WAMBO COAL PTY LIMITED

SOUTH BATES EXTENSION UNDERGROUND MINE

EXTRACTION PLAN
LONGWALLS 17 TO 20

REPORT 3
SURFACE WATER ASSESSMENT REVIEW

Peabody

REPORT:

Surface Water Technical Report for South Bates Extension Underground Mine (Longwalls 17- 20)

Wambo Coal Mine

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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) 17 to 20, extracting coal from the Whybrow Seam. WCPL has previously developed two separate Extraction Plans for underground mining at South Bates underground mine at Wambo. The first covered LWs 11 - 13 and was approved in February 2015. More recently a consolidated Extraction Plan for LWs 11 - 16 was completed and approved. This report documents the surface water technical assessment for LWs 17 - 20 that informs the development of the Extraction Plan.

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 the North Wambo Creek Diversion (NWCD), its adjacent floodplains and hill slopes that exist over the area of the South Bates Extension underground mine plan that will be subject to subsidence are the subject of this surface water technical report.

This technical report outlines the pre 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 all surface water which has an interface with the South Bates Extension and South Bates underground mine plan. This includes surface water of the 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 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

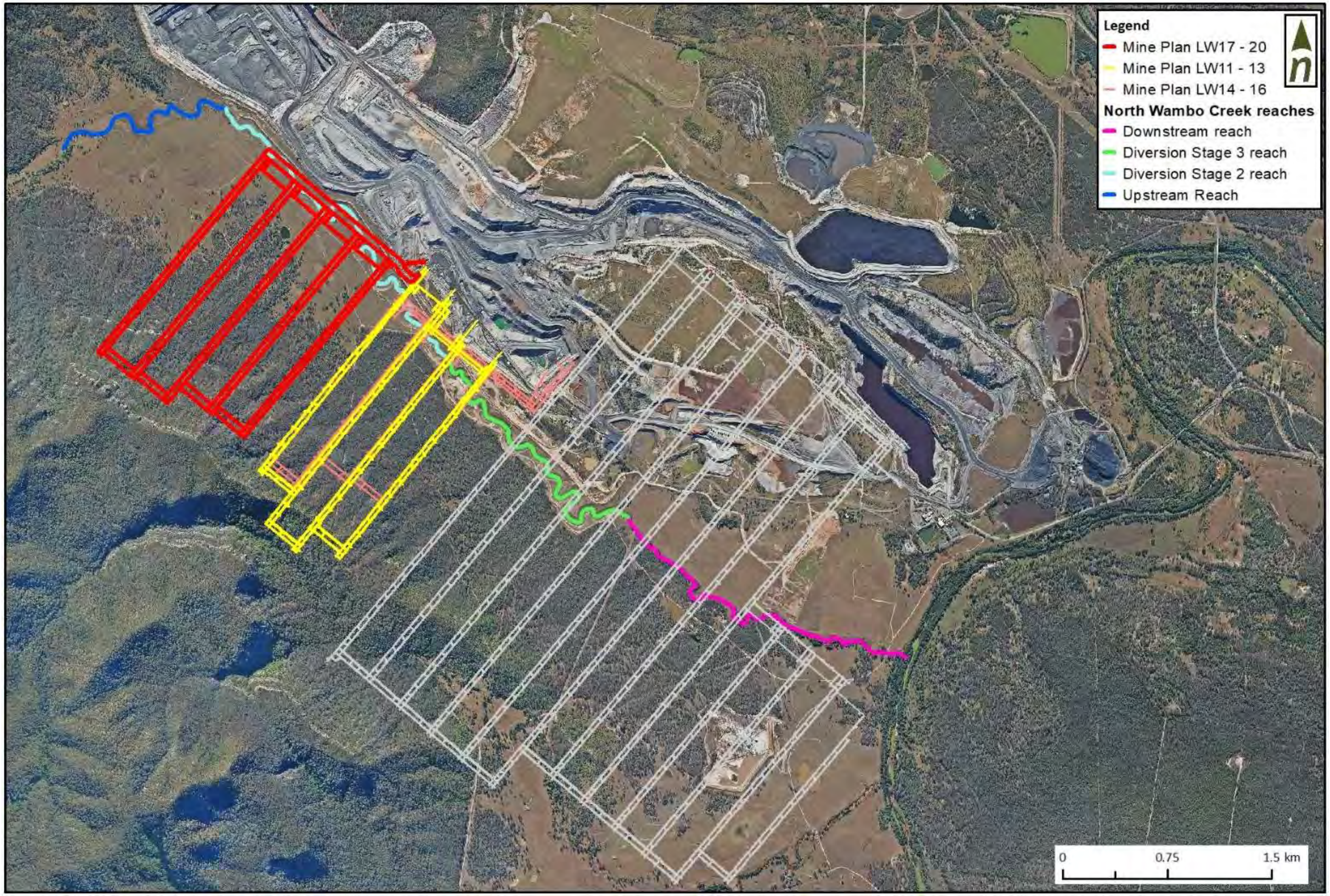

Figure 1-1. Overview of underground mining at Wambo Coal Mine

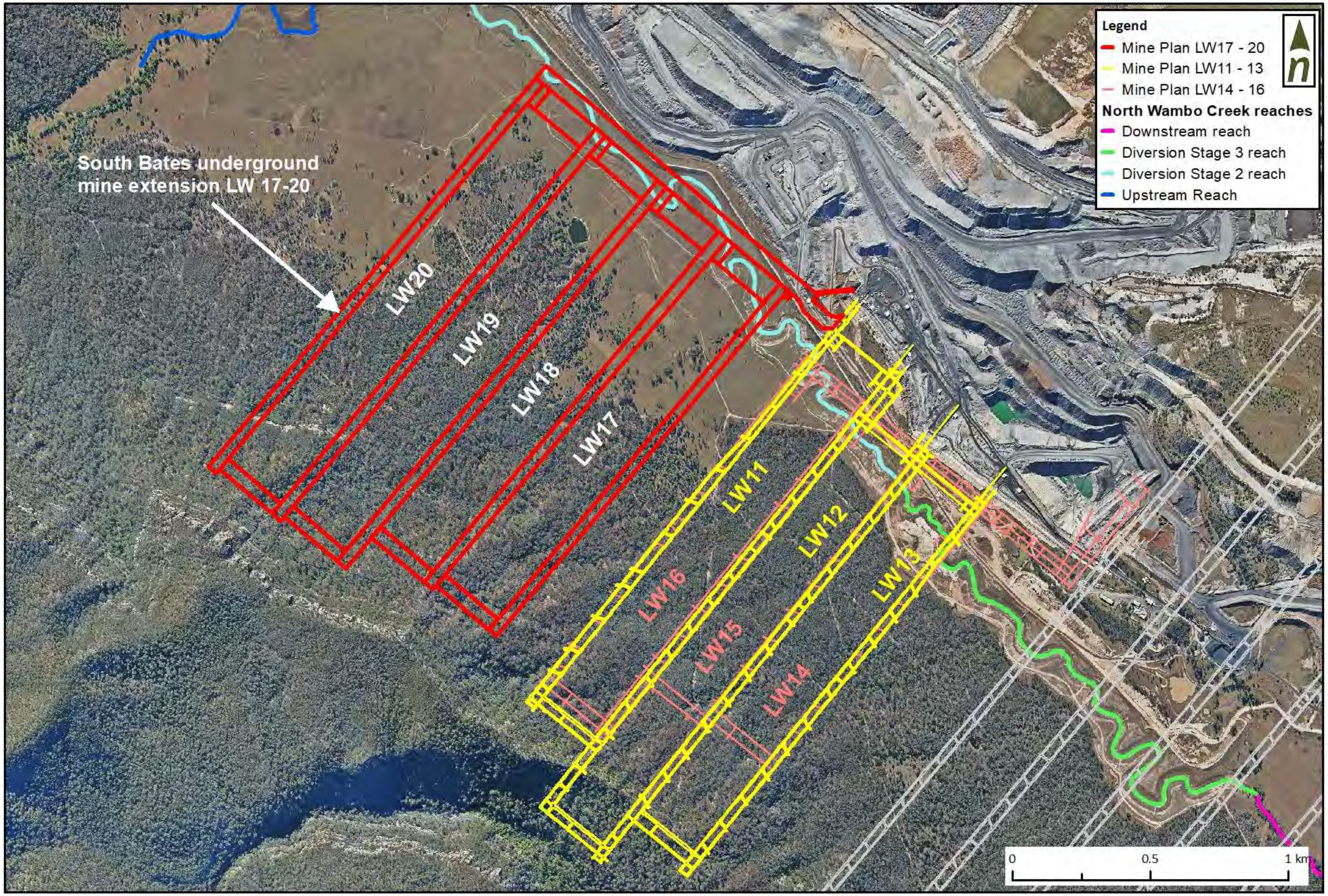

Figure 1-2. Overview of South Bates underground mine plan at Wambo Coal Mine

2 Baseline 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.

Predicted subsidence modelling indicates that LW 17 directly subsides the NWCD. The modelling indicates that LWs 18-20 will not cause any direct subsidence of the channel as the longwalls finish under the southwestern bank of the NWCD as shown on 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.

Baseline monitoring of the entire North Wambo Creek and NWCD in the study area was completed in November 2017 in response to recommendations in the extraction plan for LW 11-16 (Alluvium, 2016) (see Figure 2-1). The baseline 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*. As well as the 2017/2018 baseline monitoring information from the 2015 performance review of NWCD (Alluvium, 2015) and the November 2016 inspection were used to inform this baseline condition assessment.

LWs 11 - 14 had been fully mined at the time of the 2017/2018 inspections, including subsiding NWCD. LW 15 was almost complete but had not subsided NWCD at the time of inspection.

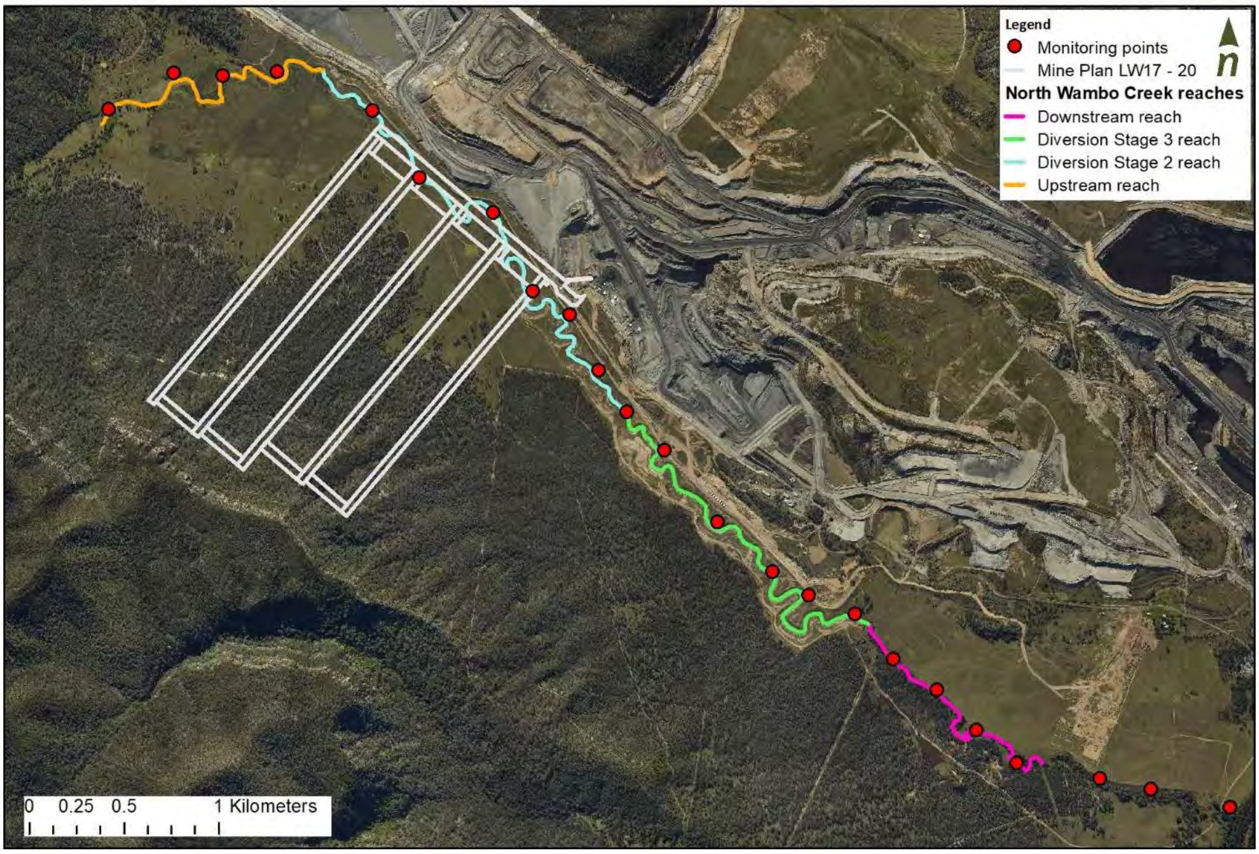

Figure 2-1. Monitoring sites for NWCD and subsidence

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 plateaux 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 2015-2018. 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.

Figure 2-2. Photographs from 2018 baseline assessment showing typical Spring Creek (left photo) and Chalkers Creek (right photo) reaches

Figure 2-3. Partly confined North Wambo Creek, downstream of confluence of Spring and Chalkers Creeks

Figure 2-4. Downstream view in fully alluvial reach, just upstream of NWCD

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. 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 subsidence has altered the location. Management of the overland flow will be undertaken to suit the post subsidence conditions.

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. This work has had limited success, a program of shallow ripping (including treatment of subsidence cracks) and seeding is in progress.

Figure 2-5. Upstream extents of Stage 2 NWCD at Div2

Figure 2-6. Minor overland flow and bank erosion in dispersive soils, mid stage 2 NWCD near Div3

Figure 2-7. Section of NWCD Stage 2 near Div 5 already undergoing erosional adjustment that will be subject to increased erosion risk from LW 11-16 subsidence

Figure 2-8. Cracking in inset floodplain over LW 11 in dispersive soils may lead to new tunnel and gully erosion

Figure 2-9. Upstream view from Div6, typical conditions in lower Stage 2 NWCD

NWCD Stage 3
Stage 3 is largely constructed in foot slopes with much of the channel boundaries being sandstone 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 very limited vegetation establishment and overland flow entry management issues that require attention. 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 combined with 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. Both of these combine to 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.

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

Figure 2-10. Steep, bedrock controlled transition zone from Stage 2 to Stage 3

Figure 2-11. Compression buckle cracks at 1-2m spacing through the sandstone in NWCD near Div8 over LW 13/14

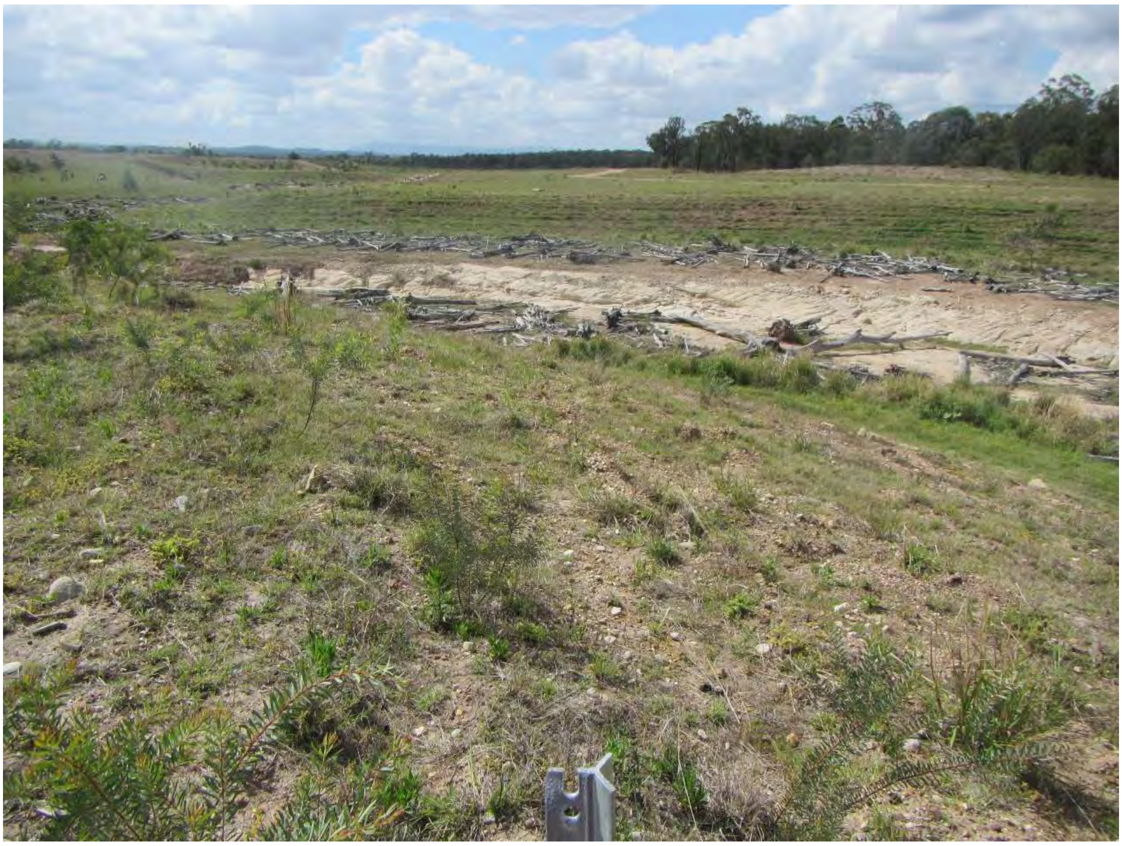

Figure 2-12. Improving woody vegetation establishment following light ripping of diversion batters

Figure 2-13. Typical conditions in mid Stage 3 of NWCD

Figure 2-14. Tunnel erosion associated with overland flow management in Stage 3 NWCD is the subject of a management program by Wambo Coal

Figure 2-15. Tunnel erosion undermining one of the overland flow entry structures that requires management

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 top of bank along the north eastern side for much of the reach.

Subsidence pools are present in the reach, providing pool habitat that is otherwise not presently common in North Wambo Creek. 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 2-16. Fully bedrock controlled invert at WS2

Figure 2-17. Deposition in subsided panel between WS2 and WS3 at risk of re-incision

Figure 2-18. Erosion head cut migrating upstream through sediments over subsided panel

Figure 2-19. Subsidence pool between WS3 and WS4

Figure 2-20. Subsidence pool where channel abuts a terrace scarp

Figure 2-21. Terrestrial vegetation colonisation of the channel bed downstream of subsidence

Figure 2-22. A significant step in bed profile through culverts near downstream extent of North Wambo Creek

Western tributaries

Several tributaries flow from the sandstone escarpment of the range to the west into NWCD in the vicinity of LWs 17-20. These tributaries transition from steep, deeply incised bedrock controlled gullies to broad alluvial flood-outs with no defined channel progressing downstream onto footslopes prior to being intercepted by a bund and drain constructed as part of NWCD arrangements that combine their entry to a single point (shown on Figure 3-8). Some of these flow paths also have stock watering dams on them upstream of the diversion bund.

Tributaries over LWs 17-20 are independent to those over LWs 11-16.

Figure 2-23. Two farm dams on tributary on the northern pillar of LW 20 (that will lose inflow due to subsidence)

Figure 2-24. Northern extent of diversion drain that runs from south to north over LWs 17-20

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 Whybrow Seam (LWs 17-20) at Wambo. It should be noted that the predictions were based on the same data set used for predicting the subsidence from extraction of the Whybrow Seam (LWs 12-13) and Wambo Seam (LWs 14-16). As such the predicted subsidence contours for LWs 12-16 were used in this project also. Subsidence from LW 11 was not considered as it had already been subsided when the modelling was undertaken.

A brief summary of the modelling results is presented below, however, for detailed information regarding the methodology please refer to the reports prepared by MSEC, titled *South Bates Extension Subsidence Assessment* (MSEC935). The subsidence predictions for LWs 17-20 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 subsidence contours output from the modelling for LW 17-20 (including combined subsidence due to LWs 12-16) is shown in Figure 3-3. A representation of the post subsidence digital terrain is presented in Figure 3-4. Shown is the 1m and 5m terrain contours derived from the LiDAR captured in July 2016 (which included the LW11 subsidence) modified to include the predicted subsidence modelled by MSEC.

Surface tensile cracking and compressional buckling
Cracking has been observed above LW11/16, LW12/15 and LW13/14 at the surface (Figure 3-1). 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.

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 3-2.

