SARAJI EAST MINING LEASE PROJECT

Environmental Impact Statement

Appendix B-2

Subsidence Modelling Report

BMA

BHP Mitsubishi Alliance



Subsidence over Longwall Panels
Saraji East Underground Mine

April 2022

prepared for

AECOM Australia Pty Ltd

Minserve

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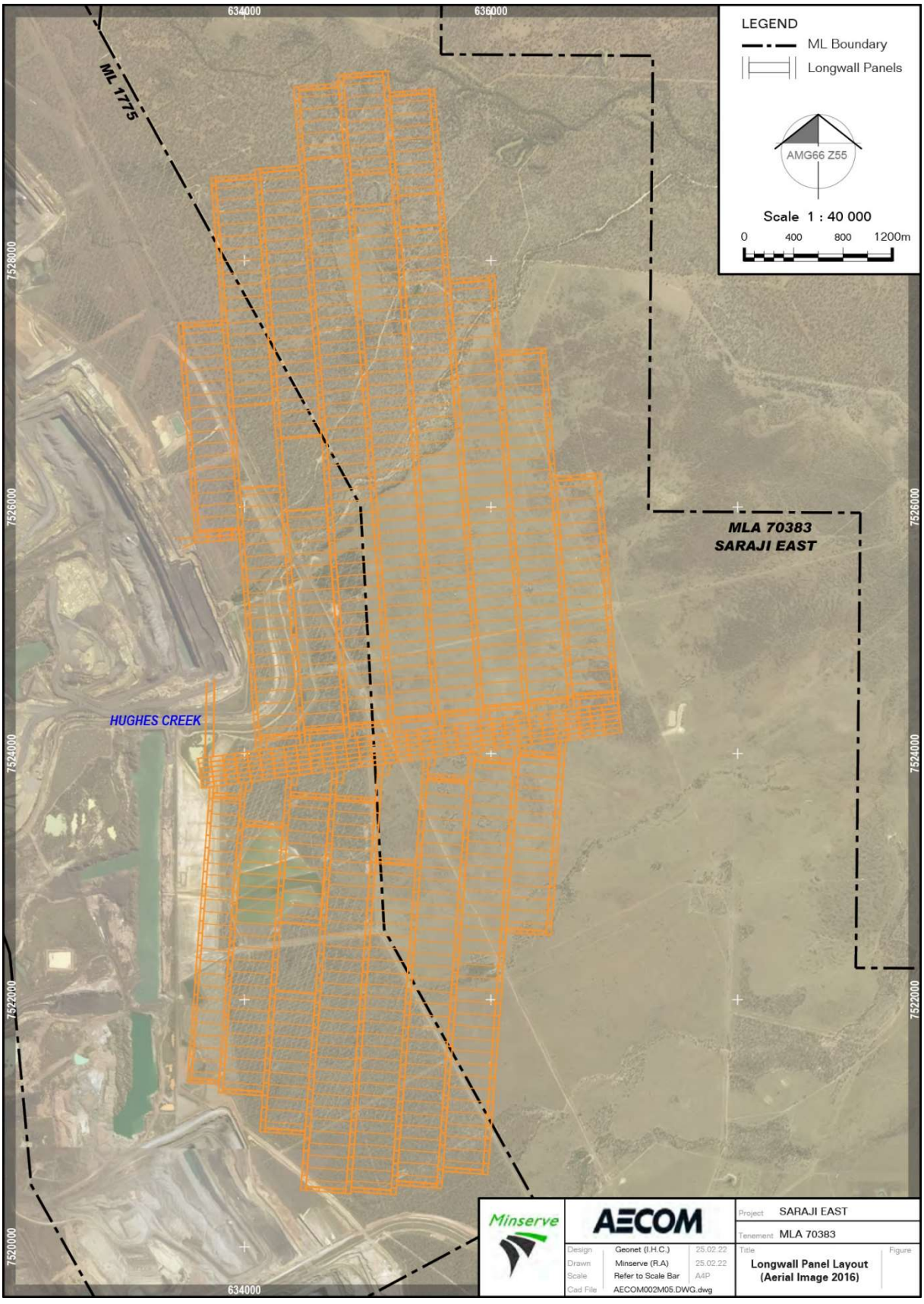
Geonet Consulting Report, April 2022: Subsidence over Longwall Panels

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- To predict the extent and magnitude of surface subsidence following successive stages of longwall panel excavation using conventional mining methods to a uniform 3.6m cut-height. Changes in surface elevation are to be presented for each of the following stages of the mining schedule, viz. Years 2025, 2026, 2028, 2032 and 2042, to establish the post-mining topography at that period.
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- To provide estimates of rockmass hydraulic properties as input for subsequent groundwater studies by assessing the altered geotechnical condition associated with deformation accompanying rock fracture and bedding plane separation.

Figure 1 — Longwall Panel Layout



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    - Subsidence contours in overburden rockmass on selected E-W cross-sections
    - Profiles of surface subsidence across each selected E-W cross-section
    - Profiles of surface subsidence along centerline of each mined longwall
- Predicted subsidence and altered topography for the scheduled years are presented in the Figures included in the following pages.
- There is significantly more subsidence induced over the southern panel compared with the northern panel. This can be attributed to the thickness of Dysart seam overburden. It is observed that subsidence in excess of 2.25m correlates directly with 250m contour.
- The fully extracted longwalls in southern panel are predicted to show maximum surface subsidence in the range 2.0m to 3.4m over all longwalls except LW208 where the overburden thickness exceeds 300m thus limiting subsidence to 1.4m.
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- Depending on the dimensions of the barrier pillar and thickness of overburden, subsidence is predicted to vary across their length from 0m and 0.5m.
- Surface subsidence over the Mains will be about 0.2m.

Figure 2 — Surface Subsidence Contours – Year 2 Schedule 2025

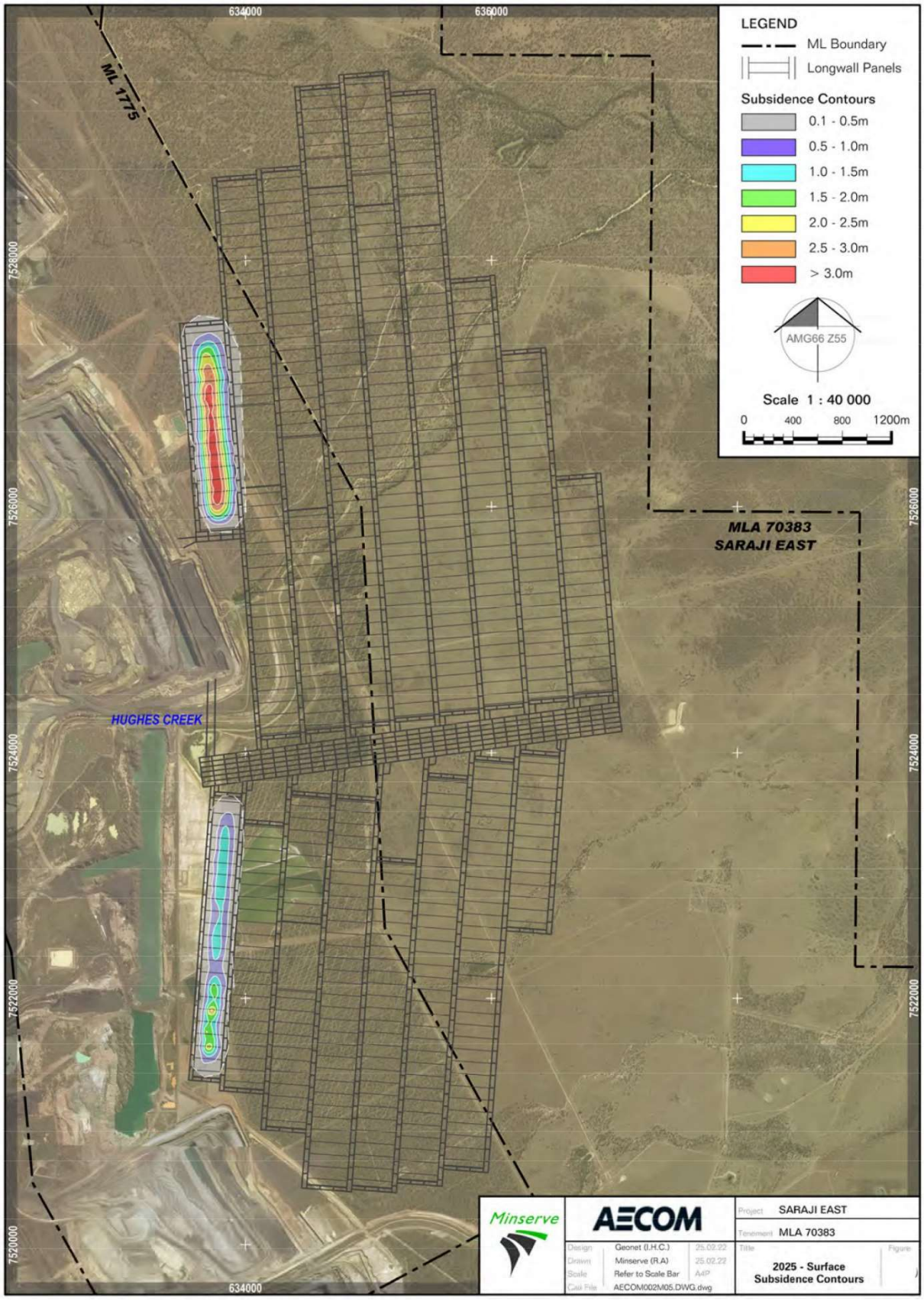


Figure 3 — Surface Subsidence Contours – Year 3 Schedule 2026

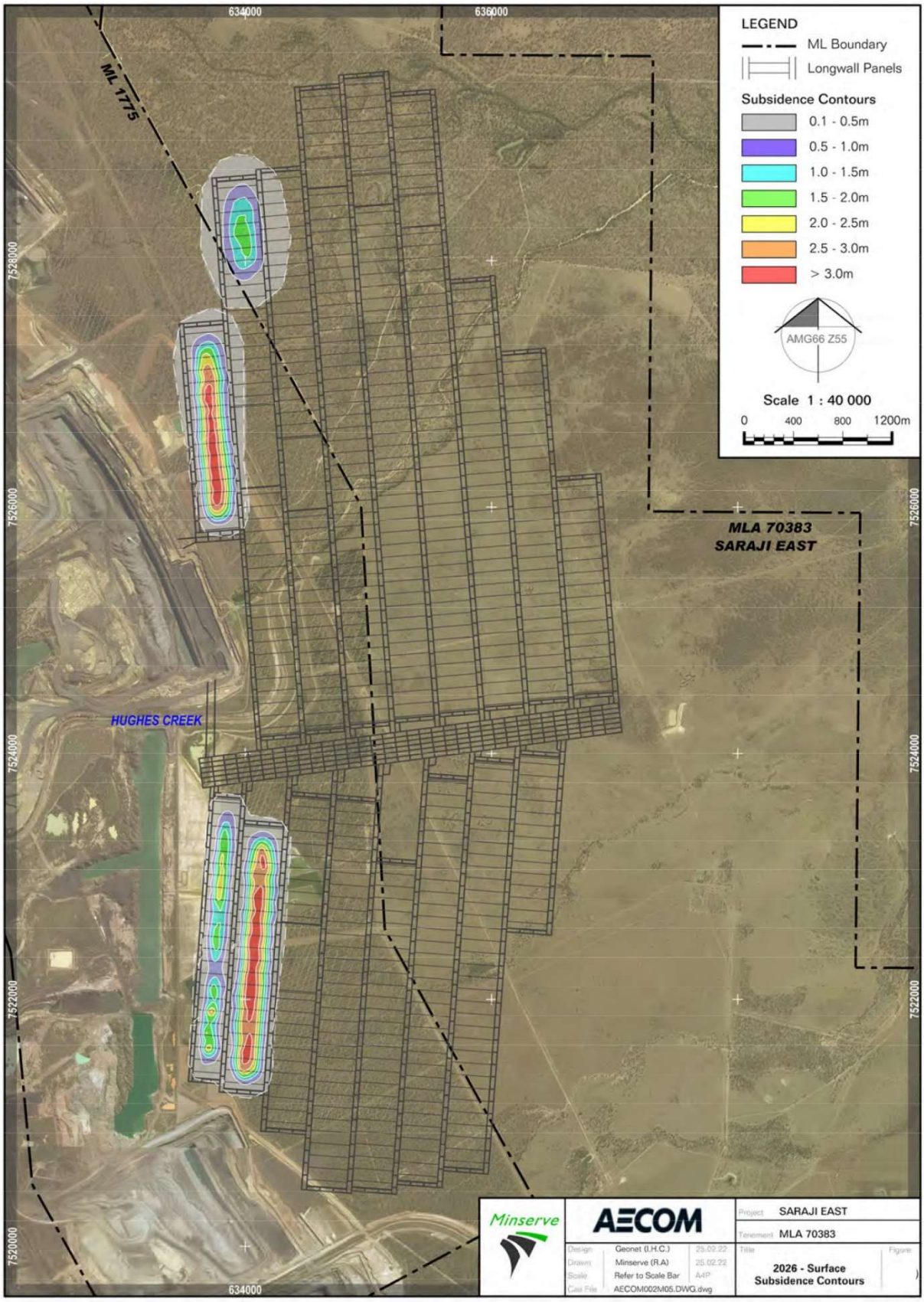


Figure 4 — Surface Subsidence Contours – Year 6 Schedule 2028

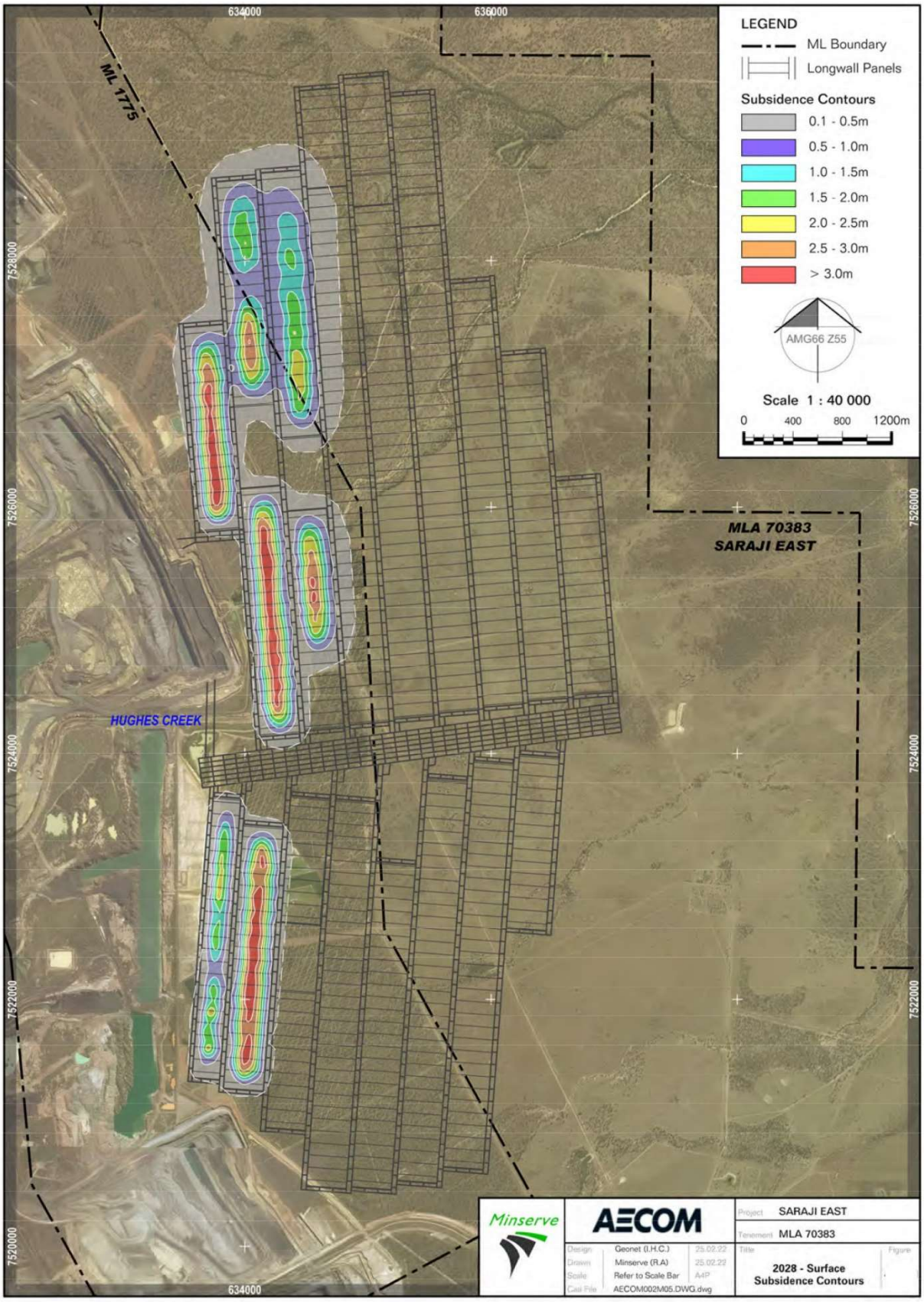


Figure 5 — Surface Subsidence Contours – Year 10 Schedule 2032

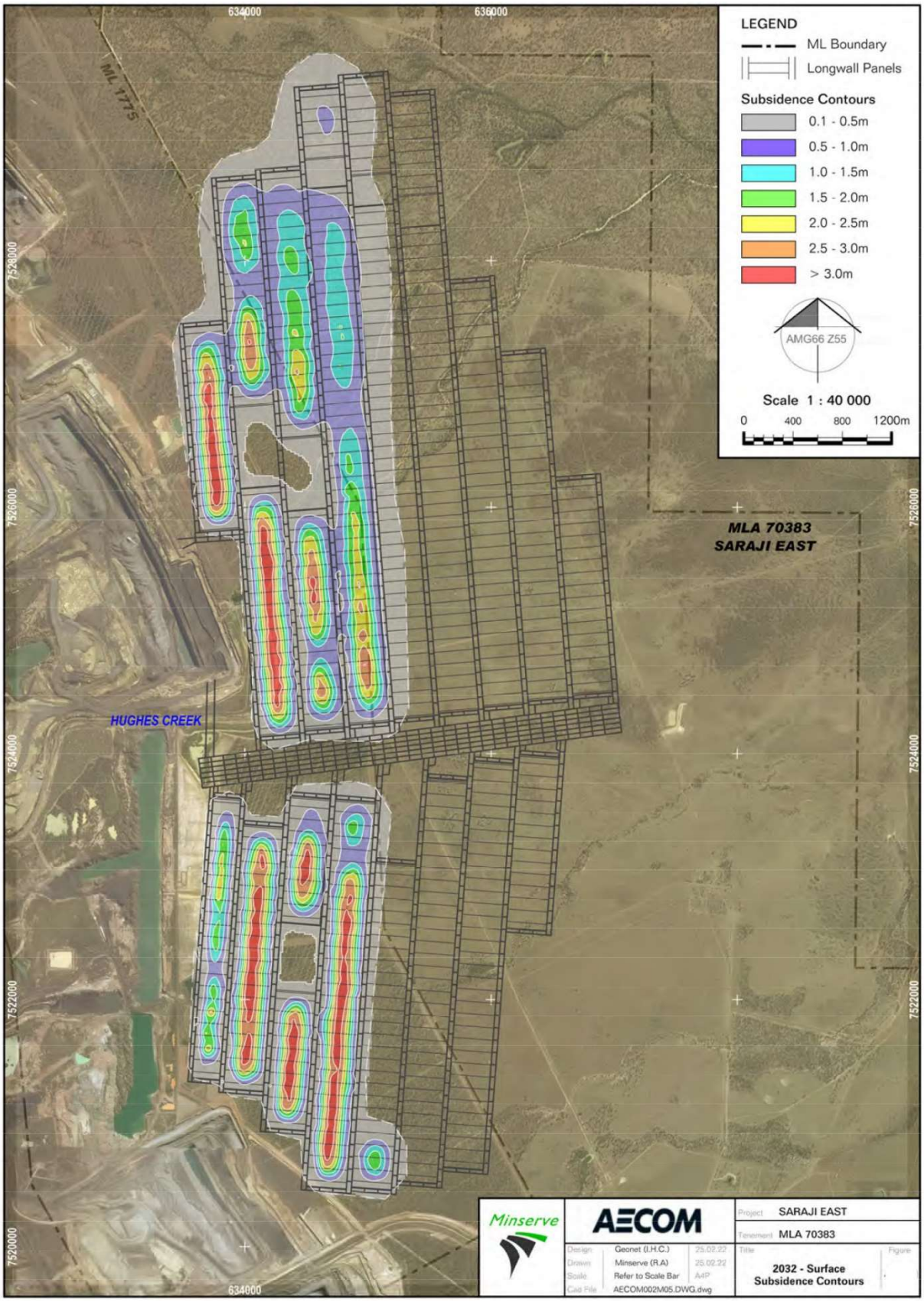


Figure 6 — Surface Subsidence Contours – Year 20 Schedule 2042

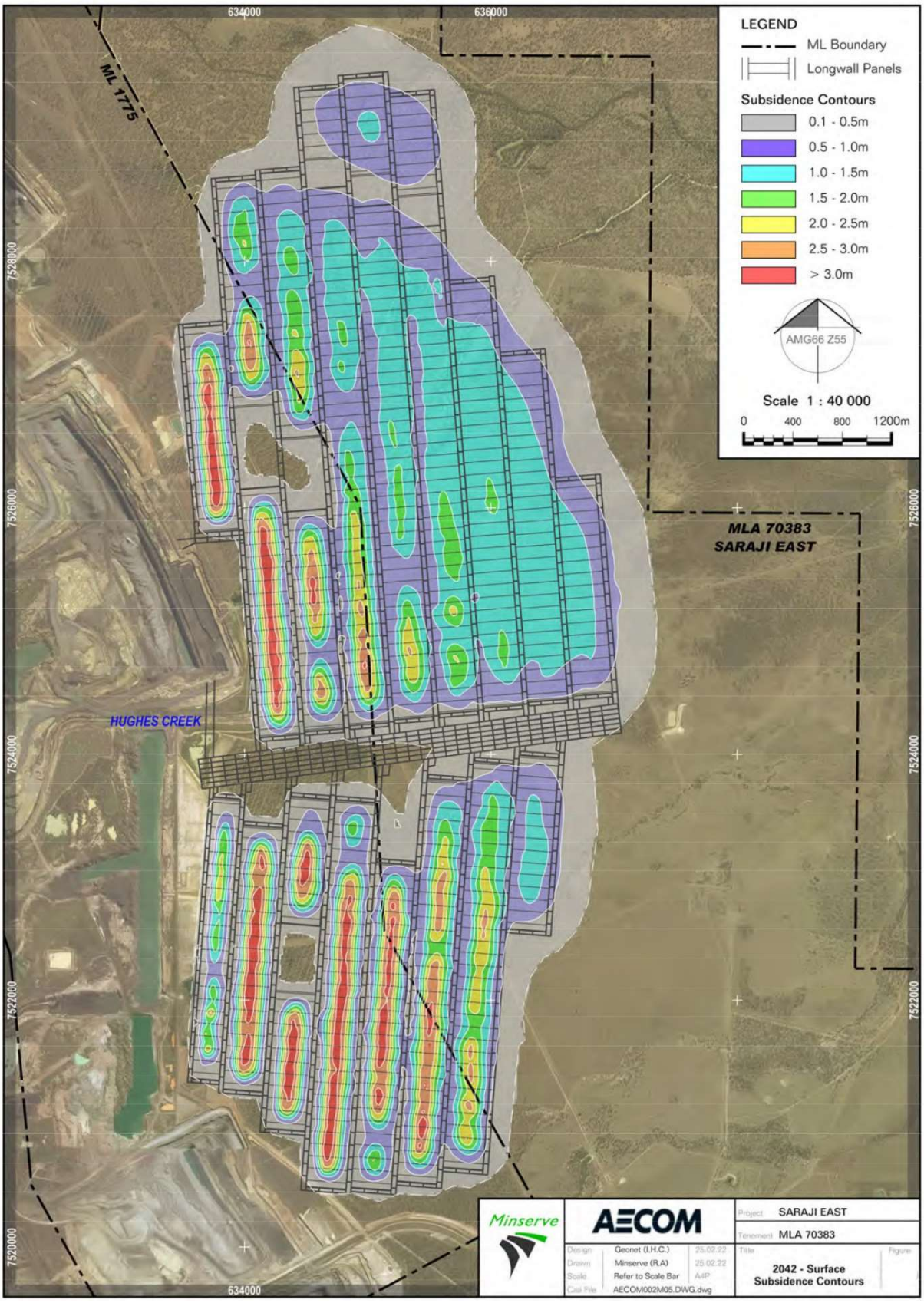


Figure 7 — Surface Topography Contours – Year 2 Schedule 2025

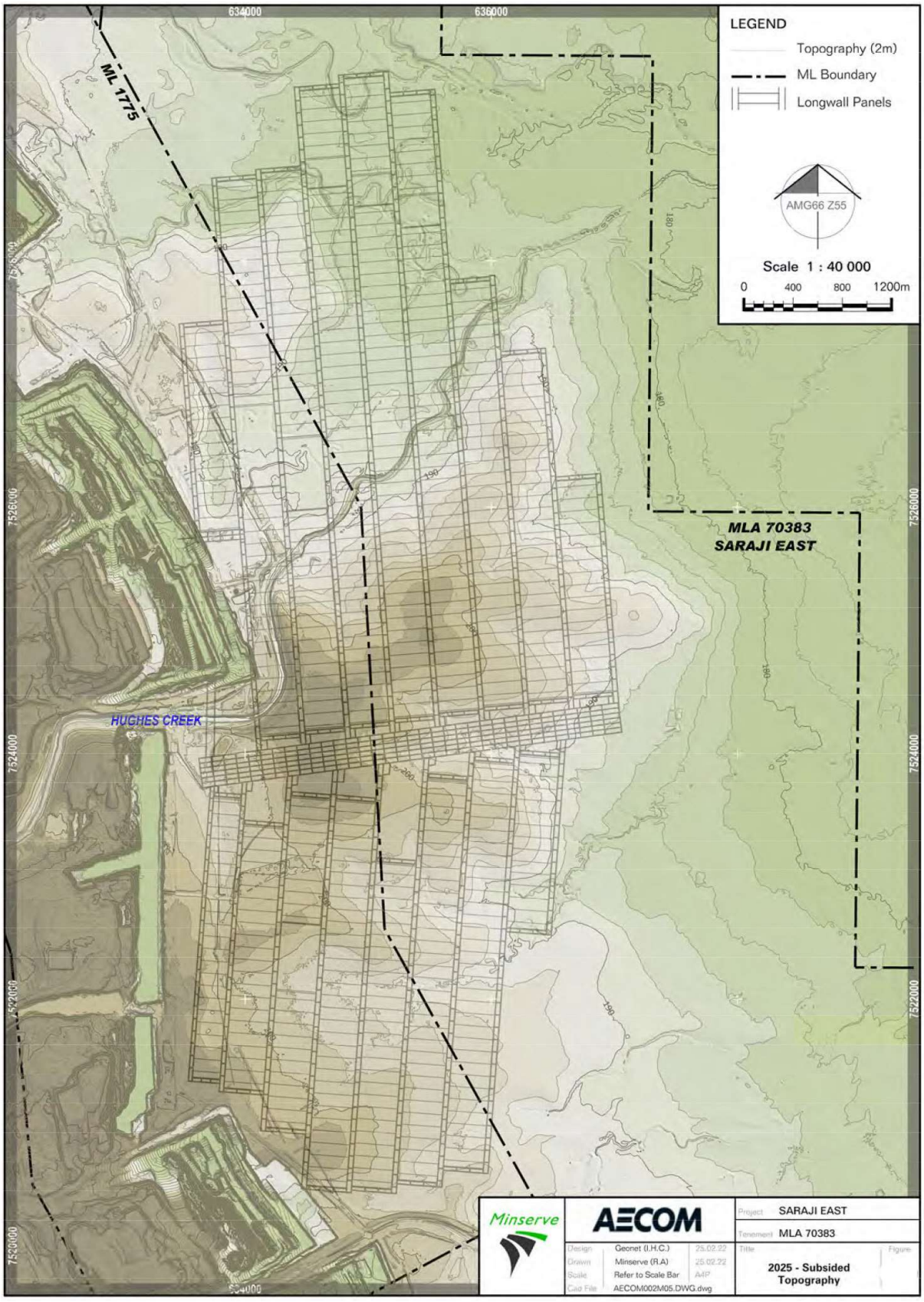


Figure 8 — Surface Topography Contours – Year 3 Schedule 2026

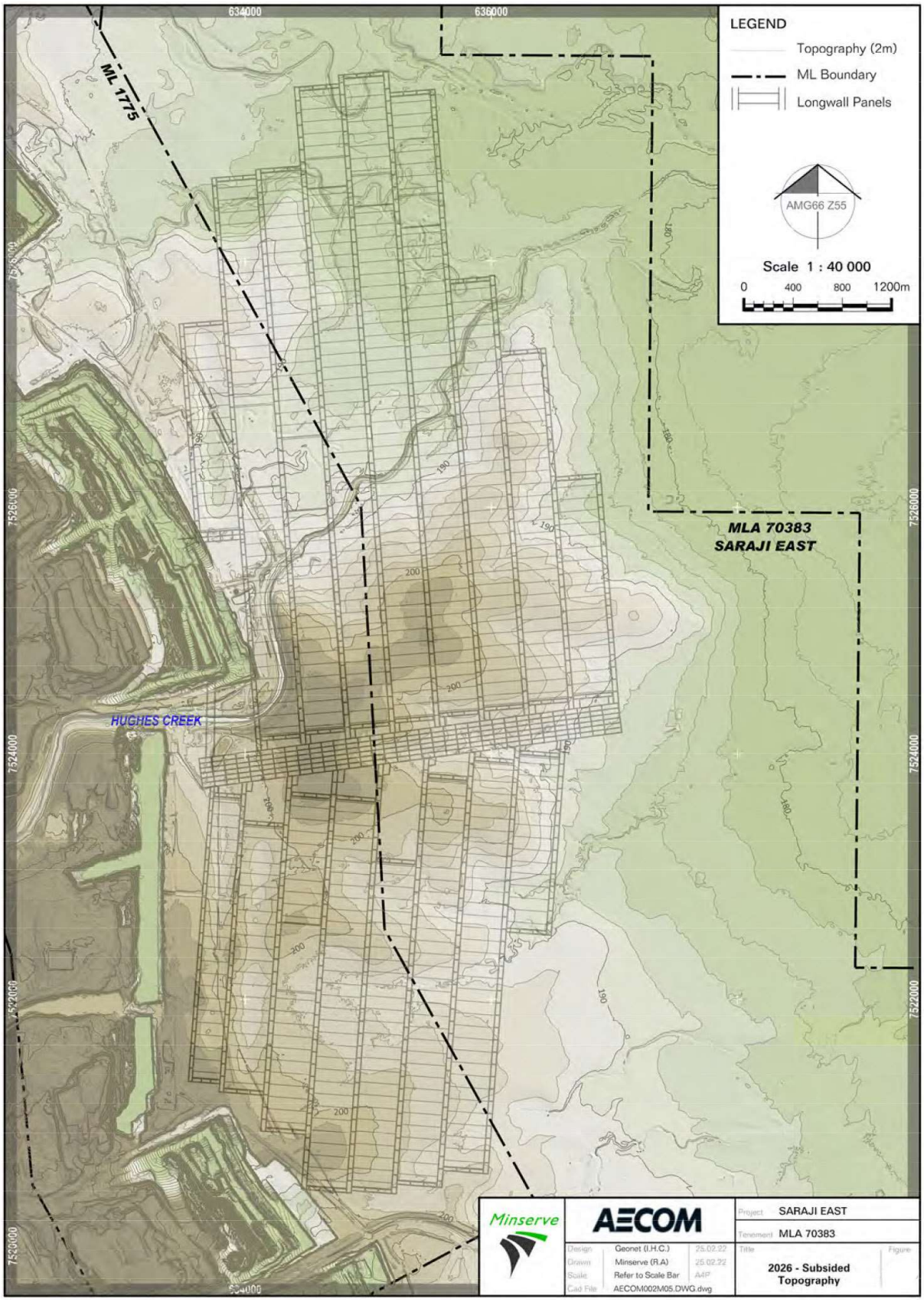


Figure 9 — Surface Topography Contours – Year 6 Schedule 2028

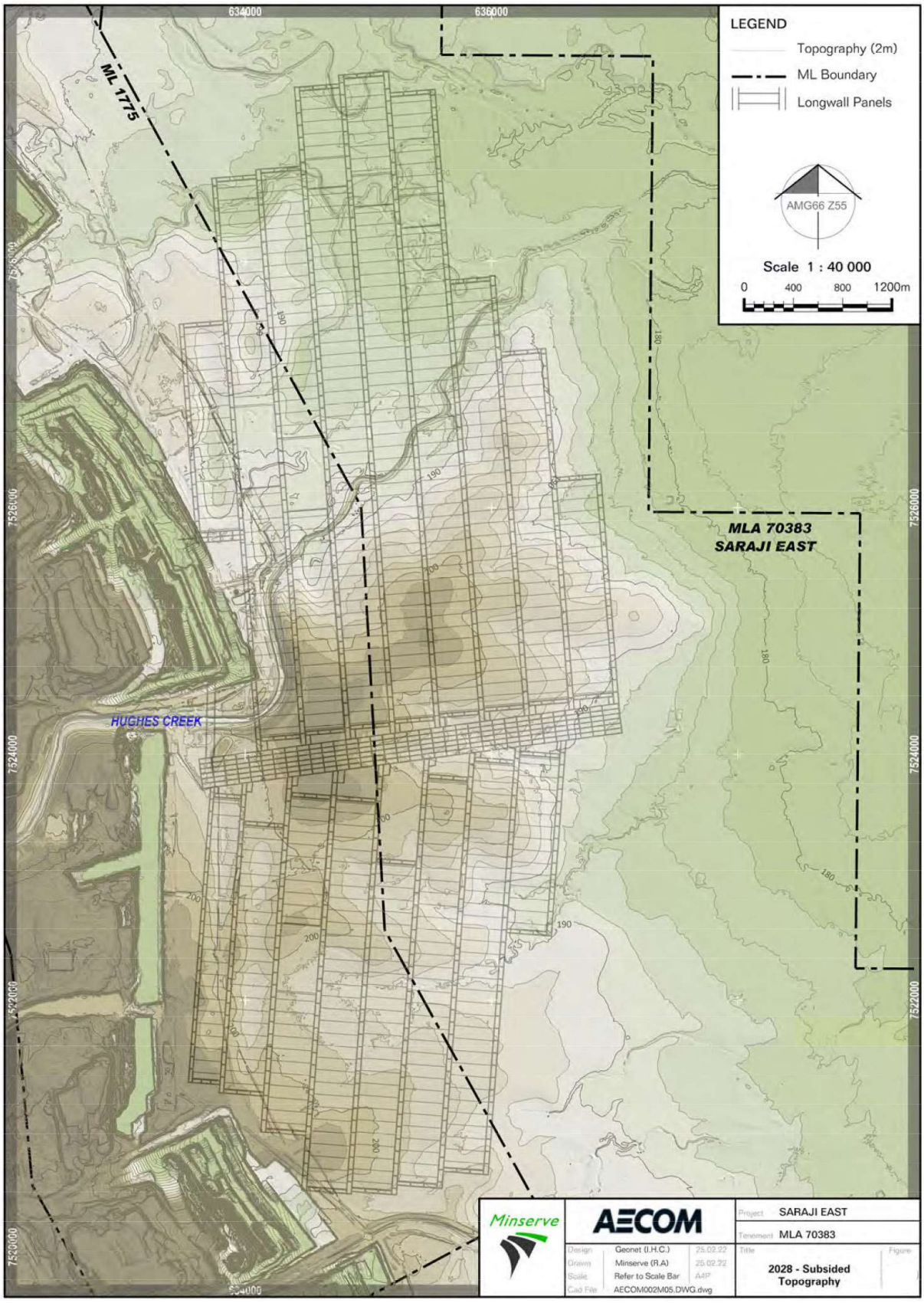


Figure 10 — Surface Topography Contours – Year 10 Schedule 2032

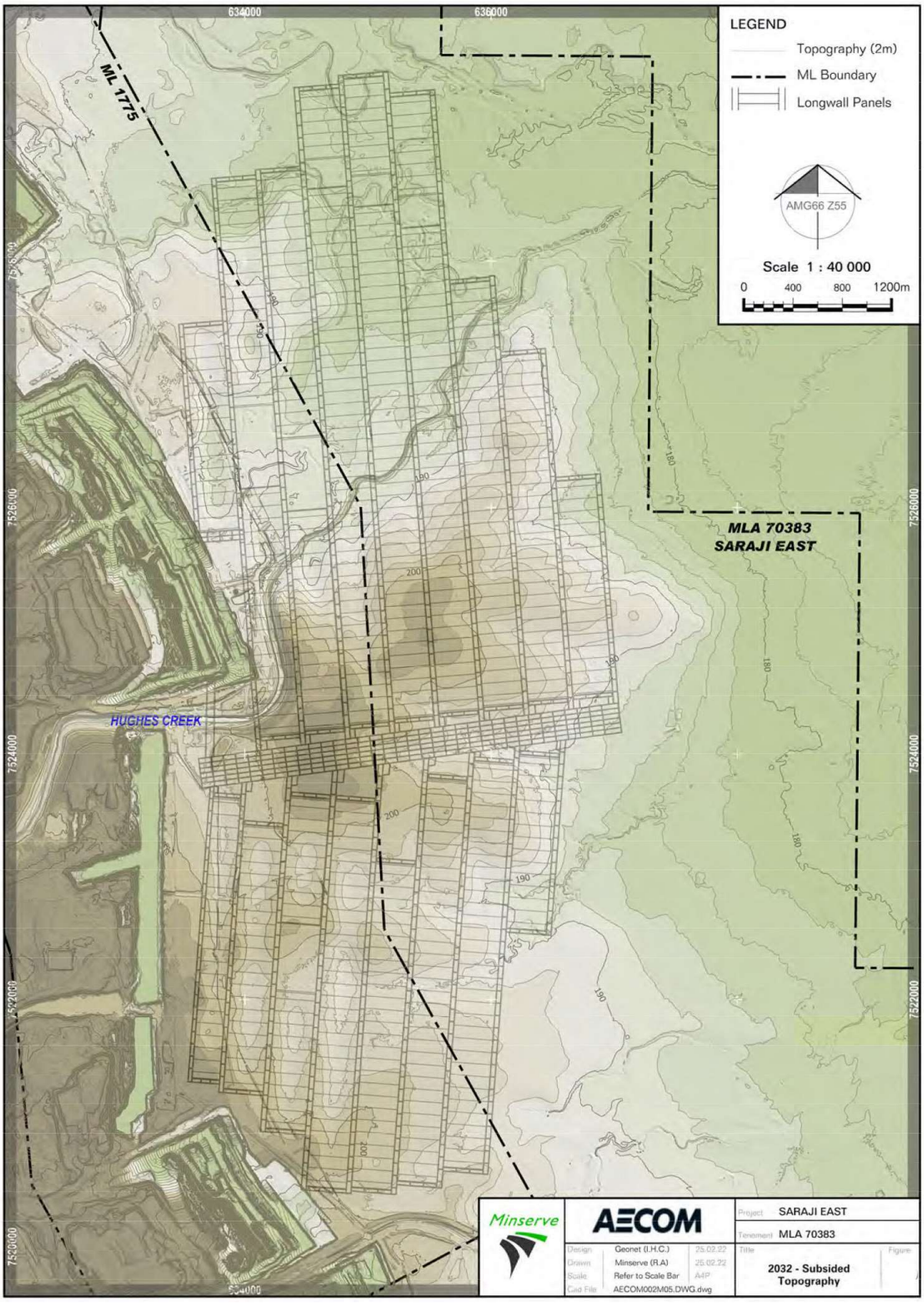
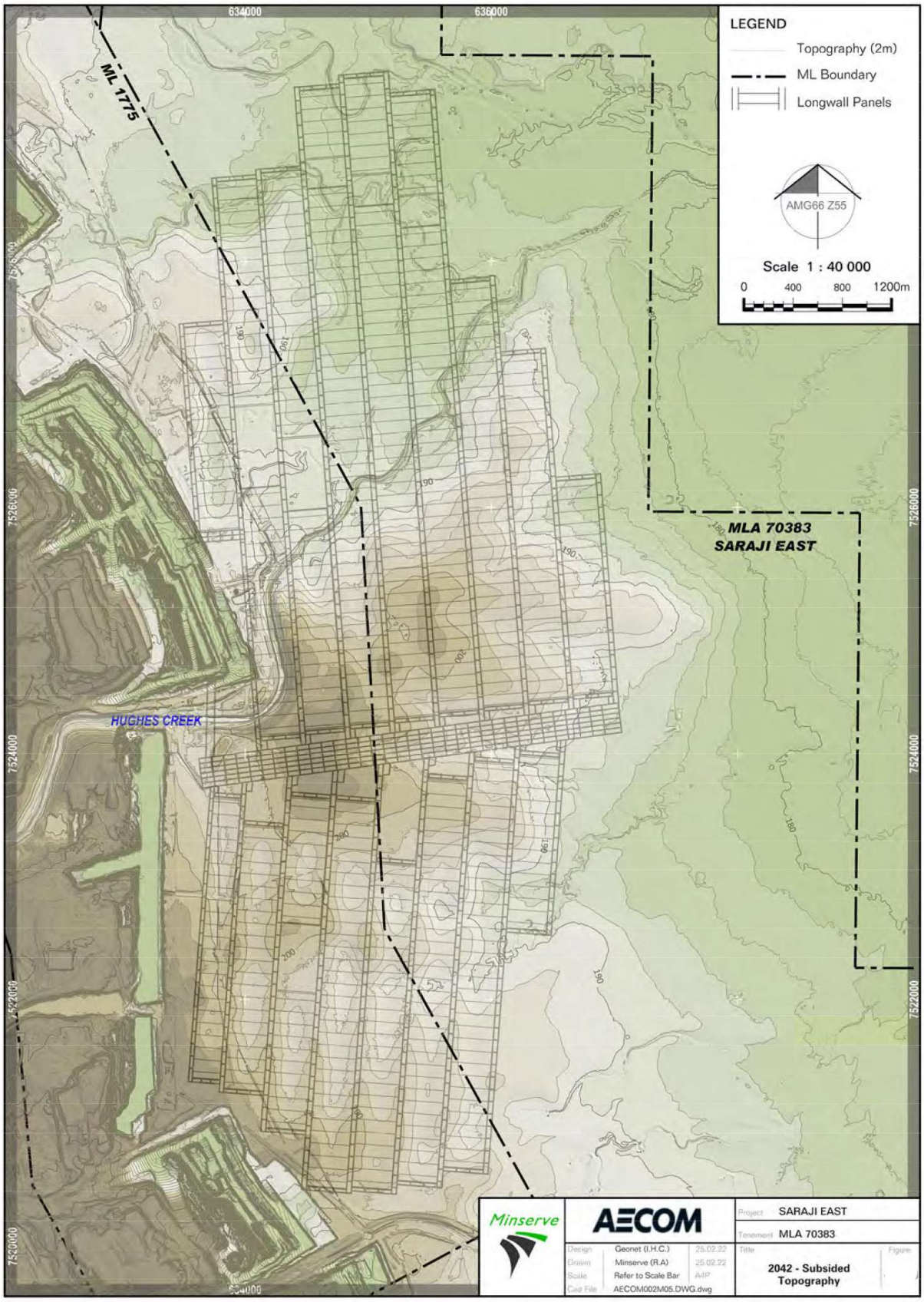


Figure 11 — Surface Topography Contours – Year 20 Schedule 2042



1.2 EXTENT OF SURFACE CRACKING

- The extent of possible tension cracks outside the longwall panel boundaries may be inferred from the 0.1m deformation contour. These are shown to be contained within the panel boundaries for shallow longwalls and to extend beyond these boundaries for the deeper panels.
- Tension cracking will form on surface above the western abutment edge of longwall LW201 in southern panel.
- Tension cracking will form on surface above the western abutment edge of longwalls LW101 and LW102 in the northern panel.
- This cracking limit extends to about 400m around the northern boundary of longwalls in the northern panel.
- Surface cracking will extend to about 380m beyond the eastern boundary of LW106 in the northern panel.
- Tension cracks on surface may extend 190m beyond LW109 footprint across the MLA 70383 boundary at 752600N. This is the only indication of subsidence induced damage extending into an adjacent mining lease.
- Subsidence cracking will extend about 200m along the eastern boundary of longwalls in the southern panel. Cracking will extend to 300m along the eastern boundary of LW208.
- The same limit extends about 80m around the southern boundary of longwalls in the southern panel.
- The thickness of overburden above the Dysart seam ranges from 120m above LW201 to 450m above LW108. Critical subsidence conditions can be expected to develop over longwalls where overburden thickness is less than 320m. This is confirmed in modelling results which show contiguous volumetric strain and rockmass damage in the overburden strata extending from longwall edge to surface corresponding with anticipated locations of major shear cracks.
- Where overburden thickness is greater than the longwall width of 320m then sub-critical subsidence conditions can be expected to occur. Contours of volumetric strain indicate that the cave and fractured zone above these longwalls extends to about 30m to 50m above the Harrow Creek seam. Overlying the fractured zone will be undamaged rockmass with localised minor shear activation on joints demarking the formation of constrained conditions in the Harrow Creek overburden.
- Over shallow longwalls (overburden thickness <300m) tension/shear cracks will form extending to a depth of 30m to 70m. As such it must expected that surface water flows above these longwalls could infiltrate the underground workings.
- Longwalls at depths greater than 300m will induce shallow (<15m) tension cracks on surface which may form tortuous connectivity with activated joints and bedding planes in the constrained zone.

1.3 SUBSURFACE ROCKMASS DAMAGE

The extent of rockmass damage developed over longwall panels at Saraji East underground mine will be affected by the following geological factors:

- Overall thickness of Dysart Seam overburden strata.
- Bedding plane separation and roof collapse extending to 100m above longwall panels in Dysart Lower (D24) seam (typically up to the H16 coal seam).
- Shear displacement induced on bedding planes through Permian strata, and
- High angle joints opening in tension through Permian strata.
- When tensile cracks propagate into the Tertiary sediments it is likely that cracks could further extend to surface but these cracks will most probably self-seal depending on the plasticity (clay content) of the sediments.

1.4 POTENTIAL IMPACT ON SUBTERRANEAN GROUNDWATER RESERVOIRS

The third major objective of this study was to define changes in rockmass permeability around the longwall panels. It is well established that the following formations are considered aquifers in the Saraji East project area:

- the various coal seams;
- the basal sand/gravel unit of the Tertiary Formation;
- clean sand beds within the Tertiary Formation; and
- alluvial sands and gravels of creek palaeo-channels.

It is most likely that open pit mining has already substantially modified the groundwater profiles within the vicinity of the mine by depressurisation of all aquifers.

Over both the longwall panels there are areas where fractures will propagate from the mining level through the overlying Permian rockmass into the overlying Tertiary sediments. These conditions will provide pathways for drainage of the groundwater reservoirs contained in Tertiary gravels and coal seams of the Fort Cooper Series and Permian strata.

The hydraulic properties of the Fort Cooper Coal Measures and Tertiary strata are affected to varying degrees depending on the depth of longwall mining. It is not possible to specify a definitive single value for either of the permeability tensor components nor porosity for the post-mining rockmass condition of each strata unit. These hydraulic properties will vary throughout the rockmass depending on the specific local subsidence characteristics.

Based on the calculated volumetric strains the following estimates are made for the range of subsided overburden rockmass hydraulic properties:

- Porosity:
  - Porosity in large open fractures will be 0.10 to 0.15
  - Typical fractured overburden strata will have porosity between 0.050 and 0.075
  - Tertiary sediment porosities will increase to the range 0.250 to 0.375.

- Horizontal Permeability (K_{11}):
  - In fractured overburden strata permeability is 2e-7 to 5e-8 m/sec
  - In subsided coal seams permeability is 2e-5 to 5e-6 m/sec
  - In Tertiary sediments permeability is 2e-3 to 5e-4 m/sec.

- Vertical Permeability (K_{22}):
  - In fractured overburden strata over longwalls permeability is 2e-5 to 5e-6 m/sec
  - In subsided coal seams permeability is 2e-4 to 5e-5 m/sec
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APPENDIX 1

Geonet Consulting Report, April 2022: Subsidence over Longwall Panels

SUBSIDENCE OVER LONGWALL PANELS
REVISED LONGWALL PANEL LAYOUT
SARAJI EAST UNDERGROUND MINE

for

AECOM Australia Pty Ltd

GEONET Consulting Group

Mining Geomechanics and Materials Engineering

SUBSIDENCE OVER LONGWALL PANELS
REVISED LONGWALL PANEL LAYOUT
SARAJI EAST UNDERGROUND MINE
AECOM Australia Pty Ltd

April 2022

Mining Geomechanics and Materials

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SARAJI EAST UNDERGROUND MINE: SUBSIDENCE OVER LONGWALL PANELS

1.0 INTRODUCTION

As part of the EIS being prepared by AECOM for the Saraji East Underground Mine, GEONET Consulting Group was requested through The Minserve Group to provide an assessment of the potential surface subsidence that would be incurred over the longwall panels. Figure 1 shows the extent of the revised layout of longwall panels which covers an area about five kilometres by eleven kilometres. This report summarises the background information provided by BHP Billiton Mitsubishi Alliance (BMA) to carry out the analysis and presents the subsidence results obtained using three-dimensional deformation modelling methods. Geotechnical rock strength data, stratigraphy and insitu stress conditions used as input for the subsidence analyses were obtained from previously reported data [1, 2, 3] and the author's professional experience.

2.0 PURPOSE OF STUDY

The principal objective of the study is to predict the extent and magnitude of surface subsidence following successive stages of longwall panel excavation using conventional mining methods to a uniform 3.6m cut-height. Note that the effect of variable cut-heights associated with LTCC mining method were considered and reported in a previous study [4].

In addition the model will provide predictions of the extent of surface cracking that may develop over the longwall panels taking into account the actual overburden lithology, surface topography and extent of mining.

In order to provide estimates of rockmass hydraulic properties as input for subsequent groundwater studies, the altered geotechnical condition associated with deformation accompanying rock fracture and bedding plane separation will be assessed.

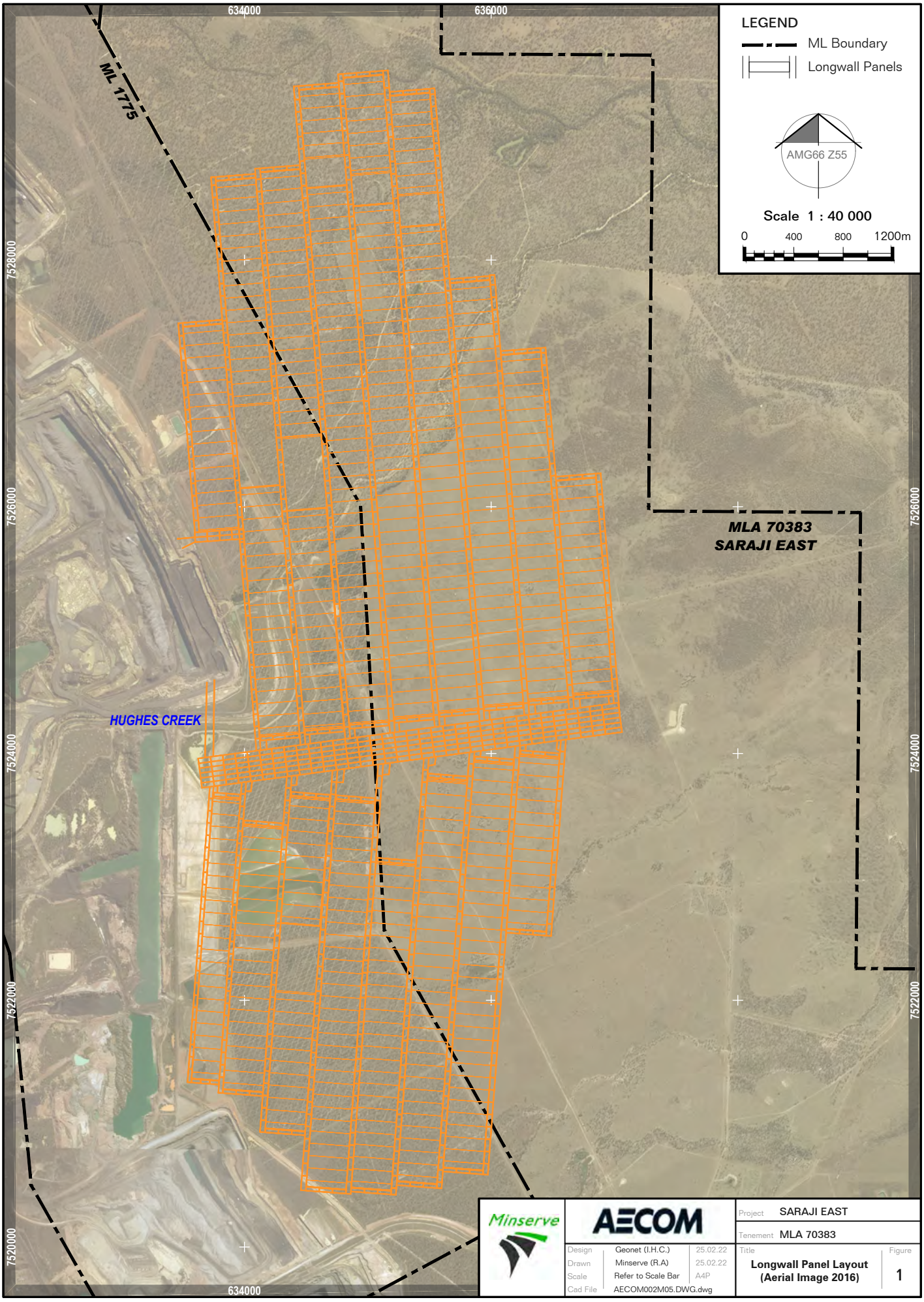
3.0 REVIEW OF ROCKMASS CONDITIONS

The area of interest for the current project is bounded between the following coordinates:

Easting:	632700E to 637692E
Northing:	7519000N to 7529944N
Elevation:	-500mRL to 260mRL

In order to set up the geological profiles within the geotechnical model the following data was provided in dxf and hardcopy formats over the coordinate range just specified:

- Overburden geological profiles as borehole logs and cross-sections
- Revised longwall panel layouts
- Surface topography
- H16 Seam roof and floor surfaces
- D24 Seam roof and floor surfaces
- Base of Tertiary surface



Minserve

AECOM

Design	Geonet (I.H.C.)	25.02.22
Drawn	Minserve (R.A)	25.02.22
Scale	Refer to Scale Bar	A4P
Cad File	AECOM002M05.DWG.dwg	

Project SARAJI EAST

Tenement MLA 70383

Title **Longwall Panel Layout (Aerial Image 2016)**

Figure 1

3.1 Geology

All longwall panels across the Saraji East Underground Mine site will extract coal from the Dysart Lower (D24 and D25) seams. A schematic diagram of the overburden coal seams is shown in Figure 2.

