Appendix C Subsidence Report

SUBSIDENCE REPORT FOR THE ENSHAM LIFE OF MINE EXTENSION – ZONES 2 AND 3

Prepared for
Ensham Resources Pty Ltd

JANUARY 2022

EXECUTIVE SUMMARY

Ensham Mine is an existing open-cut and underground bord and pillar coal mine located approximately 35 kilometres (km) east of Emerald in Queensland. The Ensham Life of Mine Extension Project - Zones 2 and 3 (the Project) proposes to increase the life of the existing underground operations by extending the underground bord and pillar mine into Zones 2 and 3 within Mining Leases (ML) 7459, ML70326, ML70365, and, ML7459 and 70366 respectively.

The Project would produce at up to approximately 4.5 million tonnes of product coal per annum and would extend the Ensham Life of Mine (LOM) by up to one year to approximately 2029. Without zones 2 and 3, the current underground operations will become physically restrained to lower production levels and would affect the overall economic viability of the mine.

The extension of the underground operation using existing infrastructure means that no material surface construction or surface disturbance (other than the installation of four flares to be located on already cleared land) will be required to facilitate the Project.

The Project will operate using the same bord and pillar and single seam mining method currently being used on site. This mining system forms a regular array of long-term stable coal pillars and roadways in each panel and does not cause large scale overburden fracturing and subsidence. Where the Nogoa River flows through Zone 2, no mining beneath the river is proposed. In addition, greater than 75% of the Project area is located outside the flood plain.

The assessment of the long-term stability of the Project coal pillars resulting from the proposed underground mine has been undertaken using the industry accepted University of New South Wales Pillar Design Procedure. The subsidence predictions from the assessment have been verified to a high level of confidence using information from the existing bord and pillar operations at Ensham Mine site. The subsidence assessment is based on the Project design minimum pillar Factor of Safety (FoS) of 1.6 for areas beneath the floodplain, and 2.11 for access roadways beneath the Nogoa River to connect bord and pillar workings, and, for bord and pillar workings beneath the Nogoa River anabranch, has confirmed the long-term stability of the proposed mine layout. The assessment also considers the width: height ratios of the pillars, as well as the estimated critical level of overburden displacement.

The design criteria used to ensure long-term stability of the pillars has also been peer reviewed by three industry recognised (RPEQ) geotechnical consultants Mine Advice (Dr Russell Frith), Byrnes Geotechnical (Dr Ross Seedsman), and BK Hebblewhite Consulting (Emeritus Professor Bruce Hebblewhite), who all concluded that the proposed bord and pillar layout is an appropriate and well developed geotechnical design.

The temporary increase in cover depth during 0.1% AEP (Q1000) flood events has also been calculated below both the flood plain and Nogoa River and anabranch channels. Conservative maximum flood depth values of 16 m in the Nogoa River channel and 4 m across the flood plain have been used in the FoS calculations. The temporary increase in depth has been applied to the design figures to calculate the required mining height to satisfy the Project FoS during 0.1% AEP flood events.

As well as the factor of safety approach, the long-term life expectancy of pillars can be estimated using empirical studies from South Africa. Using this methodology, the proposed 24 m x 28 m (centres) pillars in the Project area, at 4.5 m high and 130 m depth of cover, are calculated to be stable in excess of 26,000 years. Furthermore in regards to long-term stability, after mining is completed and the workings flood with groundwater, the buoyancy effect of the groundwater will reduce the vertical load on the pillars by up to 40%. For a pillar below the Nogoa River anabranch, designed with a FoS of 2.11, at 140 m depth of cover, reducing the vertical load on the pillar by a conservative 25%, to account for any potential strength loss in the coal and surrounding strata, increases the FoS to 2.82. This FoS has a probability of failure well in excess of 1 in 10,000,000.

Due to the nature of the bord and pillar mining method, subsidence is predicted to be less than 30 mm in majority of the Project area, with localised areas less than 35 mm. This is as a result of elastic compression of the strata i.e. compression due to the additional load on the pillars after the coal is extracted. To provide context, the Australian Government Department of the Agriculture, Water and the Environment (DAWE) states that seasonal variation in surface levels can be up to 50 mm or more as a result of changes in moisture content.

Recent RTK (Real Time Kinematic) GPS monitoring at Ensham indicates subsidence levels of less than 10 mm above mined underground panels and confirms the predictions for the Project. This monitoring has an accuracy of ±5 mm and is able to detect the low levels of movement predicted for the Project. Further baseline reference and ongoing monitoring data will continue to be collected to ensure that any minor subsidence is occurring and recorded, and if so that mitigation measures are put in place where required, consistent with the SMP.

Based on the available data for the Project, including high density exploration boreholes, 3D seismic and underground geological mapping, there are no localised features or variations in the geology, geotechnical conditions or surface topography that are considered likely to result in any significant deviations from the subsidence predictions presented in this report.

There is therefore a high degree of confidence in the subsidence predictions due to the accurate RTK-GPS monitoring data above existing bord and pillar mining areas at Ensham with the Project design having similar mining heights, depth of cover and mining methodology. This information has allowed a robust calibration to be achieved and provided a sound basis to enable conservative subsidence predictions.

Due to the low levels of subsidence and associated strains and tilts, no surface cracking is anticipated within the Project area. The expected low levels of subsidence are also unlikely to result in the formation of significant depressions in the surface topography, where ponding of the surface drainage may occur. This is consistent with experience at the existing Ensham Mine operations, where no surface cracking or ponding has been observed above the bord and pillar mine that has been operating for more than 10 years.

Based on mining experience at shallow depths of cover in the current Ensham underground workings, as well as experience at other mining operations around the world, the risk of sinkhole subsidence occurring in the Project area, where the depth of cover for the entire area of mining is greater than 75 m, is therefore considered to be negligible.

To address the monitoring and management of any subsidence impacts, a Subsidence Management Plan (SMP) has been developed. This plan includes the triggers for investigation of any potential subsidence impacts, soil types, guidance on surface inspections, groundwater monitoring, mitigation and management measures as well as guidelines for landowner consultation if required.

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List of Abbreviations

AHD - Australian Height Datum
D - Disturbance Factor
DAWE- Department of the Agriculture, Water and the Environment
EA - Environmental Authority
E_i - Laboratory Modulus
E_{rm} - Rock Mass Modulus
FoS - Factor of Safety
GGPL - Gordon Geotechniques Pty Ltd
GPS - Global Positioning System
GSI - Geological Strength Index
LIDAR- Light Detection and Ranging
LOM - Life of Mine
ML - Mining Lease
RTK - Real Time Kinematic
UCS - Uniaxial Compressive Strength

Glossary

Bell out	An area on the perimeter of the panels where coal is mined and ground support is not installed.
Bord	A roadway developed in an underground mine.
Empirical	Based or acting on observation and experiment, not on theory.
Floor	Strata immediately below the mined seam.
Inbye	Direction towards the coal face.
Modulus	The ratio between applied stress and resultant strain.
Outbye	Direction away from the coal face.
Overburden	Sequence of strata above the mined seam.
Pillar	Coal that is not mined within the underground workings.
Roof	Strata immediately above the mined seam.
Secondary Coal Recovery	Mining of floor coal and bell outs.
Stratigraphy	A branch of geology that studies rock layers and layering. It is primarily used in the study of sedimentary and layered volcanic rocks.
Subsidence	Sinking or settlement of the land surface, due to any of several processes. As commonly used, the term relates to the vertical downward movement of natural surfaces although small-scale horizontal components may be present. The term does not include landslides, which have large-scale horizontal displacements, or settlements of artificial fills.
Strain	Relative change in the volume, area or length of a body as a result of stress. The change is expressed in terms of the amount of displacement measured in the body divided by its original volume, area, or length, and referred to as either a volume strain, areal strain, or one-dimensional strain, respectively. The unit measure of strain is dimensionless, as its value represents the fractional change from the former size.
Tilt	The rate of change in vertical subsidence between two points divided by the horizontal distance between those two points.

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1 INTRODUCTION

Gordon Geotechniques Pty Ltd (GGPL) was commissioned by Ensham Resources Pty Ltd (Ensham Resources) to assess the potential impacts of the proposed Ensham Life of Mine Extension Project – Zones 2 and 3 (the Project) on subsidence values, in support of the Environmental Authority (EA) amendment application for the Project.

Ensham Mine is an existing open-cut and underground bord and pillar coal mine located approximately 35 kilometres (km) east of Emerald in Queensland. The Ensham Life of Mine Extension Project - Zones 2 and 3 proposes to increase the life of the existing underground operations by extending the underground bord and pillar mine into Zones 2 and 3 within Mining Leases (ML) 7459, ML70326, ML70365, and, ML7459 and 70366 respectively (**Figure 1**).

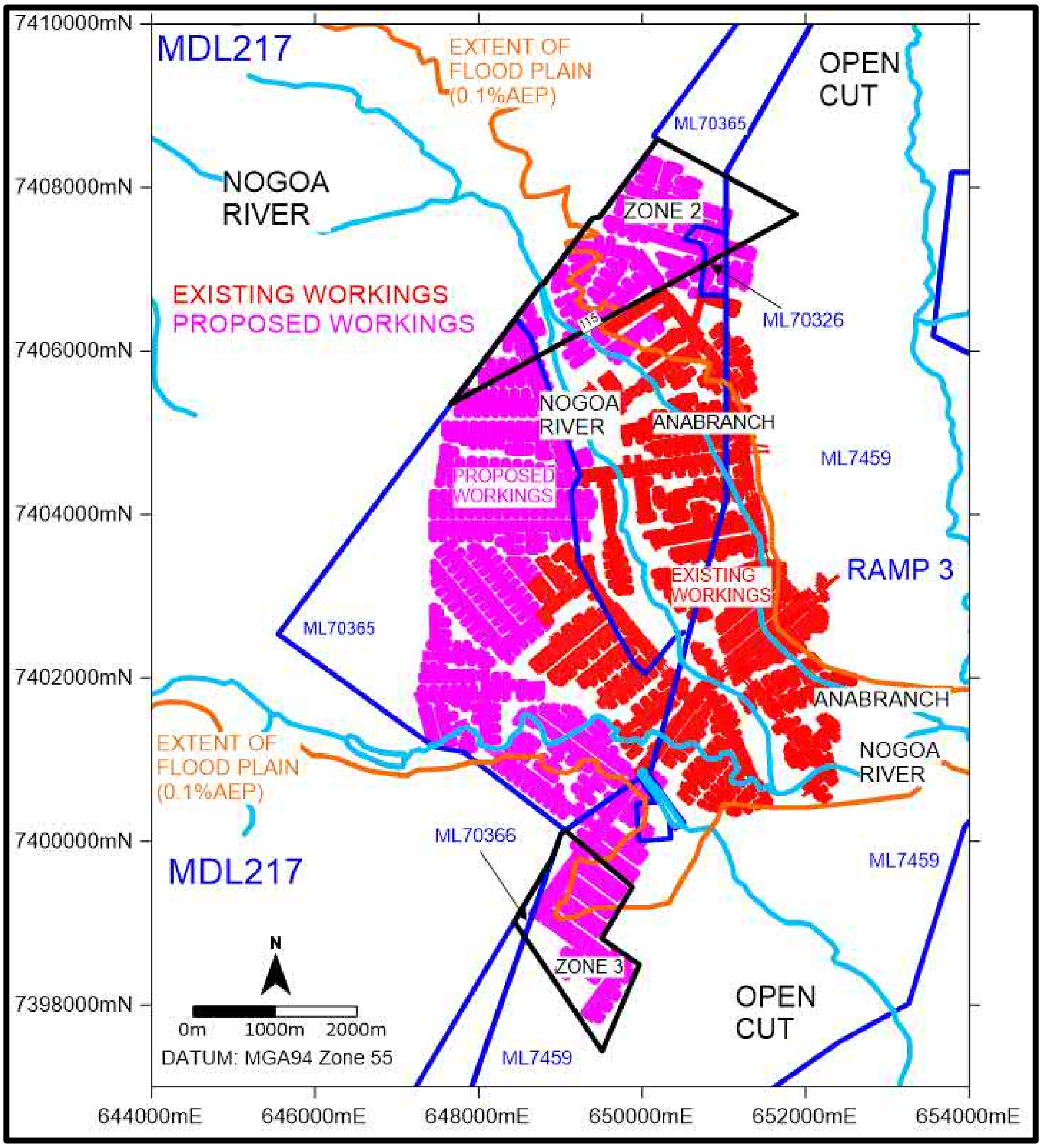


Figure 1. Location Plan – Ensham Mine Site

The Project will produce at up to approximately 4.5 million tonnes per annum and would extend the Ensham Life of Mine (LOM) by up to one year, to approximately 2029. The extension of the underground operation using existing infrastructure means that no surface construction or surface disturbance will be required to facilitate the Project other than the installation of four flares to minimise greenhouse gas production.

This assessment and the associated approvals process are focussed on the proposed mining activities within the Project area only.

1.1 Project Description

Ensham is currently operating a bord and pillar mine downdip of the open cut (**Figure 1**). Underground coal production commenced at Ensham in 2011, once the Aries-Castor Seam had been accessed by two stone drifts from Ramp 3 (**Figure 1 and Figure 2**). These drifts provide both personnel, materials and belt access from the open cut to the underground workings.

Figure 2. Access to the Underground Workings from Ramp 3

The bord and pillar mining methodology currently used at Ensham is also planned for the Project area, with access through the existing underground workings (**Figure 1**). Zones 2 and 3 are located both below and outside the flood plain of the Nogoa River (**Figure 1**). In fact, greater than 75% of Zones 2 and 3 is located outside the flood plain (**Figure 1**).

There will be no mining below the Nogoa River channel (**Figure 1 and Figure 3**). A 200 m section of the Nogoa River anabranch is located above 115 Panel in Zone 2 (**Figure 3**).

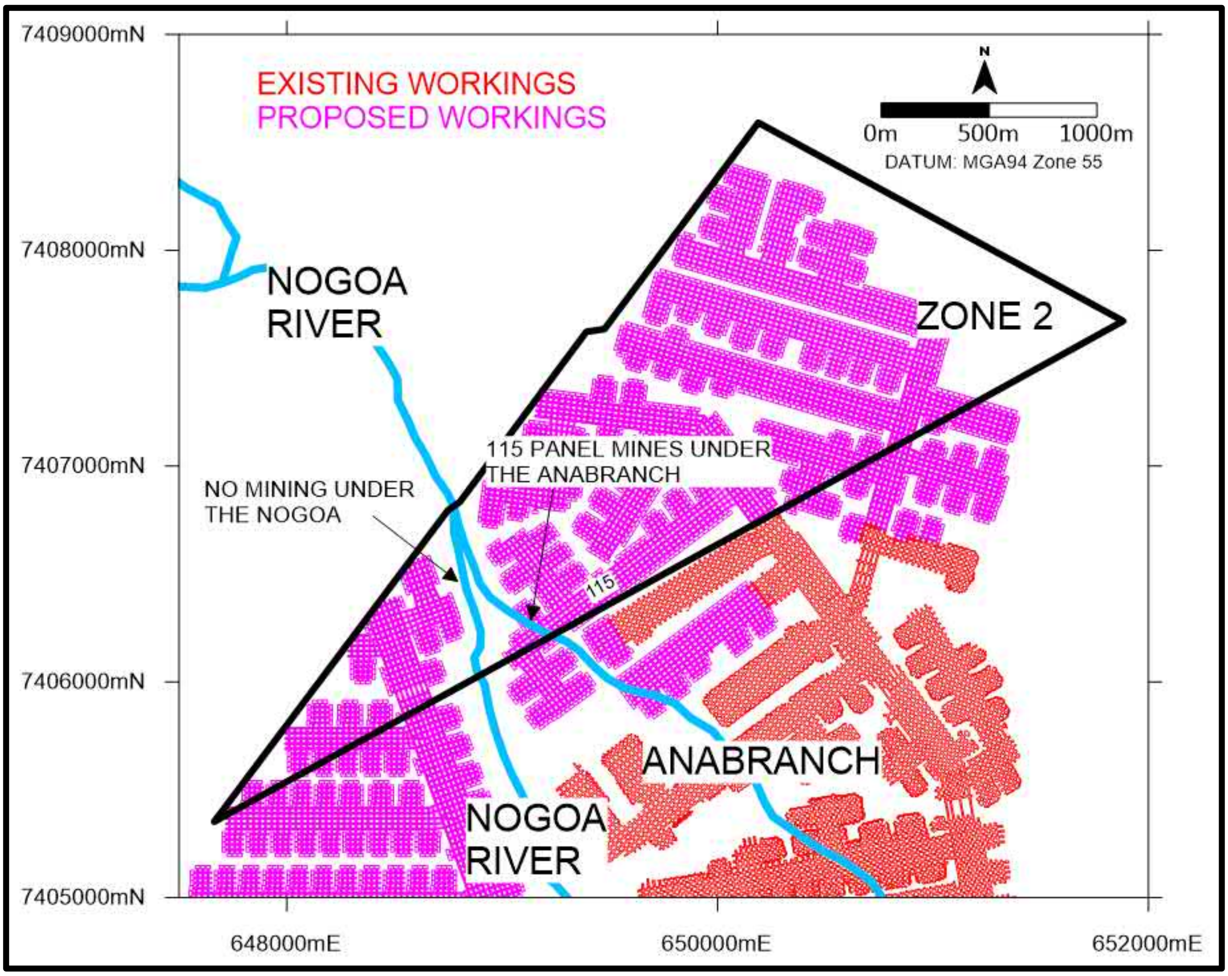


Figure 3. Location of Workings in Zone 2 under the Nogoa River and Anabranch.

1.2 Project Setting

Due to the overlying Nogoa River and flood plain, the surface topography in the majority of the Project area is relatively flat (**Figure 4**). In Zone 2, there is a localised high in the topography outside the flood plain (**Figure 4**).

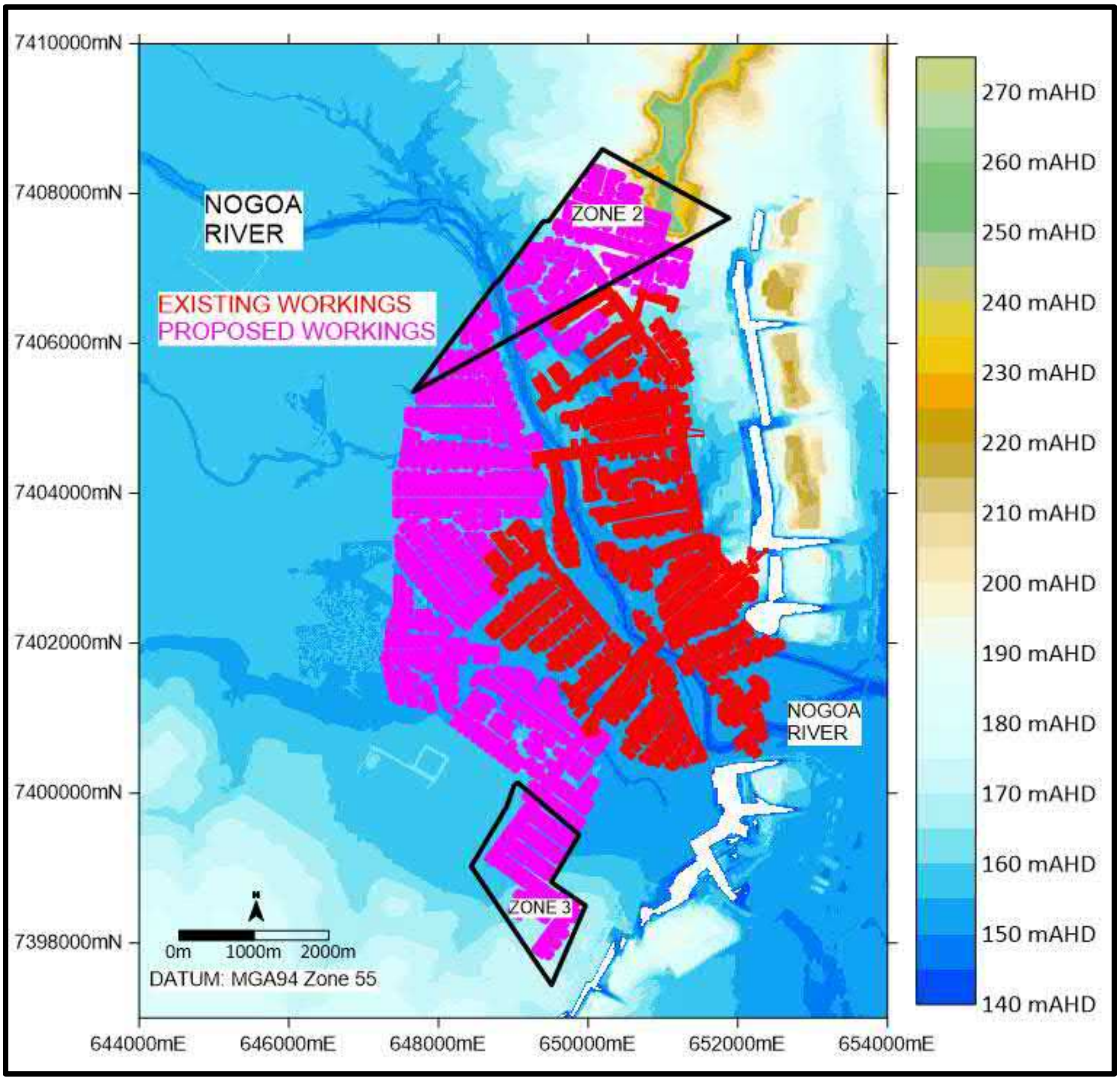


Figure 4. Surface Topography

1.3 Project Mining Method

To assist in the discussion on the subsidence aspects of the proposed bord and pillar layout in the Project area, a description of the mining method is presented below.

The fundamental concept of the bord and pillar method is that the coal seam is divided into a regular block like array, by mining the coal to form bords or roadways (**Figure 5**). The headings are intersected at regular intervals by connecting cut-throughs (**Figure 5**).

The ***bords*** are the headings and the cut-throughs and the ***pillars*** are the blocks of coal bounded by the bords (**Figure 5**). The pillars of coal support the overlying strata as the bords are driven.

Each regular array of bords is called a ***panel***. Where smaller panels are developed from the main panel, they are called ***sub panels*** (**Figure 5**).

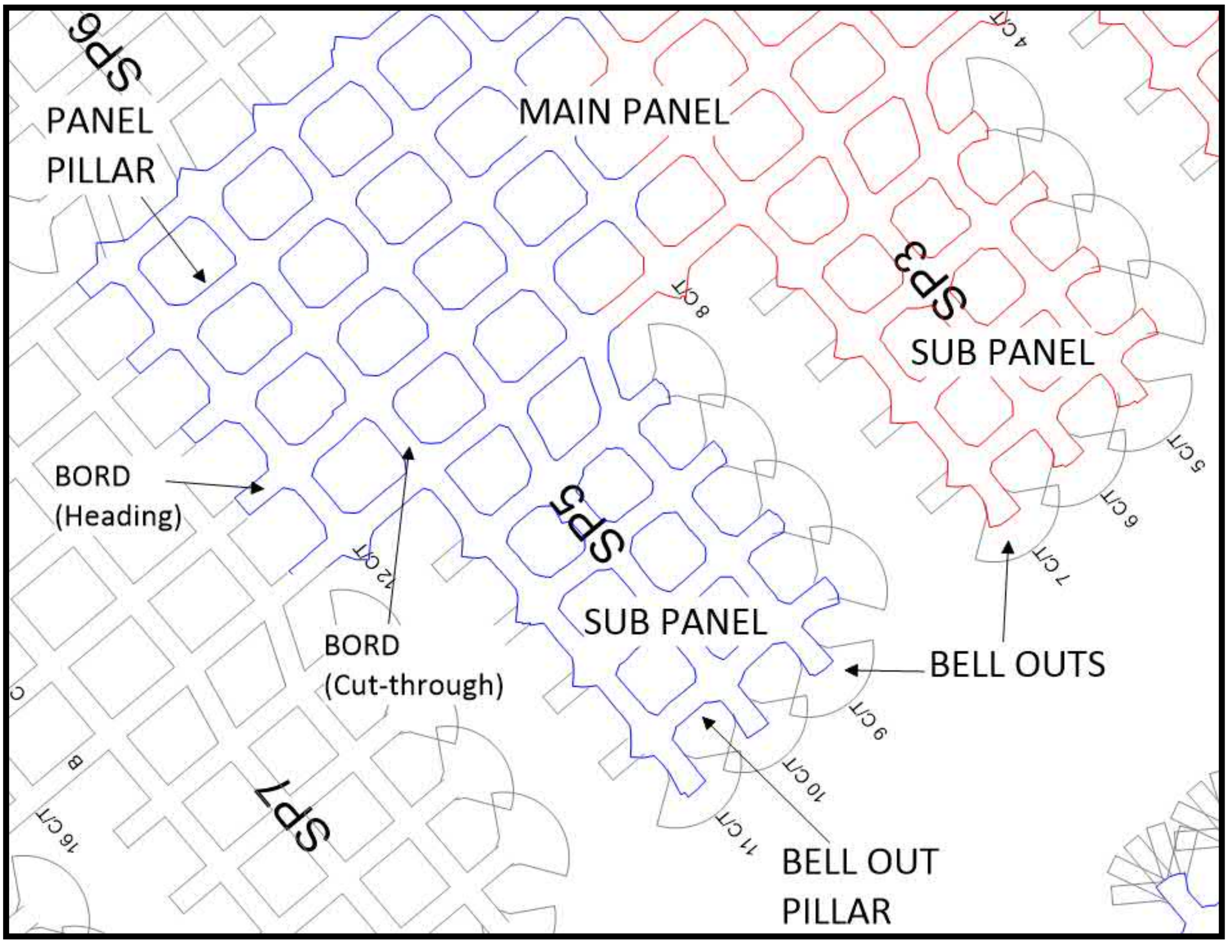


Figure 5. Bord and Pillar Layout Terminology

In the bord and pillar method, the bords are excavated, where ground conditions allow, to a maximum horizontal distance of 14 m, without the installation of roof and rib support. The maximum cut out distance is determined by the distance from the second last roof support to the operator of the shuttle car.

Excavation is carried out using the continuous miner cutting machine, which loads the coal into a shuttle car machine. The shuttle car then transports and loads the coal onto the conveyor belt system. Once the bord is excavated to the maximum distance, the continuous miner is moved to the next mining sequence and ground support is installed using a bolting machine termed a multibolter.

The development roadways (bords) in the current underground workings are typically 6.5 m wide and 3.1-3.5 m high (**Figure 6**). In poorer ground conditions, the roadway width may be reduced to 5.5-6.0 m to improve roof stability. This reduction in width also increases the factor of safety (FoS) of the pillars. In the Project area, the roadways are also planned to be 6.5 m wide. In the thinner seam areas of the Project area, a lower final roadway and pillar height is anticipated, which would increase the FoS.

