARR 2016 gives regional estimates of loss parameters for whole storm loss and continuing losses. Initial losses were adjusted based on median pre-burst depths for events of varying AEP. The initial and continuing loss values for the 1000-year ARI was linearly interpolated using a log-log of losses versus AEP as described in Book 8 of ARR 16. The adopted loss values are presented in Table B- 2.

Table B- 2. Adopted model parameters for initial loss and continuing loss prior to pre-burst

Parameter	2yr to 100-year ARI	1000-year ARI
Initial Loss	50 mm	14.4 mm
Continuing Loss	1.36 mm/hr	1.28 mm/hr

Design rainfall

Design rainfall depths were generated for events up to the 1000 year ARI for this study. The IFD table for the North Wambo Creek catchment is presented in Table B- 3. The design rainfalls were determined using the ARR method inbuilt in RORB (with site specific parameters determined from ARR (2016)).

Table B- 3. IFD Table for the North Wambo Creek catchment, total rainfall depth in mm (includes ARF)

Event	2yr ARI	50yr ARI	1% AEP	0.1% AEP
15 min	13.5	32.2	36.8	52.9
30 min	18.3	42.9	48.8	70.5
1 hour	23.2	52.4	59.3	85.7
3 hours	32.5	69.6	78.1	112
6 hours	41.0	87.4	98.1	140
12 hours	53.1	116	131	187
18 hours	62.2	139	157	226
24 hours	69.5	158	180	259
48 hours	89.1	212	241	369

Temporal patterns
The temporal patterns were taken from the Datahub with the majority of data originating from the East Coast (South) region.

The full set of temporal patterns were not run in the 2D hydrodynamic modelling. Instead the ensemble of temporal patterns was narrowed down to the most critical by the Storm Injector program. Storm Injector is a software product that can take a hydrologic model created in RORB and automatically create and analyse derivative versions of the model in accordance with ARR 2016.

The existing and diverted catchments of North Wambo creek catchment were analysed. Storm injector provided the critical durations and the temporal pattern that produced it. Table B- 4 summarises the AEP and temporal patterns selected for 2D hydrodynamic modelling.

Table B- 4. AEP, duration and corresponding temporal patterns

Durations (min)	Durations (hour)	AEP			
		0.5EY	2%	1 in 100	1 in 1000
90	1.5	N/A			25
720	12	4	30	28	22
1440	24	7	N/A		

RORB model output flow

The RORB model outputs are presented in Table B- 5. The output locations are shown in Figure B- 1.

Note that the peak flow rates did not all coincide on the same duration storm event – overall the critical duration varied from as long as the 24 hour for the 2 year ARI event to as short as the 1.5 hour for the 1000 year ARI event, depending on location within the catchment.

Table B- 5. Design discharges generated from hydrologic modelling of existing conditions

	Downstream of LW 13/14
Upstream catchment (km^2)	34
ARI/AEP	Peak Discharge (m3/s)
2 year	29
50 year	102
100 year	134
1000 year	262

Attachment C
Hydrodynamic Modelling

Hydrodynamic modelling of South Bates Extension underground mine 21-24

Hydrodynamic modelling was undertaken to assess the flood behaviour in the area around the planned longwall panels (LWs 21, 22, 23 and 24).

2D hydrodynamic model set-up

A 2D hydrodynamic model of the catchment within and adjacent to the project area was built using XPSWMM, a hydrodynamic modelling software package which couples together the SWMM 1D model and the 2D finite difference model TUFLOW.

The hydrodynamic model outfalls on North Wambo Creek, approximately 2km downstream of the diversion. The model is extended up into the catchment to the point where North Wambo Creek approaches the site from the west. The model was configured using a 4m cell size. The extent of the model is shown in Figure C- 1.

Manning's n roughness coefficient for the model was set by assessing aerial imagery and site photographs. A depth varying value of 0.04 was considered appropriate following the initial iteration of flood modelling where it was identified that the flow was predominantly in channel for all modelled events.

Design hydrographs were input into the model at the locations shown in Figure C- 1 to represent inputs from both the catchments external to the area and runoff generated locally. The catchments that covered the mining panels had hydrology applied as direct rainfall (i.e. rain on grid) to ensure the impact of subsidence on overland flow was properly captured.

It should be noted that the XPSWMM hydrodynamic model does not predict erosion and sediment transport impacts. Dam and other embankment failure scenarios have not been modelled in this assessment and therefore results are based on stable topography over the full length of the modelled events – which is unlikely to occur during a large magnitude event.

Also note that this assessment has focussed solely on the impact that the topographical changes resulting from subsidence have had on storage and flow in North Wambo Creek. The assessment does not consider the potential for losses to underground due to cracking in the vicinity of the longwall panels.

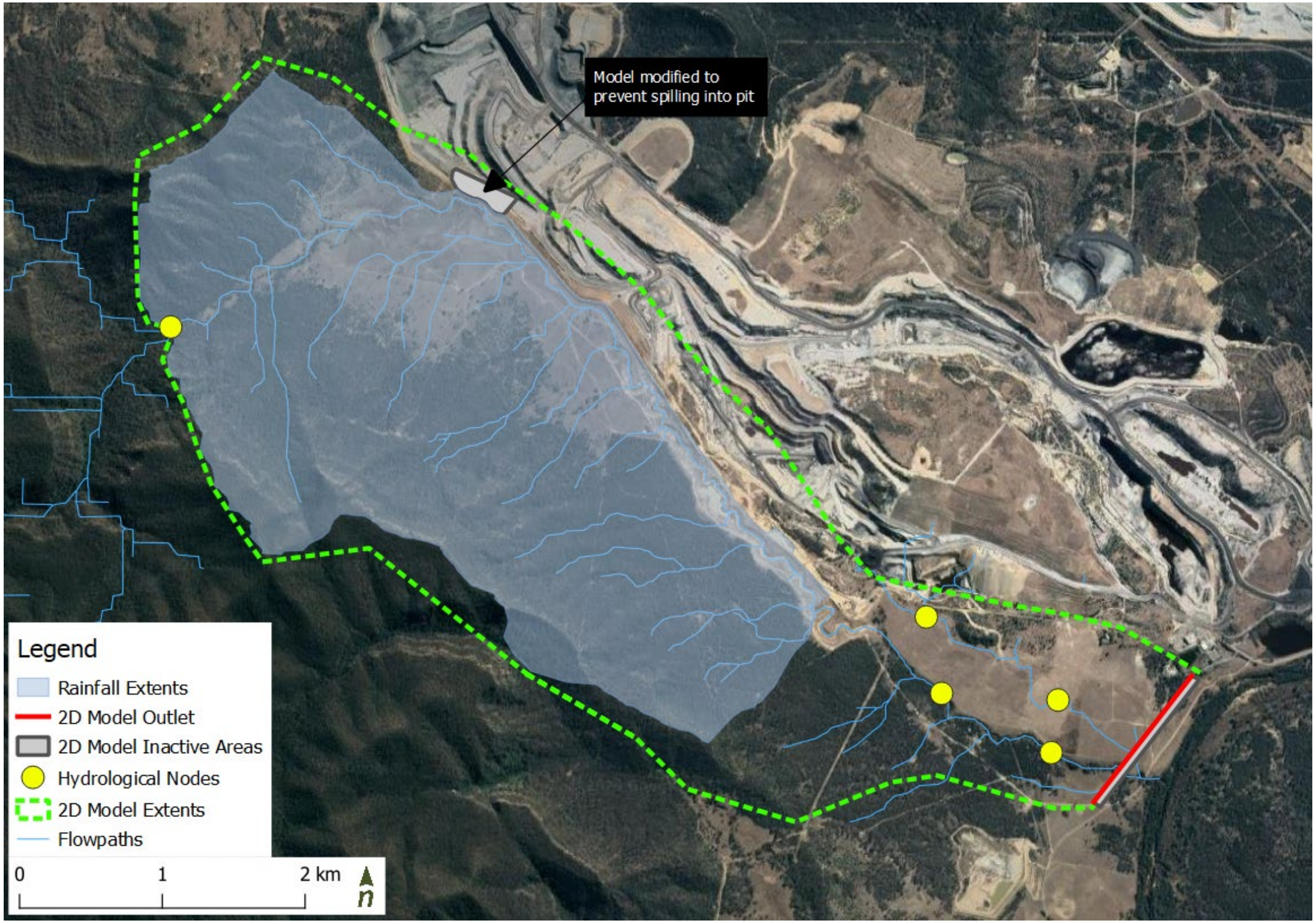


Figure C- 1. *2D hydrodynamic AEP model set up*

2D hydrodynamic modelling results

The figures below are presented in the following order:
• Depth (Figure C- 2 to Figure C- 9)
• Velocity (Figure C- 10 to Figure C- 17)

Within each group, the figures are presented in order of design flood event (i.e. 2-year, 50-year, 100-year then 1000-year ARI) for both existing and post subsidence conditions.