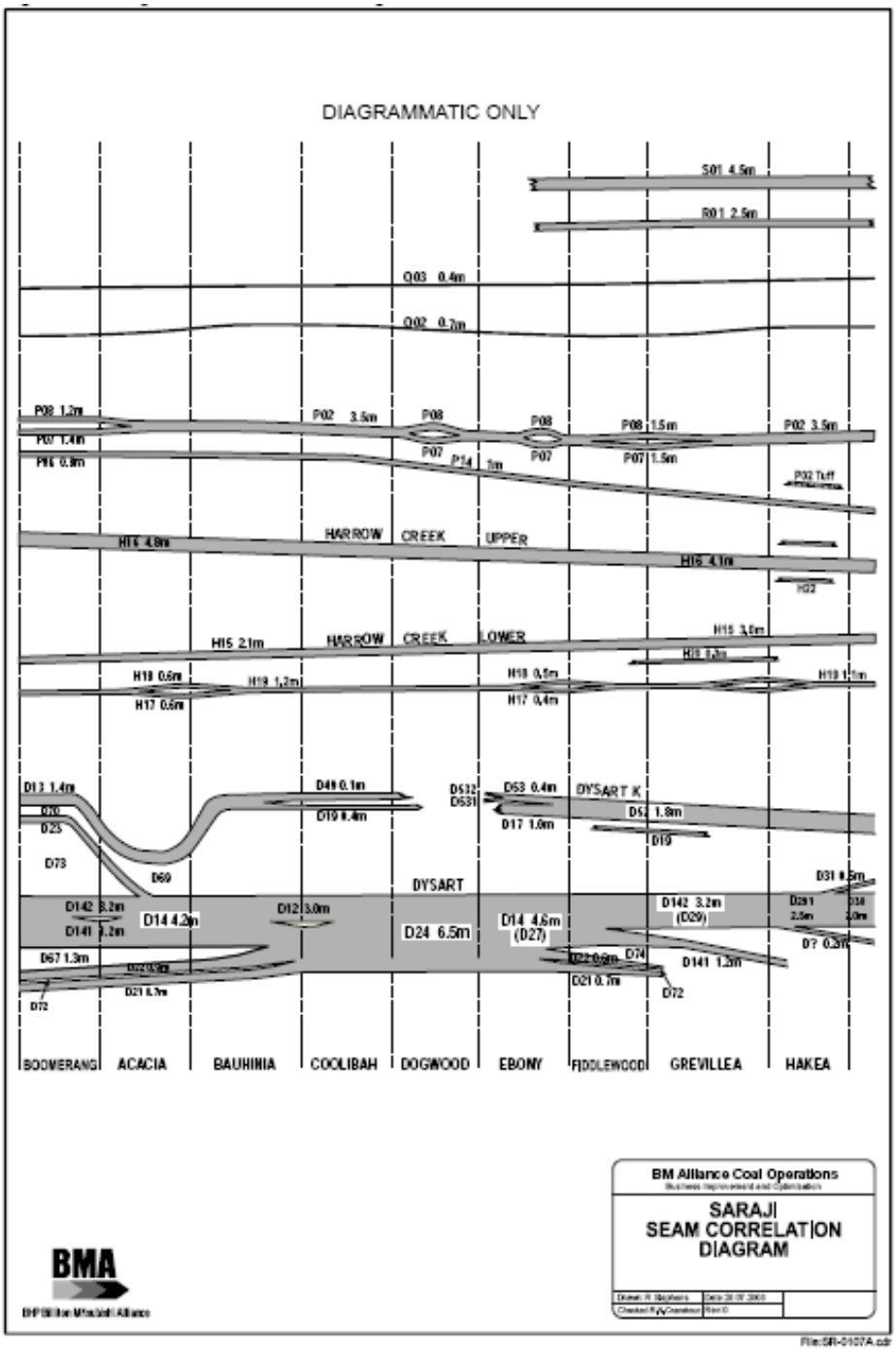


Figure 2: Correlation of major coal seams at Saraji East.

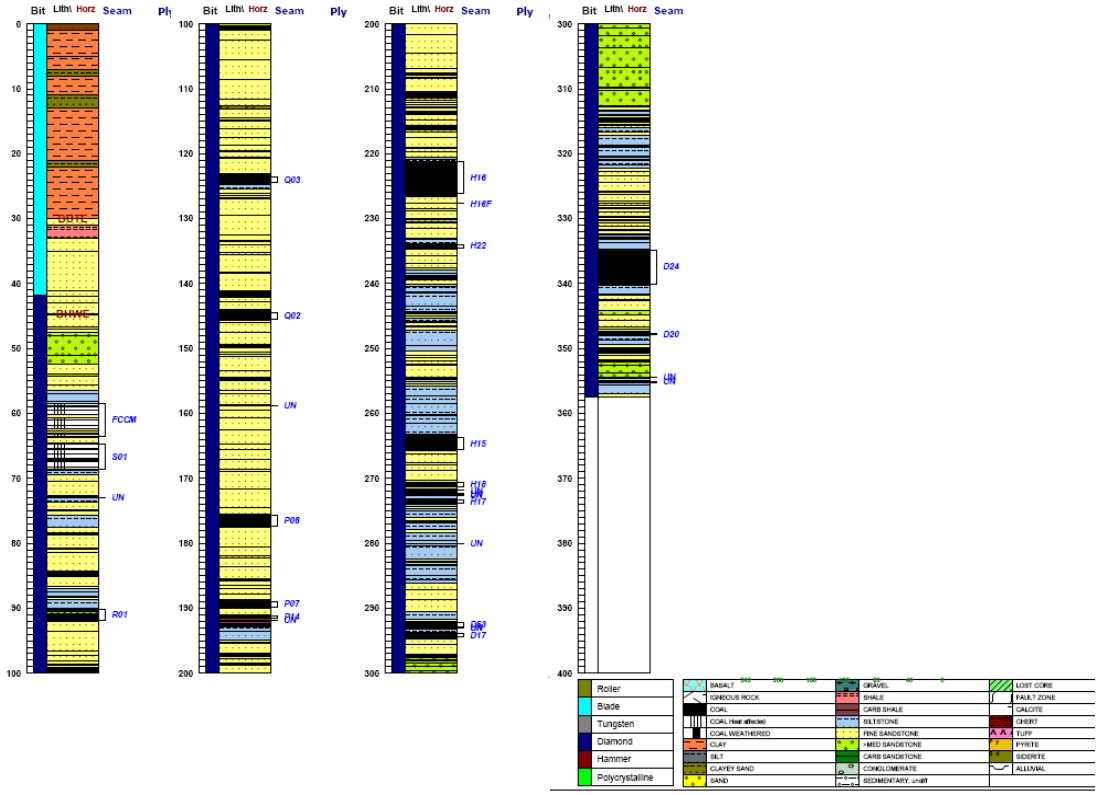


Figure 3(a): Drill log from borehole 56015.

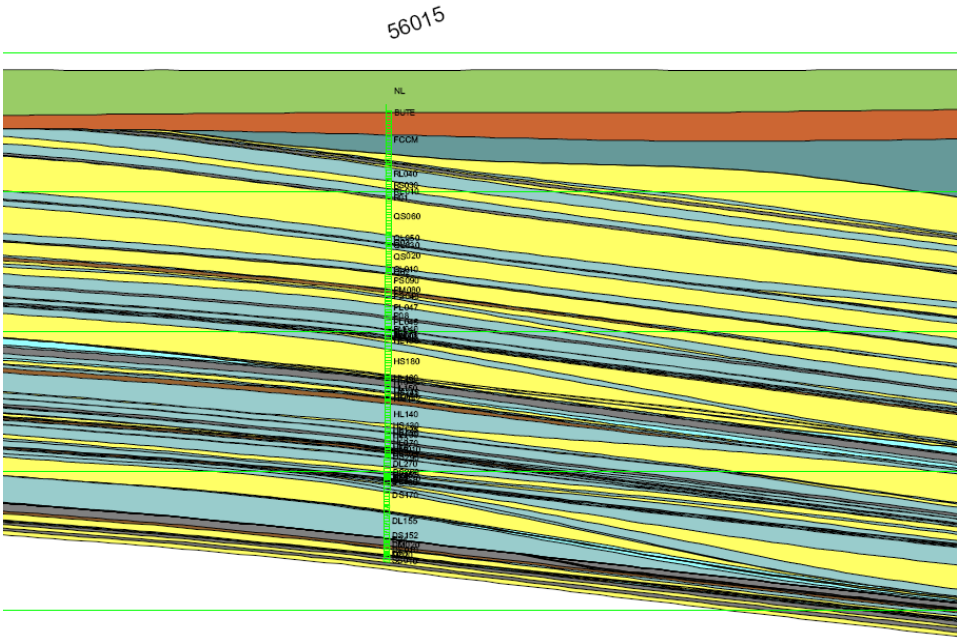


Figure 3(b): Interpreted lithological structure around borehole 56015.

Detailed geological logs, Figure 3(a), together with the interpreted lithological structures, Figure 3(b), were provided and these were used to define the major rockmass units, summarised as:

Sandstone is typically massive with broadly space bedding planes and localized areas of fracture. Intact rock strength increases with depth from very low strength to high strength. The weakest strata are within the weathering zone. Bedding planes are undulating with smooth surfaces. Cross cutting joints were not recorded in the drill logs but there is a pervasive high angle (vertical) joint set present.

Siltstone is typically bedded, massive with localized areas of minor fracturing. Intact rock strength ranges from low to high strength. Occasional undulating smooth bedding planes are present. The same pervasive joint set will be present in the siltstone units.

Carbonaceous Mudstone is well bedded and tends to be strongly jointed. Intact rock strength ranges between low to medium strength. Some bedding partings are described to be smooth with slickenside surfaces.

Coal has a well-developed cleat with localised bands of tuff and clay. The coal is of medium strength with UCS of about 5 MPa.

The target Dysart coal seam plies vary in thickness between 4.9m and 7m. The depth of the seams across the site varies between 120m and about 450m.

Overlying these strata is a cover of Tertiary sediments of thickness varying between 35m and 65m.

3.2 Rockmass Structure

Saraji East is located on the western limb of a northerly plunging syncline with uniform easterly dips of 2° to 5°, with local steepening to 9° on eastern margin of the lease where half-graben structures and monoclinal folding are related to eastern thrust complex of the Jellinbah Fault and Nebo Synclinorium [2].

It is generally found that the massive coal measure strata contain extensive bedding plane structures and joints normal to the coal seam dip. Jointing is likely to be truncated in seams that contain weaker interbedded units. A large number of joints were identified in the reports [1] on the four scanned holes (56001, 56002, 56025, 56079). There are discernible patterns in the joint data from the acoustic scanner, Figures 4(a) and 4(b).

The cleat data (defined as any feature in the coal seam so may also include coal joints) are more useful and 2 sets can be recognised, trending 160^o and 60^o magnetic (equivalent to 169^o and 069^o grid). The 070^o (grid) trend is parallel to major normal faults in the Northern Domain. The dips average 80^o, +/-10^o.

Faults mapped within the Dysart seam are shown in Figure 4(c). None of these could be confirmed to transect the overburden strata. Since the faults are all located under very shallow overburden thickness where the effects of goafing / subsidence would over-ride any structural control they might exert, they were not included in the model.

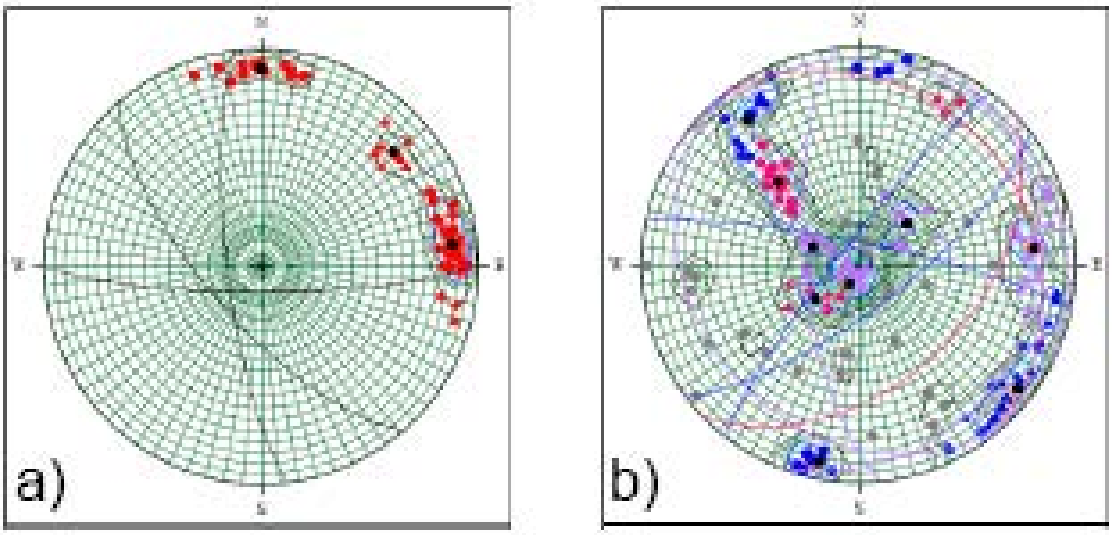


Figure 4(a): Coal cleat and 4(b) Joint set orientations, [GEMS, 2010].

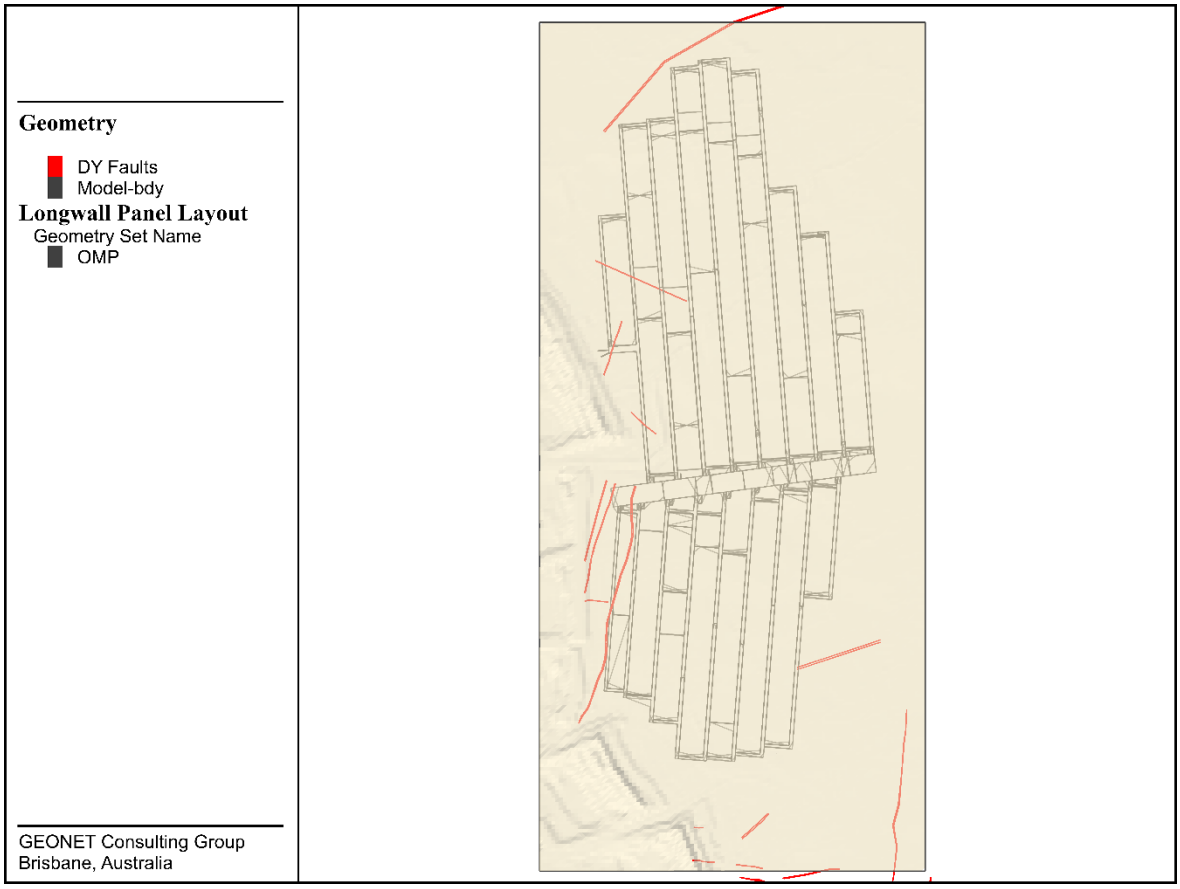


Figure 4(c): Distribution of fault traces in plane of Dysart seam

3.3 Initial Stress Conditions

Insitu stress measurements were made by Multiphase Technologies (2009) using hydraulic fracture techniques in boreholes [3].

Figure 5(a) presents the measured magnitude of the minor horizontal principal stress as a function of depth of measurement. The results correlate with the overburden pressure gradient with a slight increase in the minor horizontal stress component at depth.

Figure 5(b) presents the measured magnitude of the major principal stress with depth. These results show a greater scatter around the overburden pressure gradient consistent with changes in rock strength.

Based on these site specific results and reference from local regional database it is concluded that the horizontal to vertical stress ratios (K_o) are considered to be:

K_{oEW}=1.4 and K_{oNS}=2.2

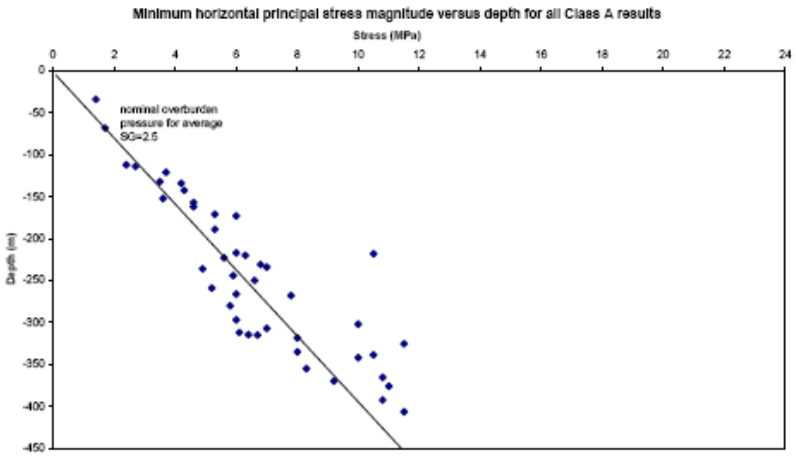


Figure 5(a) Magnitude of minor horizontal principal stress with depth [3].

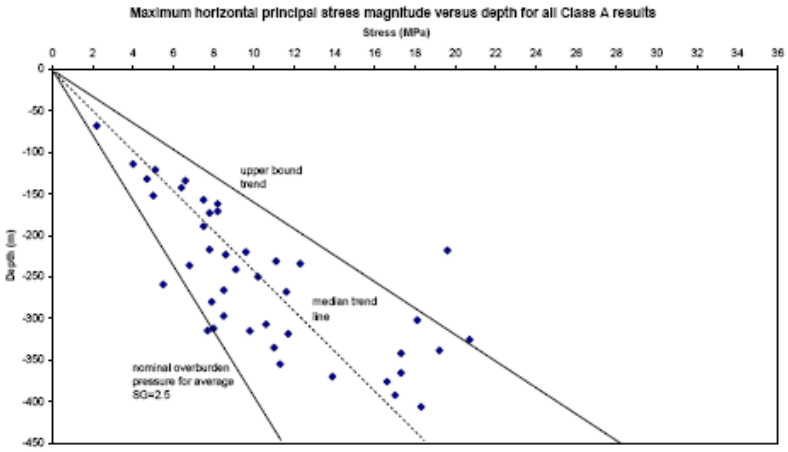


Figure 5(b) Magnitude of major horizontal principal stress with depth [3].

3.4 Rockmass Properties

Geotechnical properties of the overburden strata and coal seams were referred to by SCT [5] and Seedsman [6, 7]. Seedsman presented the data reproduced in Figure 6 below and he considered the rockmass units to be of high strength based on the mean strength values (shown as black squares). It was not clear whether these data are actual site measurements or a generalisation of data from local mines. In the SCT report no actual values of strength data are presented but they refer to weak rockmass conditions in the Dysart seam floor and overburden and in the H16 seam overburden at the site.

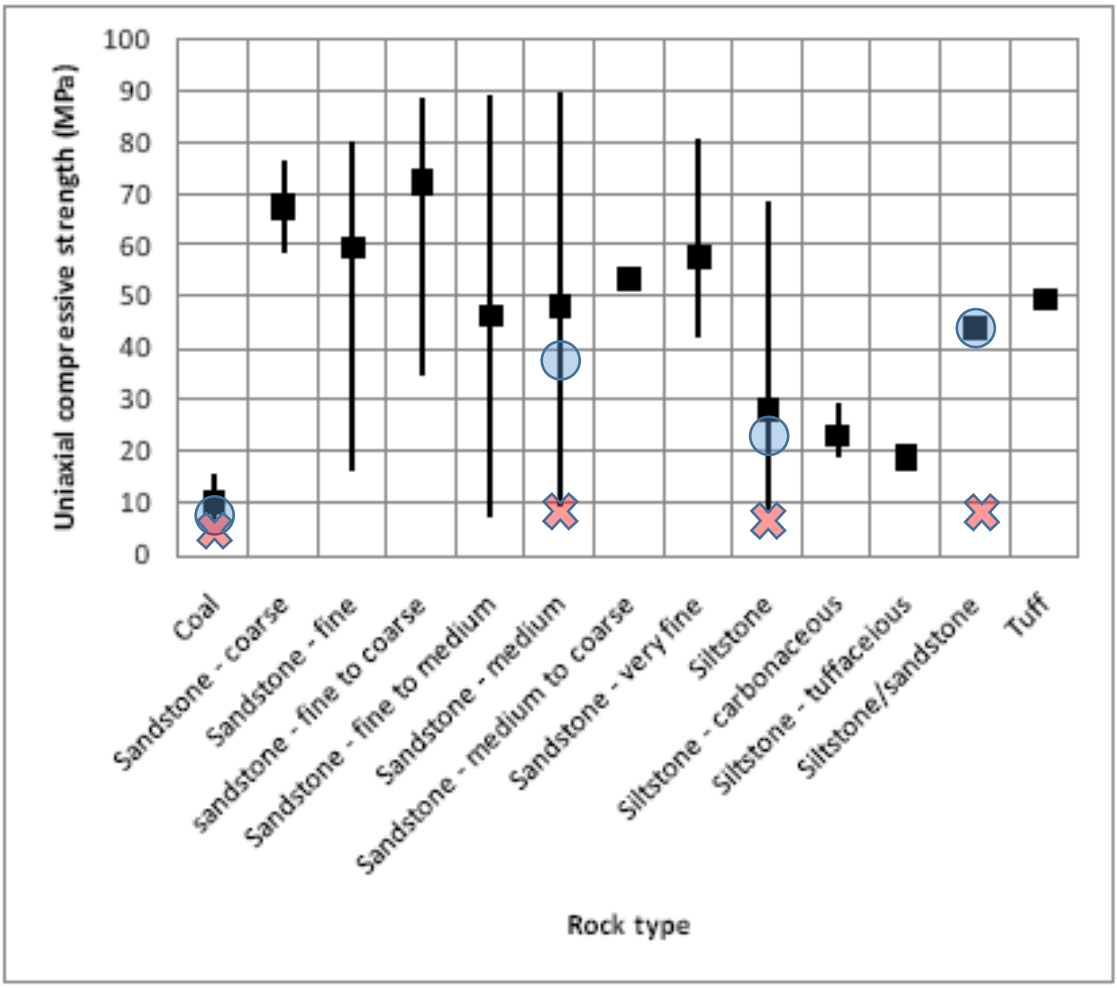


Figure 6: Measured UCS data for coal strata rock types [6].

It is well established that rockmass strength is scale dependent and typically relates towards the weakest measurement in laboratory tests. Typical estimates of strength for intact strata at Saraji are shown as blue dots on Figure 6. Based on previous experience and back analysis of rockmass deformation at other mines in the region, it is most likely that the Permian strata rockmass strength will be in the range 3 MPa to 10 MPa as shown by the superimposed red crosses on Figure 6.

One of the fundamental problems in geotechnical engineering is the estimation of rockmass strength. Because it is impossible to measure rockmass strength directly, it is usually estimated from empirical relations based on rockmass classification systems. Estimates of rockmass strength for the rock units in this study are based on the method described by Hoek and Brown (1997). For the *insitu* rockmass, estimates of GSI are used to calculate the Hoek-Brown parameter *s,* which in turn is used to calculate the rockmass unconfined compressive strength, modulus, cohesion, tension and friction angle. For good quality rockmasses, GSI is equivalent to Bieniawski's (1976) RMR.

Estimates of GSI (Geological Strength Index) are used to calculate the Hoek-Brown parameter *s* as follows.

$$s = e^{\left(\frac{GSI-100}{9}\right)}$$

The unconfined rockmass strength can then be estimated from the following relation from Hoek and Brown (1997):

$$UCS_{\text{rock mass}} = UCS_{\text{intact}} * s^{0.5}$$

The rockmass friction angle for all units was estimated from experience and knowledge of representative values. The rockmass cohesion is calculated from the following relation:

$$c = \frac{UCS_{rockmass}(1-\sin\phi)}{2\cos\phi}$$

The rockmass tensile strength was assumed to be 10% of the rockmass cohesion.

The methodology used to define the potential brittle rockmass behaviour uses a critical plastic strain parameter (ε_{crit}^{s}) to describe the amount of plastic strain required to go from peak rockmass strength to residual rockmass strength. The following relation may be used to calculate the critical strain parameter:

$$\varepsilon_{crit}^{s}\,(\%) = (12.3 - 0.125*GSI)/10$$

The rockmass modulus is calculated from the empirical relation of Serafim and Pereira (1983) as modified by Hoek and Brown (1997):

$$E_{rockmass}(GPa) = 10^{\frac{GSI-10}{40}} \quad , \ UCS_{intact} \geq 100 \text{ MPa}$$

$$E_{rockmass}(GPa) = \sqrt{\frac{UCS_{\text{int}\,act}}{100}}\,10^{\frac{GSI-10}{40}} \quad , \ UCS_{intact} < 100 \text{ MPa}$$

The Poisson's ratio was estimated from the following relation from Hoek et al (1977):

$$\nu = 0.32 - 0.0015 \cdot GSI$$

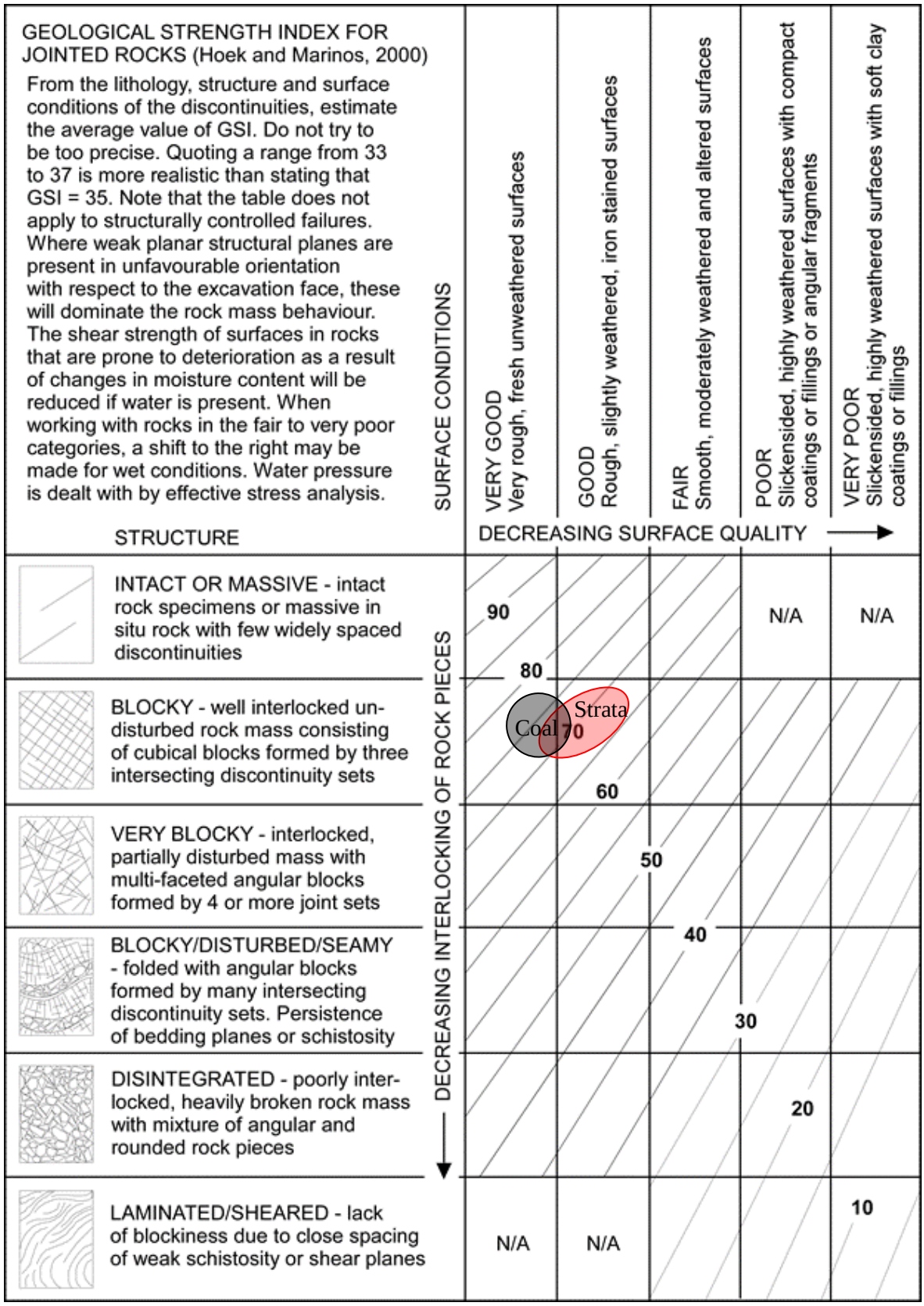


Figure 7: Chart to estimate GSI value for defined rockmass conditions

Material properties for the intact rock and corresponding rockmass for each lithostratigraphic member are summarised in Table 3.1. In this table the input values for GSI were estimated based on visual inspection of the borehole logs together with experience with similar coal measures strata as referred to Figure 7. The representative UCS input values are the maximum values reported in the data base.

Table 3.1: Material properties for the principal rockmass units

	Input		Intact Properties			Rockmass Properties			
Rock Type	**GSI**	**UCS (MPa)**	**Cohesion (MPa)**	**ϕ (o)**	**s**	**UCS_rm (MPa)**	**coh_rm (MPa)**	**E_rm (GPa)**	***v*_rm**
Tertiary Seds	45	9.39	2.60	32	0.002218	0.44	0.123	2.30	0.253
01_OB	69.4	39.80	11.03	32	0.033373	7.27	2.015	19.273	0.216
02_H16_Coal	65	22.50	5.01	42	0.020468	3.22	0.717	11.248	0.223
03_IB	73	42.00	11.64	32	0.049787	9.37	2.597	24.357	0.211
06_DY_Coal	74	22.50	5.01	42	0.055638	5.31	1.181	18.884	0.209
07_Base	78	43.50	9.46	43	0.086774	12.81	2.786	33.056	0.203

These properties are used to define the specific input parameters for the Mohr-Coulomb based ubiquitous joint constitutive model. In this model the rockmass behaviour is defined in terms of the following material properties:

Intact Rock:		Bulk Density
	Stiffness Properties:	Young's Modulus, Poisson Ratio
	Shear Strength:	Cohesion, Tensile Strength, Friction Angle, Dilation Angle
Bedding / Jointing:	Shear Strength:	Cohesion, Tensile Strength, Friction Angle, Dilation Angle

3.5 Simulated Rockmass Strength Behaviour

In order to validate the derived input properties for each of the major principal rockmass horizons assigned in the model, a simulation of the unconfined compressive strength is carried out. Simulated stress-strain graphs for the unconfined compression tests (UCS) are shown in Figures 8(a) to 8(d).

If one compares the simulated peak strength against the calculated rockmass strength (UCS_rm) in Table 3.1 then it may be concluded that the modelled results provide an accurate representation of the calculated rockmass UCS strength. The simulated mode of failure is predicted to be associated with a combination of shear fractures and tensile spalling. These are the same modes of failure typically observed in laboratory testing.

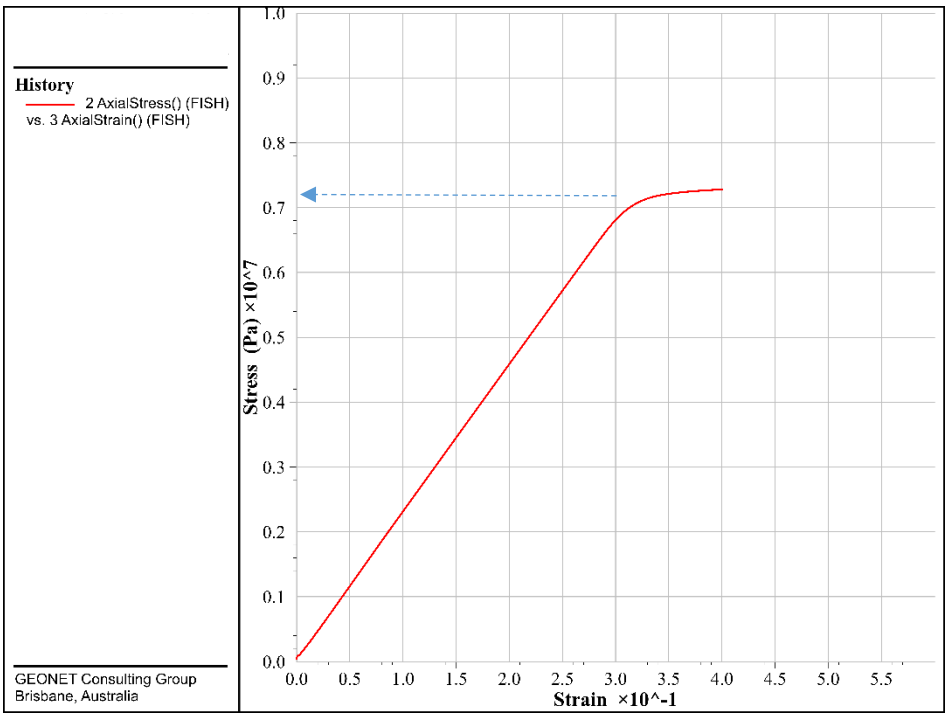


Figure 8(a): Simulated UCS of H16 Seam Overburden – UCS = 7.2 MPa

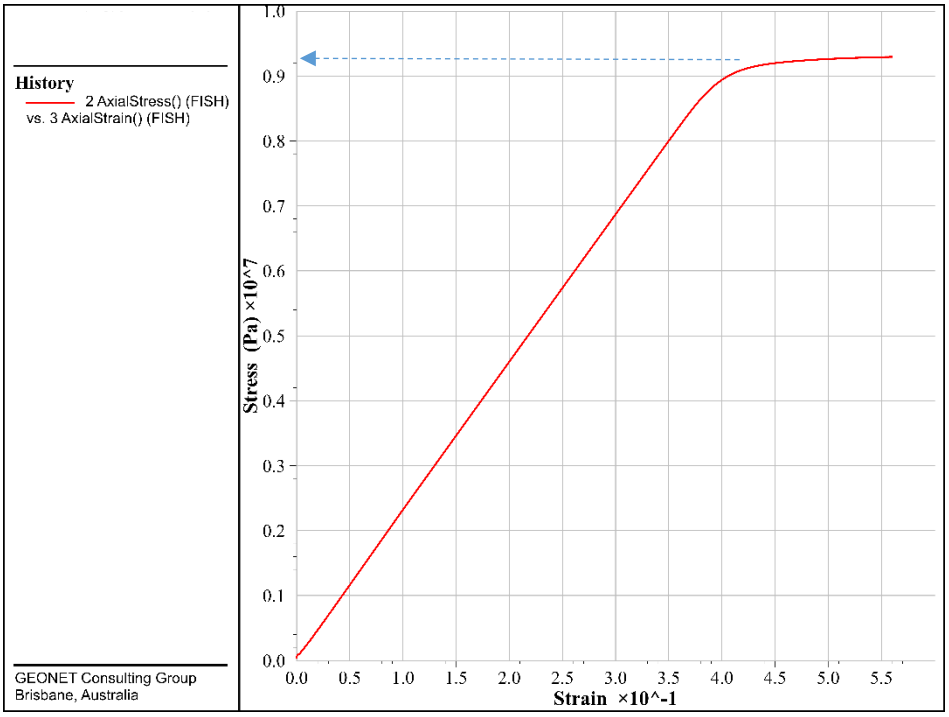


Figure 8(b): Simulated UCS of Dysart Seam Overburden – UCS = 9.3 MPa

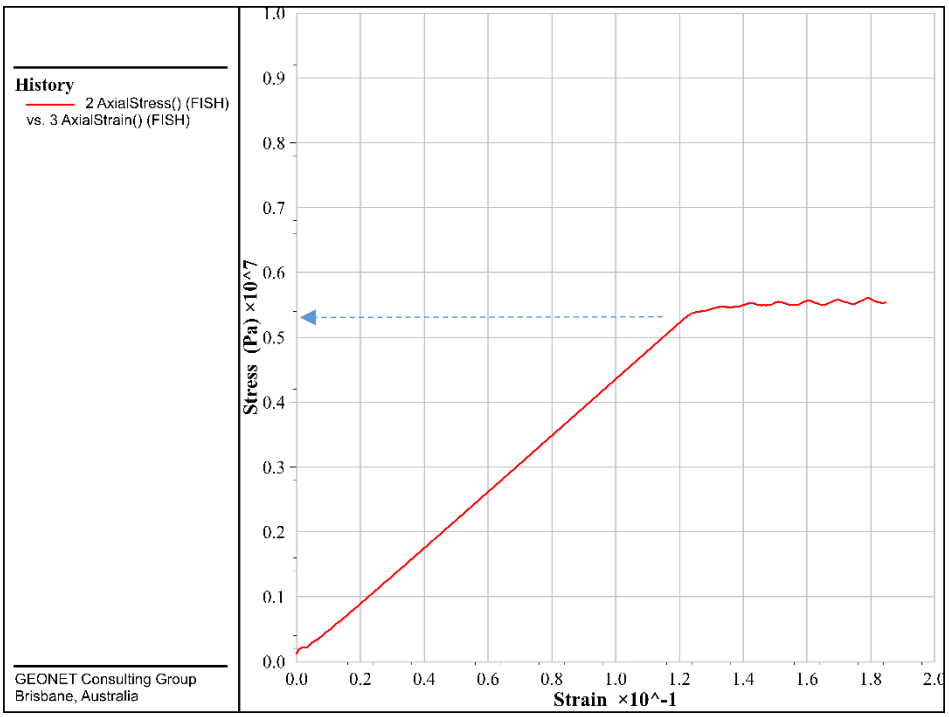


Figure 8(c): Simulated UCS of Dysart Seam Coal – UCS = 5.35 MPa

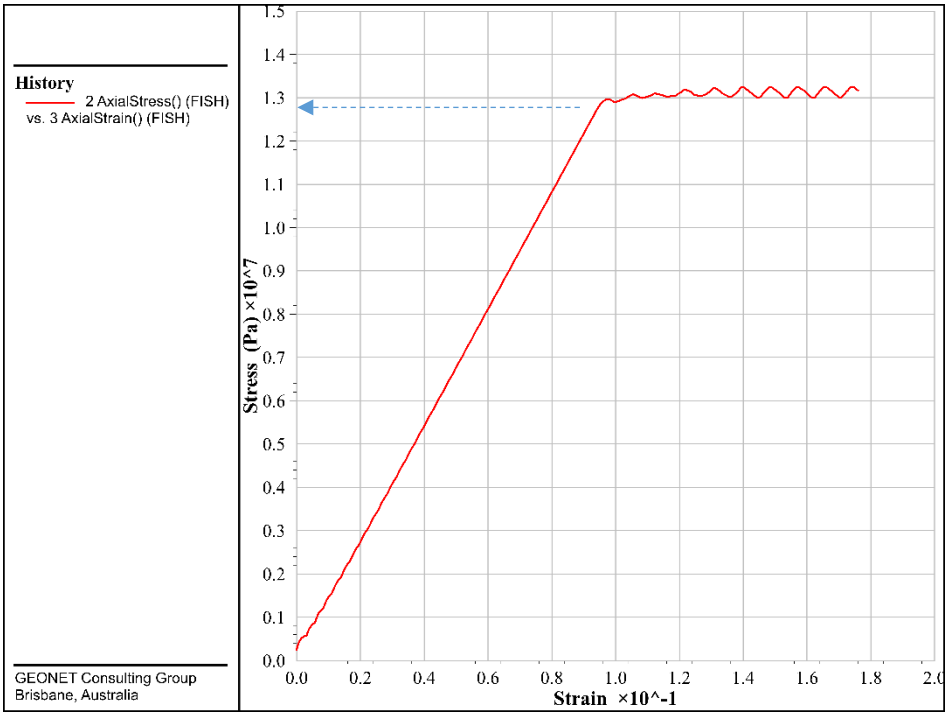
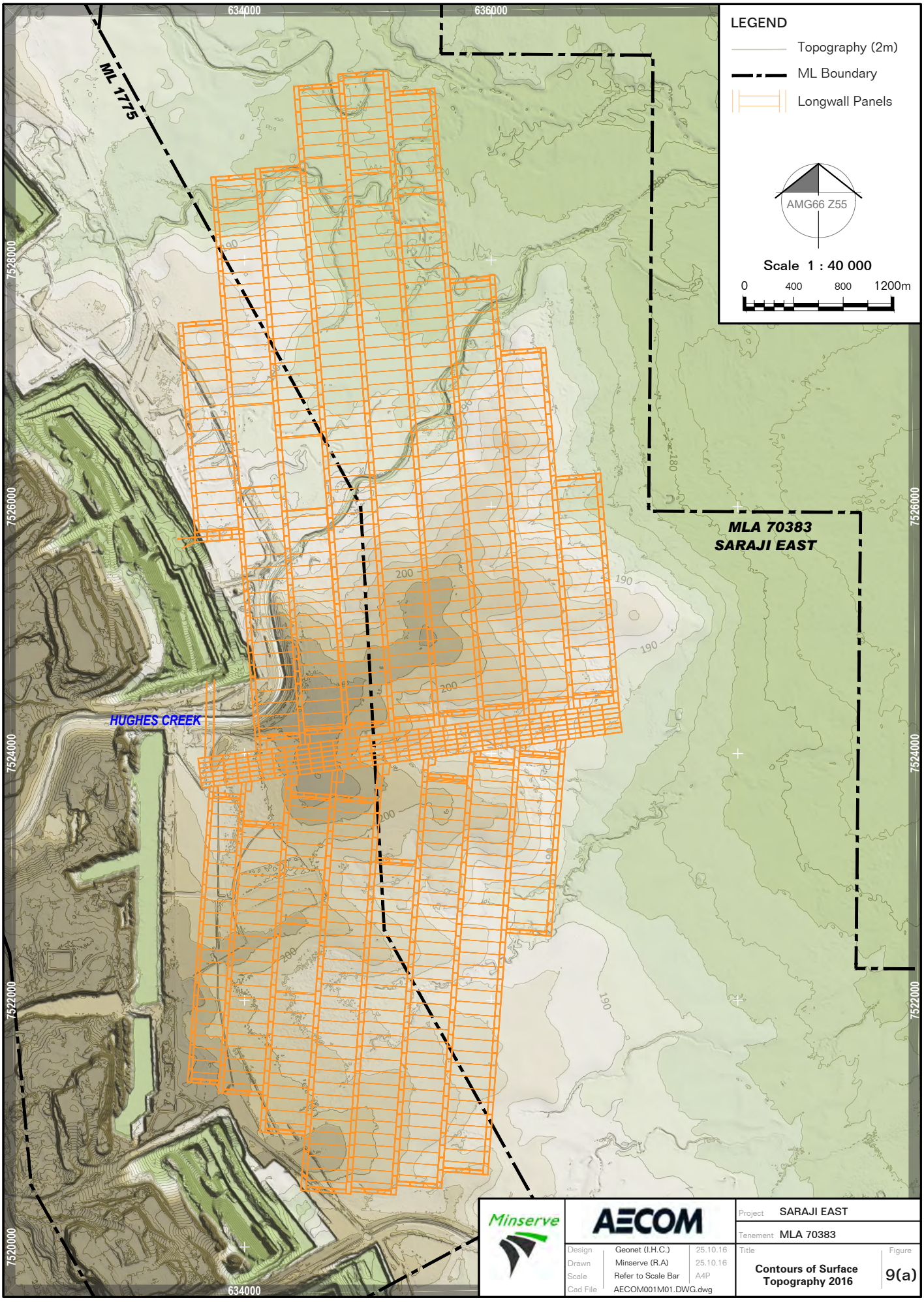
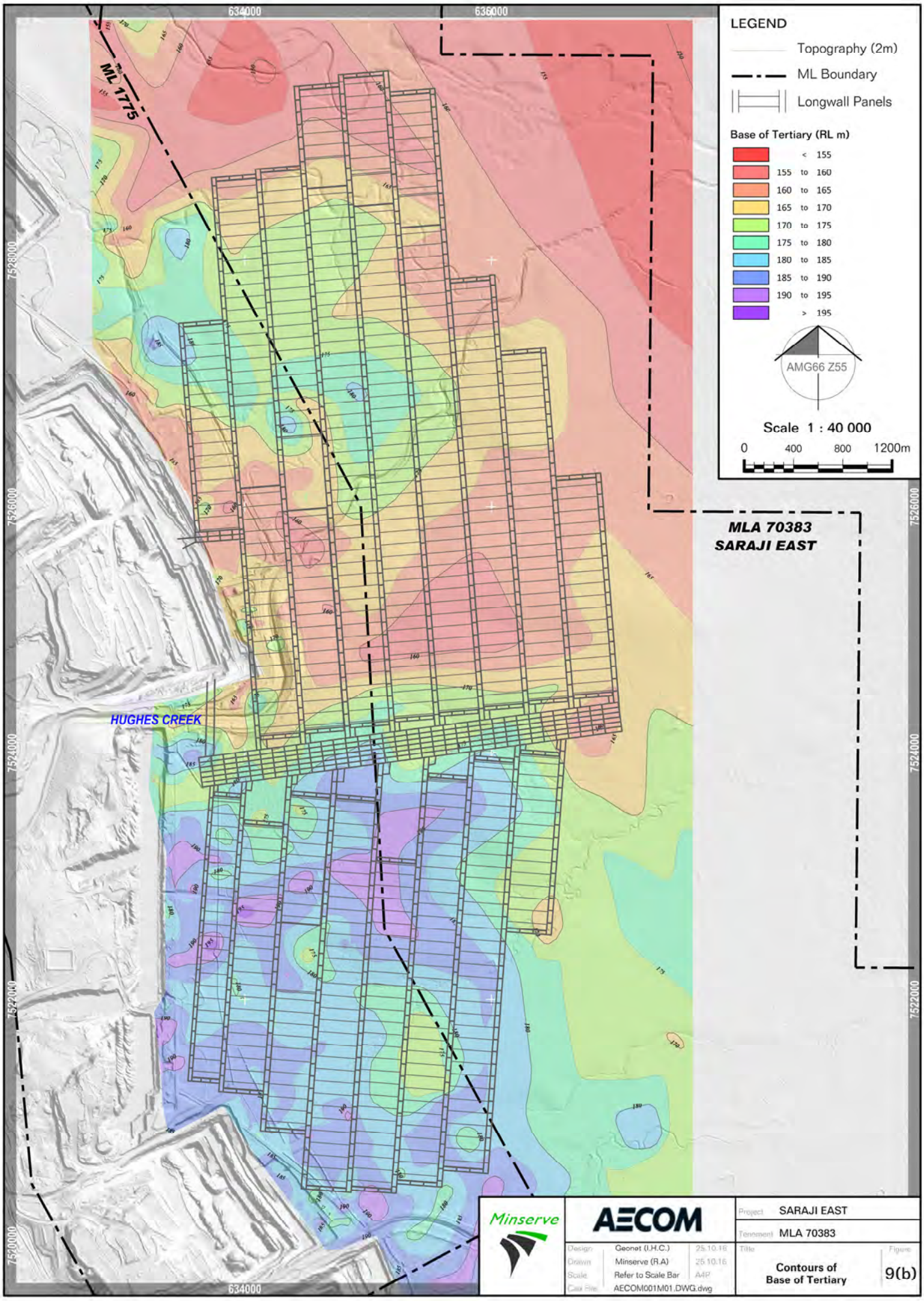


Figure 8(d): Simulated UCS of Basement Stratum – UCS = 12.9 MPa


LEGEND
Topography (2m)
ML Boundary
Longwall Panels
AMG66 Z55
Scale 1 : 40 000
0 400 800 1200m
ML 1775
MLA 70383
SARAJI EAST
HUGHES CREEK
634000
636000
7528000
7526000
7524000
7522000
7520000
Minserve
AECOM
Project SARAJI EAST
Tenement MLA 70383
Design Geonet (I.H.C.) 25.10.16
Drawn Minserve (R.A) 25.10.16
Scale Refer to Scale Bar A4P
Cad File AECOM001M01.DWG.dwg
Title Contours of Surface Topography 2016
Figure 9(a)



Minserve

AECOM

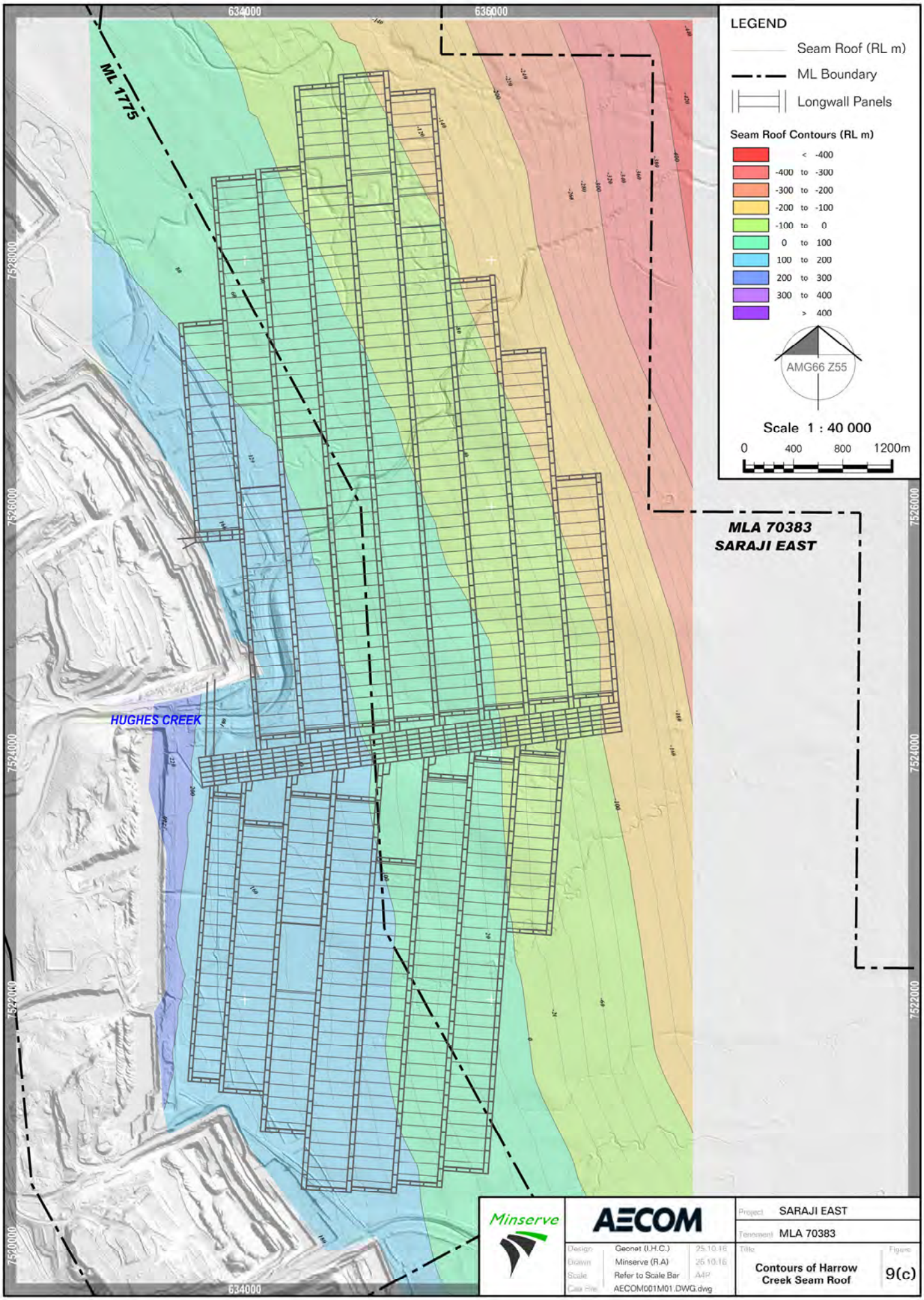
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Drawn	Minserve (R.A)	25.10.16
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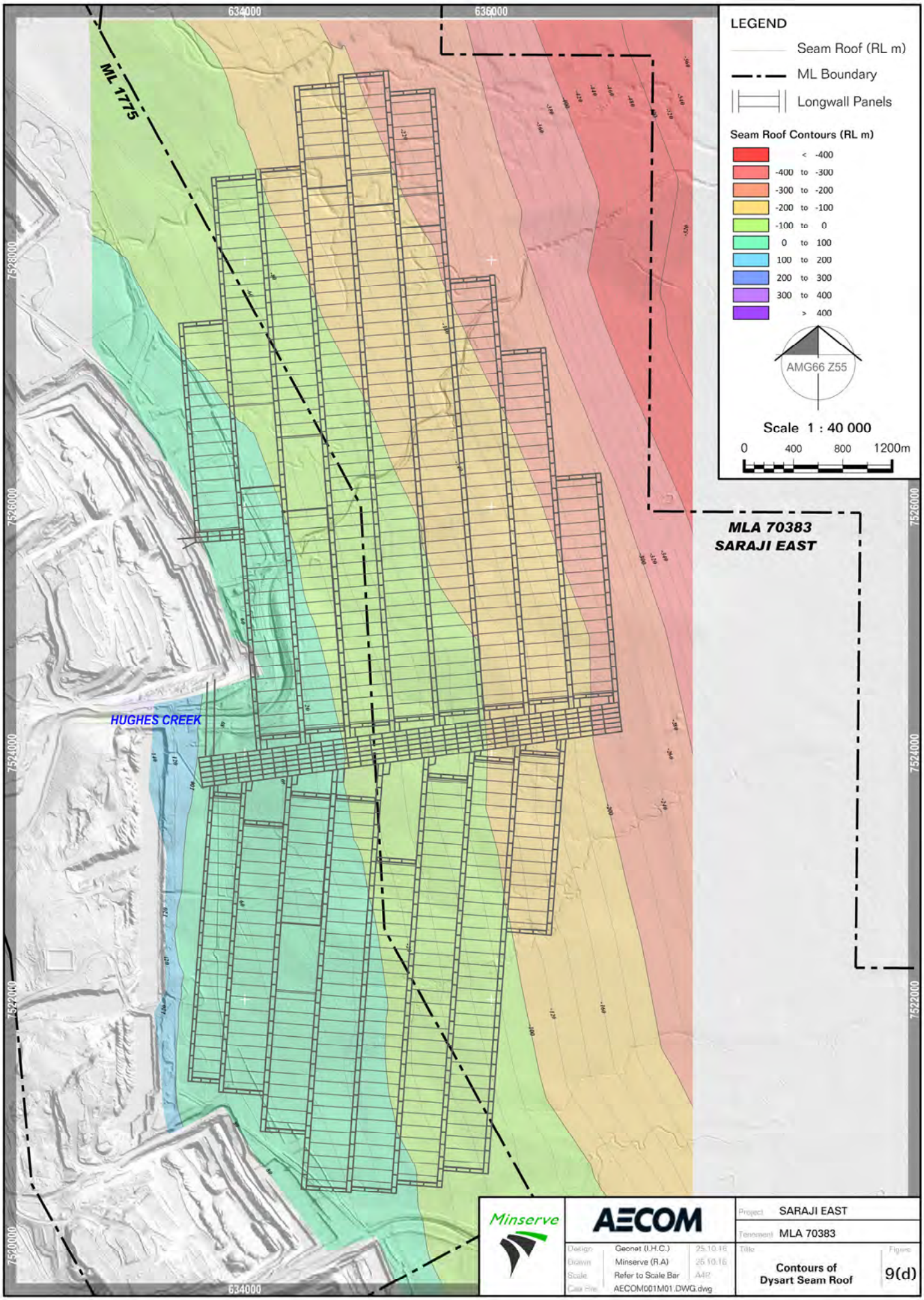
Project: SARAJI EAST

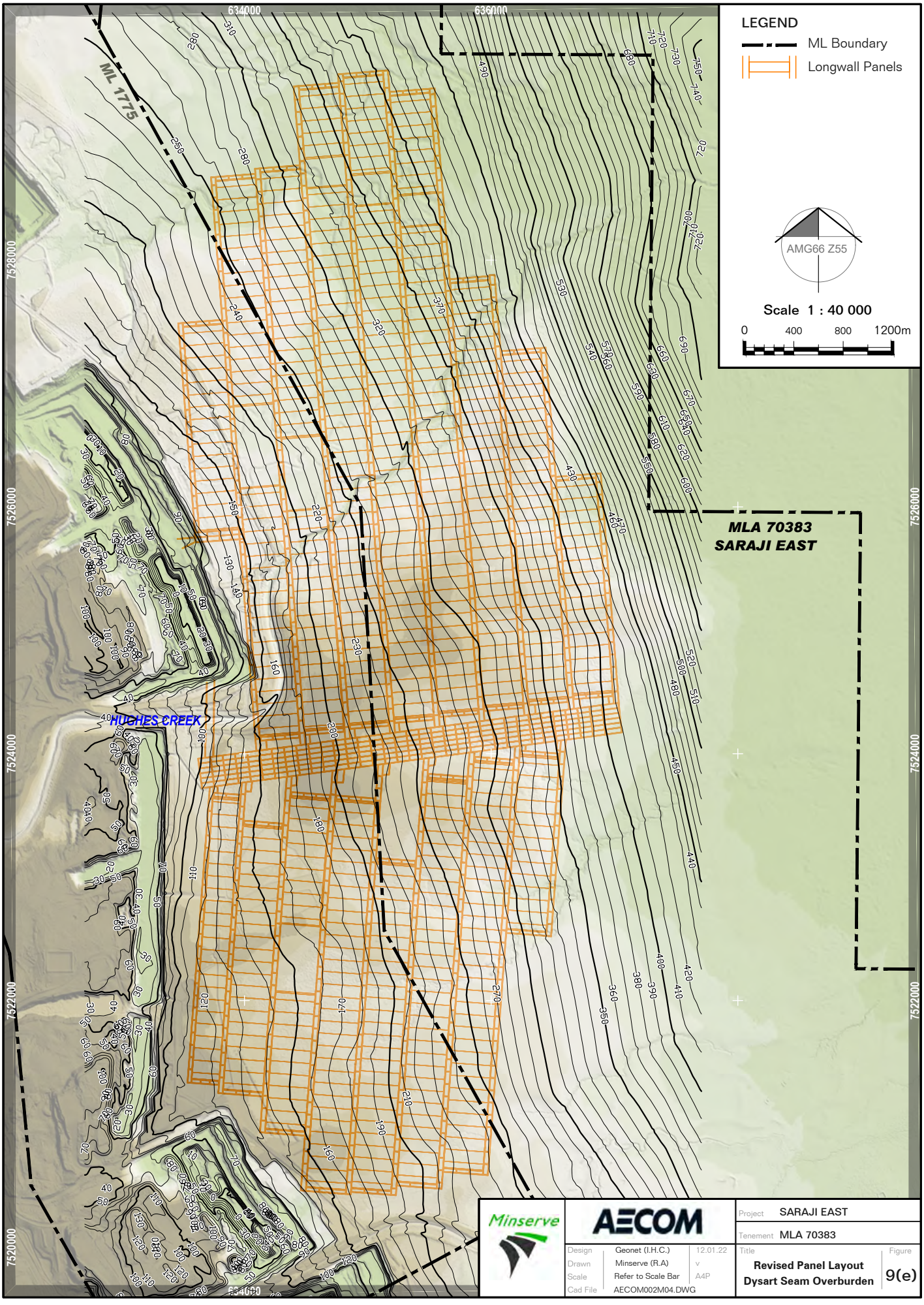
Tenement: MLA 70383

Title: **Contours of Base of Tertiary**

Figure: 9(b)


634000
636000
7528000
7526000
7524000
7522000
7520000
ML 1775
MLA 70383
SARAJI EAST
HUGHES CREEK
LEGEND
Seam Roof (RL m)
ML Boundary
Longwall Panels
Seam Roof Contours (RL m)
< -400
-400 to -300
-300 to -200
-200 to -100
-100 to 0
0 to 100
100 to 200
200 to 300
300 to 400
> 400
AMG66 Z55
Scale 1 : 40 000
0 400 800 1200m
Minserve
AECOM
Design Geonet (I.H.C.) 25.10.16
Drawn Minserve (R.A) 25.10.16
Scale Refer to Scale Bar A4P
Data File AECOM001M01.DWG.dwg
Project SARAJI EAST
Tenement MLA 70383
Title Contours of Harrow Creek Seam Roof
Figure 9(c)


634000
636000
7528000
7526000
7524000
7522000
7520000
ML 1775
MLA 70383
SARAJI EAST
HUGHES CREEK
LEGEND
Seam Roof (RL m)
ML Boundary
Longwall Panels
Seam Roof Contours (RL m)
< -400
-400 to -300
-300 to -200
-200 to -100
-100 to 0
0 to 100
100 to 200
200 to 300
300 to 400
> 400
AMG66 Z55
Scale 1 : 40 000
0 400 800 1200m
Minserve
AECOM
Design Geonet (I.H.C.) 25.10.16
Drawn Minserve (R.A) 25.10.16
Scale Refer to Scale Bar A4R
Cad File AECOM001M01.DWG.dwg
Project SARAJI EAST
Tenement MLA 70383
Title Contours of Dysart Seam Roof
Figure 9(d)



Minserve	AECOM	Project	SARAJI EAST
		Tenement	MLA 70383
Design	Geonet (I.H.C.)	12.01.22	Title: Revised Panel Layout Dysart Seam Overburden
Drawn	Minserve (R.A)	v	Figure: 9(e)
Scale	Refer to Scale Bar	A4P	
Cad File	AECOM002M04.DWG		

4.0 MODELLING METHODOLOGY

4.1 Model Design

In order to include the full extent of the Saraji East underground mine layout comprising the northern and southern panels, the geotechnical model was constructed to cover the area defined by the coordinate range:

Coordinate Range		Distance
632700 E	637700 E	5000 m
7519000 N	7530000 N	11000 m

In the model the geology was defined according to the following lithology surfaces provided by BMA: Surface topography, Base of Tertiary, Harrow Creek Upper (H16) seam roof and floor, Dysart (D24/D25) seam roof and floor.