Figure 3-1 - Cracking at surface over LW13/14

Figure 3-2 - Tunnelling over LW12/15 on track adjacent diversion

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 LW1-10 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 due to the effects 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.

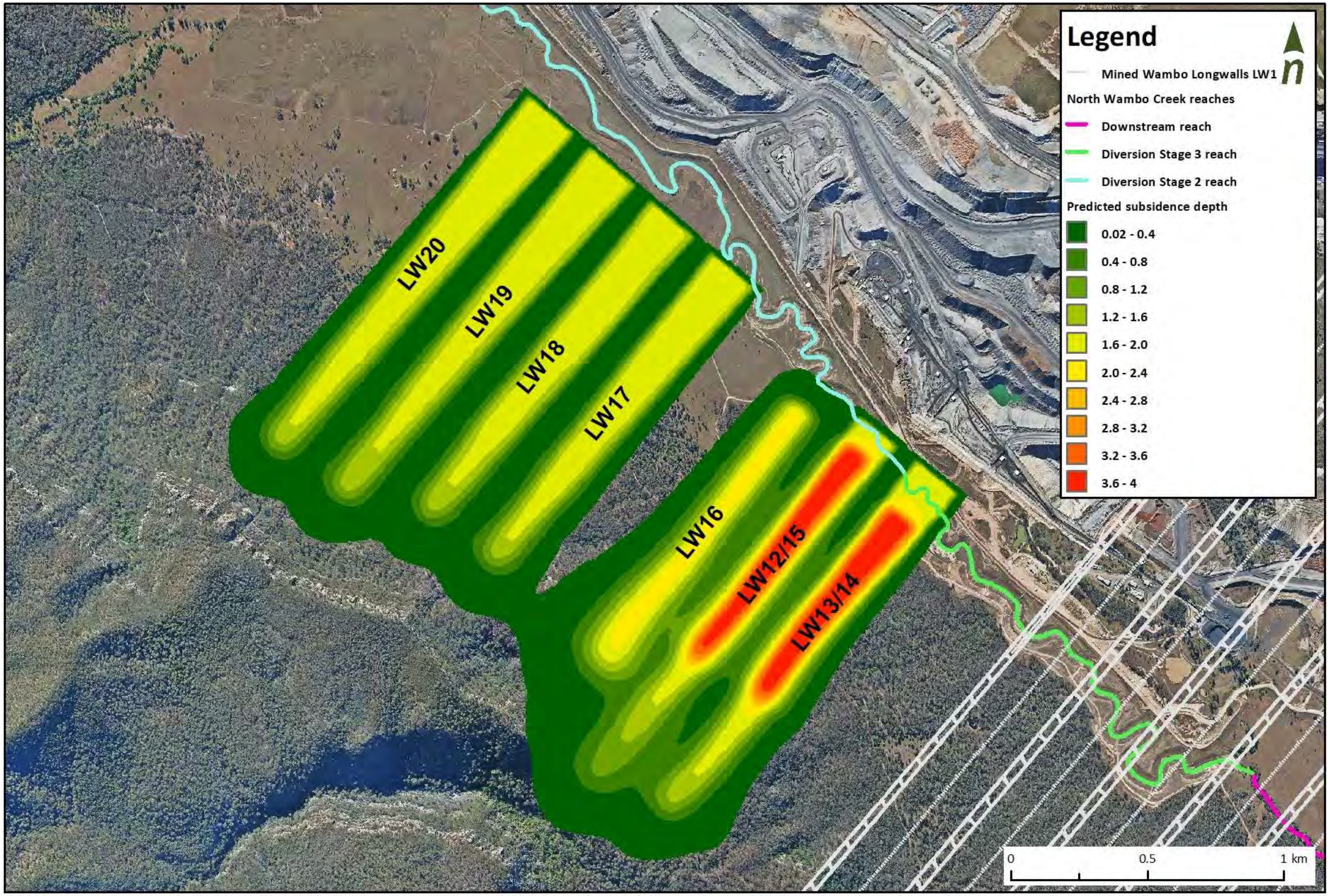

Figure 3-3. Predicted subsidence depths for South Bates underground mine extension LWs 17- 20, including LWs 12-16. Note predicted subsidence for LW11 not shown as it has already subsided prior to data collection.

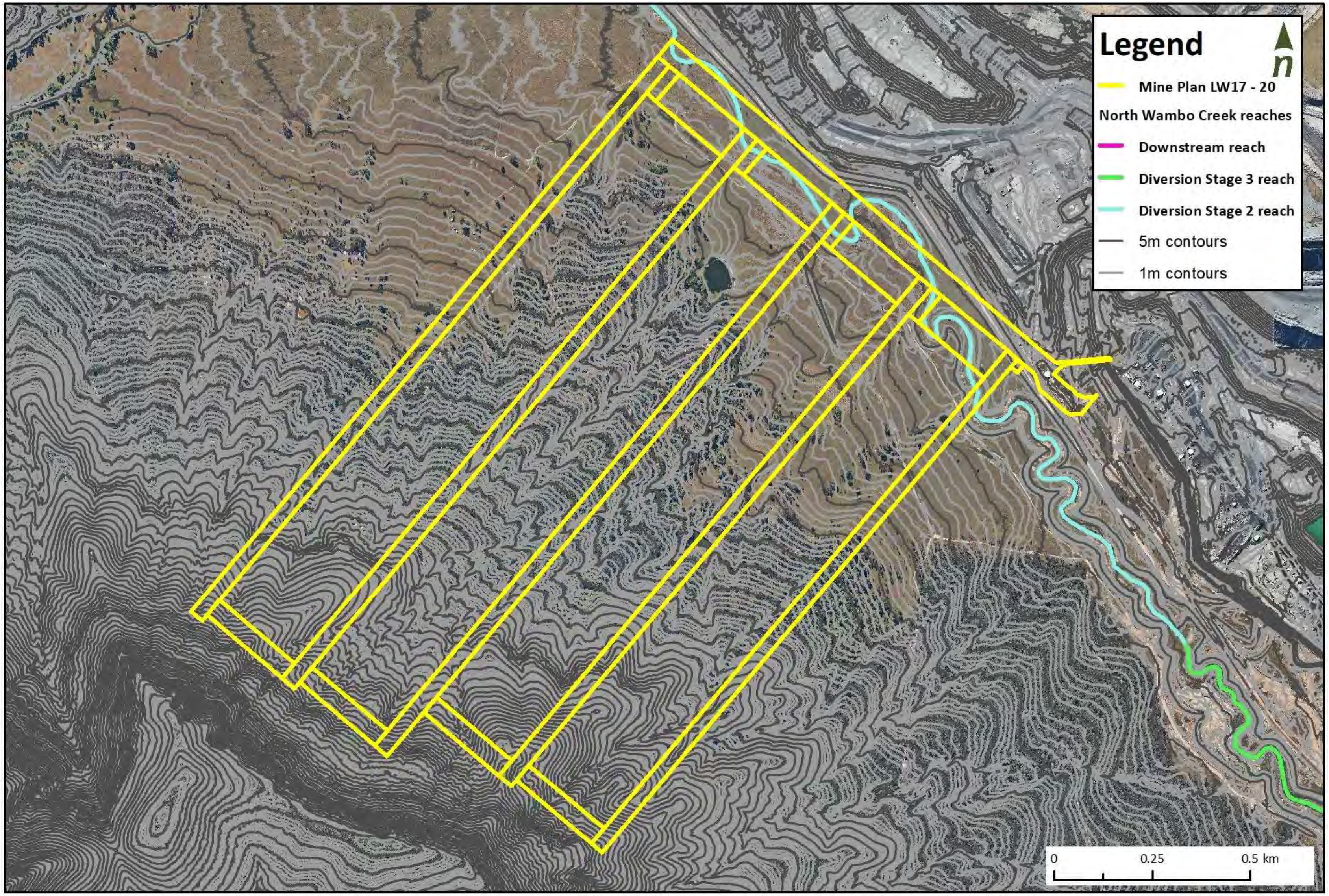

Figure 3-4. Post subsidence digital terrain contours at 1m intervals LW17-20

Predicted subsidence of panel catchments and waterways

Details of the predicted maximum subsidence within NWCD 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 3-4. As can be seen there is only a maximum of 0.3m of predicted subsidence of the NWCD channel over LW 17, this occurs over an approximate 60m reach. There is no predicted subsidence of the NWCD channel over LWs 18-20.

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 diversion channel
17	1.7	1.9	0.3
18	1.7	1.9	0
19	1.85	1.8	0
20	1.9	1.8	0

The predicted subsidence void (or pool) volume estimates within the NWCD channel following subsidence due to LW 17 is approximately 117m^3. This assumes a static channel boundary (no erosion), which in reality 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. Again it is noted that the subsidence due to LWs 18-20 add nothing to the subsidence volume in the diversion.

3.2 2nd order – predicted geomorphic response of surface water systems to 1st order impacts

NWCD

With only 0.3m of subsidence predicted over LW 17 (refer Figure 3-4) there will be minimal incremental erosion risk in NWCD due to subsidence. This is demonstrated on Figure 3-7, showing existing and post subsidence hydraulic conditions.

Erosion in the form of channel bed incision and subsequent widening and meander migration is already occurring in this extent of the diversion (see Figure 3-5). This process will be accelerated by subsidence due to LW 16 in addition to LW 11. Hence, increased rates of erosion are likely in the LW 17-20 extent of the diversion but not associated with subsidence from those panels.

Cracking may occur in the diversion channel from LW 17 and in the western bank from LWs 18-20. Bank heights and slopes in this extent of the diversion are less than those downstream, where erosion response to cracks is yet to be observed, though no rainfall has occurred to drive erosion processes.

Figure 3-5. Incision, channel widening and meander migration in NWCD between LW16 and LW17

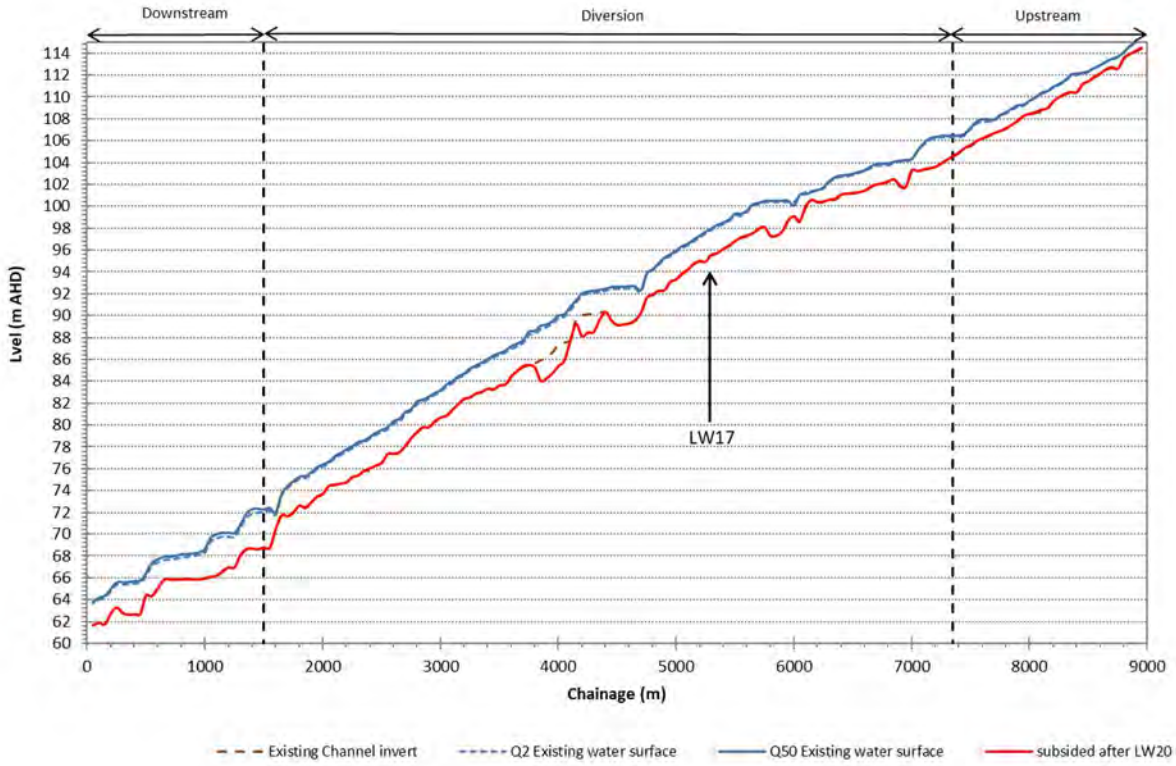

Figure 3-6. Existing and post subsidence longitudinal profile

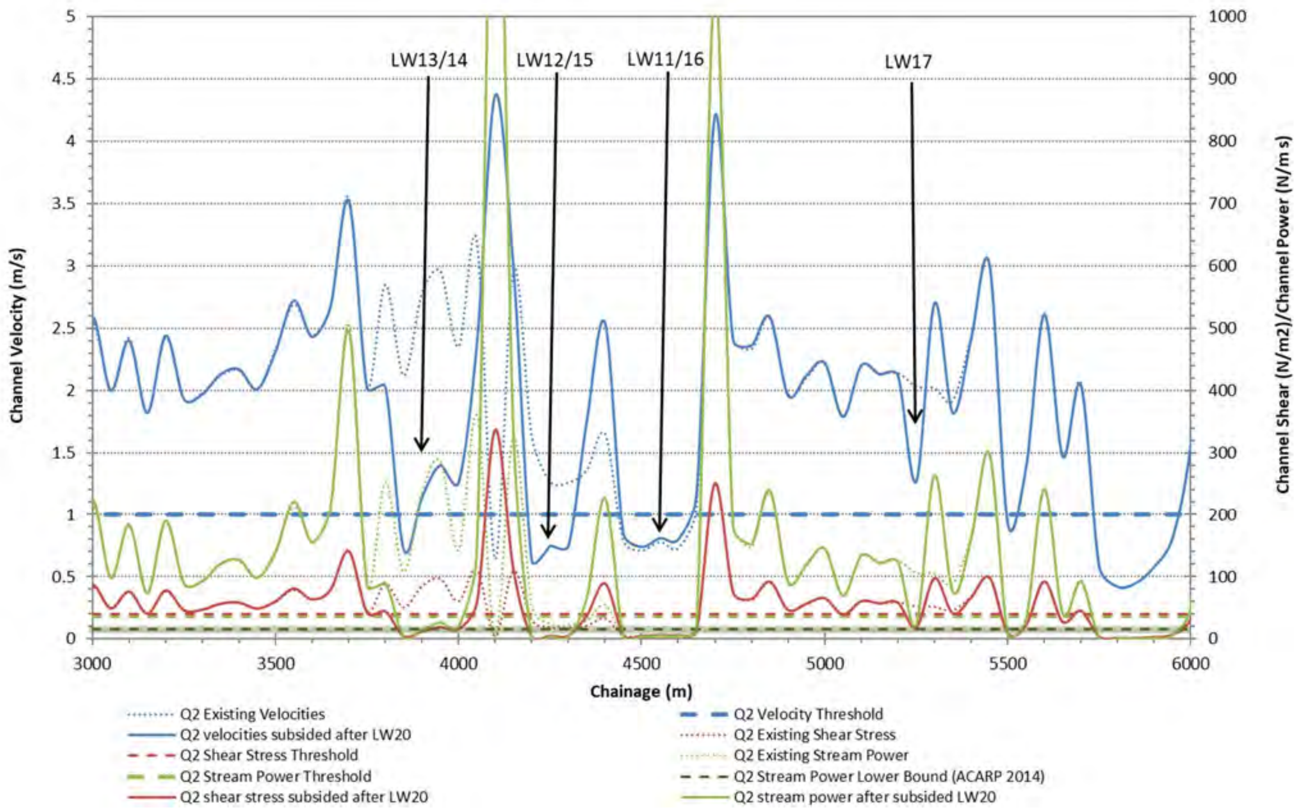

Figure 3-7. Existing and post subsidence hydraulic conditions

Western tributaries
The flow paths from the range to the west into NWCD are likely to undergo substantially more change than NWCD. This is due to the geometry of these flow paths relative to magnitude of subsidence. At present, most of these flow paths are intercepted by an existing diversion bund/drain (approximately 1m high) that directs the majority of the western tributary flows over LW17-19 north and into NWCD over the proposed location of LW19 (refer Figure 3-8). It is expected that subsidence will have an impact on the future effectiveness of this bund and it will be overtopped allowing flows to continue towards the diversion. Mitigation measures for this impact are described in section 4.4.

The predicted changes in flow paths are presented in Figure 3-9. The stream lines shown are those predicted by the software CatchmentSIM using the existing and predicted subsidence digital terrain models (DTM). The predicted post mining stream lines sit on top of the current stream lines, hence where a blue stream line is shown on the map for current conditions, not covered by red, that section of stream is abandoned post subsidence.

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 tributary inflow for LW17 shows a change from the current situation due to a lowering of the current diversion bund towards the centre of the panel. Prior to subsidence, flows below the 2yr ARI event would be contained by the bund and diverted north. Following subsidence flows from two of the western tributaries now concentrate and over top the bund towards the centre of LW17 before entering NWCD just upstream of LW17 pillar. There are substantial flows over the diversion batter that will now be more concentrated. Provision for this flow into the diversion via a correctly designed and constructed batter chute will be required. The catchment area covers approximately 48 hectares.

Following subsidence LW18 will capture two western tributaries. Prior to subsidence flows below the 2yr ARI event (approx.) would be contained by the bund and diverted north. Following subsidence these flows now concentrate and over top the bund towards the north of LW18, adjacent pillar LW18/19, before entering NWCD immediately downstream of pillar LW17/18. There are substantial flows over the diversion batter that will now be more concentrated. Provision for this flow into the diversion via a correctly designed and constructed batter chute will be required. The catchment area covers approximately 87 hectares.

The diversion bund still provides some level of functionality over LW19 however it is only minimal, collecting and diverting a small amount of water that collects on the north of the panel. Prior to subsidence flows from the western tributaries of LW19 would enter a large farm dam towards the centre of the panel (refer Figure 3-8). Overflows from this dam would then be contained by the bund and diverted north. Following subsidence the majority of these flows concentrate and over top the bund towards the south of LW19, adjacent pillar LW18/19, before entering NWCD immediately upstream of pillar LW18/19. There are substantial flows over the diversion batter that will now be more concentrated. Provision for this flow into the diversion via a correctly designed and constructed batter chute will be required. The catchment area is approximately 28 hectares. Apart from the direct subsidence and the diversion of flows away from it the farm dam may also lose water into subsidence cracks in the surface and substrata.

Over LW20 stream lines for post subsidence conditions show changes from existing towards the north over LW20 pillar zone. Flows now concentrate slightly further to the south and drain east along LW20. The location at which the tributary enters NWCD stays the same as for existing conditions. This would abandon inflows to the two small farm dams.