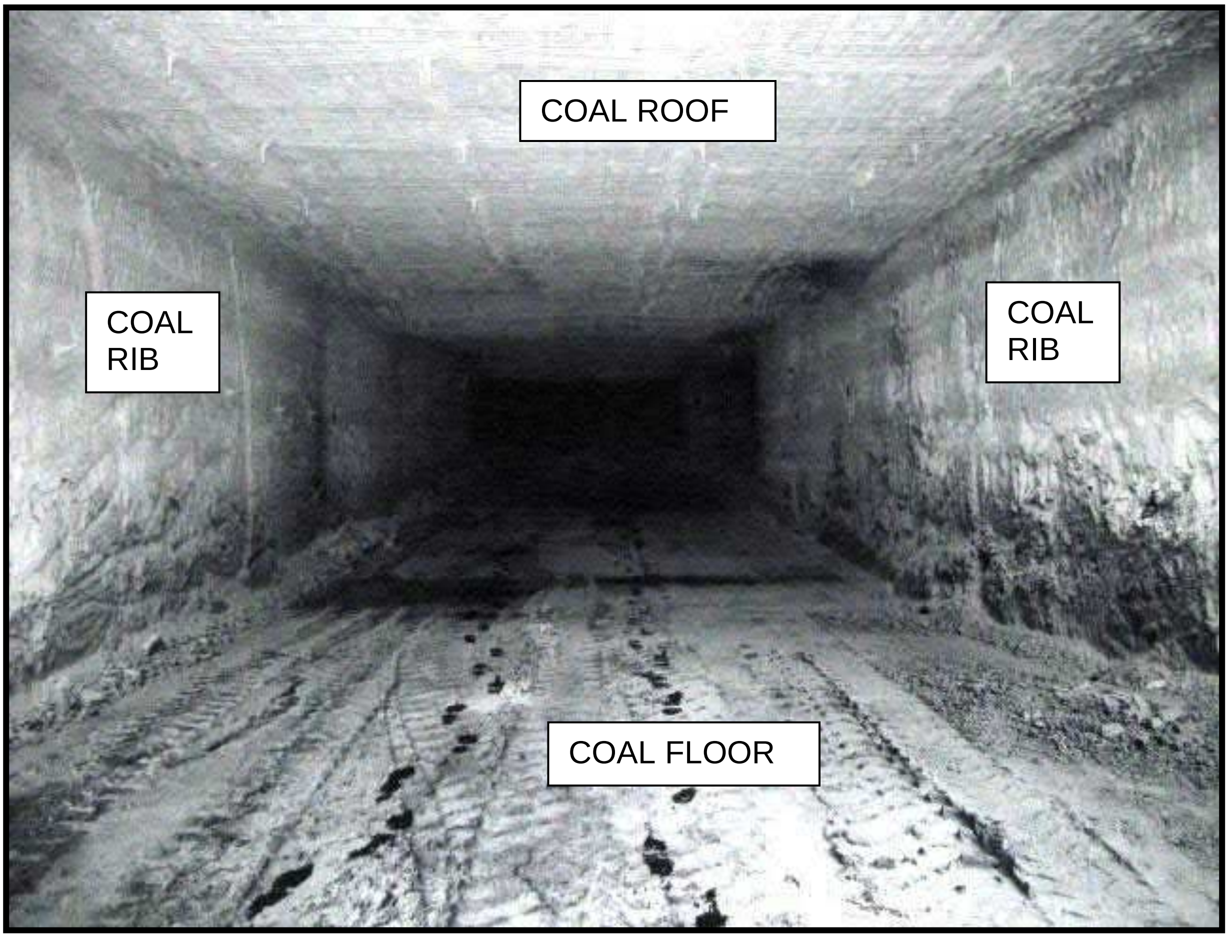


Figure 6. 6.5 m Wide x 3.3 m High Development Roadway (Bord) at Ensham

After the completion of panel development, secondary coal recovery on retreat is carried out as follows:

- Floor coal is mined in the panels and sub panels (**Figure 7**).
- Bell outs are mined at the perimeter of the panels (**Figure 5**).

During floor coal recovery, canchs (or benches) of coal, nominally 0.3-0.5 m thick, are left along the side of the roadway to protect the mining personnel from the coal rib (**Figure 7**). The maximum roadway (bord) height is determined by the FoS of the pillar (**Section 4.1**).

The same secondary coal recovery methodology is proposed for the Project area. This methodology is a non-caving mining method such that large-scale overburden fracturing and subsidence, due to overburden sag, does not occur.

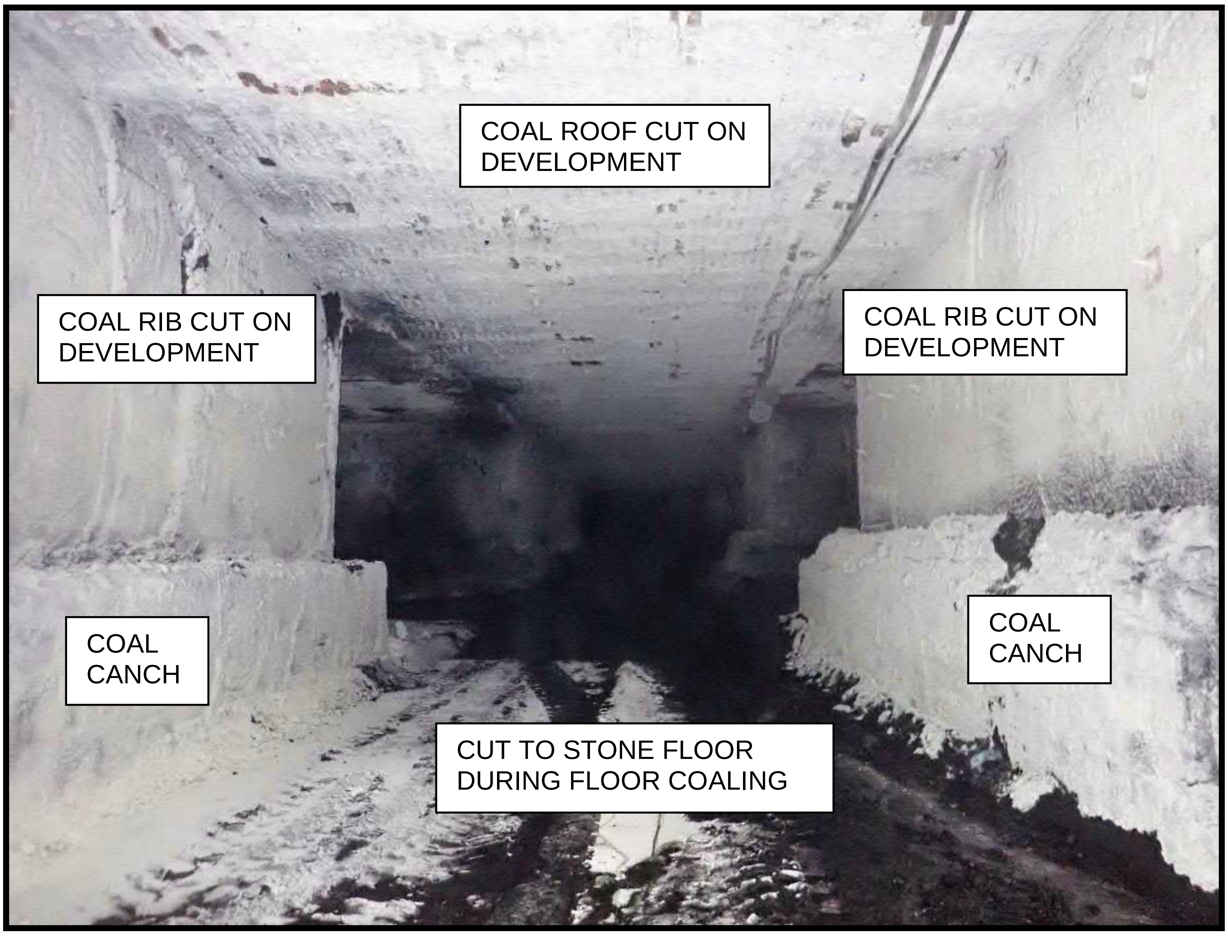


Figure 7. 5.5-6.5 m Wide x 4.8 m High Roadway after Floor Coaling at Ensham

The panel pillars in the Project area are designed with centre dimensions of 24 m x 28 m, which for 6.5 m wide roadways leaves solid 17.5 m x 21.5 m pillars (**Figure 8**). In the sub-panels, the pillars will have centre dimensions of 24 m x 24 m. The coal recovery ratios for the panel and sub-panel pillars with these dimensions are 44% and 46.8% respectively.

The naming convention for each panel is shown in **Figure 8**, for ease of reference in the subsidence assessment part of this report in **Section 4**.

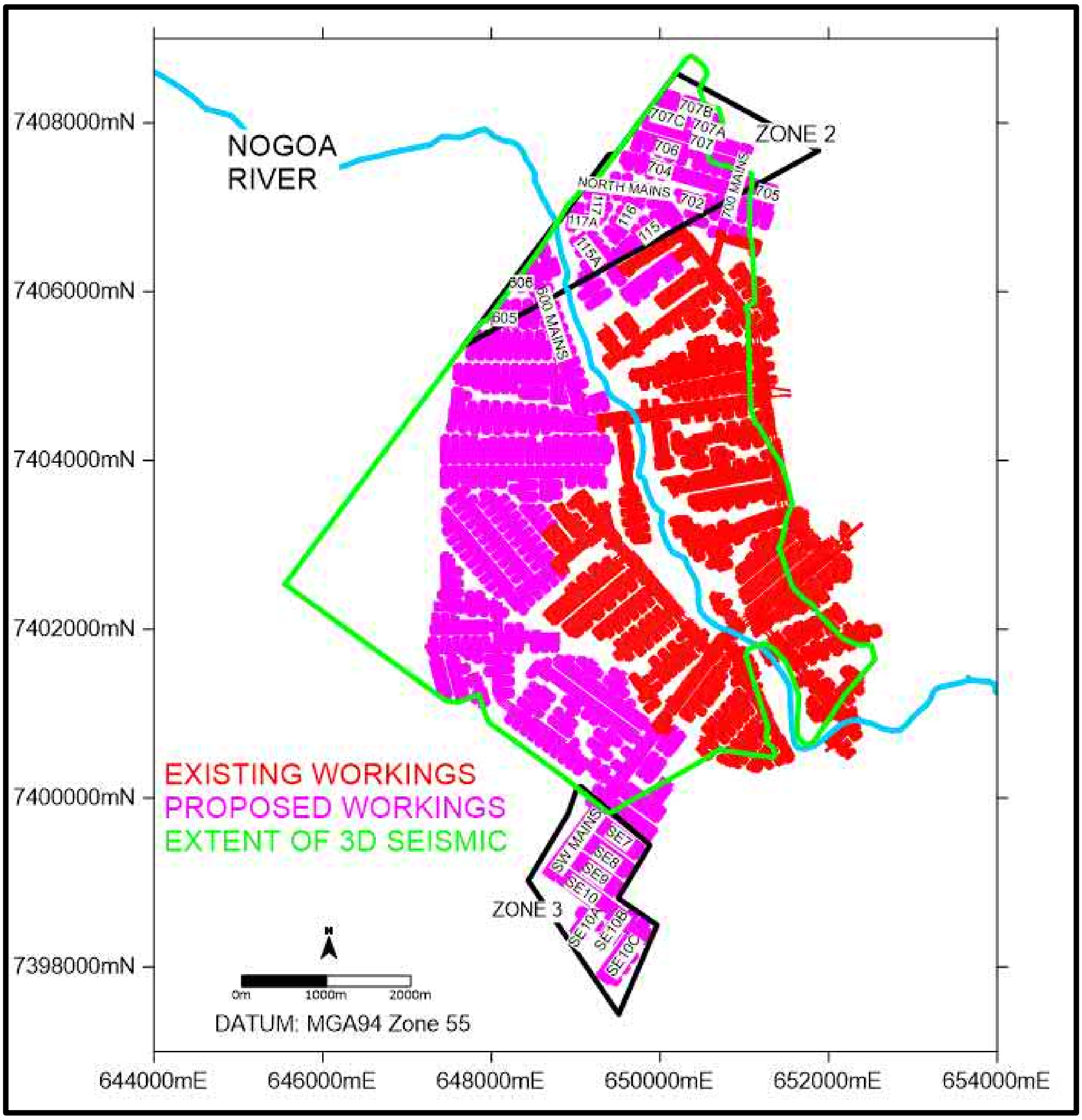


Figure 8. Bord and Pillar Panel Nomenclature and Outline of 3D Seismic

Mining is single seam only, with no multi-seam mining planned. The proposed extension of the underground into Zones 2 and 3 will extract the same coal seam and encounter similar overburden and floor strata as the Ensham underground and open cut operations.

As detailed in the Ensham SMP (2021[1]), the underground workings are designed where practical to avoid geological structures that may be associated with poorer mining conditions. For every panel that is mined, a hazard panel plan is produced that

[1] Ensham Resources (2021). Subsidence Management Plan. Document No. EIMP.06.00.06. Revision 1 - dated 3rd August 2021.

collates the available geological information such as faults, depth and seam thickness (Ensham SMP, 2021).

It should be stated that this assessment is being carried out on a generic mine layout. This layout may still be modified and optimised based on any geological features that may be encountered in areas that have not been surveyed with 3D seismic, such as parts of Zone 2 and all of Zone 3 (**Figure 8**).

These changes would not make the results of this subsidence assessment invalid. Rather, this assessment confirms that the various layout rules used by Ensham in developing the mine layout in the Project area are fit for purpose, as they return long-term stable remnant mine workings.

In the thicker seam areas, coal roof and coal floor will be left during the development part of the mining process, prior to secondary coal recovery (**Figure 6**). In the thinner seam areas, it is anticipated that the roadways will be mined to stone roof and stone floor, with no subsequent secondary floor coal recovery.

Between each panel, large 35-40 m (solid) barriers (blocks of coal) have been left and within each panel, the sub-panels are separated by a 25 m coal barrier (**Figure 8**). These barrier pillars are significantly larger than the panel pillars and minimise the interaction of overburden loads between the panels.

1.4 Objectives

The objective of this assessment is to predict the subsidence associated with the proposed mining activities within the Project area. The predictions are to be undertaken following a transparent and robust methodology.

1.5 Report Structure

Section 1 of this report introduces the Project area, including the proposed bord and pillar mining layout and methodology and setting.

Section 2 details the stratigraphy, depth of cover and coal seam thickness of the Project area.

Section 3 details previous subsidence monitoring data for the current Ensham underground workings and comparable bord and pillar mining operations.

Section 4 describes the subsidence prediction methodology, subsidence predictions and potential subsidence effects from the Project area.

Section 5 presents the key conclusions of the subsidence assessment.

2 ENGINEERING GEOLOGY

2.1 Geological Data

The Zone 2 and Zone 3 mining areas are covered by closely spaced exploration drilling, as shown in **Figure 9.** This spacing of exploration boreholes, supplemented with 3D seismic surveying, as well as geological mapping and surveying of the underground workings, is considered to be sufficiently detailed to identify any significant changes in the roof and floor strata that would affect the subsidence predictions prepared in this report.

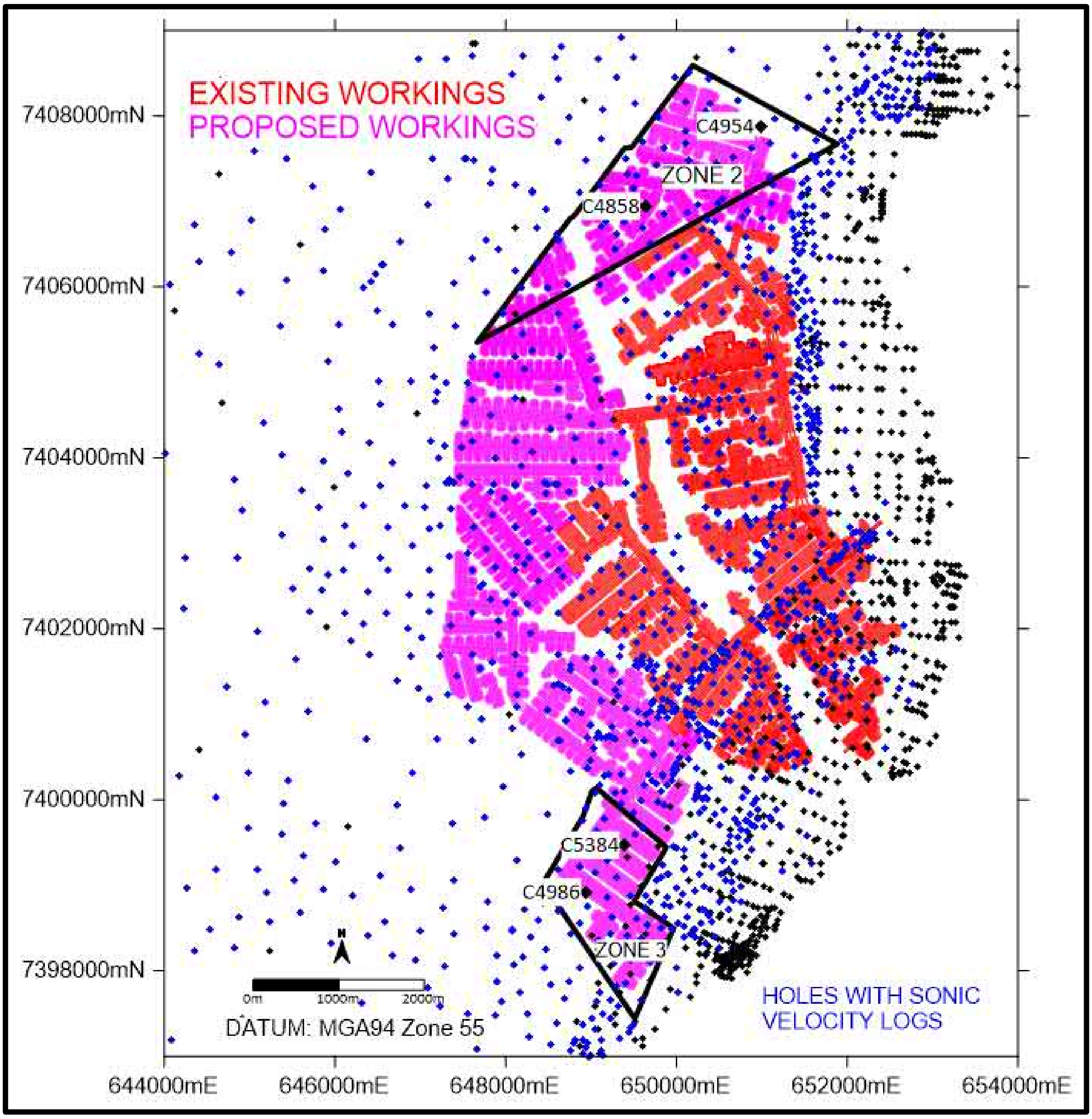


Figure 9. Location of Exploration Boreholes

These drill holes record the geological sequence of the overburden and coal seams, as well as the sediments immediately below the coalesced Aries-Castor and Castor Seams targeted for mining.

In the majority of the drill holes, geophysical logs are also available, which provide additional data on the rock and coal seam properties. This density of data provides a high level of confidence in the geological variables in the Project area. The geological data presented in this report is based on the April 2018 geological model.

Based on the available data for the Project area, including high density exploration boreholes, 3D seismic and underground geological mapping, there are no localised features or variations in the geology, geotechnical conditions or surface topography that are considered likely to result in any significant deviations from the subsidence predictions presented in this report.

2.2 Stratigraphy

The Project area is located in the central part of the Bowen Basin, a sedimentary basin comprising Permian to Triassic age geology. Within the Project area, the Aries and Castor Seams are part of the Permian Rangal Coal Measures. A generalised sequence of the coal seams in the Ensham area from north to south in the ML areas and also in the Project area is shown in **Figure 10**.

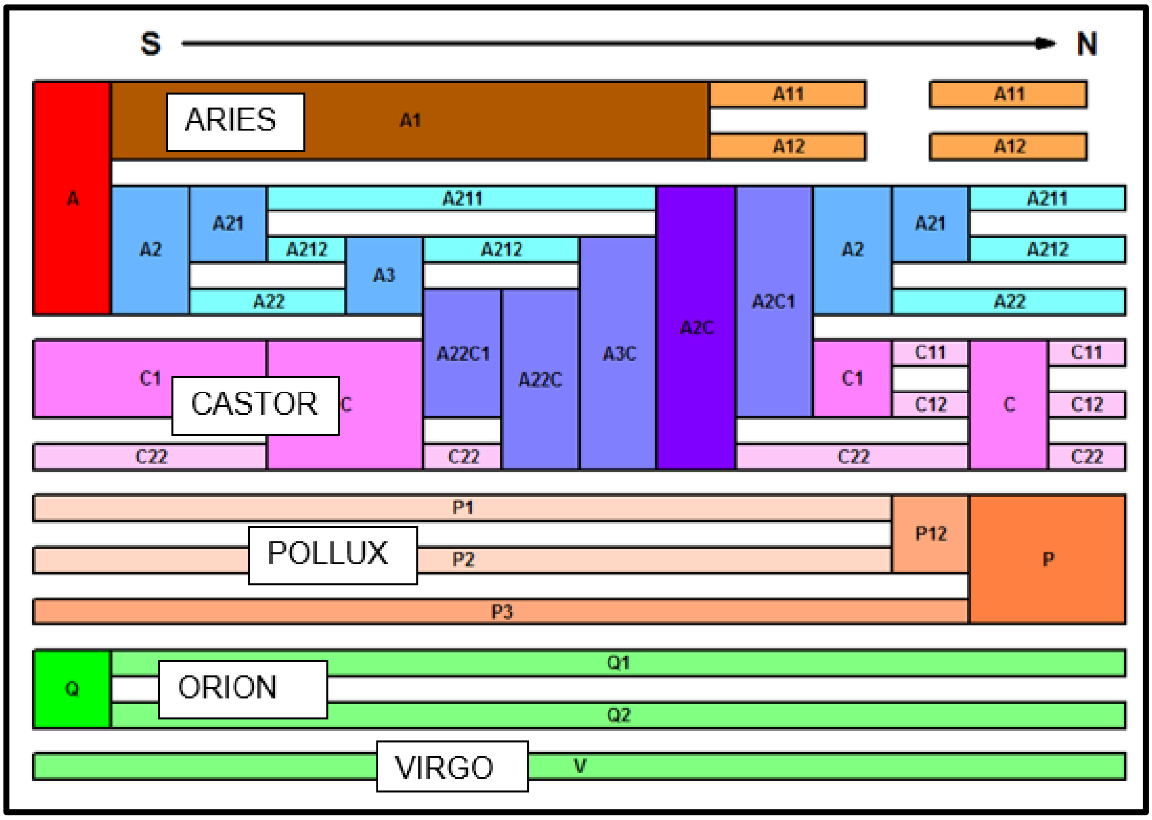


Figure 10. Permian Coal Seams across the Ensham Area

This figure illustrates the roof and floor seam splitting, which is characteristic of the Ensham area. The individual plies labelled A, C, P, Q and V refer to the Aries, Castor, Pollux, Orion and Virgo Seams respectively (**Figure 10**). The current underground mining area is located in the thicker central part of the ML area where the Aries and Castor Seams are coalesced (**Figure 10**).

2.3 Seam Thickness

The Aries and Castor Seams are coalesced in the majority of Zone 2 and Zone 3 (**Figure 11**). In Zone 2, the working section is 5-6 m in the southern part of the zone (**Figure 11**). Where the Aries and Castor seams are split in the northern part of Zone 2, the Castor Seam is the targeted working section with a typical thickness range of 2-3 m.

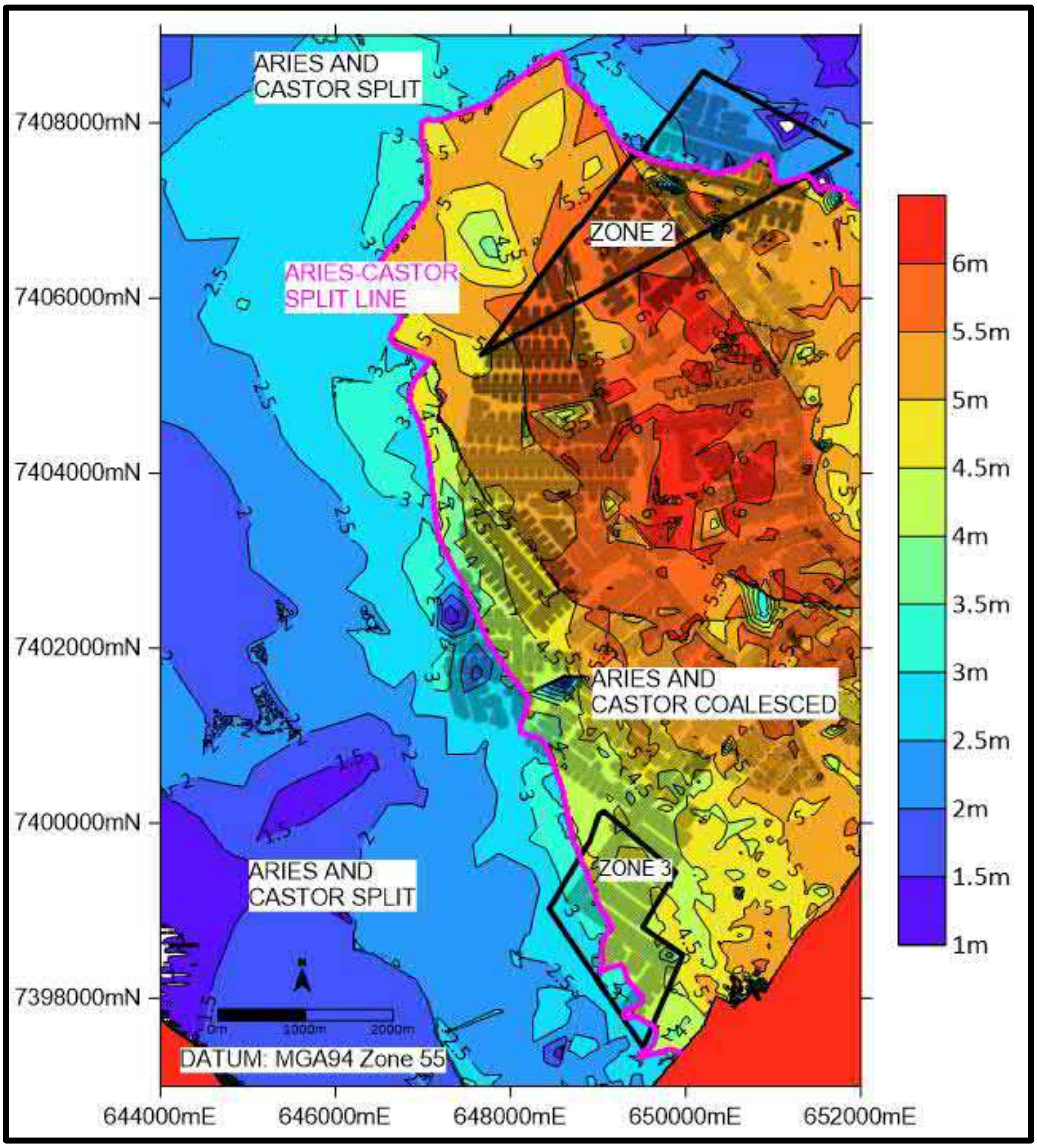


Figure 11. Working Section Thickness

In Zone 3, the working section is 3.5-4.5 m where the seams are coalesced and 3-3.5 m where the seams are split (**Figure 11**).

It should be highlighted that the thickness contours have been generated from grids that have been cropped either side of the Aries-Castor split line to ensure the accuracy of the thickness values used in the compression analysis presented later in this report (**Figure 11**).

2.4 Depth of Cover

In Zone 2, the depth of cover is typically 130-140 m (**Figure 12**). The topographic surface feature in the north-eastern part of Zone 2, locally increases the depth of cover to 200 m (**Figure 12**). In Zone 3, the depth of cover ranges from 75 m in the east, up to 160 m in the western part of the area (**Figure 12**).

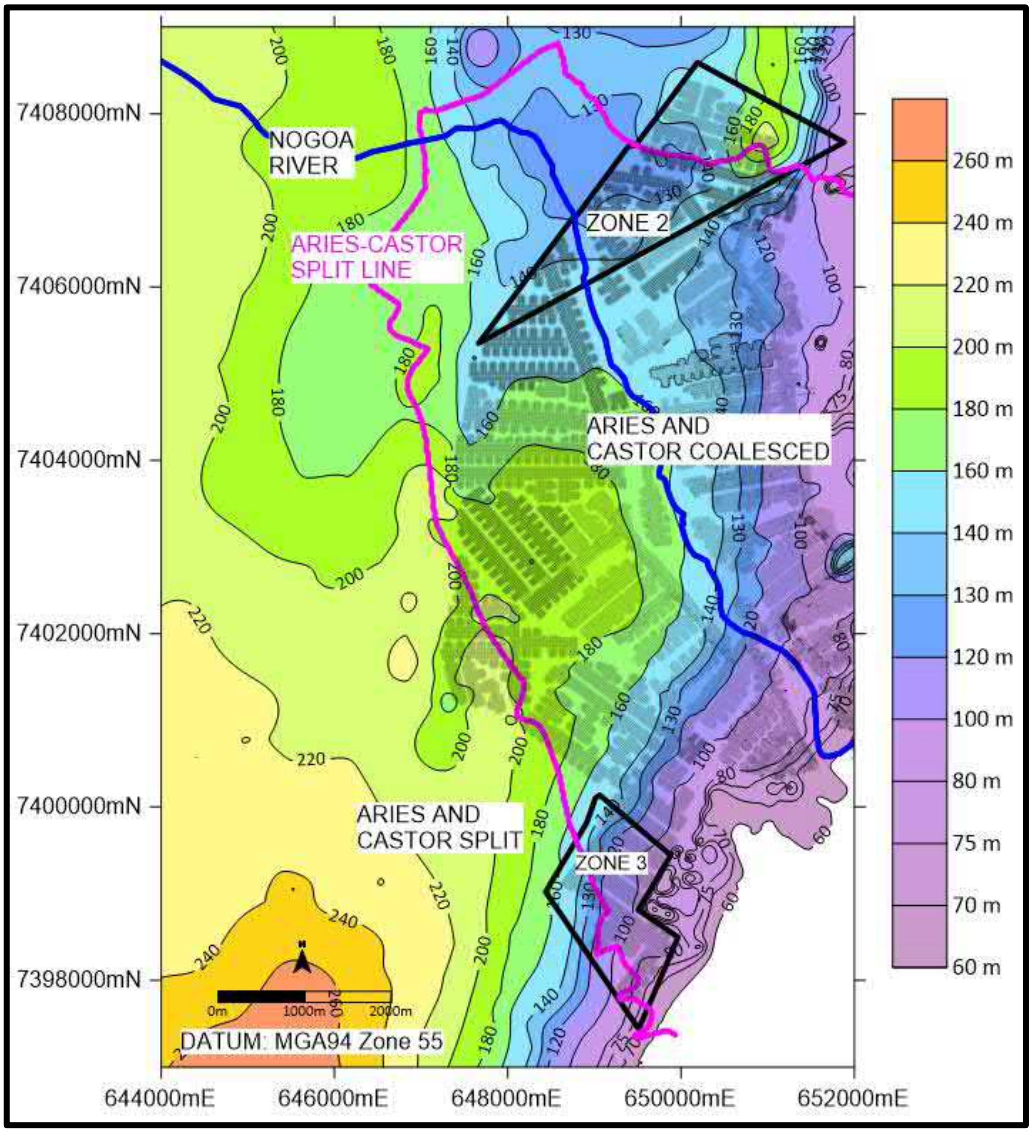


Figure 12. Working Section Depth

2.5 Depth of Weathering

The depth of weathering is typically 10-20 m thick in the majority of Zones 2 and 3 (**Figure 13**). The weathering depth locally increases to 50 m in the north-eastern part of Zone 2, due to the surface topographic feature in this area (**Figure 13**).