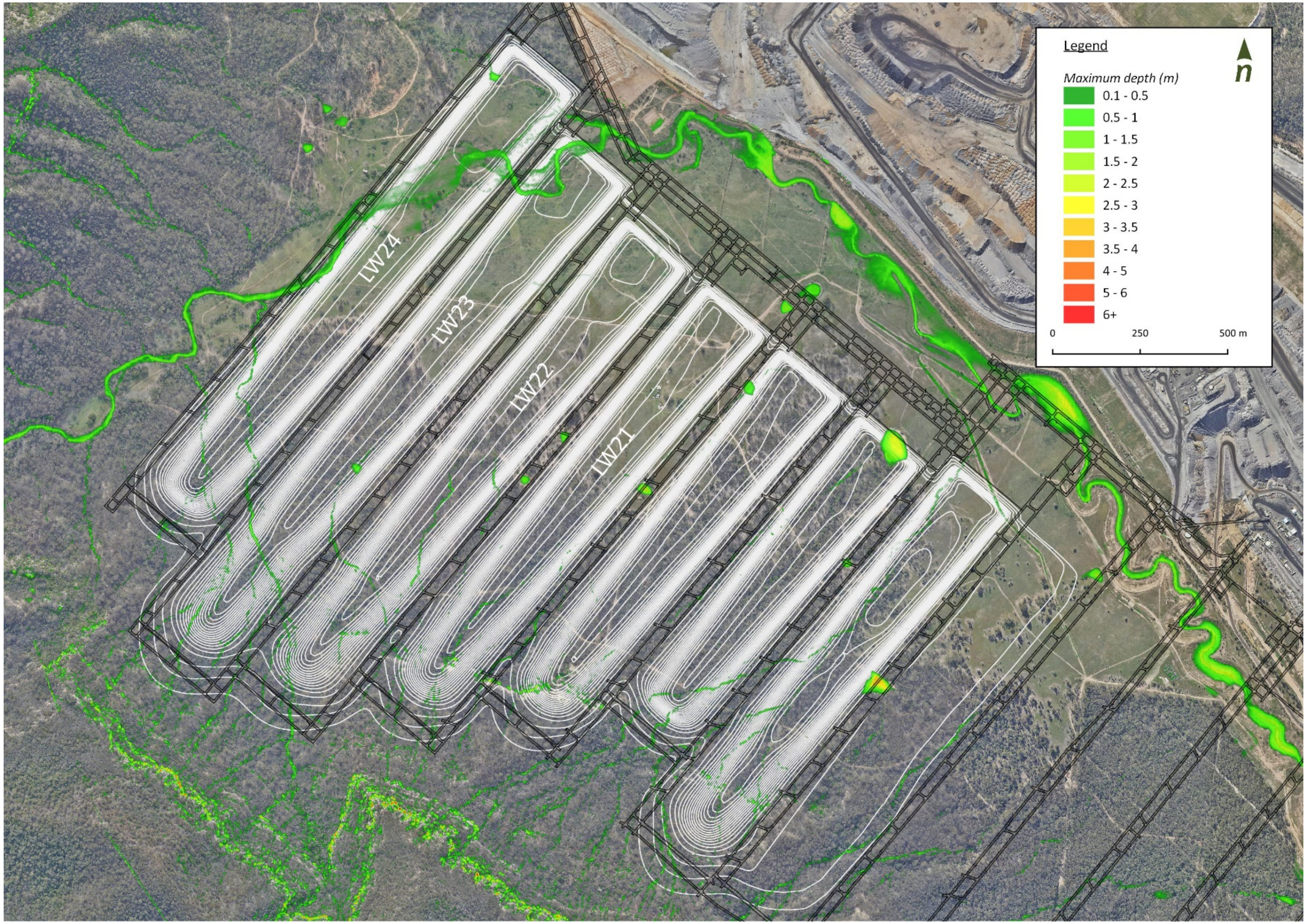


Figure C- 2. *2-year ARI flood extents and depth (existing conditions)*

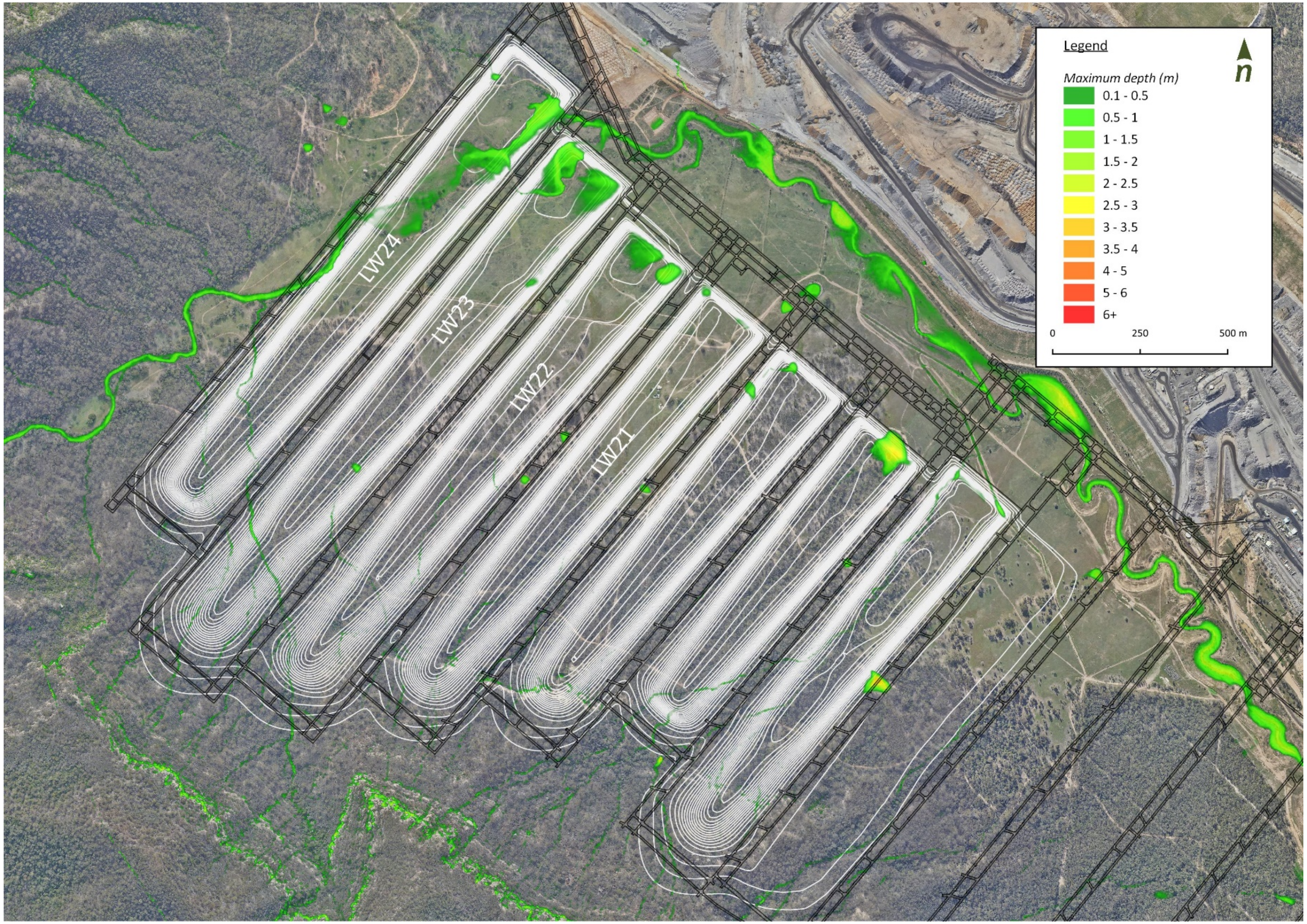


Figure C- 3. *2-year ARI flood extents and depth (subsided conditions)*

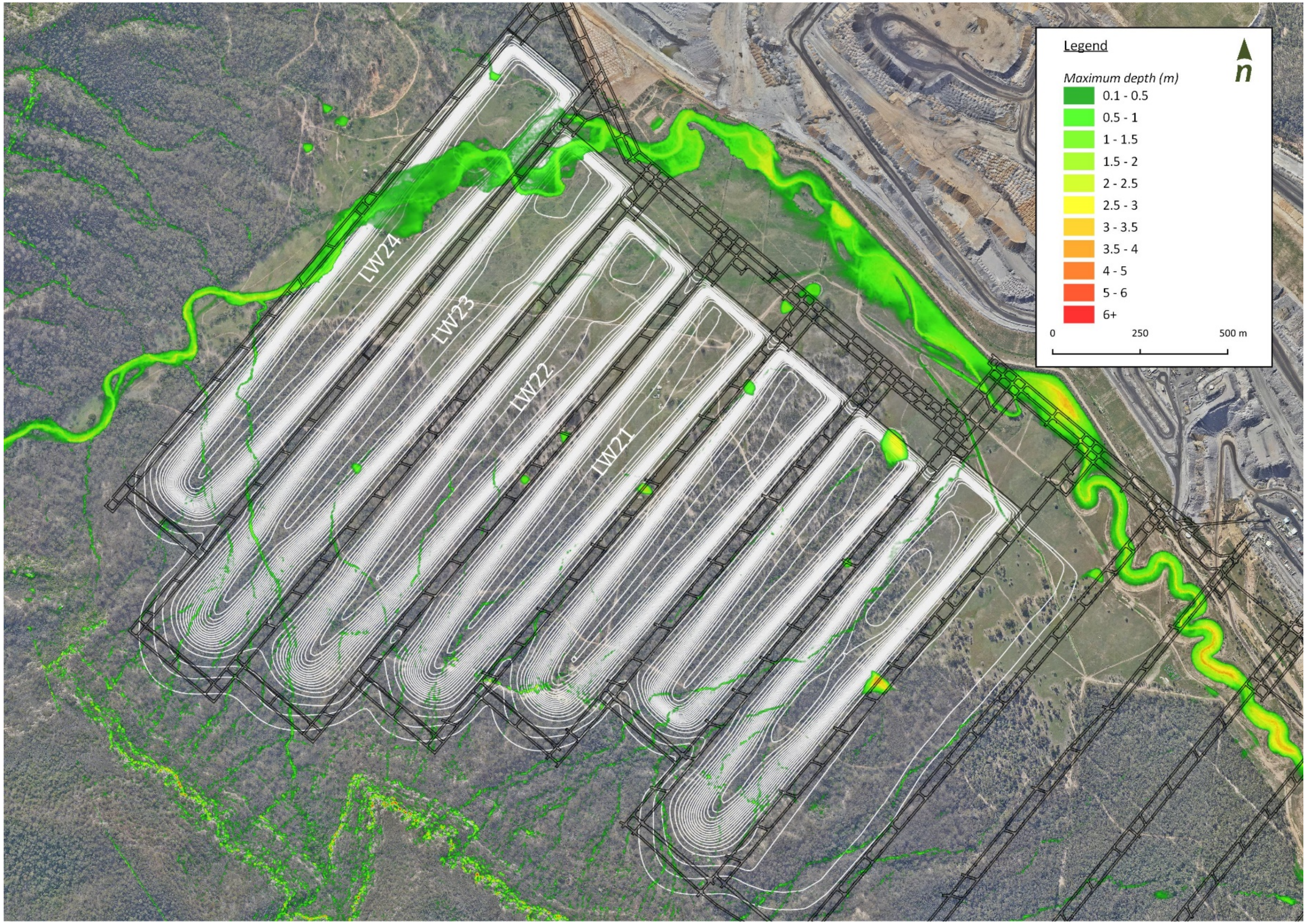