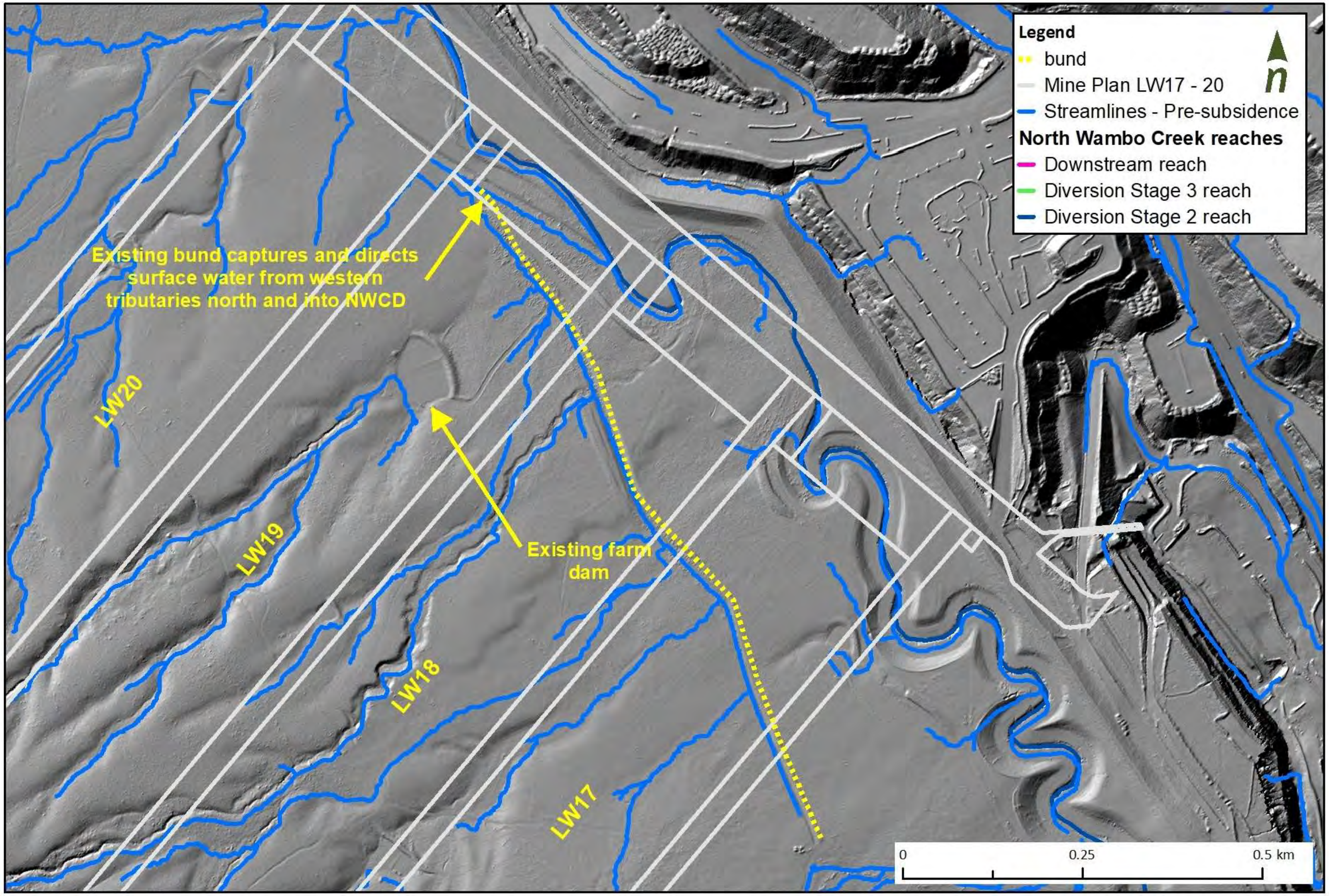

Figure 3-8 – Flow paths under existing conditions for western tributaries, showing the effect of bund

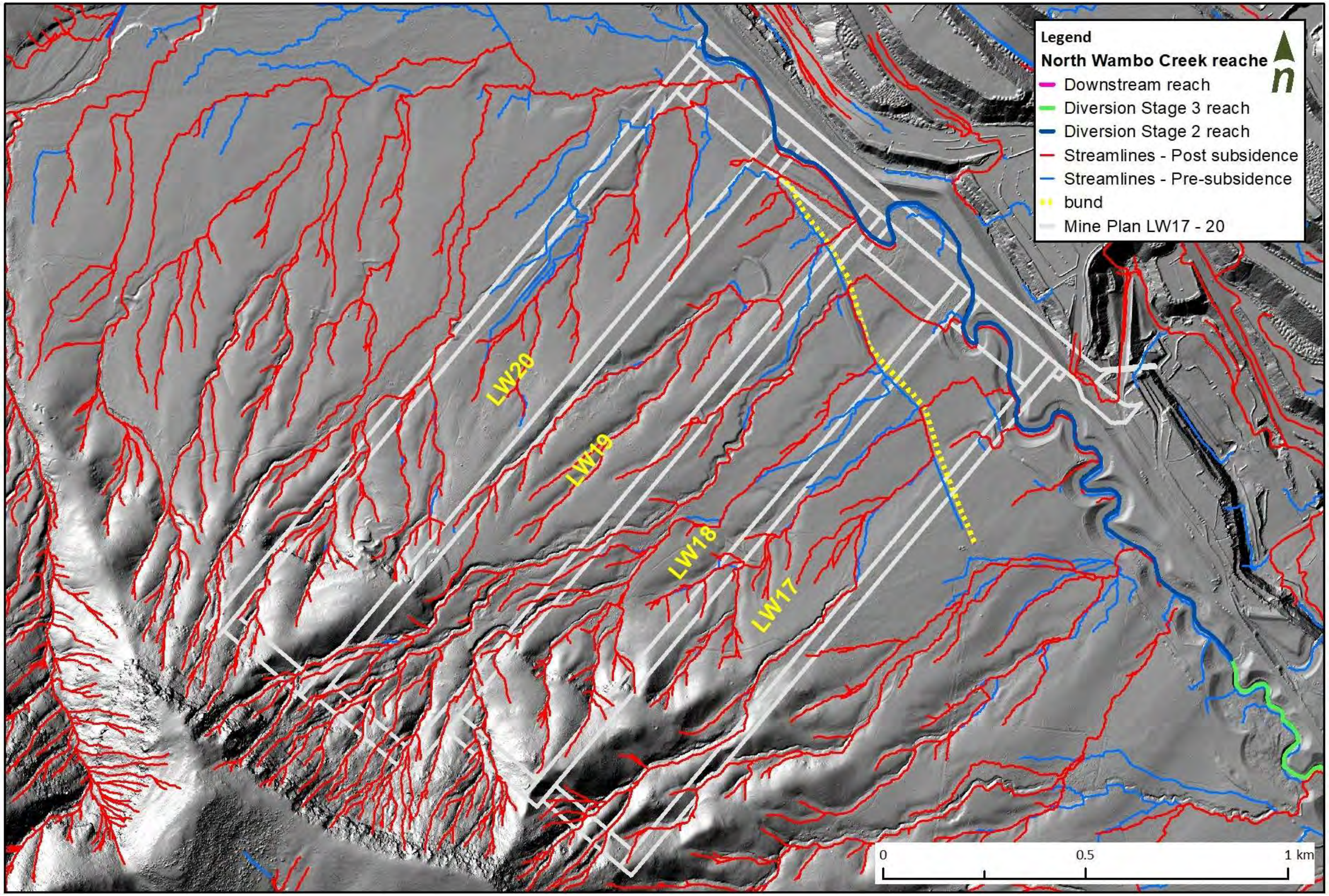

Figure 3-9. Flow path changes for western tributaries

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 LW17-20 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.

The hydrology used in the 2D model builds upon the hydrologic model used in the previous Extraction Plan for LW11-16. A higher initial loss value of 65.9mm as opposed to 25mm was used in the updated hydrological model. Since the previous hydrological model was built in 2016, Alluvium has completed a number of studies in the region with similar geomorphic settings to the North Wambo Creek catchment, as well as conducted further field inspections of the site as part of the 2017 and 2018 monitoring and baseline assessments of NWCD. This has enabled us to build up a more accurate understanding of the hydrogeological characteristics of the area. As a result of the increased initial loss values there has been a decrease in the calculated design discharges for the 2018 hydrological model compared to the 2016 design discharges as shown in Table 3-2 below.

Table 3-2. Design discharges generated from hydrologic modelling of existing conditions, 2016 estimates vs. 2018 estimates

	2016 estimates	**2018 estimates**
Upstream catchment (km^2)	34	34
ARI/AEP	**Peak Discharge (m^3/s)**	**Peak Discharge (m^3/s)**
2 year	43	10.5
50 year	154	57.6
100 year	180	75.4
1000 year	324	93

Subsidence due to LWs 17 - 20 will have a negligible effect on in-channel storage when compared to existing conditions (Figure 3-10 and Figure 3-11). The impact of subsidence due to LWs 17 - 20 on flow in North Wambo Creek is minimal. As demonstrated in Table 3-3, the greatest change is a reduction in flow volume of 0.86%. The impact on volume generally decreases as the magnitude of the design flood event increases (as the subsidence driven storage volume does not increase).

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

ARI	**Existing (m^3)**	**Subsided (m^3) after LW17**	**Difference (%)**
2 year	14,361	14,238	-0.86
50 year	53,120	52,937	-0.34
100 year	52,886	52,783	-0.19
1000 year	51,087	50,834	-0.49

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 underground due to cracking in the vicinity of the longwall panels.

In terms of ponding of surface water from the western tributaries the modelling indicates that post subsidence following extraction of LWs 17 - 20 there will be some ponding of water at the eastern ends of LWs 18 - 20.

The predicted ponding following the subsidence due to each consecutive panel are depicted in greater detail in the following figures:

- Figure 3-10. Estimates of ponding following 50 year ARI event (existing conditions)
- Figure 3-11. Estimates of ponding post subsidence following 50 year ARI event (post LW 17)
- Figure 3-12. Estimates of ponding post subsidence following 50 year ARI event (post LW 18)
- Figure 3-13. Estimates of ponding post subsidence following 50 year ARI event (post LW 19)
- Figure 3-14. Estimates of ponding post subsidence following 50 year ARI event (post LW 20)

The post subsidence figures show some ponding near the western batter of NWCD at the end of the panels. This ponding will pose some elevation of tunnel erosion risk if near top of batter. This would be managed through associated works with flow entry to the diversion from the new post subsidence flow paths.

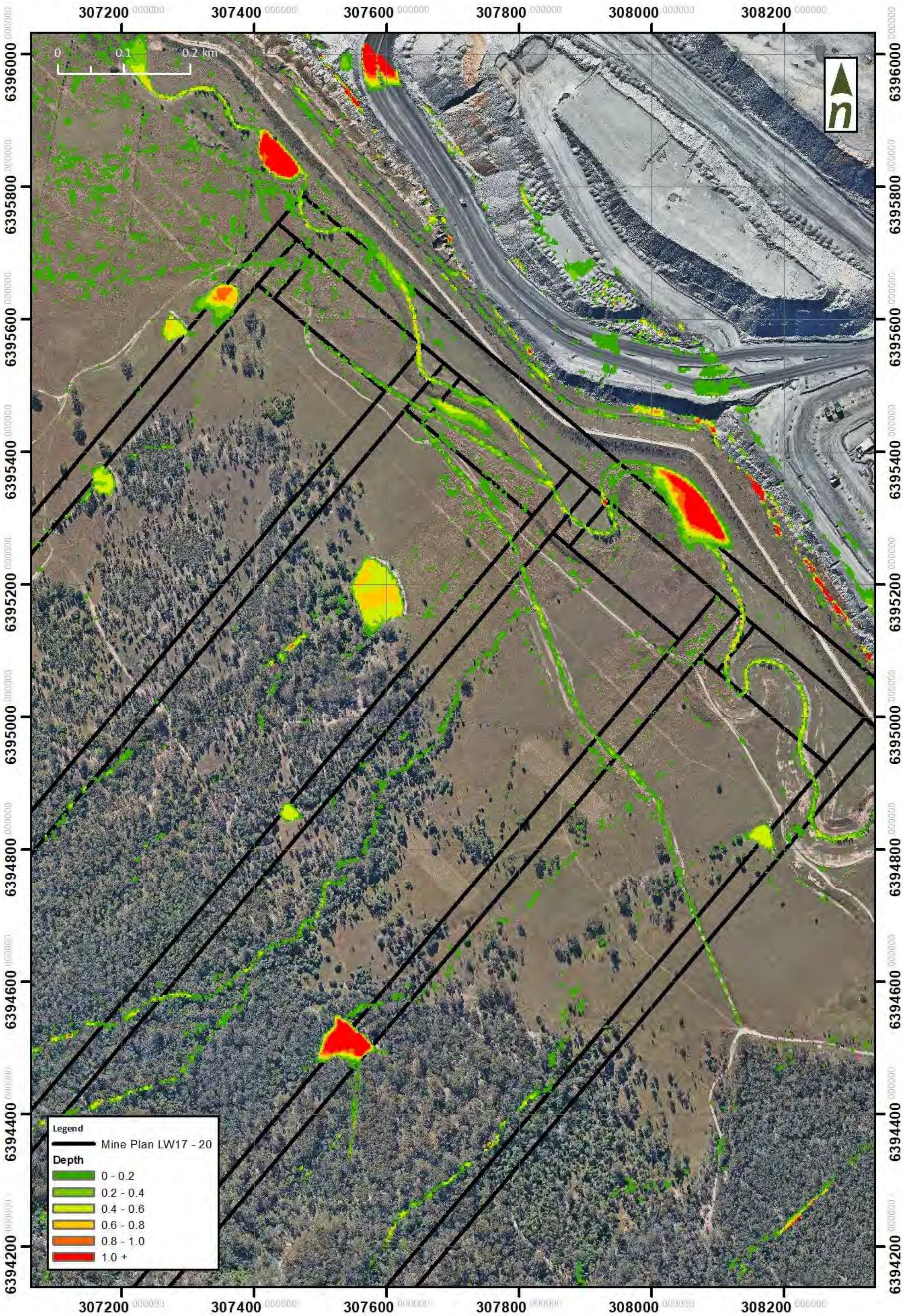

Figure 3-10. Estimates of ponding following 50 year ARI event (existing conditions)

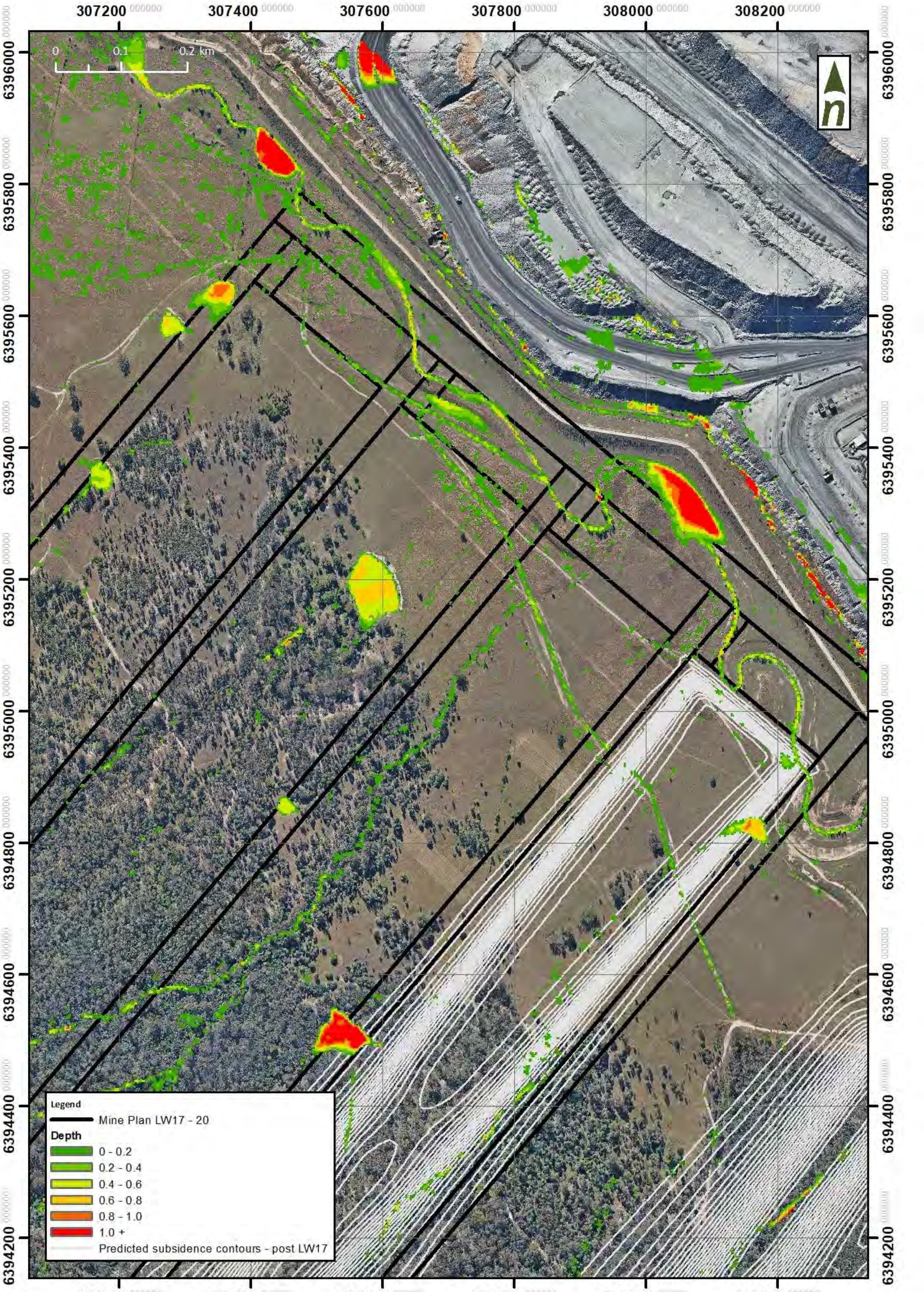

Figure 3-11. Estimates of ponding post subsidence following 50 year ARI event (post LW 17)

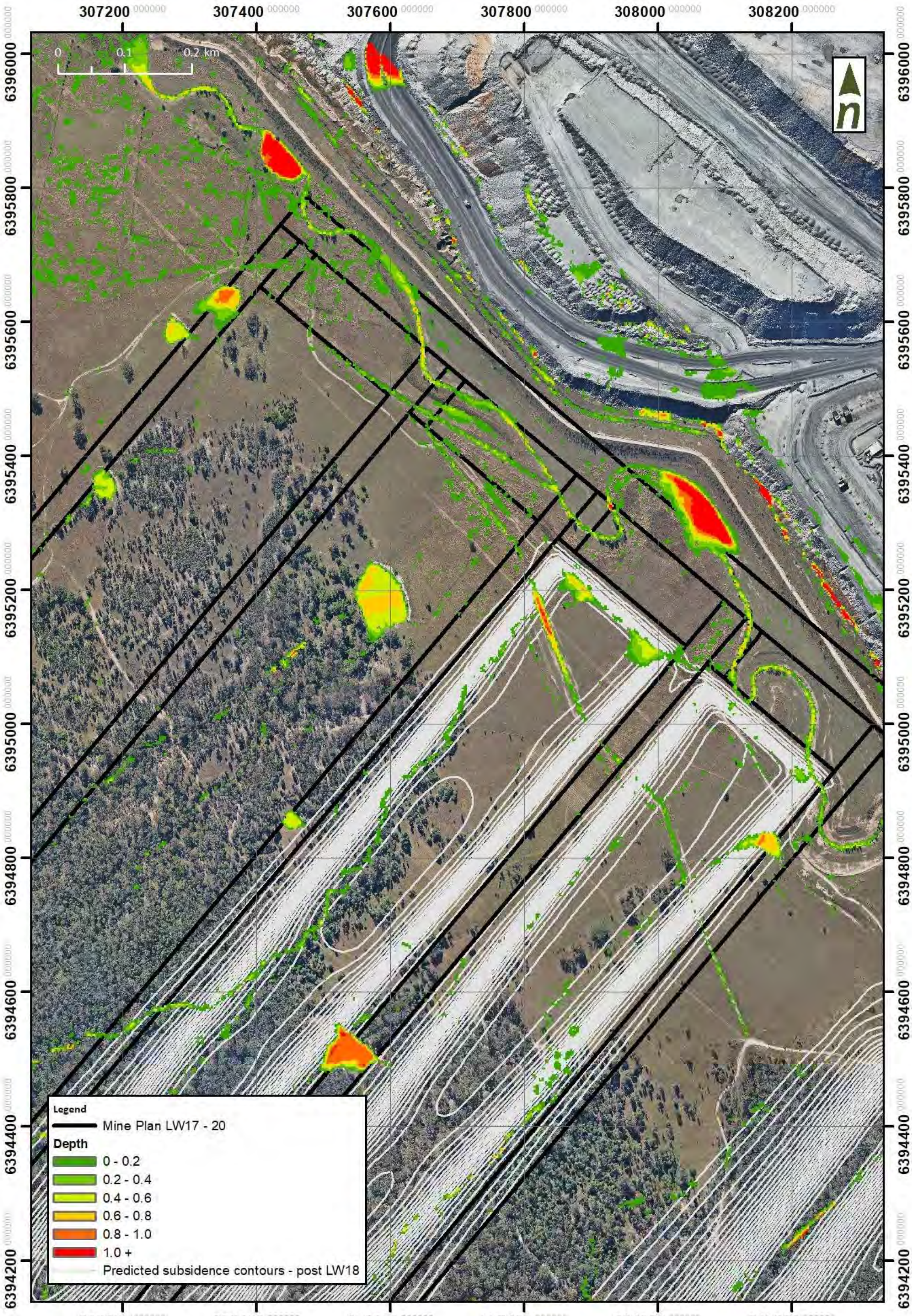

Figure 3-12. Estimates of ponding post subsidence following 50 year ARI event (post LW 18)