Contour plots of these surfaces are presented in Figures 9(a), 9(b), 9(c) and 9(d). A contour plot of the Dysart Seam overburden thickness is shown in Figure 9(e).

The constructed model is shown in aerial plan view in Figure 10 presenting the overall model geometry and exposed geology in the open pit mining area. Superimposed on this plot is the outline of the revised layout of longwall panels. Included in Figure 10 are the locations of cross-sections used to present the results. Figures 11(a) to 11(d) show the geology on each of these cross-sections.

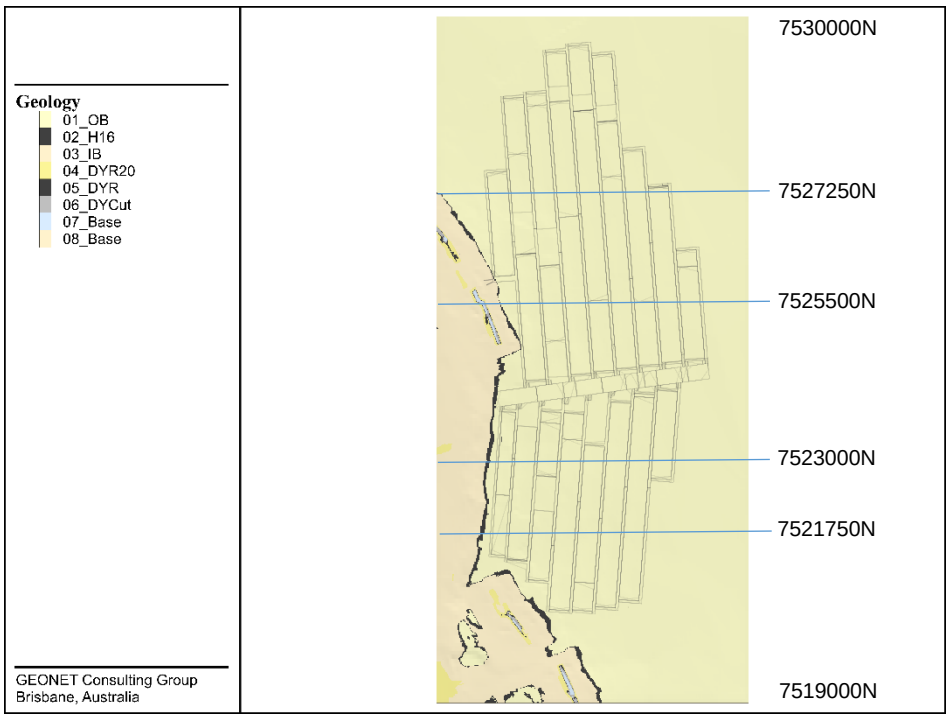


Figure 10: Plan view of over Saraji East UG Mine with location of cross-sections.

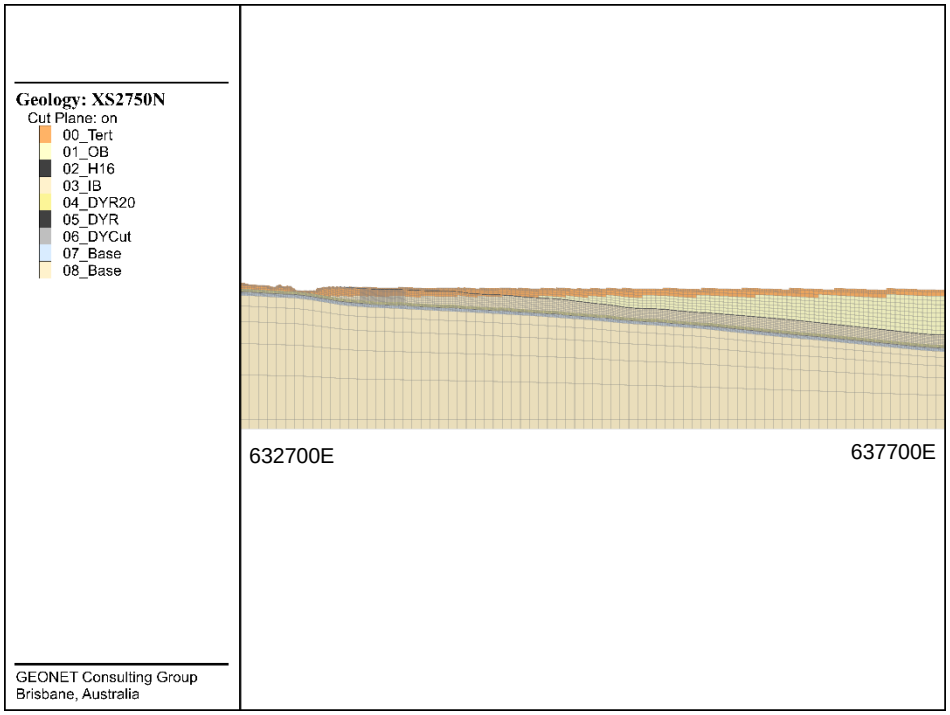


Figure 11(a) Geology on cross-section through Southern panels at 7521750N.

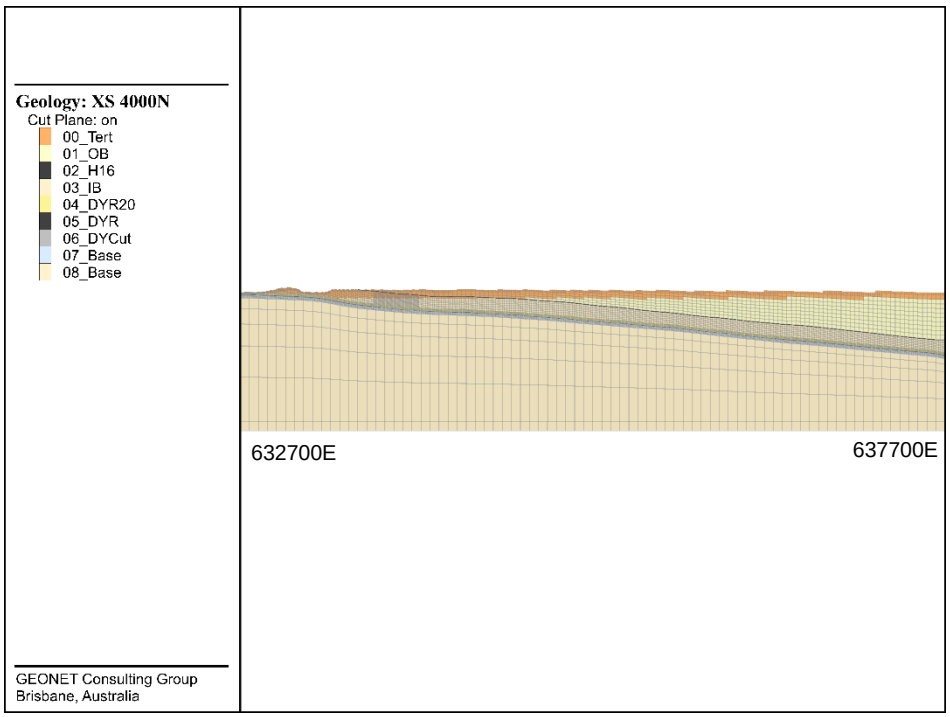


Figure 11(b) Geology on cross-section through Southern panels at 7523000N.

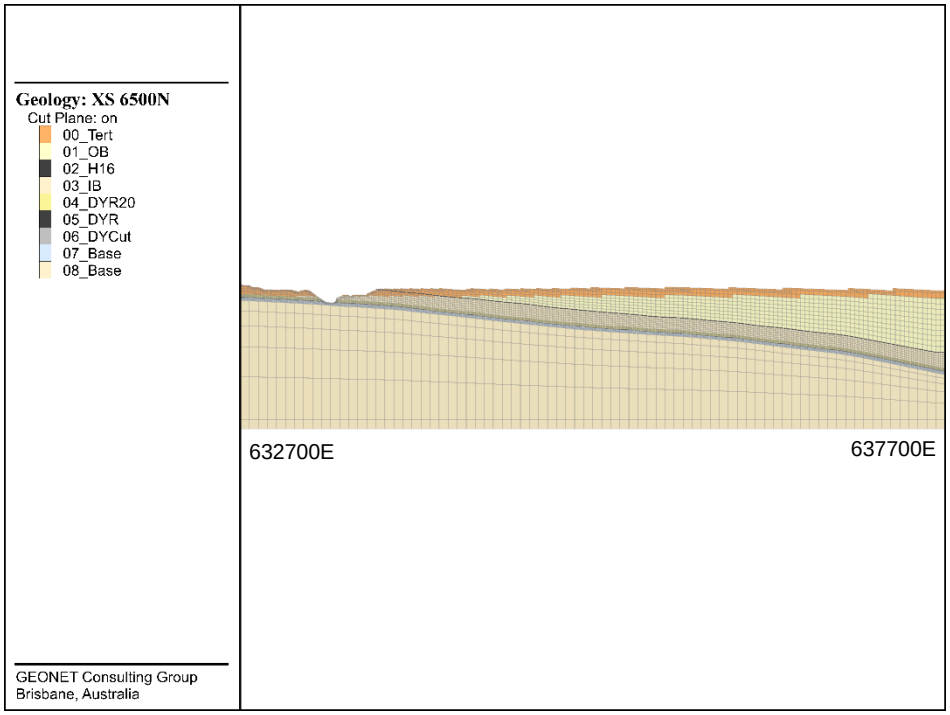


Figure 11(c) Geology on cross-section through Northern panels at 7525500N.

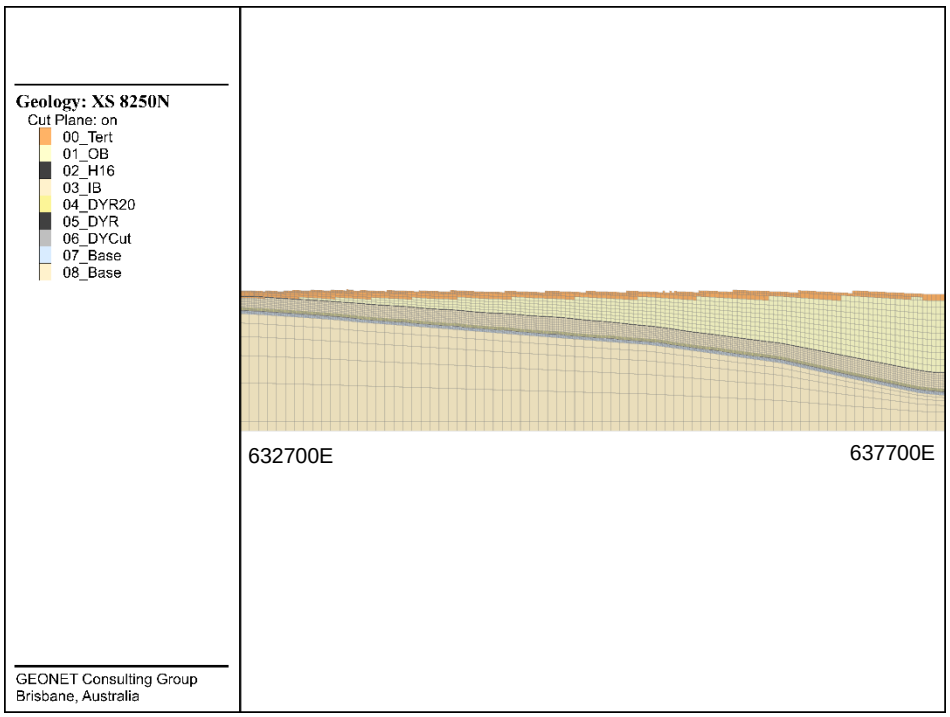


Figure 11(d) Geology on cross-section through Northern panels at 7527250N.

4.2 Modelling Method

To assess the overall rockmass subsidence over longwall mining panels, it is essential that the model simulates the critical rockmass behaviour. Thus the model must be capable of simulating the effect of bed separation, the opening of joints and the formation of new cracks in the originally intact overburden rockmass. Given the longwall panel dimensions these criteria can be adequately and accurately assessed in three-dimensional space with the program FLAC-3D [12].

The initial rockmass model extended from surface through 800m of elevation and laterally over a distance of 5000m in the east-west direction and 11000m in the north-south direction. The geology is mapped according to lithology surface profiles provided. Roller boundary conditions on the sides of the model effectively simulate an infinite lateral expanse of rockmass. This size of model provides sufficient rockmass to simulate the sequential excavation of the longwall panels without introducing edge effects.

Rockmass jointing in the overburden strata is simulated using the ubiquitous joint constitutive model where the high angle jointing and flat lying bedding planes are distributed through the overburden strata in relation to the local bedding dip angle. The proportion of joint and bedding planes is varied according to the rock type. Material input properties used in the model were validated against reported laboratory strength test data.

The mine scale modelling results provide an indication of deformation mechanisms that can be anticipated and the location and distribution of subsidence induced fractures, including the total surface subsidence across the longwall panels. Analyses have been made to determine the rockmass stress conditions, overburden rockmass damage and surface displacements associated with sequential longwall excavation.

4.3 Modelling Sequence

The model was set up to include the major geological strata with properties which reflected the original pre-mining conditions. The modelled section was then stepped through the following stages to simulate the mining operations:

i) Intact geology brought to equilibrium under applied insitu stress field and gravity.

ii) Open cut mining excavations cut into the model.

iii) Longwall panels excavated according to scheduled sequence, Figure 12.

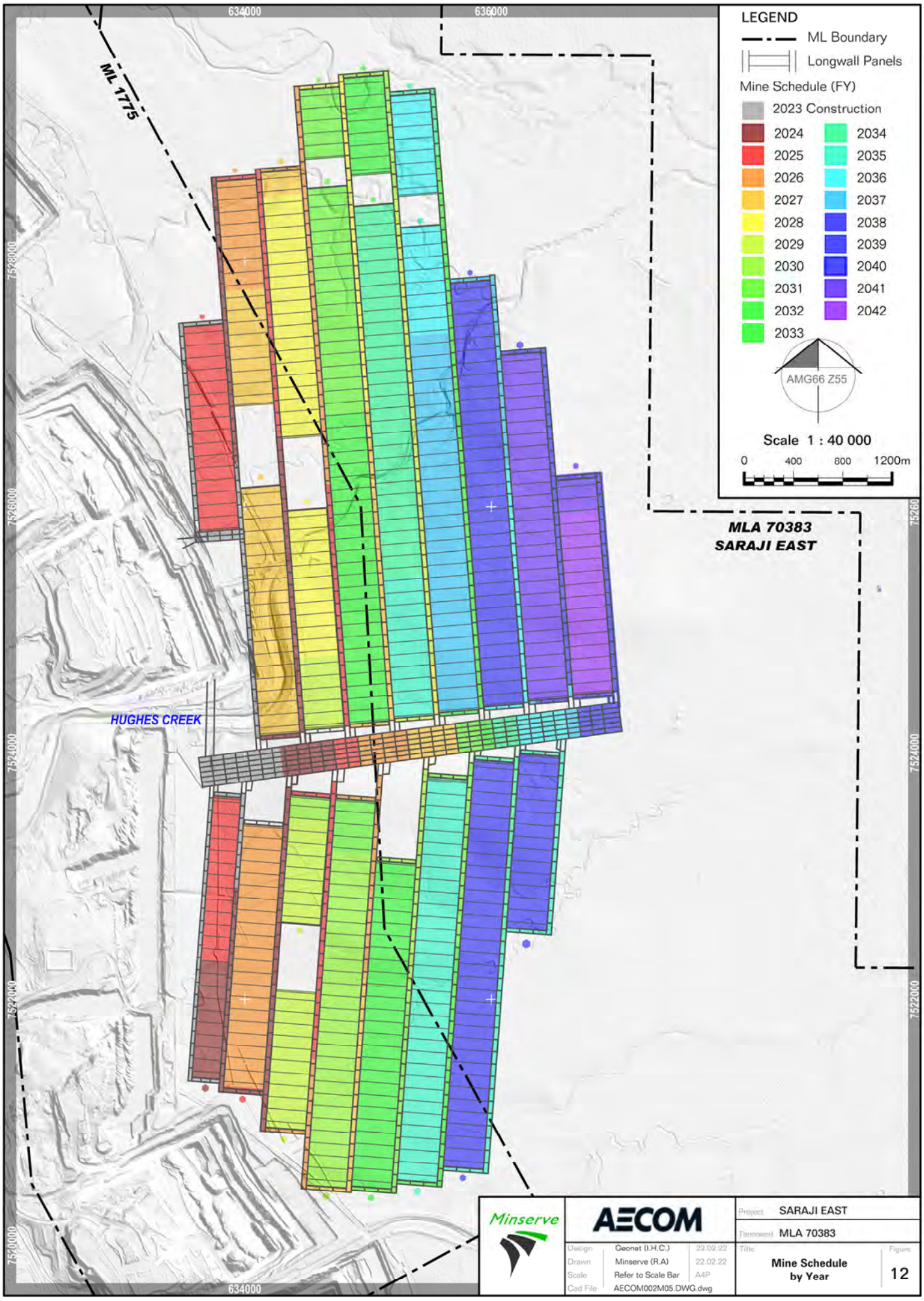
iv) Longwall coal extraction to uniform height of 3.6m.

v) After excavation of each stage, stresses and deformation were equilibrated.

vi) Roof rockmass allowed to collapse onto floor of longwall panel.

vii) Histories of displacement over the longwall panels were monitored.

viii) Changes in surface elevation calculated at each stage of mining to establish the post-mining topography at that period, viz. Years 2025, 2026, 2028, 2032 and 2042.


634000
636000
ML 1775
7528000
7526000
7524000
7522000
7520000
LEGEND
ML Boundary
Longwall Panels
Mine Schedule (FY)
2023 Construction
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034
2035
2036
2037
2038
2039
2040
2041
2042
AMG66 Z55
Scale 1 : 40 000
0
400
800
1200m
MLA 70383
SARAJI EAST
HUGHES CREEK
Minserve
AECOM
Design Geonet (I.H.C.) 22.02.22
Drawn Minserve (R.A) 22.02.22
Scale Refer to Scale Bar A4P
Cad File AECOM002M05.DWG.dwg
Project SARAJI EAST
Tenement MLA 70383
Title Mine Schedule by Year
Figure 12

5.0 SURFACE SUBSIDENCE OVER LONGWALL PANELS

5.1 Subsidence at Year 2 – Schedule 2025

Longwall mining commenced in 2024 in the southern panel LW201. Throughout year 2025 mining continued north in LW201 and then into the northern panel LW101. It is noted that LW201 is 220m wide whereas all the other longwalls are 320m wide. The extent of surface subsidence over the northern panel is shown in Figure 13(a) and in the southern panel in Figure 13(b). The following observations are made:

- Cover depth of overburden over LW201 varies between 120m and 130m whereas it ranges from 140m to 220m over LW101.
- Subsidence varies along the length and across each of the longwall panels. The maximum subsidence over LW201 is 2.7m and 3.4m over LW101.
- The surface subsidence trough over LW201 is contained within close proximity to the longwall footprint.
- The limit of continuous tension / shear cracks outside the longwall panel boundaries may be inferred from the 0.1m deformation contour (blue-white) on Figure 13. This limit extends to about 100m on the northern and north-eastern sides of LW101.
- The extent of subsidence over longwall as projected onto cross-section at 7521750N is shown in Figure 14(a) as contours of displacement. Goafing of the overburden strata extends through the Permian strata and up into the Tertiary sediments. The actual profile of surface subsidence is shown in the graph Figure 14(b). At this location the maximum surface subsidence of 2.7m is formed over LW201 where 3.6m of coal was mined under 120m of overburden.
- The extent of subsidence over longwall as projected onto cross-section at 7523000N is shown in Figure 15(a) as contours of displacement. Here goafing of the overburden strata is confined to the Permian strata. The actual profile of surface subsidence is shown in the graph Figure 15(b). At this location the maximum surface subsidence of 2.25m is developed over LW201 where 3.6m of coal was mined under 130m overburden.
- The extent of subsidence over longwall as projected onto cross-section at 7527250N is shown in Figure 16(a) as contours of displacement. Here goafing of the overburden strata is confined to the Permian strata of immediate Dysart seam overburden. The actual profile of surface subsidence is shown in the graph Figure 16(b). At this location the maximum surface subsidence of 2.2m is developed over LW101 where 3.6m of coal was mined under 210m overburden.
- The profile of surface subsidence along centerline of LW101 is shown in Figure 17(a). The subsided surface undulates along its length between 3.2m and 3.4m.
- The profile of surface subsidence along centerline of LW201 is shown in Figure 17(b). Over this longwall the maximum surface subsidence will be 2.7m over the section mined in 2024. The 2025 section has an undulating subsided surface along its length varying between 2.1m and 2.5m.

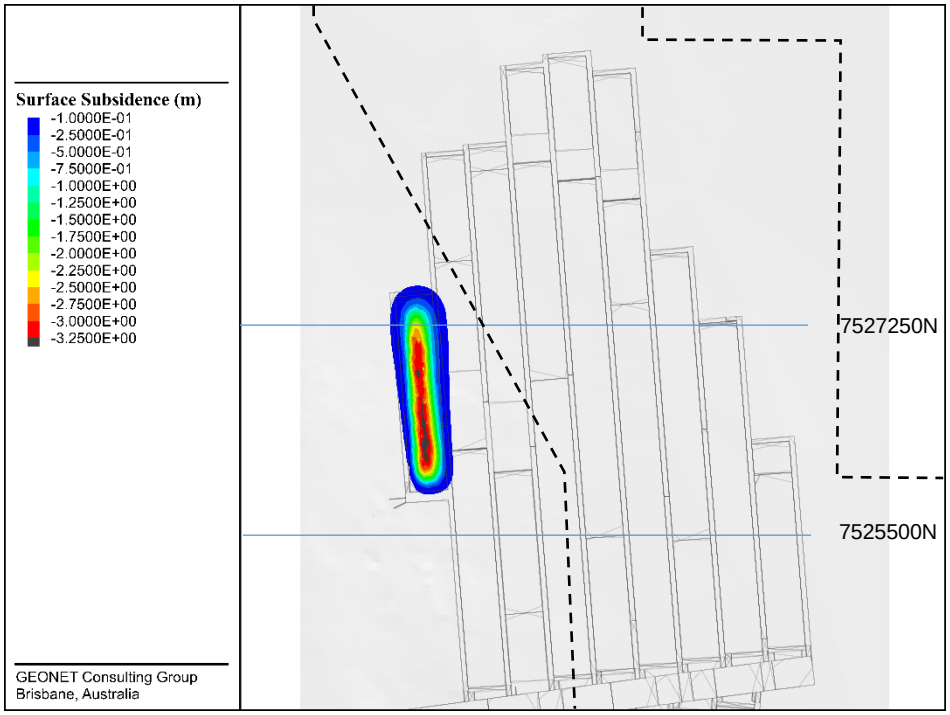


Figure 13(a): Subsidence on over Northern longwall panel LW101 at Year 2025

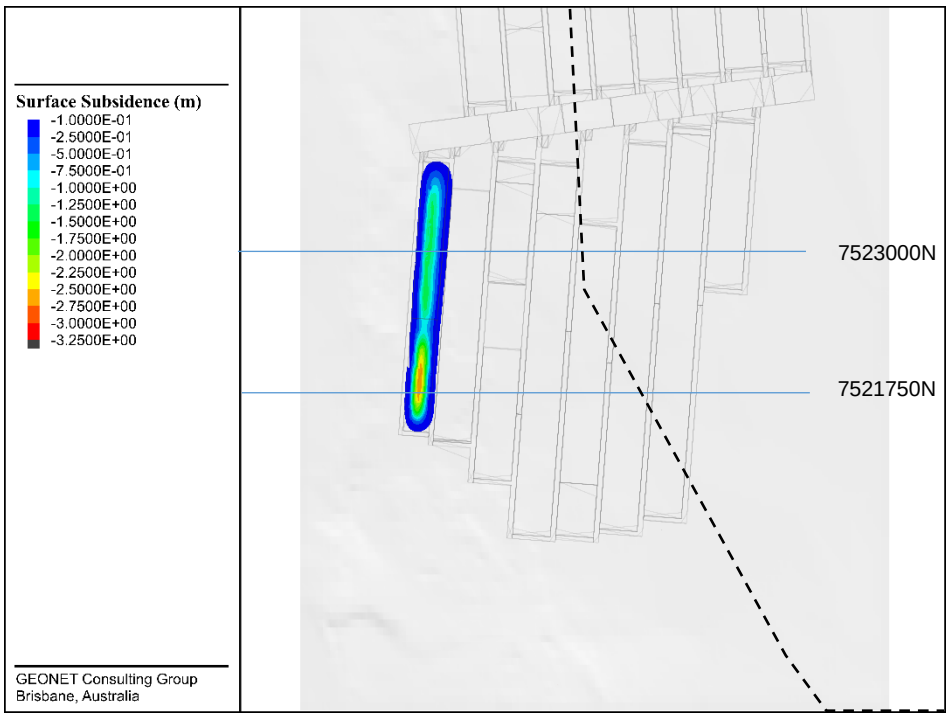


Figure 13(b): Subsidence on over Southern longwall panel LW201 at Year 2025

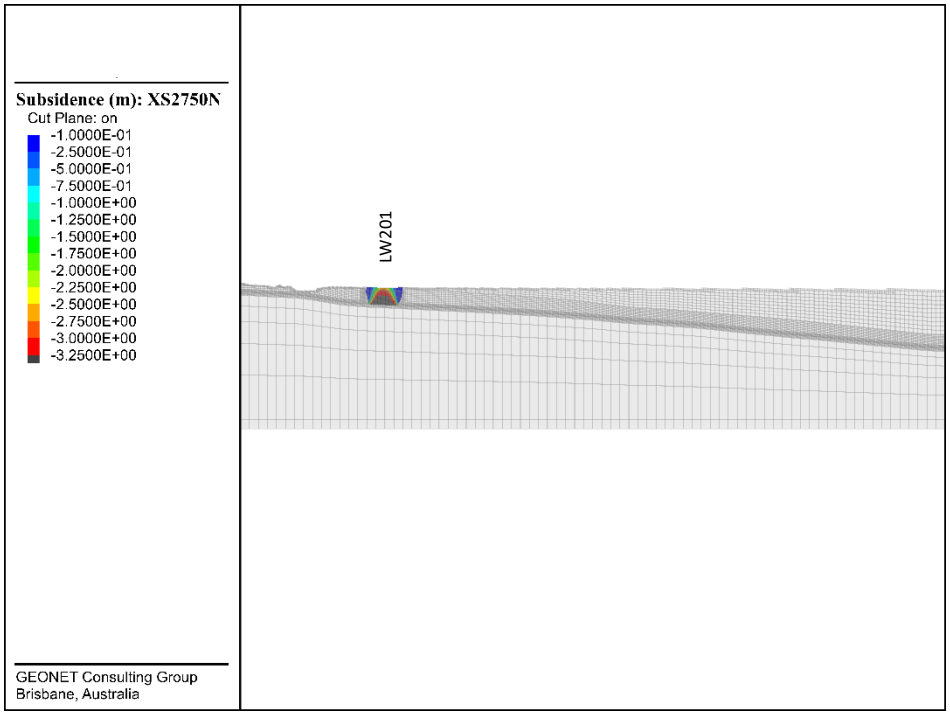


Figure 14(a): Year 2025 - Subsidence through Southern panel at 7521750N

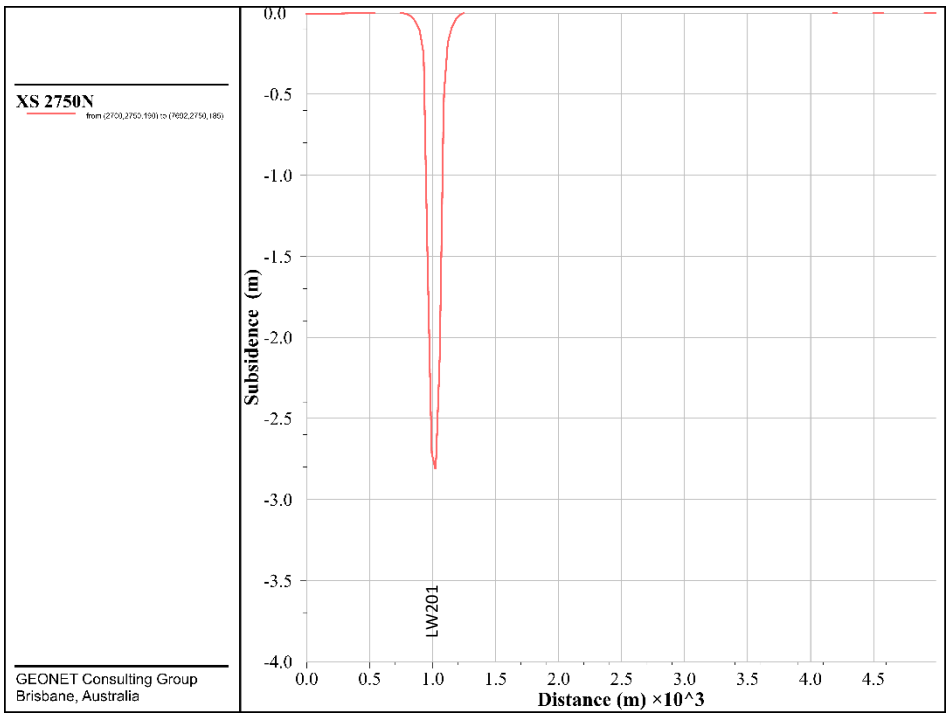


Figure 14(b): Year 2025 - Surface subsidence profile over Southern panel at 7521750N

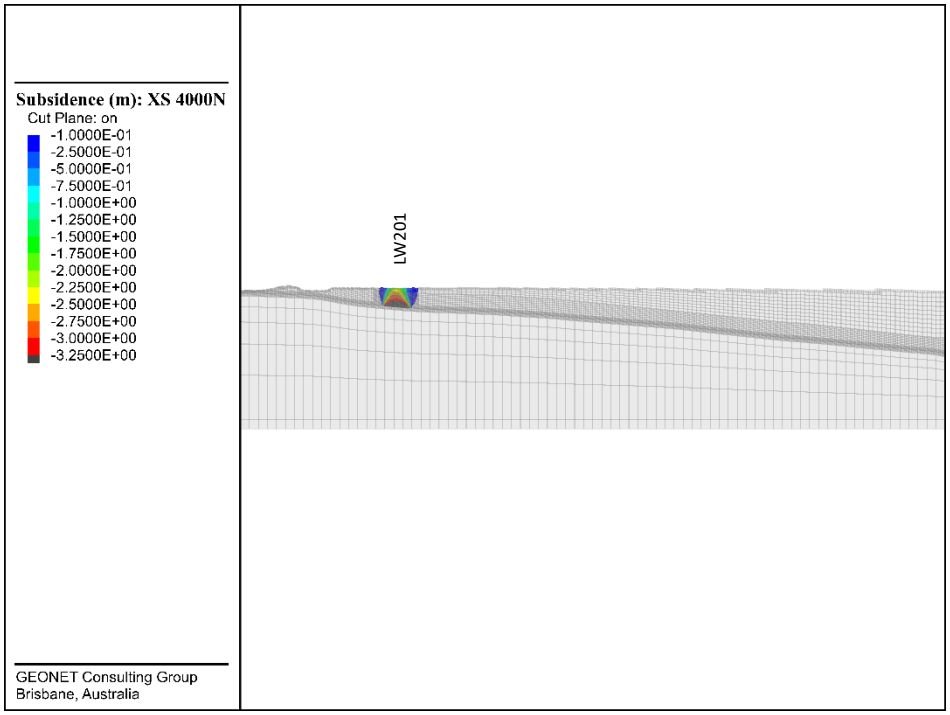


Figure 15(a): Year 2025 - Subsidence through Southern panel at 7523000N

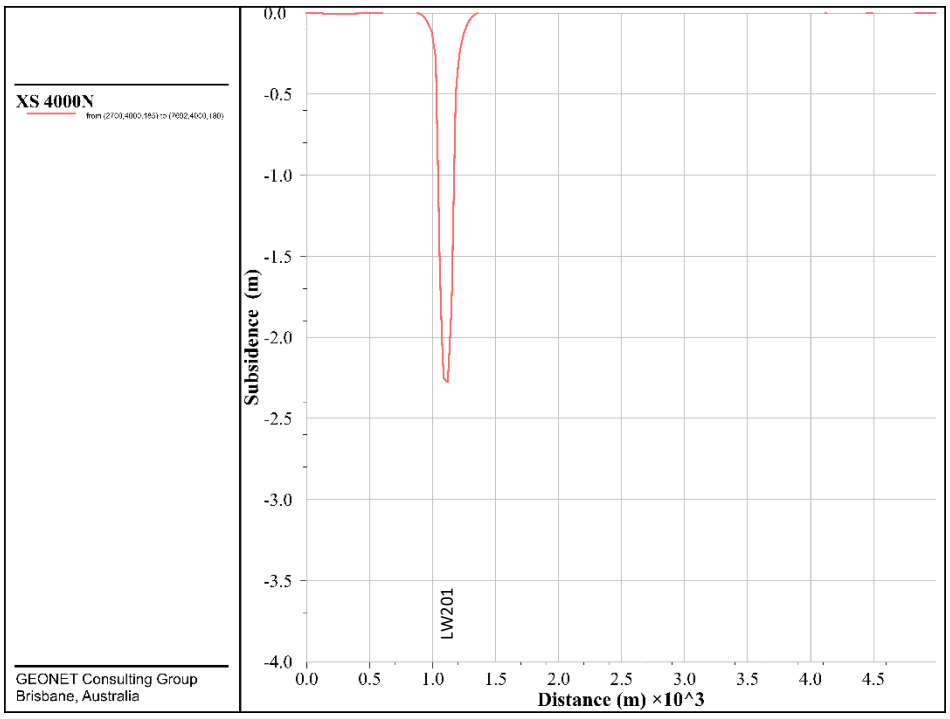


Figure 15(b): Year 2025 - Surface subsidence profile over Southern Panel at 7523000N

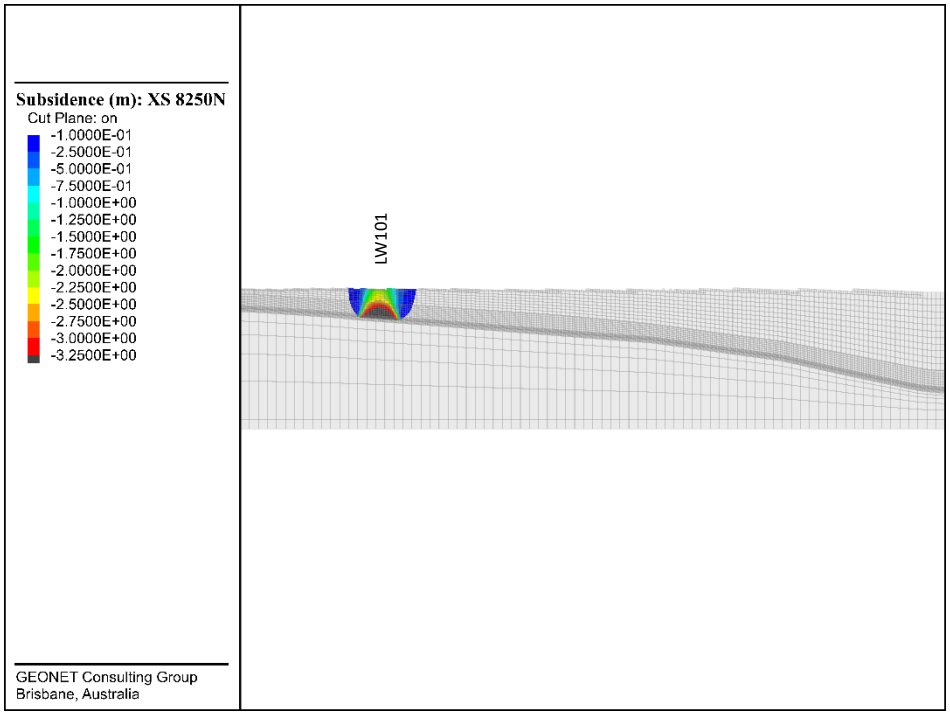


Figure 16(a): Year 2025 - Subsidence through Northern panel at 7527250N

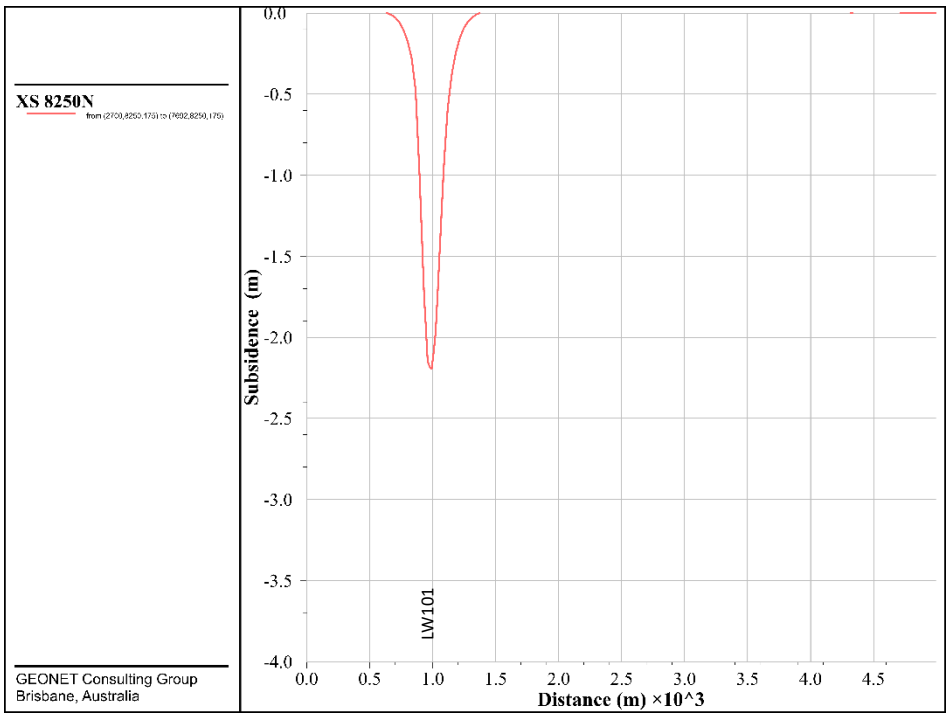


Figure 16(b): Year 2025 - Surface subsidence profile over Northern Panel at 7527250N

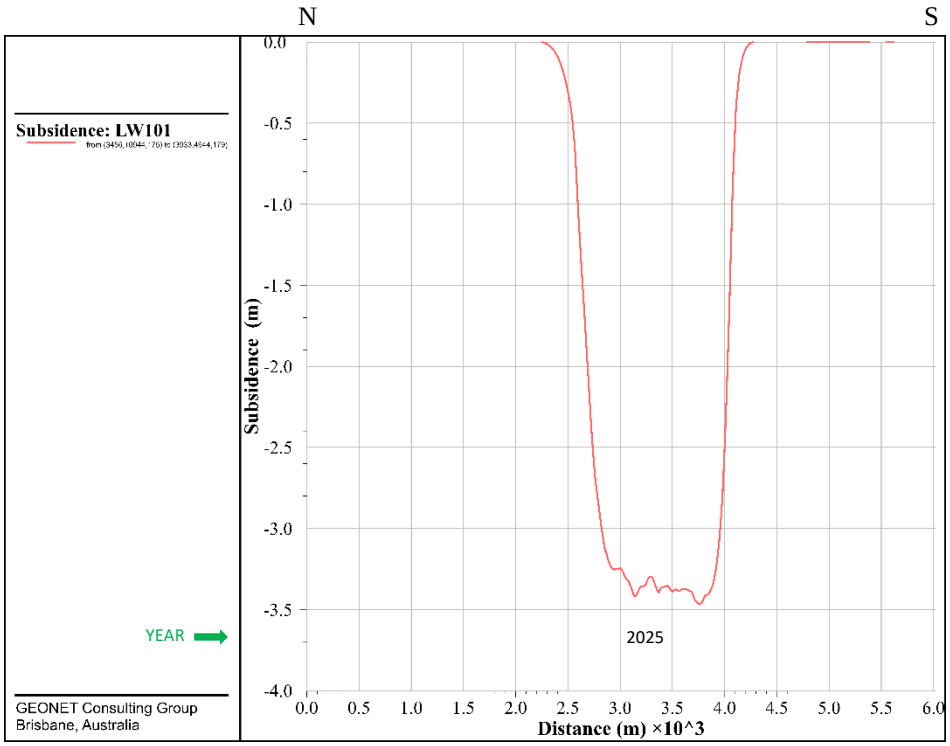


Figure 17(a): Year 2025 - Surface subsidence profile along LW101 (Northern Panel)

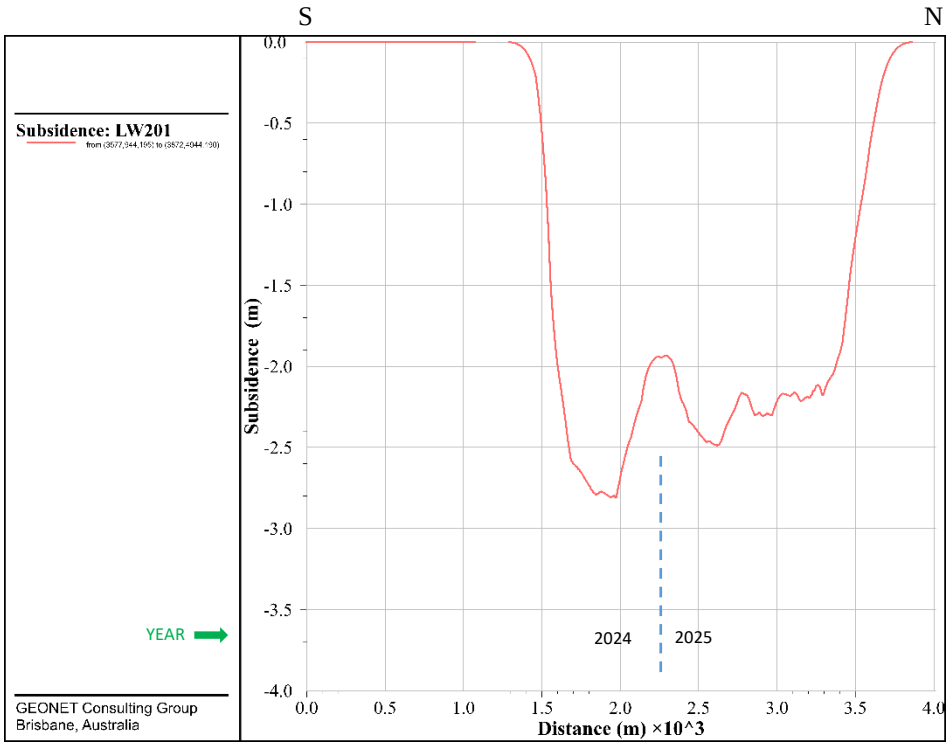


Figure 17(b): Year 2025 - Surface subsidence profile along LW201 (Southern Panel)

5.2 Subsidence at Year 3 – Schedule 2026

Longwall mining during the year 2026 is in the southern panel LW202 and in the northern portion of north panel LW102. The extent of surface subsidence over the northern panel is shown in Figure 18(a) and in the southern panel in Figure 18(b). The following observations are made:

- Cover depth of overburden over LW202 varies between 130m and 150m whereas it ranges from 250m to 270m over the northern section of LW102.
- Subsidence varies along the length and across each of the longwall sections. The maximum subsidence over LW202 is 3.4m and 2.25m over LW102.
- The surface subsidence trough over LW201 is contained within close proximity to the longwall footprint, Figure 18(b).
- The limit of continuous tension / shear cracks outside the longwall panel boundaries may be inferred from the 0.1m deformation contour (blue-white) on Figure 18(a). This limit extends to about 150m around the perimeter of extraction of LW102.
- The extent of subsidence over longwalls as projected onto the cross-section at 7521750N is shown in Figure 19(a) as contours of displacement. Goafing of the overburden strata extends through the Permian strata and up into the Tertiary sediments. The actual profile of surface subsidence is shown in the graph Figure 19(b). At this location the maximum surface subsidence of 2.7m is formed over LW201 and 3.25m over LW202 where the overburden thickness is 130m.
- The extent of subsidence over the longwalls as projected onto cross-section at 7523000N is shown in Figure 20(a) as contours of displacement. Here goafing of the overburden strata is confined to the Permian strata extending up to the base of Tertiary over LW202. The actual profile of surface subsidence is shown in the graph Figure 20(b). At this location the maximum surface subsidence of 2.25m is developed over LW201 and 3.4m over LW202 where the overburden thickness is 150m.
- The extent of subsidence over longwall as projected onto cross-section at 7527250N is shown in Figure 21(a) as contours of displacement. Here goafing of the overburden strata is confined to the Permian strata of immediate Dysart seam overburden extending up to the Harrow Creek seam. The actual profile of surface subsidence is shown in the graph Figure 21(b). At this location the maximum surface subsidence of 2.2m is developed over LW101 where 3.6m of coal was mined under 210m overburden.
- The profile of surface subsidence along centerline of LW101 is shown in Figure 22(a). The subsided surface undulates along its length between 3.2m and 3.4m. The subsidence profile for the adjacent LW102 is shown in Figure 23(a) where it can be seen that the maximum subsidence is 2.2m through 240m of overburden strata.
- The profile of surface subsidence along centerline of LW201 is shown in Figure 22(b). Over this longwall the maximum surface subsidence will be 2.7m over the section mined in 2024. The 2025 section has an undulating subsided surface along its length varying between 2.1m and 2.4m. The subsidence profile along LW102, Figure 23(a), shows subsidence to range between 3.0m and 3.4m.