Figure C- 4. *50-year ARI flood extents and depth (existing conditions)*

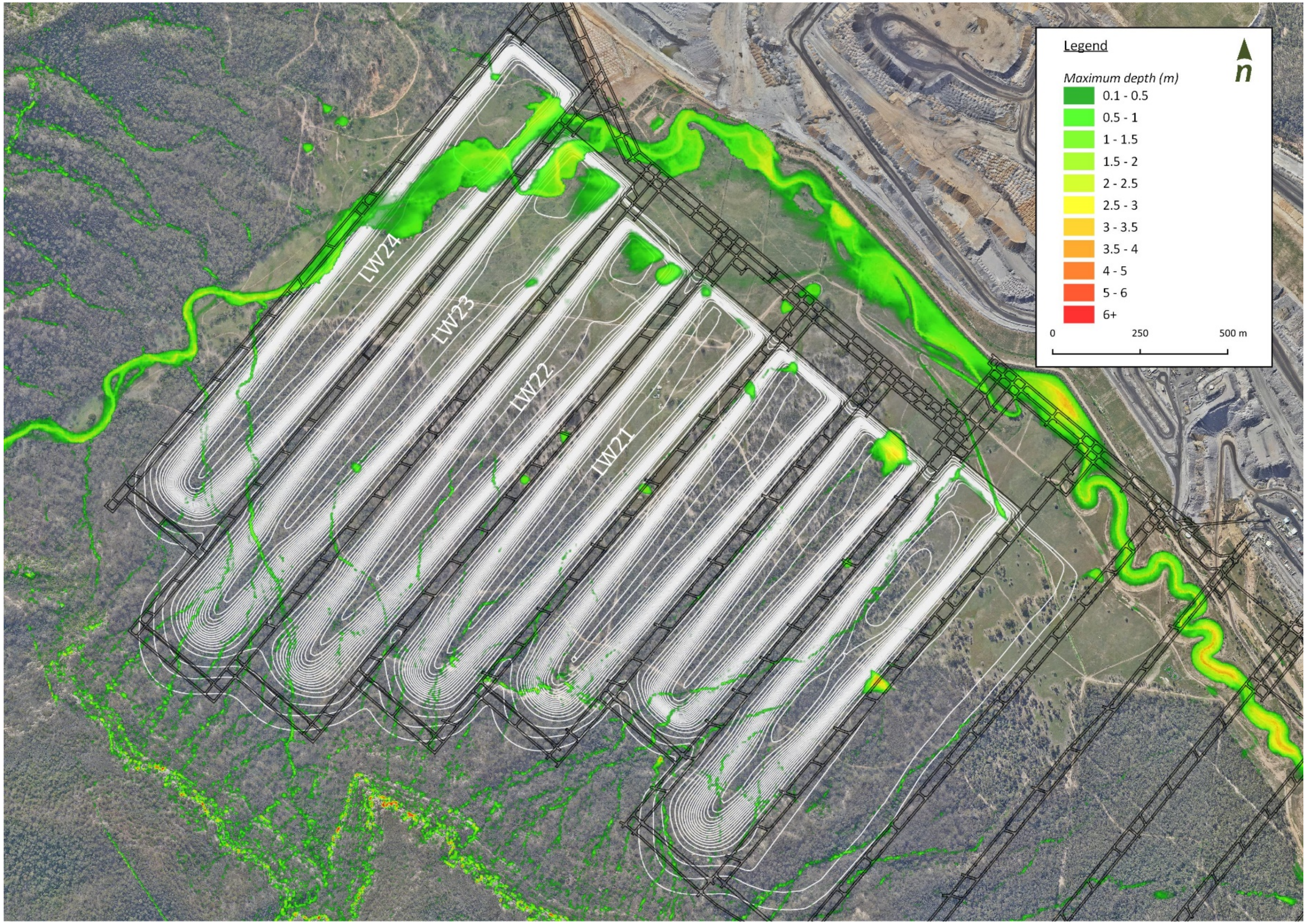


Figure C- 5. *50-year ARI flood extents and depth (subsided conditions)*

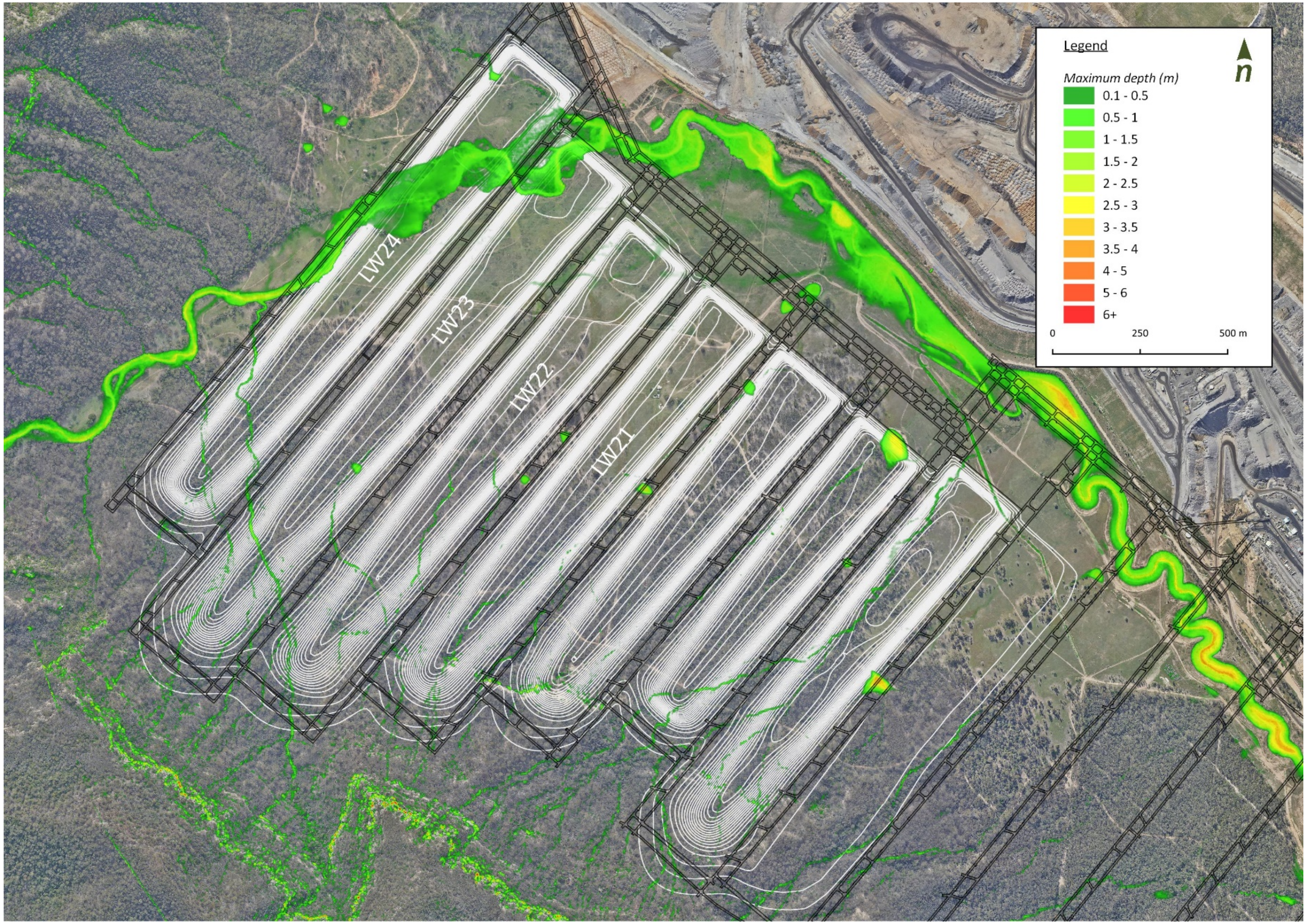


Figure C- 6. *100-year ARI flood extents and depth (existing conditions)*