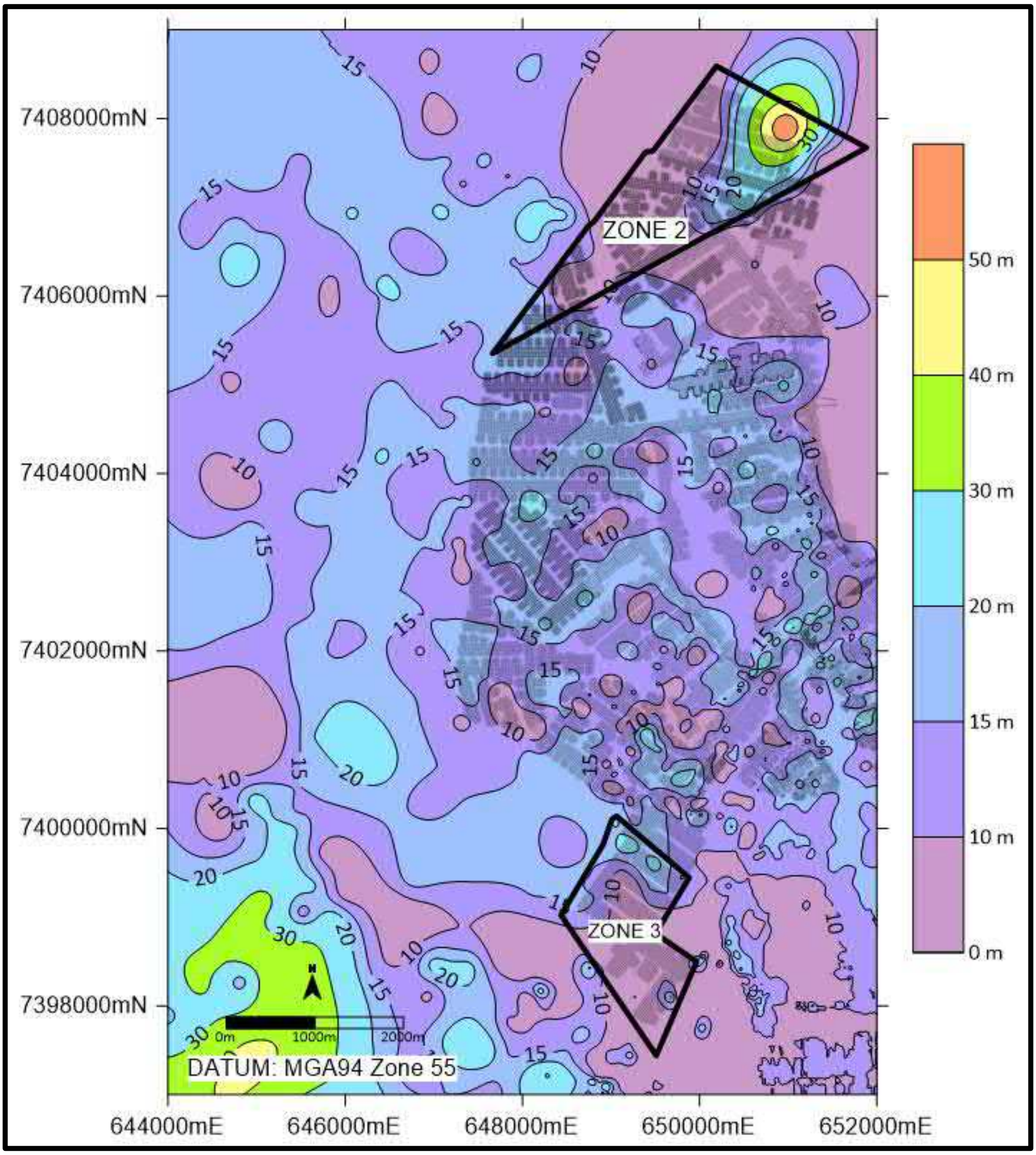


Figure 13. Depth of Weathering

3 PREVIOUS SUBSIDENCE MONITORING DATA

To assist in the prediction of subsidence in Zones 2 and 3, a review of the surface effects above the current underground workings has been carried out using both fixed RTK-GPS and LIDAR monitoring survey data.

In addition to the Ensham survey data, there is published subsidence data available from Clarence and Tasman Mines in NSW above partial extraction bord and pillar layouts. The relevant information from these three mining operations is discussed in the following sections.

3.1 Ensham Mine

3.1.1 Fixed RTK-GPS Monitoring

Fixed RTK-GPS monitoring survey stations have recently been installed above the current Ensham underground workings to provide a much higher level of survey accuracy (± 5 mm) than the LIDAR data (+/-50 mm). These stations are installed 1.5-2 m below the ground surface level (**Figure 14**). This monitoring has been set up by GNSS Monitoring and the data can be easily accessed remotely in real time.

Figure 14. Fixed GPS Monitoring Station

The six stations that have been installed are located above 114, 500 Mains, 502 and 503 Panels, as shown in **Figure 15**. It should be highlighted that the two stations above 114 Panel are adjacent to Zone 2 (**Figure 15**).

Five of the six monitoring stations started recording data in mid-April 2021. By early December 2021, development mining (primary workings) had been completed under stations 114_1, 114_2 and 502_1 and secondary workings extraction in 502 Panel had also been completed under station 502_2 (**Figure 15**).

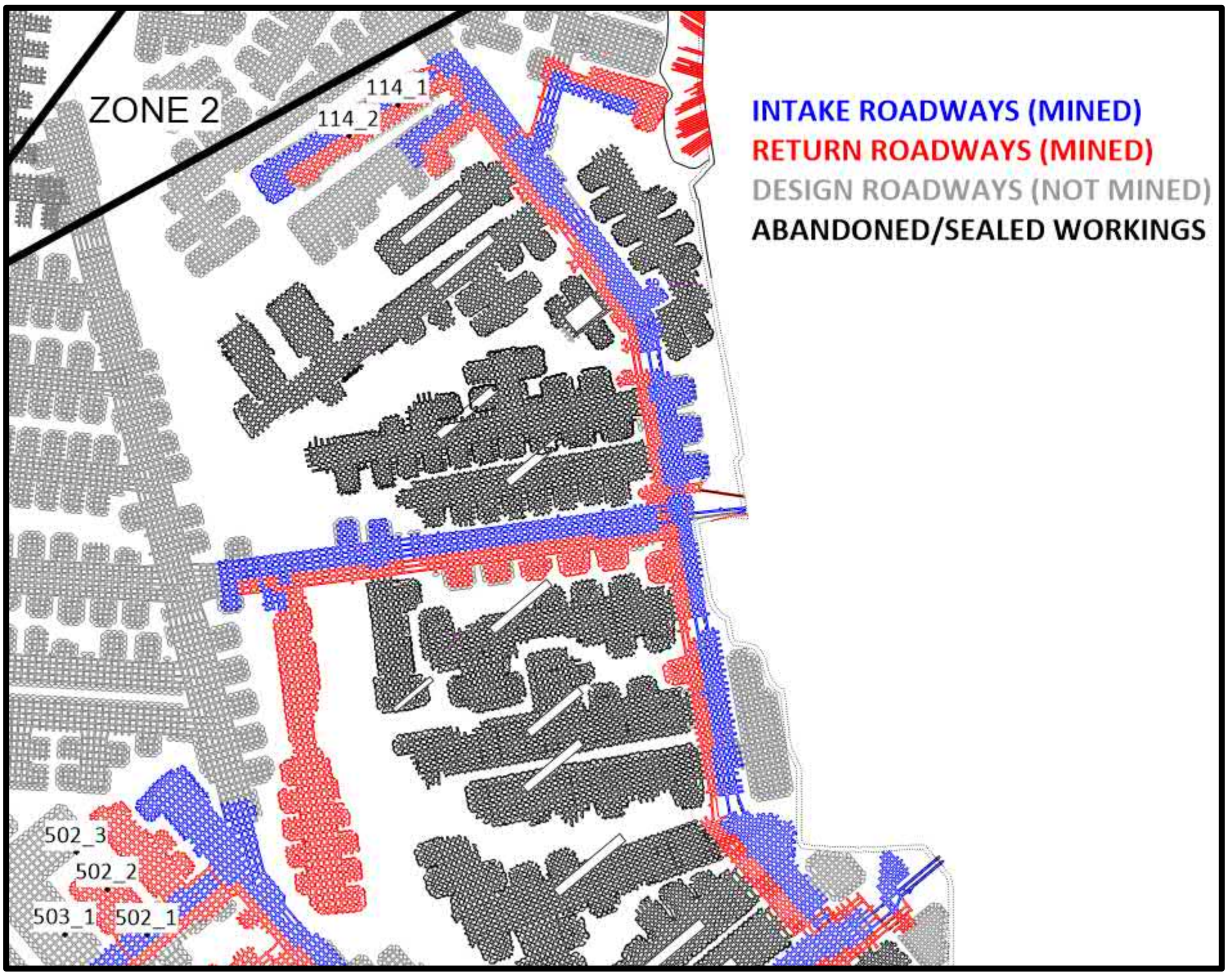


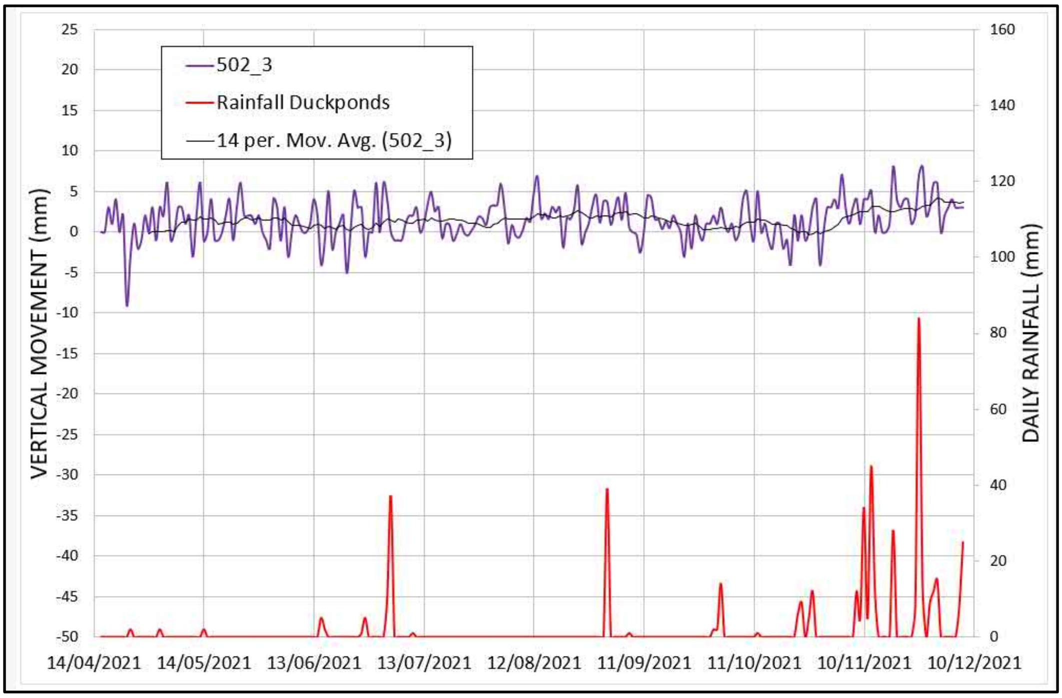
Figure 15. Location of Remote Subsidence Monitoring – Ensham Underground

The 500 Series monitoring stations are located in heavy, cracking clay soil, whereas a combination of non-cracking clay, surface duplex and loam surface soils occur in the vicinity of 114 Panel (Ensham SMP, 2021). Soils data has also been collected for Zones 2 and 3. Subsidence monitoring points will be established in the Project area and data recorded against the soil types at those locations. A map showing soil types overlaid with the locations of subsidence monitoring transects will be established as part of the SMP.

Remote survey measurements are recorded every 24 hours and these have been compared in the following figures (**Figure 16 to Figure 18**), with either the Duckponds (500 Series) or White Hill (114 Panel) rainfall gauges, to assess the effect (if any) of ground moisture on the measurements.

3.1.1.1 500 Series Panel Survey Stations

In the 500 Series Panel area, no mining has been carried out below stations 502_3 and 503_1 (**Figure 16**). The 14 day moving average curve indicates any vertical movement is less than the survey error of ±5 mm (**Figure 16**). Also of note, the rainfall events since April 2021 do not appear to have affected the survey measurements of vertical movement (**Figure 16**).



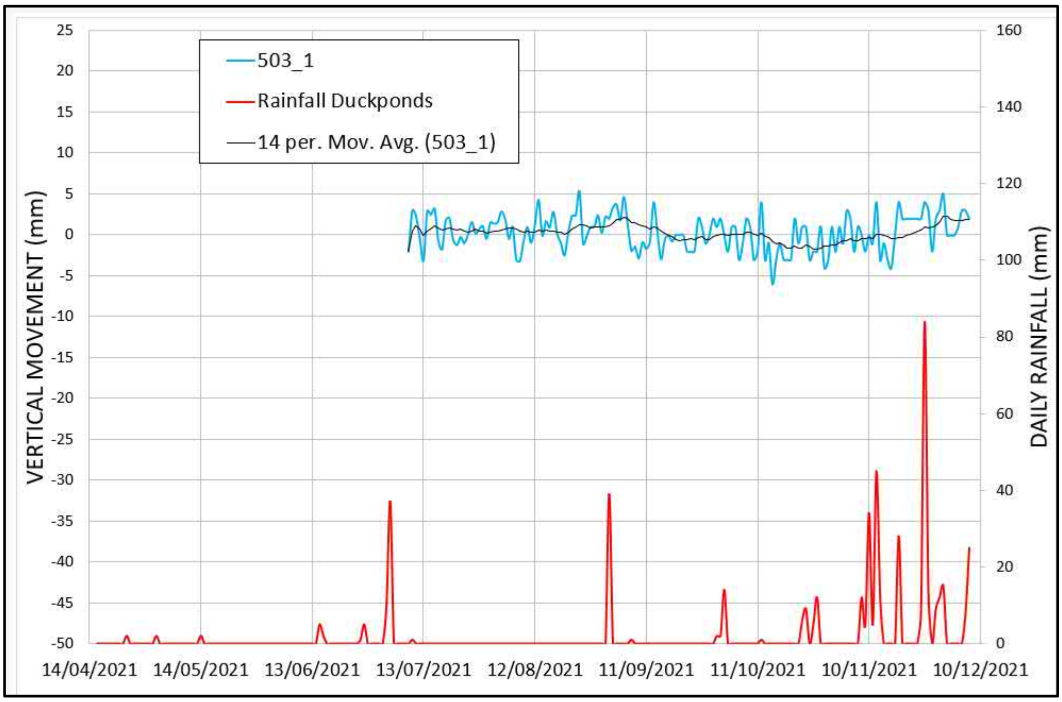


Figure 16. Subsidence Monitoring above 503 Panel

Development (primary workings) was carried out in the 500 Mains below station 502_1 in late May 2021. This mining appears to have been associated with approximately 5 mm of movement that occurred over a timeframe of a month (**Figure 17**). This timing is as anticipated based on the approximate 2-3 weeks required to mine the entire width of the panel below the survey station.

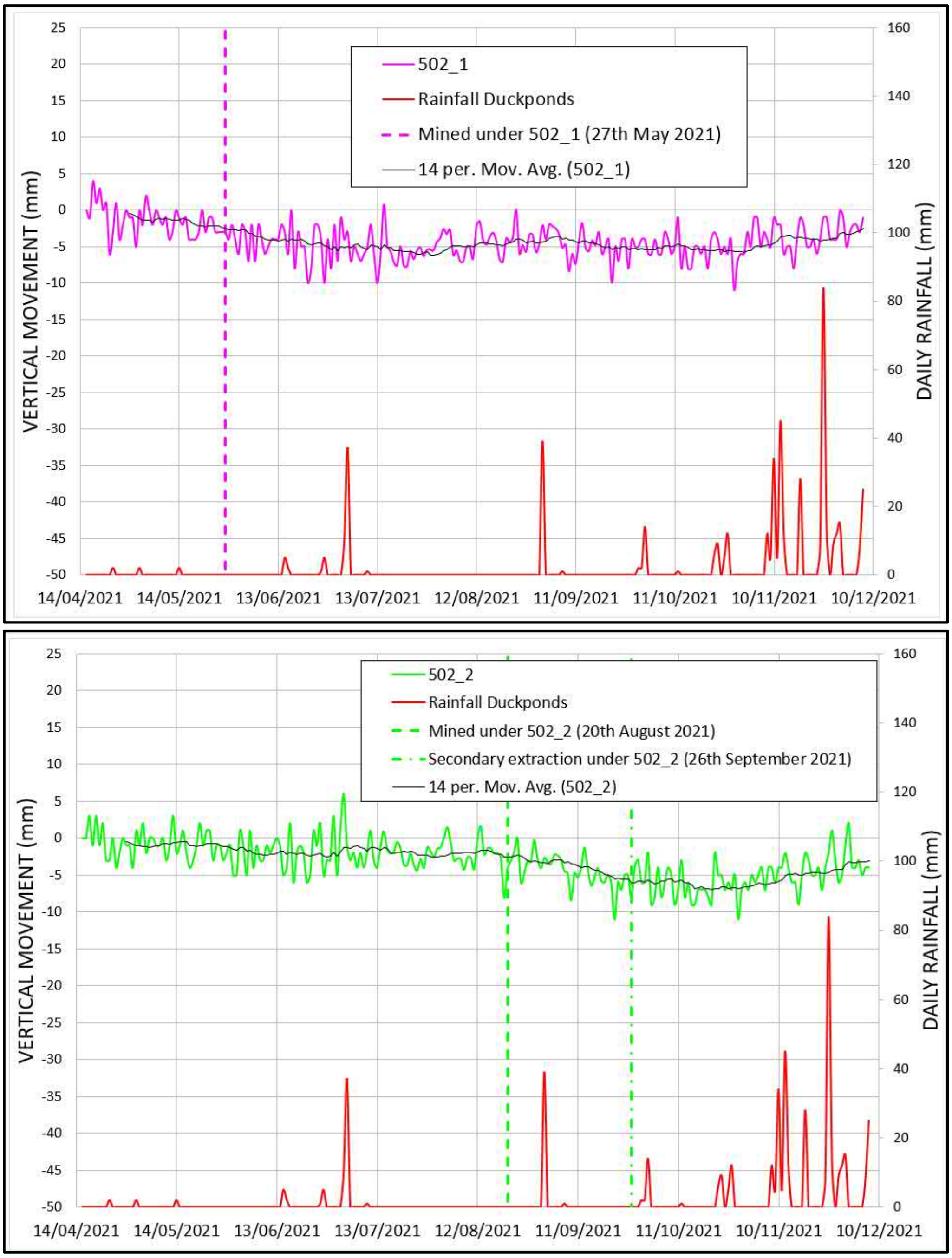


Figure 17. Subsidence Monitoring above 500 Mains and 502 Panel

502 Panel developed under station 502_2 in late August 2021, extracting coal to around 3.3 m high. Similar subsidence behaviour to 502_1 was noted on the 502_2 station (**Figure 17**). Secondary extraction of an additional 1 m of floor coal was

completed under this station by late September 2021, with no additional vertical movement measured (**Figure 17**). Similarly, rainfall events do not appear to be significantly affecting the vertical movement measurements.

3.1.1.2 114 Panel Survey Stations

Mining of development roadways (primary workings) at 3.3 m high was carried out below survey stations 114_1 and 114_2 in mid-August and mid-September 2021 respectively (**Figure 18**).

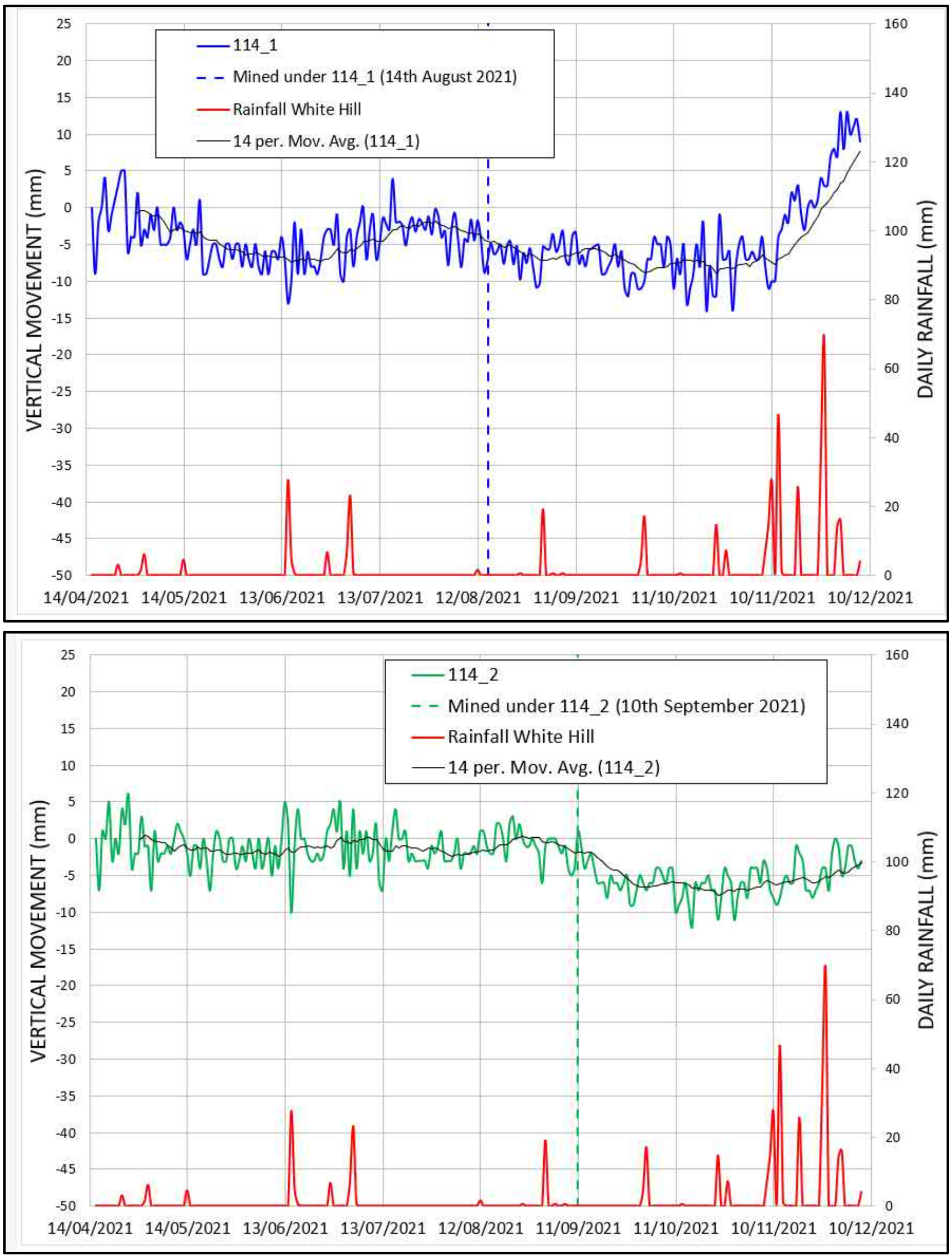


Figure 18. Subsidence Monitoring above 114 Panel

The survey data from station 114_2 indicates around a two week period for the maximum 8 mm of subsidence to occur after the completion of mining below the station (**Figure 18**). Less movement, within the ±5 mm measurement accuracy, was recorded on station 114_1 after mining was completed (**Figure 18**). Some movement of up to 10-15 mm was measured during the recent rain event on station 114_1 and can be attributed to the type of material in which the station is anchored (**Figure 18**).

3.1.2 LIDAR

LIDAR surveys flown in March 2016 and February 2017 have also been used to assess potential surface effects above mined out areas at Ensham. The extent of the underground workings at the time of these surveys is shown in **Figure 19.**

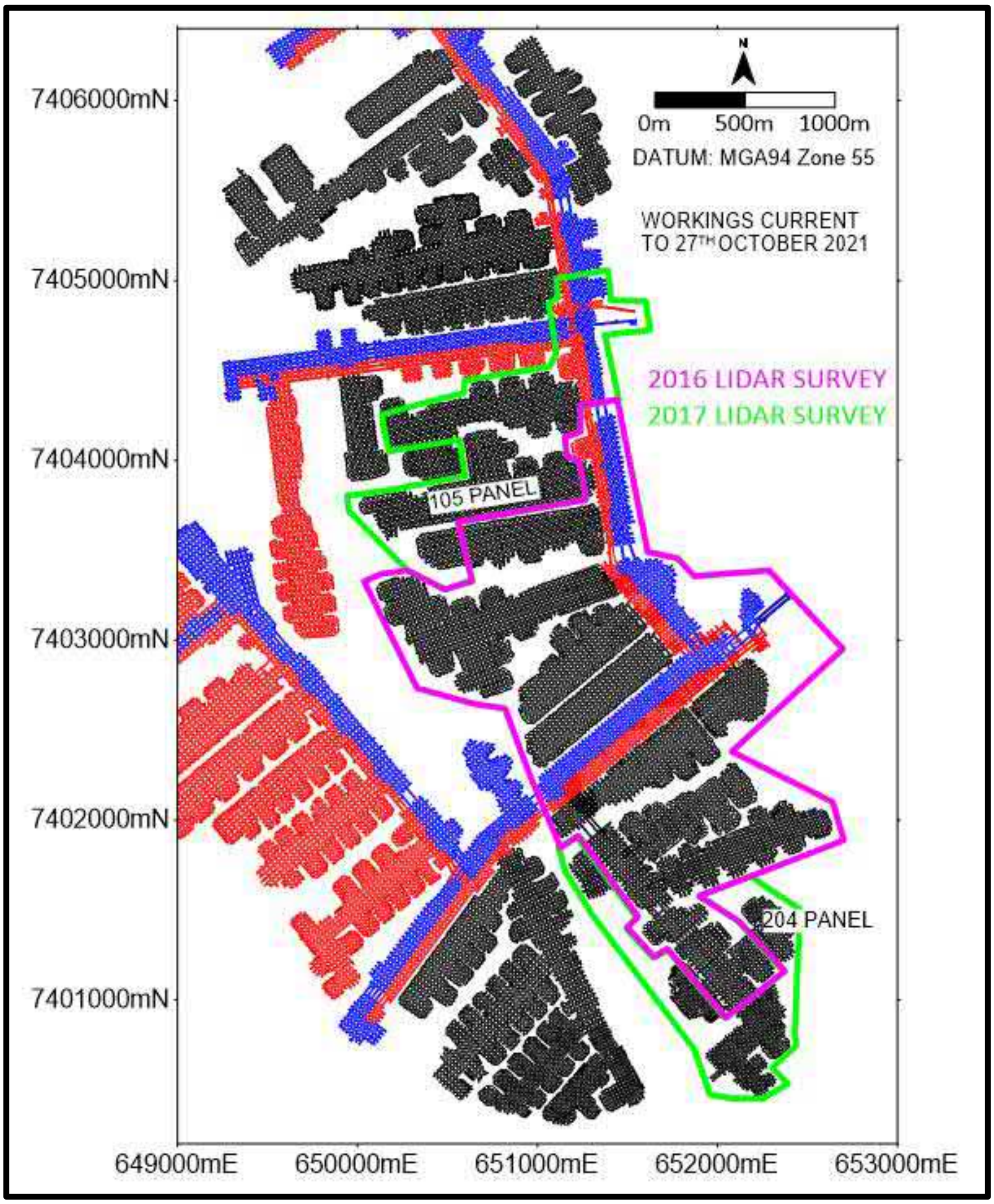


Figure 19. Extent of the Mine Workings at the time of each LIDAR Survey

It is considered that these lower accuracy (± 50 mm) LIDAR surveys will still be applicable in assessing ground movements over larger areas. This data is considered to be a back up to the more accurate RTK-GPS data and can be used to determine any trends.