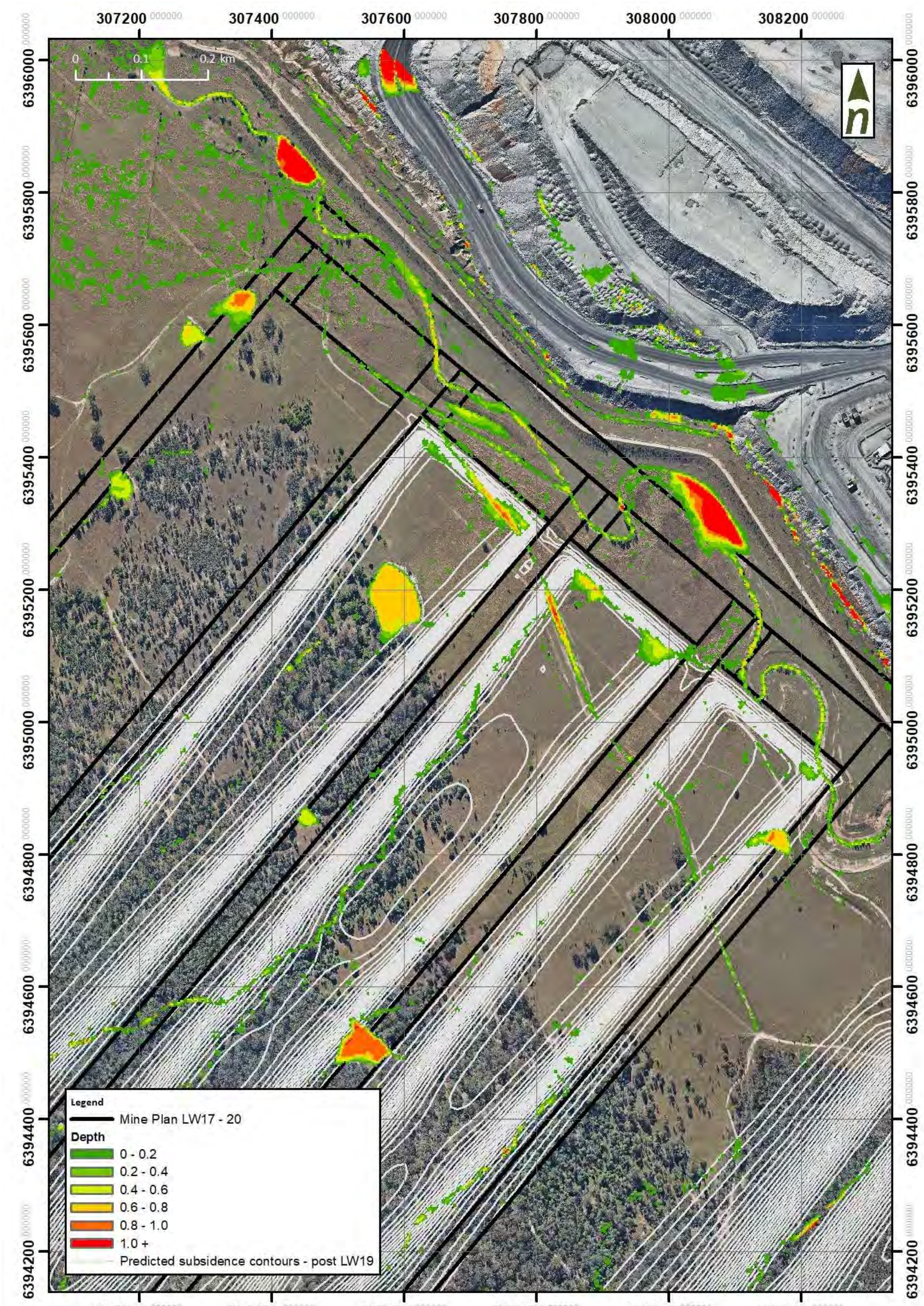

Figure 3-13. Estimates of ponding post subsidence following 50 year ARI event (post LW 19)

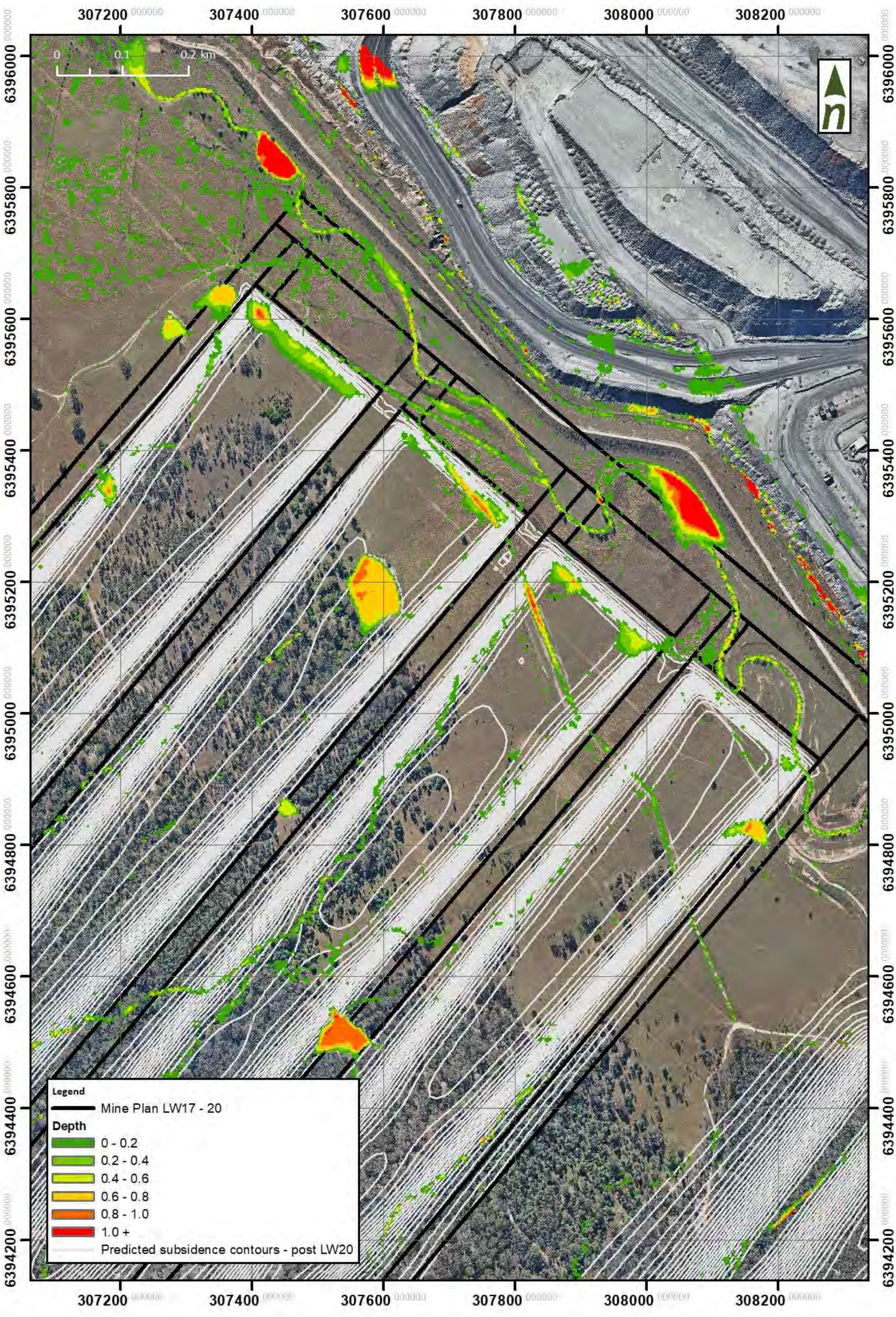

Figure 3-14. Estimates of ponding post subsidence following 50 year ARI event (post LW 20)

Changes to water quality
An increase in suspended sediments in NWCD is possible from increased erosion from tributary entry. Management measures can be put in place to reduce that risk to negligible.

Due to a predicted decrease in flows (water quantity) through the diversion as a result of losses to 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.

4 Subsidence Management

4.1 Monitoring and Evaluation

As part of the extraction plan for LW11-16 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 monitoring program implemented and developed as part of the LW11-16 extraction plan encompasses the entire diversion and all current and past longwalls, including the extents of the diversion over LW17-20. As a result no further recommendations are made in terms of monitoring as the existing monitoring program provides appropriate and sufficient coverage for LW17-20. A summary of the monitoring program is provided below. A summary of the monitoring program findings (in relation to LW17-20) from the first round of monitoring (baseline monitoring) are provided in section 2.

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
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 diversion 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
4: Relinquishment monitoring	To demonstrate North Wambo Creek through the area of subsidence and the diversion 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 2016 Alluvium began implementation of the monitoring program that was recommended as part of the Previous extraction plan for LW11-16 by completing baseline monitoring.

Baseline monitoring

The baseline data provided a reference to measure the condition of all reaches of North Wambo Creek against each other and to themselves 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 NWCD including over LW17-20. The monitoring sites for subsidence are shown in Figure 4-1.

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.

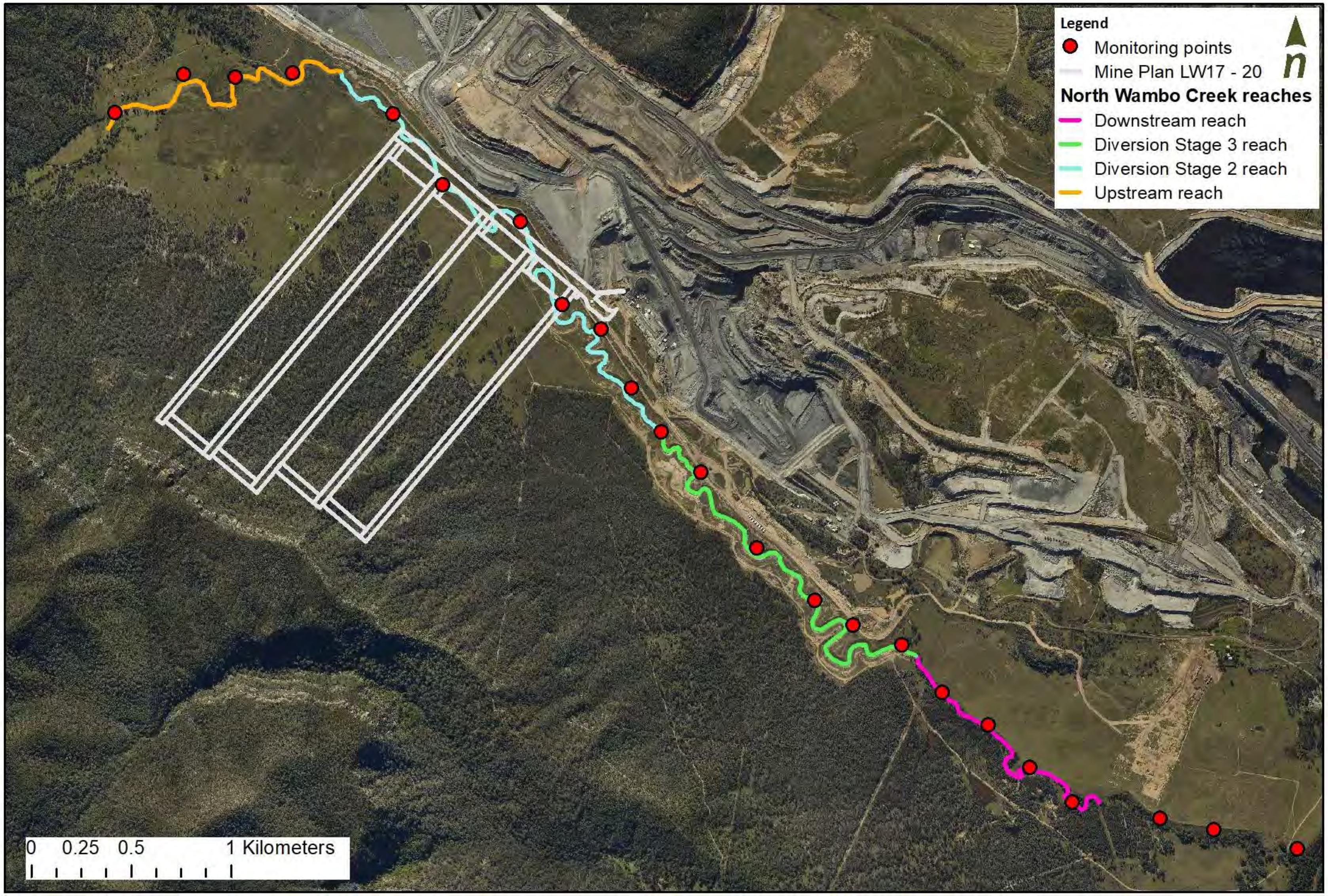

Figure 4-1. Monitoring locations for Diversion and Subsidence Monitoring Program

4.4 Recommendations for mitigation works

Levee
The levee that protects the open cut is not directly subsided by LW17-20, no management works are envisaged in response to subsidence due to extraction of these longwalls.

NWCD erosion
Based on comparison of hydraulic modelling outputs to current best practice design criteria for diversions in Australian mining (refer Attachment A) and field observation of NWCD, increased rates of erosion in response to subsidence over LW17 is likely. This is not significant however it will likely link with upstream progressing erosion processes from LW16 in an extent of the diversion already undergoing some channel bed incision, channel widening and meander migration.

To achieve a long term stable diversion arrangement in these extents a reduction of hydraulic parameters or a form of channel armouring is required. To create a self-sustaining diversion, the channel geometry (longitudinal profile and cross sectional form) would be altered to reduce hydraulic parameters into the range where stability is expected. To achieve this outcome would likely require increasing channel length by creation of new sections of diversion. However, given the diversion is an approved structure for Wambo and much of the diversion already exceeds hydraulic parameter values that are required to achieve long term stability, an alternate approach may be taken that is consistent with current approvals. This would be in the form of low flow channel armouring and increasing vegetation coverage in the diversion in the areas of concern.

Low flow channel armouring could utilise similar sandstone to that already utilised in Stage 3 of NWCD in the zone over LW17. The need for stabilisation measures for the channel bed and low flow channel banks in this area should be further investigated including armouring of selective locations. Increased woody vegetation coverage on the inset floodplain of the diversion is a complimentary measure that provides for increased potential for stability over the long term.

The mitigation works should take place after subsidence has occurred.

It is not proposed to regrade pools that may form along the diversion above LW17. These pools provide for increased aquatic habitat availability in a system that currently has limited availability.

The zone where works are recommended for NWCD associated with LW17-20 and cumulatively with LW11-16 are shown on Figure 4-2.

Overland flow entry
New batter chutes to manage concentrated overland flow entry created by subsidence from LW17-20 are required at three locations as shown on Figure 4-2. Minor ancillary earthworks may also be required to ensure these chutes capture and convey all flow from the panels into the diversion without creating further rill/pipe/tunnel/gully erosion on the diversion batters. The batter chutes will have some alterations to those currently in place on NWCD that are subject to poor performance due to specifications and construction. These alterations are important to ensure batter chute function in dispersive soil/sub soil environments.

The batter chutes should be constructed after subsidence has occurred.

A review of the previous recommended chute locations compared to the 2017 LiDAR streamlines is shown below in Figure 4-3. As can be seen there are some slight changes to the streamlines that may impact on the two downstream batter chute locations. Initial review indicates that the catchment area draining to the most southern batter chute, situated over LWs 13/14, will decrease which may enable the dimensions of the chute and the rock size used to be decreased. The batter chute situated over LWs 12/15 will now need to be moved further downstream and a small diversion bund may need to be constructed to direct all overland flows down the chute. It should be noted the exact design changes would need to be refined at the detail design stage.

Any ponded areas near top of batter of NWCD will need to be made free draining to the proposed batter chutes.

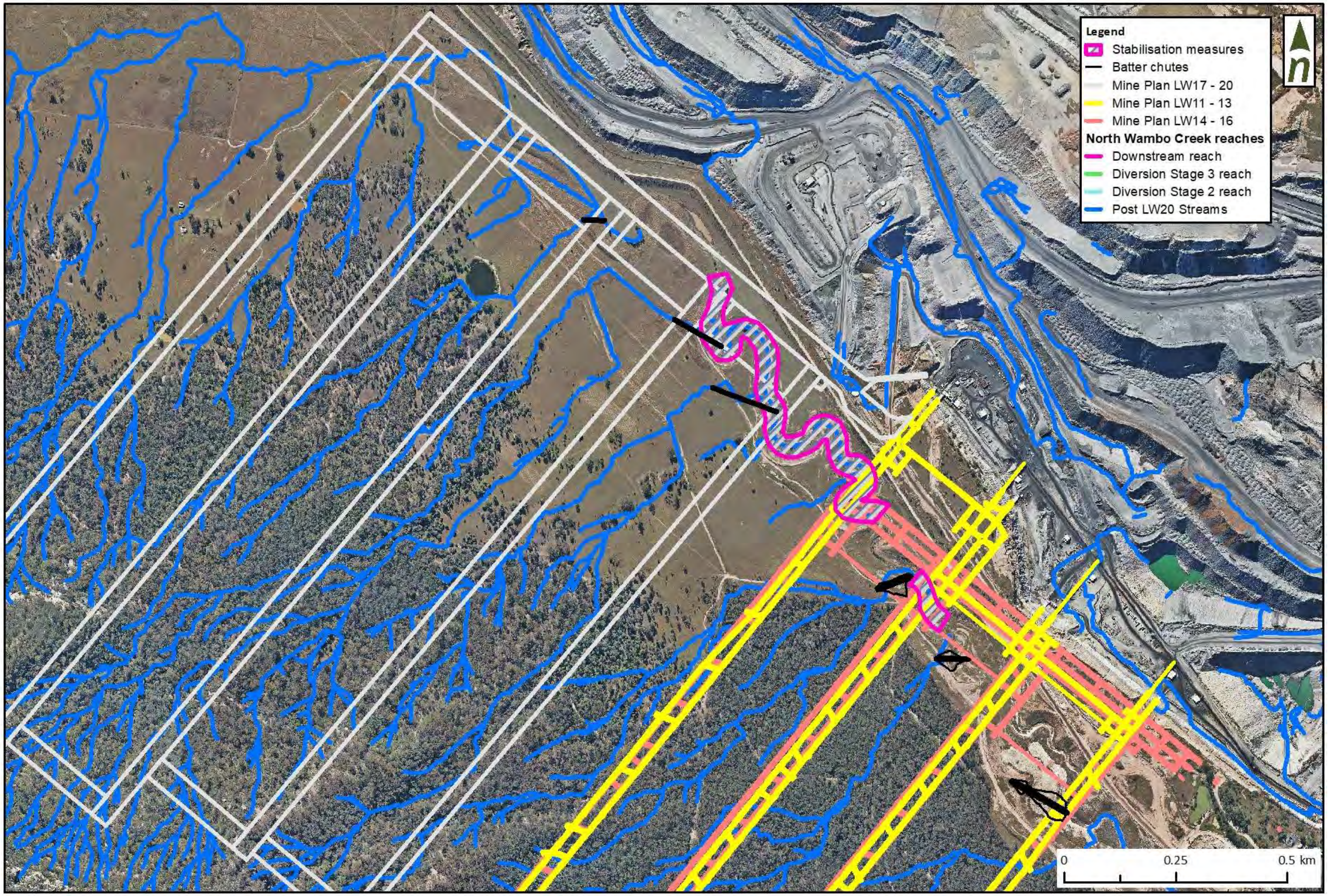

Figure 4-2. Recommended mitigation measures

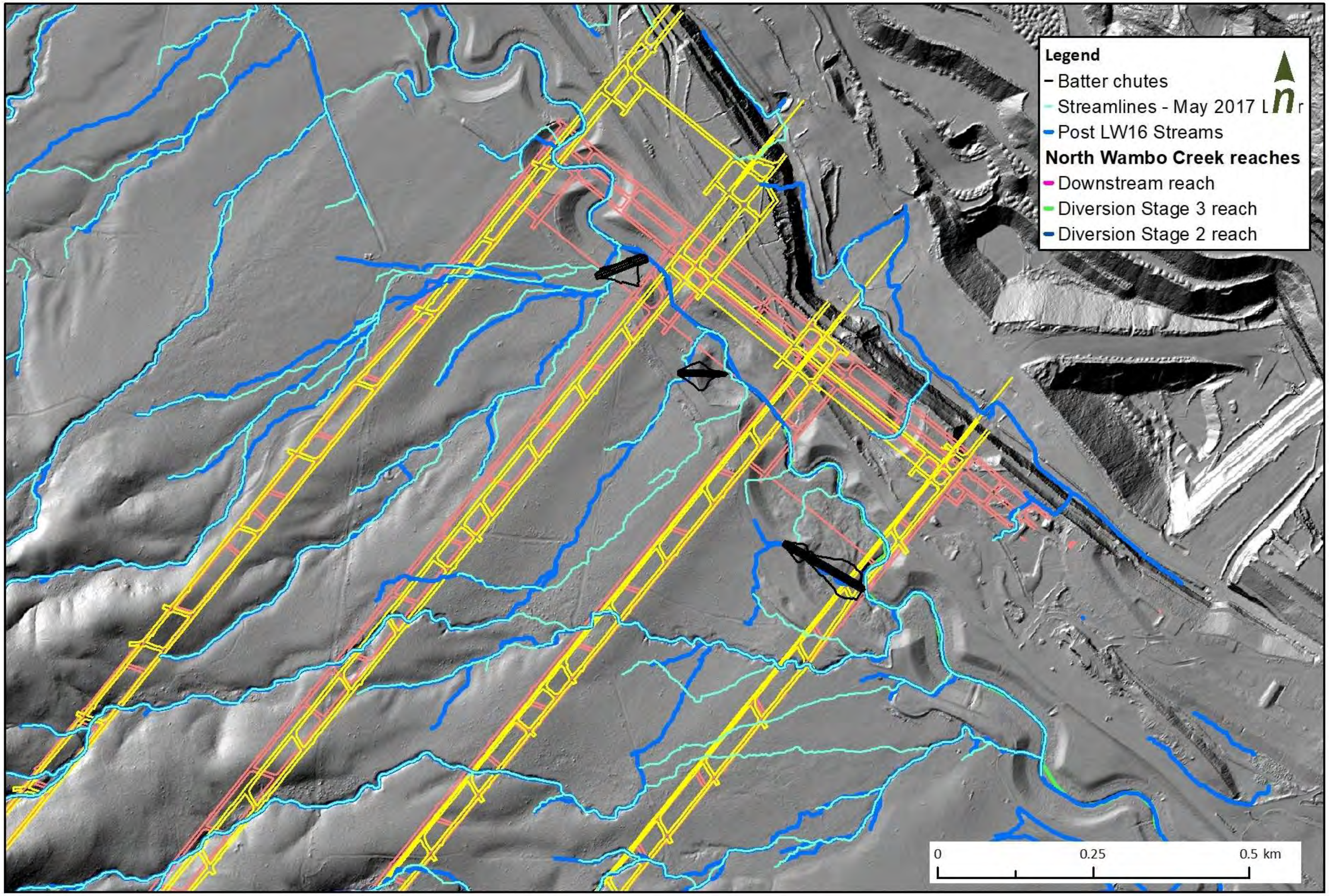

Figure 4-3. Previous predicted streamlines post LW16 subsidence, including proposed batter locations, vs 2017 streamline

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*

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

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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.