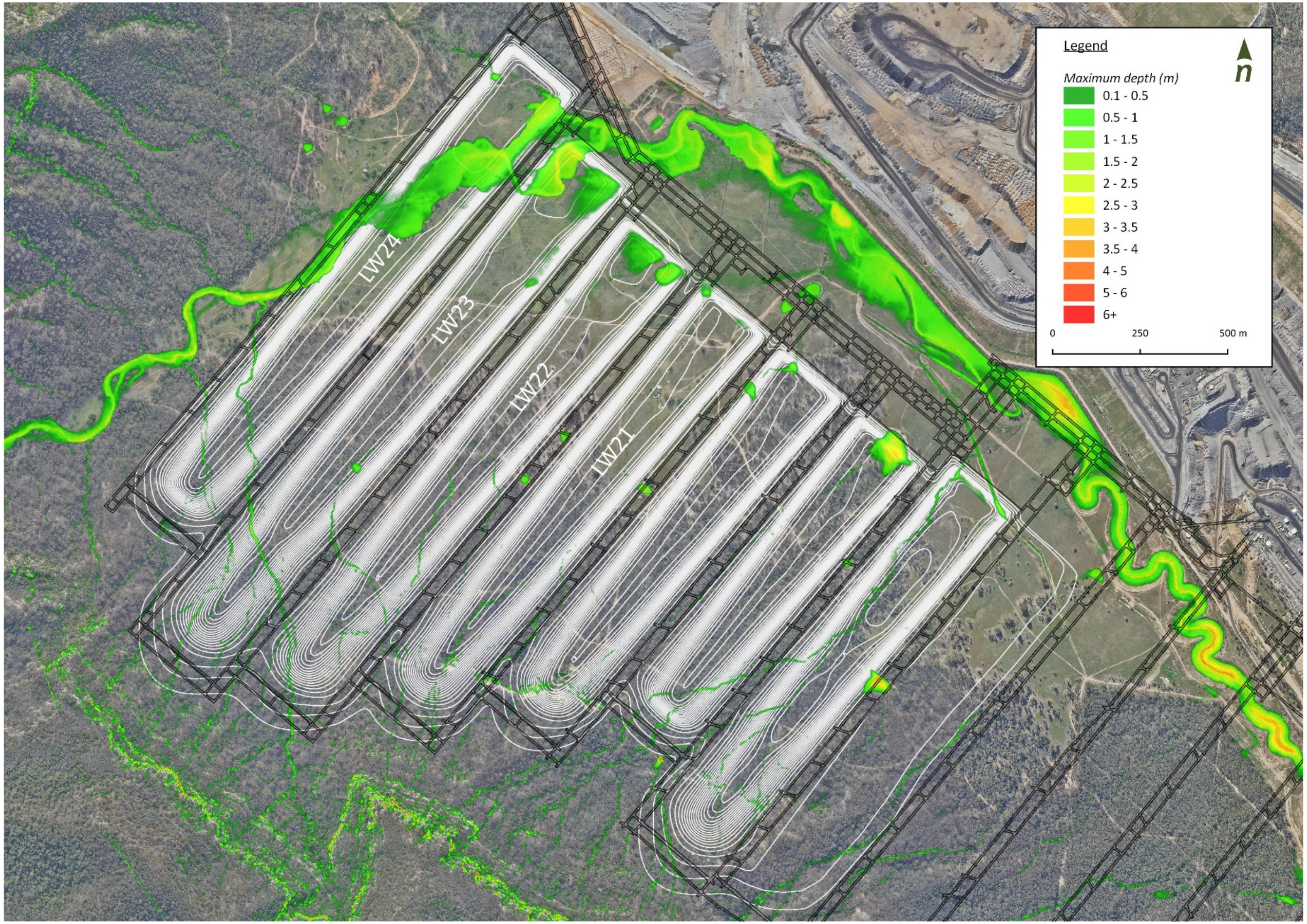


Figure C- 7. *100-year ARI flood extents and depth (subsided conditions)*

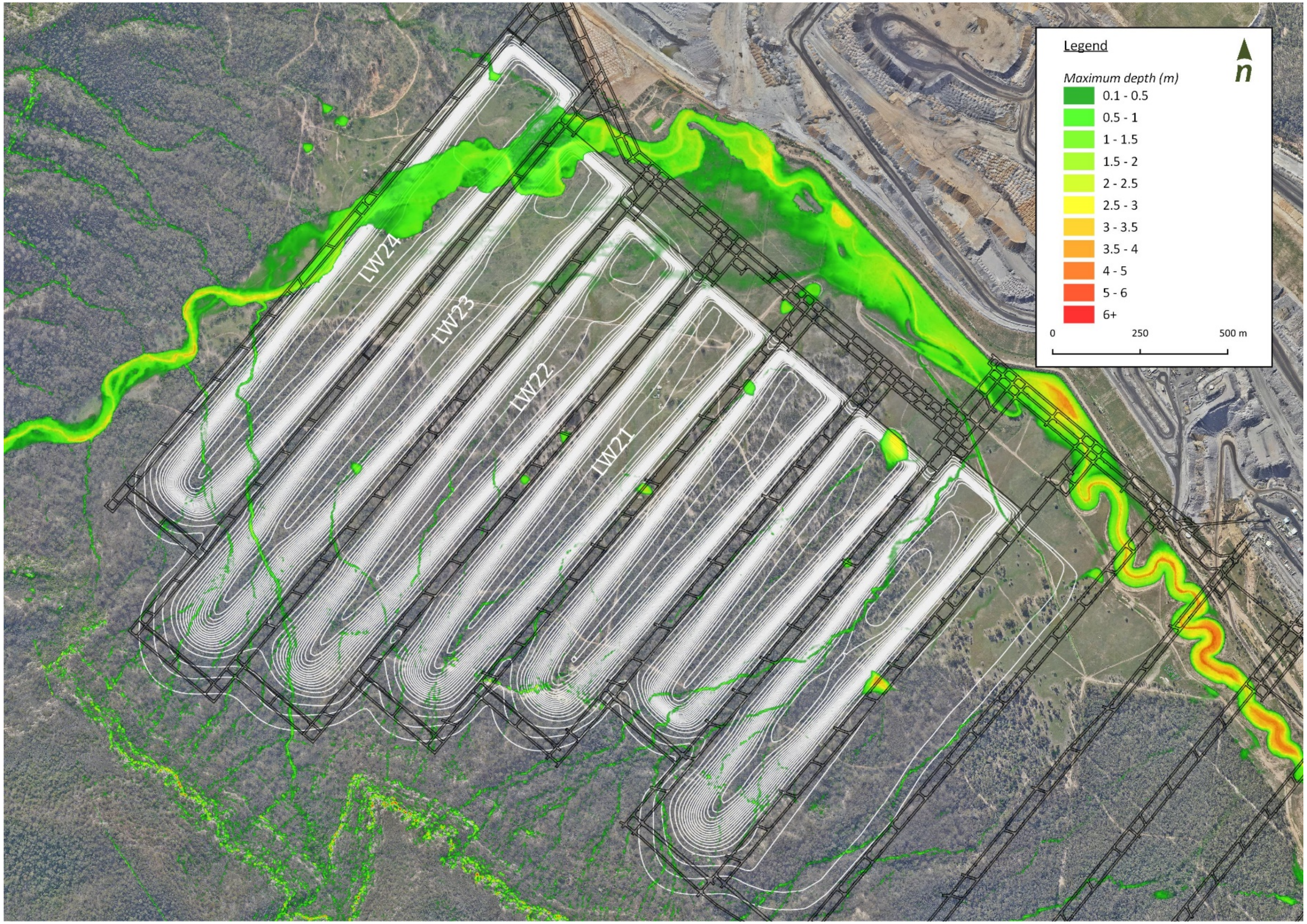


Figure C- 8. *1000-year ARI flood extents and depth (existing conditions)*