These surface effects may also include natural ground movements, as well as potential subsidence effects. In some environments, up to 50 mm or more of vertical movement may occur due to seasonal moisture changes (DAWE, 2014[2] and 2015[3]).

Mining was completed in the shallower 204 Panel in the southern part of the mining area and the deeper 105 Panel located in the central part of the mine workings between the 2016 and 2017 LIDAR surveys (**Figure 19**).

The section lines above both panels show that any ground movement is less than the ±50 mm accuracy of the LIDAR surveys (**Figure 20** and **Figure 21**). These measurements validate the subsidence predictions of typically less than 35 mm in the Project area presented in **Section 4.3** of this report.

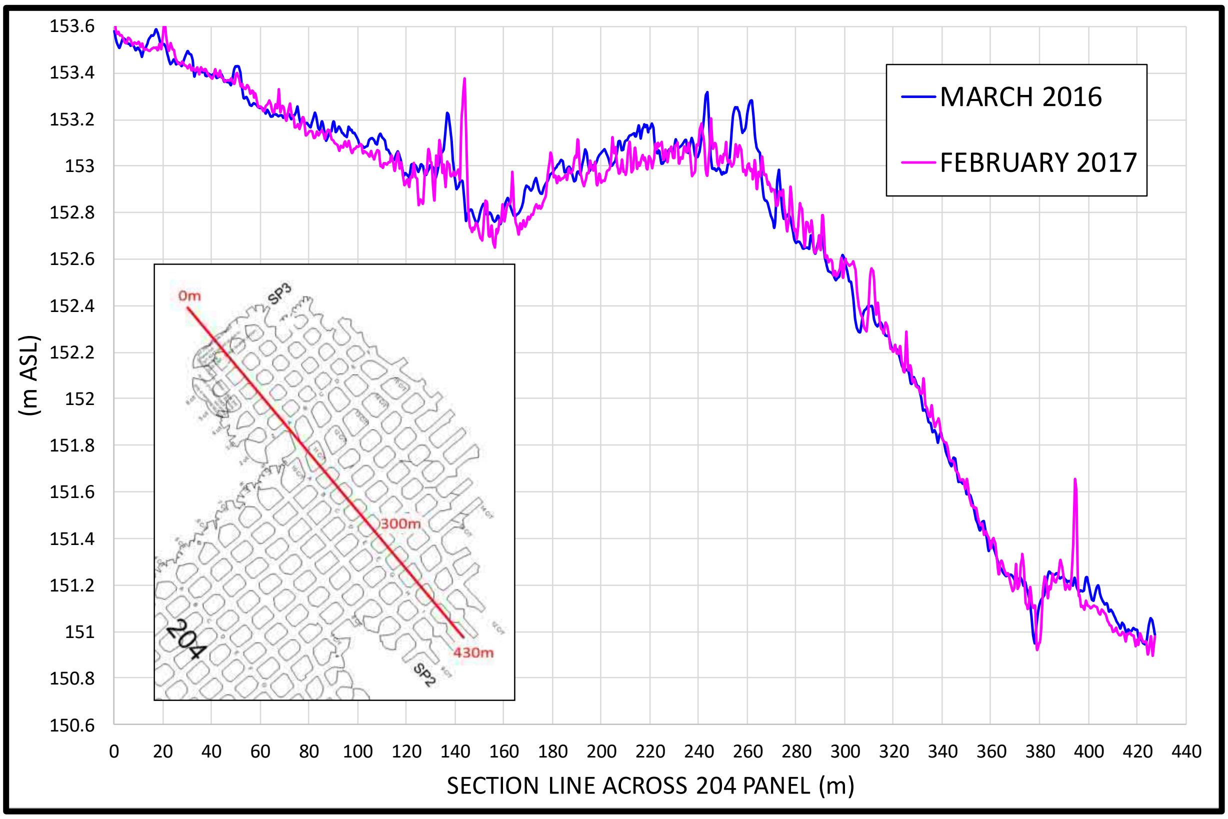


Figure 20. Section Line above 204 Panel

2 DAWE (2014). Subsidence from Coal Mining Activities. Report commissioned by the IESC and prepared by Sinclair Knight Merz Pty Ltd.

3 DAWE (2015). Monitoring and Management of Subsidence Induced by Longwall Coal Mining Activity. Report commissioned by the IESC and prepared by the Jacobs Group (Australia).

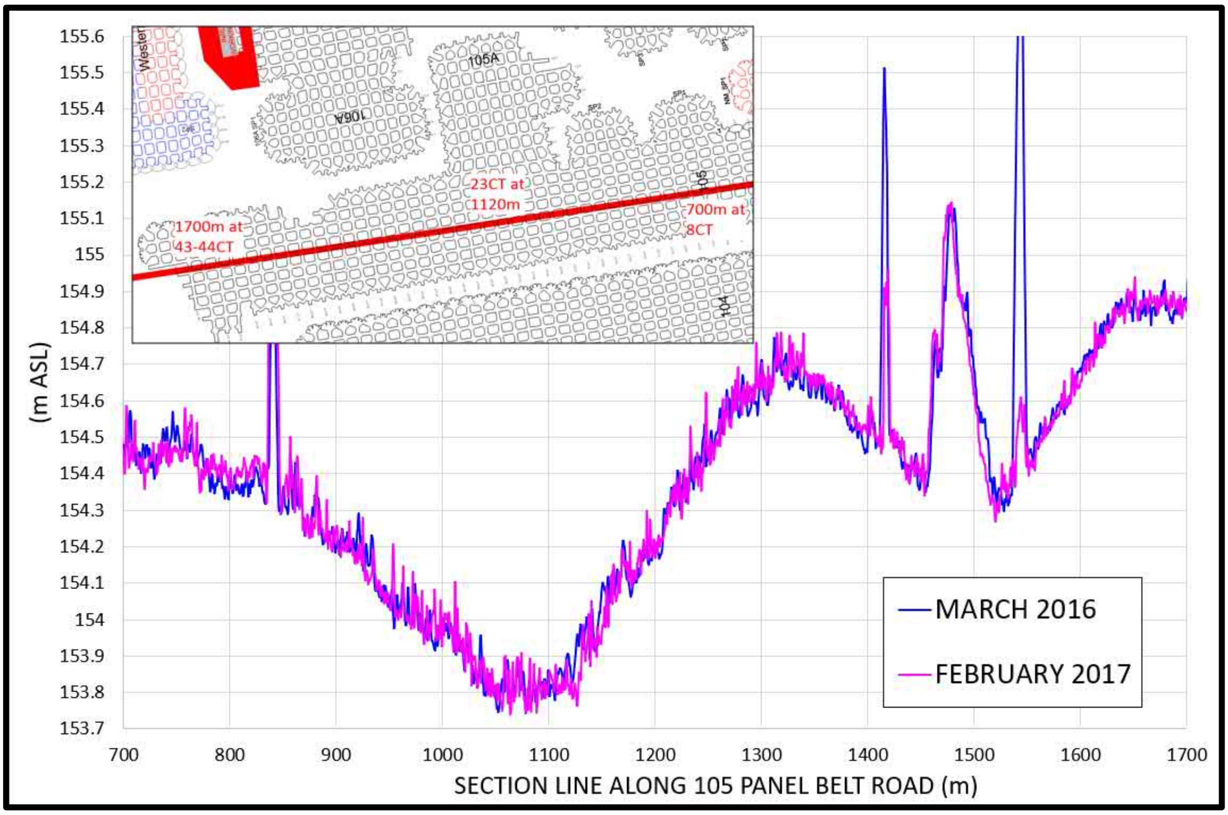


Figure 21. Section Line along the 105 Panel Belt Road

3.1.3 Monitoring Review

Almost eight months of higher accuracy (± 5 mm) monitoring survey data has now been collected over the Ensham underground workings. This data indicates that underground mining has had negligible subsidence impacts on the surface within the accuracy of the survey monitoring and validates the less than 35 mm prediction detailed in Section 4 of this report (**Figure 16 to Figure 18**).

In the 500 Series area, rainfall events appear to have had no impact on the survey measurements, whereas in 114 Panel rainfall events appear to correlate with spikes in the survey data (**Figure 16 to Figure 18**). .

The soil types have been mapped across the Ensham area, as documented in the Ensham Subsidence Management Plan (SMP) (2021) and these should be referenced when interpreting the measured subsidence.

It is anticipated that prior to mining in Zones 2 and 3, the collection of additional survey data, in conjunction with rainfall records and also the location of underground mining, will provide some guidance on the proportion of movement due to both mining induced subsidence and also the seasonal variation in ground levels due to changes in moisture content.

Further baseline, reference and ongoing monitoring data will be required to ensure that any minor subsidence is identified, recorded, and mitigation measures are put in place.

This survey monitoring should confirm the subsidence predictions and any significant changes in subsidence will trigger a review of the relevant impact assessments and associated mitigation and management measures as discussed further in Section 4.8 of the Ensham SMP.

This review will also provide additional calibration data for any future subsidence predictions and assessments of subsidence effects.

As detailed in Revision 1 (August 2021) of the Ensham SMP, a subsidence monitoring report will also be produced every two years and monitoring of subsidence impacts will be continued after the completion of mining either:

- For five years or
- Until the surrender of the mining lease or
- A suitably qualified and experienced person produces a report confirming a lesser monitoring period is appropriate.

3.2 Clarence Mine

Clarence Mine operates adjacent to the Blue Mountains World Heritage area in the Western Coalfield of NSW. The 2.8-3.6 m thick Katoomba Seam is mined at depths between 60 m and 320 m (Hill and White, 2017[4]). The in-panel extraction ratios at Clarence are around 50-60%, slightly higher than those in the Project area at Ensham (44-46.8%) where there is no partial extraction of coal pillars (**Figure 22**).

At Clarence, the Development Approval limits surface subsidence to 100 mm. Monitoring since 2003 has shown that subsidence can be characterised in four stages (Hill and White, 2017):

1. Development drivage results in 5-10 mm of subsidence.
2. Partial extraction adds 15-20 mm (i.e. 20-30 mm of cumulative subsidence).
3. Drivage and partial extraction of the subsequent adjacent panel adds 5-10 mm (i.e. 25-40 mm of cumulative subsidence).
4. Long term water accumulation and panel flooding results in an additional 30 mm (i.e. 55-70 mm of cumulative subsidence).

[4] Hill, D. and White, E. (2017). Progress in Partial Extraction Layout Design for Productivity, Safety and Subsidence Management at Clarence Colliery. Proceedings of the 10th Triennial Conference on Mine Subsidence. Pp. 235-252.

There have been no exceedances of the 100 mm subsidence limit since partial extraction started in 2003 (Hill and White, 2017).

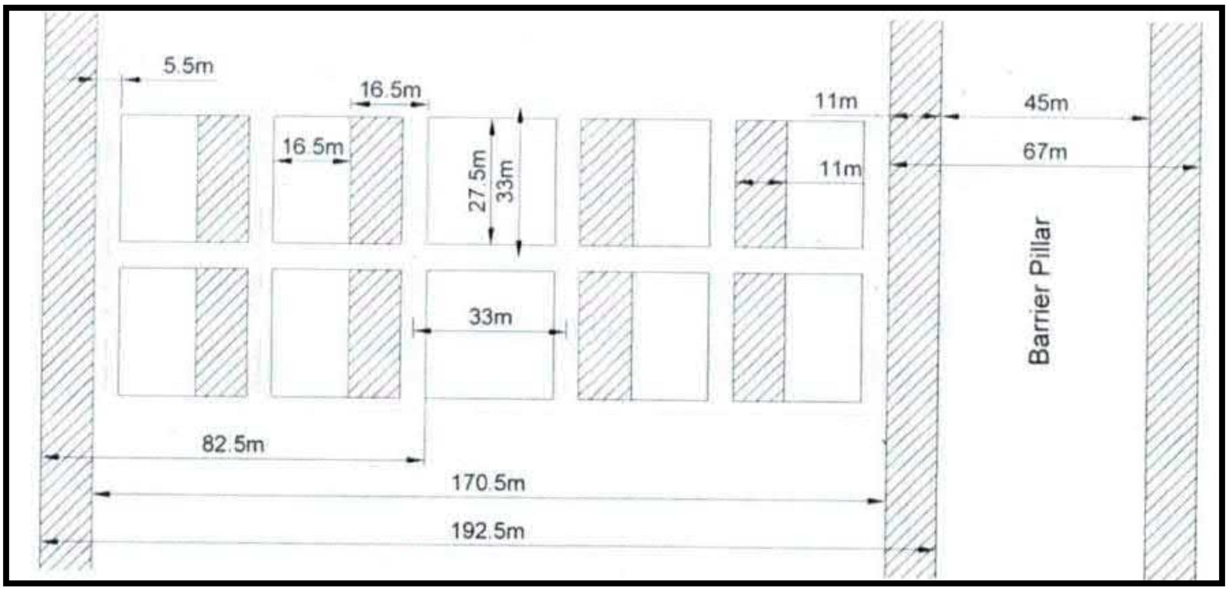


Figure 22. Bord and Pillar Layout – Clarence Mine

3.3 Tasman Mine

Tasman Mine in NSW commenced the Duncan Method of partial extraction in 2008 of the 2.2-2.5 m thick Fassifern Seam, at depths up to 250 m (McTyer and Sutherland, 2011[5]). The extraction ratios were between 67% and 82%, which are significantly higher than the 44-46.8% recovery proposed in the Project area at Ensham.

The proximity and visibility of the cliff lines of the Sugarloaf Range State Conservation Area to Newcastle, resulted in strict mine approval conditions regarding subsidence outcomes. Under the Tasman Development Consent, there was to be no impact on the high-level cliff lines as a result of subsidence (Ditton and Sutherland, 2013[6]).

Man-made features on the site included three broadcasting towers, AAPT Optical Fibre Cable (OFC) and Telstra copper cabling, four TransGrid tension towers, Ausgrid 11 kV power line, public access road and several highly significant Aboriginal archaeological sites (Ditton and Sutherland, 2013).

[5] McTyer, K. and Sutherland, T. (2011). The Duncan Method of Partial Pillar Extraction at Tasman Mine, 11th Underground Coal Operators' Conference, University of Wollongong & the Australasian Institute of Mining and Metallurgy, 2011, 8-15.

[6] Ditton, S. and Sutherland, T. (2013). Management of Subsidence at the Tasman and Abel Mines - Issues and Outcomes, 13th Coal Operators' Conference, University of Wollongong, The Australasian Institute of Mining and Metallurgy & Mine Managers Association of Australia, 2013, 86-98.

Level 1 to 4 subsidence control zones were developed for mine planning purposes for the existing surface features (Ditton and Sutherland, 2013):

1. Level 1 - (Green) no mining constraints (total extraction allowed);
2. Level 2 - (Yellow) subsidence less than 150 mm along shallow cover below ephemeral creeks, steep slopes and minor cliffs; Aboriginal Heritage sites; Optical fibre cable.
3. Level 3 - (Red) subsidence less than 100 mm below Sugarloaf area, TransGrid Towers (tension).
4. Level 4 - (White) Subsidence less than 3 mm and horizontal displacements less than 20 mm at the Mount Sugarloaf Communication Towers (NBN, TransGrid and Broadcast Australia).

Level 1 areas were considered suitable for total pillar extraction, with the maximum subsidence up to 1.2-1.3 m.

Level 2 and 3 areas required partial pillar extraction techniques that could also support abutment loading from Level 1 areas. Level 2 and 3 had similar subsidence constraints however, the remnant pillar FoS ranged from 1.6 to greater than 2.11 respectively and required squat pillar geometries (i.e. width/height ratio of greater than 5) for strain hardening response in yield (Ditton and Sutherland, 2013).

McTyer and Sutherland (2011) reported the subsidence one year after mining was completed above the 3 North partial extraction panel, to range from 51 mm to 101 mm, with a maximum tilt of 1.2 mm/m (**Figure 23**).

As documented by Ditton and Sutherland (2013), 2.5 years after mining had been completed, increased levels of subsidence up to 521 mm were measured (**Figure 23**). A surface crack of 30 mm width developed above the rib line and across a public access path after the subsidence exceeded 300 mm.

These increased levels of subsidence were inferred to be due to weak claystone layers (0.1-0.4 m thick) in the immediate 1.2 m of floor below the coal pillars, which softened to 0.15-1 MPa after mining. This softening of the floor resulted in punching of the pillar and lateral squeezing failures within the first 1.5 m of floor strata.

There is a history of similar subsidence events in the Newcastle coalfield due to the behaviour of very soft floor strata. In the 1980s, more than 1 m of subsidence was measured on the foreshore of Lake Macquarie above one of the mines in this area.

Based on these experiences in soft floor mining conditions, the subsidence assessment in the Project area at Ensham has considered the floor strata below both the coalesced Aries-Castor and Castor Seams to identify any potential weak units to eliminate the possibility of similar subsidence events (**Section 4.2.1**).

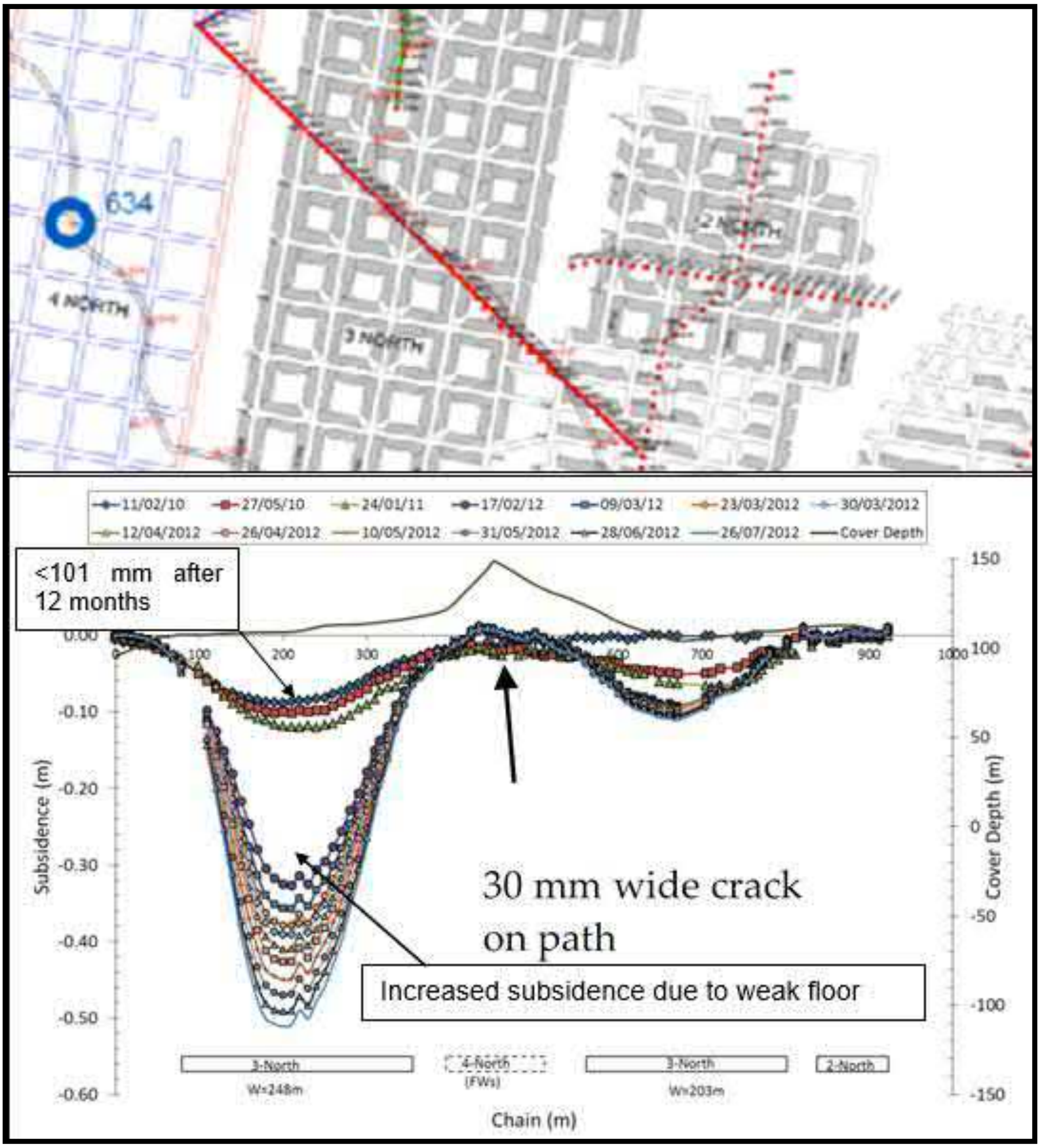


Figure 23. Subsidence over 3 North Panel at Tasman

4 SUBSIDENCE PREDICTION METHODOLOGY AND RESULTS

The bord and pillar mining method proposed in Zones 2 and 3 is described in **Section 1.3**. The proposed mine layout has been specifically designed to ensure that there will be no caving of the roof or collapse of the pillars.

The long-term stability of the proposed underground workings has been assessed in **Sections 4.1.1, 4.1.2 and 4.1.4** using the design FoS, pillar dimensions (width to height ratio) and stability of the overburden respectively.

Section 4.1.5 provides a comparison of the stability of the pillars in the Project area, to published studies of pillar failure events and experience from the current Ensham underground workings.

The subsidence behaviour and effects have been assessed in **Sections 4.2 and 4.3**.

4.1 Stability of Underground Workings

4.1.1 Factor of Safety

The assessment of the long-term stability of the coal pillars in the Project area has been carried out using the industry accepted University of New South Wales Pillar Design Procedure to determine the design FoS as follows (Galvin et al, 1998[7]):

FoS = Strength of Pillar/Load on Pillar

The strength of the pillars in the Project area was calculated using the UNSW Pillar Design Power Strength Formulae. The following FoS are planned for Zone 2 and Zone 3 in the Project area:

a) 2.11 for bord and pillar workings beneath the Nogoa River anabranch;
b) 2.11 for access roadways beneath the Nogoa River to connect the bord and pillar and longwall mining areas; and
c) 1.6 for all other bord and pillar workings beneath the floodplain of the Nogoa River.

4.1.1.1 Pillar Load

The load carried by the pillars was calculated using tributary area loading. The majority of the panels in the Project area have panel width to depth of cover ratios greater than 1, whereby the pillars experience the full tributary area load of the overlying strata.

[7] Galvin, J., Hebblewhite, B., Salamon, M. and Lin, B. (1998). Establishing the Strength of Rectangular and Irregular Pillars. Final Report, ACARP Project C5024.

A recent publication by Reed et al (2016)[8] has suggested that coal pillars may exceed their peak strength before the overburden moves enough to generate full tributary area loading conditions, as discussed further in **Section 4.1.4**.

Galvin, (2016)[9] also proposed that the pillars on the perimeter of the panels do not carry the full tributary area load (**Figure 24**). However, for the purposes of this assessment, a conservative full tributary area load assumption is considered appropriate for the pillars in the main panels and sub-panels in the Project area. The bell-out pillars on the perimeter of the panels are anticipated to carry 70% of the overburden load as shown in **Figure 24**.

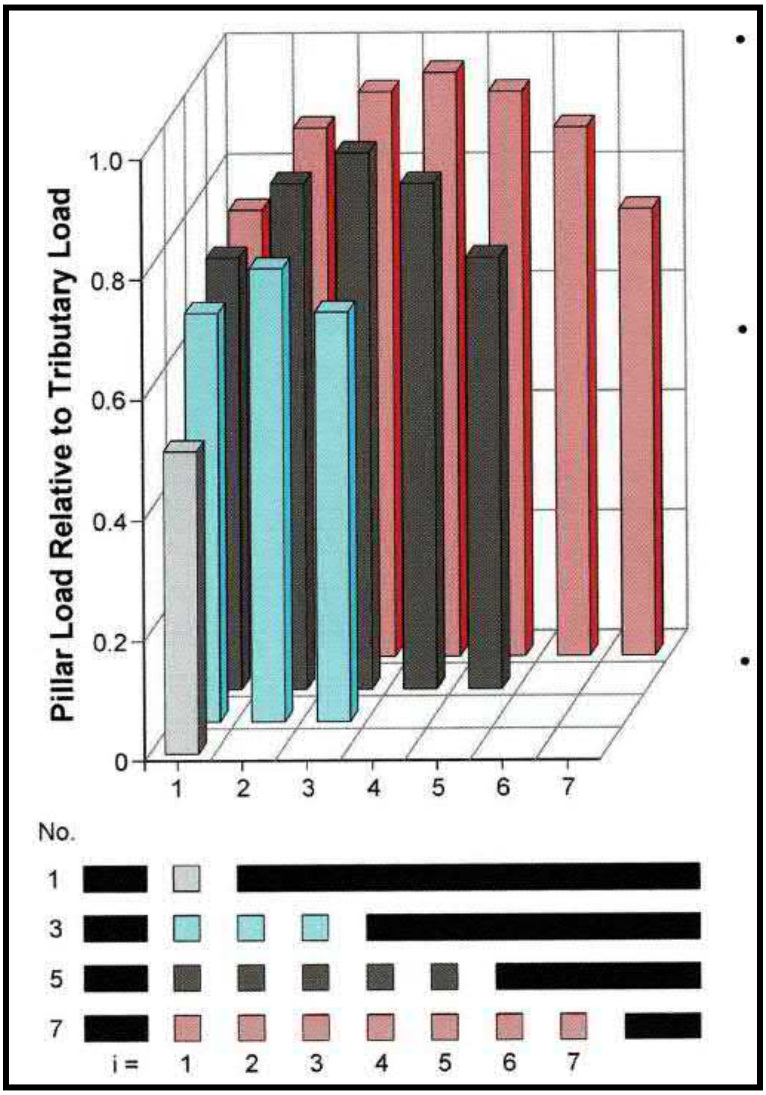


Figure 24. Influence of Panel Width on Pillar Load

[8] Reed, G., McTyer, K. and Frith, R. (2016). An Assessment of Coal Pillar System Stability Criteria Based on a Mechanistic Evaluation of the Interaction Between Coal Pillars and the Overburden. Proceedings 35th International Conference on Ground Control in Mining, Morgantown, West Virginia.

[9] Galvin, J.M. (2016). Ground Engineering – Principles and Practices for Underground Coal Mining.

The temporary increase in load on the underground workings during a flood event also needs to be considered (Hebblewhite, 2021[10]). As shown in **Figure 1**, the southern part of Zone 2 and the north-eastern corner of Zone 3 are located under the flood plain. There are no workings under the Nogoa River, however a 200 m section of the Nogoa River anabranch is located over 115 Panel (**Figure 3**).

During flood events, as well as the increase in water depth, the temporary increase in density due to saturation of the river alluvium should also be considered. For this discussion, a worst case 0.1% AEP (Q1000) flood event has been assessed.

Over the flood plain, the predicted maximum flood depth is 2-4 m (Hydro Engineering and Consulting, 2020[11]). At a conservative 4 m flood depth over the flood plain, the increase in the effective depth of cover is 1.8 m, assuming a density for the water of 1.1 t/m^3, to conservatively allow for some sediment load. In the Nogoa River anabranch, a conservative 16 m flood depth as indicated by Hebblewhite (2021), equates to an effective depth of cover of 7.2 m.

Similarly, the soil cover on the flood plain is typically less than 2 m thick and when saturated is assessed to have an upper bound density of 2.8 t/m^3. This would account for an additional 0.29 m depth of cover, assuming an average overburden density of 2.45 tm^3.

4.1.1.2 Panel Pillars

The long-term stability of the pillars in the Project area has been assessed on a panel by panel basis, using a conservative maximum depth of cover (**Figure 12**). The mining height has also been adjusted for each panel to take into account the variability in the thickness of the coalesced Aries-Castor Seam and split Castor Seam across the Project area (**Figure 11**). The depth and thickness values for each panel are tabulated in **Appendix 1** of this report for Zones 2 and 3 within the Project area.

Where the Aries-Castor Seam is coalesced within the Project area, the depth of cover is between 75 m and 200 m and the seam thickness is typically 4.0-5.5 m (**Figure 11 and Figure 12**). Based on mining experience in the current underground workings, typically 0.8 m of roof coal is left in the thicker seam areas. In thinner seam areas, the roof coal thickness is reduced to around 0.4-0.5 m.

In those areas within Zones 2 and 3 where only the Castor Seam is to be mined, the seam thickness is less than 3 m and it is anticipated that the full seam section will be mined on development, with no secondary coal recovery (**Figure 12**).

