ATTACHMENT 5

Peer Review Letters

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1 March 2022

Attn: Mr Gary Brassington
South32 Illawarra Metallurgical Coal
PO Box 514
UNANDERRA NSW 2526

Dear Gary,

Re: **Dendrobium Mine Extension Project**
Independent Review – Subsidence & Height of Fracturing Assessments

I am pleased to offer this letter as confirmation of the peer review process I have undertaken with respect to the above subsidence and height of fracturing assessments, and my satisfaction with the updated assessment documentation prepared in response to my review.

The original documents I was provided with for review were:

- MSEC Report No. MSEC1181, Rev. 4 (draft), titled: *"Dendrobium Mine Extension Project: Subsidence Predictions and Impact Assessments for the Natural and Built Features in Support of the Environmental Impact Statement Application"*, dated 1 February 2022 (hereafter referred to as the *"MSEC Report"*).
- Watershed HydroGeo Report No. R029A (draft), titled *"South32 Illawarra Metallurgical Coal Dendrobium Mine Extension Project (DMEP): Groundwater Assessment"*, (hereafter referred to as the *"Watershed Report"*).

My review was conducted with due consideration for the DPIE SEARs for the Dendrobium Extension Project (dated 23/12/2021).

My review commentary was provided in my Report No. 2201/01.1, dated 18 February 2022. I understand that my report was provided by you to both MSEC and WaterShed for consideration.

I have now received updated reports from both these two organisations, addressing both the subsidence and height of fracturing assessments (noting that my review of the Watershed report was confined only to the relevant section on height of fracturing, rather than the complete report).

The updated reports I have now received were:

- MSEC Report No. MSEC1181, Rev. 5 (draft), titled: *"Dendrobium Mine Extension Project: Subsidence Predictions and Impact Assessments for the Natural and Built Features in Support of the Environmental Impact Statement Application"*, dated 28 February 2022.
- Watershed HydroGeo Report No. R029A, Rev. A (draft), titled *"South32 Illawarra Metallurgical Coal Dendrobium Mine Extension Project (DMEP): Groundwater Assessment"*, dated 24 February 2022.

As indicated above, I am now satisfied that the two updated reports have adequately addressed all of my substantive comments raised in the peer review, and therefore represent, in my opinion, an appropriate assessment of these two issues for the Dendrobium Extension Project.

Yours sincerely,

Bruce Hebblewhite

Consultant Mining Engineer & Principal
B K Hebblewhite Consulting

REPORT TO:	South32 Illawarra Metallurgical Coal PO Box 514 UNANDERRA NSW 2526
Attn:	Mr Gary Brassington

Dendrobium Mine Extension Project
Independent Review – Subsidence & Height of Fracturing Assessments

REPORT NO:	**2201/01.1**
PREPARED BY:	**BRUCE K HEBBLEWHITE**
DATE:	**18th February 2022**

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1. INTRODUCTION

This report has been requested by South32 Illawarra Metallurgical Coal (IMC), in response to the NSW Dept of Planning, Industry & Environment (DPIE) Planning Secretary's Environmental Assessment Requirements (SEARs) for the proposed Dendrobium Mine Extension Project (SSI-33143123).

In particular, under the heading of Key Issues, clause 2 – Subsidence, the SEARs state that the EIS must address the following:

> *"an independent peer review of the subsidence and height of fracturing assessment/s prepared for the development".*

1.1 Scope of Work

The specific scope of work for this report, which is intended to satisfy the above SEARs requirement, was defined by IMC to include the following:

1) Review of the draft Subsidence Assessment (prepared by MSEC) and provision of comments.
2) Review of relevant section of the Groundwater Assessment regarding height of fracturing calculations (considering the Tammetta Equation and alternative models) and provision of comments.
3) Review of how peer review comments have been addressed in the final versions of the Subsidence Assessment and Groundwater Assessment.
4) Preparation of Independent Peer Review letter for inclusion in EIS (subject to comments being suitably addressed).