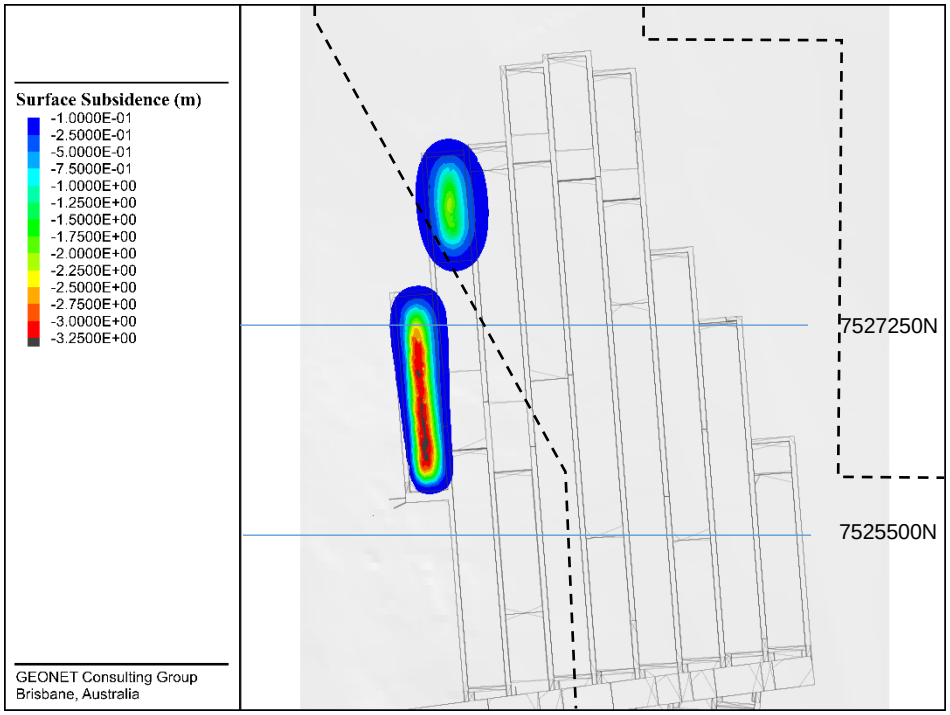


Figure 18(a): Subsidence on over Northern longwall panel at Year 2026

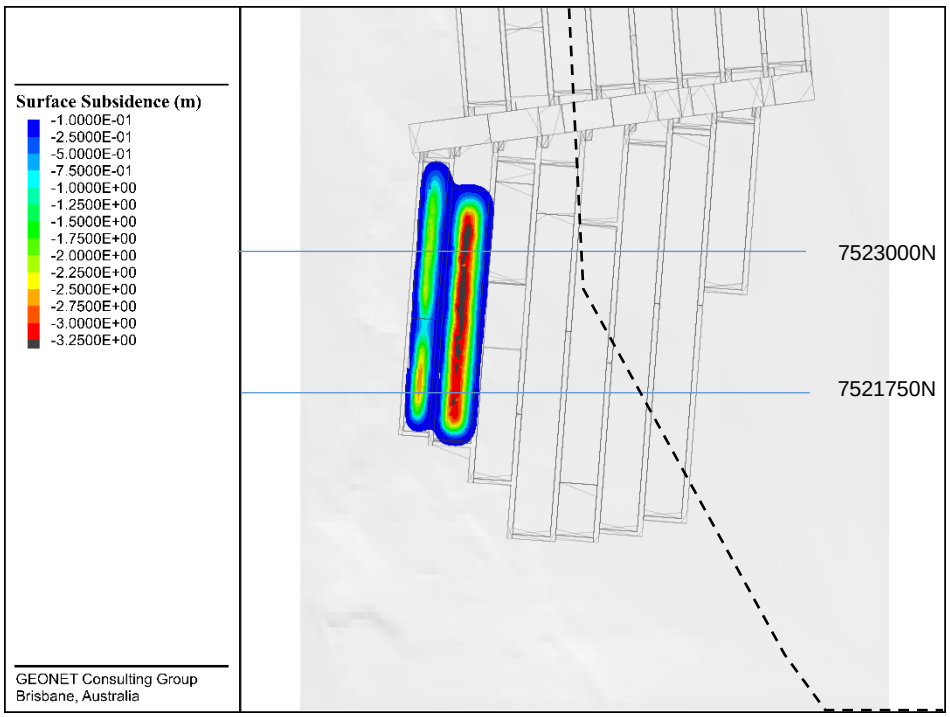


Figure 18(b): Subsidence on over Southern longwall panel at Year 2026

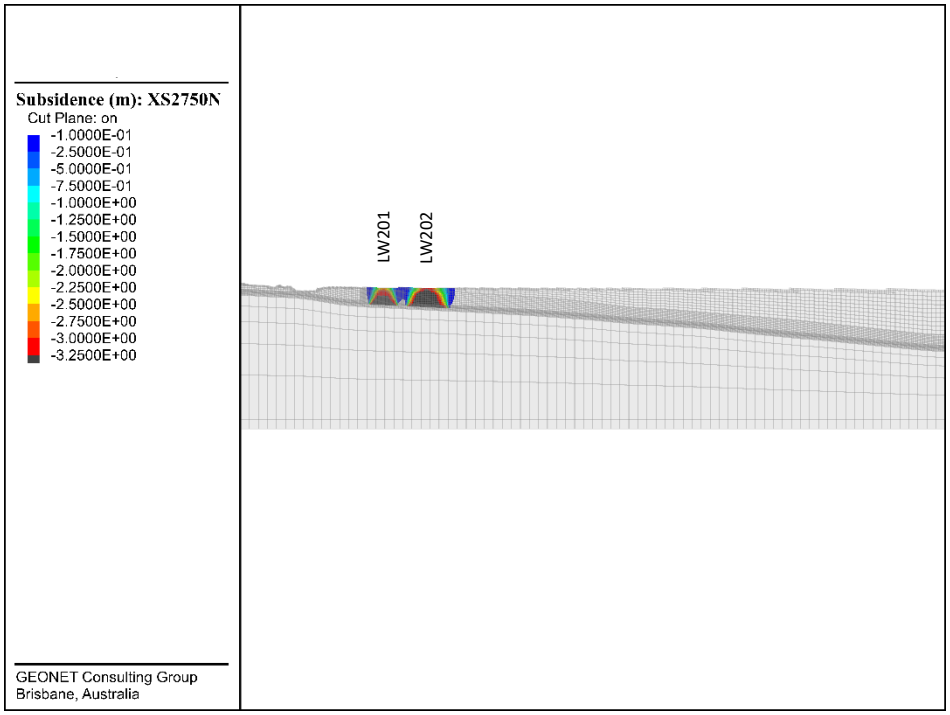


Figure 19(a): Year 2026 - Subsidence through Southern panel at 7521750N

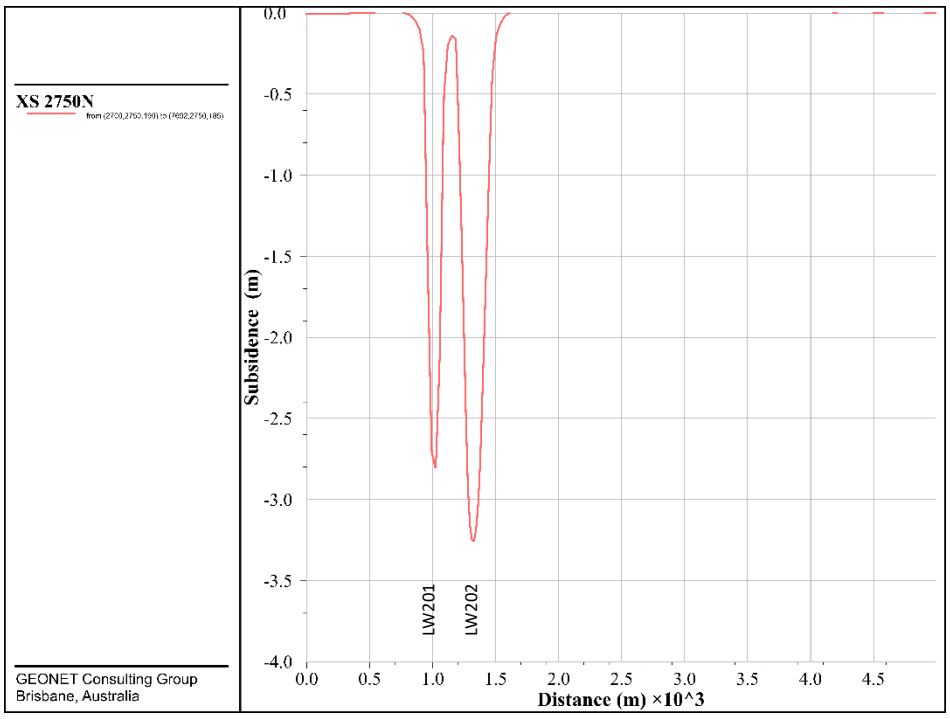


Figure 19(b): Year 2026 - Surface subsidence profile over Southern panel at 7521750N

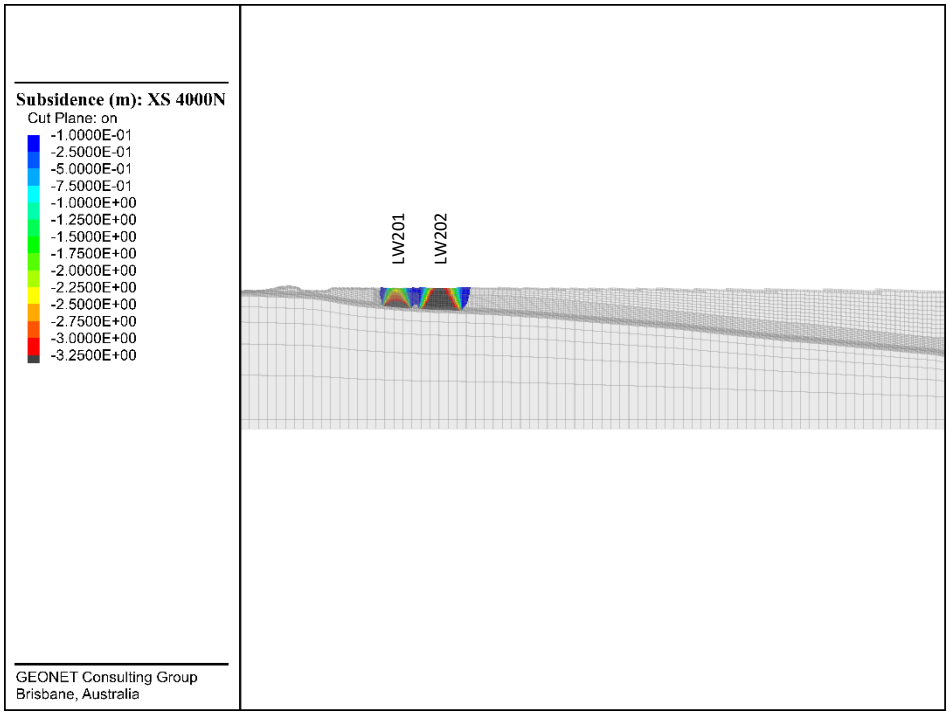


Figure 20(a): Year 2026 - Subsidence through Southern panel at 7523000N

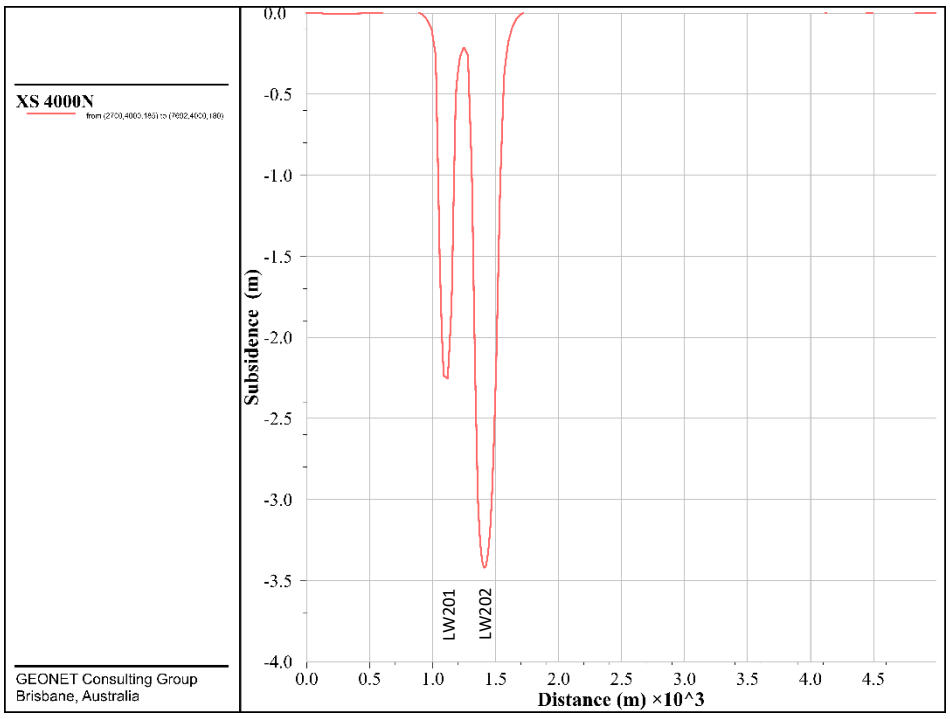


Figure 20(b): Year 2026 - Surface subsidence profile over Southern Panel at 7523000N

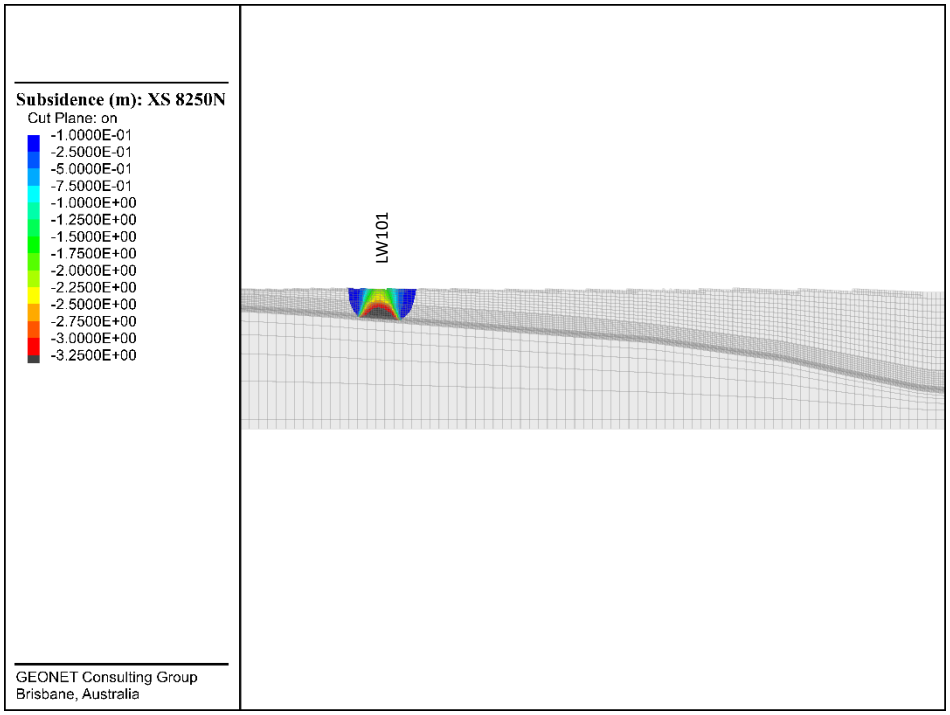


Figure 21(a): Year 2026 - Subsidence through Northern panel at 7527250N

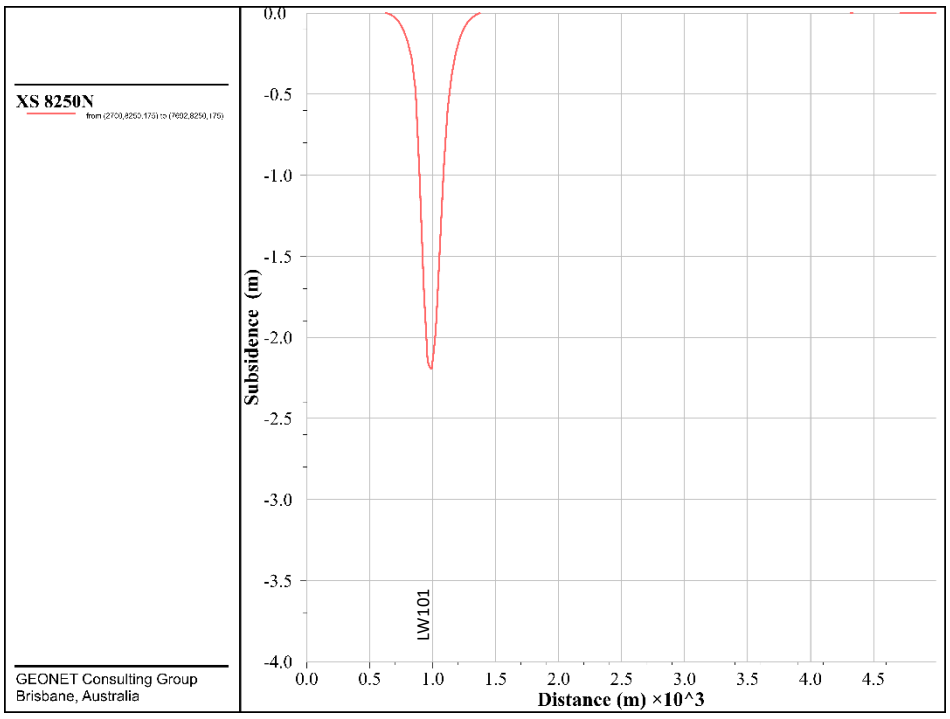


Figure 21(b): Year 2026 - Surface subsidence profile over Northern Panel at 7527250N

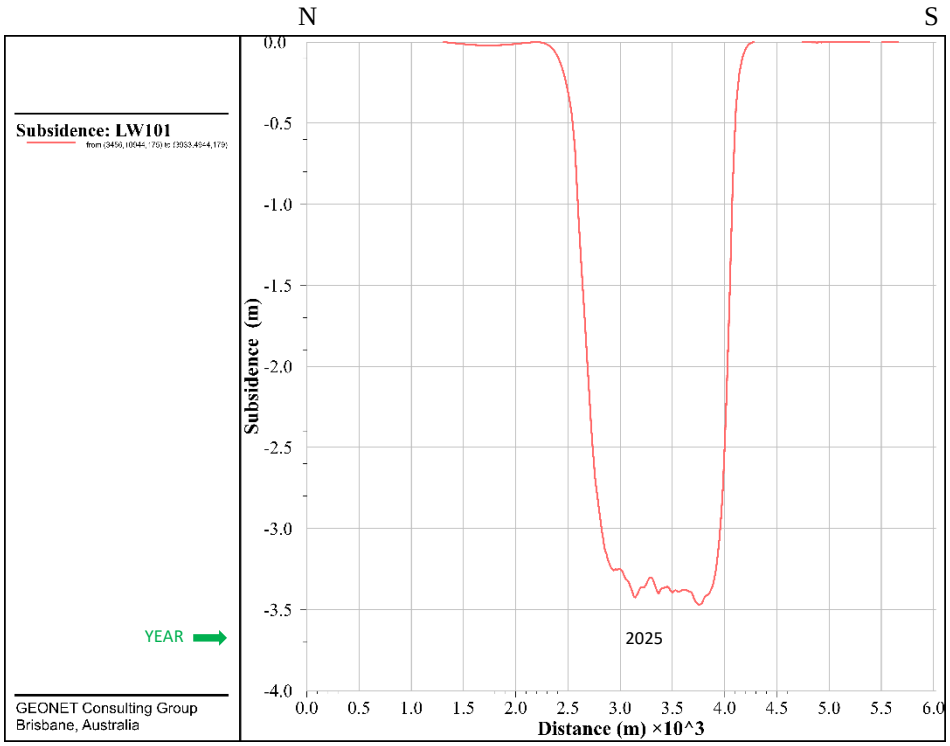


Figure 22(a): Year 2026 - Surface subsidence profile along LW101 (Northern Panel)

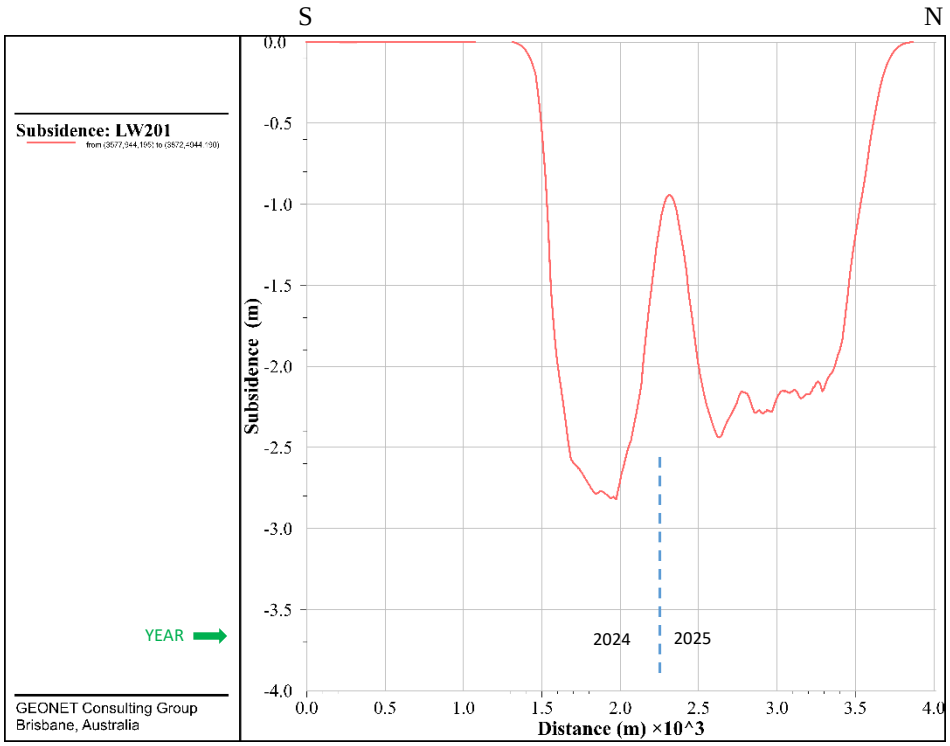


Figure 22(b): Year 2026 - Surface subsidence profile along LW201 (Southern Panel)

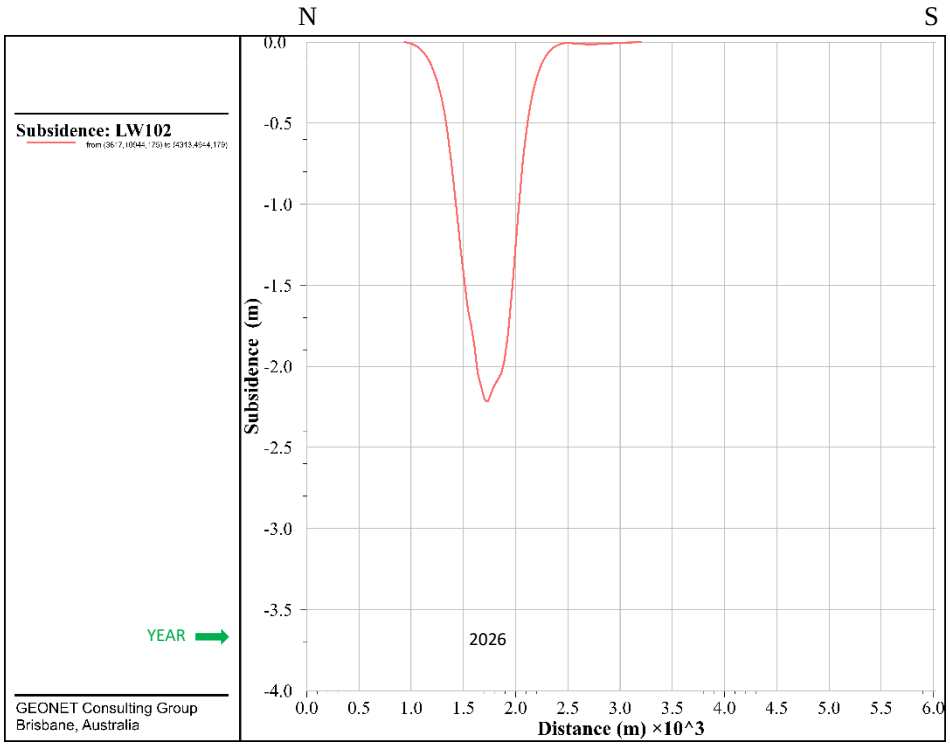


Figure 23(a): Year 2026 - Surface subsidence profile along LW102 (Northern Panel)

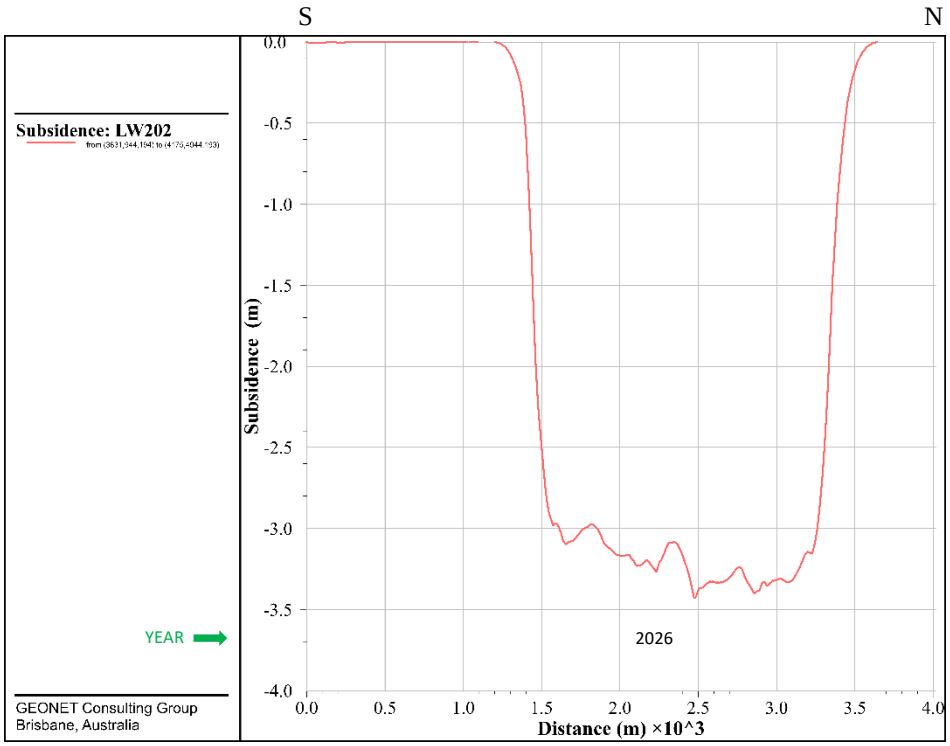


Figure 23(b): Year 2026 - Surface subsidence profile along LW202 (Southern Panel)

5.3 Subsidence at Year 6 – Schedule 2028

Longwall mining continues in to Year 2027 by extracting the section of LW102 located north of the barrier pillar, then continuing in the southern section of LW102 and starting the face set up at the northern end of LW103. During 2028 mining progresses southwards in LW103 before crossing over the LW103 barrier pillar and continuing another kilometer. There is no mining in the southern panel during the period 2026 to 2028.

The extent of surface subsidence over the northern panel is shown in Figure 24(a) and over the southern panel in Figure 24(b). The following observations are made:

- Since no longwall mining has occurred in the southern panel during this period there is negligible change in surface subsidence profiles over LW201 and LW202. For completeness the subsidence plots on the selected cross-sections and along the longwall centerline are presented in Figures 25, 26 and 30.
- The limit of continuous tension / shear cracks outside the longwall panel boundaries may be inferred from the 0.1m deformation contour (blue-white) on Figure 24(a). This limit extends to about 200m around the northern and eastern perimeter of LW103.
- The extent of subsidence over longwalls as projected onto the cross-section at 7525500N is shown in Figure 27(a) as contours of displacement. Goafing of the overburden strata extends through the Permian strata and up into the Tertiary sediments. The actual profile of surface subsidence is shown in the graph Figure 27(b). At this location the maximum surface subsidence of 3.3m is formed over LW102 and 3.1m over LW103 where the overburden thickness is 200m.
- The extent of subsidence over longwalls as projected onto the cross-section at 7527250N is shown in Figure 28(a) as contours of displacement. Goafing of the overburden strata extends through the Permian strata and up into the Tertiary sediments only over LW102. Over LW101 and LW103 goafing is confined to the Permian strata below Harrow Creek seam. The actual profile of surface subsidence is shown in the graph Figure 28(b). At this location the maximum surface subsidence is predicted to be 2.25m over LW101, 3.1m over LW102 and 2.4m over LW103 where the overburden thickness increases to 260m.
- The profile of surface subsidence along centerline of LW102 is shown in Figure 29(a) and along LW103 in Figure 29(b). The subsided surface undulates along its length with the subsidence increasing as overburden thickness reduces.
- The subsidence profile along LW103, Figure 29(b), clearly demonstrates this effect. At the far northern end, the overburden thickness is 300m and this reduces down to 230m when the longwall reaches the barrier pillar. South of the barrier pillar the overburden thickness reduces from 210m to 200m at the end of mining in Year 2028
- The profile of surface subsidence along centerline of LW201 is shown in Figure 30(a) and along LW202 in Figure 30(b). As stated previously, there was no mining in this southern panel during this period so that the changes in subsidence profile are negligible.

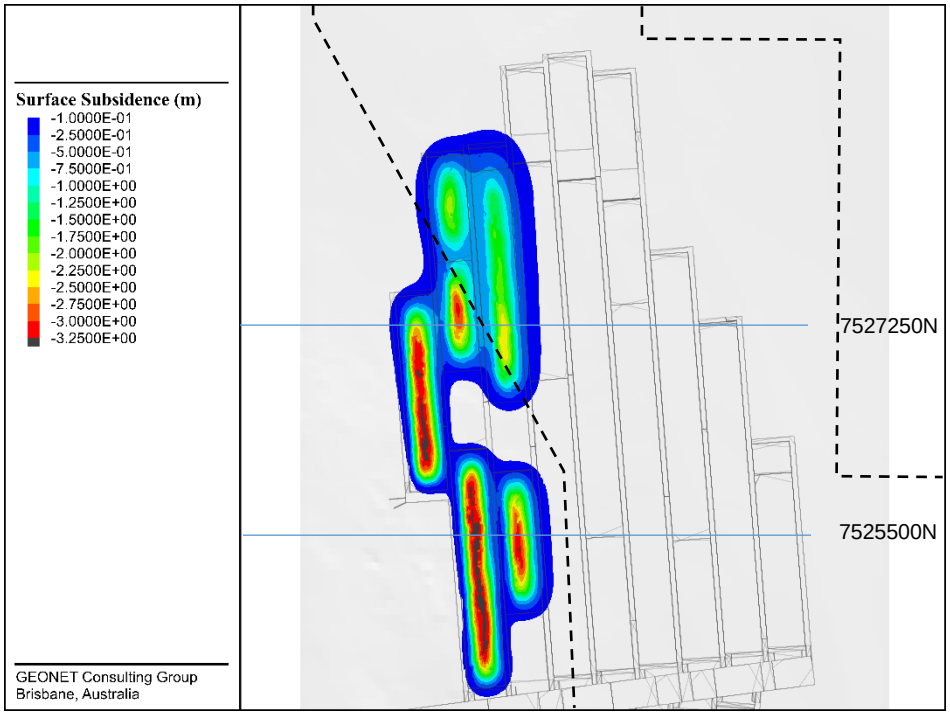


Figure 24(a): Subsidence on over Northern longwall panel at Year 2028

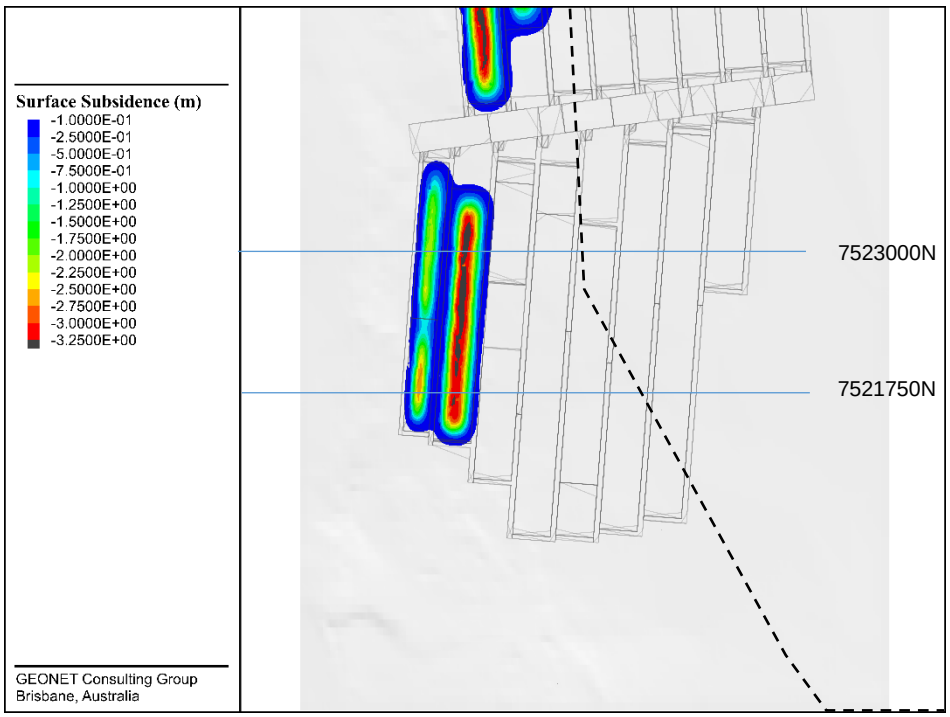


Figure 24(b): Subsidence on over Southern longwall panel at Year 2028

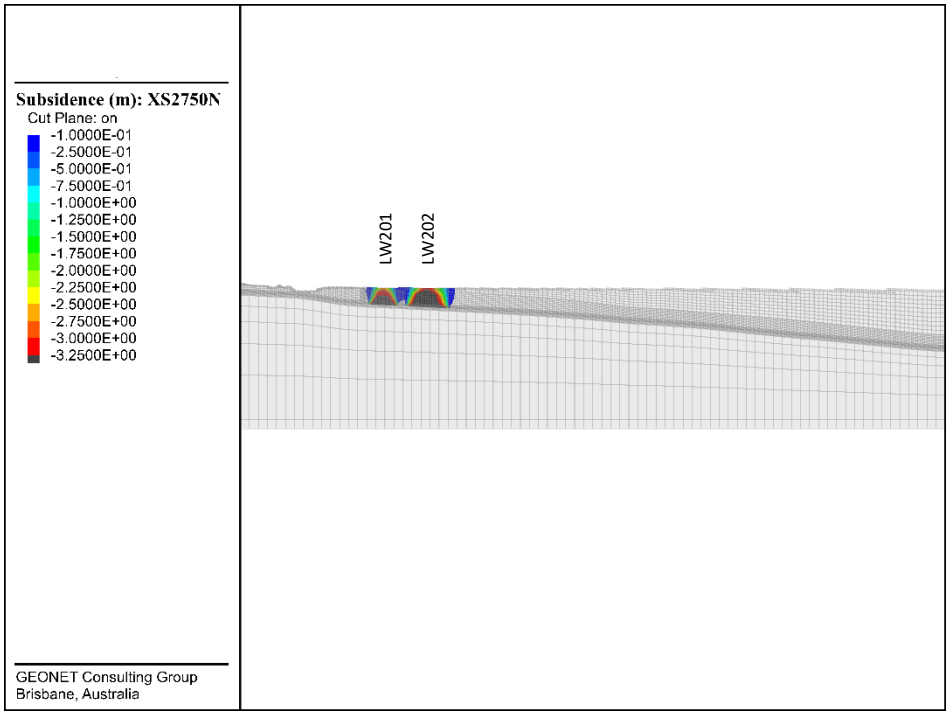


Figure 25(a): Year 2028 - Subsidence through Southern panel at 7521750N

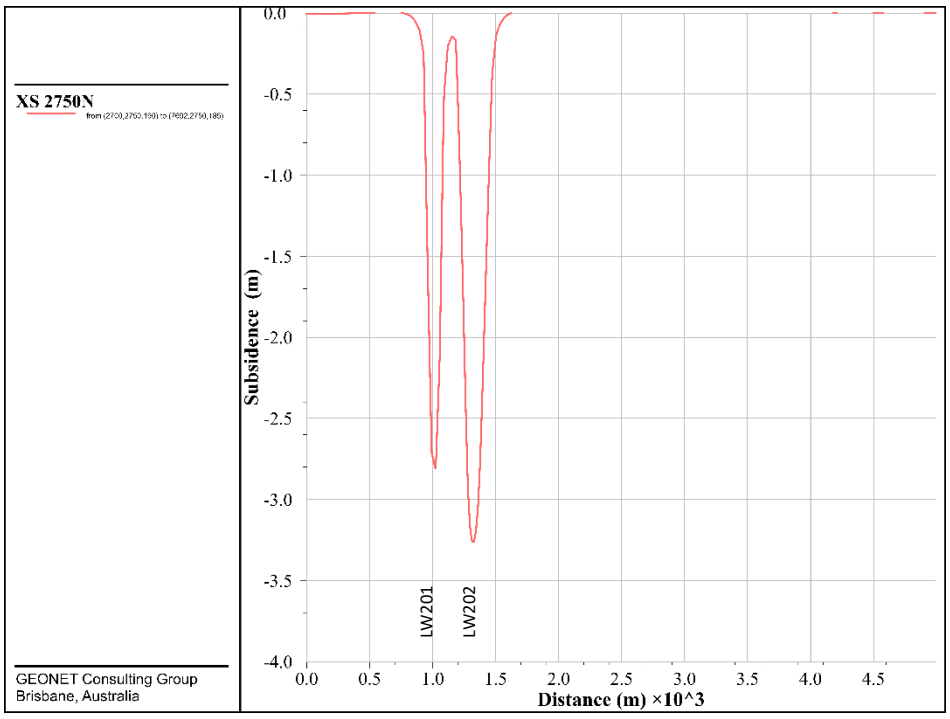


Figure 25(b): Year 2028 - Surface subsidence profile over Southern panel at 7521750N

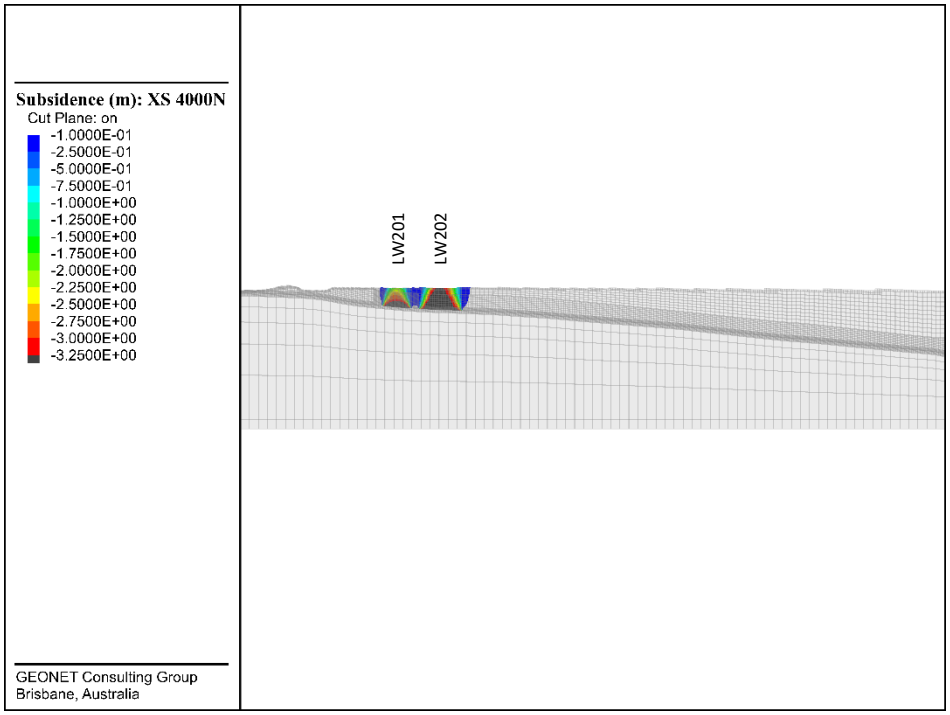


Figure 26(a): Year 2028 - Subsidence through Southern panel at 7523000N

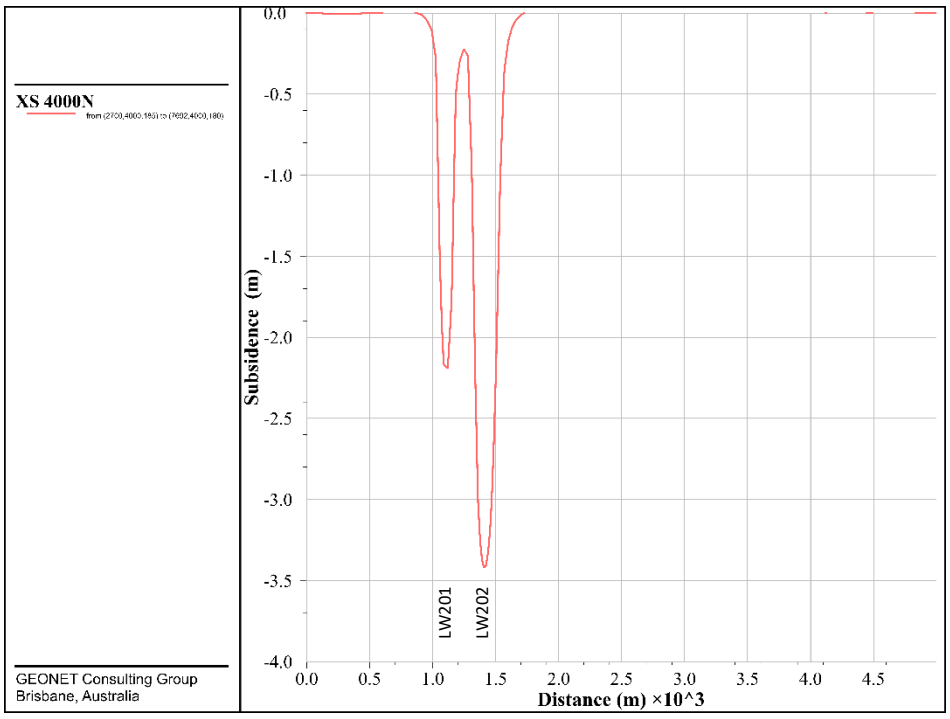


Figure 26(b): Year 2028 - Surface subsidence profile over Southern Panel at 7523000N

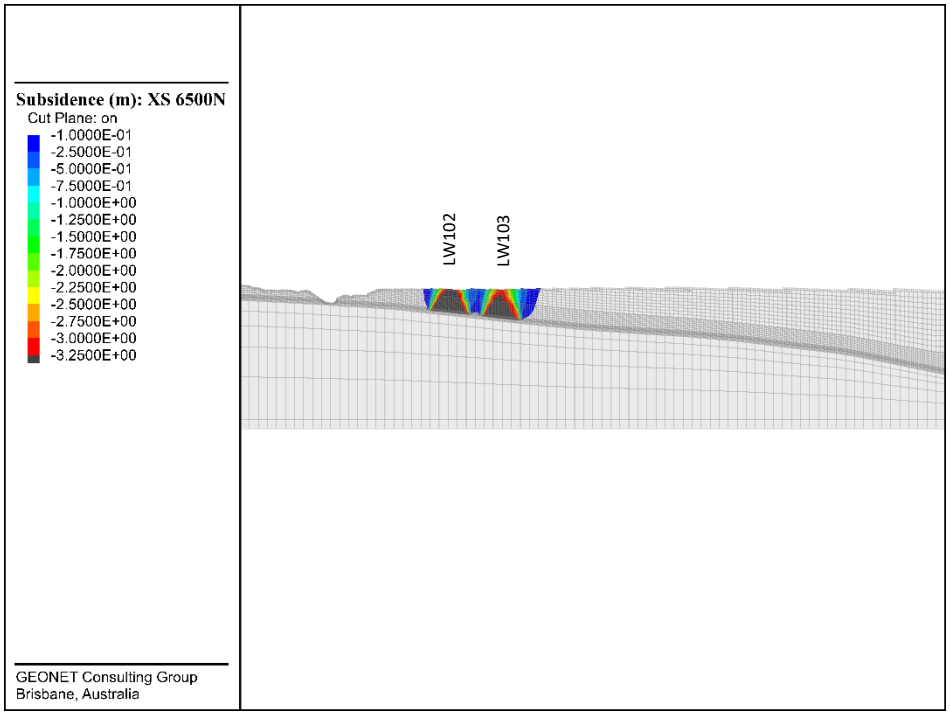


Figure 27(a): Year 2028 - Subsidence through Northern panel at 7525500N

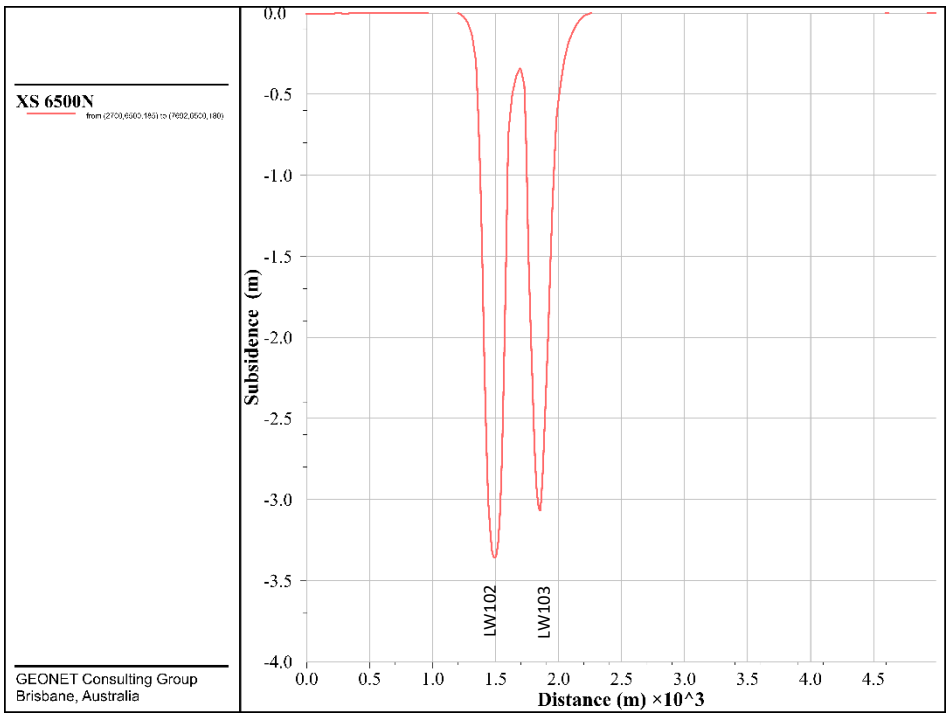


Figure 27(b): Year 2028 - Surface subsidence profile over Northern Panel at 7525500N

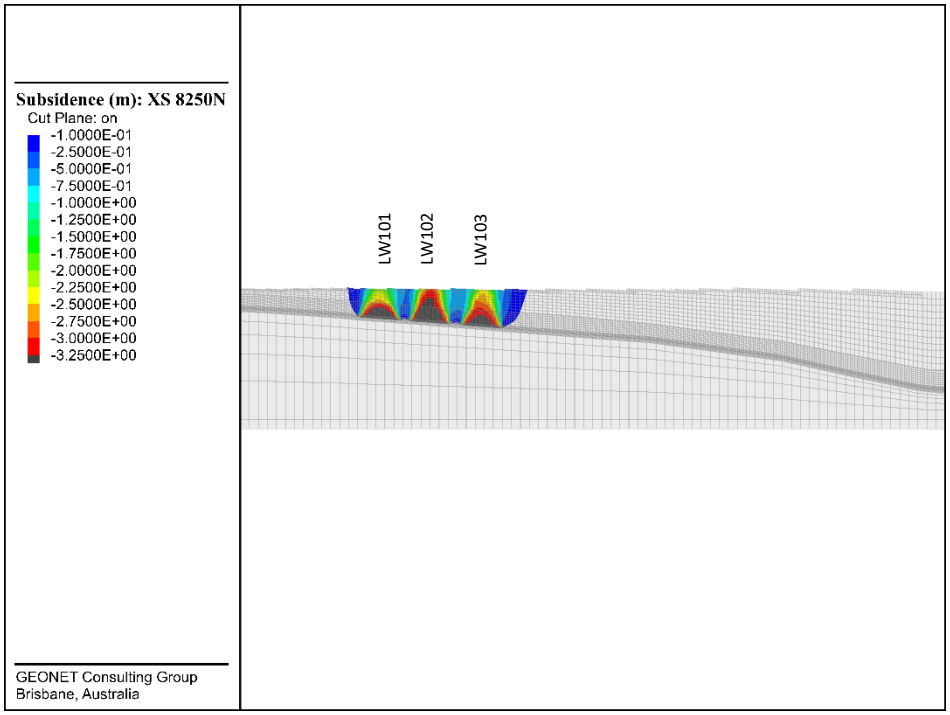


Figure 28(a): Year 2028 - Subsidence through Northern panel at 7527250N

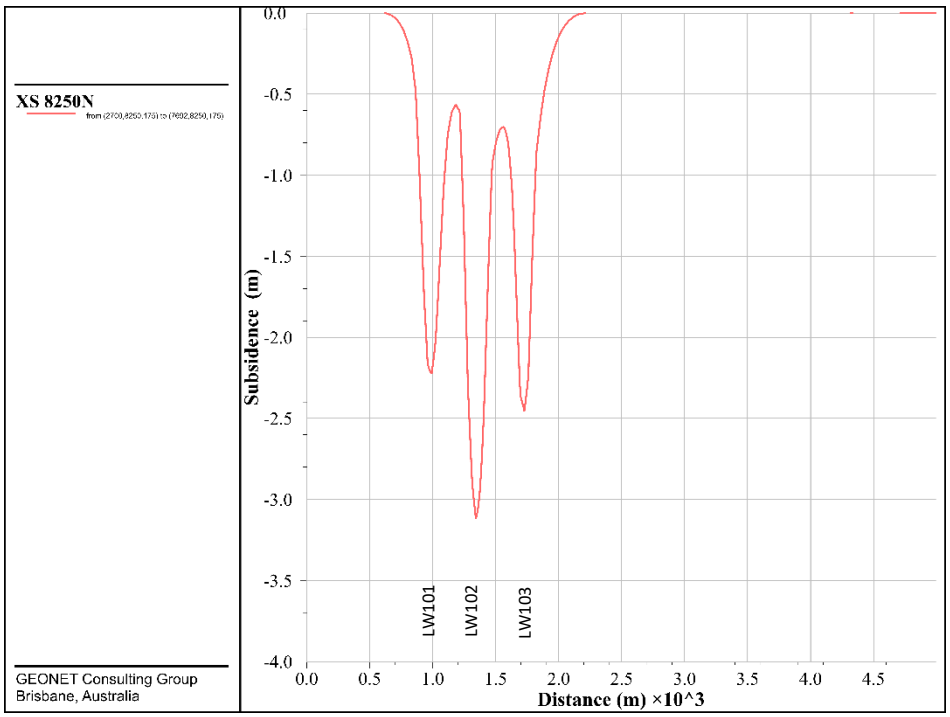


Figure 28(b): Year 2028 - Surface subsidence profile over Northern Panel at 7527250N

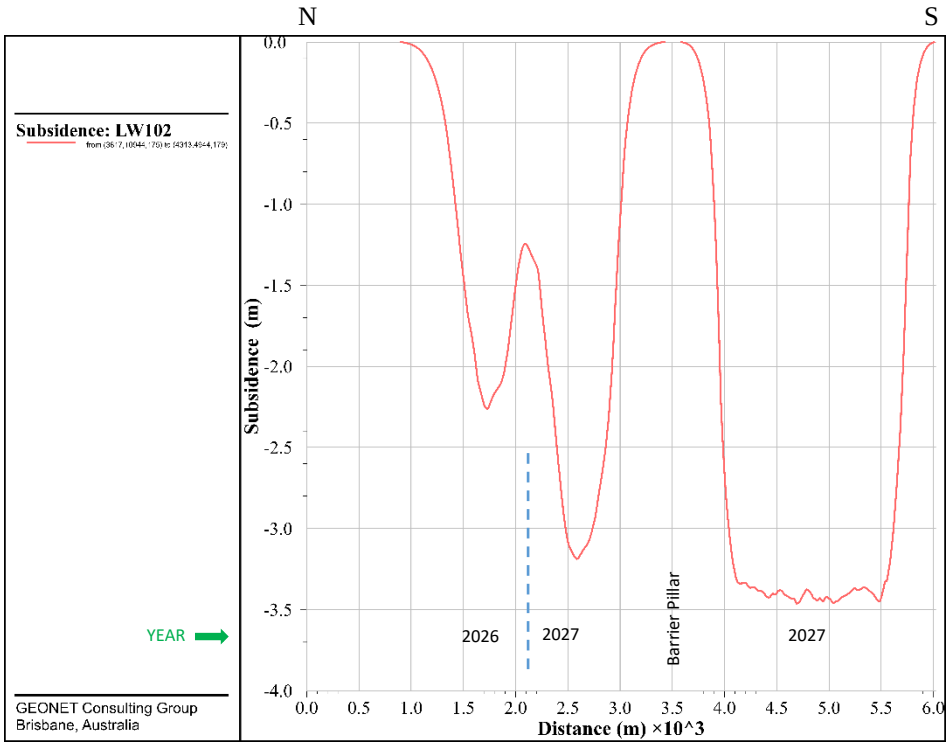


Figure 29(a): Year 2028 - Surface subsidence profile along LW102 (Northern Panel)

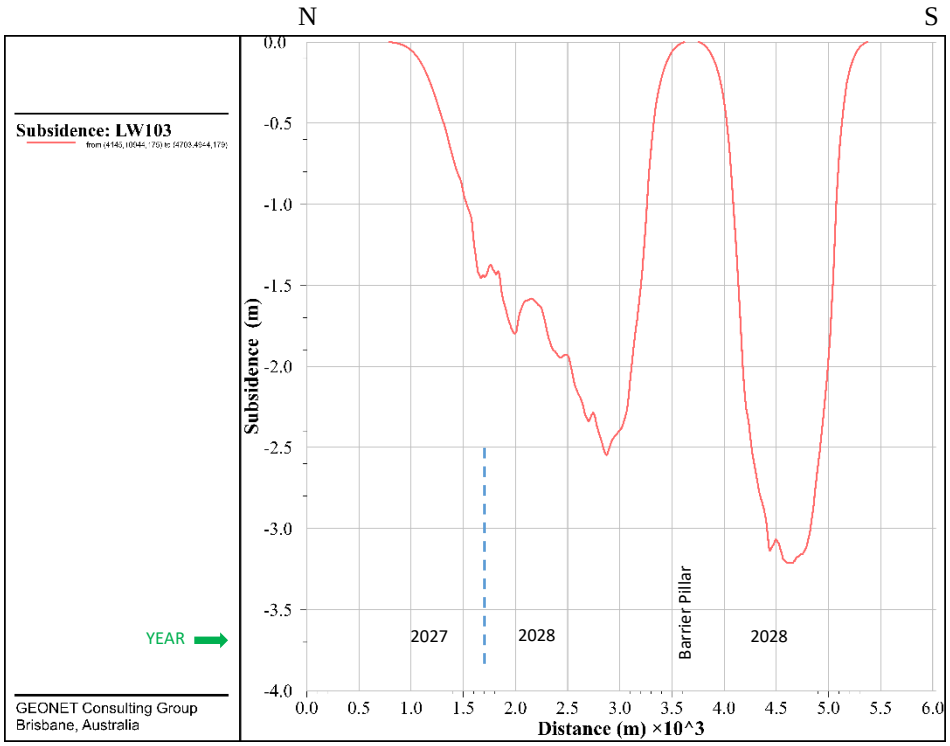


Figure 29(b): Year 2028 - Surface subsidence profile along LW103 (Northern Panel)

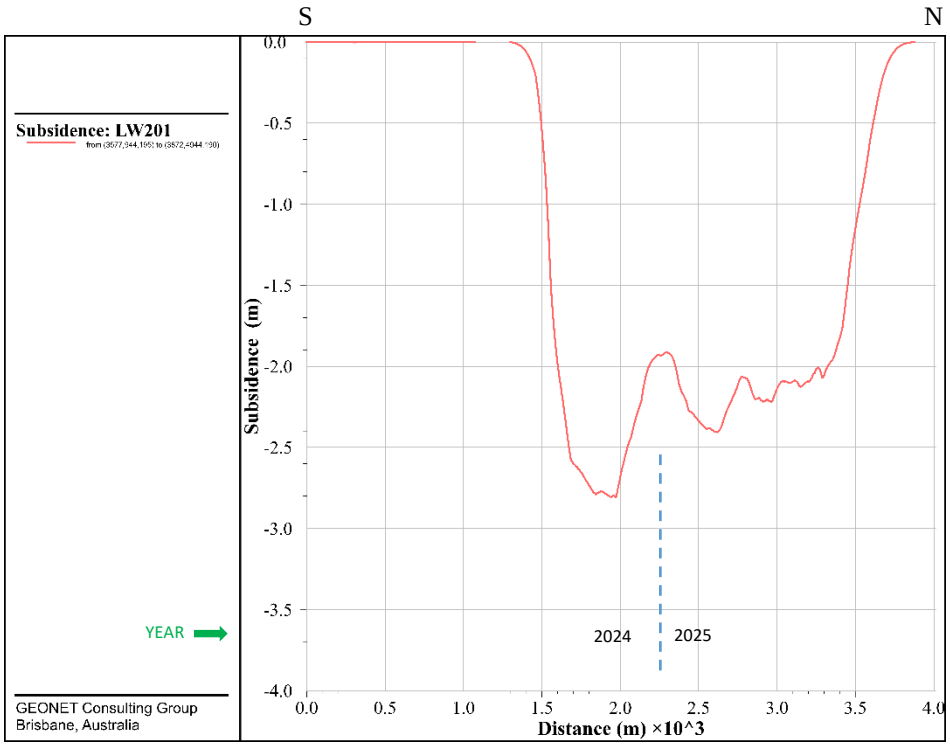


Figure 30(a): Year 2028 - Surface subsidence profile along LW201 (Southern Panel)

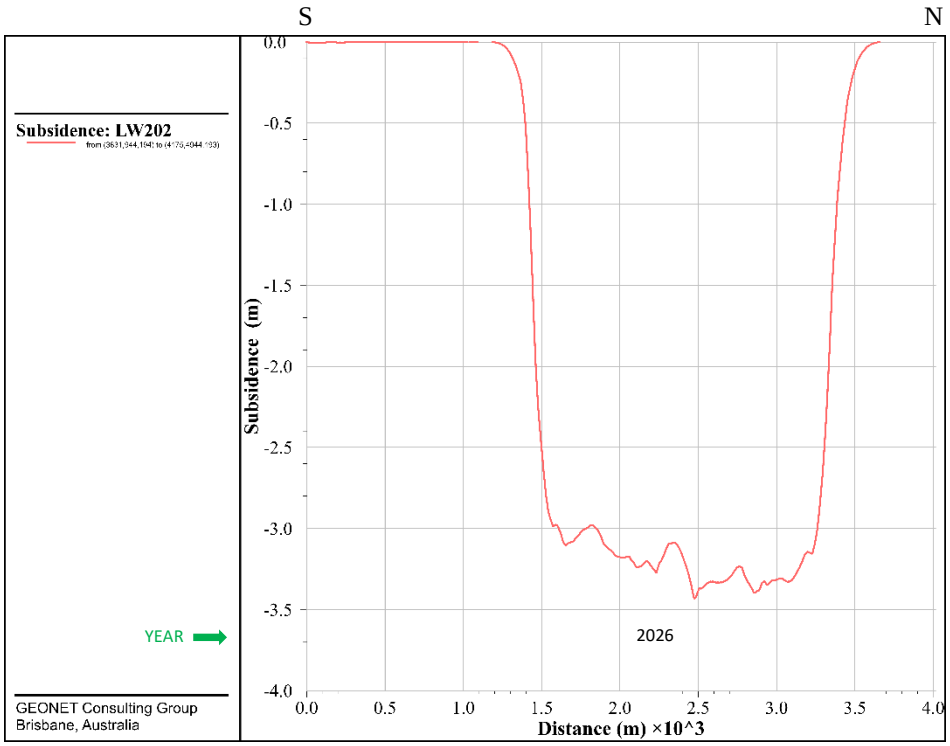


Figure 30(b): Year 2028 - Surface subsidence profile along LW202 (Southern Panel)

5.4 Subsidence at Year 10 – Schedule 2032

Longwall mining continues into Year 2029 by extracting the final section of LW103 located in the northern panel before relocating to the south of LW203 retreating northwards to the barrier pillar, then continuing to the end of LW203 at the beginning of Year 2030. For the remainder of 2030 mining is within LW204. Mining during Year 2031 starts by completing extraction in LW204 and then heading to the far north end of LW104. After leaving a small barrier pillar mining continues southwards in LW104 for the remainder of Year 2031 and most of Year 2032. The year ends after initial set up at the southern end of LW205.