[10] Hebblewhite, B.K. (2021). Peer Review of the March 2020 GGPL Subsidence Report for the Ensham Life of Mine Extension Project. Report No. 2105/01.1

[11] Hydro Engineering and Consulting. (2020). Ensham Life of Mine Extension Project Appendix E3: Hydrology and Flooding Assessment.

The maximum allowable mining heights to satisfy a FoS of 1.6 for both the 24 m x 28 m (centres) pillars in the main part of the panels, as well as the 24 m x 24 m (centres) sub panel pillars, are summarised in **Figure 26** for a range of depths. Where the Nogoa River flows through Zone 2, no mining under the river is proposed (**Figure 1**). For the 200 m section of 115 Panel that is located under the Anabranch (**Figure 3**), the mining height will need to be reduced to satisfy the required 2.11 FoS.

It is highlighted that these calculations have used an overburden density of 2.45 tonnes/m^3 based on the geophysical density logs from a large data set of exploration boreholes across the Ensham underground mining area (**Figure 9**). The pillar load calculations in **Figure 26** have also used a more accurate 9.806 ms^{-2} value for acceleration due to gravity rather than the rounded up value of 10 ms^{-2} that appears to have been used by Hebblewhite (2021) This addresses the recommendation to recalculate and apply minor adjustments to **Figure 26**.

Hebblewhite (2021) raised the issue of the requirement for a simple but reliable and effective means of managing mining heights and bell-out geometries. In the current underground workings, the thickness of floor coal is controlled during the mining process by spray painting the rib side to ensure the mined thickness does not exceed the amount specified on the sequence plan and Permit to Mine document (**Figure 25**).

Figure 25. Paint Marks to Control the Thickness of Floor Coal Mined.

Furthermore, as detailed in the Ensham SMP (2021), underground surveying of the completed mined roadways, bell outs and pillars is carried out. The FoS and width: height ratio of the as-mined pillars can be calculated and checked against the design values. These checks are carried out by the Geotechnical Engineer and reported in the monthly geotechnical inspection report. Experience to date has shown that there have been no exceedances of the planned mining heights in the secondary extraction panels at Ensham.

The temporary maximum effective depth of cover increase of 2.09 m over the flood plain, as detailed in Section 4.1.1.1, is not considered significant. For example, at 130 m depth of cover and 4.5 m extraction height, the FoS temporarily reduces during a

0.1% AEP (Q1000) flood event from 1.91 to 1.88 and as such no additional mitigation would be required.

Under the Nogoa River anabranch, a 16 m flood depth at 140 m depth of cover and 3.5 m extraction height, temporarily reduces the FoS from 2.21 to 2.11. In this area, the pillar size could either be increased to allow an increase in mining height or the 3.5 m mining height could be maintained for the proposed 24 m x 28 m pillar size.

As raised by Hebblewhite (2021), the temporary minor increase in depth during flood events should also be applied when referencing the pillar design chart for standard and bell out pillars (**Figure 26 and Figure 29**).

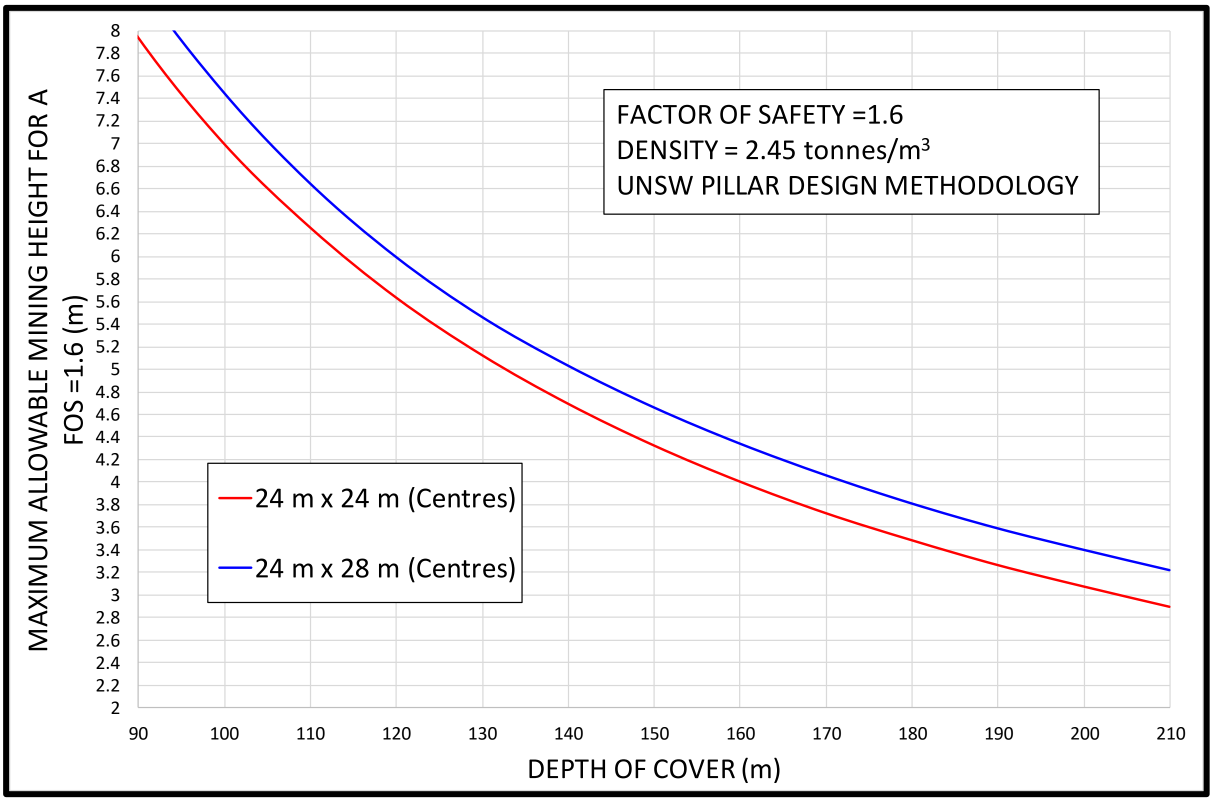


Figure 26. Standard Pillars - Maximum Mining Height for a FoS of 1.6

4.1.1.3 Bell Out Pillars

The FoS of the bell out pillars also needs to be considered. As shown in **Figure 24**, a 70% load assumption is appropriate for these pillars located on the perimeter of the panels.

It is highlighted that the secondary coal recovery methodology forms a regular pillar between the bell outs, which allows the application of standard pillar design formulae (**Figure 5** and **Figure 27**). The analysis of these pillars has conservatively assumed a 10 m wide roadway equivalent to the mined bell out (**Figure 27**).

Based on the standard bell out mining sequence, the effective width of the bell out pillar with a solid length dimension between bell out stubs of 17.5 m, is 15 m (**Figure 28**). This has been calculated using the hydraulic radius approach of Wagner (1980)[12], where the effective width (w_e) is given by:

$$w_e = 4A/P$$

where: A is the pillar solid area and
P is the pillar perimeter distance.

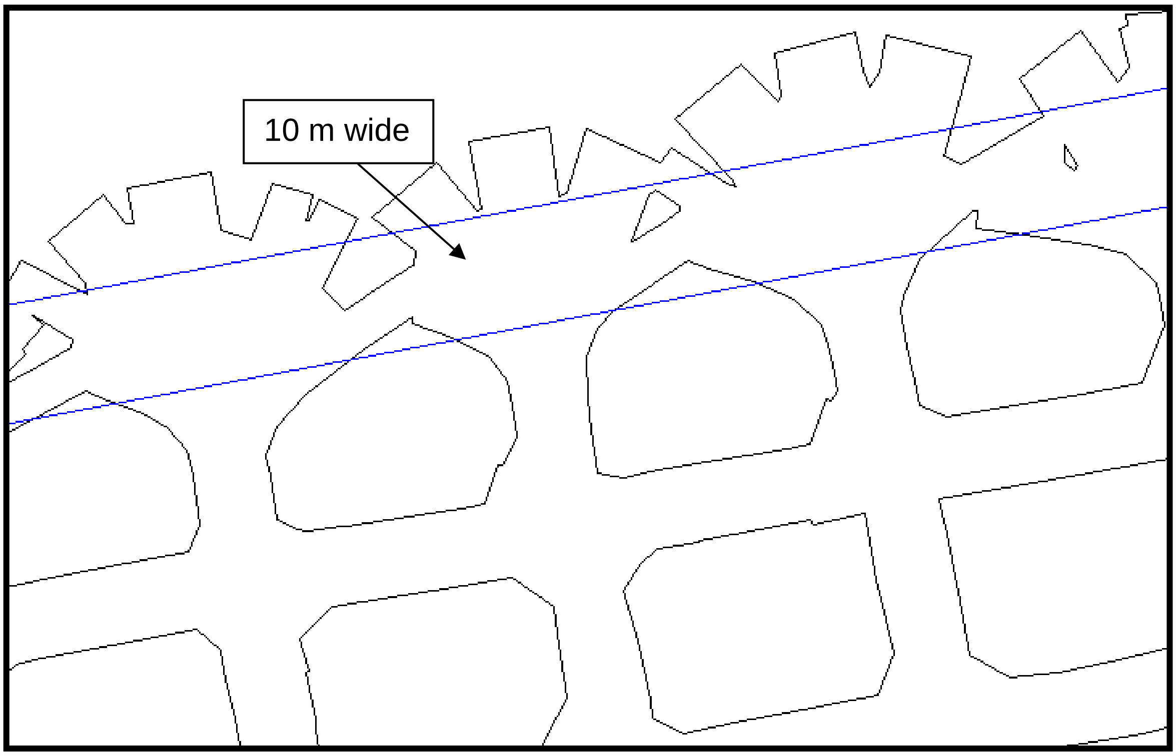


Figure 27. Comparison of Bell Out and Standard Pillars

For the bell out pillars, with an effective width of 15 m (solid) and a 70% loading assumption, the maximum allowable mining heights to satisfy the 1.6 FoS requirement are shown in **Figure 29**.

[12] Wagner, H. (1980). Pillar Design in Coal Mines. Journal of the SAIMM, pp. 37-45.

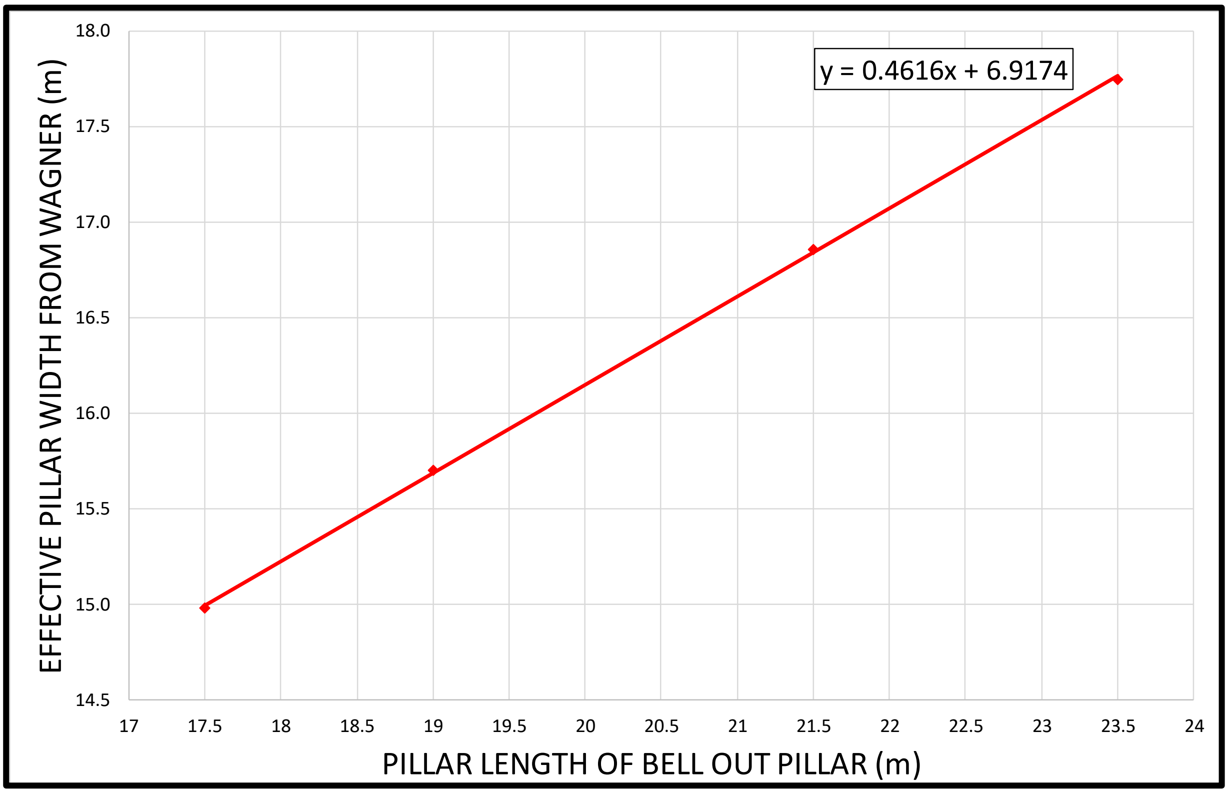


Figure 28. Calculation of the Effective Width of the Bell Out Pillars

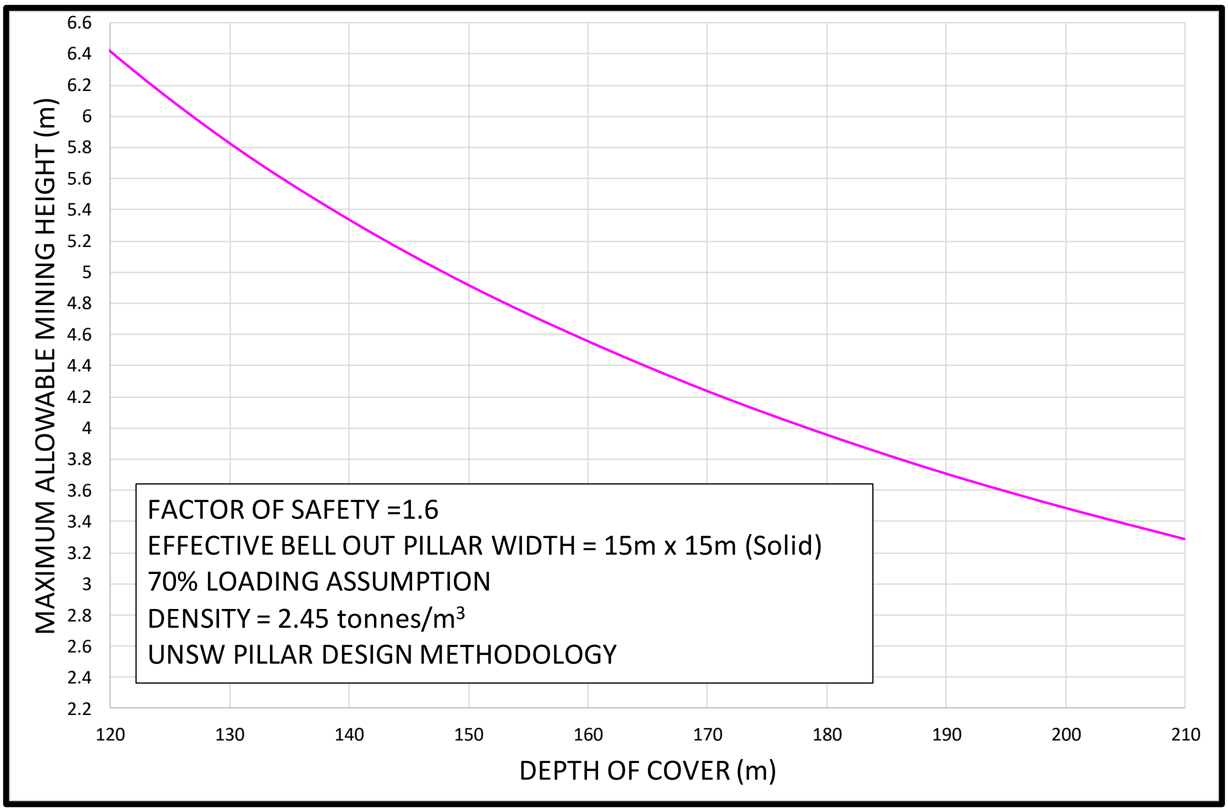


Figure 29. Bell Out Pillars - Maximum Mining Heights for a FoS of 1.6

It should be highlighted that the rib canchs left after floor coaling have conservatively not been included in the FoS calculations (**Figure 30**).

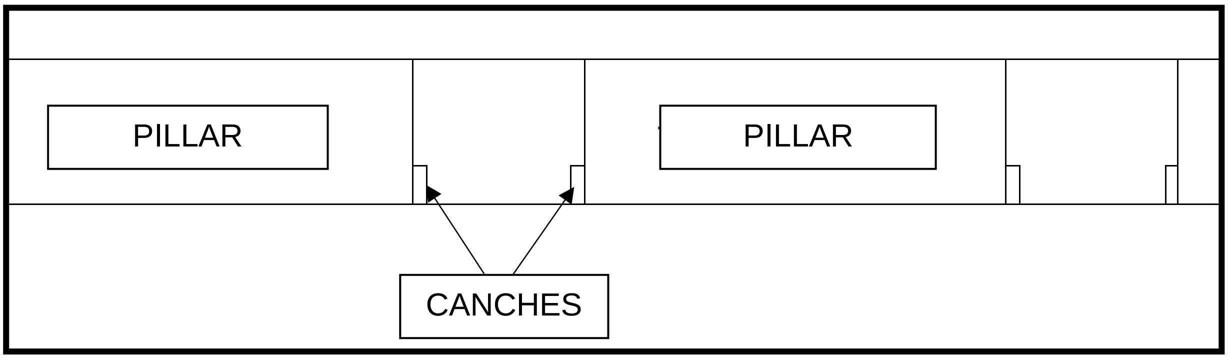


Figure 30. Scaled Diagram of the Rib Canches Left Around Pillars

4.1.1.4 Barrier Pillars

The barrier pillars between panels have a high FoS. For a conservative 5 m mining height, 10 m wide bell outs and a minimum 50 m barrier length, the FoS of the 35 m wide barriers at a typical 130 m depth of cover in Zones 2 and 3 is 3.30. This increases to 3.82 for the 40 m wide barrier pillars.

Similarly, the 25 m solid barriers between the sub-panels have minimum FoS values of 2.40 at 130 m depth of cover. This exceeds the minimum 2.11 FoS recommended by Hebblewhite (2021) for barriers in the Ensham area.

4.1.2 Width to Height Ratio

As well as the FoS, the width to height ratio of the pillars also has to be considered in the long-term stability of the pillars. This ratio has a significant controlling influence on the post-failure behaviour of the pillar, ranging from a complete structural collapse (termed strain softening), to a more controlled squeeze with the pillar becoming stronger as it is compressed further (termed strain hardening).

Reed et al (2016) suggest that the use of laboratory-based testing data may be flawed due to the very smooth top and bottom contacts in the test rig. This is particularly important as the transition to squat pillars is about the development of frictional based confinement within the core of the pillar. As such, published laboratory data shows substantial strain softening at width: height ratios as high as 9 (Das, 1986[13]).

[13] Das, M.N. (1986). Influence of Width/Height Ratio on Post Failure Behaviour of Coal. Int. J. Mining. Geological Engineering. No.4.

Reed et al (2016) refer to the available in situ testing data for coal pillars that indicates that the post-failure modulus should transition from negative (strain-softening) to positive (work-hardening) at a width/height ratio of around 4 (**Figure 31**).

Galvin (2016) also indicated that if the width to height ratio is greater than 4, any pillar failure will be controlled and may be arrested through the application of confinement to the pillar sides.

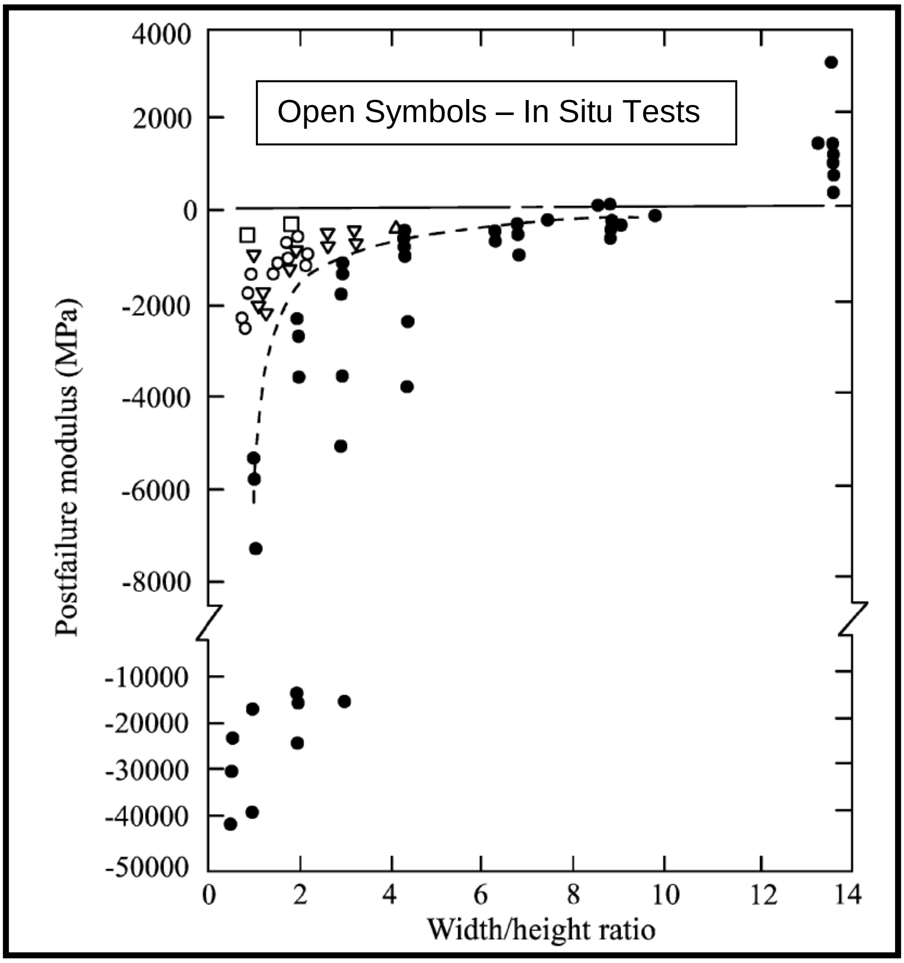


Figure 31. Post-failure Stiffness of Coal Pillars as a Function of Width to Height

4.1.3 Criteria for Pillar Design

Hill (2005[14]) presented an empirical database of Australian and South African failed pillars, in terms of both width to height ratio and FoS (**Figure 32**). This database is also consistent with the analysis of Reed et al (2016), with the majority of pillar failures occurring with width: height ratios less than 4 (**Figure 32**).

[14] Hill, D (2005). Coal Pillar Design Criteria for Surface Protection. COAL2005 – Moving Technology – Maintaining Competence. 6th Australasian Coal Operators Conference. Brisbane, pp31-37.

For the development pillars in the current underground workings at Ensham, the width to height ratios are typically 5 or greater. Using the limiting FoS of 1.6, it is not until the width to height ratio is less than 3.5 that the design criteria in **Figure 32** become relevant.

It should be highlighted that there has been technical debate over the validity of the pillar in the database with a width to height ratio of 8.16 (**Figure 32**). The implications of including this data point are that the UNSW pillar strength formulae may conservatively underestimate the pillar strength and overestimate the probability of failure.

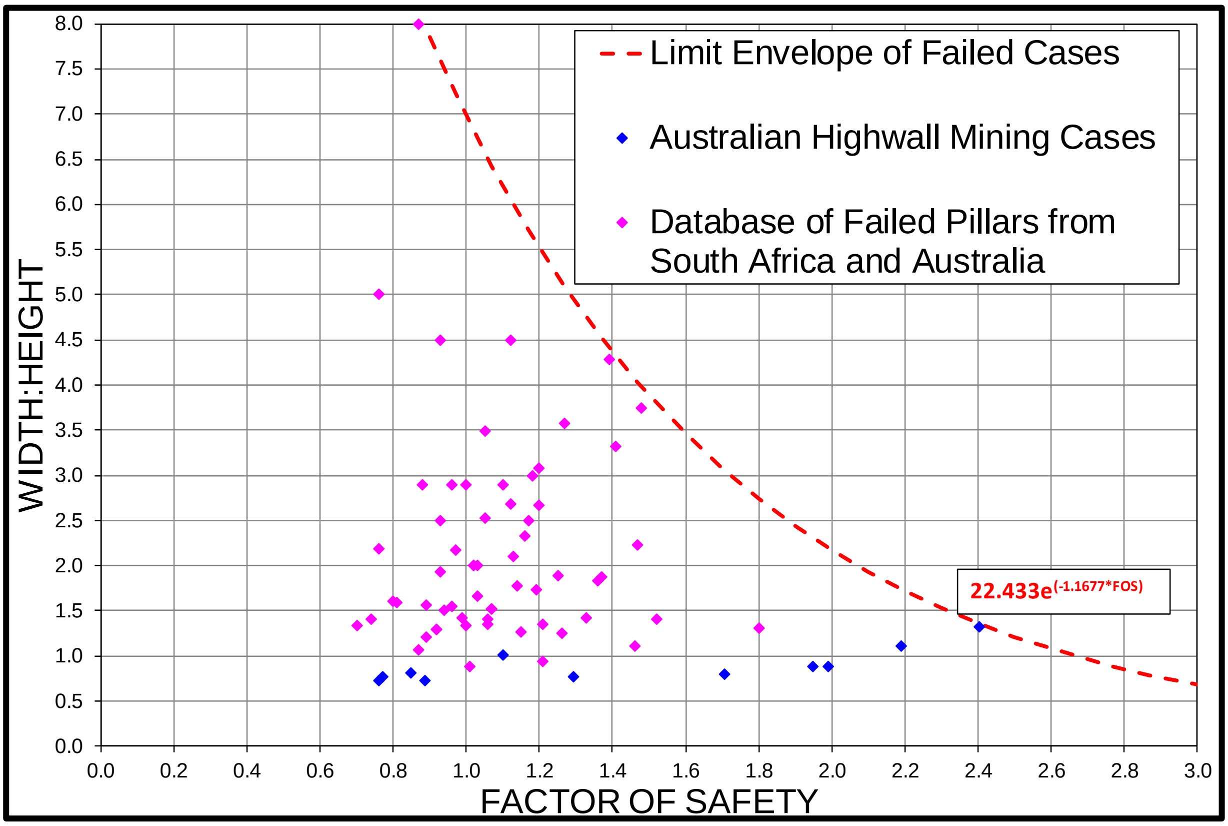


Figure 32. Design Criteria for Bord and Pillar Workings

There is value to step away from the empirical design criteria presented by Hill and consider what may be driving the upper bound for the width to height ratio. Considering the kinematic stability of a pillar that is cut diagonally from the roof on one side to the floor on the other is shown in **Figure 33**.

The top wedge may be pushed sideways depending on the shear strength developed along the roof line and on the diagonal surface. If frictional restraint only is assumed then using a conservative friction angle of 20^o for unstructured coal indicates a width to height ratio of 2.75 is required to prevent shear of the coal pillar. This is consistent with the empirical database in **Figure 32**, where the majority of failed cases have width to height ratios of less than 2.75.

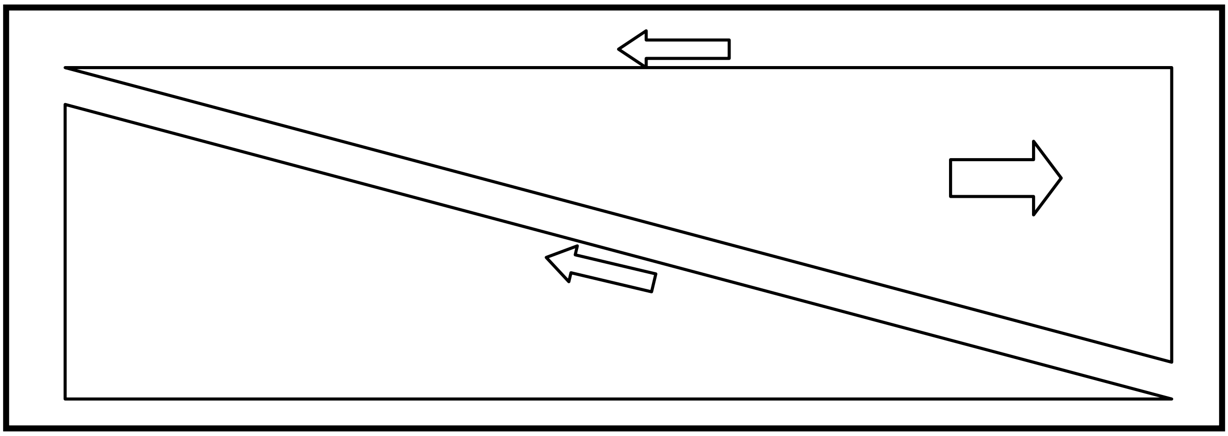


Figure 33. Kinematic Failure of Wedges

For structured coal, a lower friction angle of 15^o would be more representative, requiring a greater width to height ratio of 3.7 to prevent failure. This aspect is illustrated by Hill (2005) in **Figure 34**, where geological structure may weaken the pillar, hence reducing the FoS.