The following documentation has been provided by IMC in order to carry out this review:

- DPIE SEARs for the Dendrobium Extension Project (dated 23/12/2021).
- MSEC Report No. MSEC1181, Rev. 4 (draft), titled: *"Dendrobium Mine Extension Project: Subsidence Predictions and Impact Assessments for the Natural and Built Features in Support of the Environmental Impact Statement Application"*, dated 1 February 2022 (hereafter referred to as the *"MSEC Report"*).
- Watershed HydroGeo Report No. R029A (draft), titled *"South32 Illawarra Metallurgical Coal Dendrobium Mine Extension Project (DMEP): Groundwater Assessment"*, (hereafter referred to as the *"Watershed Report"*).

In preparing this review, I note the following points:

1. This report is authored by me as an independent "expert" in the field of underground coal mining and mine geomechanics, including mine subsidence. A copy of my summary CV appears as Appendix A to this report.

2. I have previously been engaged by IMC as an independent expert, approved by DPIE, to review various subsidence/hydrogeological reports associated with planning and performance for successive longwall panel extractions in Dendrobium Areas 3A and 3B.

3. This peer review report, whilst considering the topic of groundwater impacts, is primarily focused on the subsidence and related overburden geotechnical/fracturing parameters covered in the above scope. I do not claim to hold expertise in groundwater or hydrogeology, and my comments on these issues are only provided within the context of the geotechnical environment, and the potential impact(s) of the geotechnical conditions on groundwater in the overburden.

4. All material provided for review is assumed to be factually correct, for the purposes of this peer review.

5. Review commentary is focused on technical methodology and outcomes and does not make any value-judgement on the acceptability or otherwise of predicted subsidence impacts of longwall mining.

6. I confirm that this review has been undertaken and presented in line with the NSW Department of Planning and Environment's Peer Review Guideline (draft) (2017).

7. I confirm that the documentation provided, as listed above, is considered sufficient and appropriate for the purposes of carrying out this review which has been conducted in accordance with all relevant professional standards and practices.

8. Identified typographical errors are not reported as a matter of course.

1.2 Background

The following is a selection of relevant background information on the project, drawn directly from the MSEC Report. Not all references or diagrams are reproduced here, so the reader should refer to the original MSEC Report for such details.

> **"Background**
> Illawarra Metallurgical Coal Holdings Pty Ltd (IMC), a wholly owned subsidiary of South32 Limited (South32), operates the Dendrobium Mine, which is located in the Southern Coalfield of New South Wales (NSW). The Dendrobium Mine is located to the west of Wollongong and the Illawarra Escarpment and to the east of the township of Bargo.
>
> IMC has carried out underground longwall mining in Areas 1, 2, 3A and 3B at the Dendrobium Mine. This includes LW1 and LW2 in Area 1, LW3 to LW5 in Area 2, LW6 to LW8 in Area 3A and LW9 to LW16 in Area 3B. IMC has approval for the extraction of additional longwalls in these mining areas

including LW17 (currently active) and LW18 in Area 3B and LW19 in Area 3A and it proposes to mine LW20 to LW23 in Area 3C. The layouts of the existing, approved and proposed longwalls at the Dendrobium Mine are shown in Drawing No. MSEC1181-01, in Appendix E.

The future longwalls in Areas 3A, 3B and 3C are the subject of separate Subsidence Management Plan Applications. The predicted subsidence effects provided in this report include the existing and future longwalls in these mining areas so that the total cumulative movements are considered.

IMC previously submitted an Environmental Impact Statement (EIS) seeking an extension to its underground coal mining operations at the Dendrobium Mine by extracting longwalls in proposed Areas 5 and 6. Mine Subsidence Engineering Consultants (MSEC) prepared the Report No. MSEC856 (Rev. B) which provided subsidence predictions and impact assessments in support of that application. The longwall layout adopted in the previous EIS and Report No. MSEC856 is referred to as the Previous Layout in this report.
IMC is now preparing a new EIS based on a revised longwall layout which includes a reduction in the extent of Area 5 and removes longwall mining in Area 6. The revised mine plan is referred to as the Dendrobium Mine Extension Project (the Project). The layout of the proposed longwalls in Area 5 is shown in Drawings Nos. MSEC1181-01 and MSEC1181-02. The revised longwall layout in Area 5 is also referred to as the Revised Layout in this report. A comparison of the Previous Layout (i.e. black outlines) and Revised Layout (i.e. orange outlines) is provided in Fig. 0.1.