The extent of surface subsidence over the northern panel is shown in Figure 31(a) and over the southern panel in Figure 31(b). The following observations are made:

- Subsidence over the fully extracted longwalls in the southern panel is predicted to vary along the length of the longwalls in the range 2.0m to 3.4m.
- Over the longwalls in the northern panel where is a noticeably larger variation in maximum subsidence along their length. The maximum subsidence corresponds with sections where the overburden thickness is less than 250m.
- The limit of continuous tension / shear cracks outside the longwall panel boundaries may be inferred from the 0.1m deformation contour (blue-white) on Figures 31(a) and 31(b). This limit extends to about 200m around the northern and eastern perimeter of LW104. The same limit extends about 80m around the eastern boundary of LW204.
- The extent of subsidence over longwalls as projected onto the cross-section at 7521750N is shown in Figure 32(a) as contours of displacement. Goafing of the overburden strata extends through the Permian strata and up into the Tertiary sediments. The actual profile of surface subsidence is shown in the graph Figure 32(b). At this location the maximum surface subsidence of 3.35m is formed over LW203 and 3.25m over LW204 where the overburden thickness is 170m.
- The extent of subsidence over longwalls as projected onto the cross-section at 7523000N is shown in Figure 33(a) as contours of displacement. Goafing of the overburden strata extends through the Permian strata and up into the Tertiary sediments in LW202 and LW203. In LW204 the goafing at this stage is confined to the Permian strata over the Dysart seam. The actual profile of surface subsidence is shown in the graph Figure 33(b). At this location the maximum surface subsidence of 3.4m is formed over LW202 and LW203; it is limited to 2.6m over LW204 where the overburden thickness is 185m.
- The extent of subsidence over longwalls in northern panel projected onto cross-section at 7525500N is shown in Figure 34(a) as contours of displacement. Goafing of the overburden strata extends through the Permian strata and up into the Tertiary sediments in LW102 and LW103. In LW104 the goafing at this stage is confined to the Permian strata below the Harrow Creek seam. The actual profile of surface subsidence is shown in the graph Figure 34(b). At this location the maximum surface subsidence of 3.35m is formed over LW102. Over LW103 the subsidence is 3.1m and it is limited to 2.3m over LW104 where the overburden thickness is 240m.

- The extent of subsidence over longwalls in northern panel projected onto cross-section at 7527250N is shown in Figure 35(a) as contours of displacement. Goafing of the overburden strata extends through the Permian strata and up into the Tertiary sediments in LW102. In LW101, LW103 and LW104 the goafing is confined to the Permian strata below the Harrow Creek seam. The actual profile of surface subsidence is shown in the graph Figure 35(b). At this location the maximum surface subsidence of 3.1m is formed over LW102. Over LW103 the subsidence is 2.5m and it is limited to 1.6m over LW104 where the overburden thickness is 285m.
- The profile of surface subsidence along centerline of LW103 is shown in Figure 36(a). The subsided surface undulates along its length with the subsidence increasing as overburden thickness reduces towards the south. Subsidence is significantly reduced over the barrier pillar, varying between 0m and 0.5m.
- The profile of surface subsidence along centerline of LW104 is shown in Figure 36(b). The subsided surface undulates along its length with the subsidence increasing as overburden thickness reduces towards the south. Over the small barrier pillar subsidence will range from 0.3m to 0.5m.
- The profile of surface subsidence along centerline of LW203 is shown in Figure 37(a). The subsided surface undulates slightly around a maximum of 3.4m. Over the barrier pillar subsidence will range from 0m to 0.5m.
- The profile of surface subsidence along centerline of LW204 is shown in Figure 37(b). The subsided surface undulates between a maximum of 3.4m and 3.2m. Over the section of longwall mined during Year 2031 the maximum subsidence is 2.4m.

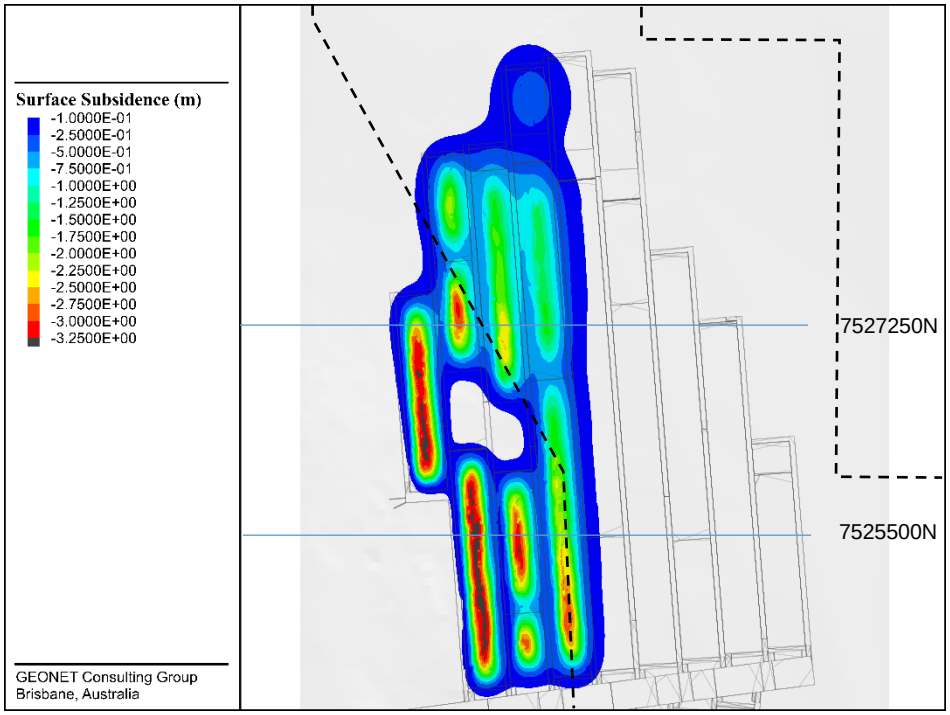


Figure 31(a): Subsidence on over Northern longwall panel at Year 2032

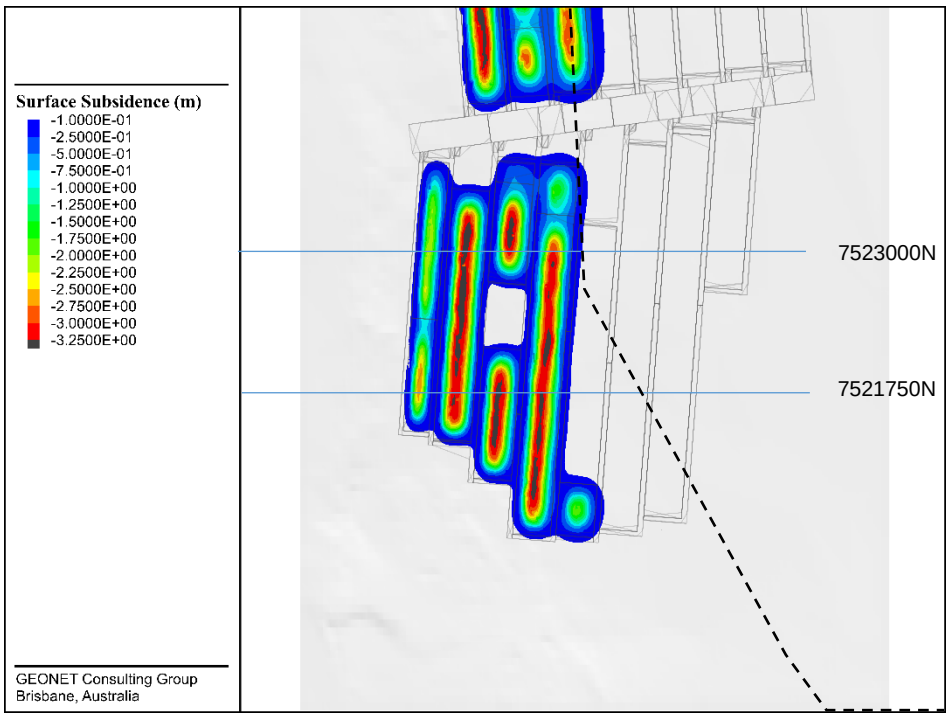


Figure 31(b): Subsidence on over Southern longwall panel at Year 2032

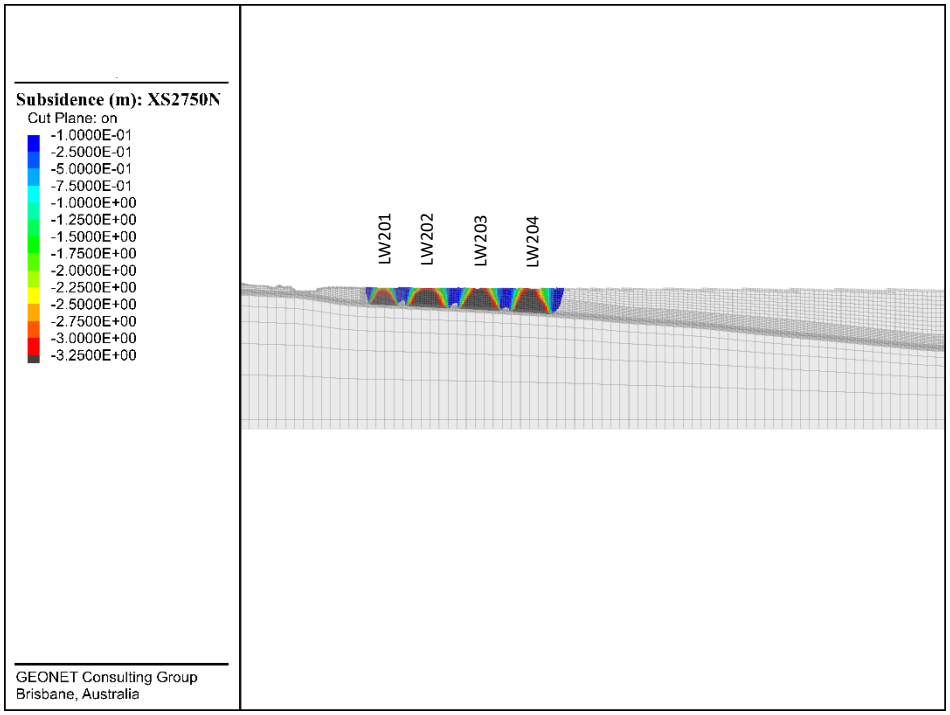


Figure 32(a): Year 2032 - Subsidence through Southern panel at 7521750N

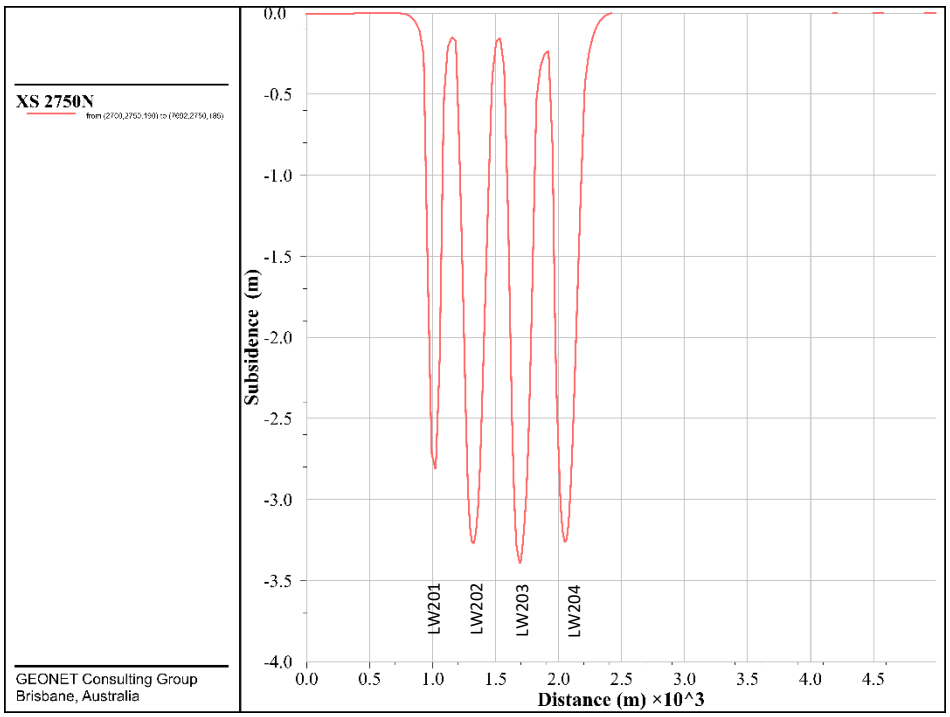


Figure 32(b): Year 2032 - Surface subsidence profile over Southern panel at 7521750N

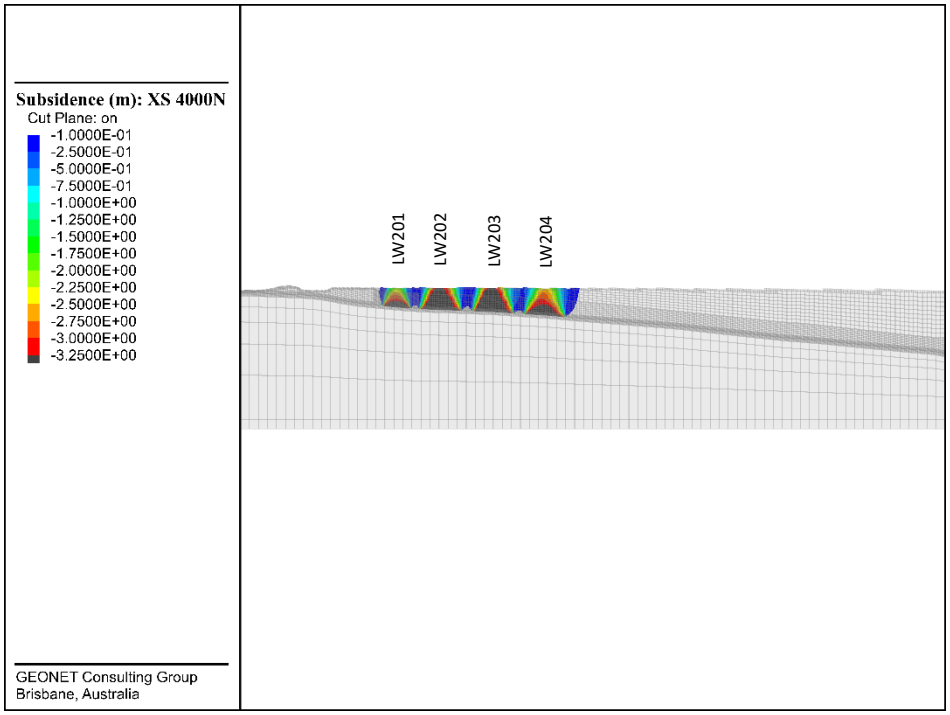


Figure 33(a): Year 2032 - Subsidence through Southern panel at 7523000N

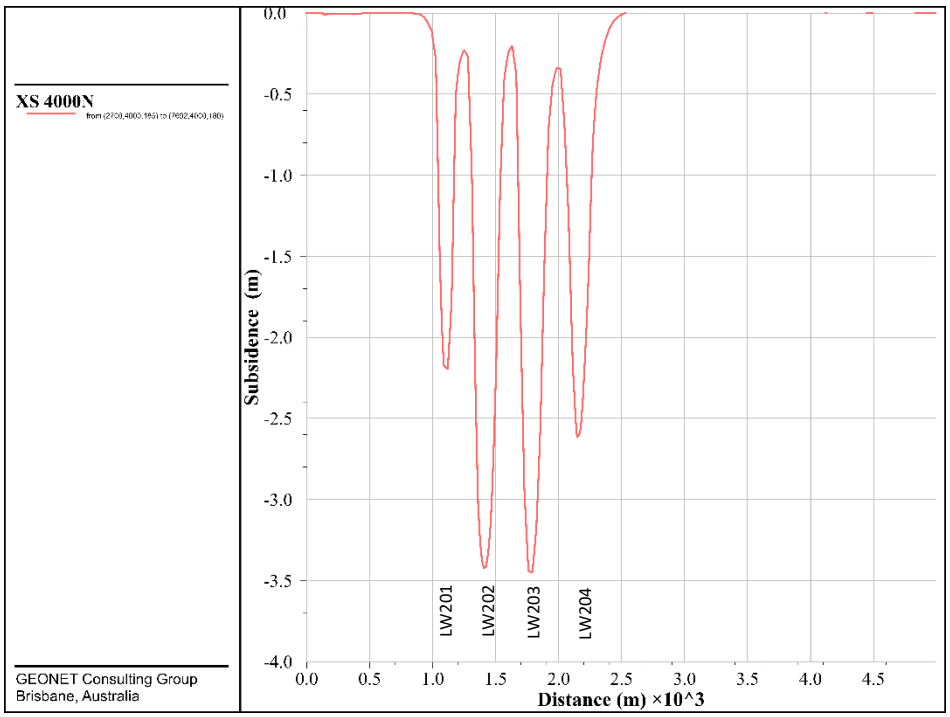


Figure 33(b): Year 2032 - Surface subsidence profile over Southern Panel at 7523000N

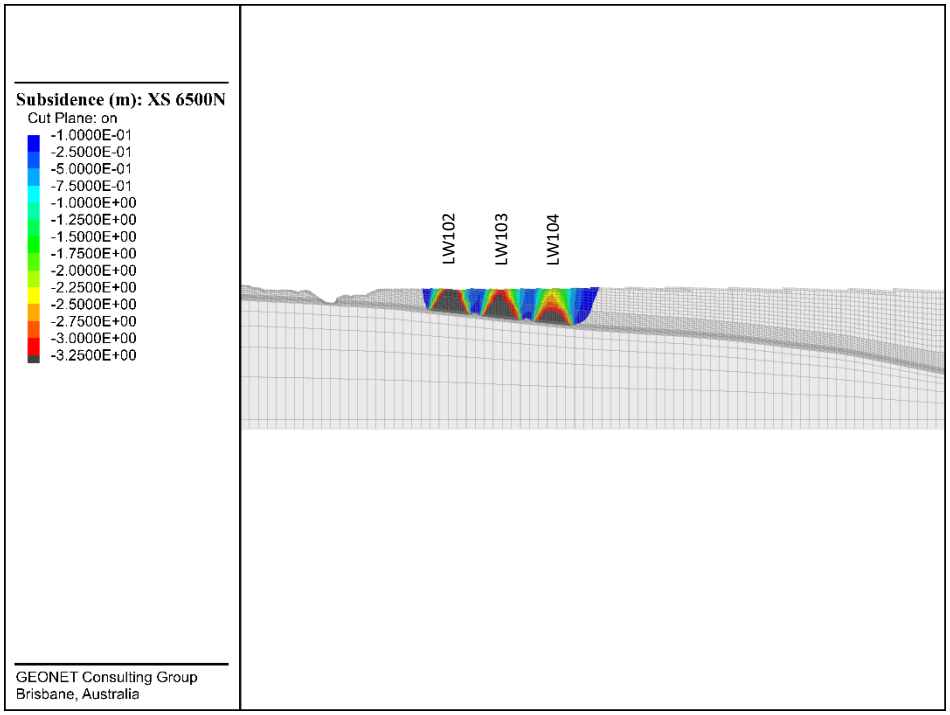


Figure 34(a): Year 2032 - Subsidence through Southern panel at 7525500N

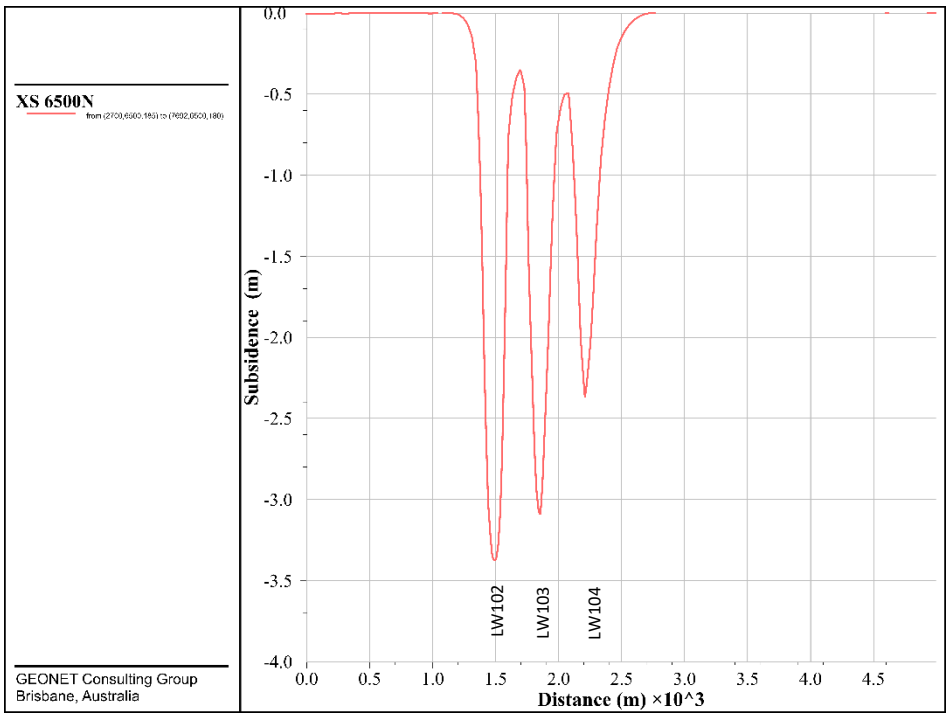


Figure 34(b): Year 2032 - Surface subsidence profile over Northern Panel at 7525500N

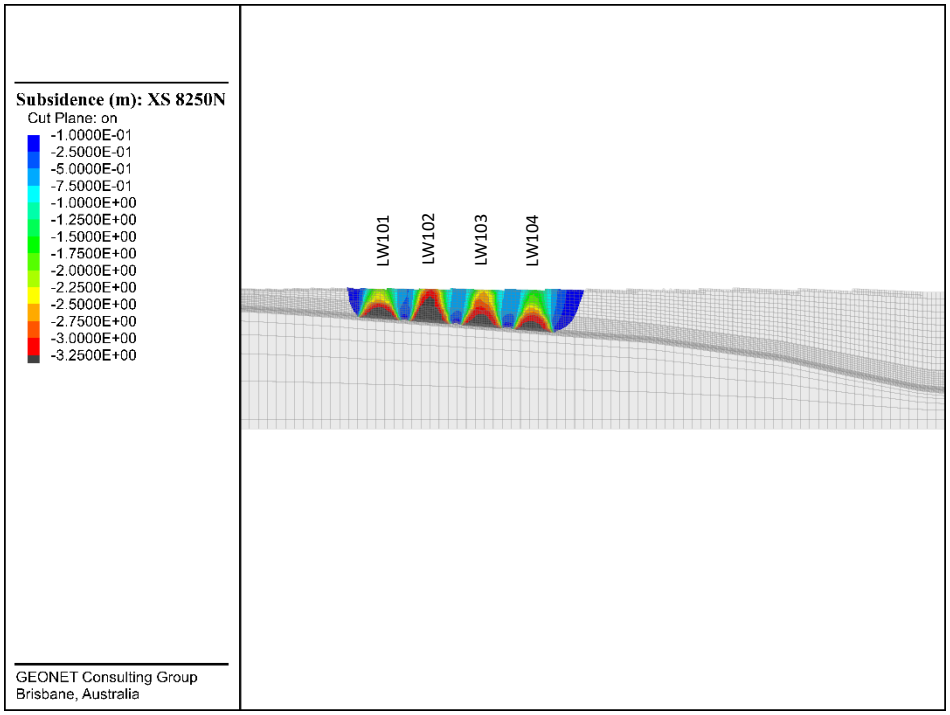


Figure 35(a): Year 2032 - Subsidence through Southern panel at 7527250N

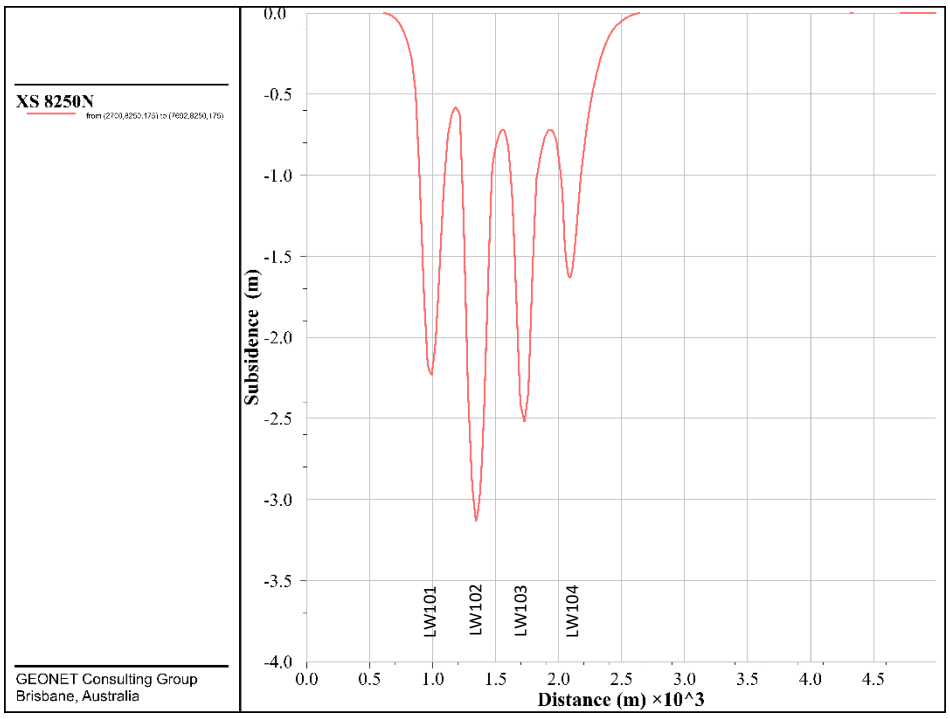


Figure 35(b): Year 2032 - Surface subsidence profile over Northern Panel at 7527250N

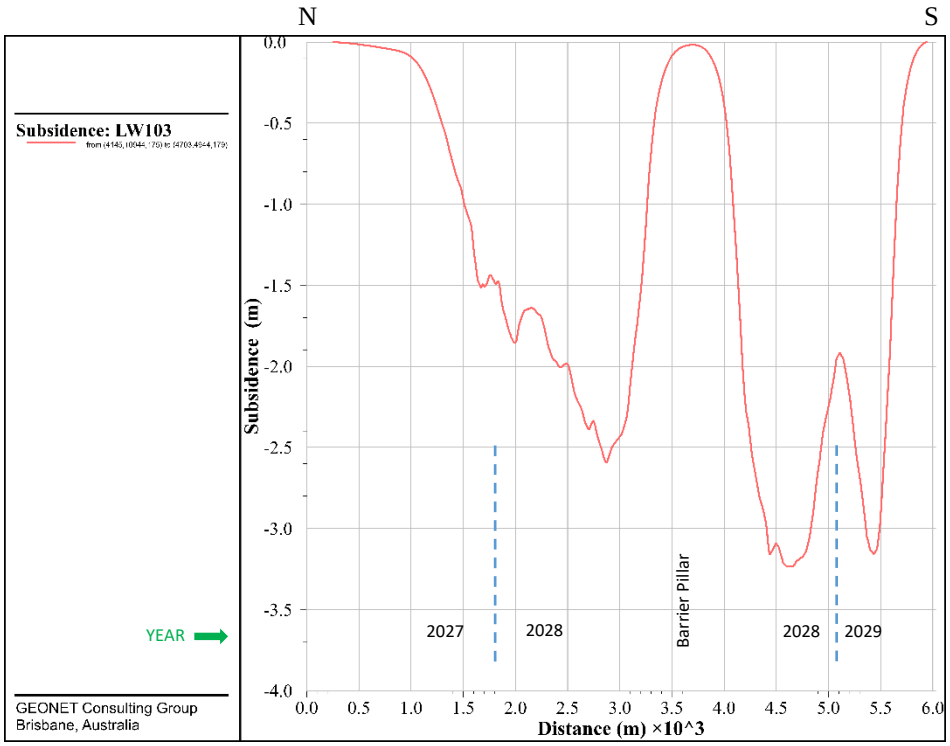


Figure 36(a): Year 2032 - Surface subsidence profile along LW103 (Northern Panel)

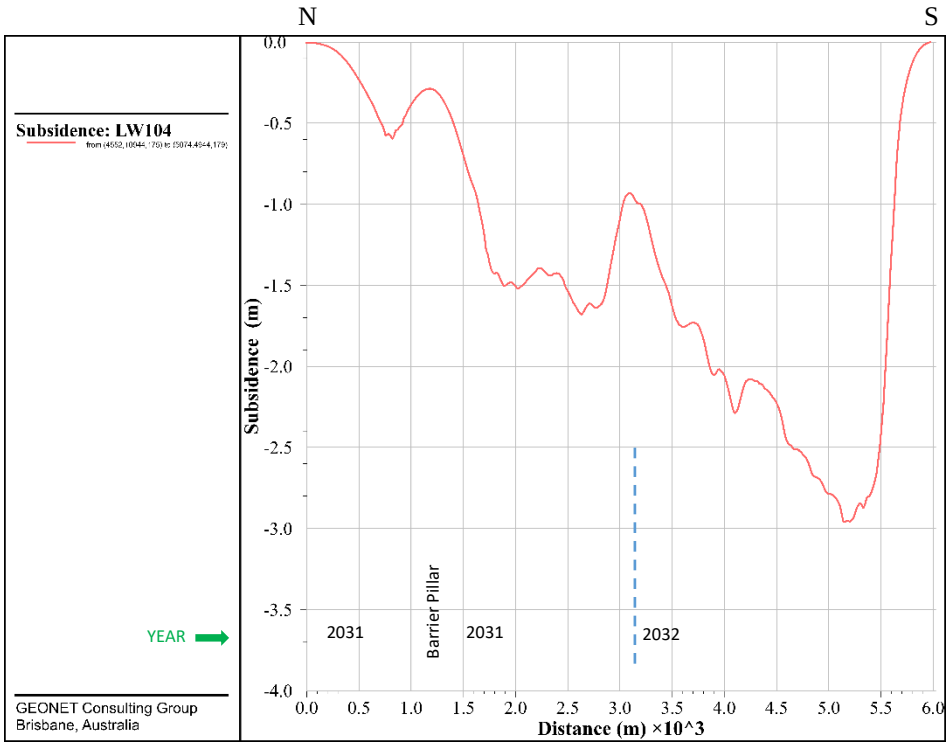


Figure 36(b): Year 2032 - Surface subsidence profile along LW104 (Northern Panel)

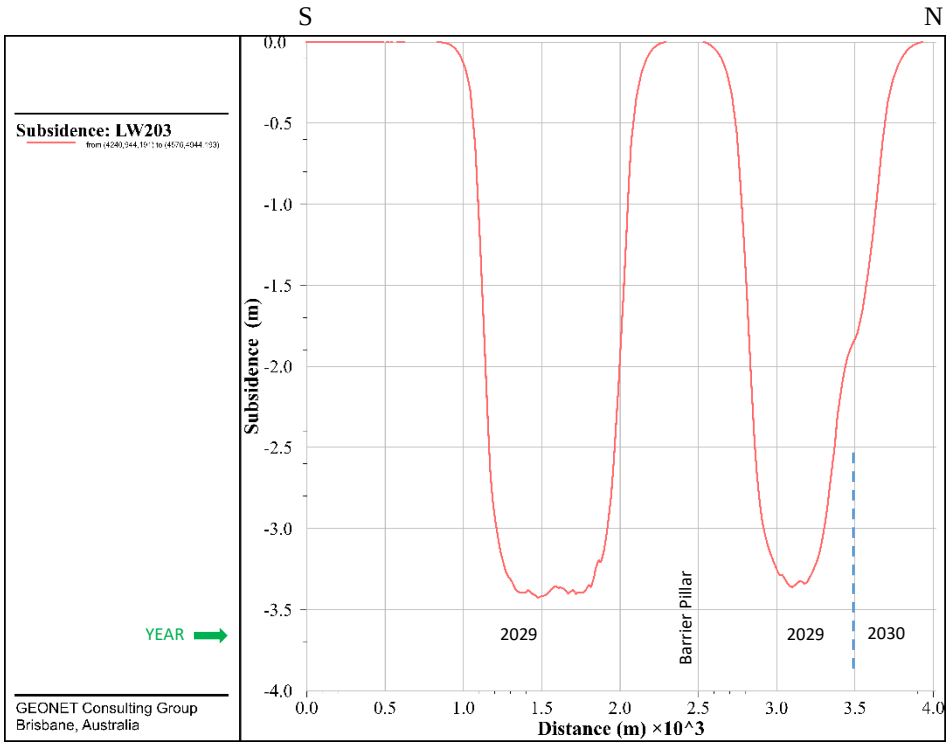


Figure 37(a): Year 2032 - Surface subsidence profile along LW203 (Southern Panel)

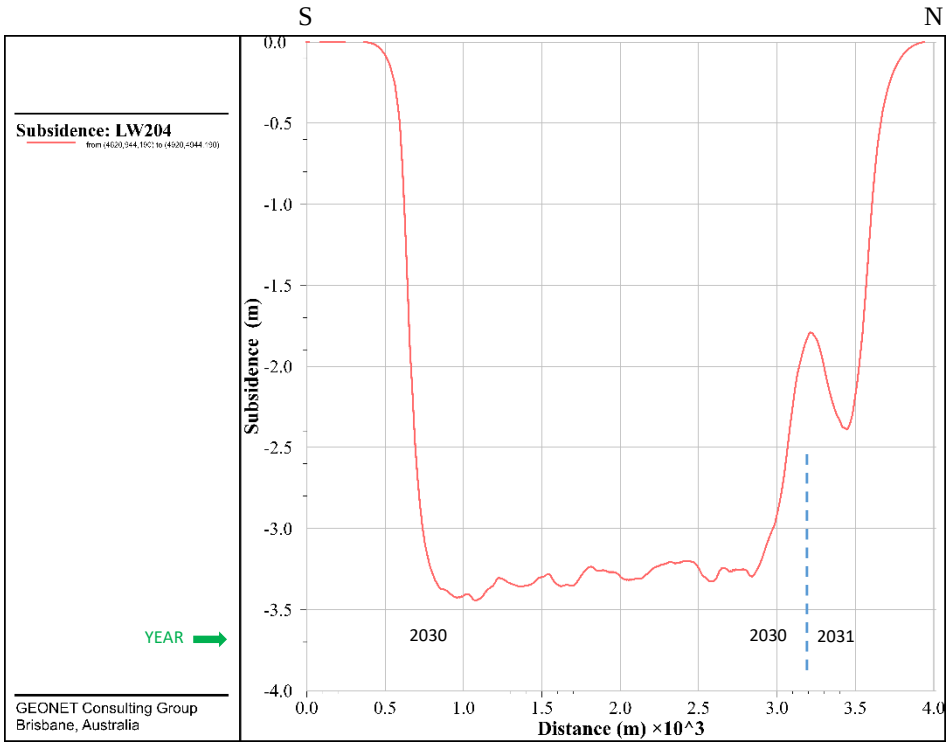


Figure 37(b): Year 2032 - Surface subsidence profile along LW204 (Southern Panel)

5.5 Subsidence at Year 20 – Schedule 2042

Starting in Year 2033 longwall mining continues in the southern panel in LW205. The sequence then follows as LW105, LW206, LW106, LW207, LW107, LW208, LW108 and finally LW109 is completed in Year 2042.

The extent of surface subsidence over the northern panel is shown in Figure 38(a) and over the southern panel in Figure 38(b). The following observations are made:

- There is significantly more subsidence induced over the southern panel compared with the northern panel. This can be attributed to the thickness of Dysart seam overburden. It is observed that subsidence in excess of 2.25m correlates directly with 250m contour.
- The fully extracted longwalls in southern panel are predicted to show maximum surface subsidence in the range 2.0m to 3.4m over all longwalls except LW208 where the overburden thickness exceeds 300m.
- Over all longwalls in the northern panel the maximum surface subsidence ranges between 0.75m and 2.25m where the overburden thickness ranges between 250m and 400m.
- The limit of continuous tension / shear cracks outside the longwall panel boundaries may be inferred from the 0.1m deformation contour (blue-white) on Figures 38(a) and 38(b). This limit extends to about 200m around the northern and eastern perimeter of longwall in the northern panel. The same limit extends about 80m around the eastern boundary of longwalls in the southern panel.

Subsidence on Cross-Sections

- The extent of subsidence over longwalls as projected onto the cross-section at 7521750N is shown in Figure 39(a) as contours of displacement. Goafing of the overburden strata extends through the Permian strata and up into the Tertiary sediments over all longwalls except LW207 where it is confined to the Permian strata below Harrow Creek seam. The actual profile of surface subsidence is shown in the graph Figure 39(b). At this location the maximum surface subsidence varies between 3.35m and 3.25m. Over LW207 the maximum subsidence is 2.7m.
- The extent of subsidence over longwalls as projected onto the cross-section at 7523000N is shown in Figure 40(a) as contours of displacement. Goafing of the overburden strata extends through the Permian strata and up into the Tertiary sediments in LW202 and LW203. In LW204 and LW205 the goafing at this location is confined to the Permian strata over the Dysart seam; this may be an artefact of influence from the proximity of barrier pillar in LW203 and the abutment in LW205. Goafing is also confined to Permian strata below Harrow Creek seam in LW206, LW207 and LW208; in these cases due to the increasing thickness of overburden. The actual profile of surface subsidence is shown in the graph Figure 40(b). At this location the maximum surface subsidence of 3.4m is formed over LW202 and LW203; it is limited to 2.6m over LW204, 1.3m over LW205, 2.7m over LW206, 2.3m over LW207 and 1.35m over LW208.
- The extent of subsidence over longwalls in northern panel projected onto cross-section at 7525500N is shown in Figure 41(a) as contours of displacement. Goafing of the

overburden strata extends through the Permian strata and up into the Tertiary sediments in LW102 and LW103. Over LW104 to LW109 goafing is confined to Permian strata below the Harrow Creek seam. The actual profile of surface subsidence is shown in the graph Figure 41(b). At this location the maximum surface subsidence of 3.35m is formed over LW102. Over LW103 the subsidence is 3.1m and it is limited to 2.3m over LW104 where the overburden thickness is 240m. Over LW105 the maximum subsidence is shown to be 1.1m. This reduced value may be an artefact associated with modelling having simulated a year change at this stage. In practice, the longwall would not pause operations at year end so that it may be anticipated that subsidence over LW105 at 7525500N could increase to about 2.1m as indicated by the adjacent longwalls. A similar artefact may be observed for LW106 which is at the cusp of Years 2039 and 2040. Under continuous mining it is anticipated that surface subsidence at this location could be about 1.5m. The maximum surface subsidence predicted over LW108 at this northing is 1.4m and over LW109 it will be 1.25m.

- The extent of subsidence over longwalls in northern panel projected onto cross-section at 7527250N is shown in Figure 42(a) as contours of displacement. Goafing of the overburden strata extends through the Permian strata and up into the Tertiary sediments in LW102. Over LW101, and all the other deeper longwalls goafing is confined to the Permian strata below the Harrow Creek seam. At this section line LW108 is located at its abutment face. LW109 is not intersected. The actual profile of surface subsidence is shown in the graph Figure 42(b). At this location the maximum surface subsidence of 3.1m is formed over LW102. Over LW103 the subsidence is 2.5m and it is limited to 1.7m over LW104 where the overburden thickness is 285m. Subsidence over LW105 is 1.45m and 1.2m over LW106 and LW107. At this northing coordinate is the abutment of LW108 so that surface subsidence at this position will be about 0.75m.

Surface Subsidence Profiles on Centerline: Northern Panel

- The profile of surface subsidence along centerline of LW102 is shown in Figure 43(a). The subsided surface from mining during Year 2026 reaches a maximum of 2.25m. The adjacent section mining to represent Year 2027 reaches a maximum of 3.2m before the barrier pillar. The apparent reduced subsidence at the junction between Year 2026 and Year 2027 is an artefact of the modelling extraction sequence. In reality if mining was continuous then then subsidence profile would also be continuous. However, should the longwall be stalled for any length of time then this effect will develop Subsidence over the southern section of LW102 will result in an undulating surface with maximum subsidence about 3.5m.
- The profile of surface subsidence along centerline of LW103 is shown in Figure 43(b). The initial profile corresponds with mining at the end of Year 2027. During Year 2028 the subsided surface undulates along its length with the subsidence increasing as overburden thickness reduces towards the south. Subsidence is significantly reduced over the barrier pillar, varying between 0m and 0.5m. When mining resumes during the latter stages of Year 2028 the maximum surface subsidence increases to 3.2m. When mining continues into Year 2029 the maximum subsidence developed is 3.15m.

- The profile of surface subsidence along centerline of LW104 is shown in Figure 43(c). Subsidence at the beginning of Year 2031 reaches 0.7m before leaving the small barrier pillar. Subsidence over the barrier pillar will be about 0.4m. For the remainder of Year 2031 the maximum subsidence that will be induced is 1.65m. During Year 2032 mining will continue with decreasing overburden thickness and corresponding increase in surface subsidence which will reach a maximum of 3.0m at the southern end of the longwall.
- The profile of surface subsidence along centerline of LW105 is shown in Figure 43(d). Mining at the far northern end of the longwall during Year 2033 will induce a maximum subsidence of 0.7m before the small barrier is left in place. Surface subsidence over the barrier pillar will be a minimum of 0.45m. Mining during Year 2034 will induce increasing and undulating surface subsidence to a maximum of 1.65m. The reduced subsidence shown at the cusp of mining years 2034 and 2035 may be an artefact of the modelling sequence which represents the effect of the longwall having stopped. Under continuous mining this may not appear and subsidence of about 1.7m can be expected. Further mining into Year 2035 will induce maximum surface subsidence of 2.7m at the far southern end of the longwall where overburden thickness has reduced to 260m.
- The profile of surface subsidence along centerline of LW106 is shown in Figure 43(e). Mining at the far northern end of the longwall during Year 2036 will induce a maximum subsidence of 0.9m before the small barrier is left in place. Surface subsidence over the barrier pillar will be a minimum of 0.4m. Mining during Year 2036 will induce increasing and undulating surface subsidence to a maximum of 1.4m. Mining into Year 2037 will induce maximum surface subsidence of 2.35m towards the southern end of the longwall where overburden thickness reduces to 280m.
- The profile of surface subsidence along centerline of LW107 is shown in Figure 43(f). The 0.2m subsidence trough indicated at 1km distance on graph represents the deformation associated with subsidence towards LW106. The maximum subsidence incurred during Year 2039 is 1.7m. The reduction of subsidence to 1.05m is associated with modelling extraction according to years. During Year 2040 the maximum subsidence will be 1.7m. Surface subsidence over the Mains will be about 0.2m.
- The profile of surface subsidence along centerline of LW108 is shown in Figure 43(g). Mining in LW108 occurs throughout Year 2041. The maximum subsidence incurred over this longwall is 1.4m towards the southern end. Surface subsidence over the Mains will be about 0.2m.
- The profile of surface subsidence along centerline of LW109 is shown in Figure 43(h). Mining in LW109 starts at the end of Year 2041 and continues through Year 2042. The maximum subsidence incurred over this longwall will be 1.1m towards the southern end where overburden thickness will be 400m.

Surface Subsidence Profiles on Centerline: Southern Panel

- The profile of surface subsidence along centerline of LW201 is shown in Figure 44(a). The subsided surface reaches a maximum of 2.8m during Year 2024. The profile over section of longwall mined during Year 2025 undulates between 2.4m and 2.0m.
- The profile of surface subsidence along centerline of LW202 is shown in Figure 44(b). This longwall is mined during Year 2026. The subsided surface undulates in the range 3.0m to 3.4m.
- The profile of surface subsidence along centerline of LW203 is shown in Figure 44(c). This longwall is mined during Year 2029 leaving a barrier pillar and finishing early in Year 2030. The subsided surface south of the barrier pillar reaches a maximum of 3.4m and similarly on the northern side of the barrier pillar for the section mined in Year 2029.
- The profile of surface subsidence along centerline of LW204 is shown in Figure 44(d). This longwall is mined during Year 2030 and into early Year 2031. The subsidence undulates in the range 3.25m to 3.4m for the section of longwall mined during 2030. In the section of longwall mined during Year 2031 the maximum subsidence will be 2.4m.
- The profile of surface subsidence along centerline of LW205 is shown in Figure 44(e). The short section of longwall mined at the end of Year 2032 induces about 2.2m of subsidence. As mining advances during Year 2033 the emerging subsidence profile undulates and gradually reduces in the range 3.35m to 3.15m as the overburden thickness increases from 200m to 270m.
- The profile of surface subsidence along centerline of LW206 is shown in Figure 44(f). This longwall is mined through Year 2035 and the subsidence profile undulates and gradually reduces in the range 3.35m to 2.5m as the overburden thickness increases to 220m.
- The profile of surface subsidence along centerline of LW207 is shown in Figure 44(g). This longwall is mined through Year 2038. The maximum subsidence of 2.75m is shown at the southern end of the longwall where overburden thickness is 230m. The subsidence profile undulates from 2.75m to 1.3m at the northern end.
- The profile of surface subsidence along centerline of LW208 is shown in Figure 44(h). This longwall is mined through Year 2040 and the subsidence profile shows a maximum subsidence of 1.4m. The overburden thickness over this longwall ranges from 300m to 330m.

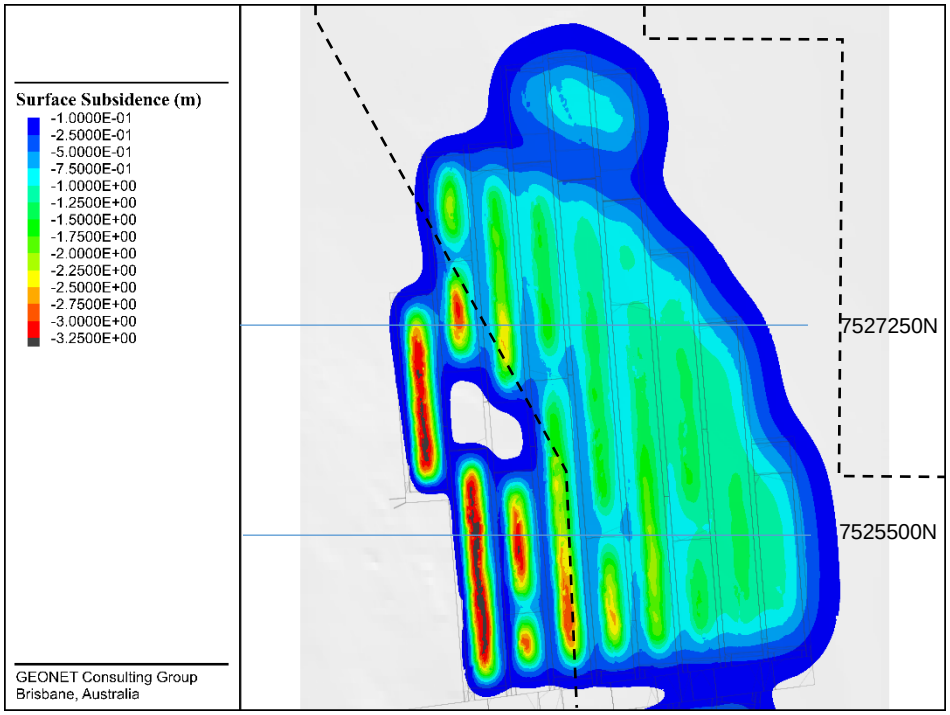


Figure 38(a): Subsidence on over Northern longwall panel at Year 2042

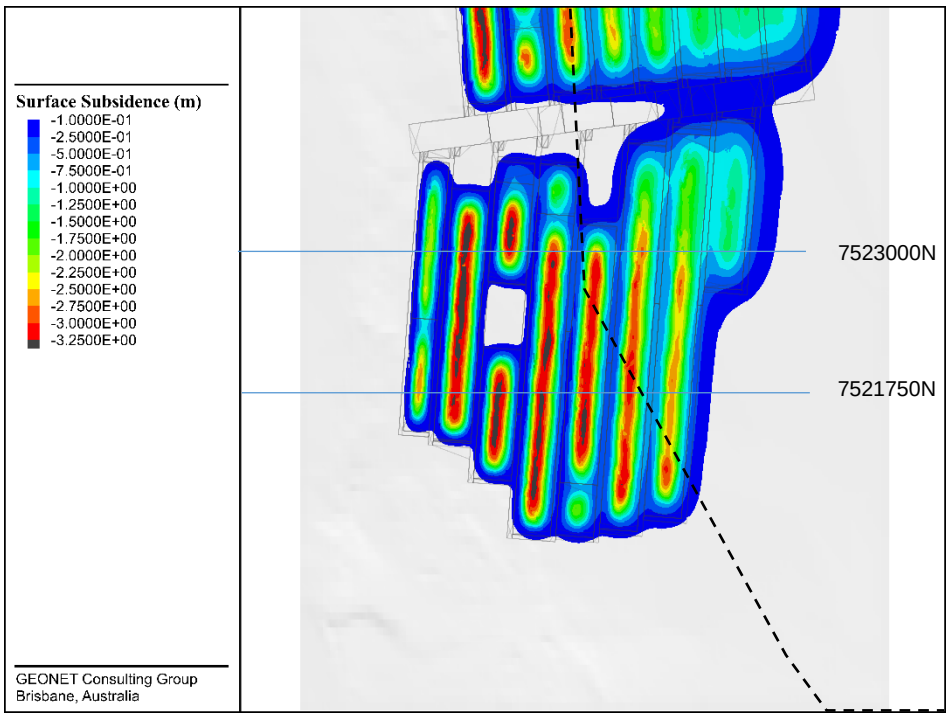


Figure 38(b): Subsidence on over Southern longwall panel at Year 2042

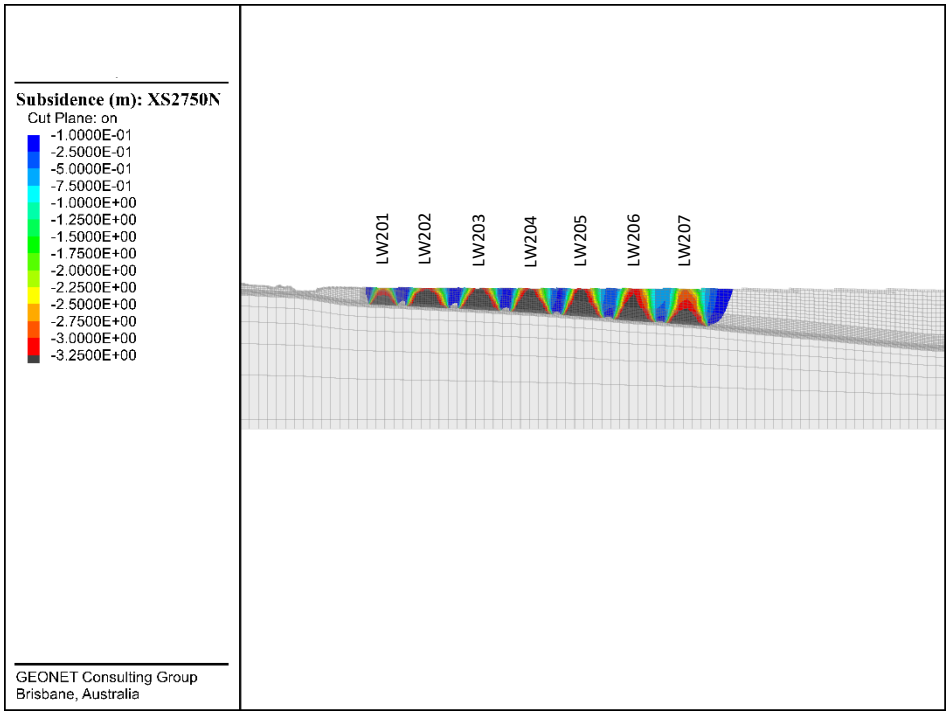


Figure 39(a): Year 2042 - Subsidence through Southern panel at 7521750N

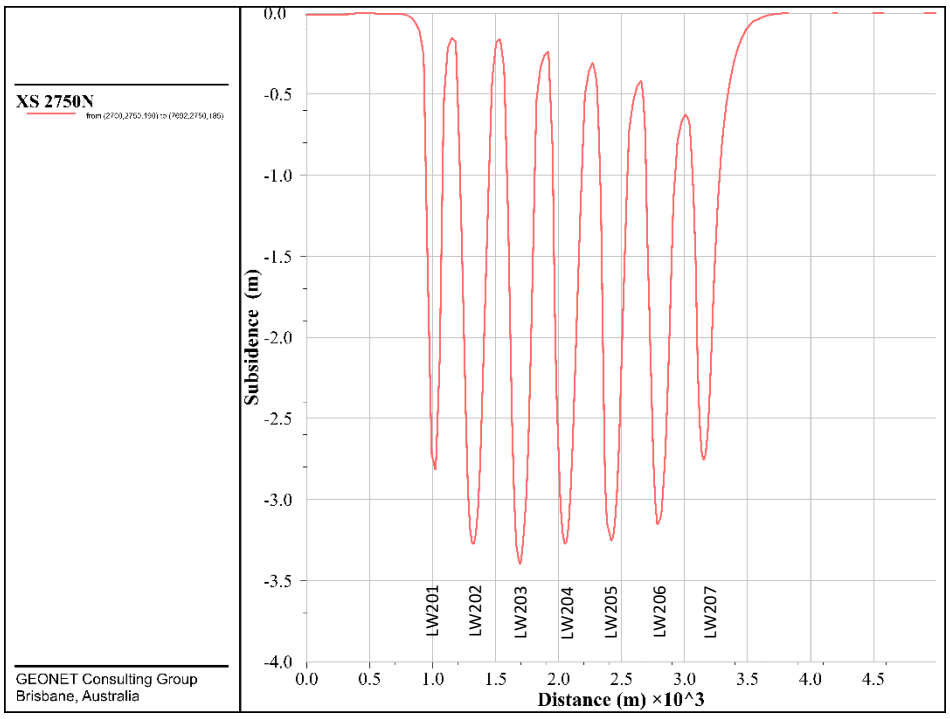


Figure 39(b): Year 2042 - Surface subsidence profile over Southern panel at 7521750N

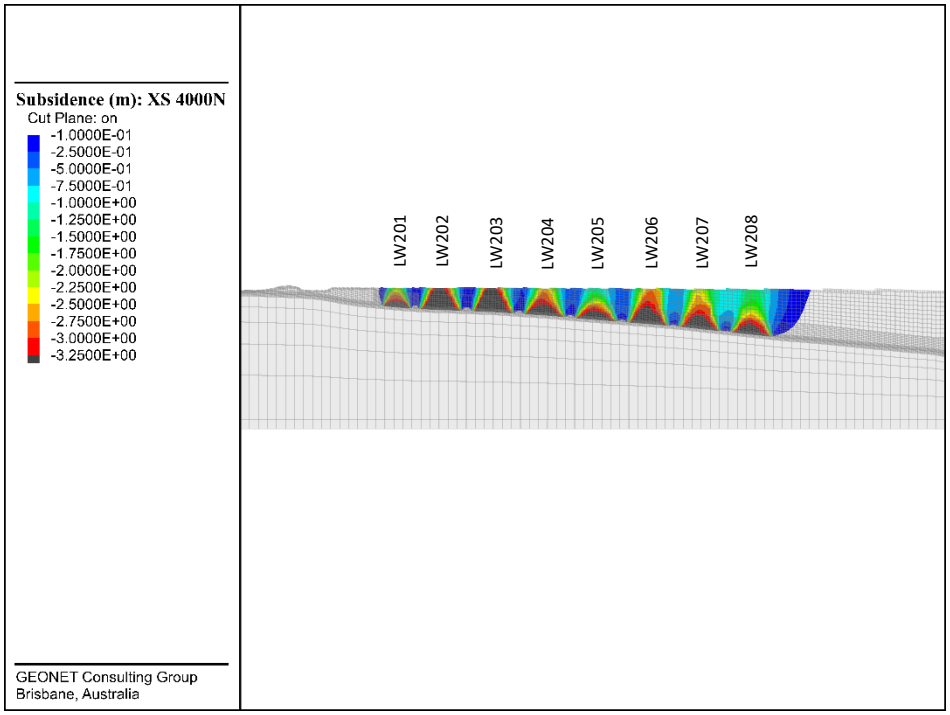


Figure 40(a): Year 2042 - Subsidence through Southern panel at 7523000N

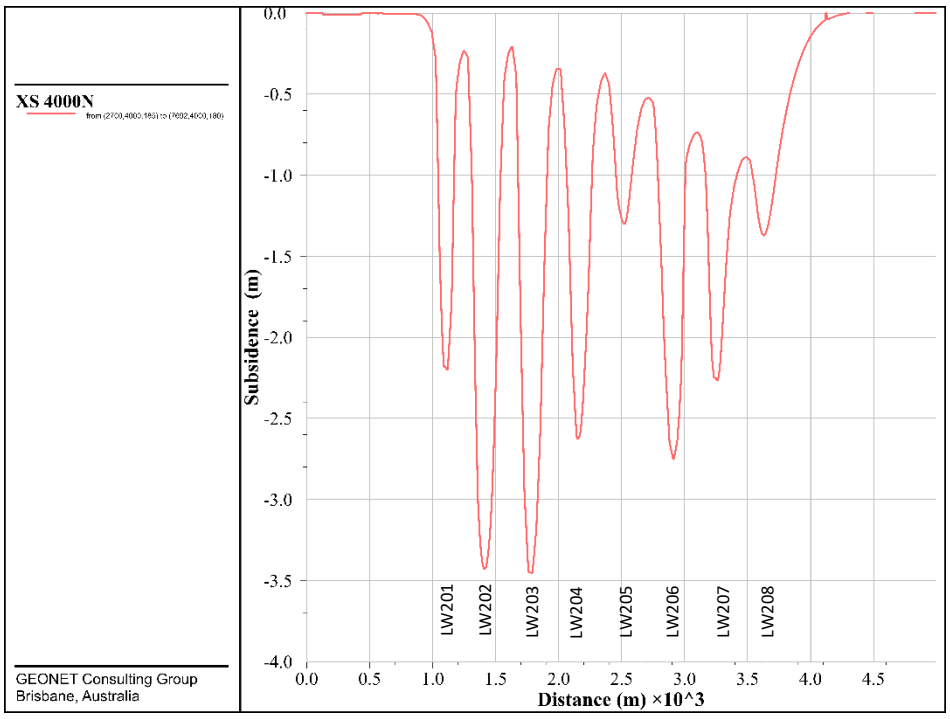


Figure 40(b): Year 2042 - Surface subsidence profile over Southern Panel at 7523000N