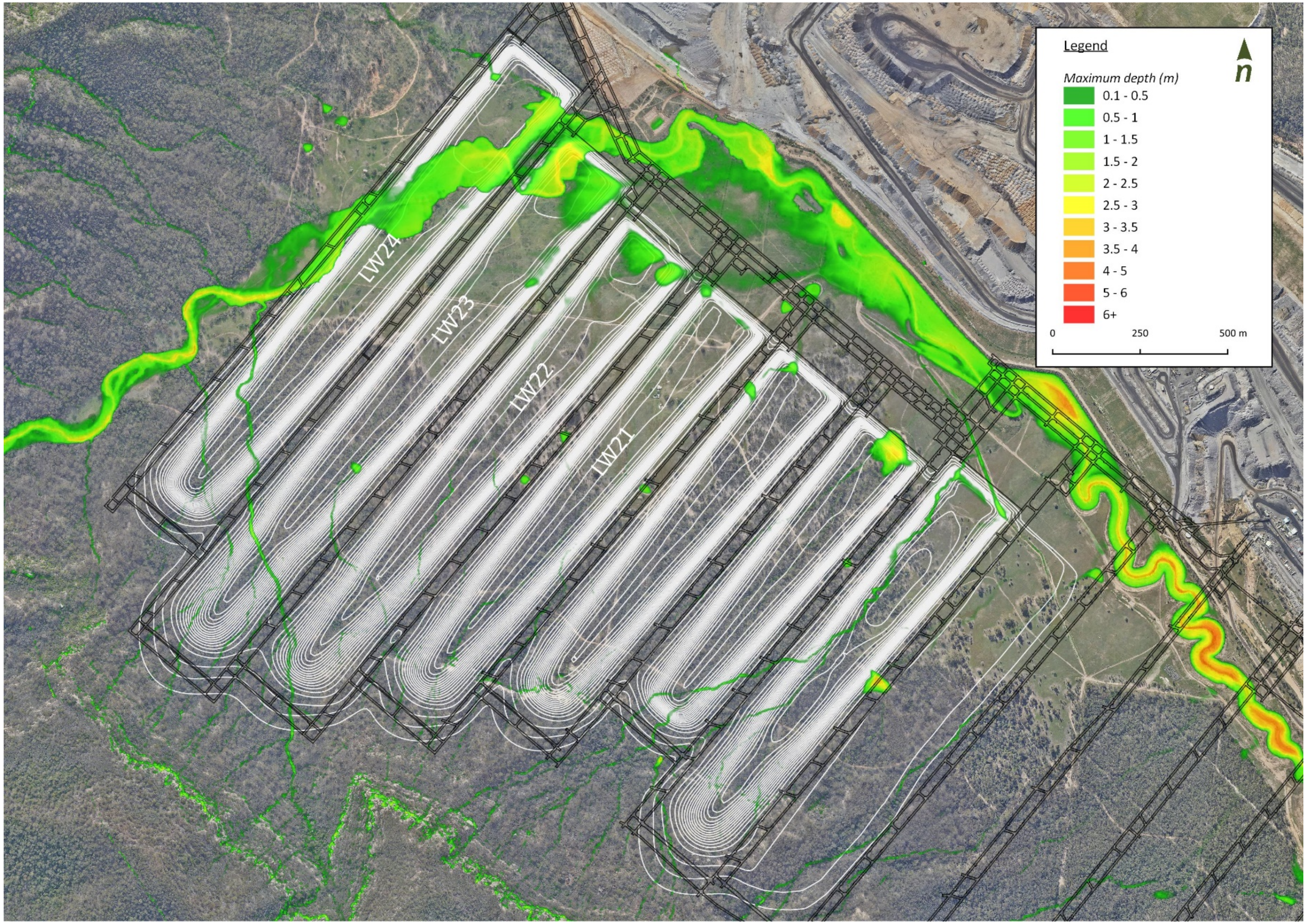


Figure C- 9. *1000-year ARI flood extents and depth (subsided conditions)*

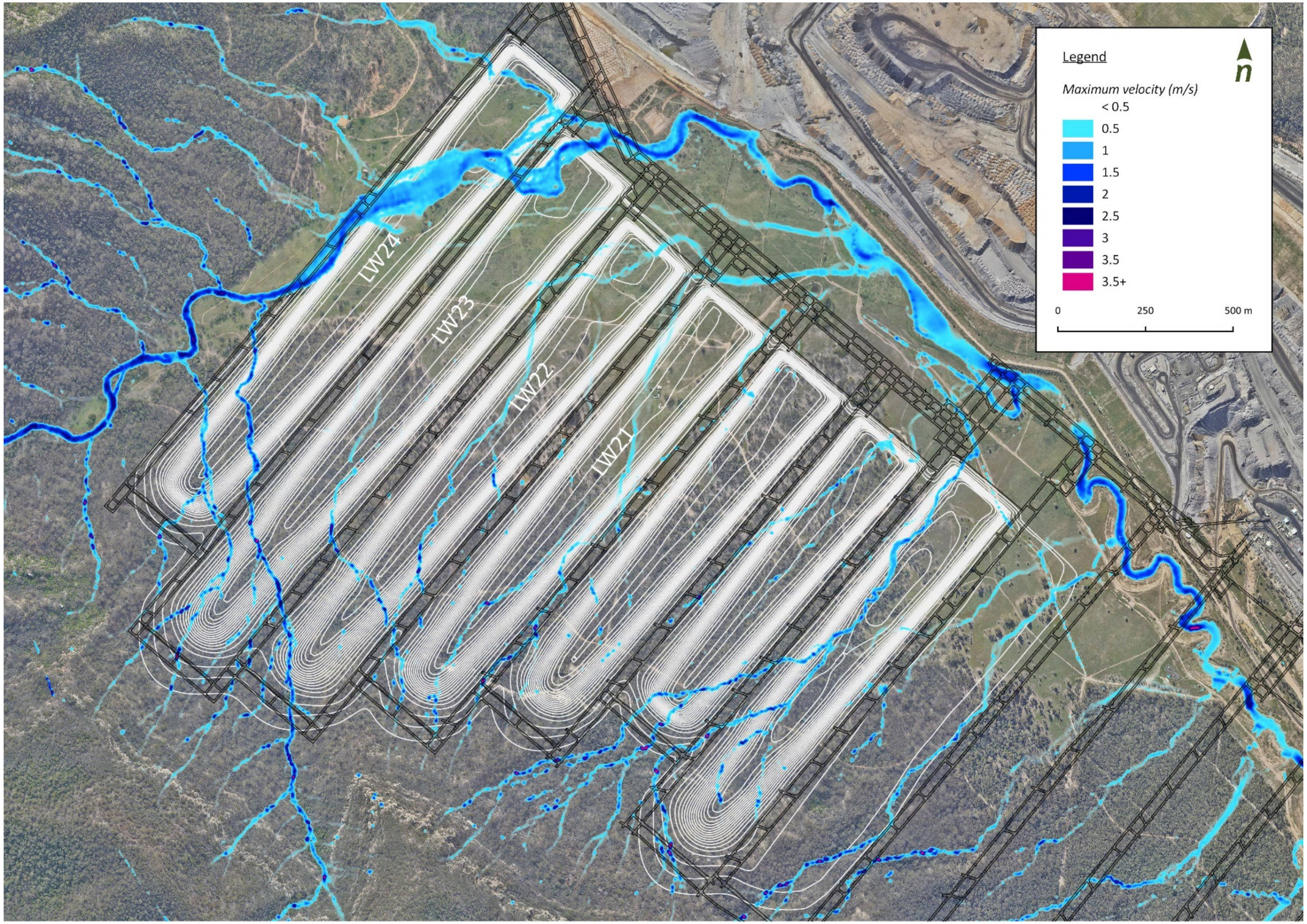


Figure C- 10. *2-year ARI flood velocities (existing conditions)*

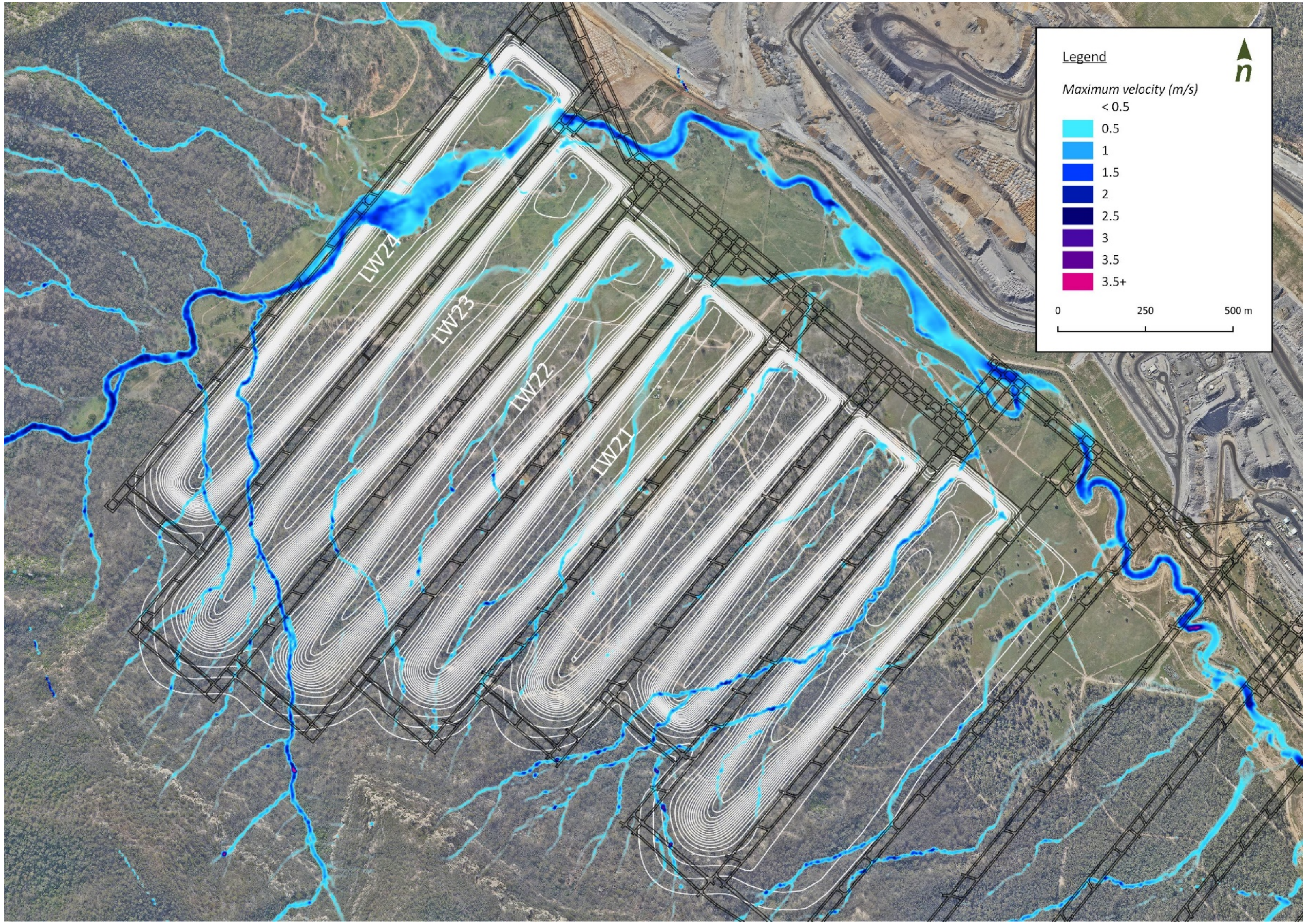