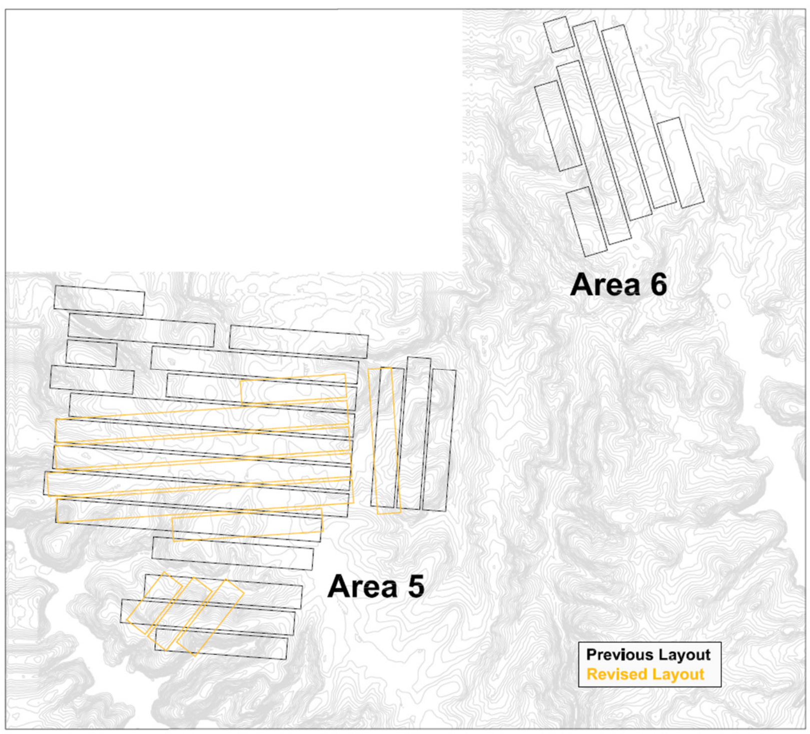


Fig. 0.1 Comparison between the Previous Layout and Revised Layout

The surface area located directly above the proposed longwalls and the chain pillars between the longwalls is approximately 1895 hectares (ha) based on the Previous Layout (i.e. Areas 5 and 6) and 792 ha based on the Revised Layout (i.e. Area 5 only). The surface above the mining area therefore reduces by approximately 1103 ha or 58 %.

The currently proposed longwalls in Area 5 and the Study Area, as defined in Section **Error! Reference source not found.**, have been overlaid on an orthophoto of the area and are shown in Fig. 0.2.