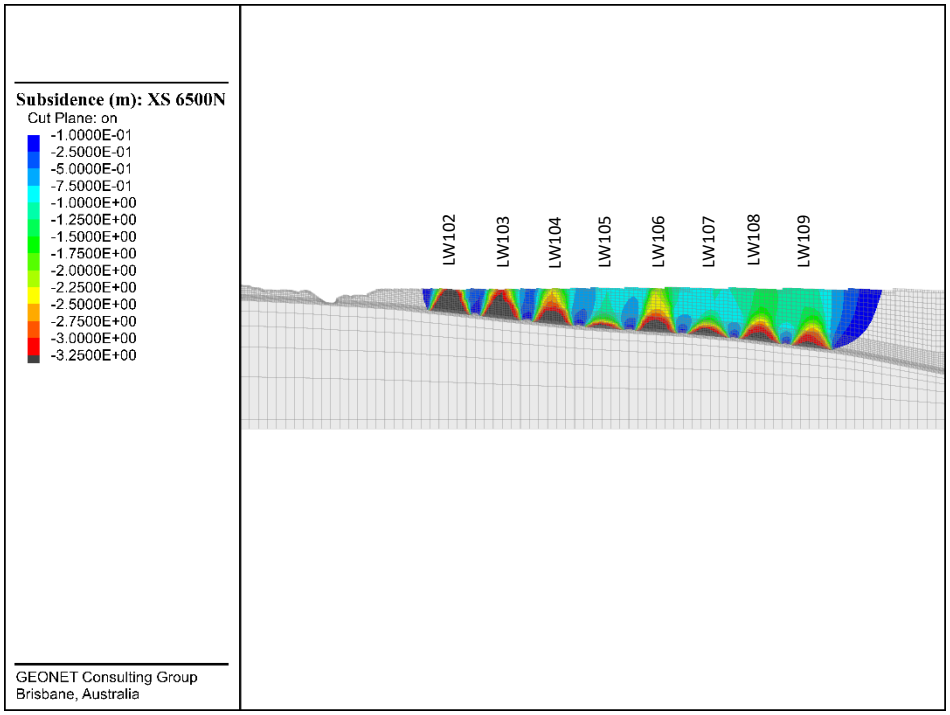


Figure 41(a): Year 2042 - Subsidence through Northern panel at 75225500N

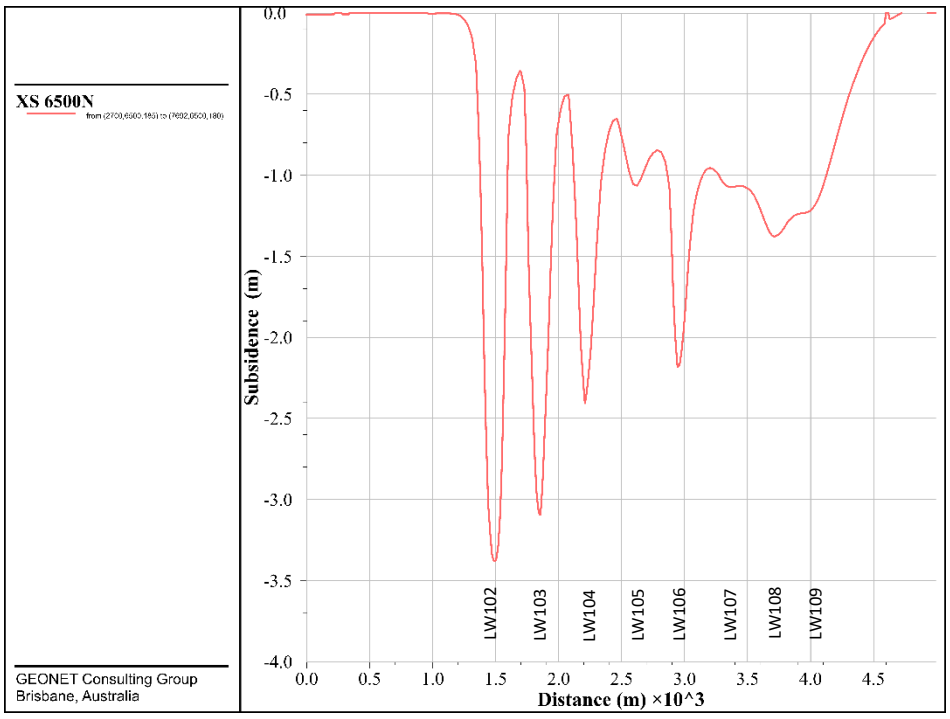


Figure 41(b): Year 2042 - Surface subsidence profile over Northern Panel at 7525500N

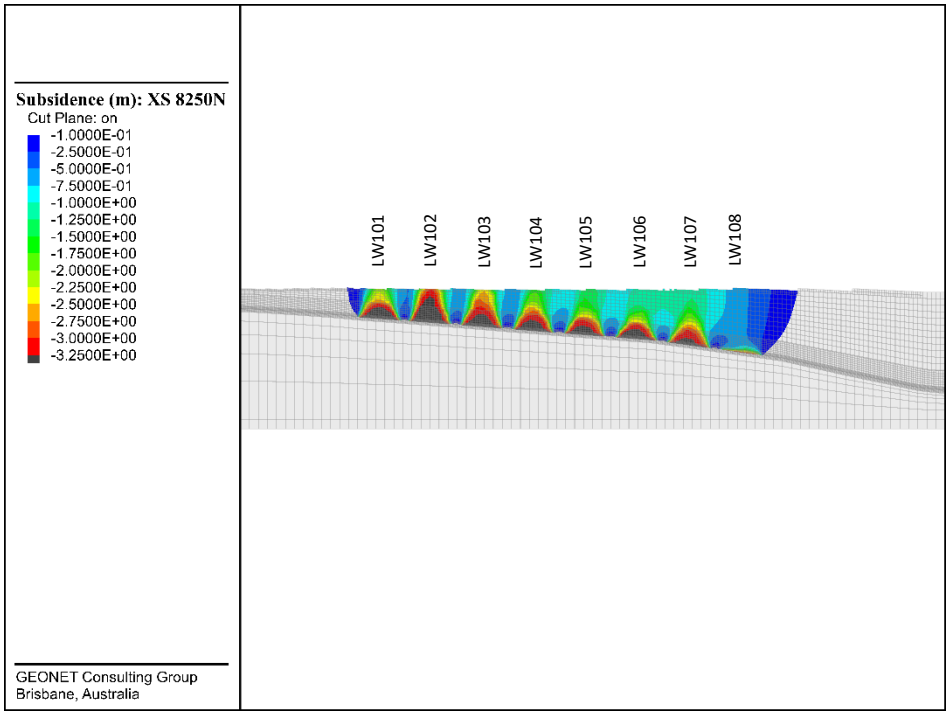


Figure 42(a): Year 2042 - Subsidence through Northern panel at 7527250N

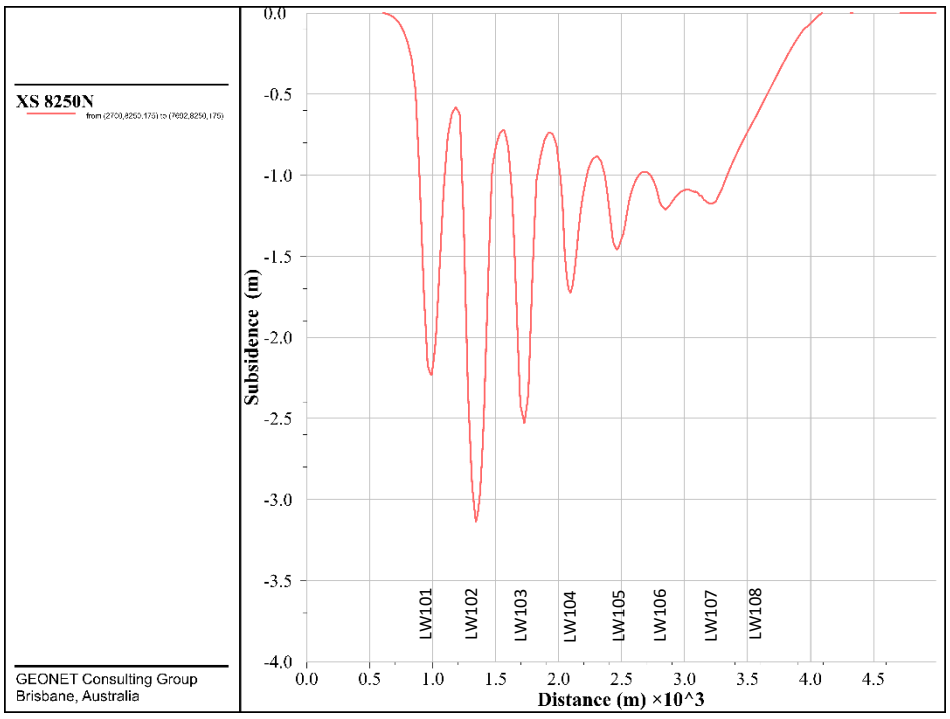


Figure 42(b): Year 2042 - Surface subsidence profile over Northern Panel at 7527250N

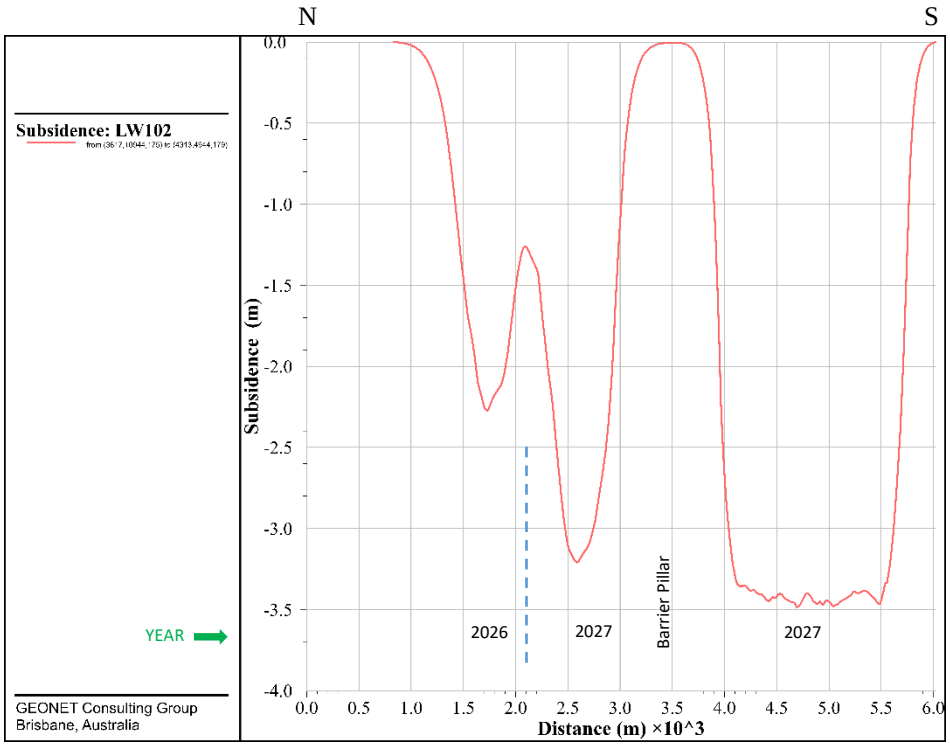


Figure 43(a): Year 2042 - Surface subsidence profile along LW102 (Northern Panel)

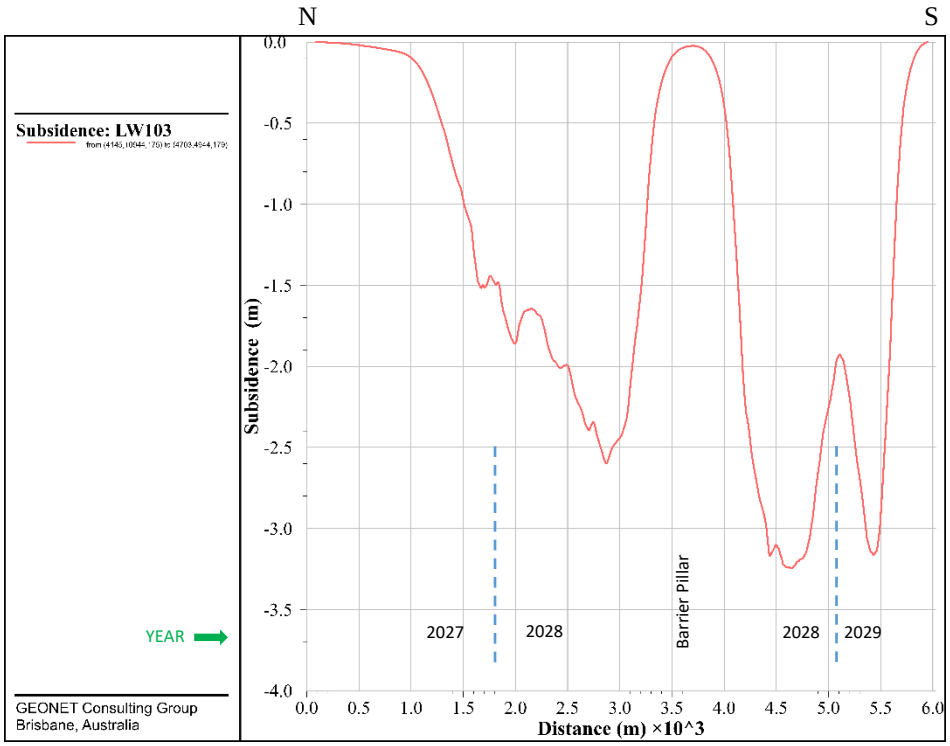


Figure 43(b): Year 2042 - Surface subsidence profile along LW103 (Northern Panel)

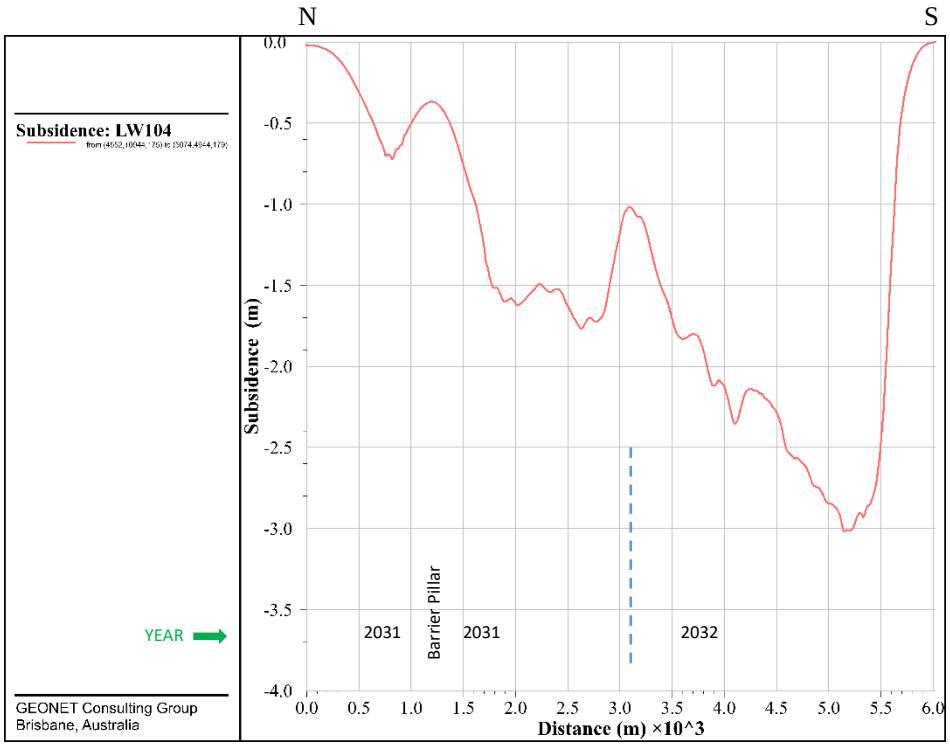


Figure 43(c): Year 2042 - Surface subsidence profile along LW104 (Northern Panel)

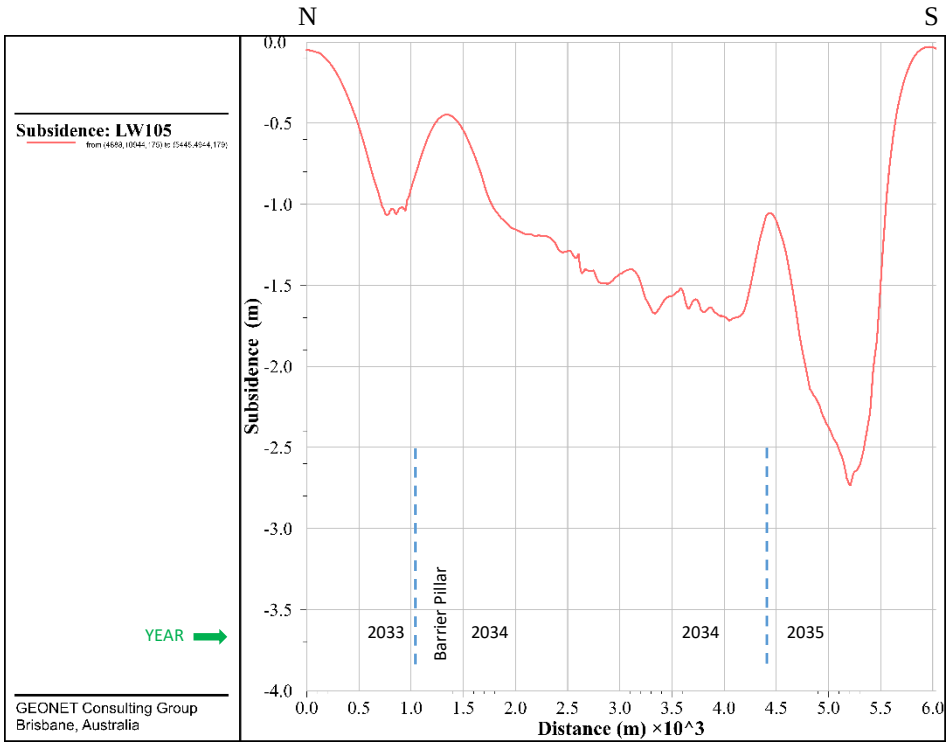


Figure 43(d): Year 2042 - Surface subsidence profile along LW105 (Northern Panel)

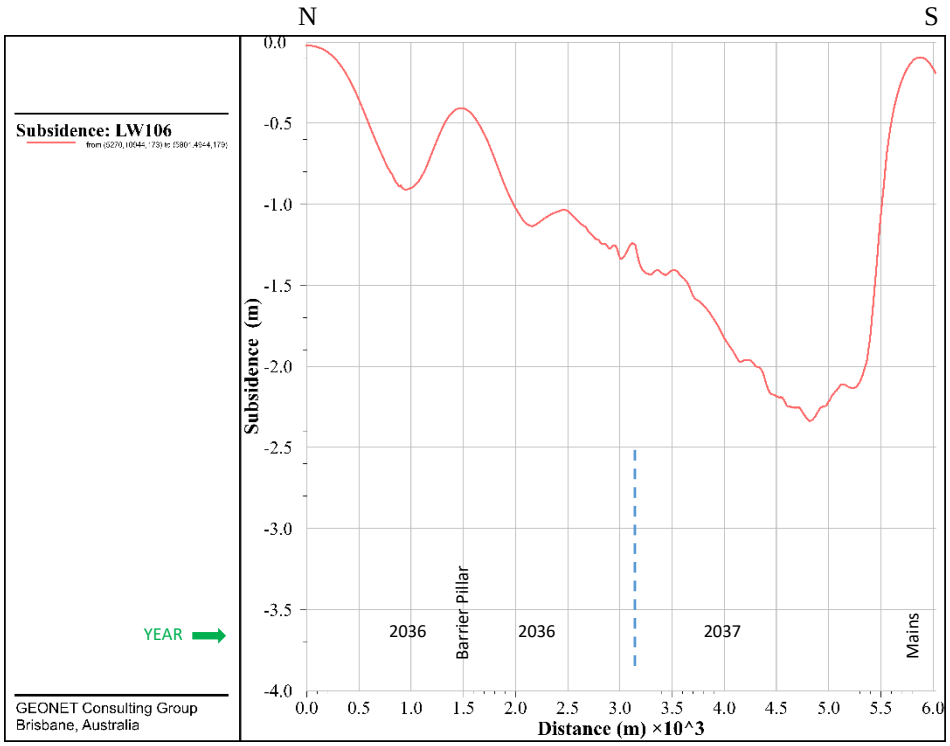


Figure 43(e): Year 2042 - Surface subsidence profile along LW106 (Northern Panel)

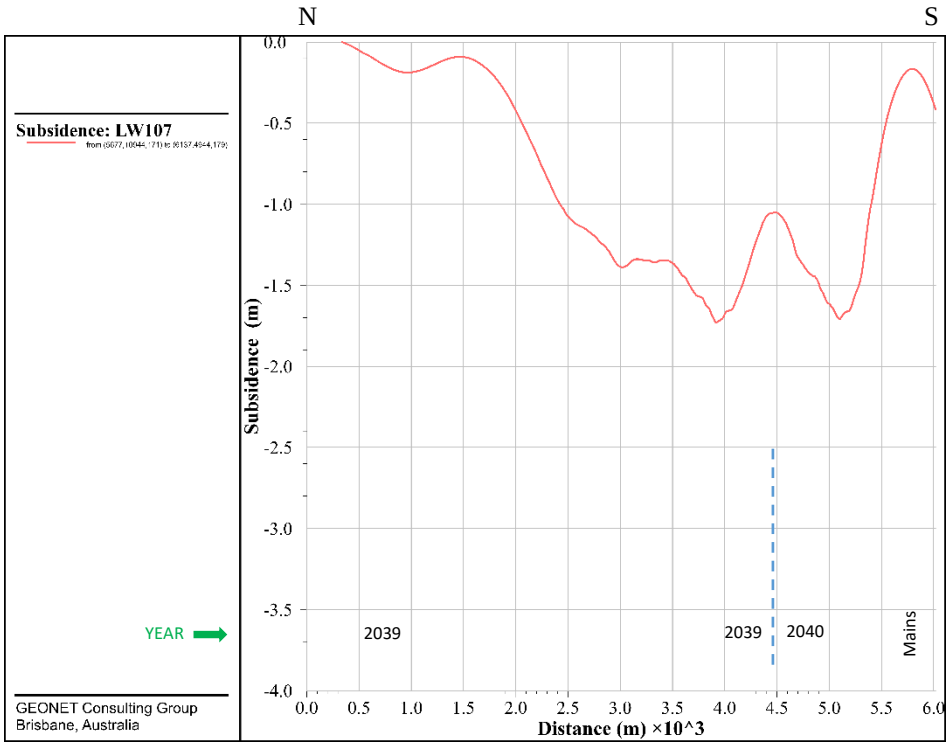


Figure 43(f): Year 2042 - Surface subsidence profile along LW107 (Northern Panel)

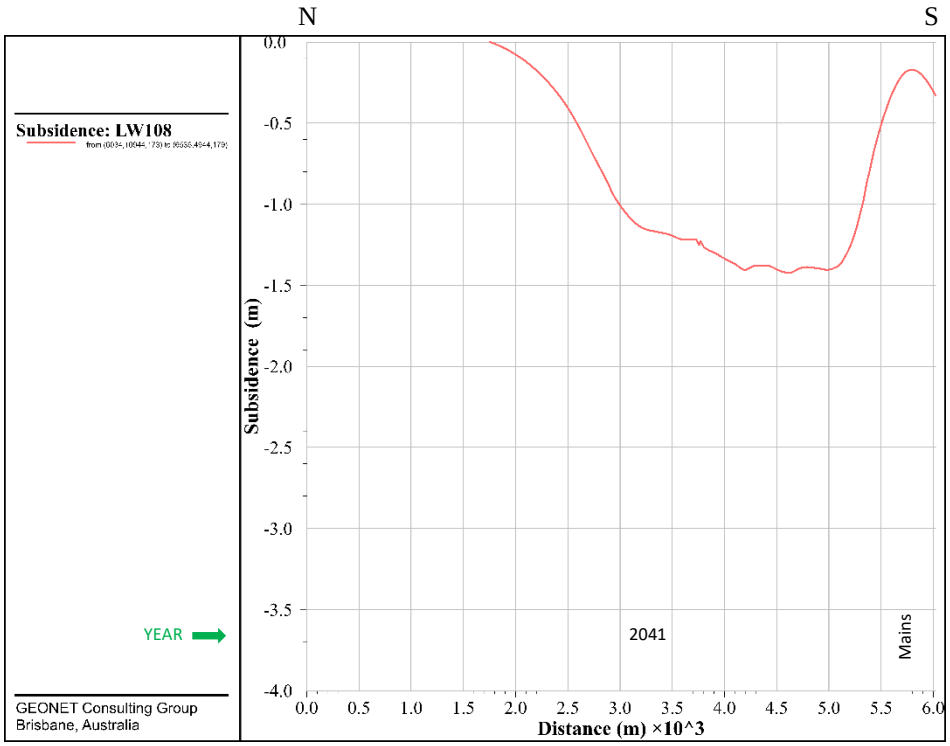


Figure 43(g): Year 2042 - Surface subsidence profile along LW108 (Northern Panel)

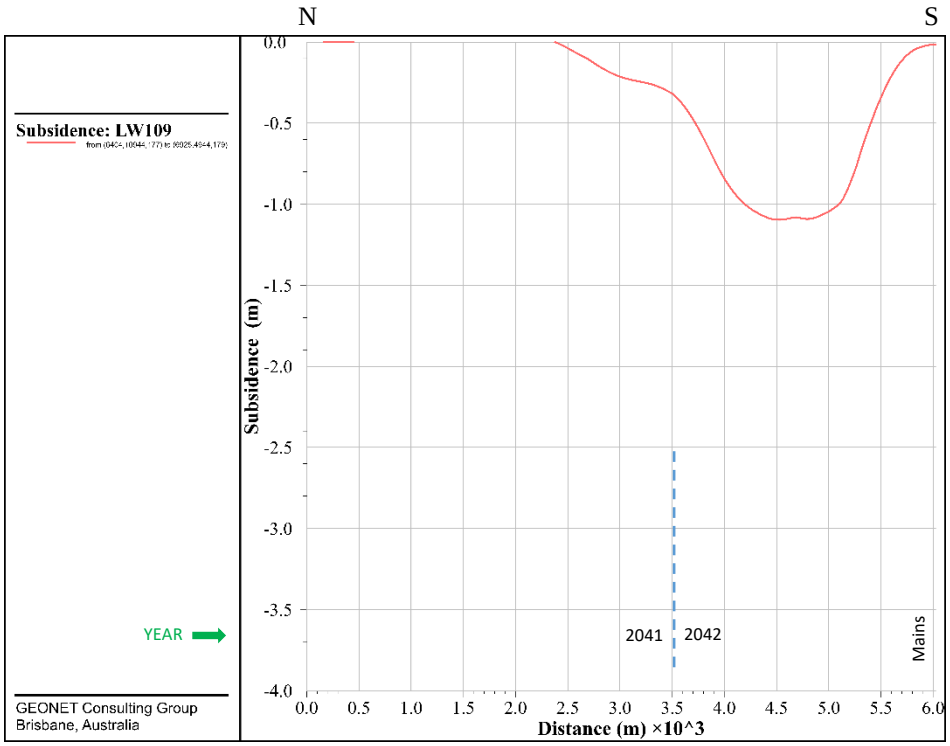


Figure 43(h): Year 2042 - Surface subsidence profile along LW109 (Northern Panel)

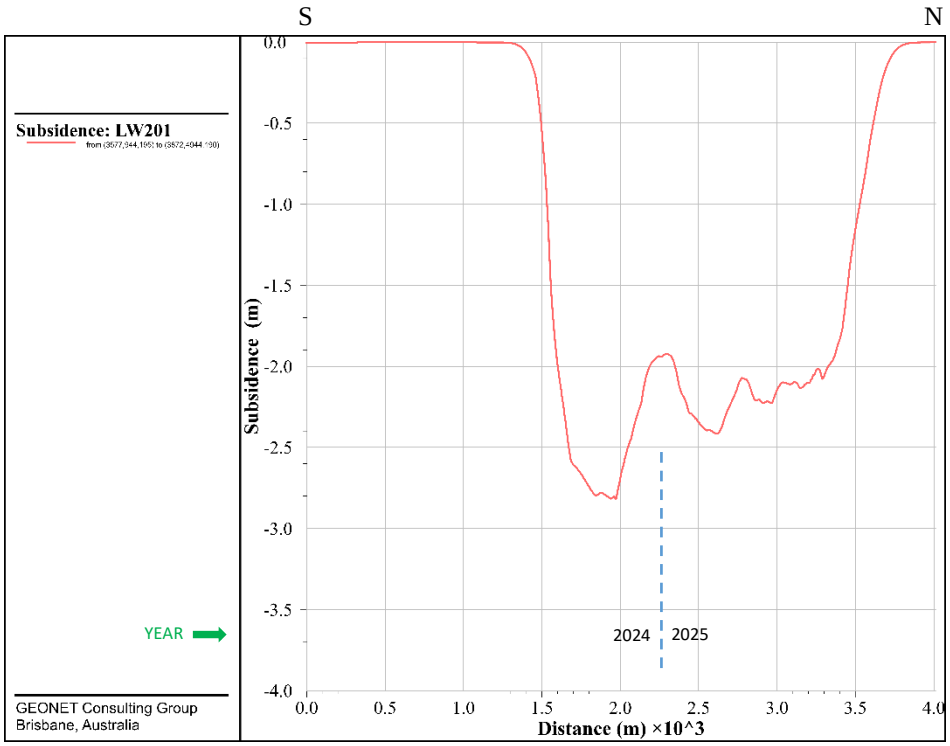


Figure 44(a): Year 2042 - Surface subsidence profile along LW201 (Southern Panel)

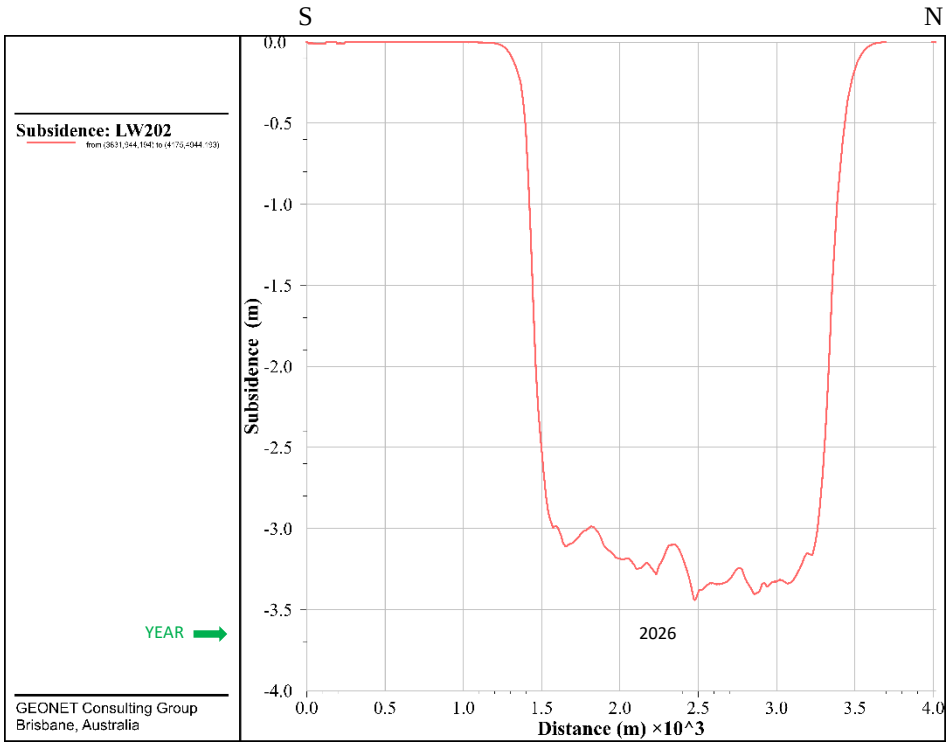


Figure 44(b): Year 2042 - Surface subsidence profile along LW202 (Southern Panel)

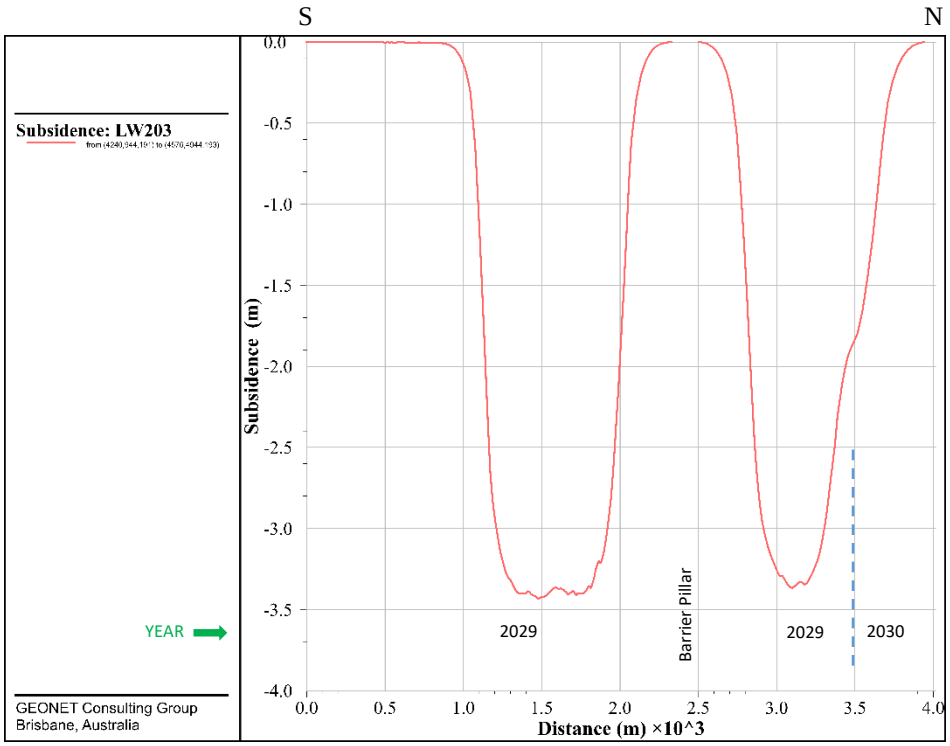


Figure 44(c): Year 2042 - Surface subsidence profile along LW203 (Southern Panel)

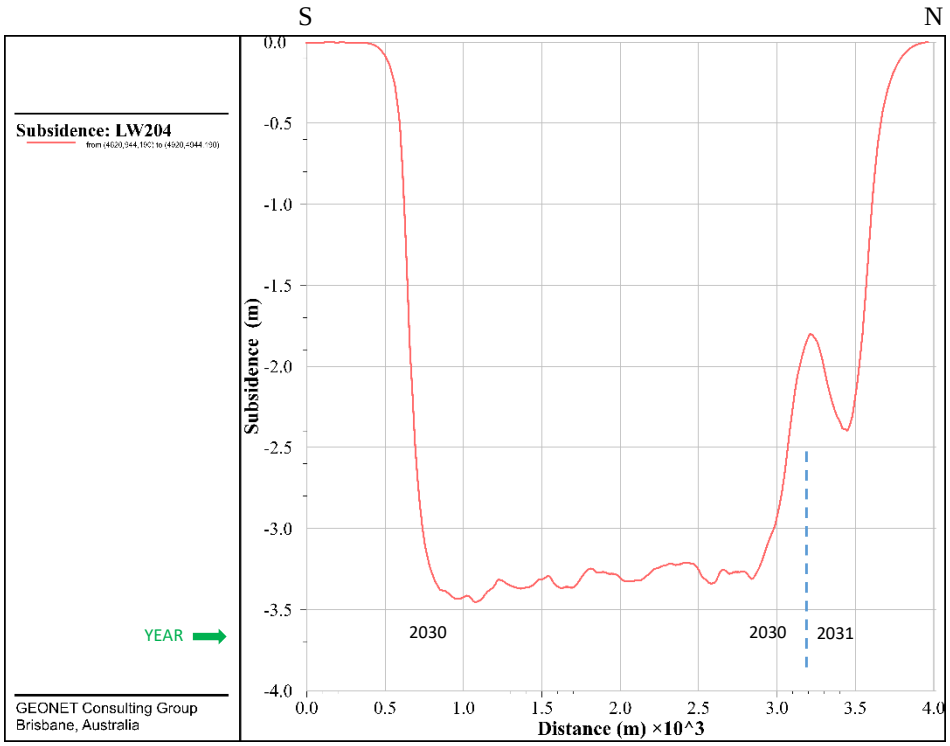


Figure 44(d): Year 2042 - Surface subsidence profile along LW204 (Southern Panel)

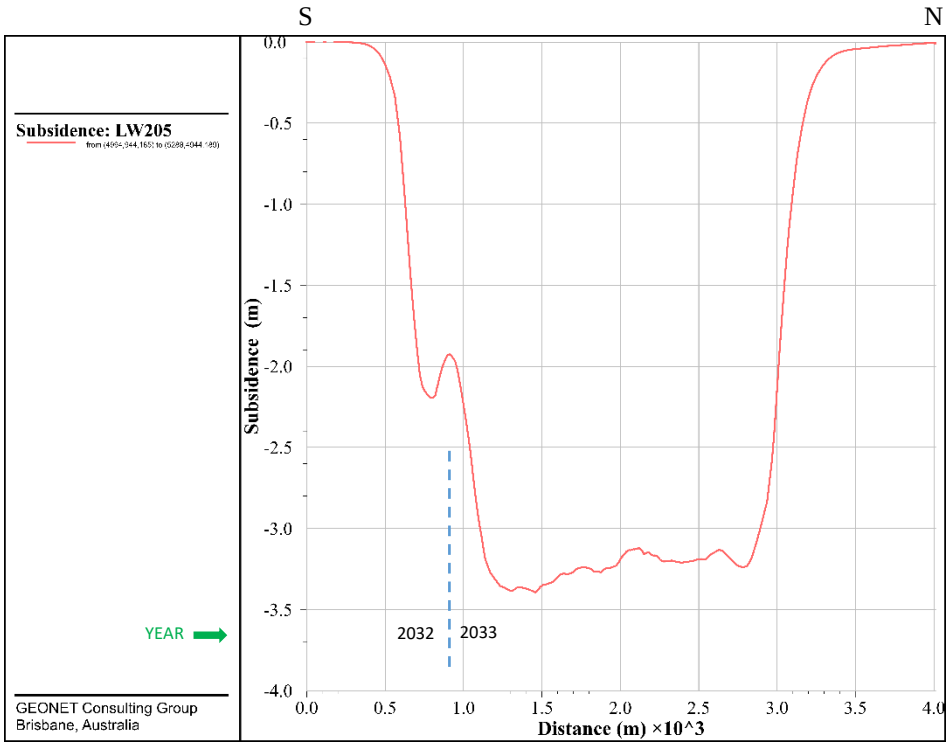


Figure 44(e): Year 2042 - Surface subsidence profile along LW205 (Southern Panel)

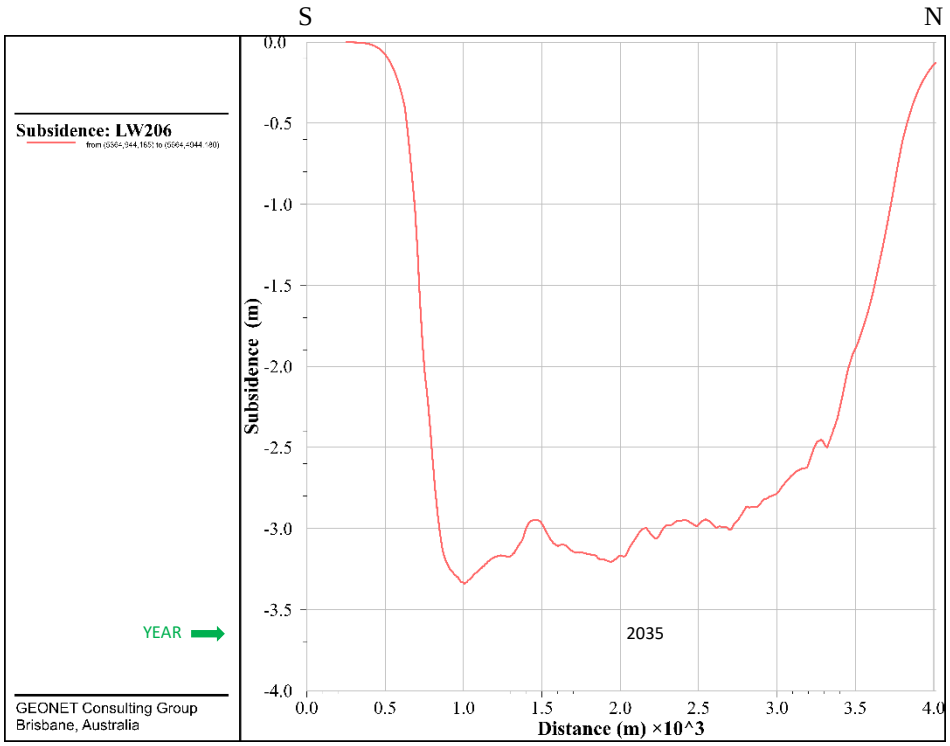


Figure 44(f): Year 2042 - Surface subsidence profile along LW206 (Southern Panel)

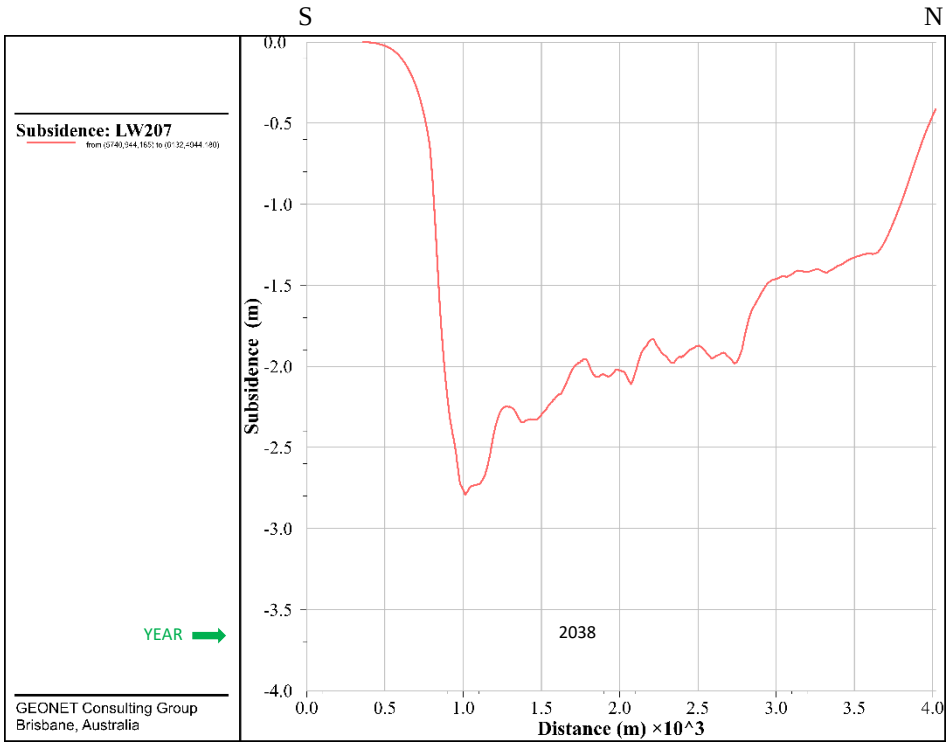


Figure 44(g): Year 2042 - Surface subsidence profile along LW207 (Southern Panel)

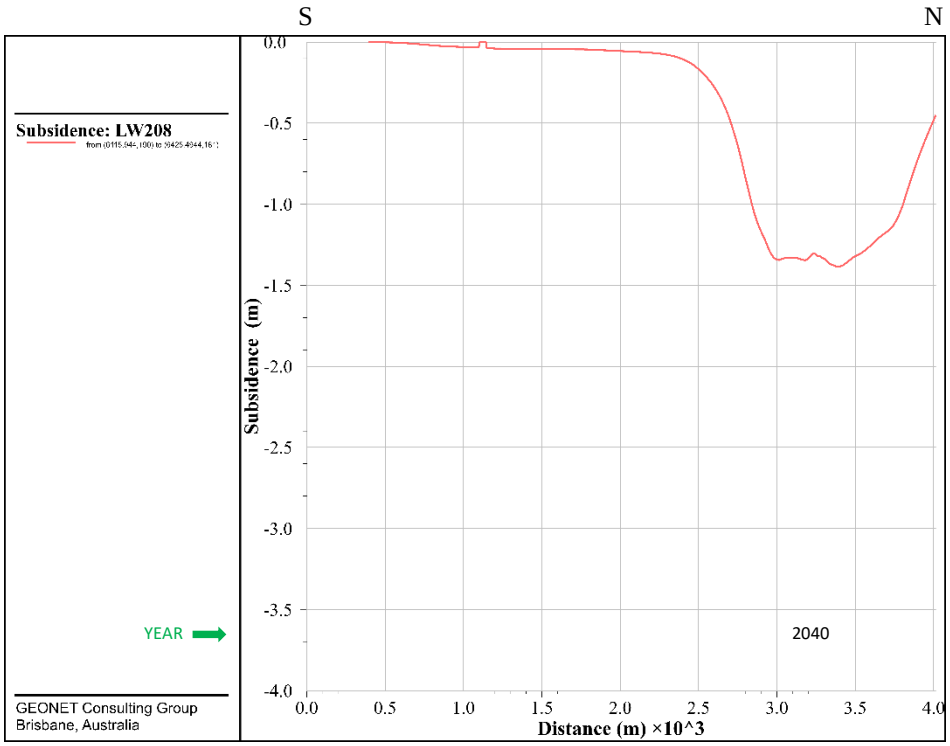


Figure 44(h): Year 2042 - Surface subsidence profile along LW208 (Southern Panel)

5.6 Post-Mining Surface Elevation

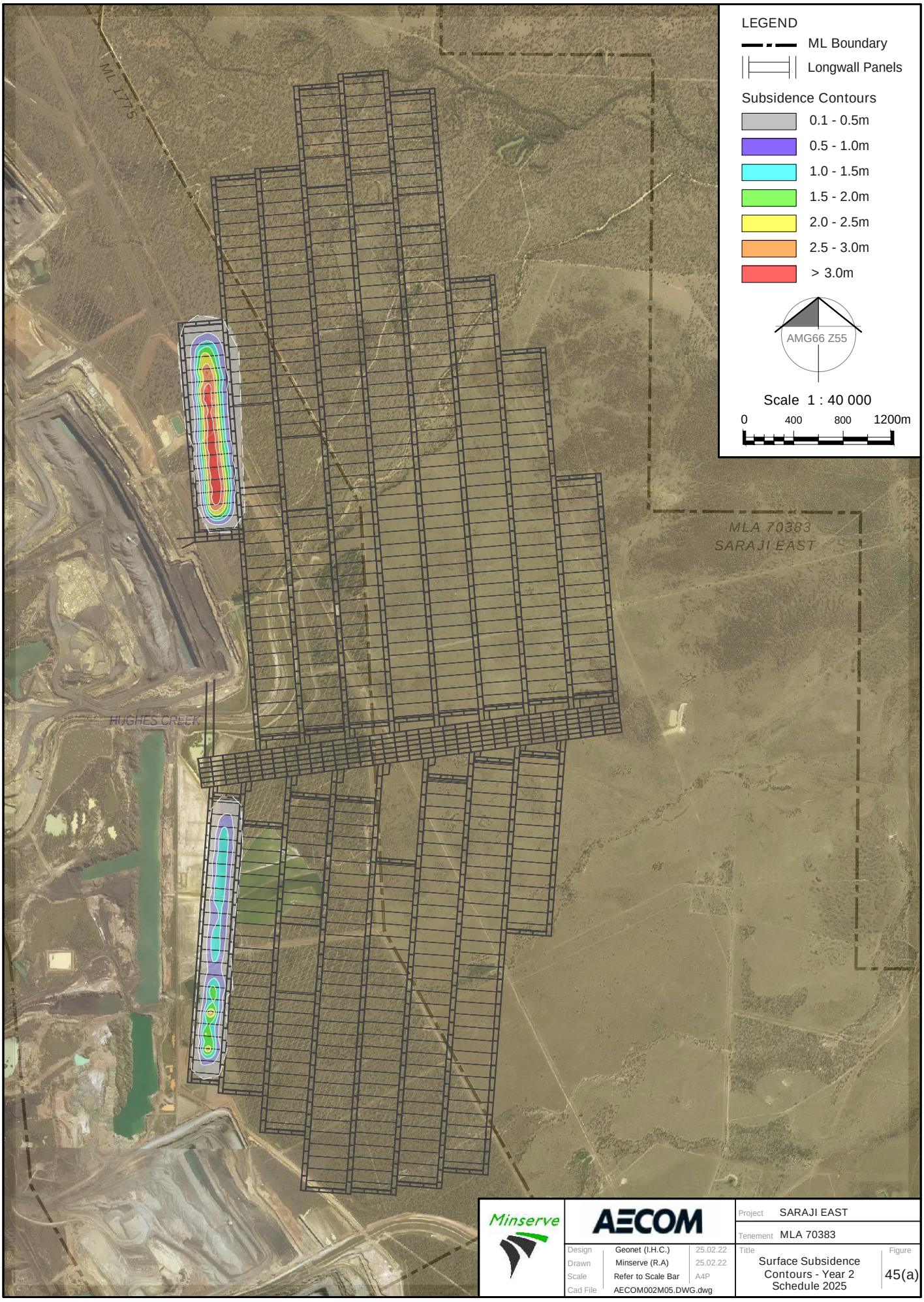
The current (pre-mining) surface topography was presented in Figure 9(a). The highest elevation is 204m in the vicinity of Boomerang Creek with another high spot over the southern end of LW204. The lowest contour is 182m over the northern end of LW106 to LW109. The elevation over LW208 is 190m.

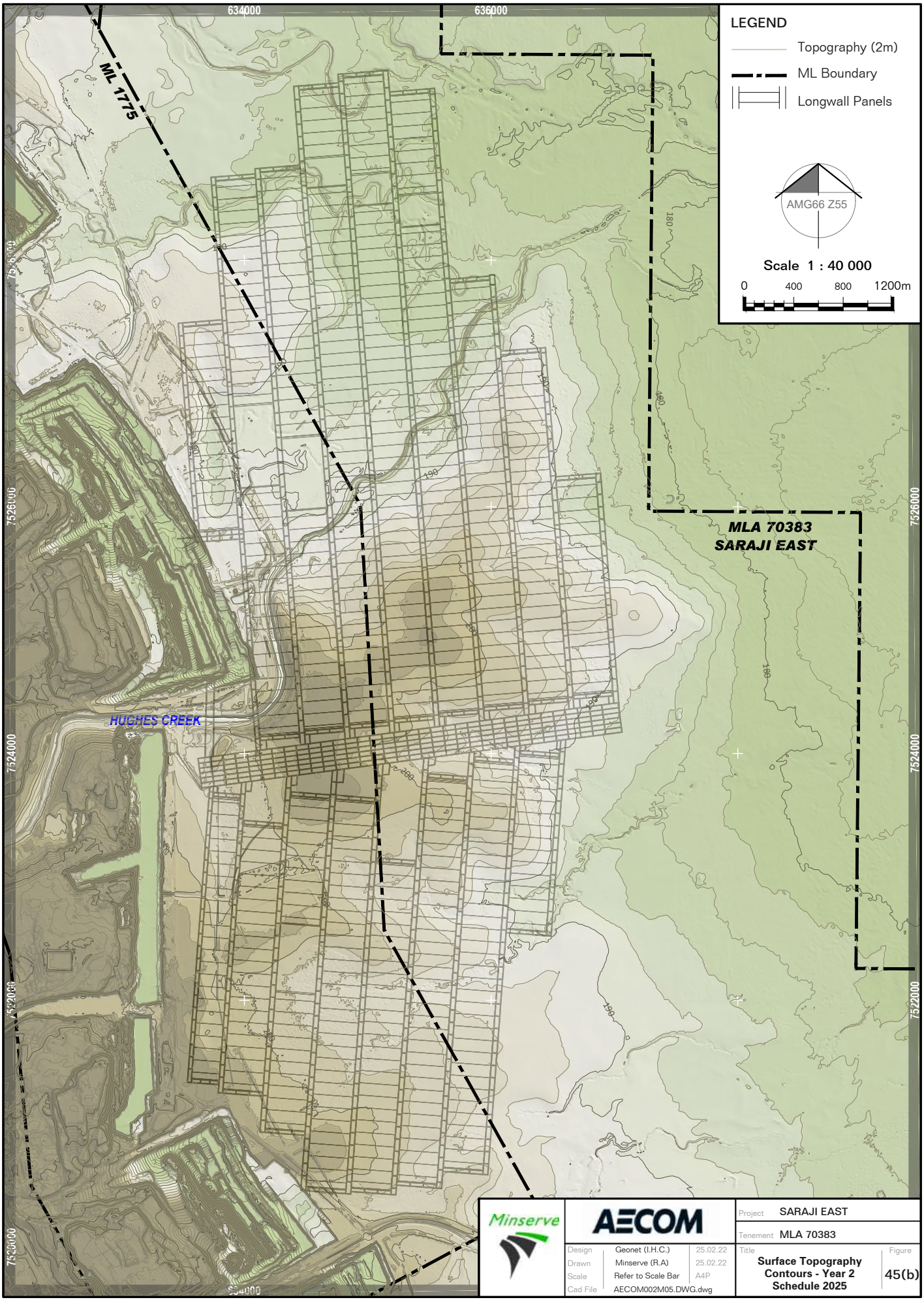
The results from the subsidence analysis are replotted at the following stages of the mining schedule, Years 2025, 2026, 2028, 2032 and 2042 in Figures 45(a) to 49(a), respectively, at contour intervals of 0.5m. On these plots, the 0.1m contour is included to delimit the extent of subsidence induced tensile cracking that is likely to form post-mining.

The post-mining surface elevation is established by subtracting the subsidence contours from the current topography. The resultant surface topography contours, plotted at 2m intervals, for these same scheduled mining stages are shown in Figures 45(b) to 49(b), respectively.