Figure C- 11. *2-year ARI flood velocities (subsided conditions)*

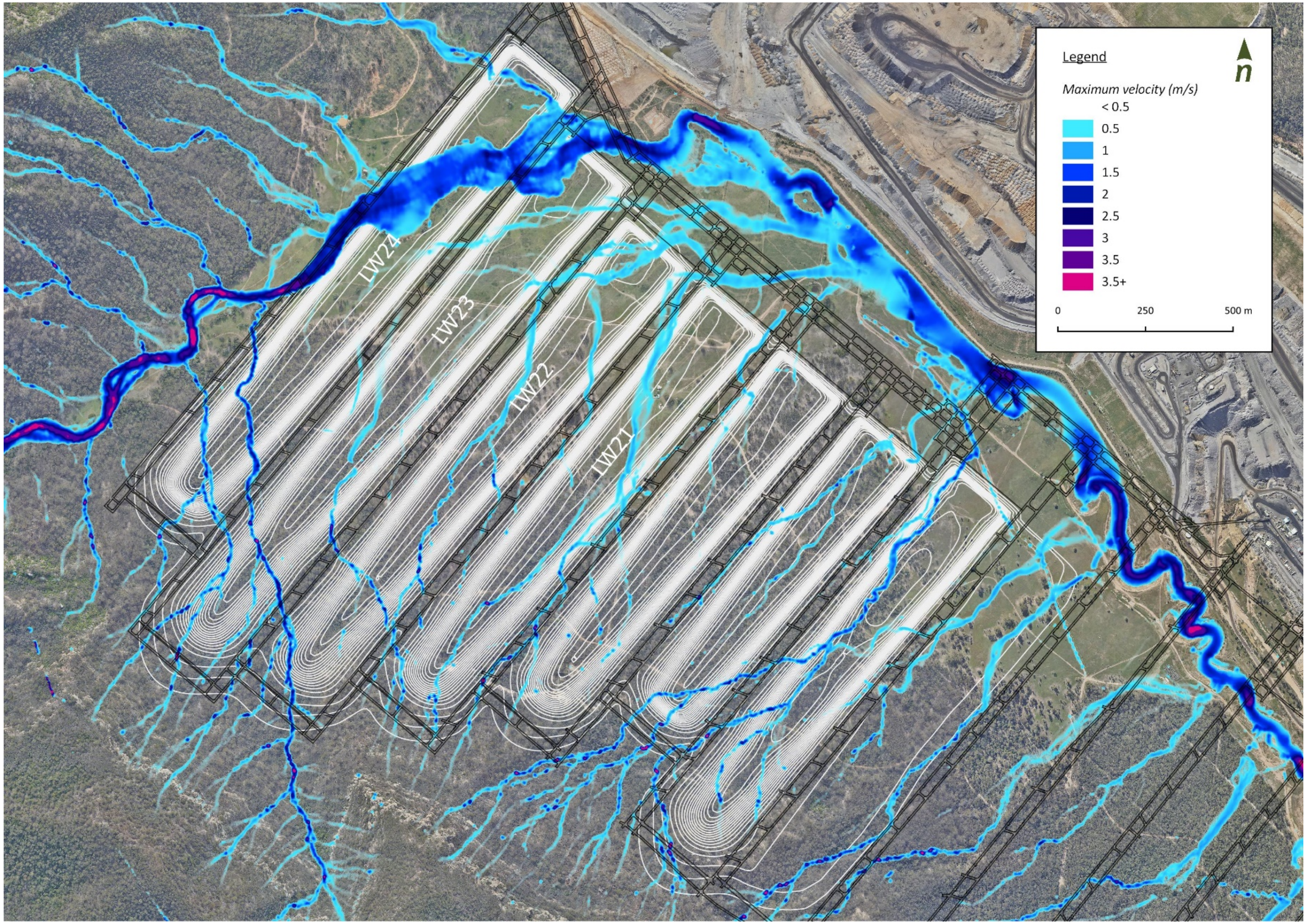


Figure C- 12. *50-year ARI flood velocities (existing conditions)*

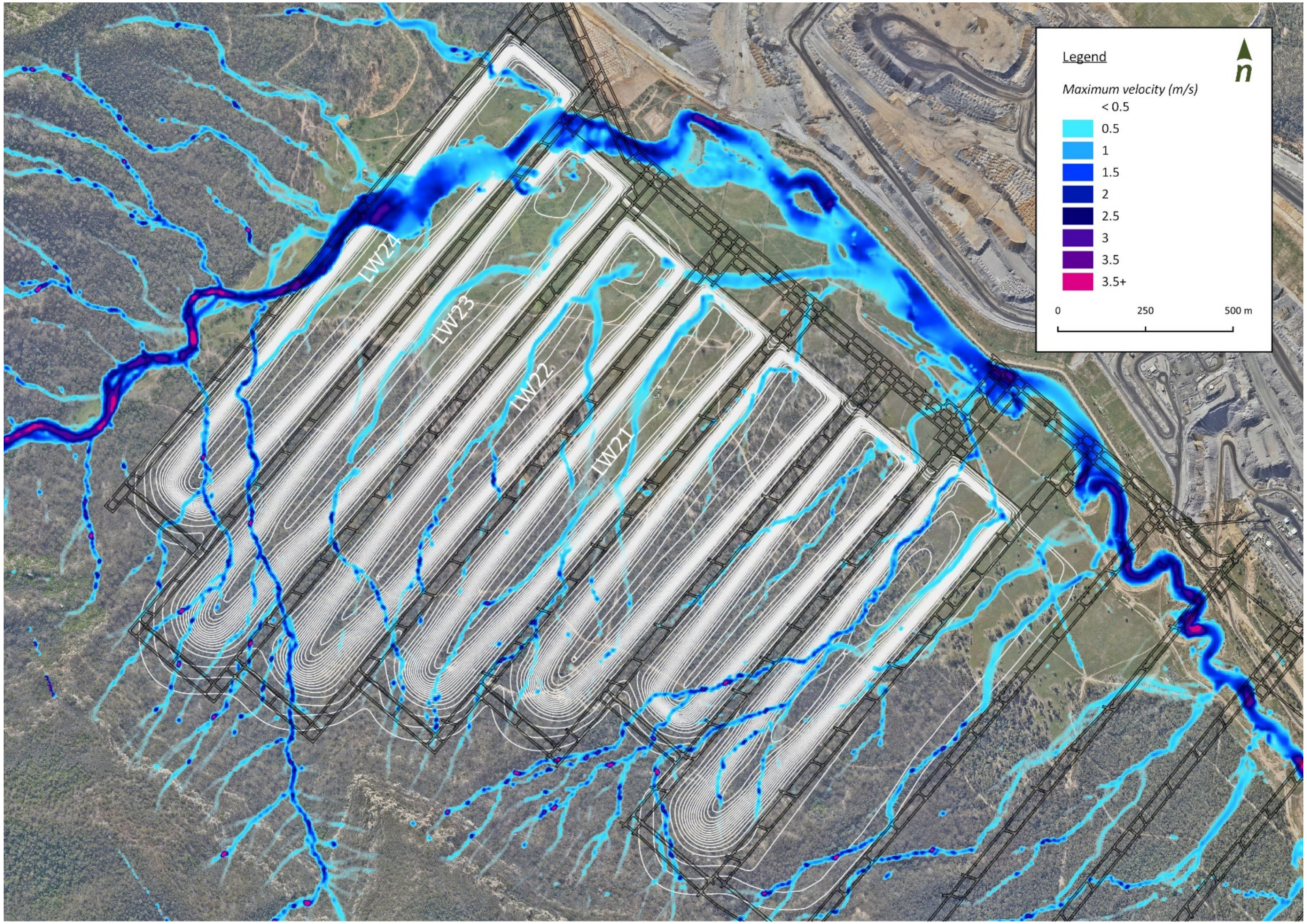


Figure C- 13. *50-year ARI flood velocities (subsided conditions)*