Attachment A
1D hydraulic modelling graphs

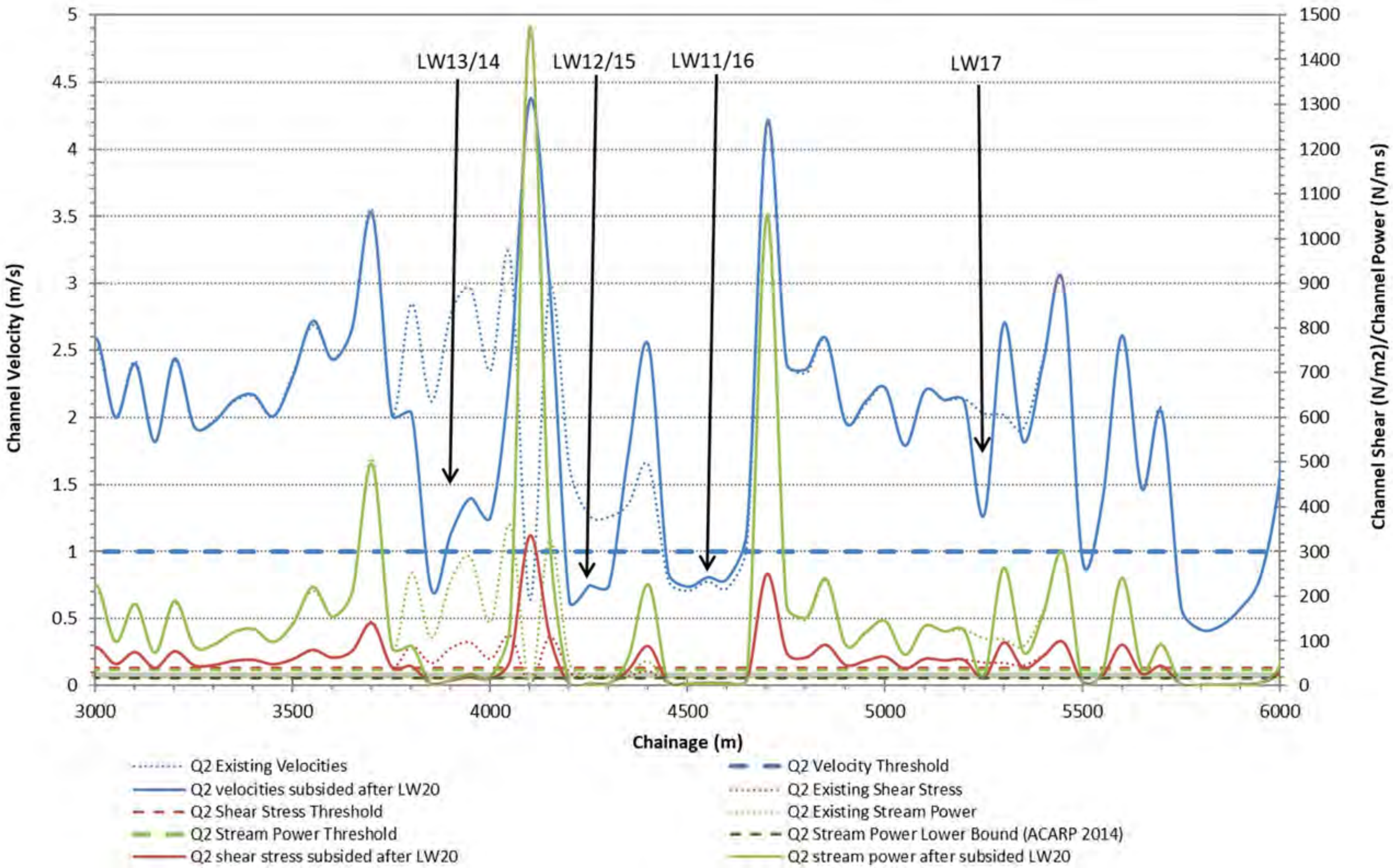

Figure A- 1. Existing and subsided conditions 2 year ARI hydraulic performance

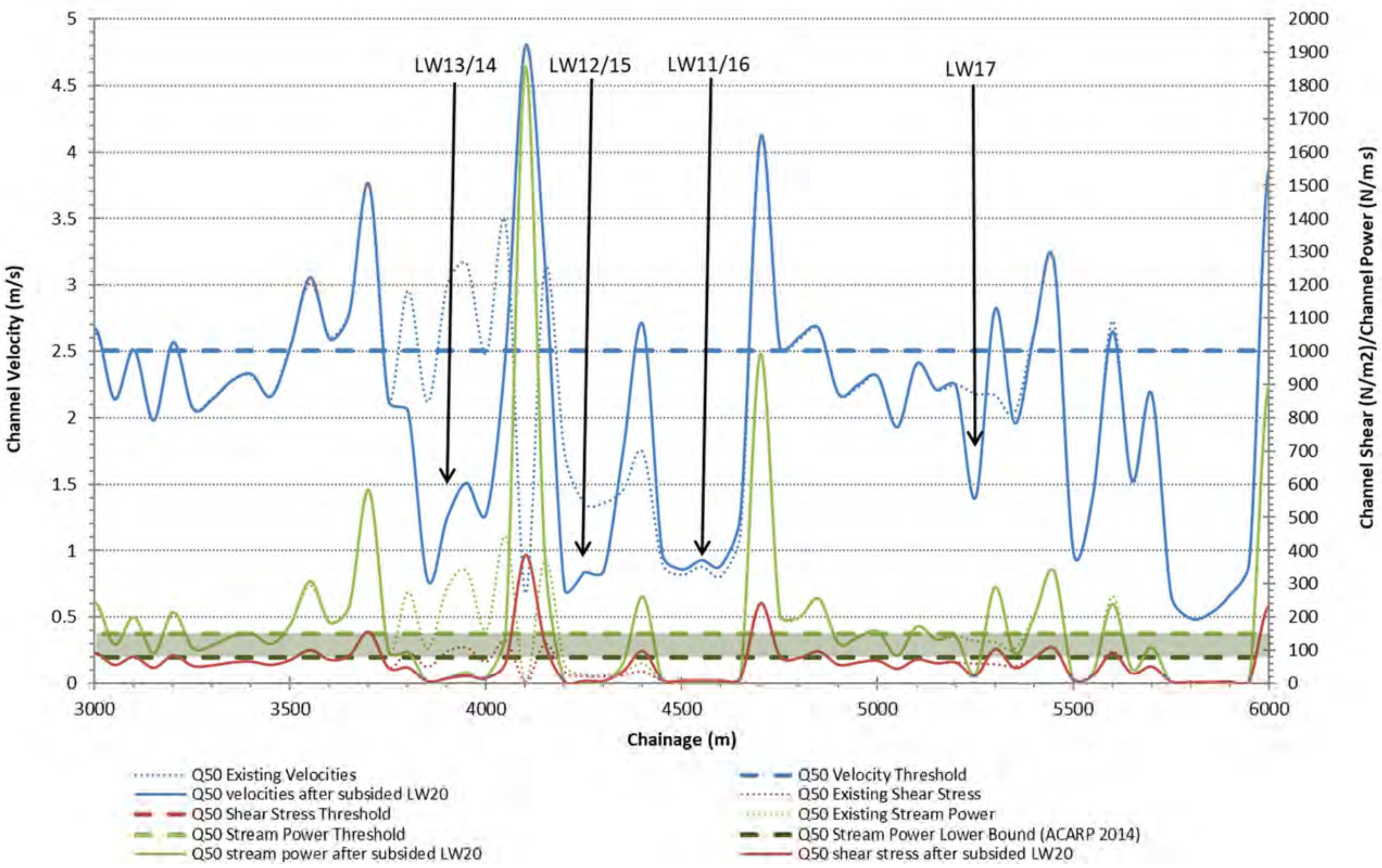

Figure A- 2. Existing and subsided conditions 50 year ARI hydraulic performance

Attachment B
Hydrology

Hydrologic modelling

The North Wambo Creek catchment passes by the Wambo Coal Mine site, 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 B-0-1.

A hydrologic model was built for the entire catchment and flows were generated for up to the 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 RORBW in version 6.15, 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-0-1.

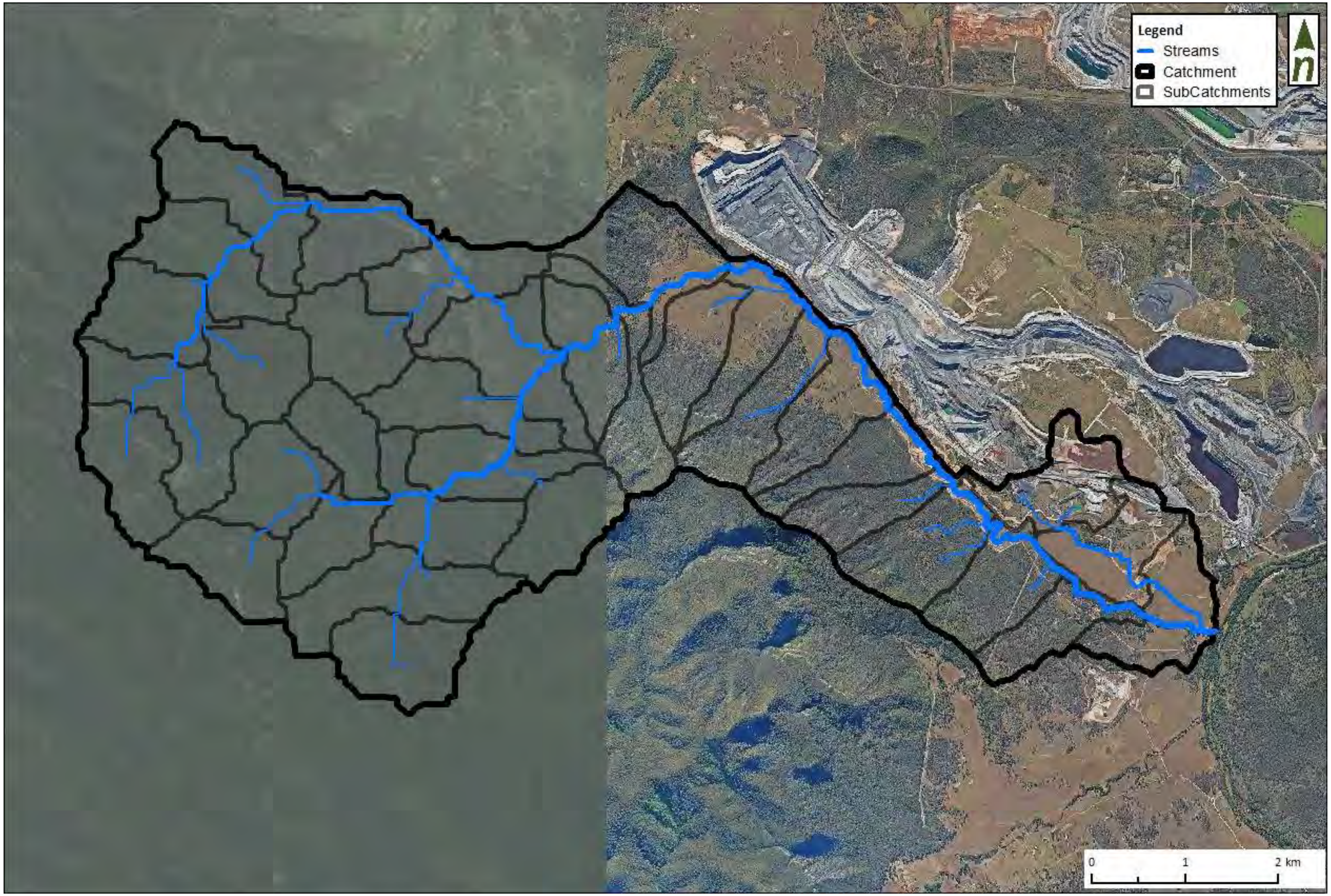

Figure B-0-1. North Wambo Creek catchment watercourse and features surrounding mine

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 use the Kleemola method.

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 takes the form:

$$k_c = 1.22 * Area^{0.46}$$

Table B-0-1, below, lists the Kleemola derived k_c values for existing conditions.

Table B-0-1. Calculated Kleemola value based on existing conditions scenario

Scenario	Catchment Area (km^2)	Kleemola k_c Value*
Existing Conditions	39.5	6.62

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

Other modelling parameters
These losses adopted for this study are presented in Table B-0-2.

Table B-0-2. Adopted model parameters for initial loss and continuing loss

Parameter	2yr to 100 year ARI	1000 year
Initial Loss	65.9mm	0mm
Continuing Loss	2.5mm/hr	1 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-0-3.

The 2 year to 100 year ARI design rainfalls were determined using the ARR method inbuilt in RORB (with site specific parameters determined from ARR (1987) Vol 2). The ARR (1987) Areal Reduction Factors (ARF) were used to convert the point rainfall estimates to areal estimates.

The 1000 year ARI design rainfall was derived by apply the updated Co-operative Research Centre Focussed Rainfall Growth Estimation (CRCFORGE) method detailed in Jordan et al. (2005). CRC Areal Reduction Factors (ARF) were used.

Table B-0-3. 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	11.8	23.8	26.7	37.1
30 min	16.5	32.3	36.2	51.9
1 hour	23.2	44.0	49.0	69.5
3 hours	35.5	69.8	78.1	110.2
6 hours	45.3	91.1	102.3	146.2
12 hours	57.2	117.9	132.8	194.1
18 hours	67.6	139.3	157.0	230.6
24 hours	75.3	155.3	175.0	(estimated) 260
48 hours	95.7	197.6	222.7	(estimated) 330

Temporal patterns

For events ranging from the 2 to 100 year ARI the ARR zone 1 temporal patterns were used.

A design temporal pattern suitable for the 1000 year ARI was derived from the 10 patterns provided in the Jordan et al. (2005) paper combined with the Bulletin 53 pattern from the Generalised Short Duration Method (GSDM) PMP BOM (2003). The resulting "Rare Design" temporal pattern is depicted in Figure B-0-2.

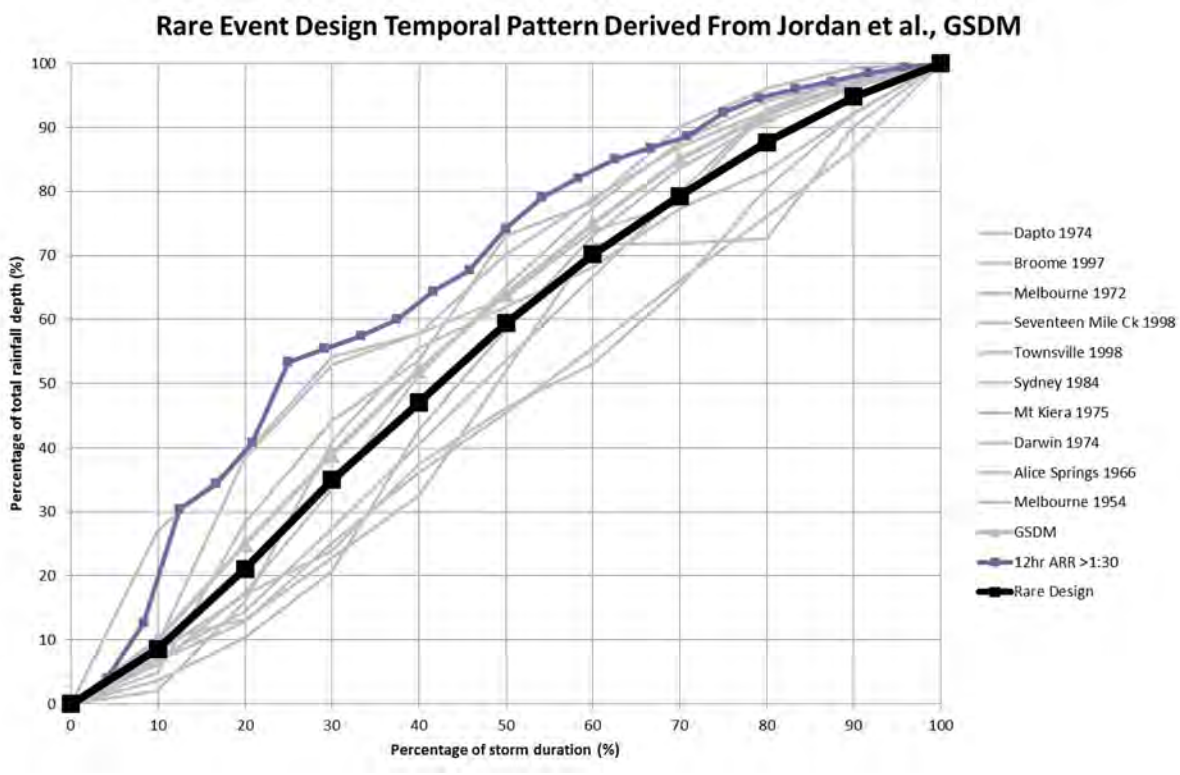

Figure B-0-2. Selection of the design temporal pattern for rare events

RORB model output flow

The RORB model outputs are presented in Table B-0-4. The output locations are shown in Figure B-0-1.

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 36 hour for the 2 year ARI event to as short as the 3 hour for the 1000 year ARI event, depending on location within the catchment.

Table B-0-4. Design discharges generated from hydrologic modelling of existing conditions

	Downstream of LW 13/14
Upstream catchment (km^2)	34
ARI/AEP	**Peak Discharge (m^3/s)**
2 year	10.5
50 year	57.6
100 year	75.4
1000 year	93

Attachment C
Hydrodynamic Modelling

Hydrodynamic modelling of South Bates Extension underground mine 17-20

Hydrodynamic modelling was undertaken to assess the flood behaviour in the area around the planned longwall panels (LWs 17 - 20).

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. See Figure C-0-1.

The model was configured using a 4m cell size. The extent of the model is shown in Figure C-0-1.

Manning's n roughness coefficient for the model was set by assessing aerial imagery and site photographs. A single 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-0-1 to represent inputs from both the catchments external to the area and runoff generated locally. The hydrodynamic model was tested with a series of storm durations for each event to confirm the critical duration(s) which generated the greatest flood extents.

A second model was developed to assess the impact of subsidence on overland flow. This model was configured the same as the first, with the exception that the hydrology was applied as direct rainfall (ie. rain on grid). The extent of this model is shown in Figure C-0-2.

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.