The results are presented in the following Figures:

- Figure 45(a): Year 2025 - Surface Subsidence Contours
- Figure 45(b): Year 2025 – Subsided Topography
- Figure 46(a): Year 2026 - Surface Subsidence Contours
- Figure 46(b): Year 2026 – Subsided Topography
- Figure 47(a): Year 2028 - Surface Subsidence Contours
- Figure 47(b): Year 2028 – Subsided Topography
- Figure 48(a): Year 2032 - Surface Subsidence Contours
- Figure 48(b): Year 2032 – Subsided Topography
- Figure 49(a): Year 2042 - Surface Subsidence Contours
- Figure 49(b): Year 2042 – Subsided Topography


LEGEND
ML Boundary
Longwall Panels
Subsidence Contours
0.1 - 0.5m
0.5 - 1.0m
1.0 - 1.5m
1.5 - 2.0m
2.0 - 2.5m
2.5 - 3.0m
> 3.0m
AMG66 Z55
Scale 1 : 40 000
0
400
800
1200m
ML 1775
MLA 70383
SARAJI EAST
HUGHES CREEK
Minserve
AECOM
Project SARAJI EAST
Tenement MLA 70383
Design Geonet (I.H.C.) 25.02.22
Drawn Minserve (R.A) 25.02.22
Scale Refer to Scale Bar A4P
Cad File AECOM002M05.DWG.dwg
Title
Surface Subsidence Contours - Year 2 Schedule 2025
Figure
45(a)



Minserve

AECOM

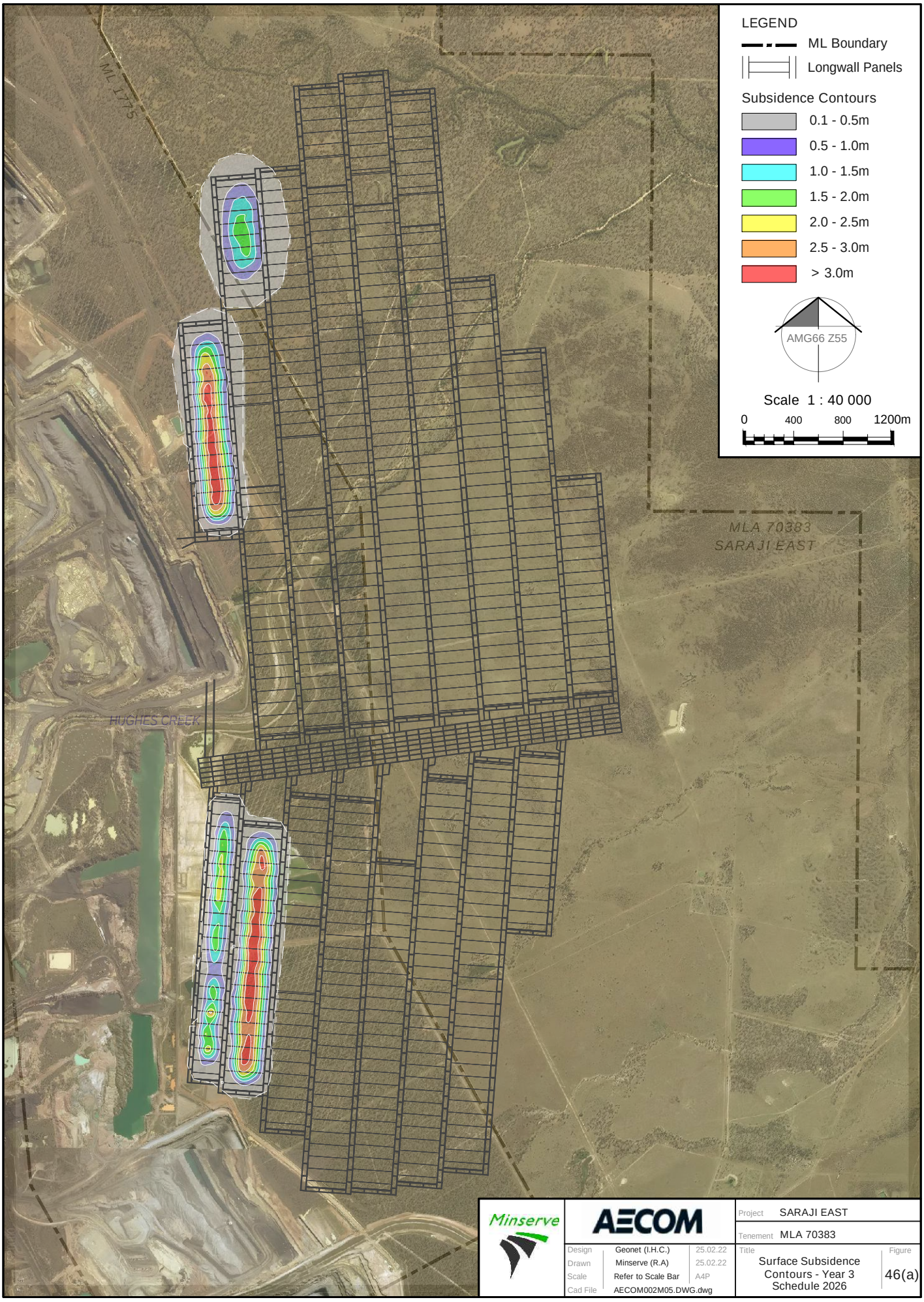
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Drawn	Minserve (R.A)	25.02.22
Scale	Refer to Scale Bar	A4P
Cad File	AECOM002M05.DWG.dwg	

Project: SARAJI EAST

Tenement: MLA 70383

Title: **Surface Topography Contours - Year 2 Schedule 2025**

Figure: 45(b)



Minserve

AECOM

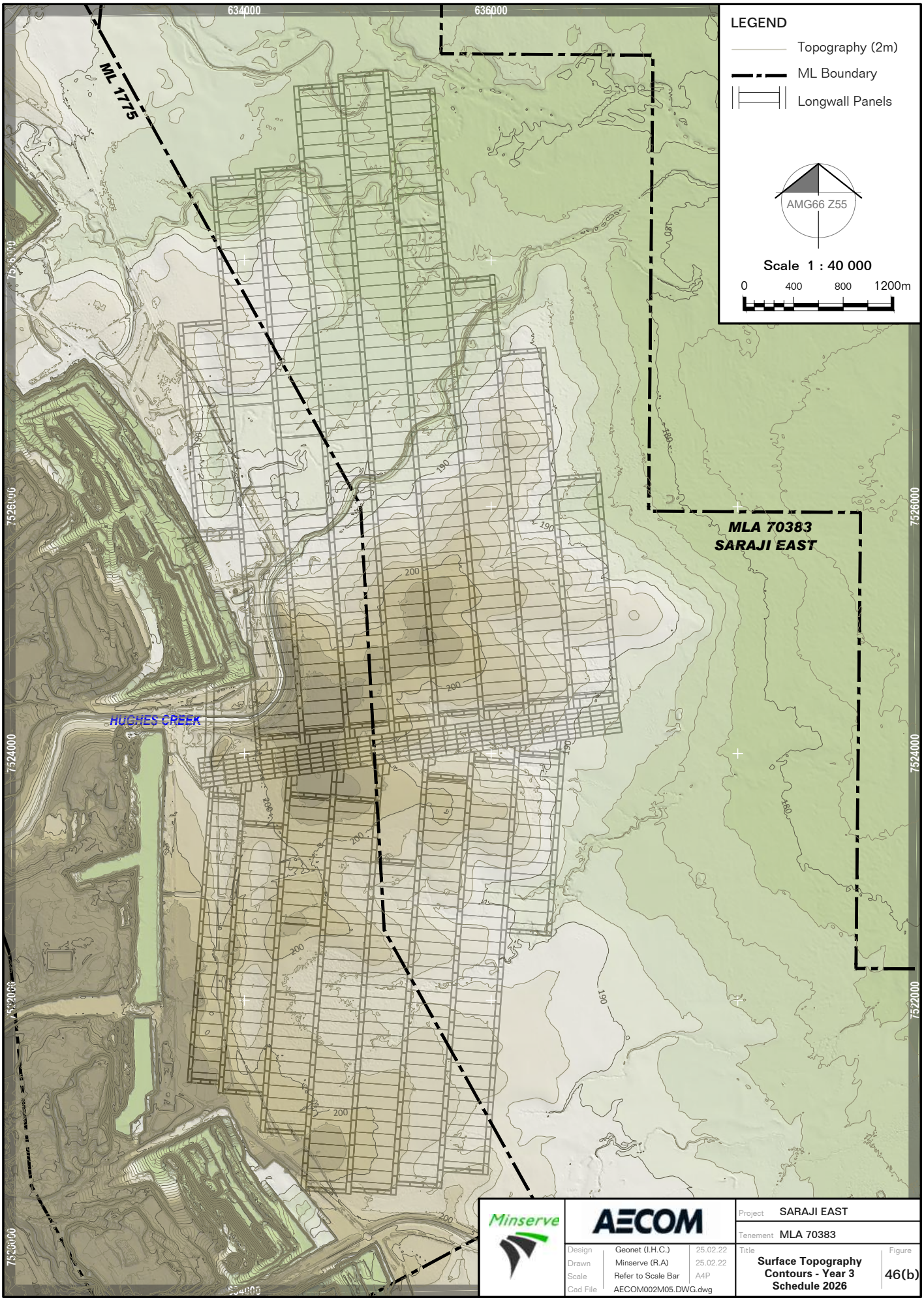
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Drawn	Minserve (R.A)	25.02.22
Scale	Refer to Scale Bar	A4P
Cad File	AECOM002M05.DWG.dwg	

Project SARAJI EAST

Tenement MLA 70383

Title: Surface Subsidence Contours - Year 3 Schedule 2026

Figure: 46(a)



Minserve

AECOM

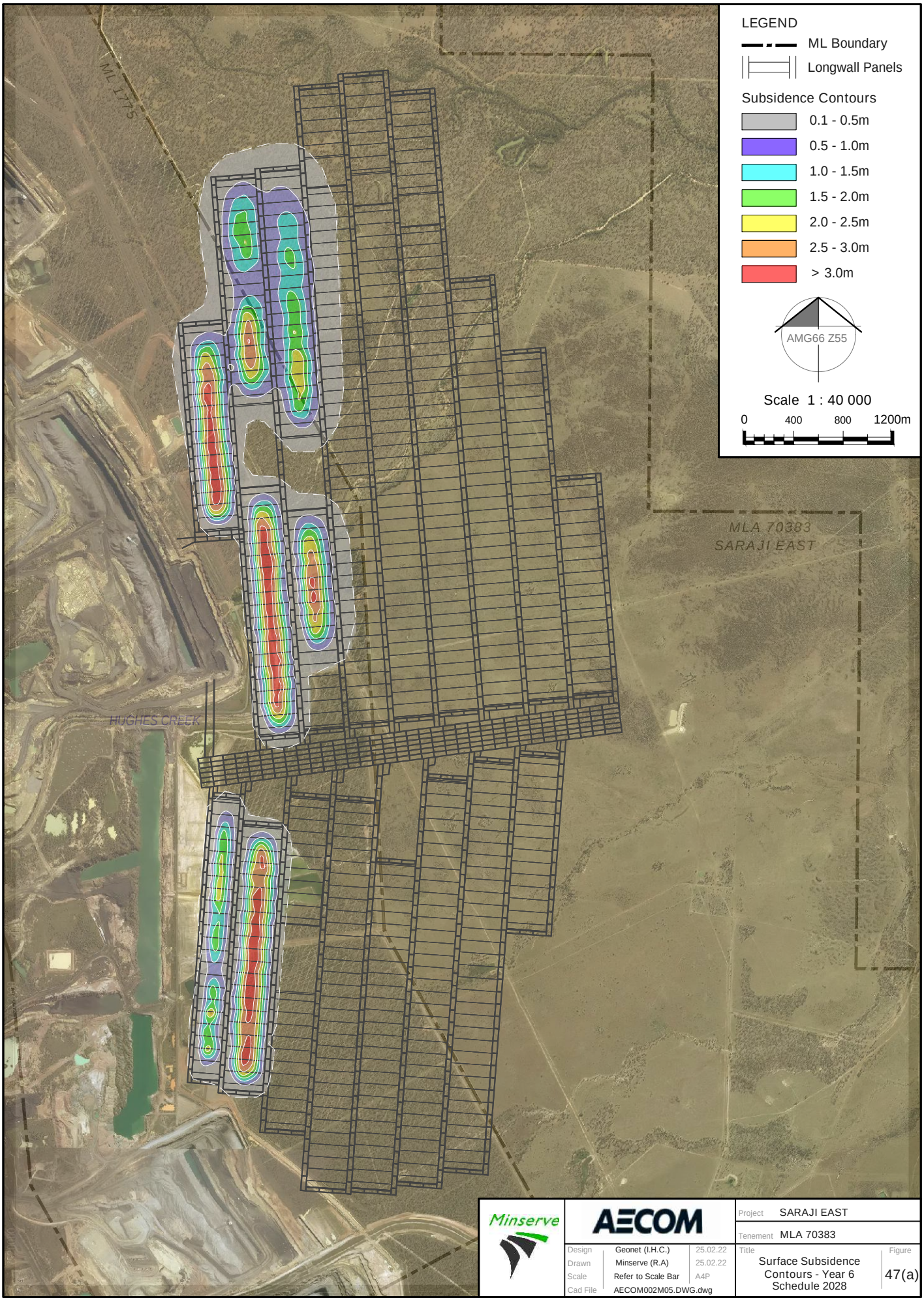
Design	Geonet (I.H.C.)	25.02.22
Drawn	Minserve (R.A)	25.02.22
Scale	Refer to Scale Bar	A4P
Cad File	AECOM002M05.DWG.dwg	

Project: SARAJI EAST

Tenement: MLA 70383

Title: **Surface Topography Contours - Year 3 Schedule 2026**

Figure: 46(b)



Minserve

AECOM

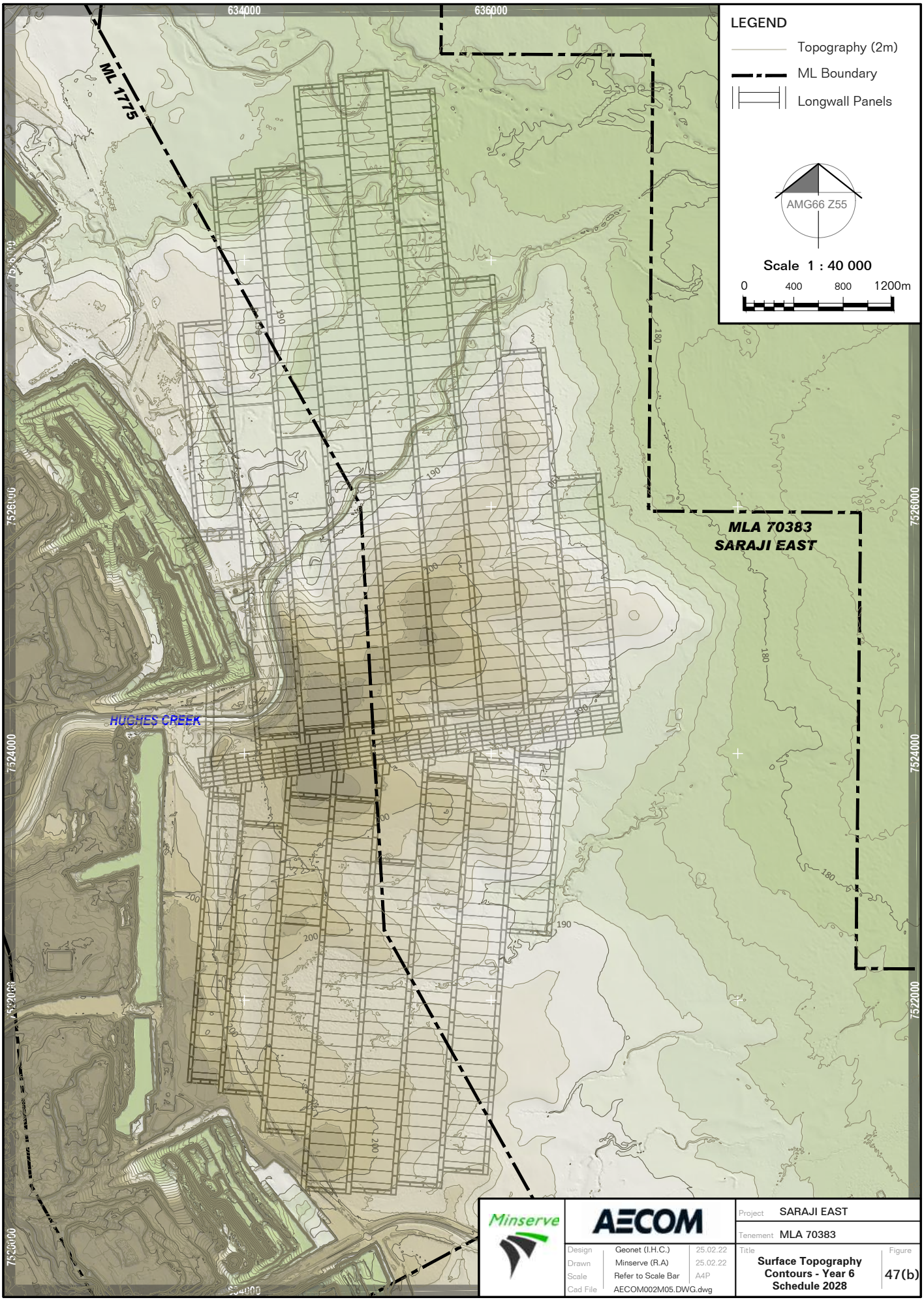
Design	Geonet (I.H.C.)	25.02.22
Drawn	Minserve (R.A)	25.02.22
Scale	Refer to Scale Bar	A4P
Cad File	AECOM002M05.DWG.dwg	

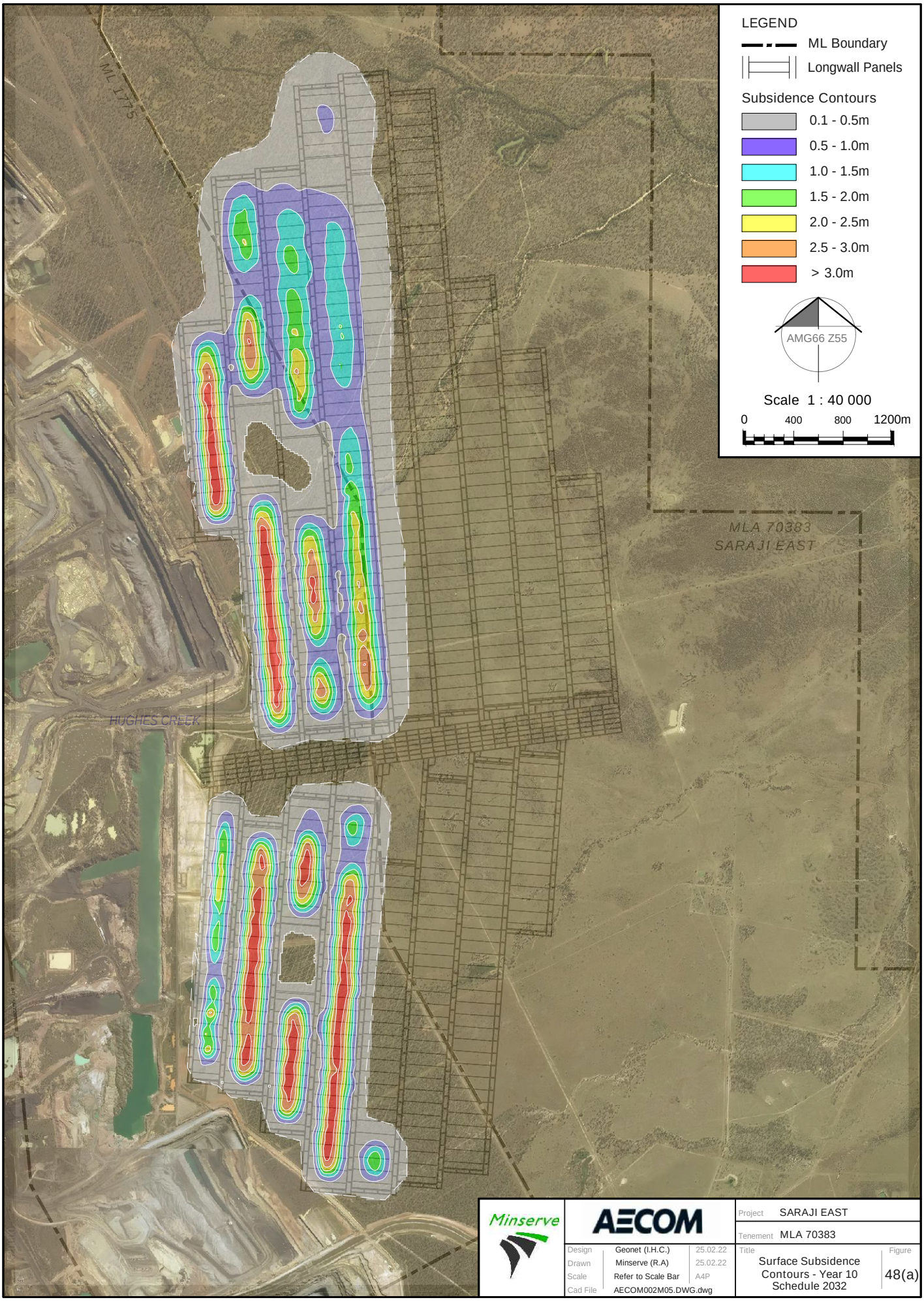
Project SARAJI EAST

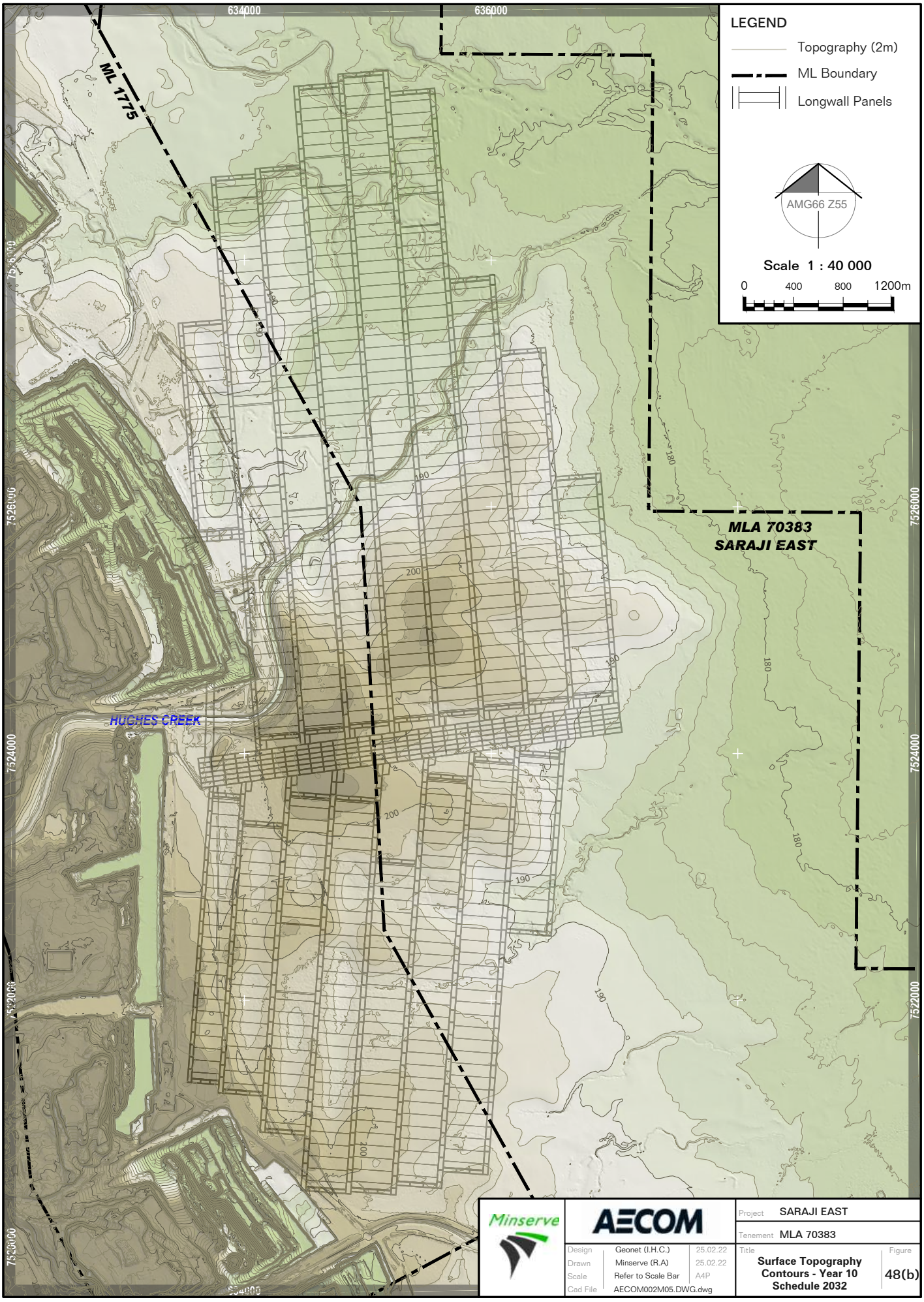
Tenement MLA 70383

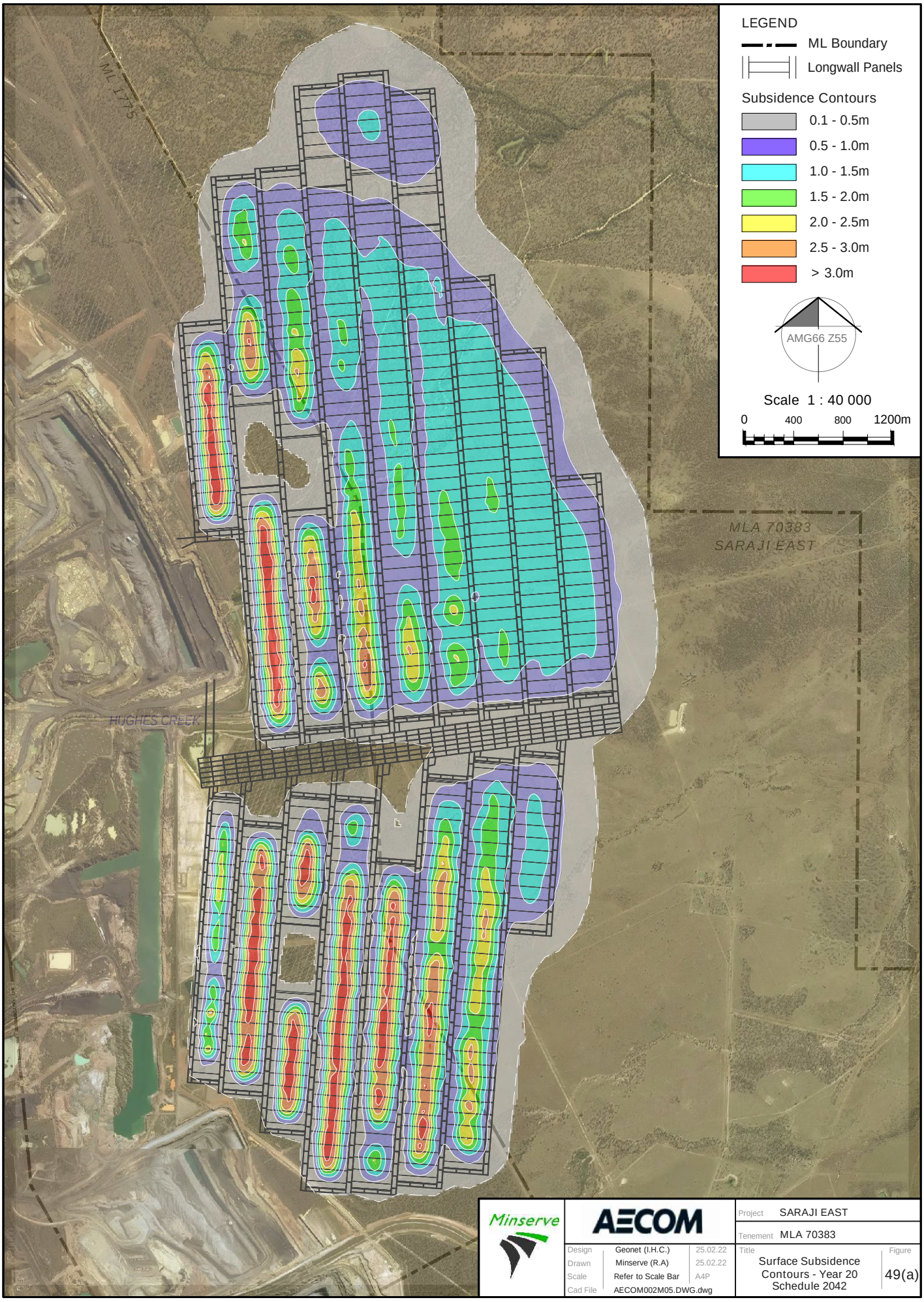
Title: Surface Subsidence Contours - Year 6 Schedule 2028

Figure: 47(a)


LEGEND
Topography (2m)
ML Boundary
Longwall Panels
AMG66 Z55
Scale 1 : 40 000
0 400 800 1200m
ML 1775
MLA 70383
SARAJI EAST
HUGHES CREEK
634000
636000
7526000
7524000
7522000
Minserve
AECOM
Project SARAJI EAST
Tenement MLA 70383
Design Geonet (I.H.C.) 25.02.22
Drawn Minserve (R.A) 25.02.22
Scale Refer to Scale Bar A4P
Cad File AECOM002M05.DWG.dwg
Title Surface Topography Contours - Year 6 Schedule 2028
Figure 47(b)


LEGEND
ML Boundary
Longwall Panels
Subsidence Contours
0.1 - 0.5m
0.5 - 1.0m
1.0 - 1.5m
1.5 - 2.0m
2.0 - 2.5m
2.5 - 3.0m
> 3.0m
AMG66 Z55
Scale 1 : 40 000
0
400
800
1200m
ML 1775
MLA 70383
SARAJI EAST
HUGHES CREEK
Minserve
AECOM
Project SARAJI EAST
Tenement MLA 70383
Design Geonet (I.H.C.) 25.02.22
Drawn Minserve (R.A) 25.02.22
Scale Refer to Scale Bar A4P
Cad File AECOM002M05.DWG.dwg
Title Surface Subsidence Contours - Year 10 Schedule 2032
Figure 48(a)


LEGEND
Topography (2m)
ML Boundary
Longwall Panels
AMG66 Z55
Scale 1 : 40 000
0 400 800 1200m
ML 1775
MLA 70383
SARAJI EAST
HUGHES CREEK
634000
636000
7526000
7524000
7522000
180
190
200
Minserve
AECOM
Project SARAJI EAST
Tenement MLA 70383
Design Geonet (I.H.C.) 25.02.22
Drawn Minserve (R.A) 25.02.22
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Cad File AECOM002M05.DWG.dwg
Title Surface Topography Contours - Year 10 Schedule 2032
Figure 48(b)



Minserve

AECOM

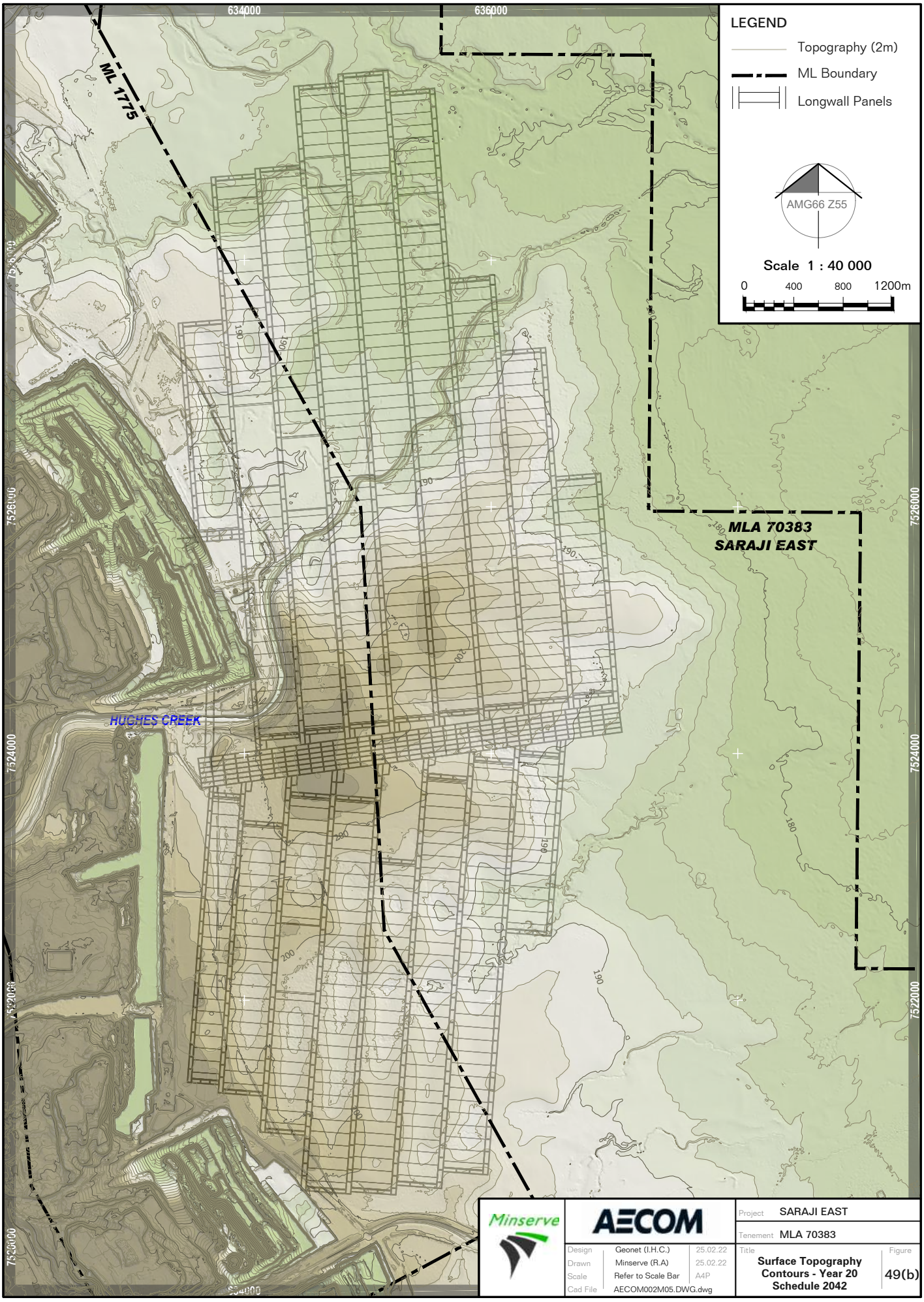
Design	Geonet (I.H.C.)	25.02.22
Drawn	Minserve (R.A)	25.02.22
Scale	Refer to Scale Bar	A4P
Cad File	AECOM002M05.DWG.dwg	

Project: SARAJI EAST

Tenement: MLA 70383

Title: Surface Subsidence Contours - Year 20 Schedule 2042

Figure: 49(a)


LEGEND
Topography (2m)
ML Boundary
Longwall Panels
AMG66 Z55
Scale 1 : 40 000
0 400 800 1200m
ML 1775
MLA 70383
SARAJI EAST
HUGHES CREEK
634000
636000
7526000
7524000
7522000
Minserve
AECOM
Project SARAJI EAST
Tenement MLA 70383
Design Geonet (I.H.C.) 25.02.22
Drawn Minserve (R.A) 25.02.22
Scale Refer to Scale Bar A4P
Cad File AECOM002M05.DWG.dwg
Title Surface Topography Contours - Year 20 Schedule 2042
Figure 49(b)

6.0 CHANGES IN HYDRAULIC PROPERTIES OF OVERBURDEN STRATA

6.1 Rockmass Permeability

Rockmass permeability is effectively the hydraulic conductivity (k) which is defined as the rate of movement of water through a porous medium such as a soil or aquifer. It is the constant of proportionality in Darcy's Law and as such is defined as the flow volume per unit cross-sectional area of porous medium under the influence of a unit hydraulic gradient. This translates in SI units to m^3/m^2/second or m/sec. A qualitative description of flow measurement units is summarised in Table 6.1.

Table 6.1: Commonly used units for hydraulic conductivity (k)

Flow Description	Permeability (m/s)	Example Rock Type
Extremely slow	1.5741×10^{-11}	Mudstone
Very Slow	1.5741×10^{-9}	Siltstone
Slow	1.5741×10^{-7}	Sandstone
Moderate	1.5741×10^{-5}	Fine Sand
Fast	1.5741×10^{-4}	Med Sand
Very Fast	1.5741×10^{-3}	Gravel

Measurement of hydraulic conductivity is problematic, considering the parameter can differ over several orders of magnitude across the spectrum of sediments and rock types. The parameter can also vary markedly in space, even with apparently minor changes in sediment characteristics. Hydraulic conductivity is also influenced by the properties of the fluid being transmitted (such as viscosity) as well as the porous medium. Hydraulic conductivity is also scale dependent, so that measurements taken at the core sample level may not be directly extrapolated to the aquifer or longwall panel scale. It is also direction dependent, so that hydraulic conductivity can be markedly different in the vertical from the horizontal.

In the overburden rockmass, the initial permeability is negligible as the joints and bedding planes are essentially closed. Following seam extraction the overburden deformation causes joint planes to open in tension or in shear and new cracks may be formed by fracturing of intact rock. The net effect of the increased density of cracking is to increase the overall rockmass permeability. The presence of horizontal bedding and high angle jointing suggests that there will also be a directional control on the permeability.

Permeabilities of coal measure strata range from 10^{-6} to 10^{-9} m/sec [13]. Results of packer tests carried out at Oaky Creek established the conductivities range from 1.16×10^{-8} m/sec for sandstone to in excess of 5.8×10^{-5} m/sec for severely fractured zones. The wide range of measured permeability reflects the extent of fracturing and bedding plane separation in

the strata, rather than variations in primary permeability of the sedimentary strata. The intrinsic permeability (K_f) of the fractured overburden rockmass may be estimated using the expression:

$$K_f = \frac{n\ a^3}{12\ u}$$

where

n = number of joints per metre

a = fracture width (m)

u = unit length (=1m)

Using a lower bound value for joint spacing in interburden strata of 3.2 joints per metre, it is calculated that this represents a fracture spacing of 0.3125 metres.

Experimental studies reported in the literature have indicated that the cubic law governs flow in rock fractures if the fracture aperture is more than 20 microns. Assuming the fracture width to be 0.5 mm, then the intrinsic permeability of high angle jointed overburden rock is calculated as follows:

$$K_f = (3.2)\ (0.0005)^3\ /\ (12)\ .\ (1.0) \quad = \quad 3.33 \times 10^{-11}\ m$$

The hydraulic conductivity of the high angle joints is:

$$k_v = K_f\ .\ g\ .\ \gamma_w \quad = \quad 3.33 \times 10^{-11}\ .\ 9.81\ .\ 1000$$

$$= \quad 3.27 \times 10^{-7}\ \ m/sec$$

This value falls well within the range of 1.5×10^{-6} m/sec to 4.5×10^{-9} m/sec measured by Whittaker [13] and is equal to the hydraulic conductivity for medium coarse sandstone measured at Oaky Creek. The relationship of rockmass permeability to fracture width and joint spacing is shown in Figure 48. On this graph the typical coal measures data are superimposed.

The permeability of the overlying Tertiary sediments has not been measured directly but will be consistent with medium to coarse silty sand. Typical permeability values quoted in the soil mechanics literature are in the range 10^{-3} to 10^{-5} cm/sec. It has been noted that the insitu behaviour of Tertiary sediments is to develop clean tensile cracks to a depth of about 10m to 15m from surface due to subsidence over mined longwall panels. When water flows into these open cracks they tend to swell and self-seal. It can be assumed therefore that overall permeability of the Tertiary sediments will remain the same as its initial condition even when disturbed by subsidence.

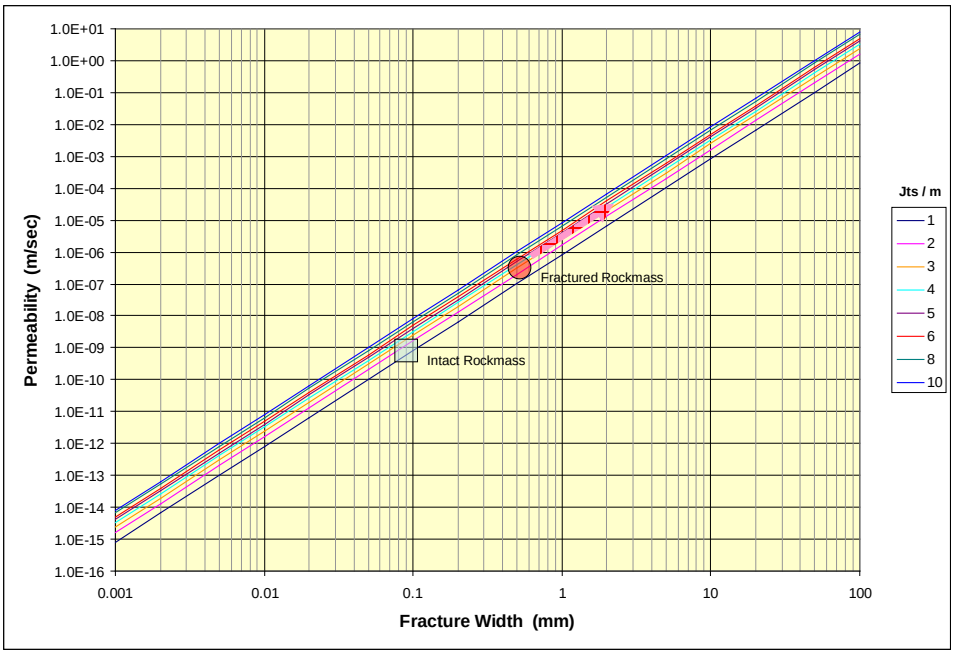


Figure 48: Influence of fracture width and joint density on rockmass permeability.

A listing of typical coal measures rockmass hydraulic properties is shown in Table 6.2.

TABLE 6.2: Typical Rockmass Hydraulic Properties

MATERIAL	K_{11} (m/s)	K_{22} (m/s)	Porosity
Tertiary Sediments	3.0e-5	3.0e-5	0.3 – 0.4
Weathered Sandstone	5.0e-6	8.7e-6	0.25
Shale	2.4e-9	7.1e-8	0.005
Sandstone	2.4e-9	7.1e-8	0.006
Mudstone	2.4e-9	7.1e-8	0.004
Coal	5.0e-7	5.5e-7	0.10

where

k_{11} is the horizontal component of permeability

k_{22} is the vertical component of permeability

6.2 Rockmass Porosity

The porosity of the intact rockmass is roughly calculated as follows. By way of an example, consider a cubic metre of rock with a joint density of 3.2 per metre and a joint opening width of 0.5 millimetres.

Volume of the joints is (1m x 1m x 0.0005m) x 3.2 = 0.0016 m^3

Porosity = volume joints / total volume = 0.0016/1 = 0.0016

The overall porosity of the subsided overburden can be estimated by considering the change in volume of the rockmass. Thus, for an extraction height of 5.0m and a surface subsidence of 0.350m rockmass porosity is calculated as follows:

Porosity = Volume void / Original volume

= (Extraction Height – Surface Subsidence) / Thickness of Overburden

= (5.0 – 0.50) / 120 = 0.0375

This value only represents the average porosity through the overburden. Clearly there will be zones where joint apertures are open and others where joints are closed. Typical values for rockmass porosity of subsided strata over longwall mining layouts are:

i) 3.75% for the first 20m of roof strata above the mined panel,

ii) 1.25% for the overlying competent strata, and

iii) Tertiary sediment cover will be about 35 to 40 percent.

6.3 Strain Dependent Permeability and Porosity

In order to estimate the changes in rockmass hydraulic properties, porosity and permeability, accompanying the sequential excavation of longwall panels, the following method was developed.

The rockmass porosity was derived by the following procedure:

Porosity, n, is related to the total volume, V_o, as:

$$n = 1 - V_s / V$$

where V_s is the volume of solid material in the element, which is assumed to remain constant (e.g. the material consists of incompressible material). A similar relation exists for the initial porosity, n_o, and the initial element volume, V_o:

$$n_o = 1 - V_s / V_o$$

Eliminating V_s between these two equations, yields:

$$n = 1 - (V_o/V)\ (1-n_o)$$

In small-strain mode of analysis, the volumetric strain is approximated as:

$$\varepsilon_v = \frac{V - V_o}{V_o}$$

Substituting the resulting value for (V_o/V) into previous equation for porosity:

$$n = \frac{1 - n_o}{1 + \varepsilon_v}$$

This empirical relationship for porosity is plotted as a function of volumetric strain for different initial porosities in Figure 49.

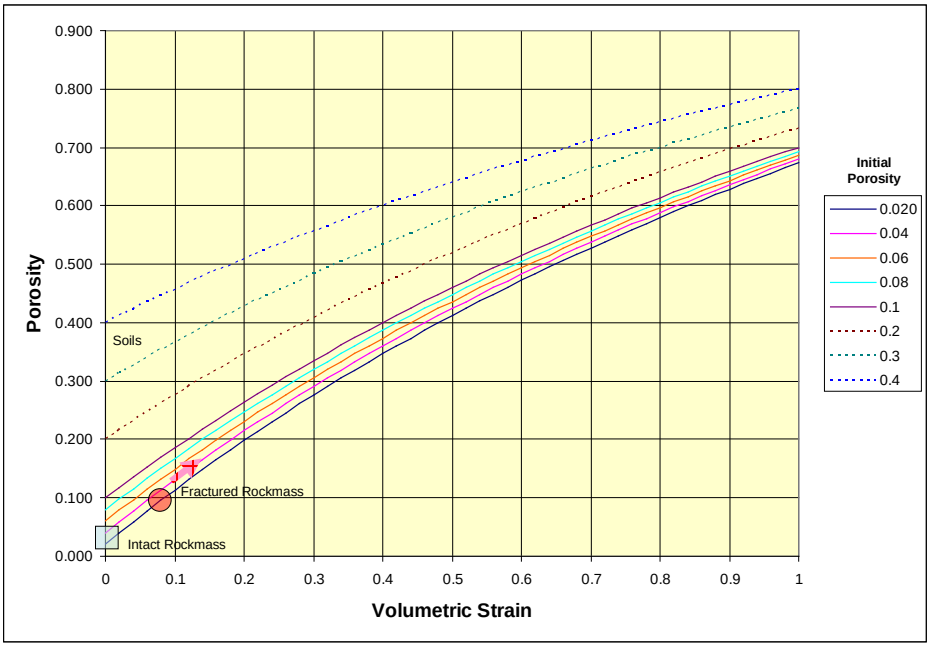


Figure 49: Empirical relationship between porosity and volumetric strain for different initial joint density in the rockmass.

The altered rockmass condition is shown in Figures 50 and 51 by means of plots of the volumetric strain induced by subsidence of the overburden strata. In Figures 50(a) and 50(b) the surface distribution of volumetric strain is shown for the northern and southern longwall panels, respectively. Figures 51(a) to 51d) show the distribution of volumetric strain on the selected cross-sections. The contour interval ranges from 0.1% to 1% strain.

Based on the graph in Figure 49 it can be seen that 1% volumetric strain correlates with 65% to 70% rockmass porosity. Locations where the volumetric strain exceeds 1% are shown by the black contours in Figure 50 and the cardinal coloured contours in Figure 51. In these zones it can expected that there will be contiguous connection between surface and the longwall panel. It can also be observed from the cross-section plots that the interburden strata between the Dysart and Harrow Creek seams is completely dilated (ε_v > 1%) following goafing of the roof strata.

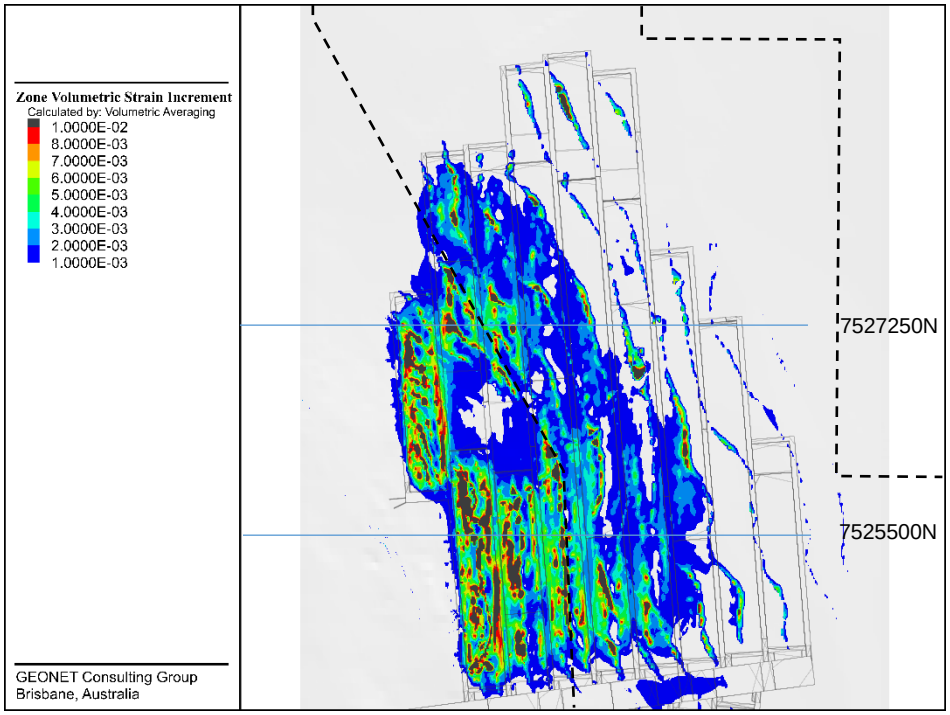


Figure 50(a): Subsidence induced volumetric strain over Northern longwall panel

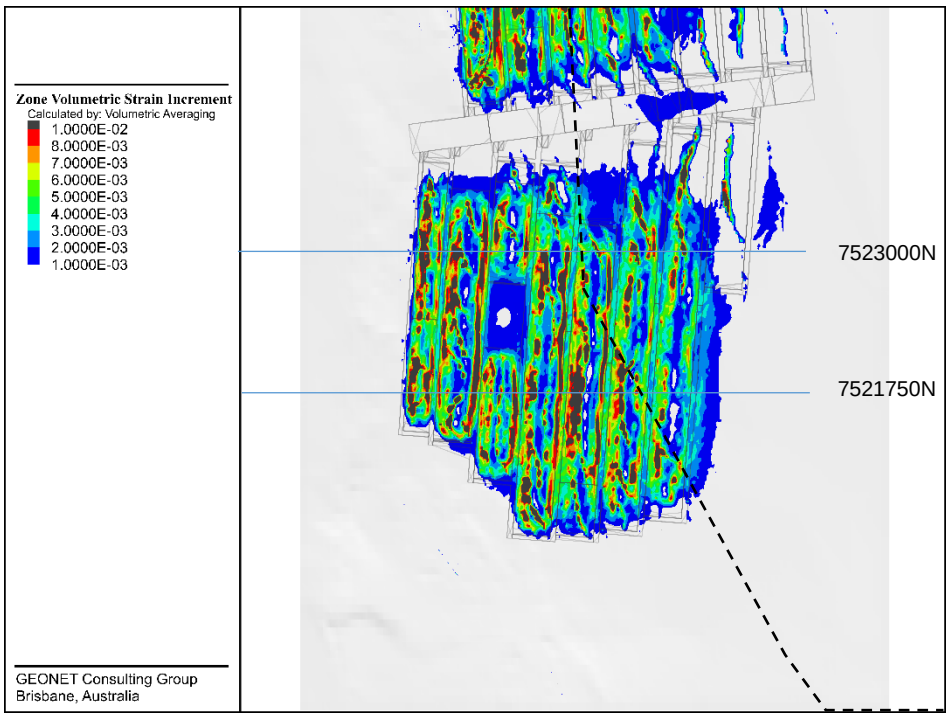


Figure 50(b): Subsidence induced volumetric strain over Southern longwall panel

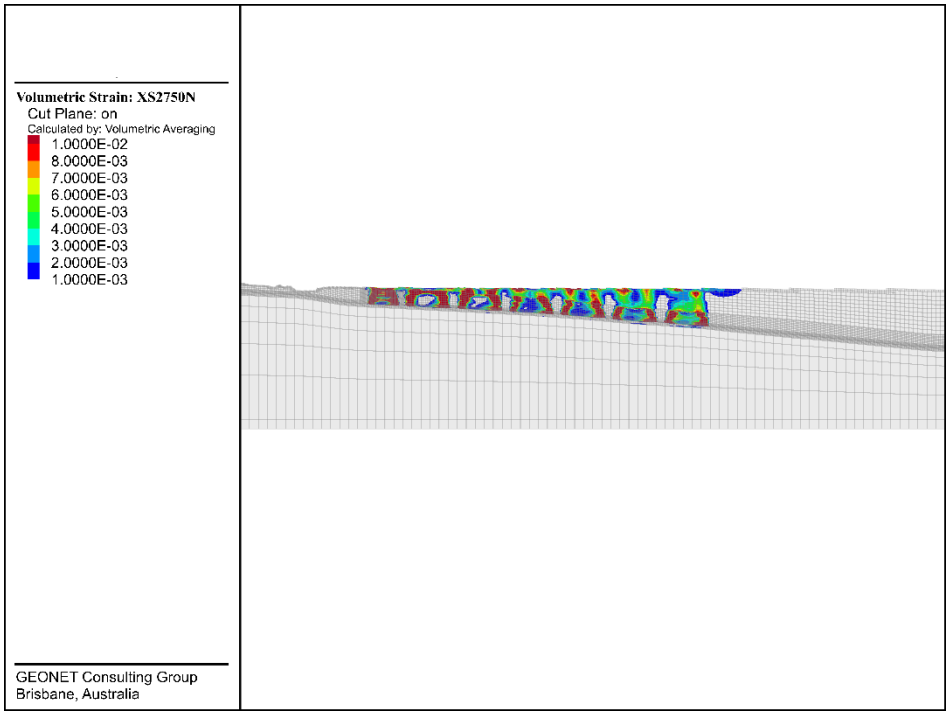


Figure 51(a): Subsidence induced volumetric strain on cross-section at 7521750N.

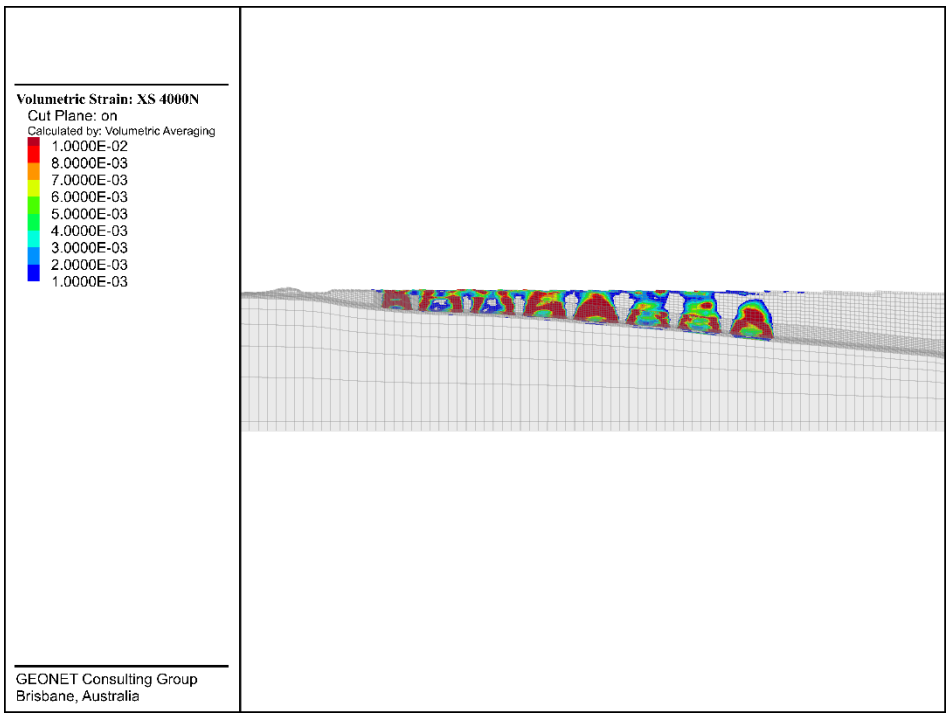


Figure 51(b): Subsidence induced volumetric strain on cross-section at 7523000N.