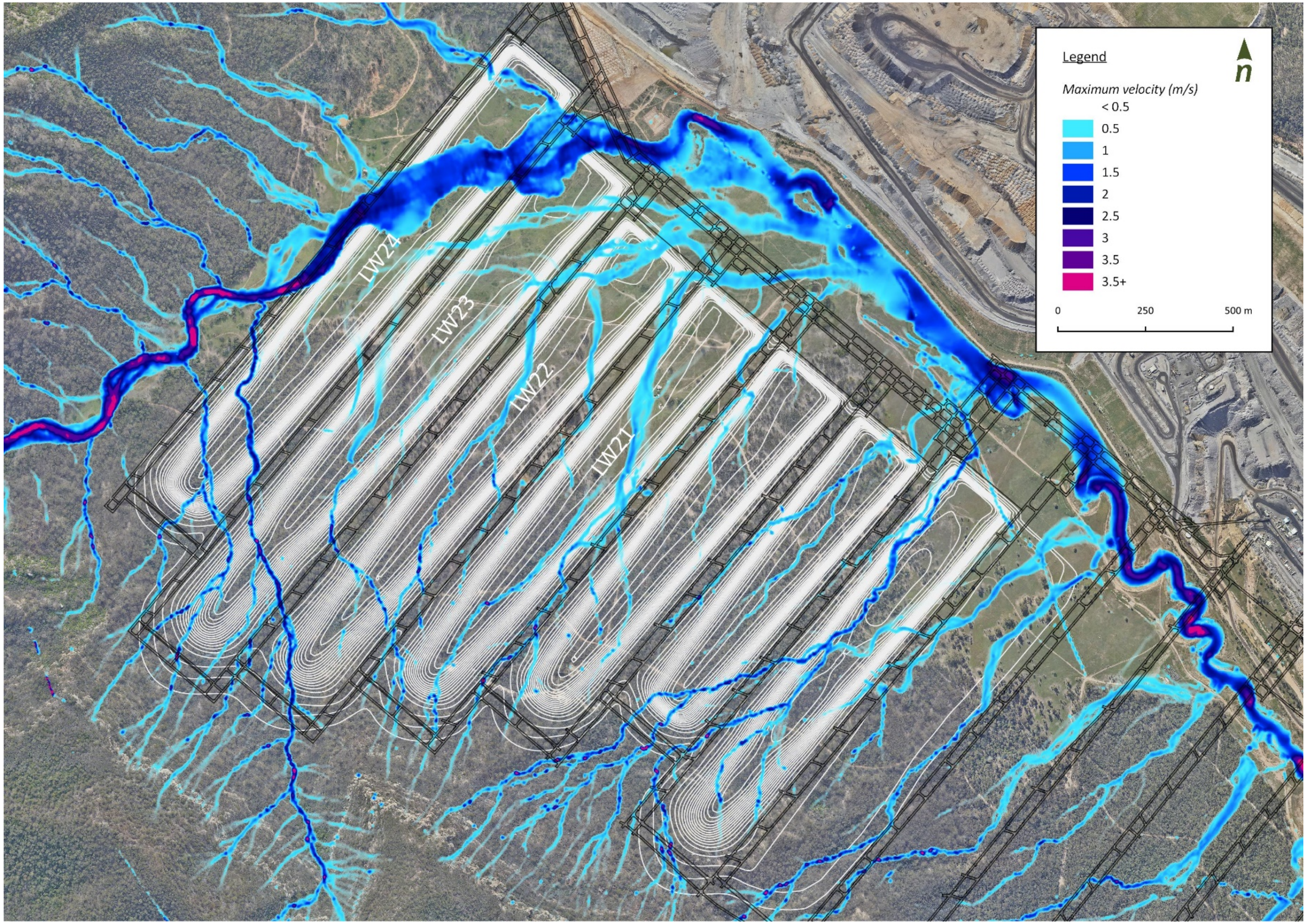


Figure C- 14. *100-year ARI flood velocities (existing conditions)*

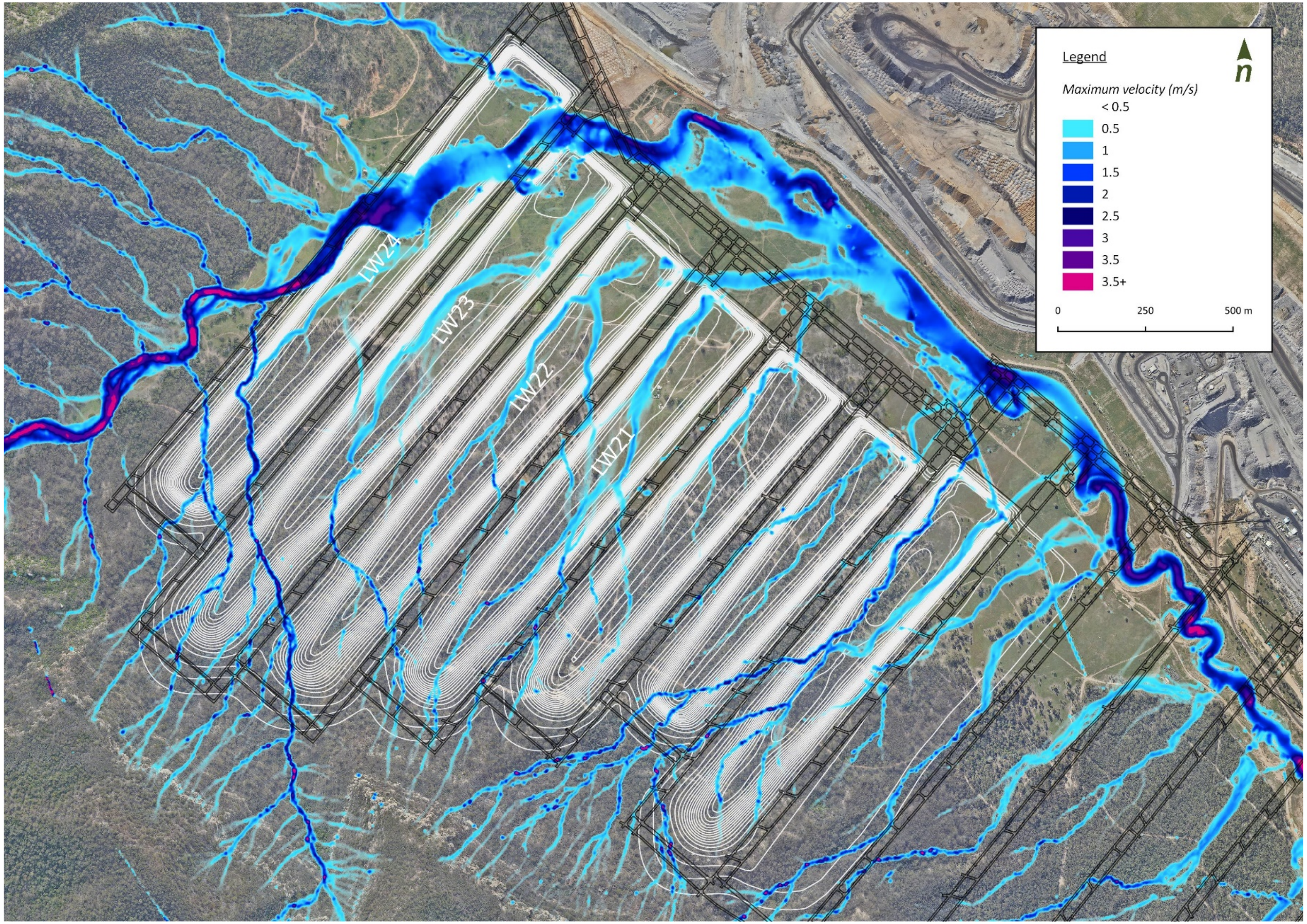


Figure C- 15. *100-year ARI flood velocities (subsided conditions)*

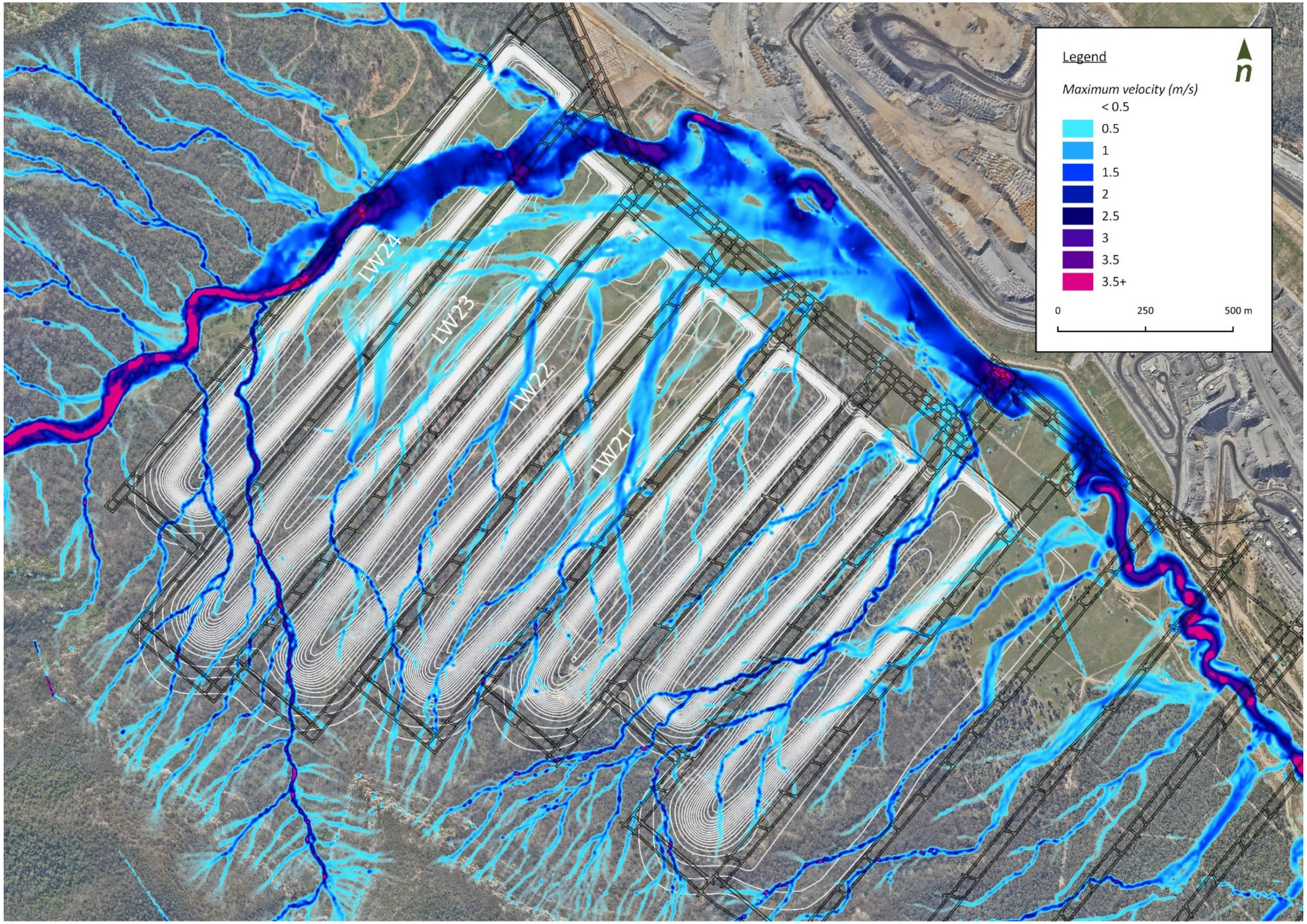