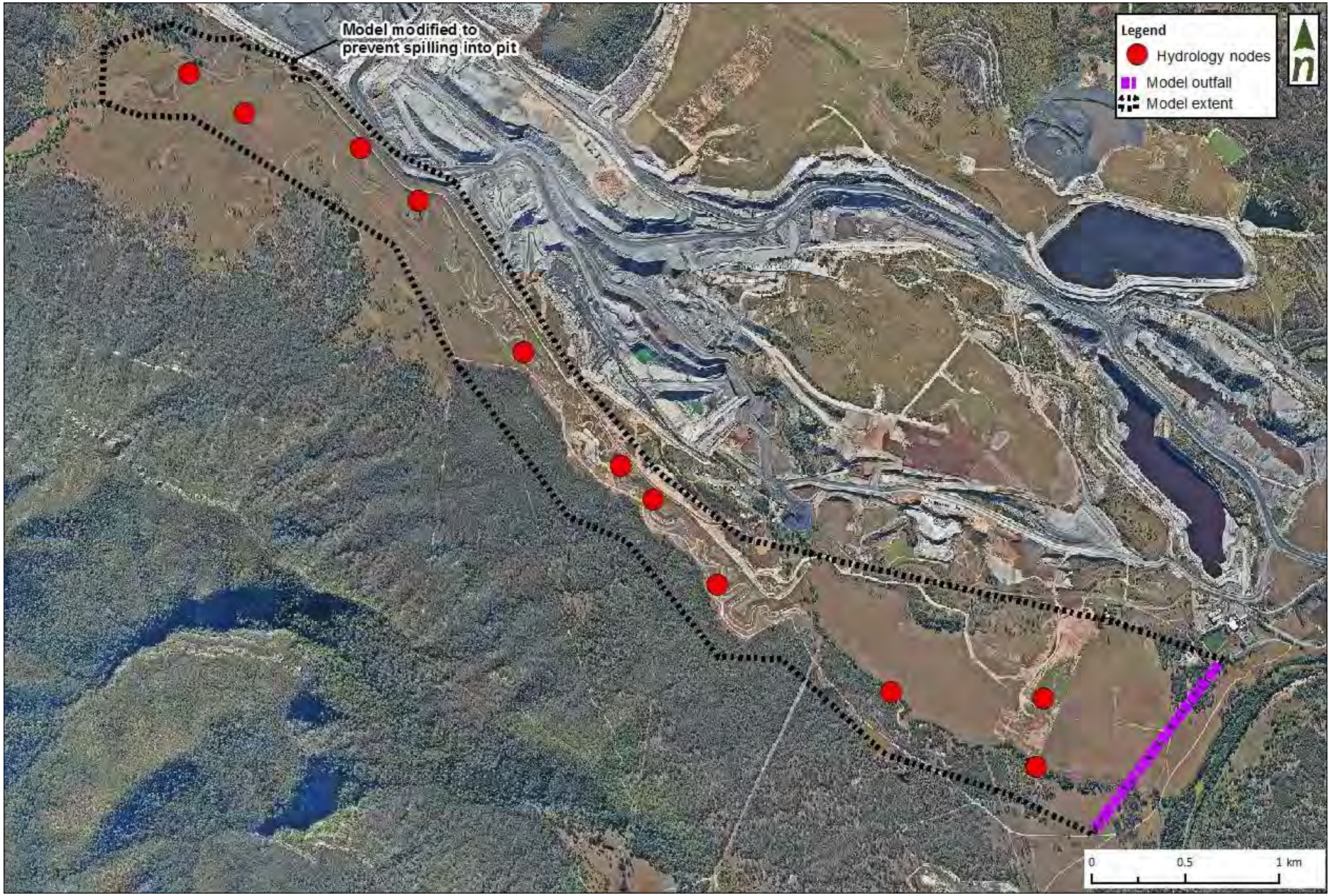

Figure C-0-1. **2D hydrodynamic 0.1% AEP model set up (existing conditions)**

Figure C-0-2. **2D hydrodynamic 0.1% AEP model set up (existing conditions)**

Attachment D
Batter Chutes

Hydrology

Streamflow estimates for flow entry points into the NWCD channel have been estimated using the Regional Flood Frequency Estimation Model (RFFEM). The RFFEM is a method developed by Dr Ataur Rahman and Dr Khaled Haddad from Western Sydney University for the draft 4th edition of Australian Rainfall and Runoff and is suitable for use in small, rural catchments. The post subsidence flow estimates are summarised in Table D-0- 1 and their locations shown on Figure D-0- 1.

Table D-0- 1. Predicted flows for flow paths over South Bates Extension post subsidence

Outlet ID	Location	Catchment area (km^2)	Discharge (m^3/s)					
			50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
1	LW19 flow entry point	0.039	0.26	0.61	0.95	1.38	2.12	2.83
2	LW18/LW19 predicted new flow entry point	0.282	0.78	1.8	2.82	4.1	6.29	8.39
3	LW17/LW18 predicted new flow entry point	0.87	1.47	3.39	5.31	7.72	11.8	15.8
4	LW17 predicted new flow entry point	0.48	1.14	2.62	4.09	5.96	9.15	12.2
5	LW17 predicted new minor flow entry point (existing dam outlet)	0.028	0.24	0.56	0.86	1.26	1.93	2.58

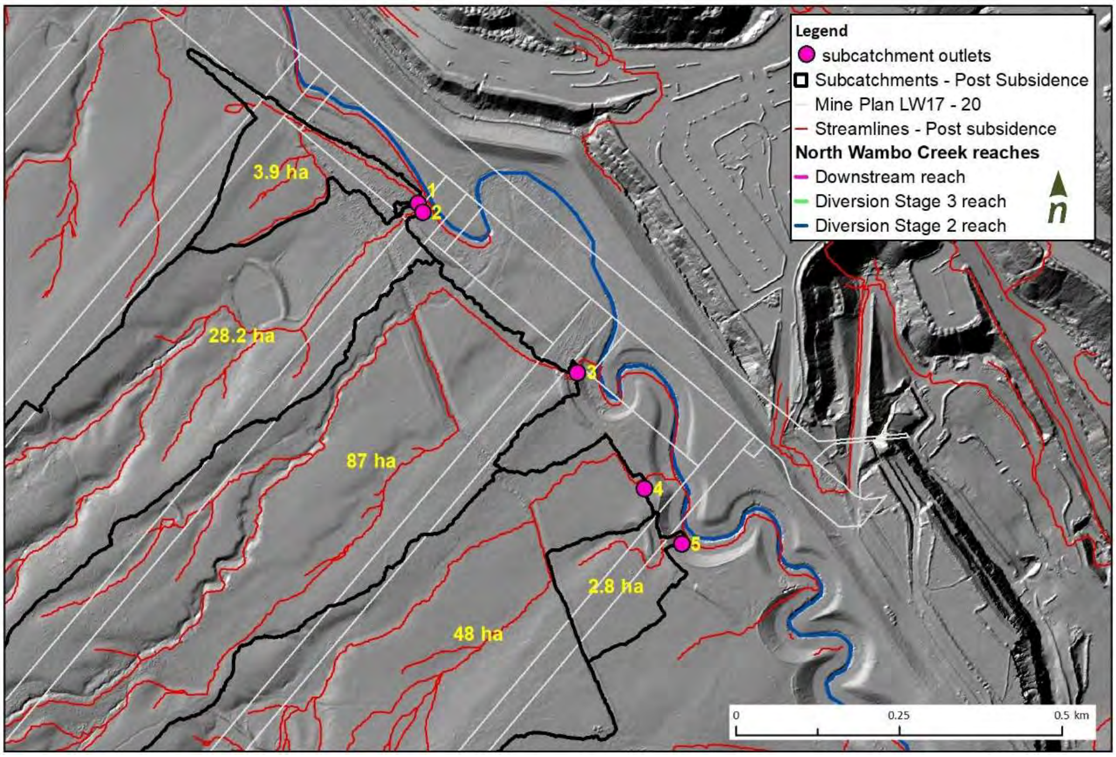

Figure D-0- 1. Post-subsidence flow paths and hydrology outlets over South Bates Extension Underground Panels

Post subsidence terrain analysis and recommendations

Based on the predicted flow paths, post subsidence of LWs 17-20, it is likely that batter chutes will be required at outlet locations 2, 3 and 4.

A rock chute is already present at outlet 1. This rock chute previously served the wider catchment area over LWs 17-20 so its reduced catchment will mean that no redesign of the rock chute is required. Flows from outlet 5 shall be directed to the rock chute at outlet 4 by the construction of a small diversion bund.

Concept design of batter chutes

LW19 Flow entry point (Outlet 1)

The location of the existing flow entry point for LW19 is shown in Figure D-0- 2.

Figure D-0- 2. Plan view showing approximate location of existing rock beaching at outlet 1

Figure D-0- 3. Rock beaching along existing outlet to NWCD (outlet 1)

Following subsidence of LW17 to LW20 the catchment area being drained via outlet 1 will decrease from 165ha to 3.9ha. It is for this reason and the fact that there are no observable signs of instabilities at outlet 1 that no works are recommended at this outlet location.

LW18/LW19 predicted new flow entry point (outlet 2)

The location of the proposed batter chute for panel catchment LW18/LW19 is shown in Figure D-0- 4.

Figure D-0- 4. Proposed location of LW18/LW19 batter chute

The 5% AEP peak flow of 4.1 m^3/s was adopted for the design of the batter drain.

The batter drain has been designed with an upper batter slope of 1V:4H and an abutment batter slope of 1V:2.5H, with an abutment height of 1m. Rock beaching is only required in the bed and on the abutment batter slope of the batter drain, with the remaining upper batter slope to be topsoiled (150mm thickness) and seeded. The design details for the batter drain are shown below in Table D-0- 2.

Table D-0- 2. Batter chute details

Element	Units	Outlet 2 Chute specs
Drain Length	m	45
Drain Drop	m	3
Crest length	m	1
Crest width	m	6
Apron length	m	10
Apron width	m	6
Size of rock	m	0.3
Volume of rock	m^3	619

Abutment protection height (min)	m	1
Abutment slope	m/m	1:5
Granular filter thickness	mm	50
Granular filter material size	mm	25
Volume of filter rock	m^3	42

LW17/LW18 predicted new flow entry point (Outlet 3)

The location of the proposed batter chute for panel catchment LW17/LW18 is shown in Figure D-0- 5.

Figure D-0- 5. Proposed location of LW17/LW18 batter chute

The 5% AEP peak flow of 7.7 m^3/s was adopted for the design of the batter drain.

The batter drain has been designed with an upper batter slope of 1V:4H and an abutment batter slope of 1V:2.5H, with an abutment height of 1m. Rock beaching is only required in the bed and on the abutment batter slope of the batter drain, with the remaining upper batter slope to be topsoiled (150mm thickness) and seeded. The design details for the batter drain are shown below in Table D-0- 3.

Table D-0- 3. Batter chute details

Element	Units	Outlet 3 Chute specs
Drain Length	m	120
Drain Drop	m	5.1
Crest length	m	1
Crest width	m	6
Apron length	m	10
Apron width	m	6
Size of rock	m	0.3
Volume of rock	m^3	1,421
Abutment protection height (min)	m	1
Abutment slope	m/m	1:5
Granular filter thickness	mm	50
Granular filter material size	mm	25
Volume of filter rock	m^3	102

Figure D-0- 6. NWCD at base of proposed batter chute location

LW17 predicted new flow entry point (Outlet 4)

The location of the proposed batter chute for panel catchment LW17 is shown in Figure D-0- 7.

Figure D-0- 7. Proposed location of LW17 batter chute

Figure D-0- 8. In channel of NWCD near proposed batter chute location

The combined 5% AEP peak flow for outlets 4(5.96 m^3/s) and 5(1.26 m^3/s) was adopted for the design of the batter drain, 7.22 m^3/s.

The batter drain has been designed with an upper batter slope of 1V:4H and an abutment batter slope of 1V:2.5H, with an abutment height of 1m. Rock beaching is only required in the bed and on the abutment batter slope of the batter drain, with the remaining upper batter slope to be topsoiled (150mm thickness) and seeded. The design details for the batter drain are shown below in Table D-0- 4.

Table D-0- 4. Batter chute details

Element	Units	Outlet 4 Chute specs
Drain Length	m	150
Drain Drop	m	7.5
Crest length	m	1
Crest width	m	6
Apron length	m	10
Apron width	m	6
Size of rock	m	0.35
Volume of rock	m^3	1,430
Abutment protection height (min)	m	1
Abutment slope	m/m	1:5
Granular filter thickness	mm	50
Granular filter material size	mm	25
Volume of filter rock	m^3	100

Attachment E
North Wambo Creek – Baseline assessment geomorphic context statement

alluvium

REPORT:

North Wambo Creek – Baseline assessment geomorphic context statement

February 2018

Document history

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1 Introduction

This report provides a qualitative and quantitative geomorphic assessment of North Wambo Creek above the future South Bates Extension Underground Mine. This geomorphic context statement forms part of a baseline condition assessment of the watercourse character, behaviour and condition trajectory. This report addresses the requirements of Condition 33A (b) and (c), Schedule 4 of the Development Consent DA 305-7-2003.

North Wambo Creek forms at the confluence of its two tributaries, Spring Creek and Chalkers Creek (see Figure 1). Further downstream, North Wambo Creek has been subject to diversion around the open cut operations by construction of a new channel in several stages. This diversion makes up approximately 5.8km of the remaining 7.3km before its confluence with Wollombi Brook (see Figure 1).

The assessment has been completed based on review of aerial photography and LiDAR flown May 2017 and a site inspection completed on 22 February 2018.

The waterway system was very dry at the time of assessment with no residual pools and dry alluvials, including Wombat burrows in the bed of the waterways where sandy silt. This may be an indication that much of the transport of rainfall from the ranges is via infiltration and sub-surface flow, typical of much of the region with similar geologic conditions.

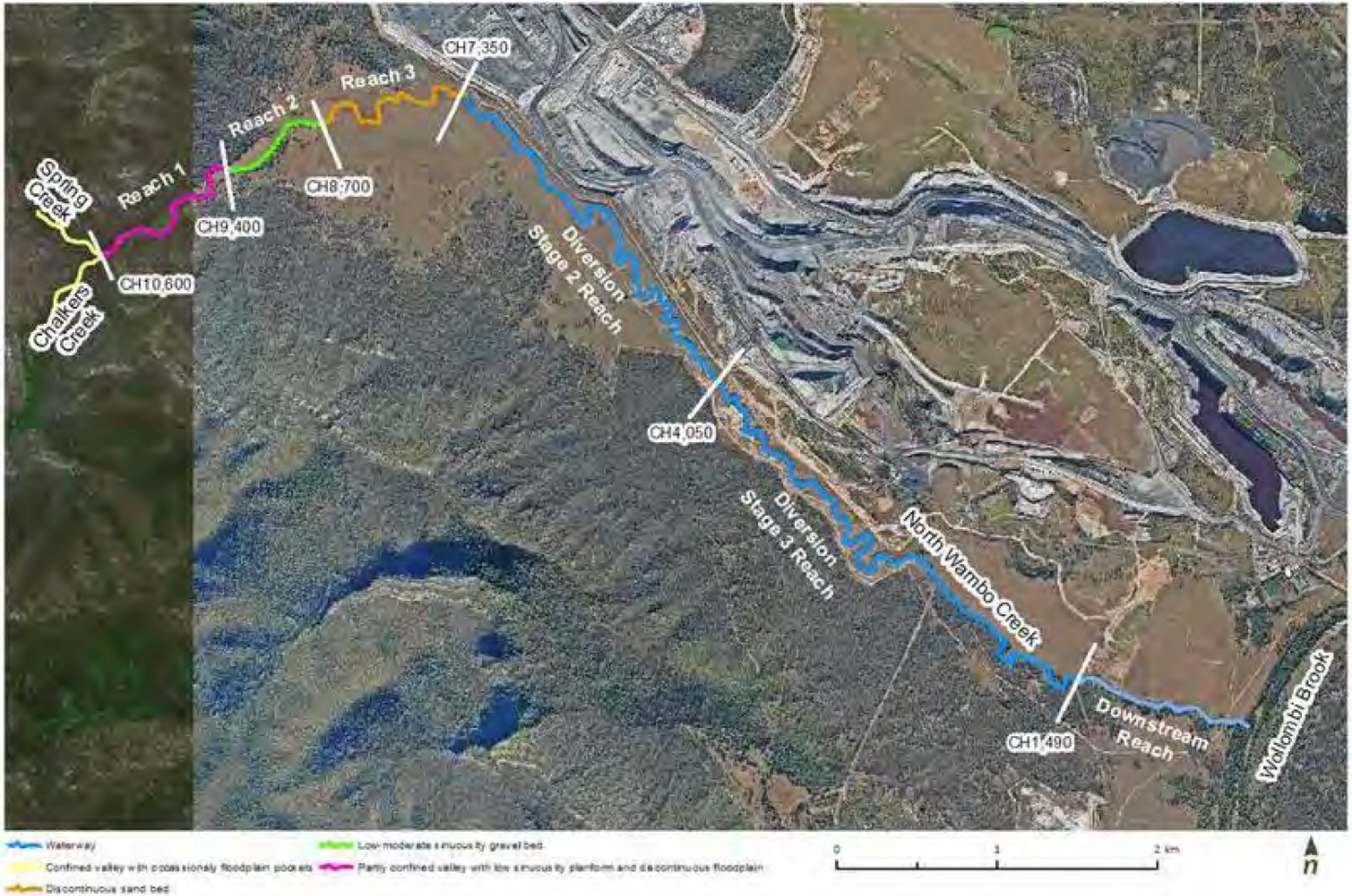

Figure 1 - extents of North Wambo Creek (Wollombi Brook, bottom right)

2 Geomorphic assessment

2.1 Qualitative assessment – River Styles

The reaches of North Wambo Creek above the future South Bates Extension Underground Mine and its upstream tributaries Spring and Chalkers Creeks have been categorised in accordance with the River Styles Framework (Brierely and Fryirs, 2002) that has been widely utilised in NSW in the past. The author of this report is an accredited River Styler.

The Spring and Chalkers Creek tributaries originate in the dissected sandstone capped ranges to the east 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.

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 a number of 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 reaches 2 and 3, they have infilled and exhibit very little fluvial bed form activity. They appear to be returning to a discontinuous alluvial form, inset below the former surface. Each of the reaches is assessed in more detail below. A River Styles assessment of the extents assessed is provided in Figure 2.

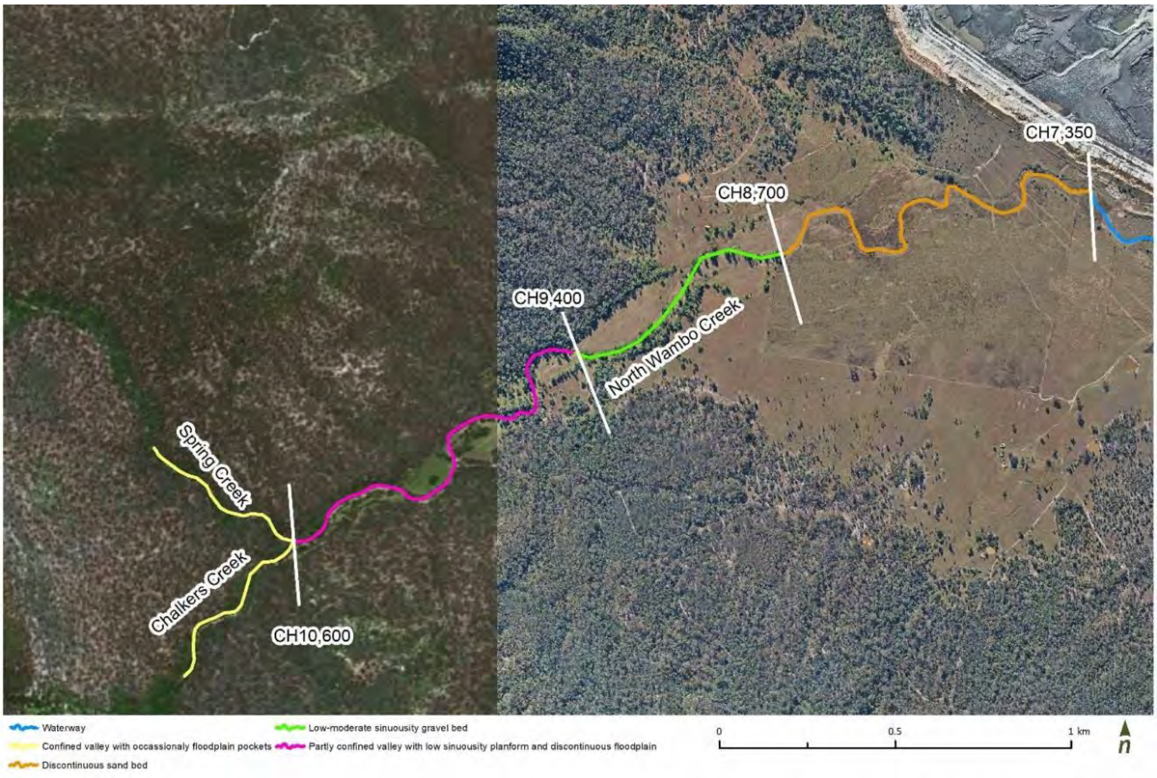

Figure 2 - River Styles overview

2.2 Quantitative assessment

Energy conditions in each of the reaches has been assessed to inform the broader assessment and likely future trajectory of the geomorphic character, behaviour and condition of the waterway. Parameters for 2 year and 50 year ARI events for Stream Power, Shear Stress and Velocity are provided. For perspective they are assessed against well-established criteria for design of stable alluvial constructed watercourse diversion channels (Alluvium, 2015) in Table 1. The steep bedrock controlled Reach 1 and Spring and Chalkers Creeks all exhibit high energy conditions. This is consistent with their longitudinal grade (see Figure 3) and narrow valley floors, river style, the presence of bedrock and boulders and limited presence of fine alluvial deposits in the valley floor. The decreasing energy conditions in Reaches 2 and 3 is consistent with their alluvial character, lower gradient and broad cross section.