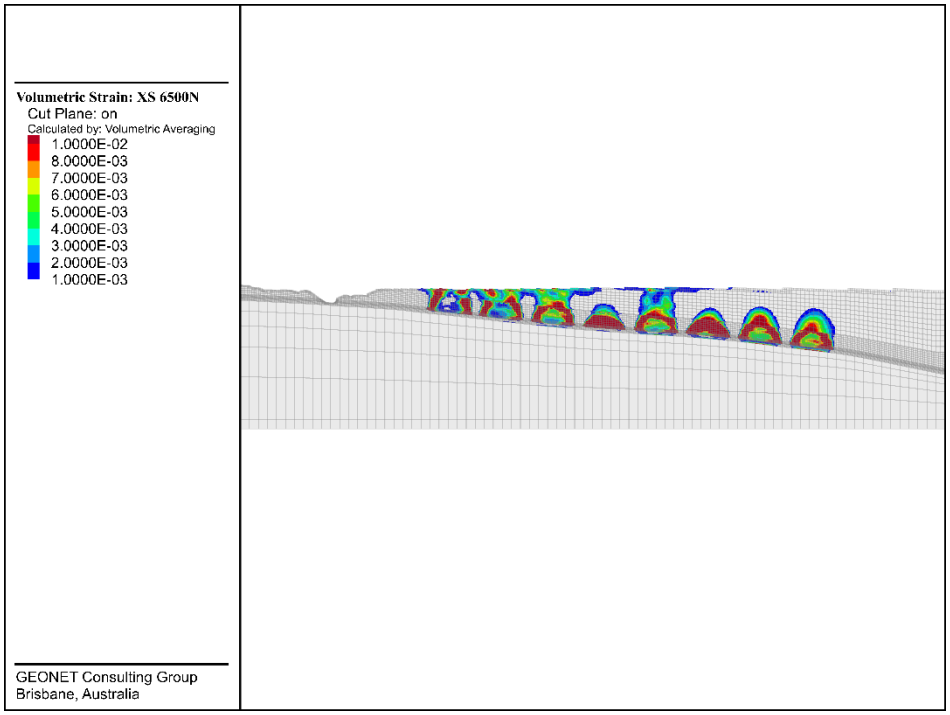


Figure 51(c) Subsidence induced volumetric strain on cross-section at 7525500N.

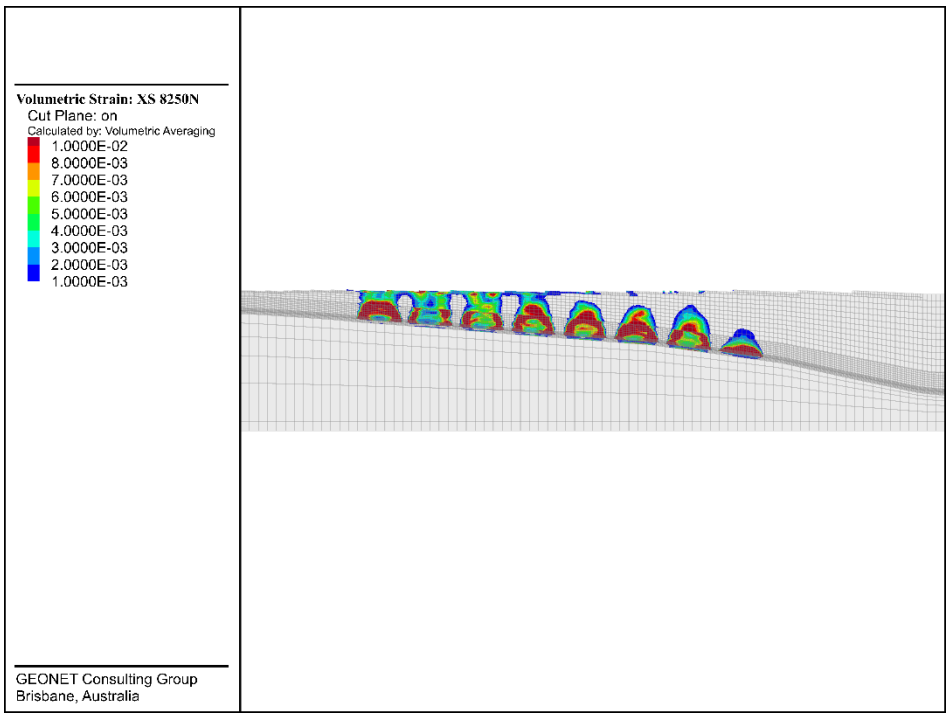


Figure 51(d) Subsidence induced volumetric strain on cross-section at 7527250N.

The hydraulic properties of the Fort Cooper Coal Measures and Tertiary strata are affected to varying degrees depending on the depth of longwall mining. Subsided surface strata (Tertiary strata) directly over the longwall panels typically exhibit volumetric strains in the range 0.2% to 0.5%. This correlates with an effective rockmass porosity range of 0.2 to 0.4.

Similarly, the two components of the permeability tensor, k_{11} and k_{22}, can be updated in relation to their pre-mining condition via the initial permeability tensor components (k_{11o} and k_{22o}), the local induced volumetric strain (ε_v) and a multiplier. The multiplier is arbitrarily chosen to reflect the case of vertical joints opening more than horizontal (bedding) planes. Thus:

$$k_{11} = \frac{k_{11o}}{(1 - \varepsilon_v)} \times 10$$

$$K_{22} = \frac{k_{22o}}{(1 - \varepsilon_v)} \times 50$$

Clearly it is not possible to specify a definitive single value for either of the permeability tensor components nor porosity for the post-mining rockmass condition of each strata unit. These hydraulic properties will vary throughout the rockmass depending on the specific local subsidence characteristics. Based on the calculated volumetric strains the following estimates are made for the range of subsided overburden rockmass hydraulic properties:

- Porosity:
  - Large fractures over longwall panel open 100m to 150m above panel in overburden
  - Porosity in large open fractures will be 0.10 to 0.15
  - Typical fractured overburden strata will have porosity between 0.050 and 0.075
  - Tertiary sediment porosities will increase to the range 0.250 to 0.375.
    - In compression zones of the subsidence troughs the porosity of overburden strata will be 0.225 to 0.250
    - Tensile conditions at the base of Tertiary yield porosities 0.1 to 0.15.

- Horizontal Permeability (K_{11}):
  - In fractured overburden strata permeability is 2e-7 to 5e-8 m/sec
  - In subsided coal seams permeability is 2e-5 to 5e-6 m/sec
  - In Tertiary sediments permeability is 2e-3 to 5e-4 m/sec.

- Vertical Permeability (K_{22}):
  - In fractured overburden strata over longwalls permeability is 2e-5 to 5e-6 m/sec
  - In subsided coal seams permeability is 2e-4 to 5e-5 m/sec
  - In Tertiary sediments permeability is 2e-3 to 5e-4 m/sec.

7.0 FORM and EXTENT OF SUBSIDENCE CRACKING

In such a greenfield prefeasibility study, subsidence is the principal element of interest for the environmental impact assessment. This refers specifically to the vertical displacement of overburden strata to surface above the mined longwall panels. However, a key component accompanying the subsidence will be the formation of surface and sub-surface cracking. Figure 52(a) presents a conceptual model for zones of fracturing that may be encountered. Figure 52(b) shows the subsidence and deformation in a physical model (Whittaker and Reddish, 1989).

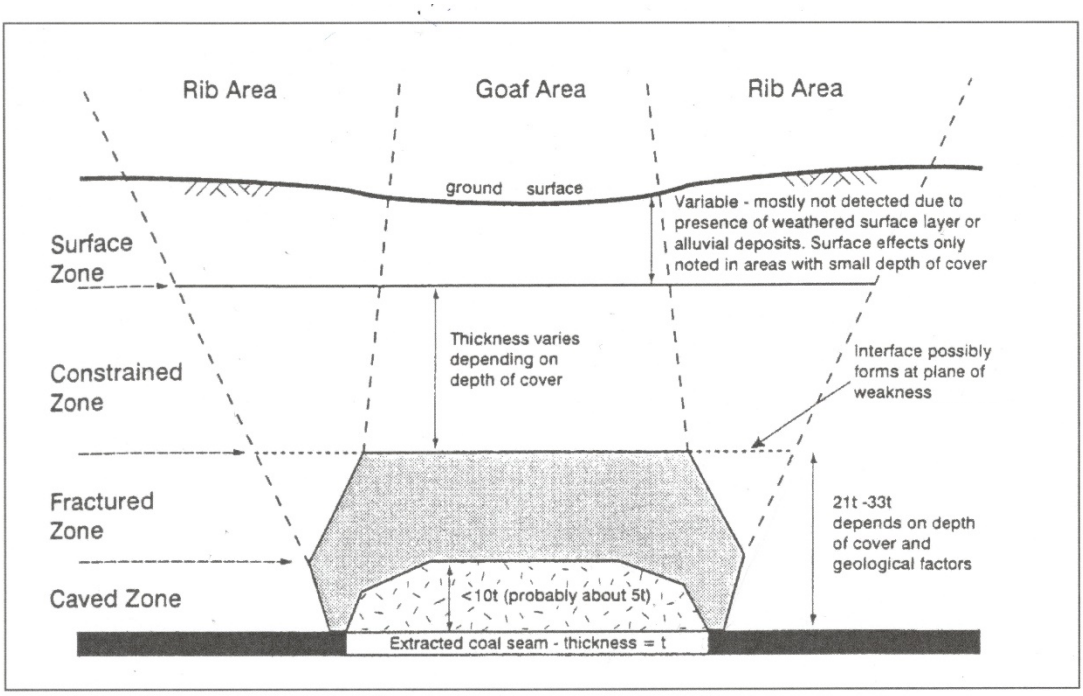


Figure 52(a): Zones of Overburden Disturbance following Longwall Mining

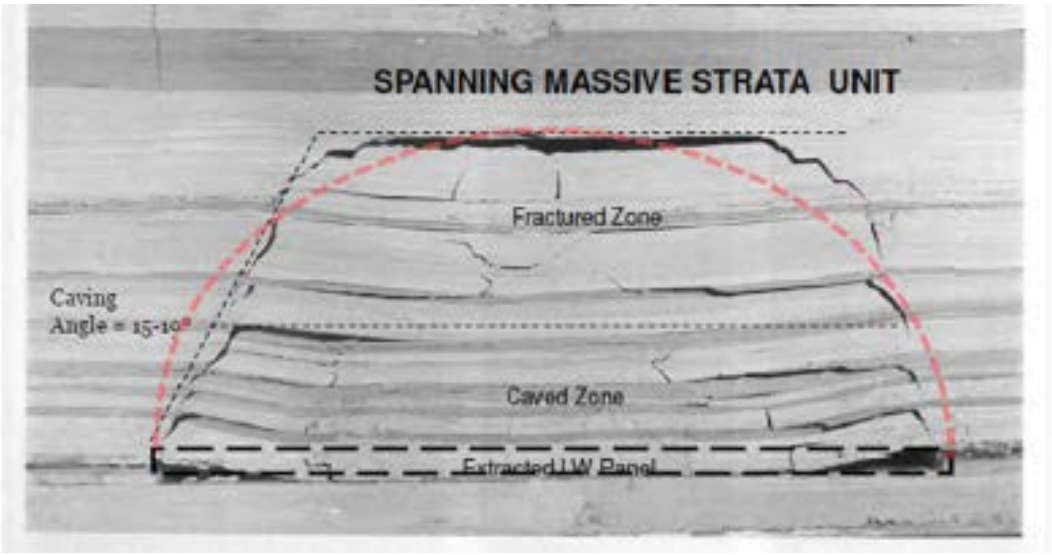


Figure 52(b): Physical Model of Caving and Fracturing above a Mined Panel

Associated with the overburden subsidence following longwall mining it may be expected that within each of the zones of disturbance shown in Figure 52(a), the physical and hydraulic characteristics of the rockmass may be altered as follows:

Caved zone: – is located immediately above the extracted longwall panel and comprises loose blocks that have collapsed from the roof. Upward migration of the cave is limited by bulking of the collapsed loose rocks. The caved zone will be parabolic or arch shaped with the maximum height of fracturing occurring above the centre-line of a longwall panel. The caved zone height typically ranges from 5 to 10 times the mined height.

Fractured zone: – this zone contains disturbed units supported by the underlying caved zone. These units have sagged downwards, undergoing bending, fracturing, joint opening and bedding separation. Increases in both vertical and horizontal permeability will develop in response to formation of new fractures and opening of joints and bedding planes. It is estimated that the upper limit of the fractured zone can be 20 to 33 times the thickness of the mined height.

Constrained zone: – the constrained zone comprises intact strata overlying the fractured zone that have sagged without significant fracture or change to hydrogeologic properties. Some tensile opening of bedding planes and shear on vertical joints and fractures can be present. It is within this zone where hydraulic pressures can be maintained so as to form an effective barrier to vertical flow. It stands to reason that slight increases in horizontal permeability may develop but with little or no appreciable increase in vertical permeability.

Surface Zone: – subsidence resulting from longwall mining induces both tensile and compressive strains at the surface, which may manifest as cracks or ground heave. The surface zone typically comprises weathered strata and overlying detrital sediments. These materials are prone to cycles of desiccation and saturation. In the desiccated state tension cracks will readily form. However, once saturated these cracks tend to seal by infilling of washed sediments or swelling of inherent clay content. These surface cracks may typically extend 15m to 30m below ground surface.

Rib Zone: – is present at the sides of the longwall extraction area and provides a transition area between the subsiding overburden and surrounding rock present over solid coal.

As stated in the introduction to this chapter, the principal objective of this report was to provide an estimate of the magnitude and extent of subsidence over the provided optimised longwall design. A thorough assessment of the subsidence was presented in the previous chapter of this report. Results were presented in the form of contour plots of deformation and line graphs of subsidence along the length of selected longwalls or across the panels.

In order to provide further substantiation to the study, particularly with regard to the surface conditions as may affect groundwater conditions the extent of cracking will be discussed with specific reference to the shear strain, volumetric strain and damage formed within the overburden rockmass. In this case, damage refers specifically to the effect on rockmass joints and bedding planes (either in tension or shear) or the initiation of new fractures in the intact rock (again in either tension or shear).

7.1 Tilt Measurement

Tilt is the first derivative of the subsidence profile, calculated as the change in subsidence between two points divided by the horizontal distance between those points. As such it is just a two-dimensional mathematical manipulation of the already provided surface subsidence data for profiles along the length of selected longwall panels and on four cross-sections across the longwall panels.

Tilt is really only reported when assessing the effect of subsidence on structural damage to buildings and infrastructure. It is of little relevance for the assessment of changes to greenfield topography.

The primary interest at this stage of environmental impact assessment is the effect of subsidence on the overall groundwater characteristics of the overburden. Hence, this report included in the previous chapter a thorough presentation of the distribution of volumetric strain induced in the rockmass. This parameter has the most significant influence on rockmass permeability and porosity, properties which are essential for subsequent groundwater studies.

7.2 Surface Strain Measurements

Many mining practitioners utilise surface strain as an indicative measure of the potential for crack formation in the overburden strata extending to ground surface. Figures 53(a) and 53(b) present the calculated surface strain over the northern and southern longwall panels, respectively.

The unit of strain is reported as millimetres per metre (mm/m). The scale on the plots ranges from 1mm/m (1.0e-3) to 10mm/m (1.0e-2). Strains less than 1mm/m are considered negligible and are not plotted. The limit of 1mm/m is represented by the dark blue-white contour edge. Large strains (>10mm/m) are plotted as cardinal (dark red) coloured contours.

The 1mm/m strain contour represents the limit of surface exposed tensile cracking. These cracks will be narrow (<0.01m in width) and shallow (<10m depth) in Tertiary sediments. Similar strains are observed over the chain pillars between deeper longwall panels. Where there is substantial subsidence over the shallow longwall panels strains are shown to be in excess of 10mm/m. And strains over the chain pillars between the shallow longwall panels are in the range 4mm/m to 8mm/m depending on the local overburden thickness.

Tension cracks on surface will extend to about 100m beyond the longwall footprint over the western and southern boundaries of shallow panels. However, on the eastern margin of LW208 at 7523000N surface cracking will extend about 350m beyond the longwall edge.

Tension cracks on surface may extend 190m beyond LW109 footprint across the MLA 70383 boundary at 752600N. This is the only indication of subsidence induced damage extending into an adjacent mining lease.

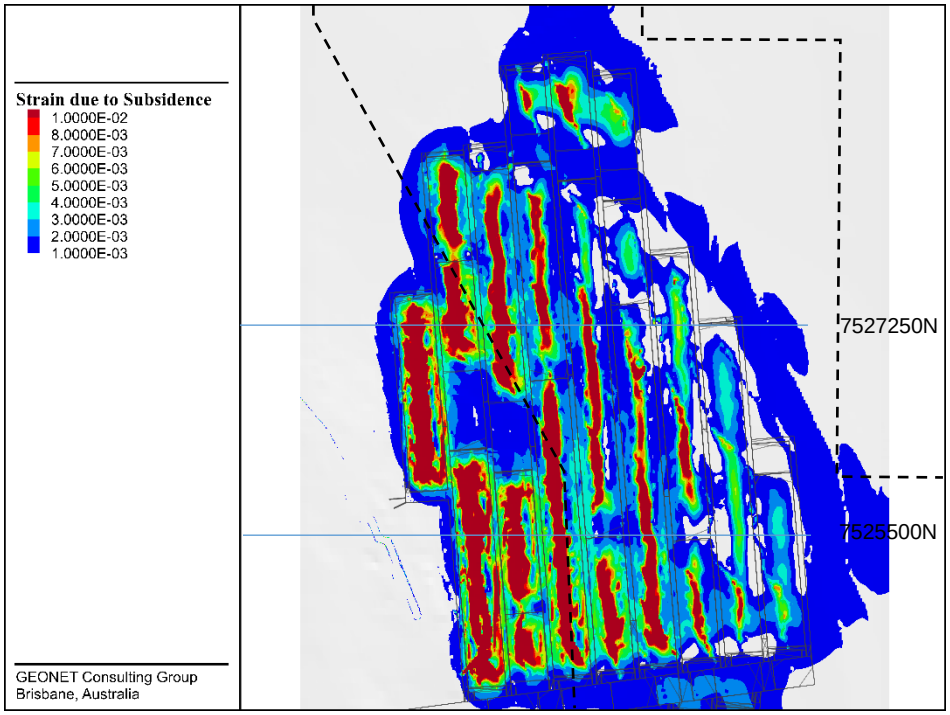


Figure 53(a): Strain (mm/m) **due to subsidence over Northern longwall panel.**

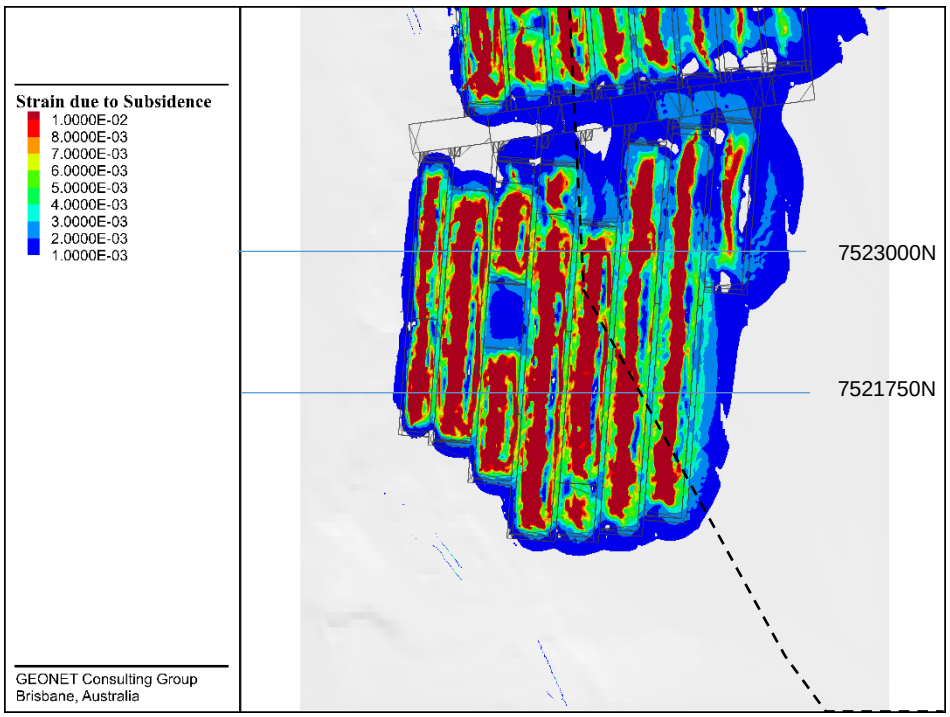


Figure 53(b): Strain (mm/m) **due to subsidence over Southern longwall panel.**

7.3 Extent of Subsidence Cracking

The proposed Saraji East underground mine is located in an area where the local geology will have a significant effect on the subsidence behaviour. Specifically, the Harrow Creek seam which is located uniformly 100m to 120m above the Dysart seam will provide a convenient locus for limiting the cave migration as both seams dip increasingly towards the north-east. Where longwall panels are located at depths less than the panel width of 320m, critical subsidence conditions will prevail, i.e. it must be expected that entire profile of overburden strata will subside evenly since there is no opportunity for restraint by formation of a supporting stress arch. In this case the cave front will migrate through the Harrow Creek seam and progress to surface bounded by very well defined shear fractures.

The form and extent of cracking that is likely to develop in response to the longwall mining will be described with reference to plots of (a) volumetric strain and (b) rockmass damage for each of the four E-W cross-sections previously defined, Figures 54 to 57. The contours of volumetric strain are shown for the range 0.1% to 1%. The rockmass damage plots present the current stress state with reference to the limiting stress state. Thus the condition of a zone within the model will indicate its stress history in terms of the following:

- shear on joint / bedding now (-n) or in the past (-p)
- tension on joint / bedding now (-n) or in the past (-p)
- shear of intact material now (-n) or in the past (-p)
- tension of intact material now (-n) or in the past (-p)

On the plot each stress history state is coloured accordingly, hence the apparent jumble of colours. Without interrogating every zone in the model suffice it to say that the presence of a coloured zone indicates that the rock or joint in that zone has been incurred sufficient stress to cause damage in some manner.

7.3.1 Section at 7521750N

For the section located at 7521750N across the southern longwall panel the subsidence induced volumetric strain contours are shown in Figure 54(a). At this location the thickness of overburden above the Dysart seam ranges from 120m above LW201 to 250m above LW207. As such critical subsidence conditions must be expected over each longwall. It can be inferred from the continuous 1% volumetric strain contour (dark red colour) that continuous shear fractures will form from the longwall edges up to surface for LW201, LW202 and LW203. Figure 54(b) indicates that damage is pervasive to surface.

For LW204 and LW205 the shear fractures will extend form Dysart seam level to above the Harrow Creek seam. The relatively narrow (70m to 90m) section of overburden over the Harrow Creek seam will be extensively fractured with deep (30m to 70m) tension cracks formed on surface extending through the Tertiary sediments into the underlying weathered Permian strata. Figure 54(b) shows damage is pervasive to surface over these longwalls.

Over LW206 and LW207 the caved zone will extend to the Harrow Creek seam. The 140m to 165m thick overburden above Harrow Creek seam will be extensively fractured up to surface as shown in Figure 54(b) with 30m to 70m deep tension cracks on surface as inferred from the red-yellow contour in Figure 54(a).

7.3.2 Section at 7523000N

For the section located at 7523000N across the southern longwall panel the thickness of overburden above the Dysart seam ranges from 130m above LW201 to 320m above LW208. As such critical subsidence conditions must be expected over each longwall. In Figure 55(a) it can be inferred from the continuous 1% volumetric strain contour (dark red colour) that continuous shear fractures will form from the longwall edges up to surface for LW201, LW202, LW203 and LW204. Figure 55(b) indicates that overburden rockmass damage is pervasive to surface over these longwalls.

Over LW205 shear fractures extend form Dysart seam level to the base of Tertiary. Note that on this section LW205 is located very close to the endwall thus constraining the shear fractures from extending to surface.

The overburden thickness over LW206, LW207 and LW208 ranges from 250m to 320m. The 100m of interburden to the Harrow Creek seam will have collapsed with the cave front extending a further 50m to 70m into the overlying Permian strata. Above this caved zone the strata will be fractured and semi-constrained. This observation is inferred from Figure 55(b) where it can be seen that there are some elements in the model which indicate only activation on joints (i.e. coloured dark green) around and above the cave fractured zone.

On surface above LW206 and LW207 tension cracks will most probably form extending 30m to 70m depth. Only shallow (<10m) tension cracks will form in Tertiary over LW208.

7.3.3 Section at 7525500N

For the section located at 7525500N across the northern longwall panel the thickness of overburden above the Dysart seam ranges from 160m above LW102 to 400m above LW109. As such critical subsidence conditions can be expected to develop over longwalls LW102 to LW106. This is confirmed in Figures 56(a) and 56(b) which show contiguous volumetric strain and rockmass damage in the overburden strata extending to surface. Note that LW105 shows limited extent of volumetric strain in the overburden due to this sections proximity to an end of year face position. Contiguous damage is shown to extend to surface over LW105.

Overburden thickness over LW107, LW108 and LW109 ranges from 320m to 400m so that sub-critical subsidence conditions can be expected to occur. The volumetric strain contours indicate that the cave and fractured zone above these longwalls extends to about 30m to 50m above the Harrow Creek seam. The presence of undamaged zones (white coloured indicators) in Figure 56(b) together with minor shear activation on joints (green coloured indicators) demarks the formation of constrained conditions in the Harrow Creek overburden above these longwalls.

The presence of damage indicators in the Tertiary sediments across this entire cross-section indicates that surface cracking will develop. Over longwalls LW102 to LW106 tension/shear cracks will form extending to a depth of about 30m. Over the deeper longwalls LW107, LW108 and LW109 shallow (<15m) tension cracks will form which may establish tortuous connectivity with activated joints and bedding planes in the constrained zone.

7.3.4 Section at 7527250N

For the section located at 7527250N across the northern longwall panel the thickness of overburden above the Dysart seam ranges from 210m above LW101 to 450m above LW108. As such critical subsidence conditions can be expected to develop over longwalls LW101 to LW104. This is confirmed in Figures 57(a) and 57(b) which show contiguous volumetric strain and rockmass damage in the overburden strata extending to surface.

Note that LW108 shows limited extent of volumetric strain and rockmass damage in the overburden over the mined section. This is due to the location of this cross-section coinciding with the endwall.

Overburden thickness over LW105, LW106 and LW107 ranges from 320m to 390m so that sub-critical subsidence conditions can be expected to occur. The volumetric strain contours indicate that the cave and fractured zone above these longwalls extends to about 30m to 50m above the Harrow Creek seam. The presence of undamaged zones (white coloured indicators) in Figure 56(b) together with minor shear activation on joints (green coloured indicators) demarks the formation of constrained conditions in the Harrow Creek overburden above these longwalls.

The presence of damage indicators in the Tertiary sediments across this entire cross-section indicates that surface cracking will develop. Over longwalls LW101 to LW104 tension/shear cracks will form extending to a depth of 30m to 50m. As such it must expected that surface water flows above these four longwalls could infiltrate the underground workings. Similar but limited connectivity could also be established over LW105 and LW106.

Over the deeper longwalls LW107 and LW108 shallow (<15m) tension cracks will form which may establish tortuous connectivity with activated joints and bedding planes in the constrained zone.

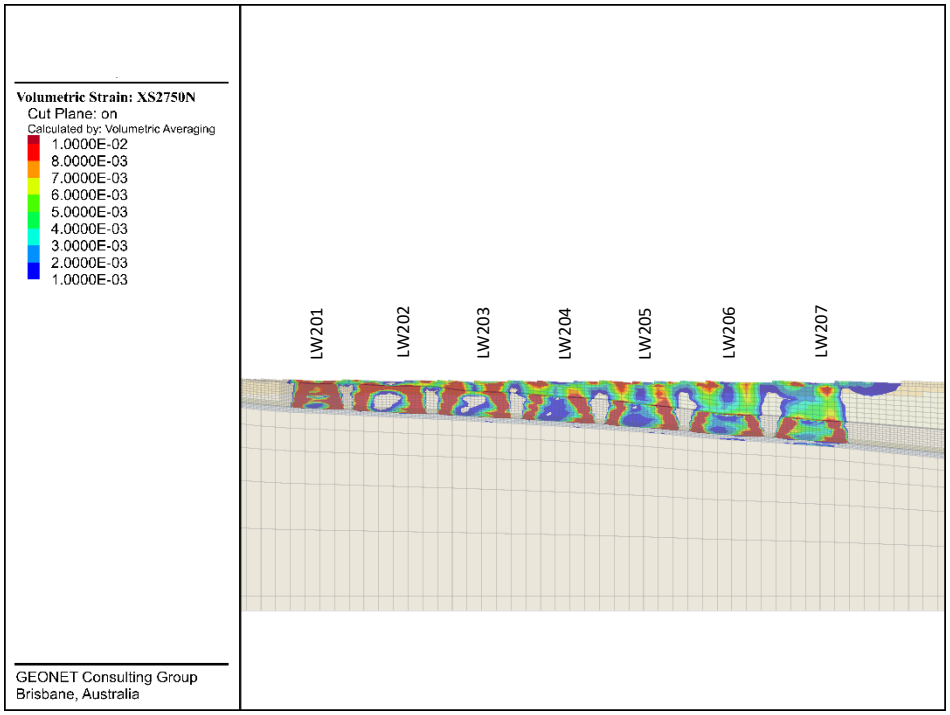


Figure 54(a): Subsidence induced volumetric strain on cross-section at 7521750N

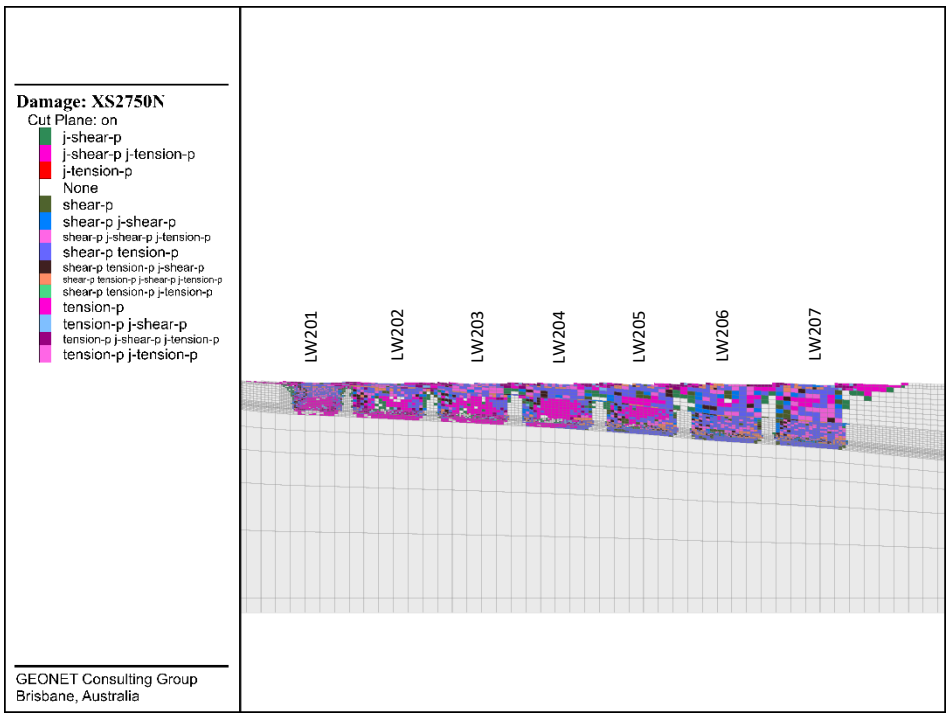


Figure 54(b): Subsidence induced rockmass damage on cross-section at 7521750N

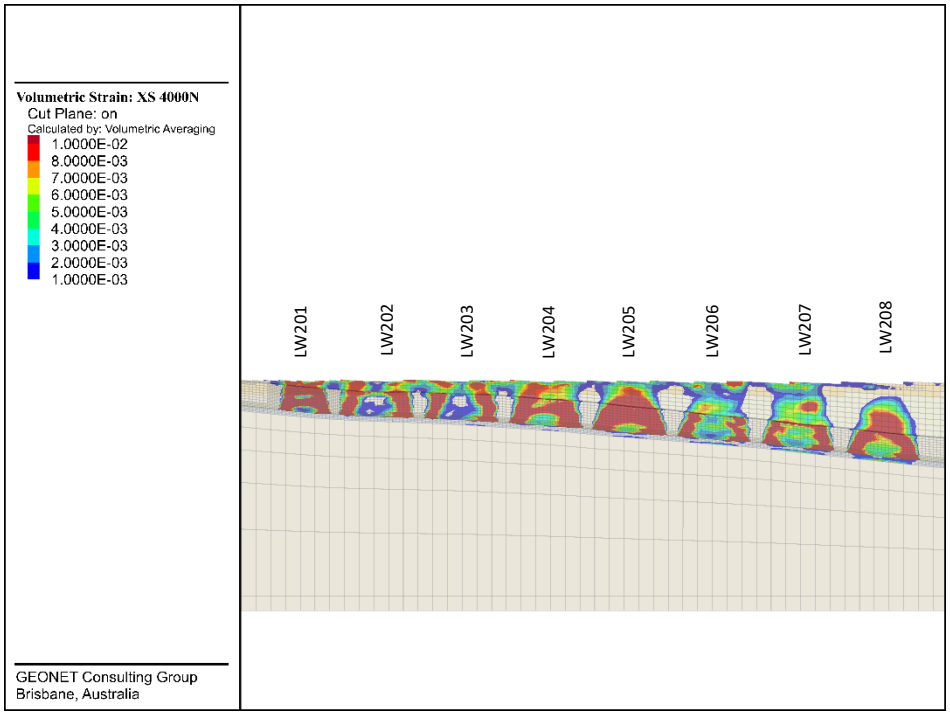


Figure 55(a): Subsidence induced volumetric strain on cross-section at 7523000N

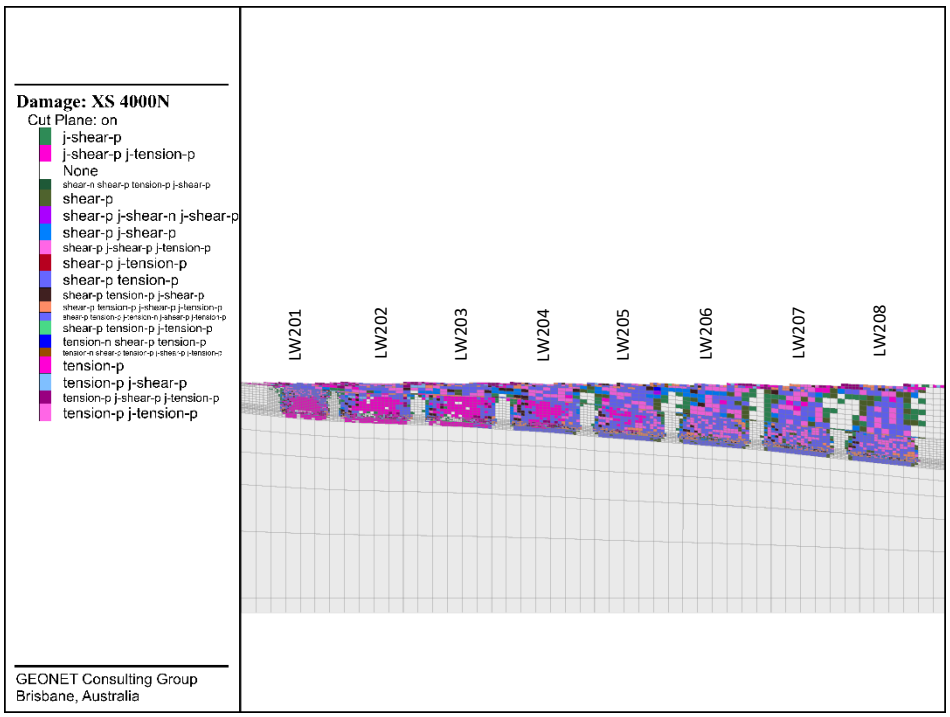


Figure 55(b): Subsidence induced rockmass damage on cross-section at 7523000N

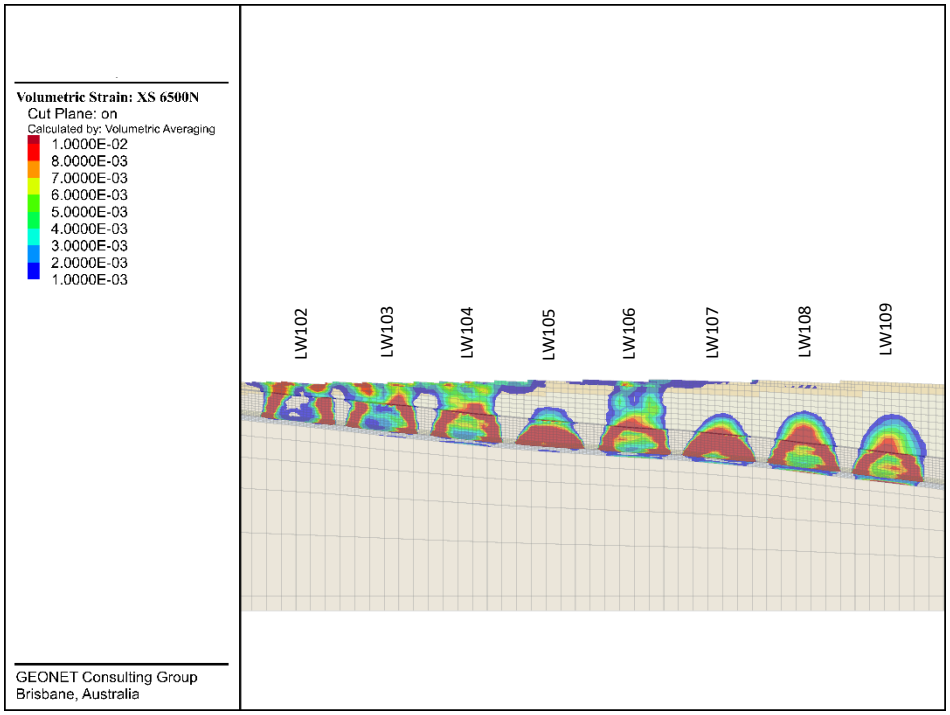


Figure 56(a): Subsidence induced volumetric strain on cross-section at 7525500N

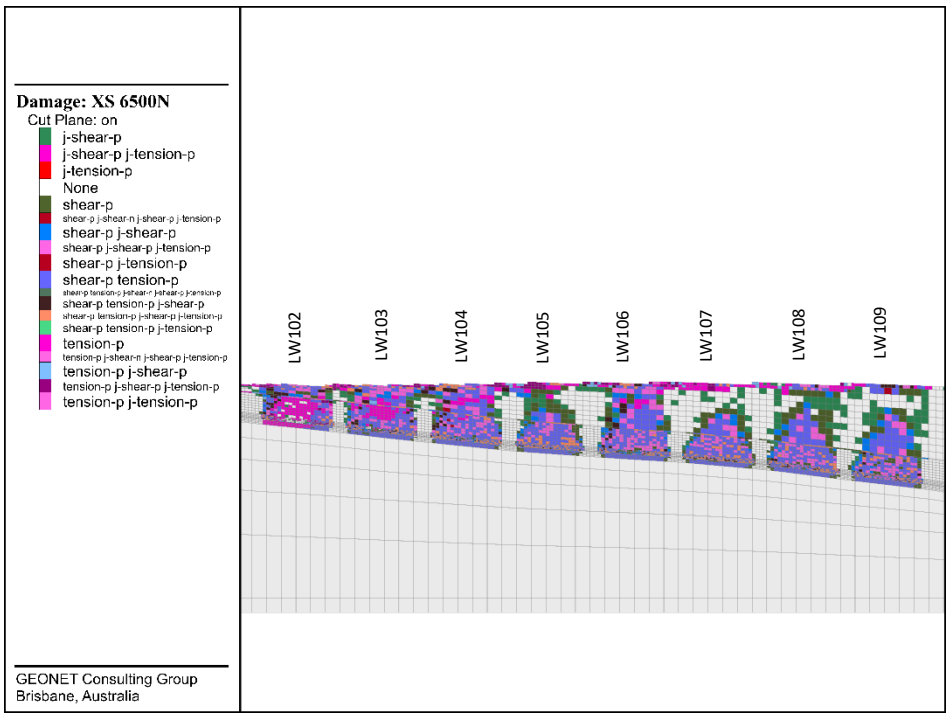


Figure 56(b): Subsidence induced rockmass damage on cross-section at 7525500N

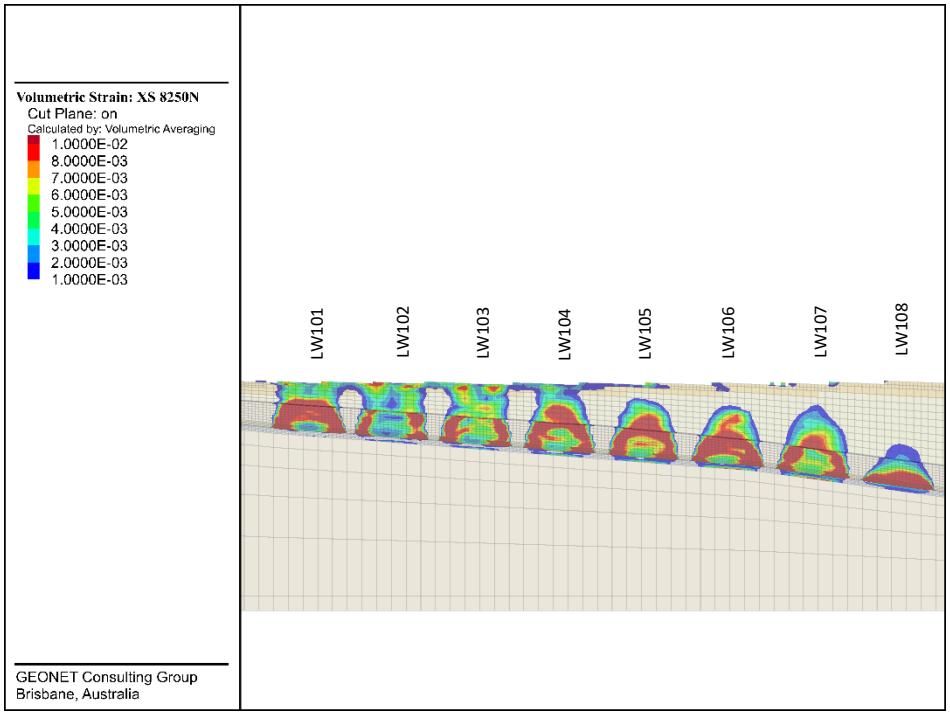


Figure 57(a): Subsidence induced volumetric strain on cross-section at 7527250N

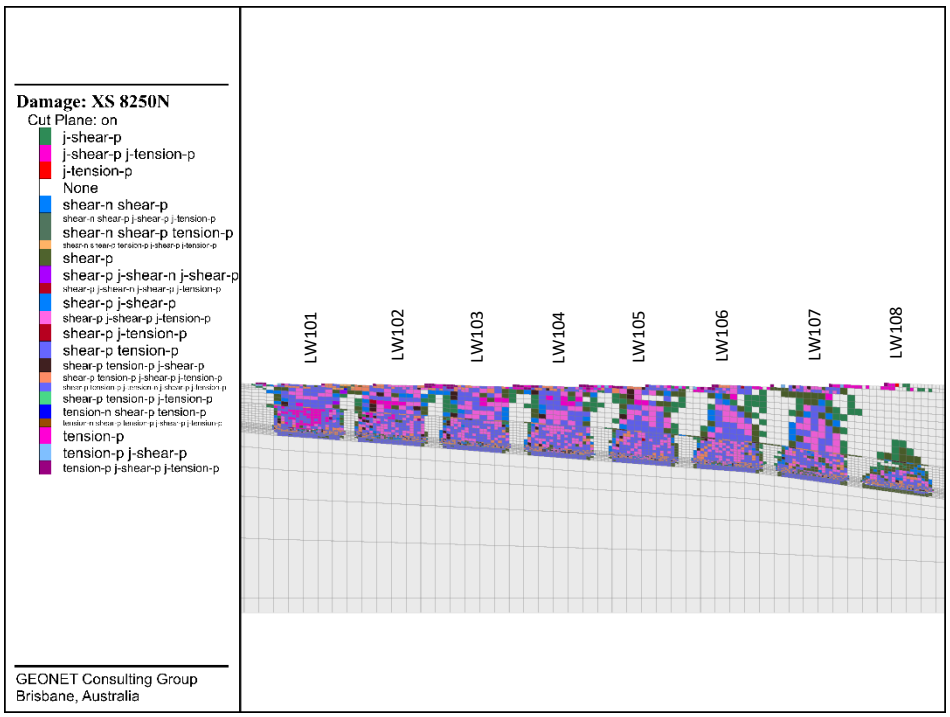


Figure 57(b): Subsidence induced rockmass damage on cross-section at 7527250N

8.0 CONCLUSIONS

The principal objectives of this study were stated as follows:

- To predict the extent and magnitude of surface subsidence following successive stages of longwall panel excavation using conventional mining methods to a uniform 3.6m cut-height. Changes in surface elevation are to be presented for each of the following stages of mining, viz. Years 2025, 2026, 2028, 2032 and 2042, to establish the post-mining topography at that period.

- To provide predictions of the extent of surface cracking that may develop over the longwall panels taking into account the actual overburden lithology, surface topography and extent of mining.

- To provide estimates of rockmass hydraulic properties as input for subsequent groundwater studies by assessing the altered geotechnical condition associated with deformation accompanying rock fracture and bedding plane separation.

Conclusions from the geotechnical modelling are summarised as follows:

Surface Subsidence

- Surface subsidence was calculated at each of the following annual stages of the mining schedule, Years 2025, 2026, 2028, 2032 and 2042. The extent and magnitude of subsidence for each stage was presented as a series of graphs representing:
  - Surface subsidence contours in plan view over mined longwalls
  - Subsidence contours in overburden rockmass on selected E-W cross-sections
  - Profiles of surface subsidence across each selected E-W cross-section
  - Profiles of surface subsidence along centerline of each mined longwall
- The surface subsidence profile along the length of any longwall panel consists of distinct rolls in the subsided topography.
- There is significantly more subsidence induced over the southern panel compared with the northern panel. This can be attributed to the thickness of Dysart seam overburden. It is observed that subsidence in excess of 2.25m correlates directly with 250m contour.
- The fully extracted longwalls in southern panel are predicted to show maximum surface subsidence in the range 2.0m to 3.4m over all longwalls except LW208 where the overburden thickness exceeds 300m thus limiting subsidence to 1.4m.
- Over all longwalls in the northern panel the maximum surface subsidence ranges between 0.75m and 2.25m where the overburden thickness ranges between 160m and 450m.
- The extent of subsidence over longwalls as projected onto the selected E-W cross-sections shows that goafing of overburden strata extends through the Permian strata and up into the Tertiary sediments over longwalls where the overburden thickness is less than 250m.

- For the current mining layout goafing is confined to Permian strata below Harrow Creek seam when the overburden thickness exceeds 250m.
- Profiles of surface subsidence along centerline indicate that the subsided surface undulates along its length with the subsidence increasing as overburden thickness reduces.
- Subsidence is significantly reduced over barrier pillars left in longwalls. Depending on the dimensions of the barrier pillar and thickness of overburden, subsidence is predicted to vary across from 0m and 0.5m.
- Surface subsidence over the Mains will be about 0.2m.

Extent of Surface Cracking

- The extent of possible tension cracks outside the longwall panel boundaries may be inferred from the 0.1m deformation contour. These are shown to be contained within the panel boundaries for shallow longwalls and to extend beyond these boundaries for the deeper panels.
- Tension cracking will form on surface above the western abutment edge of longwall LW201 in southern panel.
- Tension cracking will form on surface above the western abutment edge of longwalls LW101 and LW102 in the northern panel.
- This cracking limit extends to about 400m around the northern boundary of longwalls in the northern panel.
- Surface cracking will extend to about 380m beyond the eastern boundary of LW106 in the northern panel.
- Tension cracks on surface may extend 190m beyond LW109 footprint across the MLA 70383 boundary at 752600N. This is the only indication of subsidence induced damage extending into an adjacent mining lease.
- Subsidence cracking will extend about 200m along the eastern boundary of longwalls in the southern panel. Cracking will extend to 300m along the eastern boundary of LW208.
- The same limit extends about 80m around the southern boundary of longwalls in the southern panel.
- The thickness of overburden above the Dysart seam ranges from 120m above LW201 to 450m above LW108. Critical subsidence conditions can be expected to develop over longwalls where overburden thickness is less than 320m. This is confirmed in modelling results which show contiguous volumetric strain and rockmass damage in the overburden strata extending from longwall edge to surface corresponding with anticipated location of major shear cracks.
- Where overburden thickness is greater than the longwall width of 320m then sub-critical subsidence conditions can be expected to occur. Contours of volumetric strain indicate

that the cave and fractured zone above these longwalls extends to about 30m to 50m above the Harrow Creek seam. Overlying the fractured zone will be undamaged rockmass with localised minor shear activation on joints demarking the formation of constrained conditions in the Harrow Creek overburden.

- Over shallow longwalls (overburden thickness <300m) tension/shear cracks will form extending to a depth of 30m to 70m. As such it must expected that surface water flows above these longwalls could infiltrate the underground workings.
- Longwalls at depths greater than 300m will induce shallow (<15m) tension cracks on surface which may form tortuous connectivity with activated joints and bedding planes in the constrained zone.

Subsurface Rockmass Damage

The extent of rockmass damage developed over longwall panels at Saraji East underground mine will be affected by the following geological factors:

- Overall thickness of Dysart Seam overburden strata.
- Bedding plane separation and roof collapse extending to 120m above longwall panels in Dysart Lower (D24) seam (typically up to the H16 coal seam).
- Shear displacement induced on bedding planes through Permian strata, and
- High angle joints opening in tension through Permian strata.
- When tensile cracks propagate into the Tertiary sediments it is likely that cracks could further extend to surface but these cracks will most probably self-seal depending on the plasticity (clay content) of the sediments.

Potential Impact on Subterranean Groundwater Reservoirs

The third major objective of this study was to define changes in rockmass permeability around the longwall panels. It is well established that the following formations are considered aquifers in the Saraji East project area:

- the various coal seams;
- the basal sand/gravel unit of the Tertiary Formation;
- clean sand beds within the Tertiary Formation; and
- alluvial sands and gravels of creek palaeo-channels.

It is most likely that open pit mining has already substantially modified the groundwater profiles within the vicinity of the mine by depressurisation of all aquifers.

Over both the longwall panels there are areas where fractures will propagate from the mining level through the overlying Permian rockmass into the overlying Tertiary sediments. These conditions will provide pathways for drainage of the groundwater reservoirs contained in Tertiary gravels and coal seams of the Fort Cooper Series and Permian strata.

The hydraulic properties of the Fort Cooper Coal Measures and Tertiary strata are affected to varying degrees depending on the depth of longwall mining. It is not possible to specify a definitive single value for either of the permeability tensor components nor porosity for the post-mining rockmass condition of each strata unit. These hydraulic properties will vary throughout the rockmass depending on the specific local subsidence characteristics. Based on the calculated volumetric strains the following estimates are made for the range of subsided overburden rockmass hydraulic properties:

- Porosity:
  - Porosity in large open fractures will be 0.10 to 0.15
  - Typical fractured overburden strata will have porosity between 0.050 and 0.075
  - Tertiary sediment porosities will increase to the range 0.250 to 0.375.

- Horizontal Permeability (K_{11}):
  - In fractured overburden strata permeability is 2e-7 to 5e-8 m/sec
  - In subsided coal seams permeability is 2e-5 to 5e-6 m/sec
  - In Tertiary sediments permeability is 2e-3 to 5e-4 m/sec.

- Vertical Permeability (K_{22}):
  - In fractured overburden strata over longwalls permeability is 2e-5 to 5e-6 m/sec
  - In subsided coal seams permeability is 2e-4 to 5e-5 m/sec
  - In Tertiary sediments permeability is 2e-3 to 5e-4 m/sec.

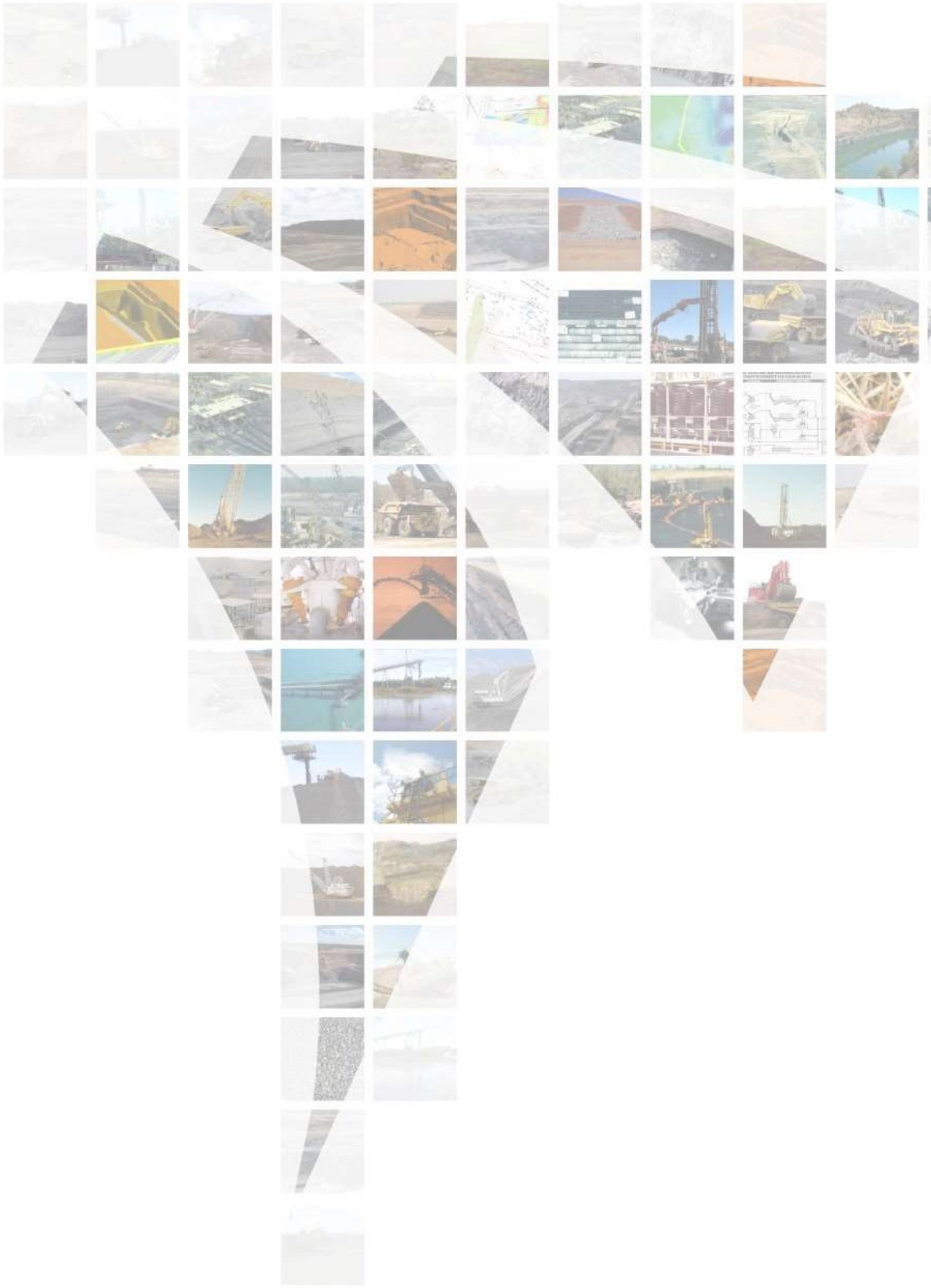
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Disclaimer

This report has been prepared in good faith and with all due care and diligence. It is based on the geological and geotechnical data provided by the client and referred to where utilised, in combination with the author's experience with geotechnical modelling techniques, and as tempered by the geological and stratigraphic evidence presented in various forms.

As such, the report represents a collation of opinions, conclusions and recommendations, the majority of which remain untested at the time of preparation. In the light of these facts it must be clearly understood that neither GEONET Consulting Group nor The Minserve Group, their respective proprietors and employees cannot take responsibility for any consequences arising from this report.



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