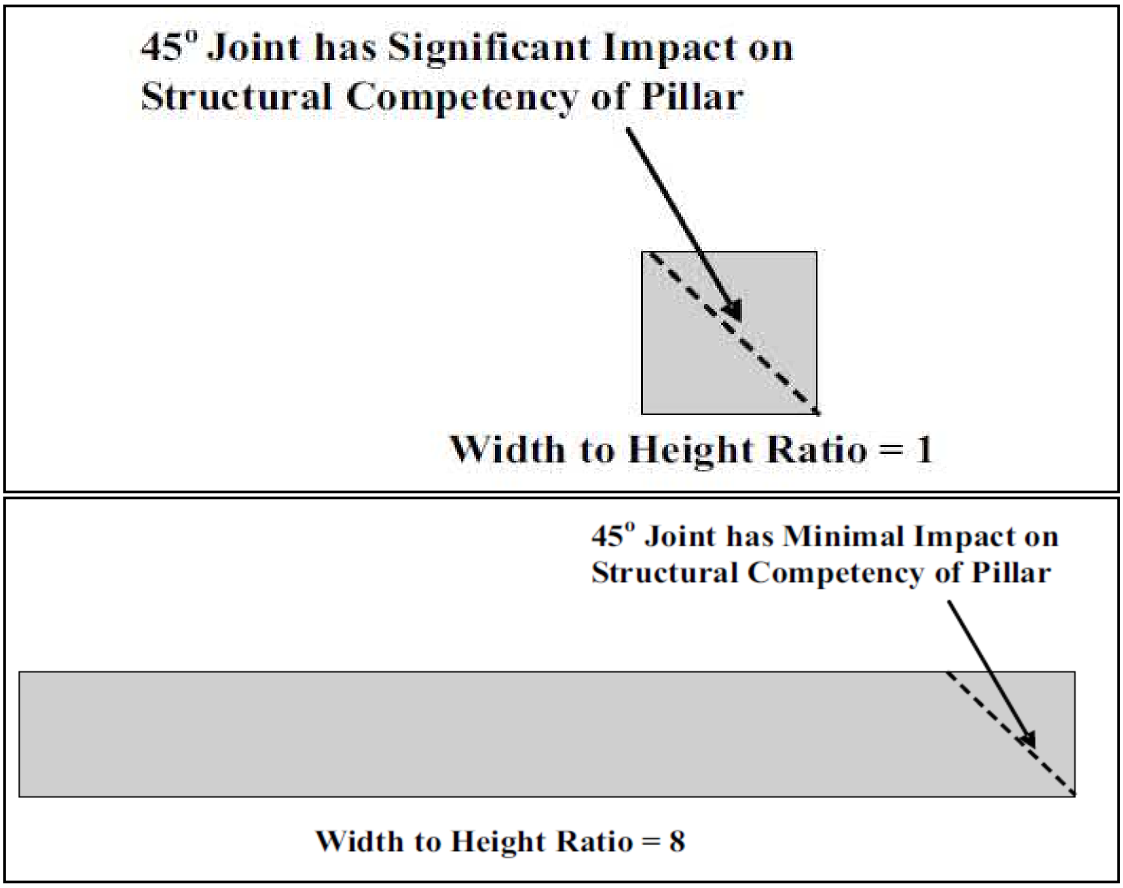


Figure 34. Impact of Geological Structure

Hebblewhite (2021) also requested further clarity with respect to known geological structures across the Project area and how these have been taken into account of within the design. Due to the poorer ground conditions associated with geological structures, these are avoided where practical and are not considered to have an impact on both pillar stability and overburden integrity, with respect to both subsidence and hydrogeological impacts. In the majority of the workings, development and secondary extraction is carried out in geologically unstructured areas.

4.1.4 Long Term Stability of the Overburden

Mine Advice (2018[15]) demonstrated for the Hume Project in NSW, that for the overburden to become critically unstable and so drive the coal pillars to a collapsed state or high levels of yield, a critical level of overburden settlement is first needed to be exceeded.

If the critical level of settlement is not exceeded, then the stability of the workings is strongly controlled by the stability of the overburden. If however the critical level is exceeded, then the stability of the workings is almost entirely reliant upon the coal pillars.

The idea of evaluating global mine stability via displacement criteria in addition to pillar loading criteria, was raised by Emeritus Professor Ted Brown during the experts review meeting of the Hume Project (Mine Advice, 2018).

With reference to the Hume Project, the predicted surface settlements were in the order of 20 mm. Published data indicates that surface settlements of at least 150 mm are required before the overburden starts to lose its stability.

Based on this discussion, Mine Advice (2018) defined the term system stability according to an overburden displacement FoS, to complement that of the pillar system. In the case of the Hume Project, the system stability FoS was found to be in the order of 7 (150/20).

This displacement based FoS for the overburden provides a measure to the level of conservatism involved in making the full tributary area assumption detailed in Section 4.1.1. This discussion adds further stability arguments to pillar FoS and width: height criteria for long term stability in the Project area.

4.1.5 Comparison to Other Mines

As shown in **Figure 35**, the pillar dimensions in the underground workings at Ensham after secondary coal recovery, plot to the right of the red design curve of Hill (2005) and the width: height ratio is typically between 3 and 4 (**Figure 35**).

[15] Mine Advice Pty Ltd (2018). Interpretation of the Numerical Modelling Study of the Proposed Hume Project EIS Mine Layout. Report No. HUME22/1.

The lower width to height ratio pillars shown on **Figure 35**, were mined in the shallowest part of the Ensham underground workings with centre dimensions of 20 m x 20 m. These are smaller than the pillars planned in the Project area. With reference to **Figure 35**, the majority of the failed pillars have width to height ratios less than 3.

In the Project area, the FoS and width to height ratios of the pillars after secondary coal recovery, are also well above any of the failed cases from South Africa and Australia presented by Hill (**Figure 35**).

Furthermore, with reference to **Figure 35**, there are no cases of failed pillars with the design factors of safety and width to height ratios exhibited by the mine layout in the Project area.

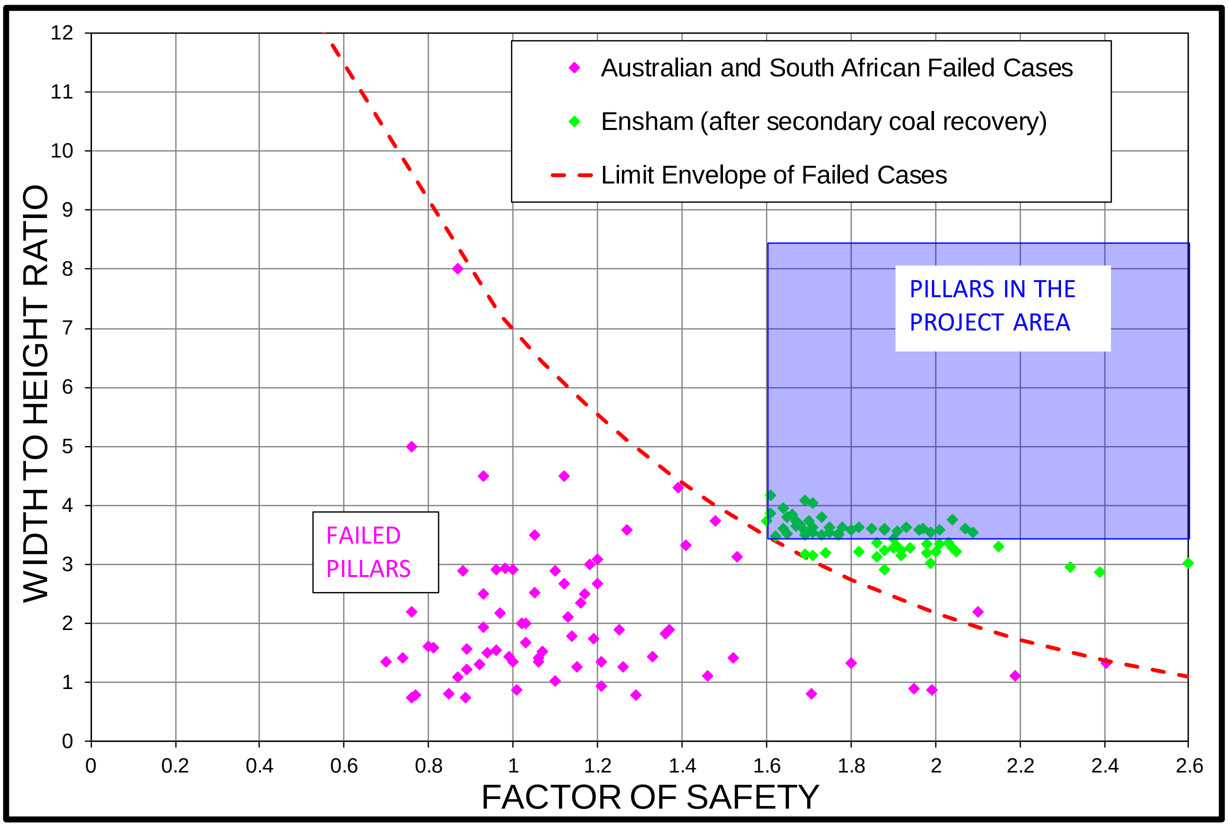


Figure 35. Summary of Pillar Design at Ensham

It is also highlighted that none of the failed cases with FoS greater than 1.6 have occurred more than five years after mining based on the data of Hill (2005) shown in **Figure 36**. It is now more than eight years since the completion of secondary coal recovery in SE2, the first extraction panel at Ensham.

These FoS and W:H design criteria have also been peer reviewed by three industry recognised (RPEQ) geotechnical consultants namely Mine Advice[16], Byrnes Geotechnical[17] and Professor Bruce Hebblewhite, who all concluded that the proposed bord and pillar layout is an appropriate and well developed geotechnical design.

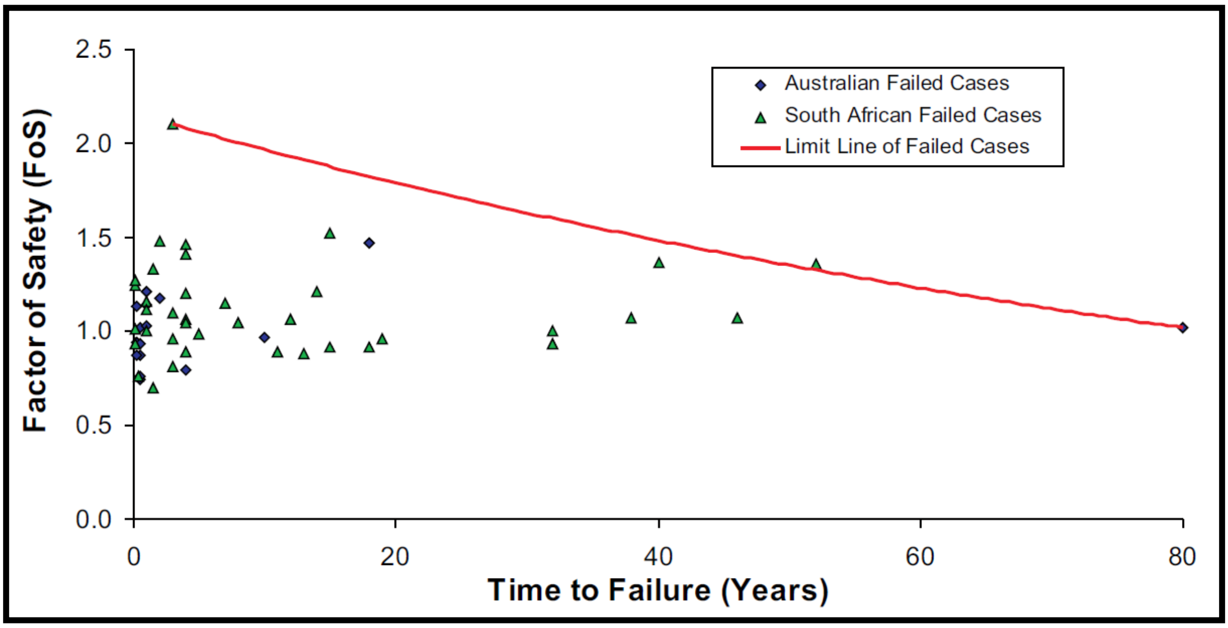


Figure 36. Factor of Safety versus Time to Failure

4.1.6 Pillar Spalling

It is noted that Canbulat (2010[18]) has published data from South African collapsed cases using the original Salamon and Munro pillar strength formula. The data has a number of pillars with FoS greater than 1.6 that have failed due to time dependent spalling or scaling of the pillars.

Frith and Reed (2019[19]) have provided an explanation for this apparent conundrum of these high FoS collapsed cases. Additional failed cases from South Africa with high FoS are also included in **Figure 37**. It is noted that the majority of failed cases occur at depths less than 100 m. The majority of the proposed workings in the Project area are at depths greater than 100 m.

[16] Mine Advice Pty Ltd (2020). Peer Review Outcomes – GGPL Subsidence Report.

[17] Byrnes Geotechnical (2020). Peer Review of Ensham Life of Mine Extension Project Subsidence Report. Report No. Ensh-01.

[18] Canbulat I. (2010). Life of Coal Pillars and Design Considerations. In: Proceedings of the 2nd Australasian Ground Control in Mining Conference. Victoria (Australia): AusIMM; 2010. p. 57–66.

[19] Frith, R. and Reed, G. (2019). Limitations and Potential Design Risks When Applying Empirically Derived Coal Pillar Strength Equations to Real-Life Mine Stability Problems. International Journal of Mining Science and Technology 29 (2019) 17–25.

These additional cases were published by Salamon et al (1998[20]) who put forward the idea of swelling clays driving pillar scaling as a possible explanation to explain the collapsed cases. The authors however did clarify that "no direct evidence appears to exist to substantiate the proposed model of pillar scaling". The same model was used by Canbulat (2010) in his analysis of the time to failure of high FoS pillars.

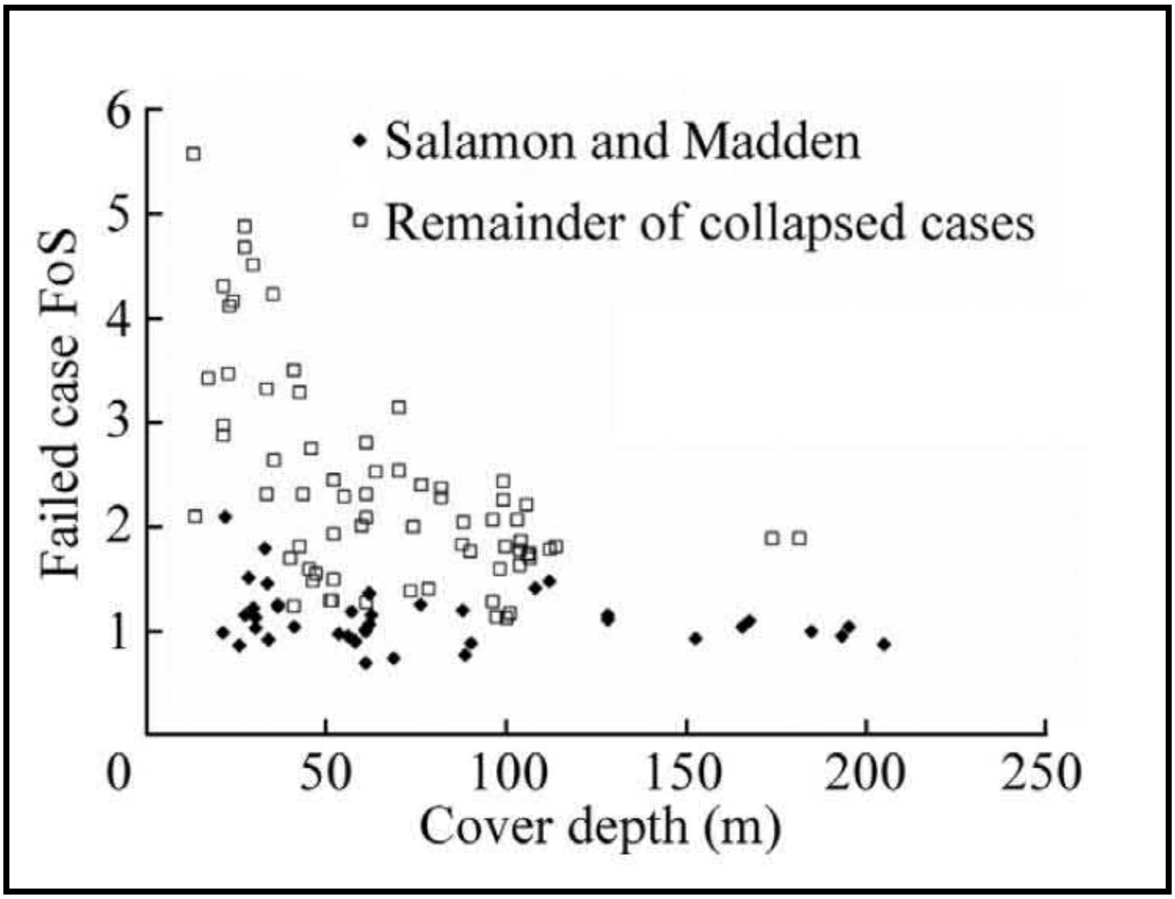


Figure 37. Factor of Safety vs Depth of Cover

Frith and Reed (2019) suggest that the high FoS values in **Figure 37** may be erroneous due to the pillar strength equation used, substantially overestimating the actual coal pillar strength. They concluded that the scaling is due to under designed pillars rather than the presence of swelling clays.

In comparison, the author of this subsidence assessment report for the Project area inspected the abandoned workings of 106 Panel in July 2019, where secondary coal recovery had been completed. It was noted that the ground conditions had not deteriorated significantly since the panel was mined in 2017 (GGPL, 2019[21]). Where

[20] Salamon, M.D.G, Ozba, M.U and Madden, B. J. (1998). Life and Design of Bord and Pillar Workings Affected by Pillar Spalling. J. S. Afr. Min. Metall. 1998;98(3):135–45.

[21] GGPL (2019). Inspection of the Underground Workings on 22-23rd July 2019. Report No. Ensham19-R8.

rib spall occurs at Ensham, it is typified by thin 100-200 mm slabs and large-scale pillar spalling as documented by Canbulat (2010) is not present (**Figure 38**).

It should also be highlighted that there are no swelling clay bands, such as those referenced by Canbulat (2010), present within the Aries and Castor Seams in the Ensham underground mining area neither existing, nor proposed.

Figure 38. Typical Thin Rib Spall at Ensham after Secondary Coal Recovery – F23-24, 109A Panel

Van der Merwe (2016[22]) also presented a formula to calculate the long-term life expectancy of pillars, as follows:

$$T = [d_c/(m*h^x)]^{(1/(1-x))}$$

Where: T = Time to failure (years)
h = Mining height (m)
m = 0.1799
x = 0.7549

and d_c is the critical scaling distance, which for an ultimate safety factor of 0.5 is given by:

[22] Van der Merwe, J.N. (2016). Review of Coal Pillar Lifespan Prediction for the Witbank and Highveld Coal Seams. The Journal of the Southern African Institute of Mining and Metallurgy. Pp. 1083-1090, Volume 116.

$$d_c = w - [0.002285*H*h*C^2]^{0.3571}$$

Where: H = Depth of cover (m)
C = Pillar centre distance (m)
w = Pillar width (m)
h = Mining height (m)

Using this approach, the proposed 24 m x 28 m (centres) pillars in Zones 2 and 3 at 4.5 m high and 130 m depth of cover, are stable in excess of 26,000 years. It should be highlighted that the database used by Van der Merwe (2016) was sourced from South African mines with a maximum solid pillar width of 10.5 m and maximum depth of cover of 102 m and hence some extrapolation of the technique is required.

It is also noted that the Van der Merwe data shows that absolute scaling is independent of the age of the pillar, leading to the conclusion that the scaling rate must reduce with time. It is therefore assessed that pillar scaling or spalling will not lead to pillar collapse with the pillar sizes proposed for Zones 2 and 3.

4.1.7 Potential For Sinkhole Subsidence

In addition to overall pillar stability, the risk of roadway (intersection) collapse such that sinkholes develop at the surface should be considered in the Ensham underground area. Significantly, it is reported in the technical literature that sinkholes are restricted to shallow mining areas and generally only reach the surface at depths **less than 50 m**[23,24,25].

As shown in **Figure 12**, the depth of cover in Zones 2 and 3 area is **greater than 75 m**. This shallower area in the southern part of Zone 3 is also located outside the flood plain (**Figure 1**).

Furthermore, underground mining has already been carried out in the currently approved Ensham bord and pillar workings at depths of 40 m, with no evidence of sinkhole subsidence occurring above the excavated roadways.

These observations are confirmed by the following discussion on the mechanism of sinkhole subsidence and supplemented with design calculations for a potential failure

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23 Mahar, J.W. and Marino, G.G., (1982). Building response and mitigation measures for building damage in Illinois. Proceedings of Workshop on Surface Subsidence due to Underground Mining, Morgantown, West Virginia University, pp. 238-252.

24 Whittaker, B.N. and Reddish, D.J., (1989). Subsidence: Occurrence, prediction and control, Elsevier, Amsterdam, 528p.

25 Nielen Van Der Merwe, J and Madden, B.V.J. (2002) Rock Engineering for Underground Coal Mining. South African Institute of Mining and Metallurgy. Special Publications Serries 7.

to occur. These design calculations were also peer reviewed by geotechnical consultants Mine Advice in 2016[26].

4.1.7.1 Mechanism of Sinkhole Development

Whittaker and Reddish (1989) devote an entire chapter to sinkhole subsidence above bord and pillar mines. They present various analyses examining the development and propagation of sinkholes and also review the published literature, supplemented with some case examples.

Whittaker and Reddish concluded that the local geology and the natural strength of the immediate roof are important factors in assessing the potential for sinkhole development. The mining dimensions and geometry of workings are also of equal importance and should be considered in making an assessment of subsidence risks above bord and pillar mines.

Mine Advice (2016) provided further analysis of this aspect and one of the key issues in regards to sinkhole development through fresh rock material is the extent by which the upwards progression of a roof cavity is truncated by either lithology or natural arching (**Figure 39**). **Figure 39** shows that sinkholes develop with vertical sides rather than any form of natural arching, which will cause the effective span to decrease higher into the cavity.

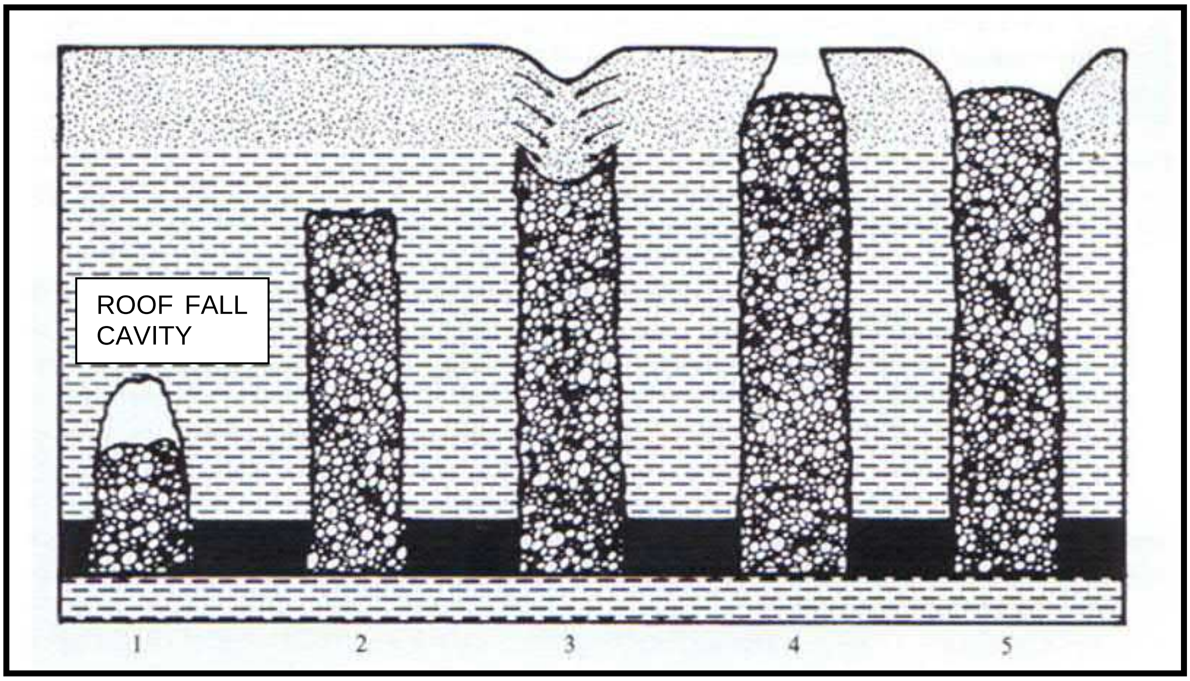

Figure 39. Illustration of Suggested Sinkhole Development Mechanism (Whittaker and Reddish, 1989).

[26] Mine Advice Pty Ltd (2016). Peer Review of Gordon Geotechniques (GGPL) Report to Ensham Coal – Geotechnical Review of the Ensham Mine Plan in Areas 1 and 2 (Dated March 2015).

As discussed by Mine Advice, this failure mechanism is commonly observed in underground coal mines and along with roof lithology acts to restrict the height of roadway roof fall cavities to typically only a few metres rather than propagating higher as shown in **Figure 39**. This is consistent with observations in the current Ensham underground workings.

4.1.7.2 Analysis of Sinkhole Subsidence

The risk of sinkhole subsidence of shallow workings to the surface has been assessed using a limiting equilibrium analysis as detailed below. The analysis is presented in Brady and Brown (2006[27]) as follows:

For **dry** conditions:

$$F_1 = \frac{2c'(a + b\cos\alpha)}{\upsilon ab\cos\alpha} + \frac{k\tan\phi'}{(2h - b\sin\alpha)} * \left\{\frac{h^2 + (h - b\sin\alpha)^2}{b\cos\alpha} + \frac{2}{a}\left[h(h - b\sin\alpha) + \frac{b^2\sin^2\alpha}{3}\right]\right\}$$

For **saturated** conditions:

$$F = F_1 - \frac{2\upsilon_w\tan\phi'}{3\upsilon(2h - b\sin\alpha)} * \left\{\frac{h^2 + (h - b\sin\alpha)^2 - 2d(2h - b\sin\alpha - d)}{b\cos\alpha} + \frac{2}{3a}\left[3h(h - b\sin\alpha) + b^2\sin^2\alpha - 3d(2h - b\sin\alpha - d)\right]\right\}$$

where:

	F, F_1	= factor of safety
	c'	= cohesion in kPa
	ϕ'	= friction angle in degrees
	a	= intersection width 1 (metres)
	b	= intersection width 2 (metres)
	k	= average of the horizontal to vertical stresses
	α	= seam dip in degrees
	υ	= rock density in kN/m^3
	υ_w	= water density in kN/m^3
	d	= water table depth (metres)
	h	= thickness of fresh rock (metres)

For the Ensham mining area, cohesion (c') and friction angle (ϕ') values of 0 kPa and 30^o have been used respectively, assuming the failure mode is along joints, with some surface roughness. The roadway width is 6.5 m and the seam dip 3^o.

[27] Brady, B.H.G. and Brown, E.T. (2006) Rock Mechanics in Underground Mining. 3rd Edition.

The stress ratio value (k) has been reduced to 1.2 for the shallow depth of cover in the Project area. This value is also consistent with the in-situ stress measurements presented in Brady and Brown (2006).

The analysis has been carried out for both dry and saturated conditions. To maintain a Factor of Safety of greater than 2 in saturated conditions, **at least 12 m** of fresh rock is required for 6.5 m wide roadways (**Figure 40**).

Ensham technical personnel applied a conservative minimum 20 m of fresh rock for the extraction of bord and pillar panels in the southern part of the mining area. In this area, the total depth of cover including weathered rock, was 40 m.