Flow estimates utilised in this modelling are from previous studies undertaken by Alluvium for Wambo Coal. Those flow estimates are under review based on improved geomorphological understanding of the catchment conditions which indicated that initial losses and continuing losses may be at the higher end of Australian Rainfall and Runoff recommendations for the area. It is likely that flow estimates for a given event will decrease, meaning the energy conditions reported here may be higher than actual for those events.

Table 1 - 1D hydraulic model results

Parameter	Units	ARI	Diversion criteria (Alluvium, 2015)	Reach average hydraulic parameters							
				Chalkers Creek	**Spring Creek**	**Reach 1**	**Reach 2**	**Reach 3**	**Diversion Stage 2**	**Diversion Stage 3**	**Downstream**
Shear Stress	N/m^2	2 year	<40	**85.3**	**84.9**	**75.2**	35.0	30.4	29.6	**50.4**	37.5
		50 year	<80	**127.9**	**113.7**	**104.7**	72.9	40.6	43.8	68.0	68.4
Stream Power	N/m.s	2 year	35-60	**213.4**	**208.3**	**179.0**	58.4	49.3	57.6	**106.7**	74.8
		50 year	80-150	**437.8**	**364.1**	**326.9**	**192.0**	87.0	107.2	**173.9**	195.7
Velocity	m/s	2 year	no vegetation <1.0 with vegetation<1.5	**2.5**	**2.5**	**2.3**	1.4	1.3	1.2	**1.9**	1.1
		50 year	<2.5	**3.4**	**3.1**	**3.0**	2.3	1.7	1.8	2.3	1.7

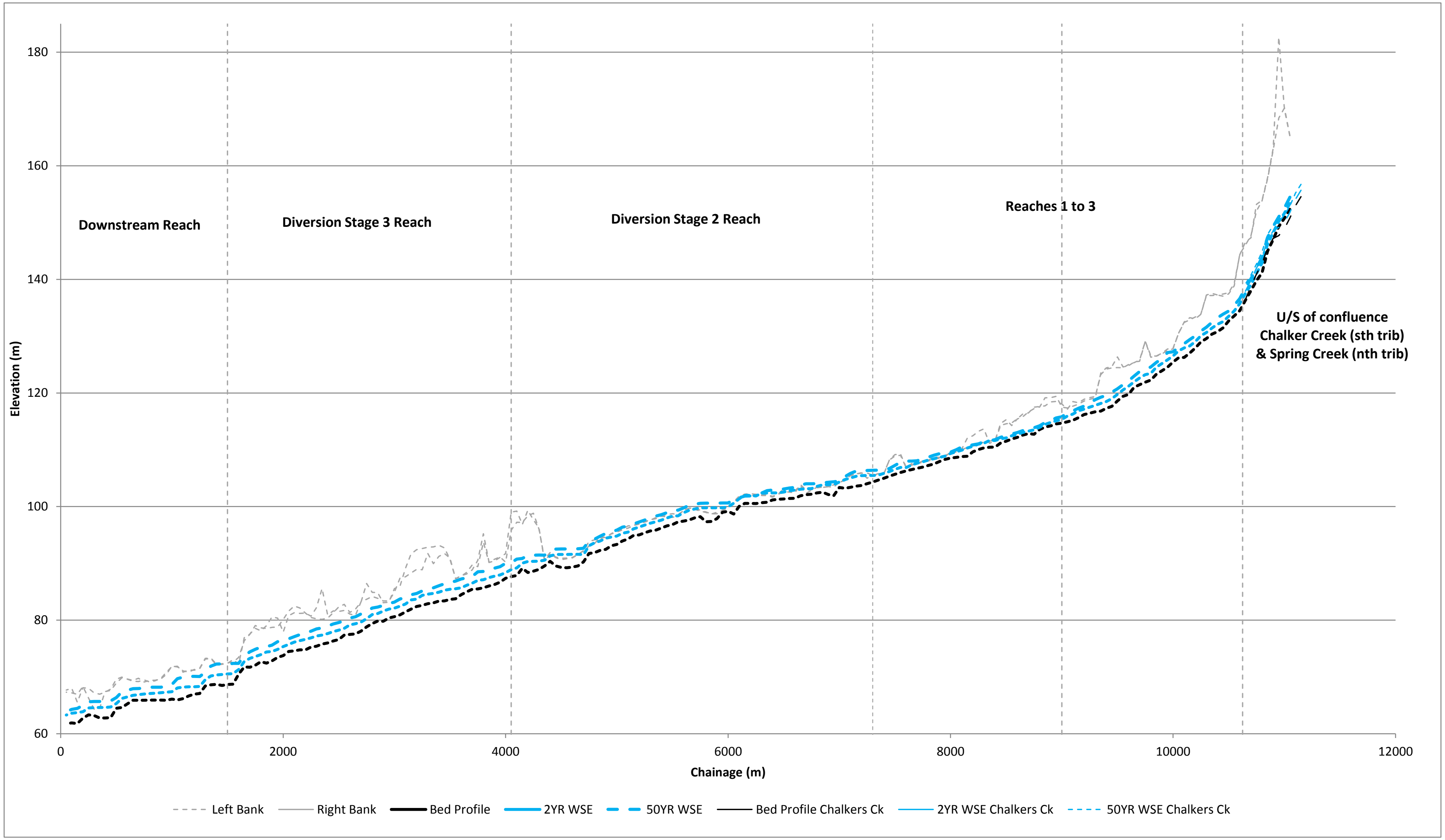

Figure 3 - longitudinal profile

2.3 Reach 1

This reach extends from the confluence of Spring and Chalkers Creek downstream to where the hillslopes cease to be the margin of the floodplain/valley. This largely corresponds with extents of clearing. Through the reach, floodplain pockets are cleared, while the immediate riparian strip remains (or has regenerated) and the steep valley sides are uncleared.

The reach is categorised as a partly confined low to moderate sinuosity planform with discontinuous floodplain. The channel planform is partly dictated by the planform of the valley with the channel alternating from side to side in a low to moderate sinuosity single channel pattern. The presence of in situ bedrock or large conglomerate boulders provides considerable controls over the horizontal alignment and minimises potential for any channel incision. The channel cross section generally consists of a simple asymmetric profile with a steeper outside of bend bank and shallower (sometimes stepped) inside of bend. Floodplain pockets are up to 40m wide on the inside of bends, generally consisting of fine sands and would be prone to reworking in out of channel flow events.

Mobile bed sediment in the reach is dominated by cobbles and gravels, fining quickly downstream through the reach to gravels. Bedforms are generally cobble riffles and gravelly runs. These are punctuated by boulder bars. Scour pools on bends are of shallow depth and generally infilled with coarse bed sediment. Finer sediments in the floodplain pockets are subject to some bank erosion where meander migration is occurring though this is not prevalent.

A typical view of this reach is shown in Figure 4, an overview of the reach and further examples in Figure 5 and a cross section plot with the 2 year flow event (near bank full) shown in channel in Figure 6.

Figure 4 - typical Reach 1 configuration

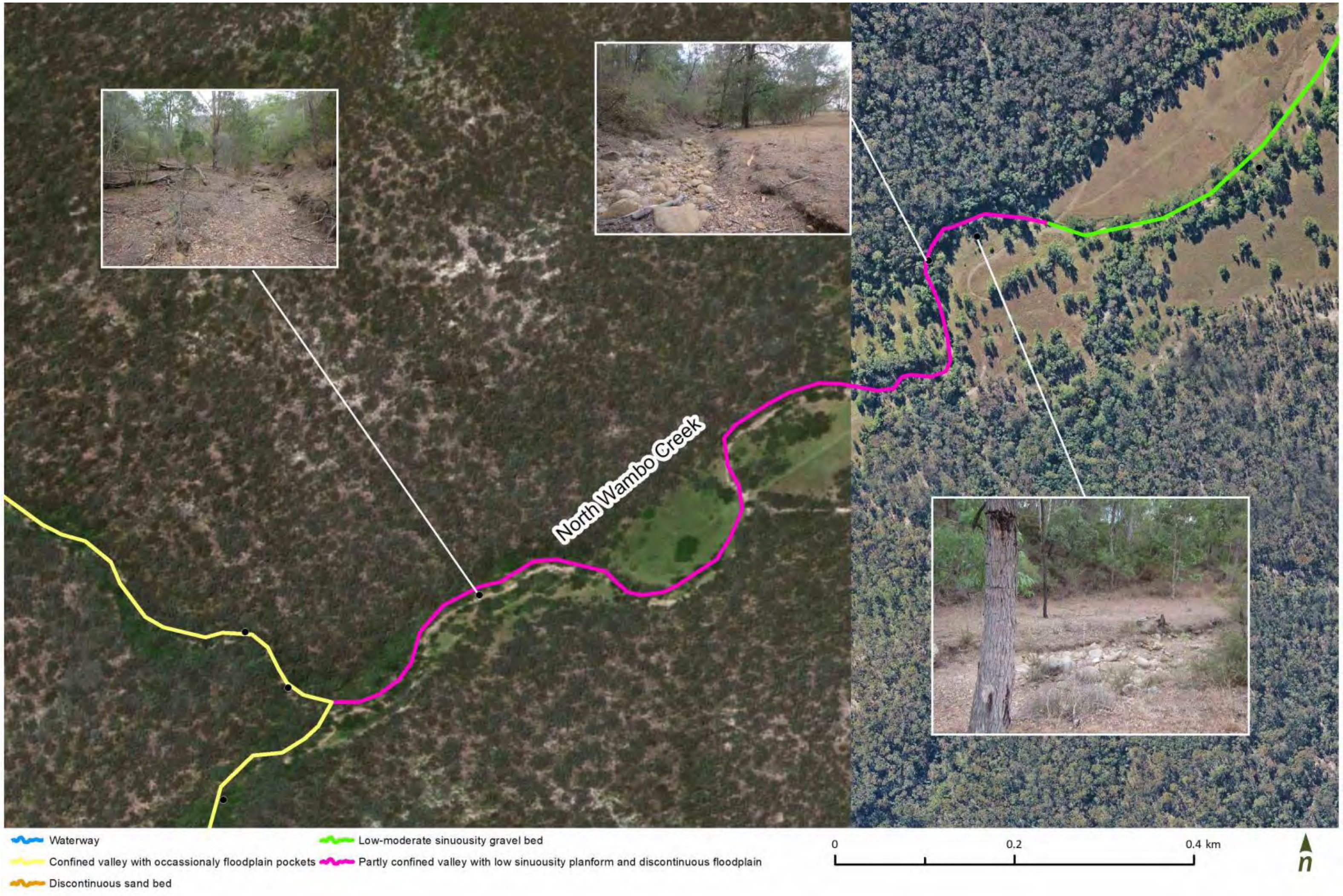

Figure 5 - Reach 1 overview

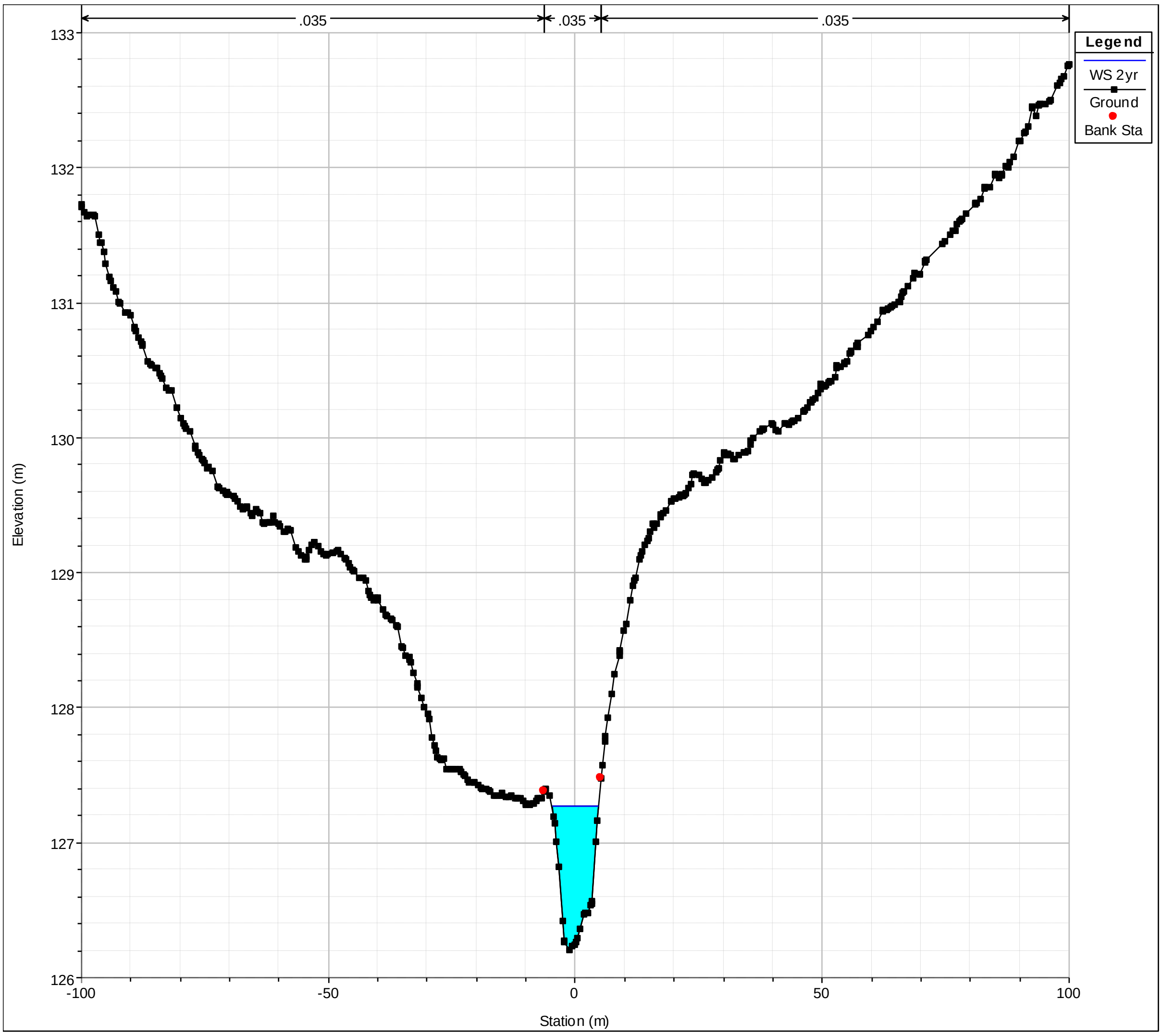

Figure 6 - Typical cross section and 2 year ARI water surface, reach 1

2.4 Reach 2

Reach 2 extends from the retreat of the hillslope margins, which are replaced by a colluvial/alluvial terrace that bounds the floodplain. The reach boundary between reaches 2 and 3 corresponds with the downstream extent of any trees in the waterway. Reach 2 has the appearance of being highly altered by past farming practices, changing both the physical form and vegetation characteristics. Presently there is a gravel bed that is barely below the level of the floodplain, meaning the whole floodplain acts as the channel in most flows.

The reach is categorised as low sinuosity gravel bed. However the reach is infilling and becoming more like a coarse grained valley fill. It has limited morphological diversity in cross or long section within the reach and none of the typical riffle-run-pool sequences that this river style normally possesses. This highlights that past land use has altered the behaviour and the watercourse is currently on a recovery trajectory, potentially to a different form, more like that of the Reach 3. It may also highlight climatic conditions which have resulted in a period of very low flows. It may also point to the alluvial aquifer being dry and that saturation of that aquifer absorbs most smaller runoff events from the ranges, with only very high intensity rainfall generating surficial flows.

Figure 7 - typical views in Reach 2 of gravel bed barely below broader floodplain