Figure C- 16. *1000-year ARI flood velocities (existing conditions)*

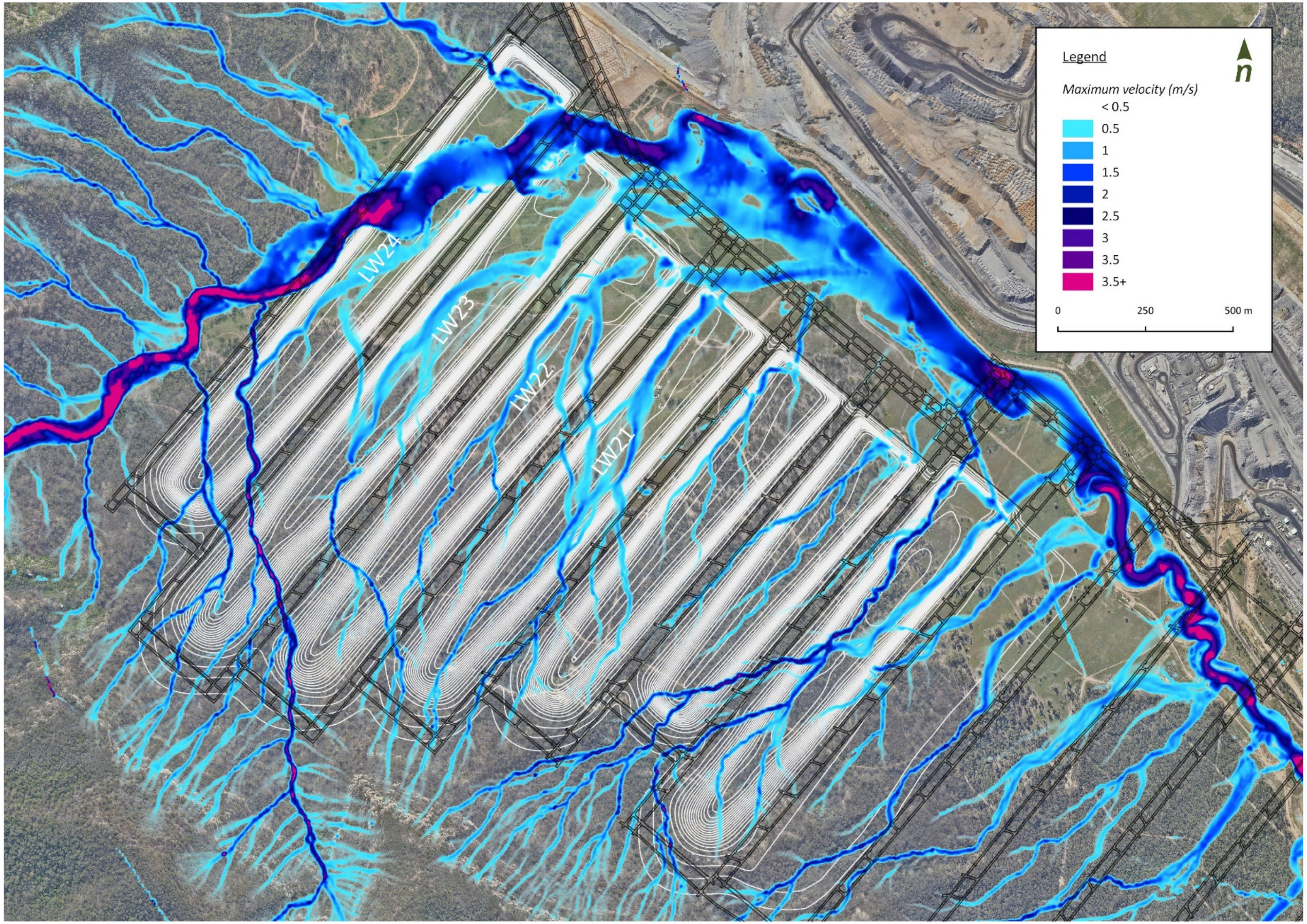


Figure C- 17. *1000-year ARI flood velocities (subsided conditions)*

Attachment D
North Wambo Creek – Baseline assessment geomorphic context statement