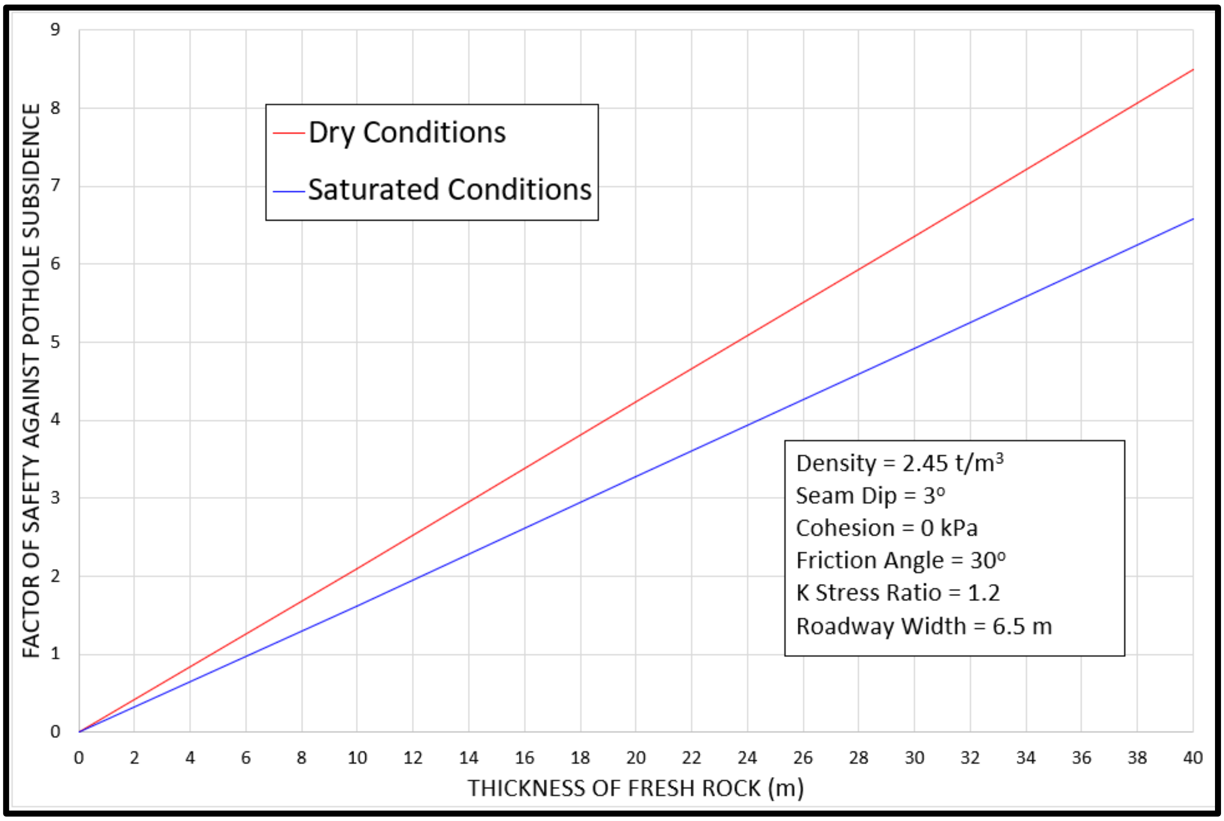

Figure 40. Limiting Equilibrium Analysis for Sinkhole Subsidence above 6.5 m Wide Roadways.

Larger intersections and bell out excavations also need to be considered. For a large intersection, with an average diagonal span of 14 m, the side dimensions would be 9.9 m. In this case, the required thickness of fresh rock would approach 20 m in saturated conditions, applying a Factor of Safety of 2 (**Figure 41**). For a 15 m wide bell out, this approaches 30 m of fresh rock (**Figure 41**).

These calculations endorse the conservative design criteria of a minimum 40 m depth of cover and a Factor of Safety of 2 applied to the shallow Ensham underground workings.

Based on mining experience at shallow depths of cover in the current Ensham underground workings, as well as experience at other mining operations around the world, the risk of sinkhole subsidence occurring in the Zone 2 and Zone 3 underground area, where the depth of cover is greater than 75 m, is considered to be negligible.

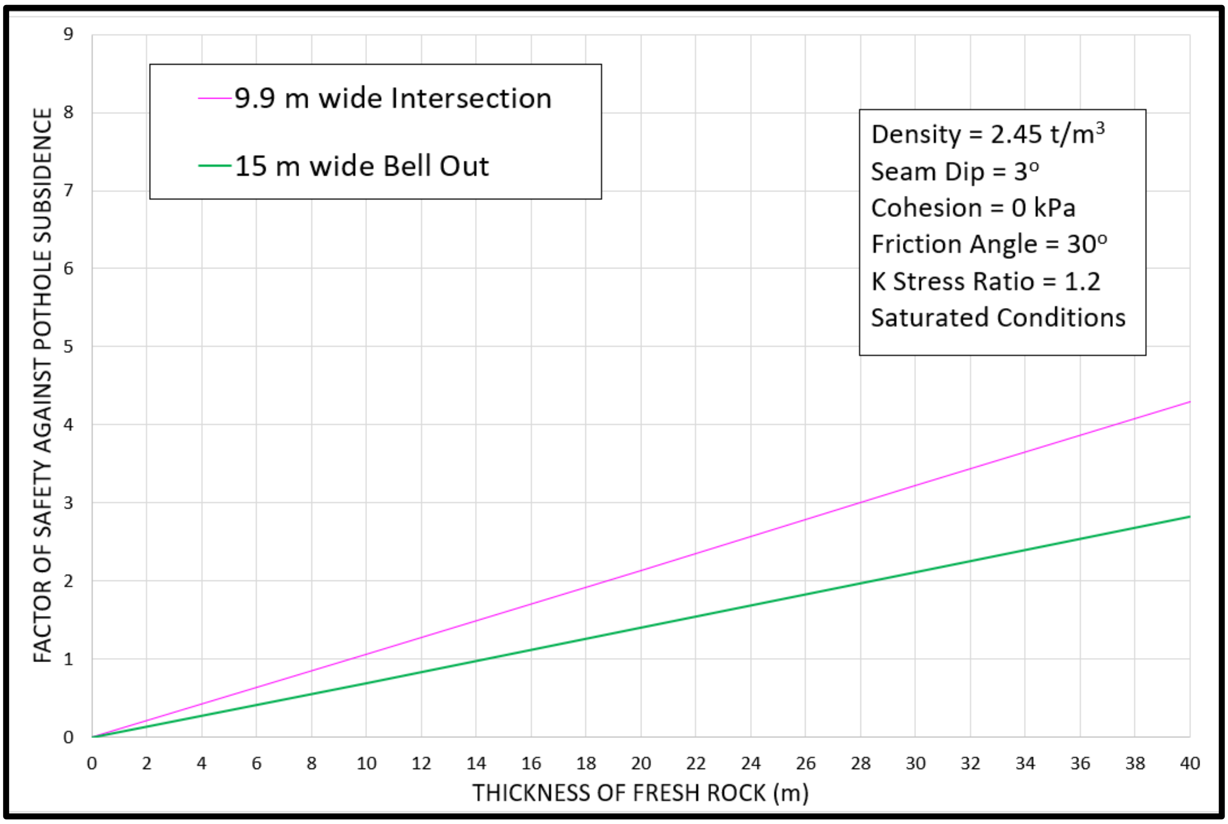

Figure 41. Limiting Equilibrium Analysis for Sinkhole Subsidence above Intersections and Bell Outs.

4.2 Subsidence Behaviour

Unlike longwall mining, where the subsidence comprises two main components namely sag subsidence and strata compression, in the Project area, the subsidence will be due to strata compression alone. This results in low levels of surface lowering and minimal associated surface effects due to the associated low tilts, curvatures and strains.

Before a compression analysis of the roof, floor and coal in the Project area can be carried out, the potential for bearing capacity failure of weak floor strata below the coal pillars needs to be assessed. A commentary is also included on the effect of flooding the workings after mining is completed.

4.2.1 Bearing Capacity Failure of the Floor Beneath the Pillars

Several years ago, in the Newcastle coalfield in NSW, the stone floor beneath the pillars failed in a panel designed with FoS greater than 2.11. In this area, very soft layers (less than 1 MPa) were present in the immediate stone floor below the seam. The overburden consisted of thick conglomerate, which was able to span over more than 50 m.

The potential for bearing capacity failure of the floor beneath the pillars in the Project area has therefore been analysed using the following formula:

Bearing Capacity of the Floor (MPa) = UCS/2*(4.14159+0.5*W/T)

Where: W = Pillar Width (m)
T = Thickness of Weak Floor (m)
UCS = Floor Strength (Mpa)

The factor of safety for floor failure is equal to the bearing capacity of the floor divided by the stress on the pillar.

For the proposed pillar sizes in the deeper part of the Project area, a bearing capacity failure beneath these pillars after secondary coal recovery could only occur if there were layers of floor rock with a low strength of 1.8 MPa and a thickness of 2 m (**Figure 42**). For a 10 m floor layer, the strength required for failure marginally increases to 2.9 MPa.

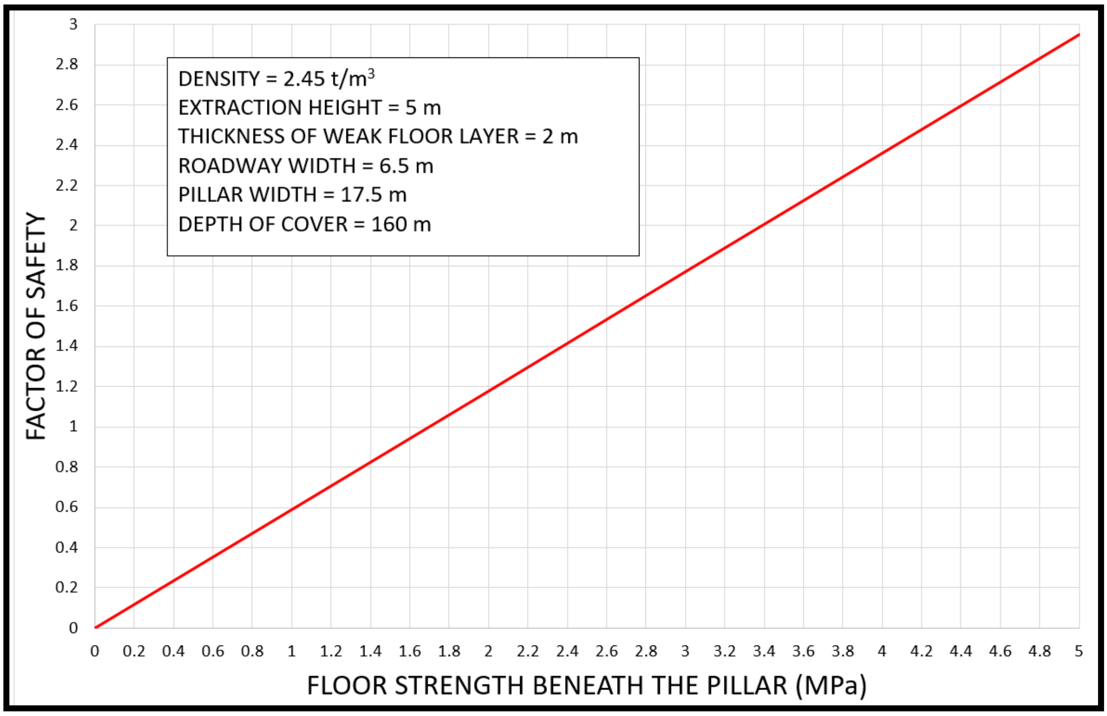

Figure 42. Bearing Capacity Analysis

Review of the geophysical sonic velocity logs in the Project area identified that the weakest floor strata layers are less than 0.5 m thick and have a floor strength of 10 MPa. This demonstrates that a bearing capacity failure of the floor beneath the pillars is unlikely with a high FoS.

This analysis is consistent with the lack of any noticeable heave in the Ensham underground workings. Very minor floor cracking (less than 100 mm) has only been observed in localised areas after secondary coal recovery (**Figure 43**). This cracking is typically restricted to the higher quality, friable C22 ply that may have been left in the floor after secondary coal recovery has been completed. Heave and cracking of the stone floor has not been observed.

Figure 43. Minor Cracking of the Coal Floor, 101 Panel

4.2.2 Flooding Workings

In the longer term, the flooding of old panels in the Project area needs to be considered. Galvin (2008[28]) discusses this aspect in more detail and suggested that flooding of mine workings could influence the pillar load in two ways.

1. The water pressure acting on the roof of the workings would function as a hydraulic jack to unload the pillars or
2. The overburden may be fully saturated over the full water head, effectively reducing the density, resulting in lower loads on the pillars.

Both these mechanisms have a <u>positive</u> impact on the long-term stability of old workings.

The other aspect that needs to be considered is the effect of water on the strength of the pillar system. Galvin (2008) details that water can reduce friction on fracture planes

[28] Galvin, J. (2008). Geotechnical Engineering in Underground Coal Mining – Basic Principles of Pillar Behaviour and Design. ACARP Report.

and roof/floor interfaces. The water can also accelerate the degradation of clay rich minerals in the roof, floor and coal seam.

The buoyancy effect of water will reduce the vertical load on the pillars by up to 40% and hence increase the factor of safety. This effect is calculated using the formula:

Effective Stress on Pillar = Total stress on Pillar – Pore Pressure due to Flooding

The effective stress on the pillar is therefore 1.5 (2.5-1) or 60% (1.5/2.5) of the total stress. The extent of the increase in stability will depend on any strength loss in the coal and the surrounding strata, which may be up to 10-15%.

It should be highlighted that the coal seam and immediate roof and floor strata in the Project area do not contain puggy or water sensitive material that could degrade over time. Furthermore, failure of the floor due to transient strength reduction effects is unlikely as the groundwater recovers.

A conservative 25% reduction in load would significantly increase the FoS of 24 m x 28 m (centre) pillars at 5 m high and 130 m depth of cover, from 1.76 to 2.31.

There is a case of a pillar collapse in a flooded bord and pillar iron ore mine in France. Conversely, many of the mines in the Newcastle Coalfield of NSW have been flooded for years without adverse effect on stability.

Galvin cautions that careful consideration needs to be given to the possible adverse effects on stability by dewatering the workings, as there is a history of pillar collapses soon after being dewatered.

4.2.3 Strata Compression

The induced surface deformation due to strata compression has been estimated analytically by calculating the combined pillar, roof and floor compression using modulus values. This is discussed in the following sections.

4.2.3.1 Coal Strength Modulus

An in-situ modulus value of 2500 MPa has been used for the Aries-Castor and Castor Seams in the Project area, based on geotechnical testing of coal core samples recovered during exploration drilling at Ensham.

4.2.3.2 Strength of the Stone Roof and Stone Floor

For a 17.5 m wide pillar, the influence into the roof and floor is one pillar width. As such, the average strength of both the stone roof and stone floor above and below the coal seam for this distance in the Project area has been determined from the geological model.

The average strength of these intervals typically ranges from 20 to 40 MPa (**Figure 44 and Figure 45**).

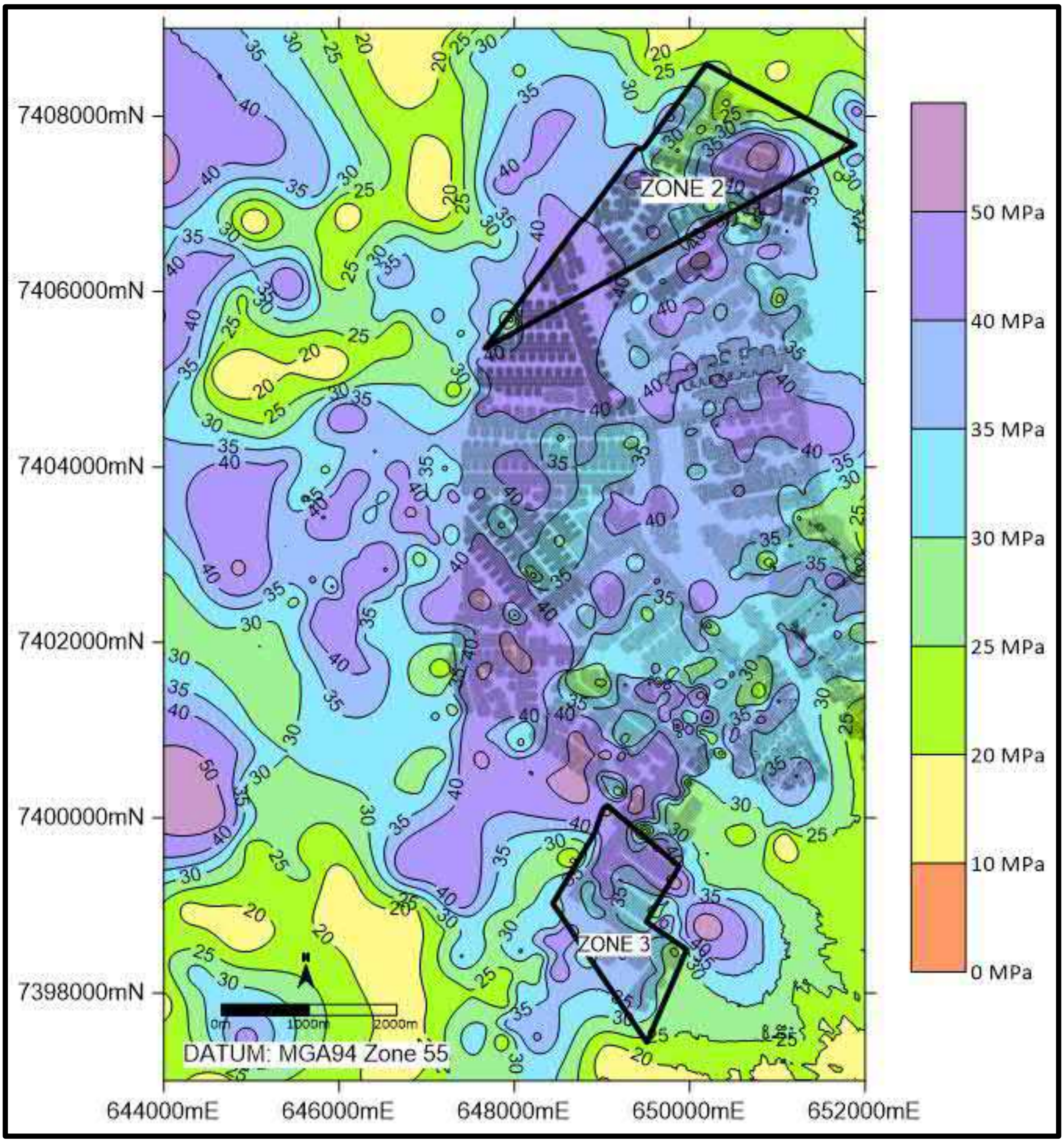

Figure 44. Average Strength for the Stone Roof 0 m to 17.5 m Interval

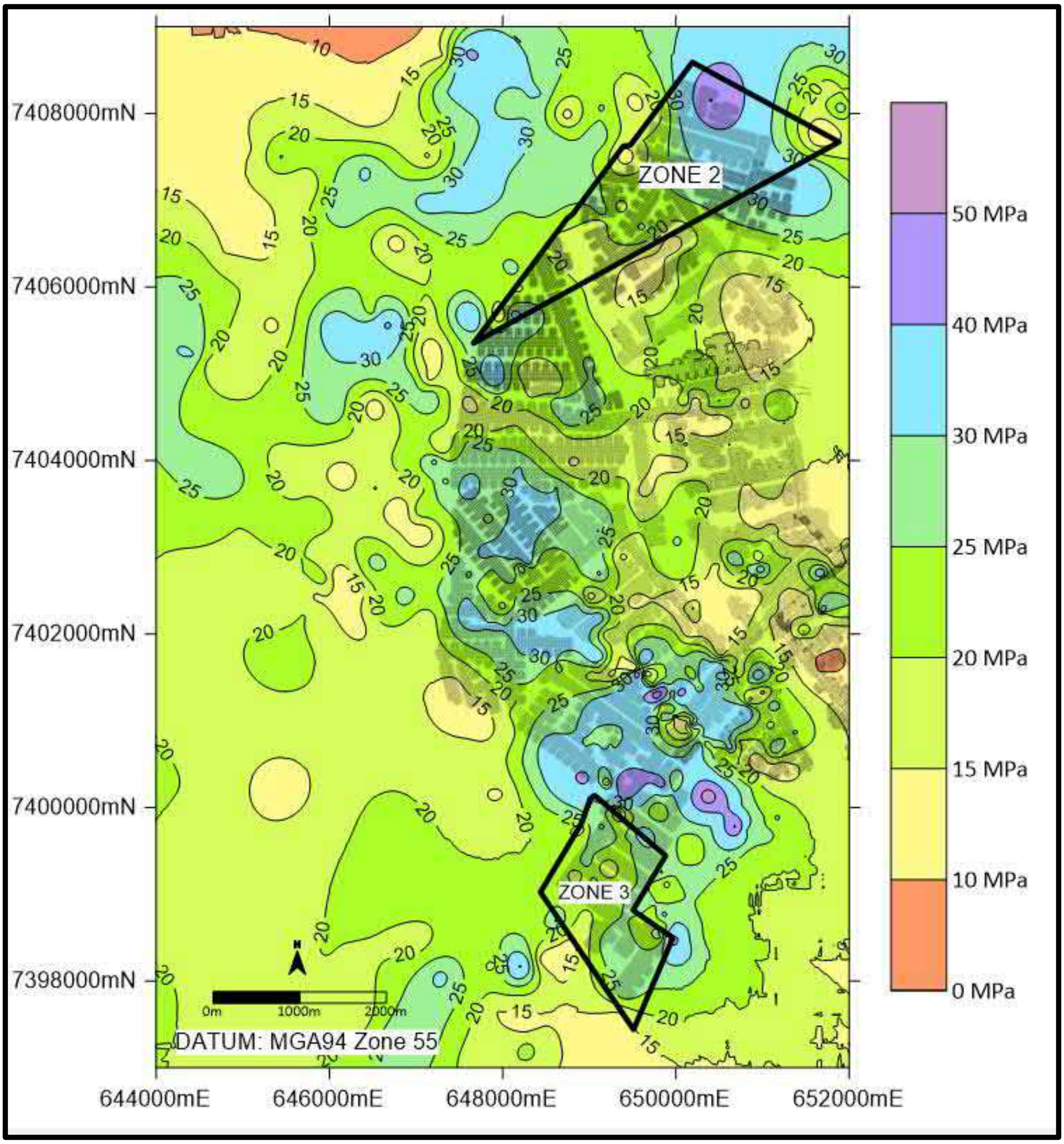

Figure 45. Average Strength for the Stone Floor 0 m to 17.5 m Interval

These values have been determined from the extensive database of sonic velocity logs recorded in the exploration boreholes in the Project area, which have been converted to strength using the Ensham site correlation, as follows (**Figure 9**):

$$UCS = 0.583e^{(0.00117*t)}$$

Where: UCS = Uniaxial Compressive Strength in MPa

t = Sonic Transit Time in m/sec

4.2.3.3 Compression Analysis

As part of the strata compression analysis, the strength values have been converted to a laboratory modulus value using the formula from the geotechnical testing of core samples at Ensham (GGPL, 2021[29]):

$$\text{Laboratory Modulus (GPa)} = 0.325 * \text{Strength (MPa)}$$

The methodology of Hoek and Diederichs (2006[30]) is then used to reduce the roof and floor laboratory modulus values (E_i) to rock mass values (E_{rm}), to consider the discontinuities in the rock mass.

$$E_{rm} = E_i * \{0.02 + (1\text{-}D/2)/\ (1 + \exp((60+15D–GSI)/11))\}$$

The laboratory modulus values are reduced using a Disturbance Factor (D) of 0 and representative Geological Strength Index (GSI) values for the roof and floor (**Figure 46**).

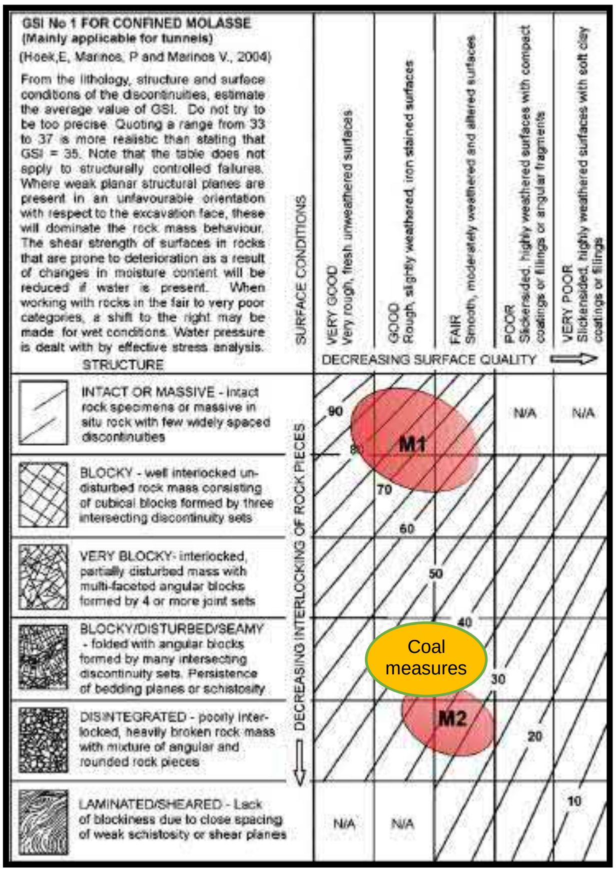

Figure 46. Determination of the Geological Strength Index (GSI)

[29] GGPL (2021). Geotechnical Reference Report for the Ensham Underground Mine. Report No. Ensham GRR - Rev C.

[30] Hoek, E. and Diederichs, M. (2006). Empirical Estimates of Rock Mass Modulus. International Journal of Rock Mechanics and Mining Sciences, 43, 203-215.

Based on the lithological and bedding characteristics shown in **Figure 47 and Figure 48** for the Aries-Castor Seam and **Figure 49 and Figure 50** for the Castor Seam, roof and floor GSI values of 55 and 50 respectively have been applied. The location of these four boreholes are shown on **Figure 9**.