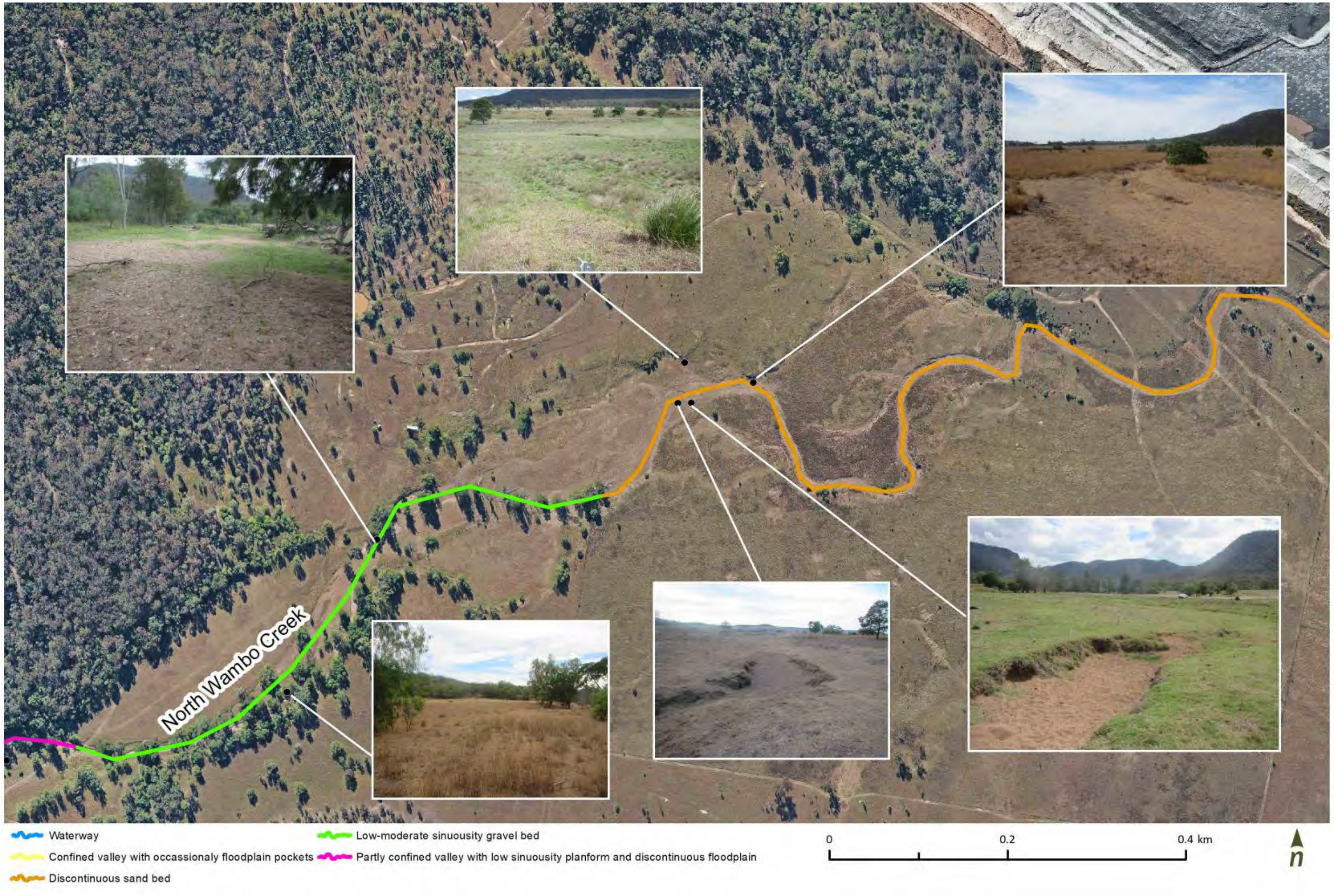

Figure 8 - reaches 2 and 3 overview

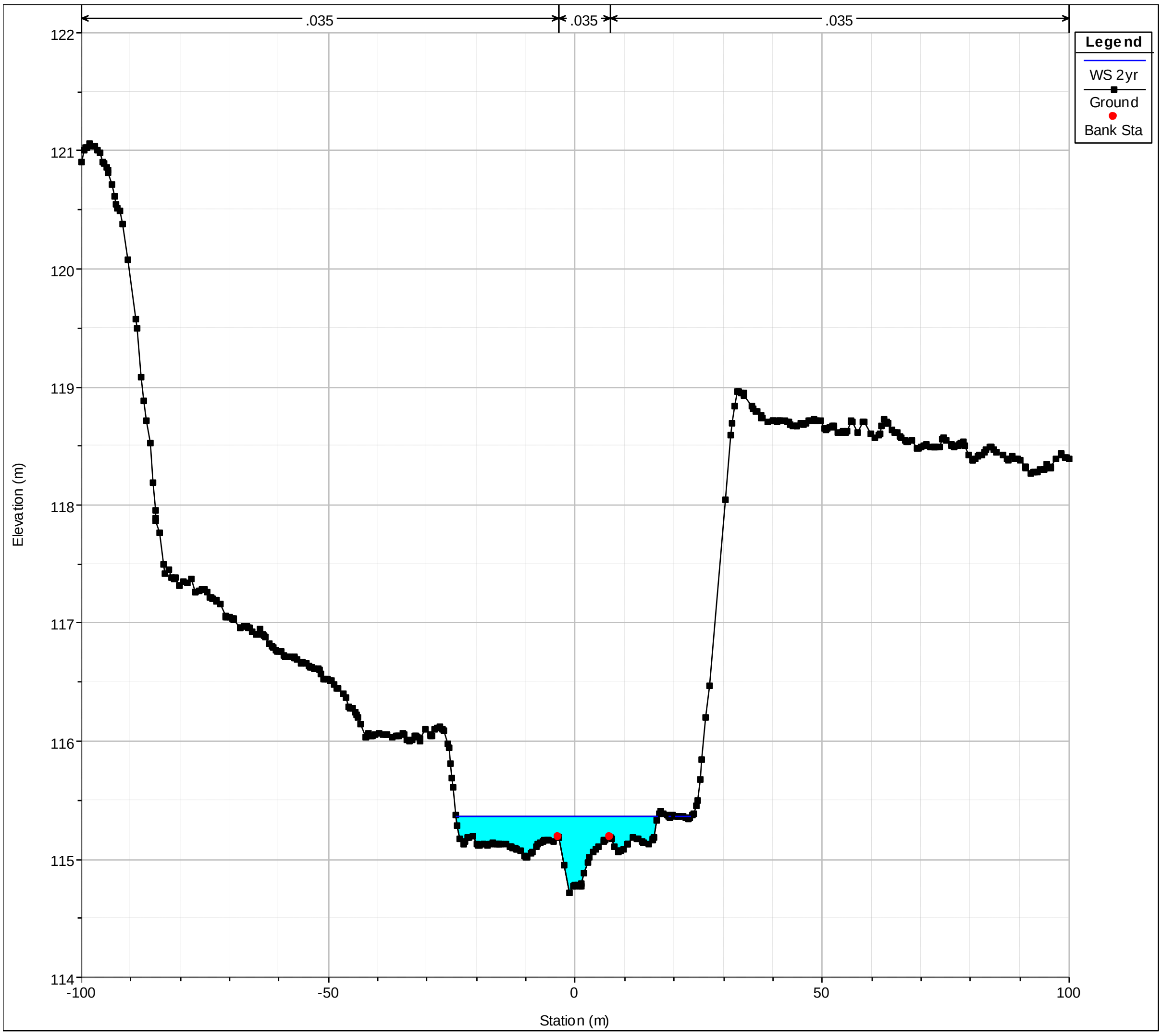

Figure 9 - Typical cross section and 2 year ARI water surface, reach 2

2.1 Reach 3

With a widening of the floodplain and decrease in longitudinal gradient, the ability to transport gravels diminishes and the River Style transitions to a discontinuous sand bed in Reach 3. Like Reach 2, this reach is also recovering from past land use influences and is infilling due to many of the same reasons. There is little evidence of active fluvial bed forms other than a few scour pools (dry) along the reach.

Figure 10 - typical Reach 3 conditions and wombat hole in dry alluvial scour

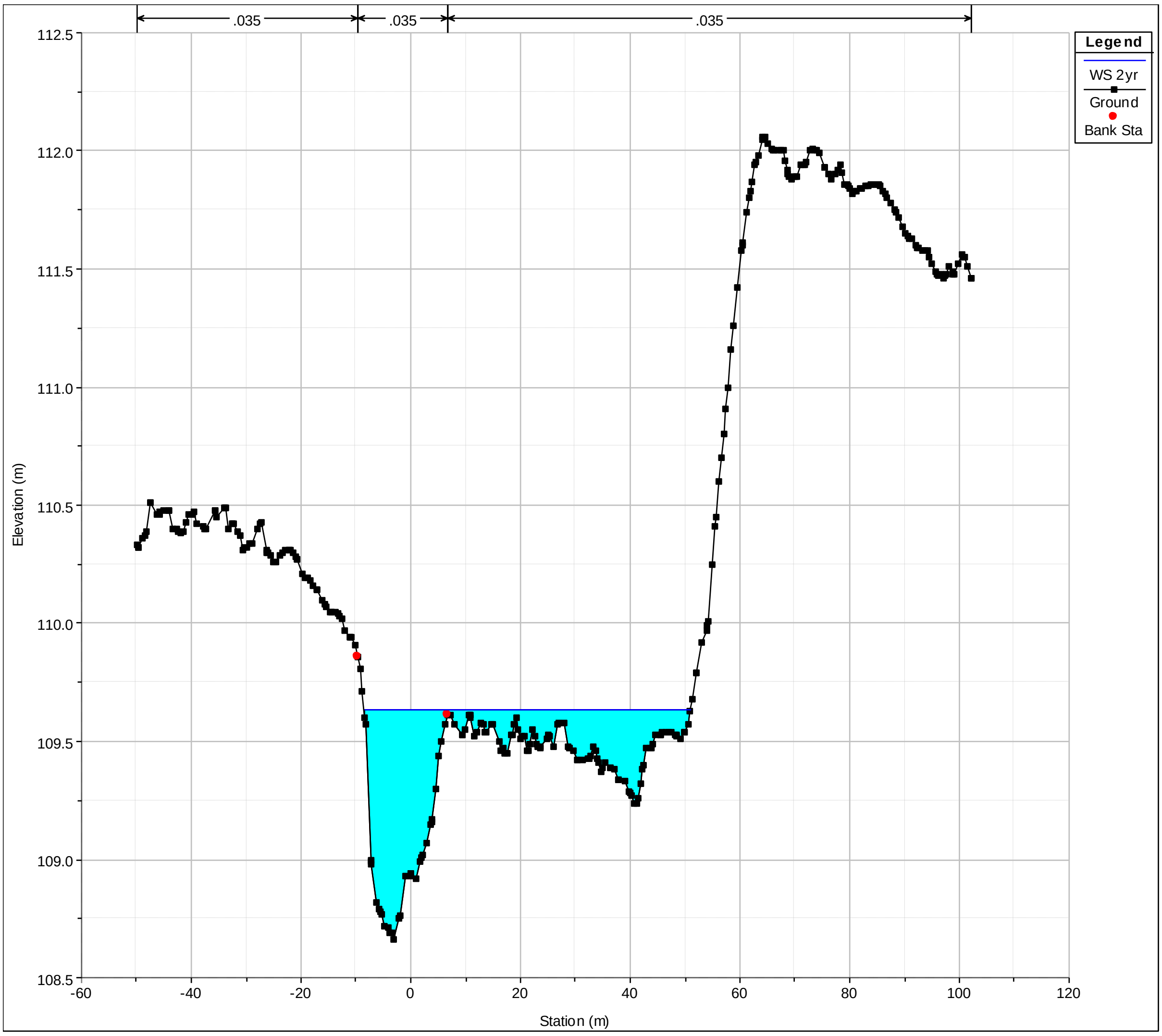

Figure 11 - Typical cross section and 2 year ARI water surface, reach 3

2.2 Spring Creek

Spring Creek is categorised as Confined with occasional floodplain pockets. The waterway is steep and has steps over boulder cascades. Vertical and horizontal bedrock controls are prevalent as are conglomerate boulders that are larger than the waterway has the capacity to transport. The potential for physical adjustment in this watercourse is limited.

Figure 12 - A typical straight section (top photo) and a boulder cascade (bottom photo)

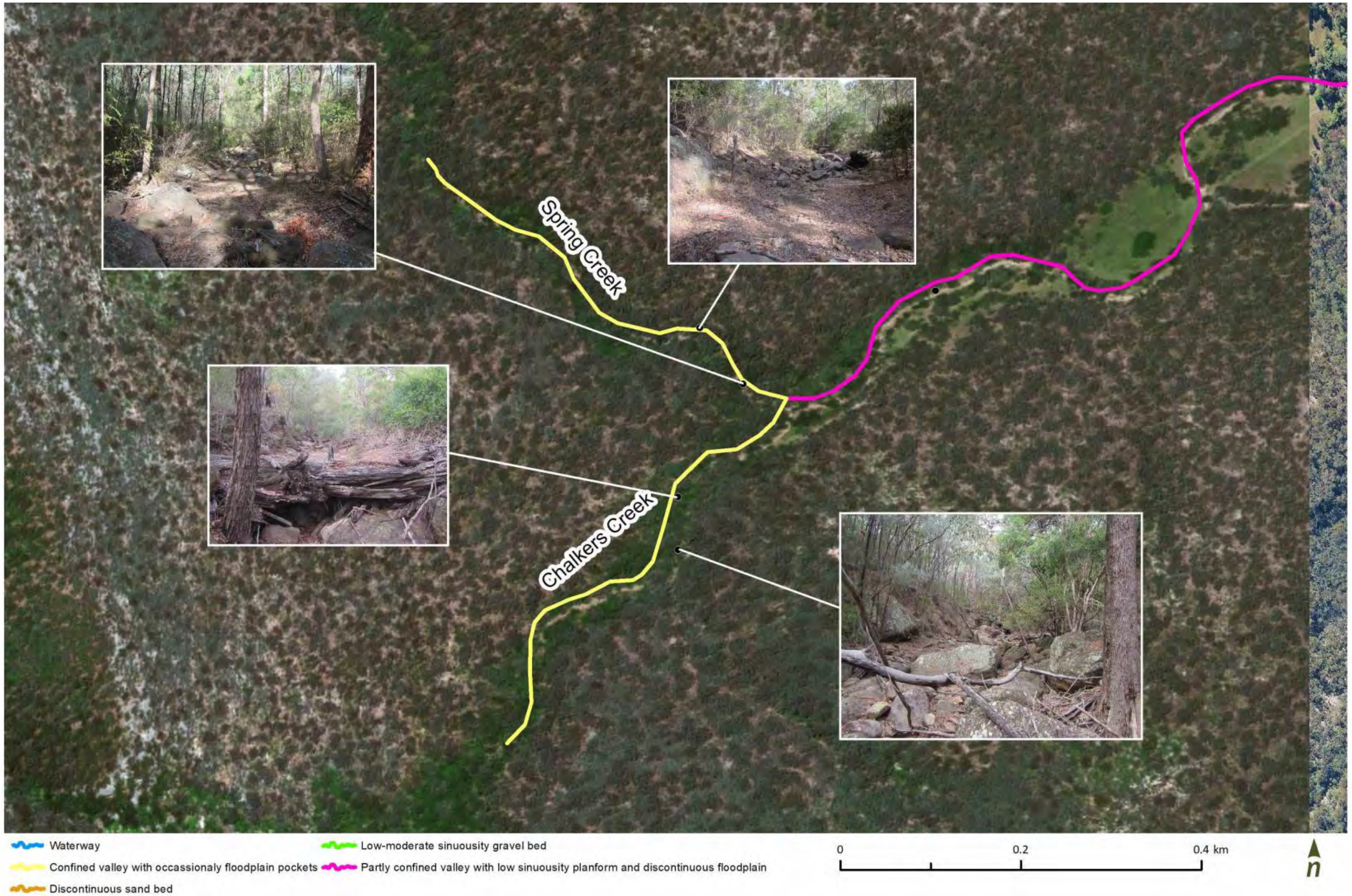

Figure 13 – Spring Creek and Chalkers Creek overview

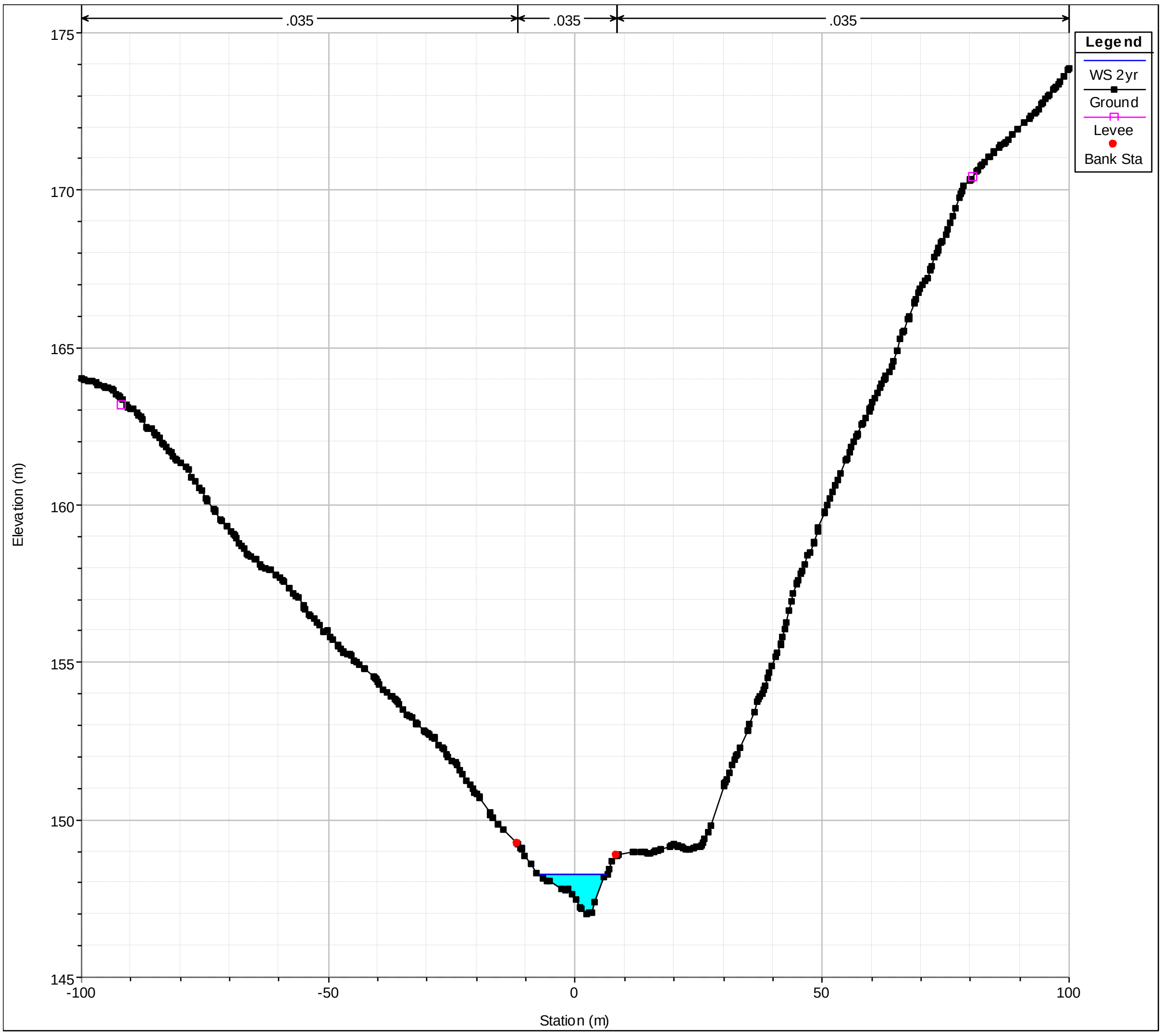

Figure 14 - Typical cross section and 2 year ARI water surface, Spring Creek

2.3 Chalkers Creek

Chalkers Creek is also categorised as Confined with occasional floodplain pockets. It varies from Spring Creek with a slightly broader valley floor which allows for greater fine grained colluvial and alluvial deposits at base of slope (Figure 15).

Figure 15 - Typical Chalkers Creek near confluence with Spring Creek

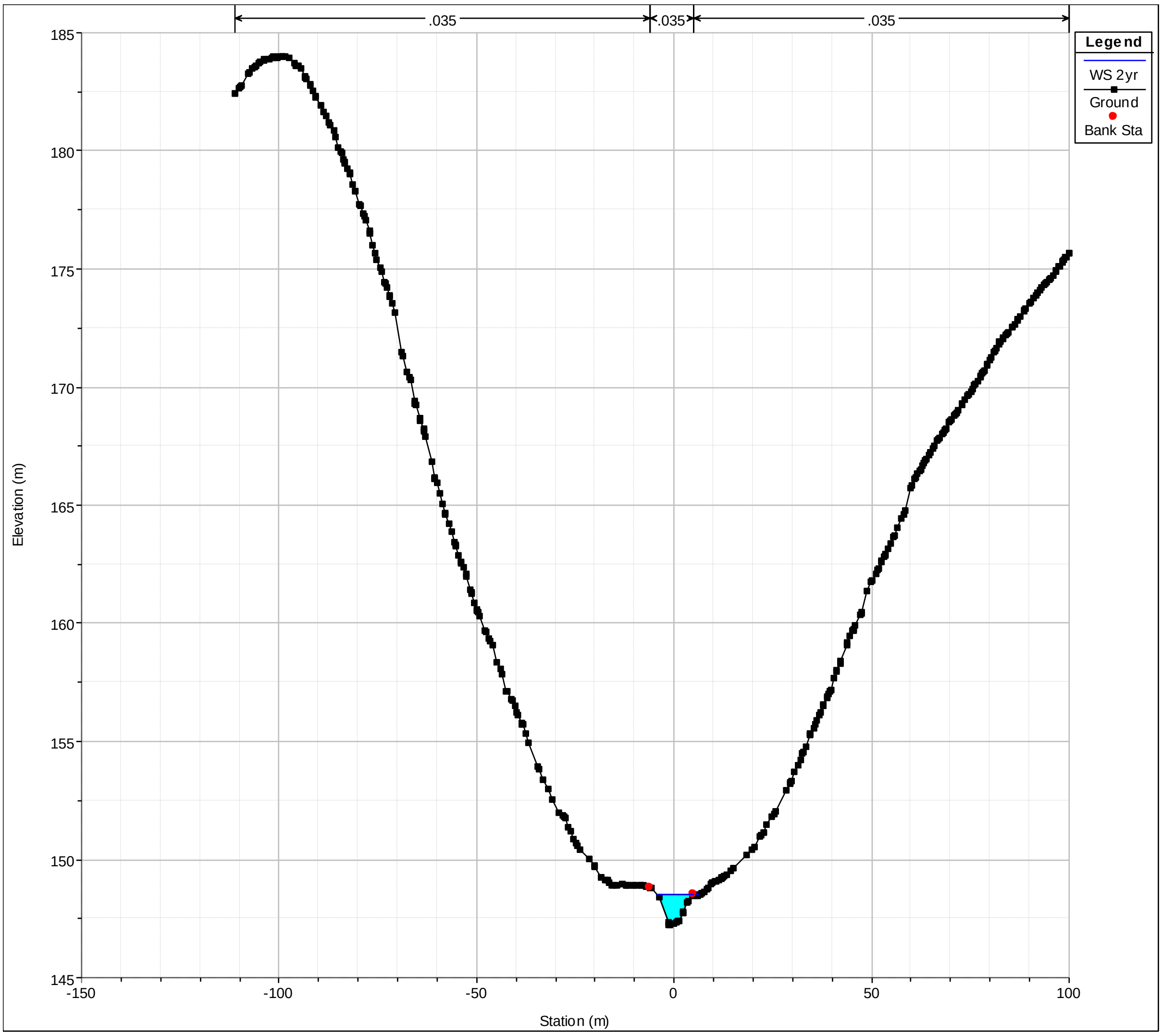

Figure 16 - Typical cross section and 2 year ARI water surface, Chalkers Creek

3 References

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Brierely, G. and Fryirs, K., 2002. *The River Styles Framework*. Macquarie University.