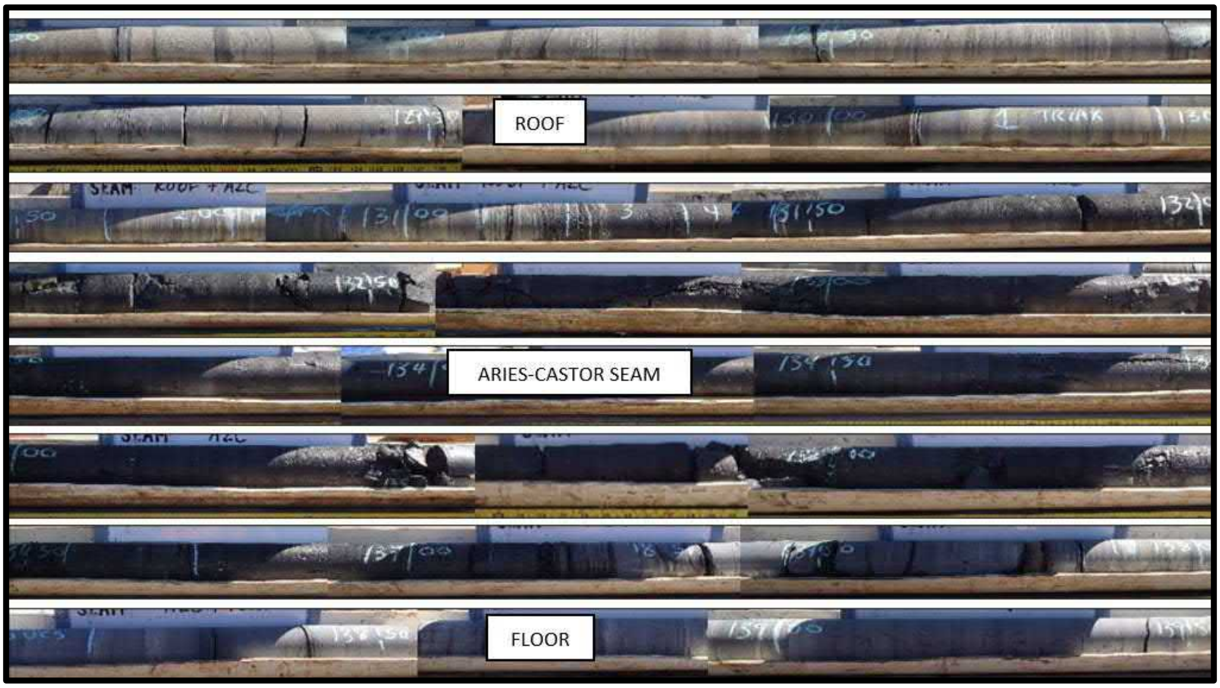

Figure 47. Aries-Castor Seam Roof and Floor (Zone 2) – Borehole C4858

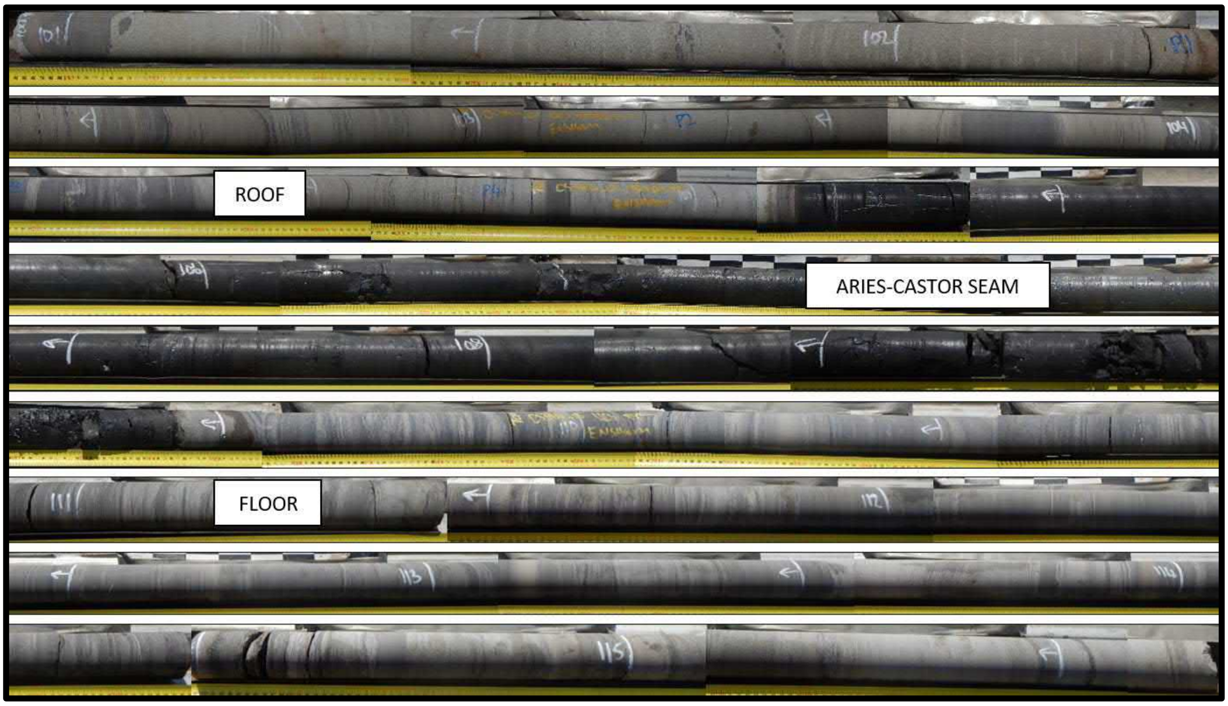

Figure 48. Aries-Castor Seam Roof and Floor (Zone 3) – Borehole C5384

Figure 49. Castor Seam Roof and Floor (Zone 2) - Borehole C4954

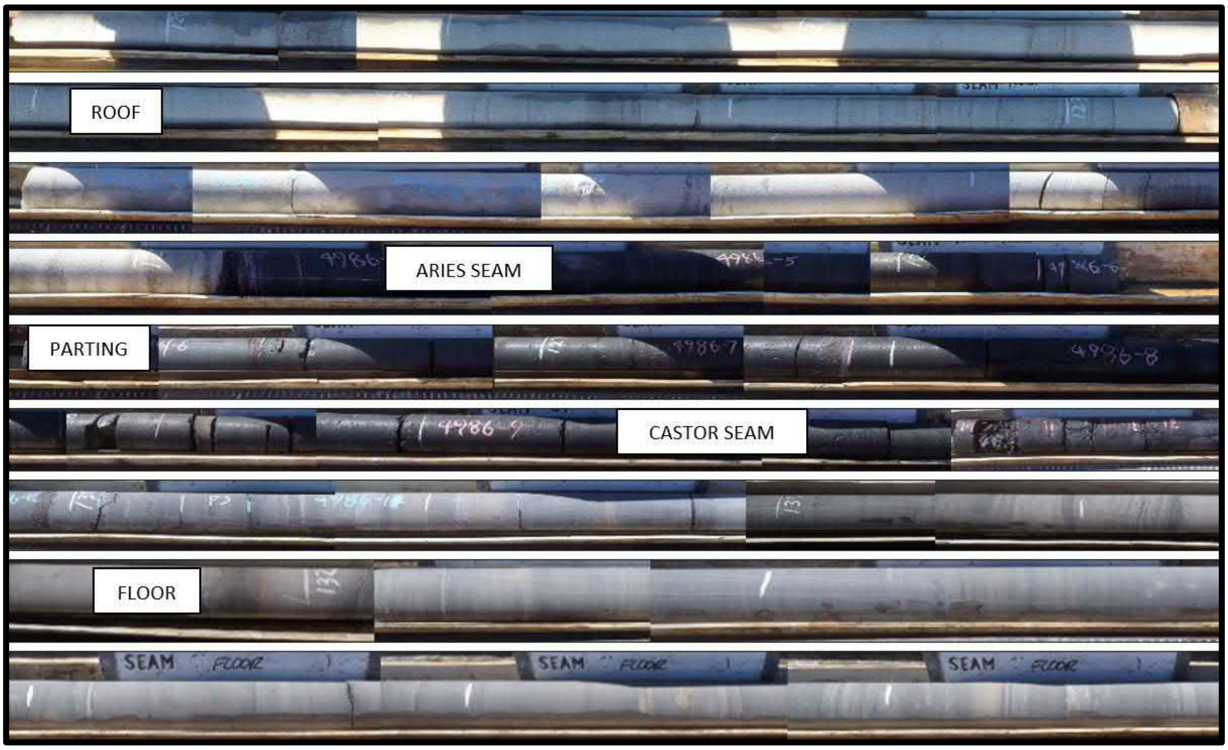

Figure 50. Castor Seam Roof and Floor (Zone 3) - Borehole C4986

The pillar compression is then calculated as follows using the methodology of Poulos and Davis (1974)[31] for analysing rigid footings:

$$Compression_{pillar} = (\sigma_c * h)/E$$

Where: σ_c = Vertical stress change (MPa)
h = Pillar height (m)
E = Young's modulus of coal pillars (MPa)

[31] Poulos, H.G. and Davis, E.H. (1974). Elastic Solutions for Soil and Rock Mechanics.

The compression of the roof and floor is calculated as follows:

$$Compression_{roof\ or\ floor} = I_P*(\sigma_c * w/2)/E$$

Where: σ_c = Vertical stress change (MPa)
I_P = Influence Factor (for a rigid footing) = 1.4
w = Pillar width (m)
E = Young's modulus of roof or floor (MPa)

The change in vertical stress on the pillars can be estimated as:

$$\sigma_c = \text{Tributary Area Stress} - \text{Virgin Stress}$$

4.3 Prediction of Project Subsidence Effects

4.3.1 Subsidence in the Project Mining Area

The compression analysis has been carried out for the maximum depth of cover above each panel pillar and bell out pillar in the Project area, using the roof and floor strength values shown in **Figure 44** and **Figure 45**. The maximum seam thickness has also been applied. These assumptions provide the likely worst-case subsidence effects and therefore is a conservative scenario for the assessment of the impacts in the Project area.

The strength values selected for each panel in the Project area are tabulated in **Appendix 1**.

Where the maximum seam thickness is greater than the maximum allowable extraction thickness for a FoS of 1.6, the reduced thickness has been used in the compression analysis.

Based on this analysis, the predicted subsidence above the panel and sub panel pillars following secondary coal recovery in the Project area is typically less than 35 mm (**Figure 51** and **Figure 52**). This reduces to typically less than 20 mm above the bell out pillars, as they do not carry the full tributary area load on the perimeter of the panels (**Figure 53**). This level of subsidence is assessed to have negligible impact on soil composition and structure.

In relation to bord and pillar mining, guidance published by DAWE (2014) states:

"Where the pillars have been designed to be stable, the vertical subsidence is typically less than 20 mm. Natural or seasonal variations in the surface levels, due to the wetting and drying of soils, are approximately 20 mm; hence, vertical subsidence of less than 20 mm can be considered to be no more than the variations that occur from natural processes and should have negligible impact on surface infrastructure."

This is consistent with Ensham's approach of developing long-term stable pillars that result in negligible subsidence. Whilst the Commonwealth guidance discusses seasonal variation of 20 mm having a negligible effect on surface infrastructure, the guidance also states that seasonal variation can be as high as 50 mm or more due to changes in moisture content (DAWE, 2014).

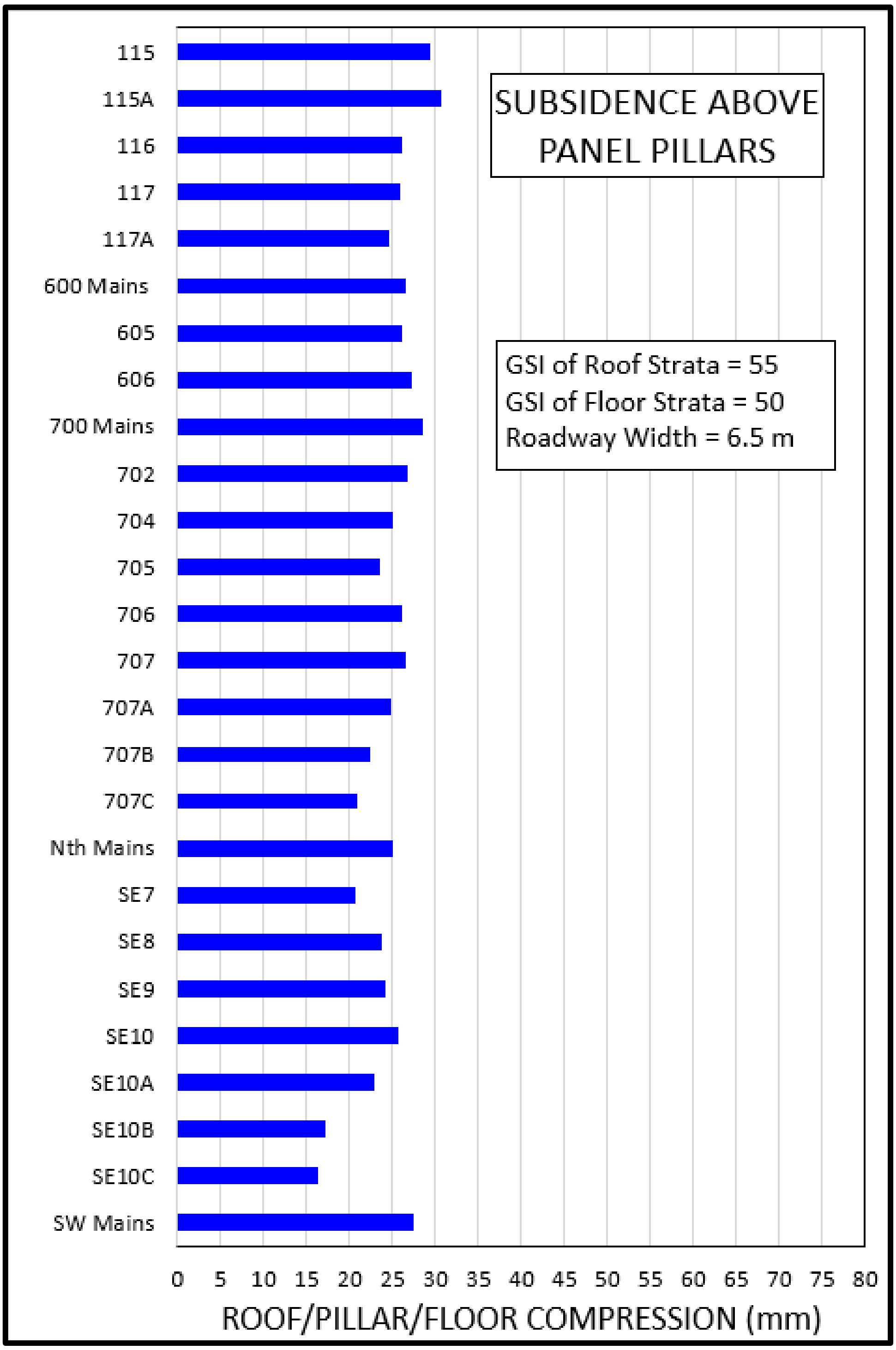

Figure 51. Subsidence above the Panel Pillars in the Project area

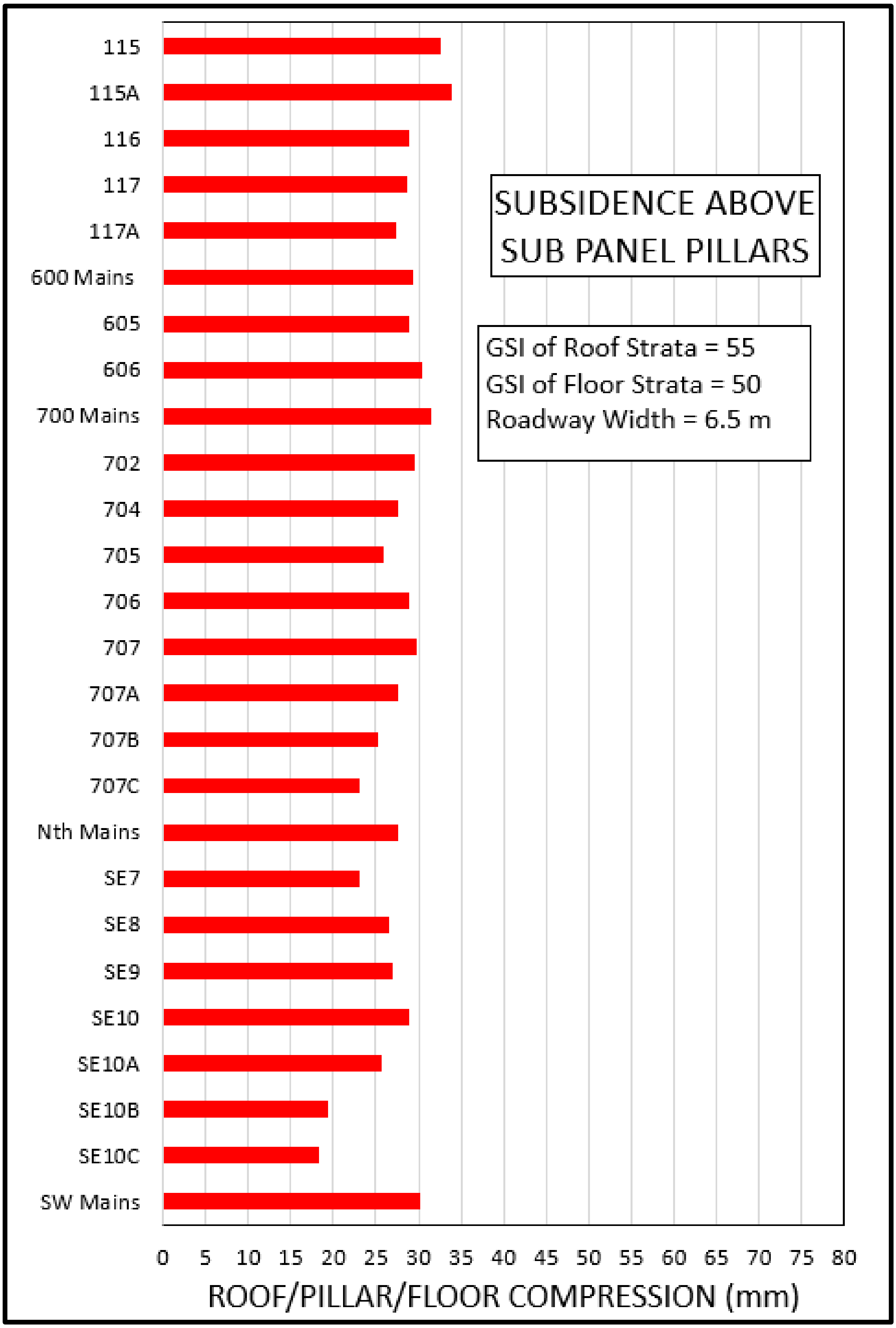

Figure 52. Subsidence above the Sub Panel Pillars in the Project area

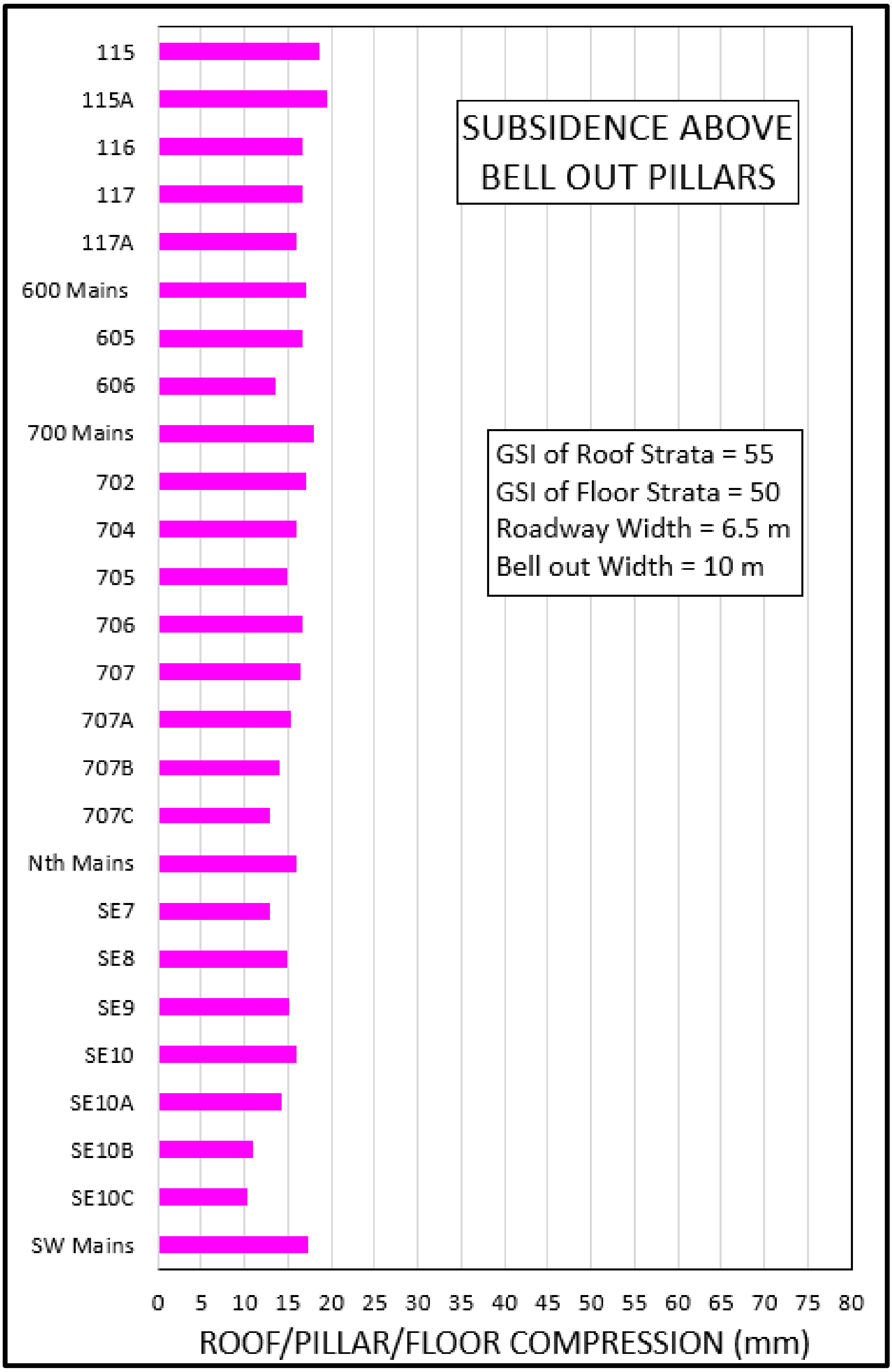

Figure 53. Subsidence above the Bell Out Pillars in the Project area

4.3.1.1 Calibration of the Compression Analysis

The monitoring of six RTK-GPS survey stations over the current Ensham underground area since April 2021 has allowed the compression analysis, used to predict the subsidence in Zones 2 and 3, to be calibrated (See Section 3.1.1).

Two stations 502_2 and 114_2 show the most consistent monitoring results and have been chosen for this analysis (**Figure 17 and Figure 18**). The results are summarised in **Table 1**.

Monitoring Station	Depth (m)	Solid Pillar Width (m)	Solid Pillar Length (m)	Roadway Width (m)	Extraction Height (m)	Actual Subsidence (mm)	Predicted Subsidence (mm)
502_2	195	20	24	6	4.3	6	27.8
114_2	140	17.5	21.5	6.5	3.2	8	25.1

Table 1. Calibration of Subsidence Data.

It is evident that at both stations the actual subsidence measured is less than the predicted subsidence using the compression analysis presented in this report (**Table 1**). As detailed in Section 4.2.3 of this report, there are number of input parameters required in the strata compression analysis. These include:

- Coal modulus.
- Conversion formulae to estimate strength and modulus.
- Roof and floor strata strength and modulus.
- Geological Strength Index (GSI) for the roof and floor strata
- Influence factor in the compression analysis.

For example, a small increase of 10 MPa in the strength of the roof and floor strata and an increase in the GSI values from 50-55 to 65, reduces the subsidence significantly from 25.1 mm to less than 12 mm.

This analysis of measured subsidence data in the Ensham mining area therefore provides greater confidence that the subsidence predictions are a conservative estimate of the anticipated subsidence in Zones 2 and 3.

4.3.2 Surface Cracking

As detailed in **Section 3.3**, a surface crack of 30 mm width developed above the rib line of 3 North Panel and across a public access path at the Tasman bord and pillar mine in NSW, only after the subsidence exceeded 300 mm. No surface cracking developed in areas where the subsidence was less than 300 mm.

Based on this observation from NSW, and GGPL's experience at comparable Queensland bord and pillar mines, surface cracking is not predicted above the Project area due to the predicted low levels of maximum surface subsidence of less than 35 mm.

4.3.3 Sub-surface Cracking

The nature of the proposed mining method in the Project area indicates that the surface subsidence will be due to elastic compression of the strata (**Section 4.2.3**). The mining activities do not create areas of caving, which could result in fracturing of the overburden.

This is confirmed by experience in NSW at Clarence Mine, which uses partial extraction bord and pillar methods at the north western edge of the Blue Mountains Heritage Area (**Section 3.2**). As detailed by Hill and White (2017), there have been no exceedances of the 100 mm subsidence limit and interaction with the overlying perched groundwater system since partial extraction started in 2003.

4.3.4 Limitations of the Subsidence Predictions

Based on the available data for the Project area, there are no localised features or variations in the geology, geotechnical conditions or surface topography that are considered likely to result in any significant deviations from the subsidence predictions presented in this report.

There is a high degree of confidence in the subsidence predictions due to the amount of information from the existing bord and pillar mining at Ensham with similar mining heights, depth of cover and mining methodology. This information has allowed a robust calibration to be achieved and provided a sound basis to enable conservative subsidence predictions.

5 CONCLUSIONS

The key conclusions from this report include:

1. Due to the nature of the bord and pillar mining method, low levels of subsidence, typically less than 35 mm, are predicted in the Project area as a result of elastic compression of the strata. Recent RTK-GPS monitoring at Ensham indicates subsidence levels of less than 10 mm above mined underground panels and confirms this prediction for the Project.

2. The magnitude of the predicted subsidence is less than the natural ground movements of up to 50 mm or more that can occur (DAWE, 2014 and 2015).

3. The subsidence assessment is based on the Project design Factor of Safety (FoS) and width: height ratios of the pillars, as well as the estimated critical level of overburden displacement. This assessment, using a minimum pillar FoS of 1.6 for areas beneath the floodplain, and 2.11 for access roadways beneath the Nogoa River to connect bord and pillar workings, and, for bord and pillar workings beneath the Nogoa River anabranch, has confirmed the long-term stability of the proposed mine layout.

4. The temporary increase in cover depth during 0.1% AEP (Q1000) flood events has been calculated below both the flood plain and Nogoa River and anabranch channels. Conservative maximum flood depth values of 16 m in the Nogoa River channel and 4 m across the flood plain have been used in the FoS calculations. The temporary increase in depth has been applied to the design figures to calculate the required mining height to satisfy the Project FoS during 0.1% AEP flood events.

5. The design criteria used to ensure long-term stability of the pillars has been peer reviewed by three industry recognised (RPEQ) geotechnical consultants Mine Advice (Dr Russell Frith), Byrnes Geotechnical (Dr Ross Seedsman), and BK Hebblewhite Consulting (Emeritus Professor Bruce Hebblewhite), who all concluded that the proposed bord and pillar layout is an appropriate and well developed geotechnical design.

6. As well as the factor of safety approach, the long-term life expectancy of pillars can be estimated using empirical studies from South Africa. Using this approach, the proposed 24 m x 28 m (centres) pillars in Zones 2 and 3 at 4.5 m high and 130 m depth of cover, are calculated to be stable for greater than 26,000 years.

7. After mining is completed and the workings flood with groundwater, the buoyancy effect of water will reduce the vertical load on the pillars by up to 40%. For a pillar below the Nogoa River anabranch designed with a FoS of 2.11, at 140 m depth of cover, reducing the vertical load on the pillar by a conservative

25%, to account for any potential strength loss in the coal and surrounding strata, increases the FoS to 2.82. This FoS has a probability of failure well in excess of 1 in 10,000,000.

8. The nature of the mining method generating only elastic compression of the strata indicates that sub-surface cracking above the Project area is not expected.

9. Due to the predicted low levels of subsidence and associated strains and tilts, no surface cracking is predicted above the Project area. This is consistent with operational experience in the current Ensham underground where surface cracking has not been observed above the bord and pillar mining areas and is supported by experience at other comparable bord and pillar mines in Queensland and NSW.

10. The expected low levels of subsidence are unlikely to result in the formation of significant depressions in the surface topography where ponding of the surface drainage may occur. This is also consistent with operational experience in NSW and Queensland where ponding has not been observed above previous similar bord and pillar mining areas.

11. Based on mining experience at shallow depths of cover in the current Ensham underground workings, as well as experience at other mining operations around the world, the risk of sinkhole subsidence occurring in the Project area, where the depth of cover is greater than 75 m, is considered to be negligible.

6 APPENDIX 1. PANEL DATA – ZONE 2 AND ZONE 3

Panel	Min Depth (m)	Max Depth (m)	Max Thick (m)	Average 0-17.5 m Roof Strength (MPa)	Average 0-17.5 m Floor Strength (MPa)	Strata Compression above 17.5 m x 21.5 m (Solid) Pillars (mm)	Strata Compression above 17.5 m x 17.5 m (Solid) Pillars (mm)	Strata Compression above 15 m x 15 m Bell Out (Solid) Pillars (mm)
ZONE 2 MINING AREA								
600 Mains	140	140	5.6	44	22	26.5	29.3	16.9
115	140	150	5.8	36	22	29.3	32.4	18.5
115A	130	140	6	40	18	30.5	33.8	19.3
116	130	140	5.8	38	24	26.1	28.8	16.6
117	130	130	5.8	38	22	25.7	28.6	16.5
117A	130	130	6	38	24	24.5	27.2	15.8
North Mains	130	130	5.8	36	24	24.9	27.6	16.0
605	150	150	5.6	40	26	26.0	28.7	16.5
606	140	140	5.6	44	22	27.1	30.4	13.4
700 Mains	150	200	5.2	44	32	28.5	31.4	17.9
702	140	150	5.4	32	28	26.7	29.5	17.0
704	130	160	5.2	42	30	25.0	27.6	15.9
705	150	150	5.2	40	32	23.4	25.8	14.9
706	130	190	5.2	42	36	26.1	28.7	16.5
707	140	200	2.4	36	38	26.4	29.6	16.4
707A	150	170	2.2	28	38	24.6	27.6	15.2
707B	150	150	2.2	26	38	22.4	25.1	13.9
707C	140	150	2.4	32	38	20.7	23.0	12.9
ZONE 3 MINING AREA								
SE7	80	120	4.6	42	26	20.5	23.0	12.9
SE8	90	130	4.4	38	24	23.6	26.5	14.8
SE9	90	130	4.4	36	24	24.0	26.8	15.0
SE10	80	140	4.2	36	24	25.6	28.7	16.0
SE10A	100	120	4.2	38	22	22.7	25.5	14.2
SE10B	90	100	4.2	38	26	17.2	19.3	10.8
SE10C	75	90	4.4	34	26	16.2	18.1	10.1
SW Mains	130	160	4.4	40	26	27.4	30.2	17.2