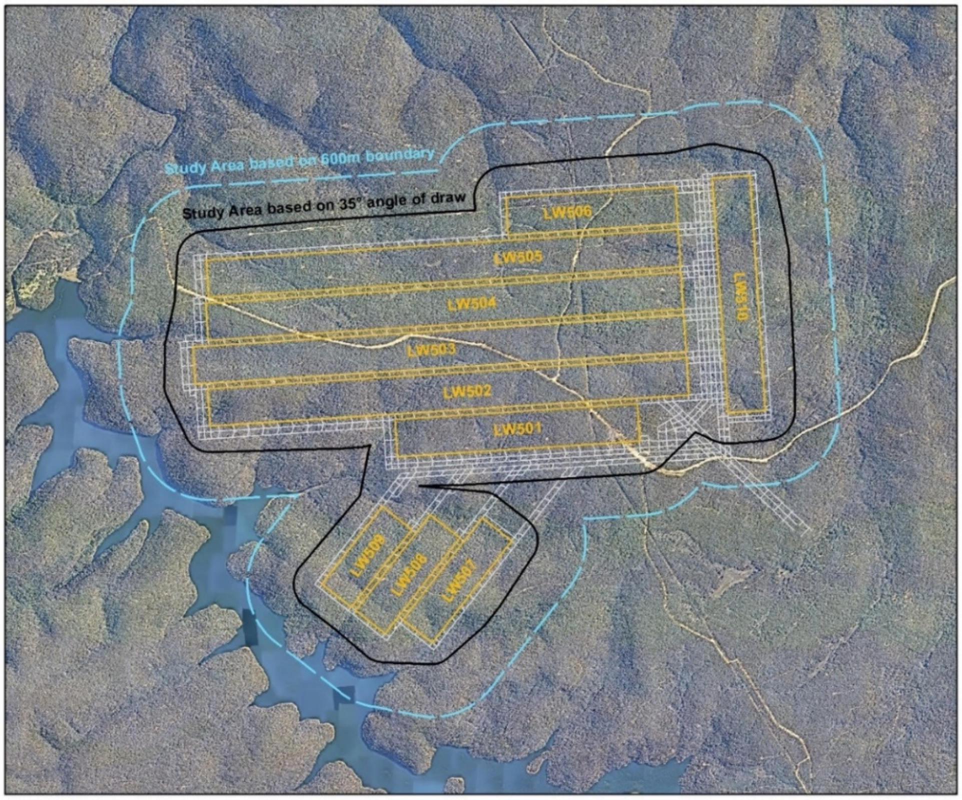


Fig. 0.2 Aerial photograph showing the proposed longwalls and the Study Area

Mining Geometry

The layout of the proposed longwalls in Area 5 is shown in Drawings Nos. MSEC1181-01 and MSEC1181-02, in Appendix E. A summary of the dimensions of these longwalls is provided in Table 0.1.

Table 0.1 Geometry of the proposed longwalls in Area 5

Longwall	Overall void length including installation heading (m)	Overall void width including first workings (m)	Overall tailgate chain pillar width (m)
LW501	1970	305	-
LW502	3890	305	42
LW503	3990	305	42
LW504	3860	305	42
LW505	3835	305	42
LW506	1380	305	42
LW507	1050	305	-
LW508	985	305	42
LW509	800	305	42
LW510	1910	305	-

The lengths of longwall extraction excluding the installation headings are approximately 9 m less than the overall void lengths provided in Table 0.1. The longwall face widths excluding the first workings are 295 m.

The mining in Area 3C has been approved and is the subject of separate Subsidence Management Plan applications. The predicted mine subsidence movements for the proposed longwalls in Area 3C have been included in this report, so that the impact assessments for the natural and built features considered the cumulative movements from all current and future mining areas.

Surface and seam levels

The surface level contours are shown in Drawing No. MSEC1181-03, in Appendix E. The proposed longwalls are located beneath the undulating land between the larger streams and lakes. The proposed longwalls in Area 5 are located east of Lake Avon and the Avon River and west of Donalds Castle Creek.

The surface levels directly above the proposed longwalls in Area 5 vary between a minimum of 335 metres above Australian Height Datum (mAHD) at the northern end of LW509 and a maximum of 440 mAHD at the southern end of LW507.

The longwalls in Area 5 are proposed to be extracted in the Bulli Seam. The seam floor contours, seam thickness contours and depth of cover contours for the Bulli Seam are shown in Drawings Nos. MSEC1181-04, MSEC1181-05 and MSEC1181-06, respectively.

The depths of cover above the proposed longwalls in Area 5 vary between a minimum of 250 m at the southern extent of the proposed mining area and a maximum of 400 m in the north-eastern part of the mining area. The average depth of cover above the proposed longwalls is 360 m.

The thickness of the Bulli Seam varies between a minimum of 2.1 m at the southern extent of the proposed mining area and a maximum of 3.2 m near the mid-length of LW505. The longwalls will mine a minimum thickness of 2.4 m.

A summary of the ranges of the depth of cover, seam thickness and proposed mining heights for the proposed longwalls in Area 5 is provided in Table 0.2.

Table 0.2 Seam thicknesses and proposed mining heights

Location	Depth of cover (m)	Seam thickness (m)	Mining height (m)
LW501 to LW510	250 to 400 (360 average)	2.1 to 3.2 (2.6 average)	2.4 to 3.2 (2.6 average)

The levels of the natural surface and the Bulli Seam in Area 5 are illustrated along Cross-sections 1 to 4 in Fig. 0.3 to Fig. 0.6, respectively. The locations of these cross-sections are shown in Drawings Nos. MSEC1181-03 to MSEC1181-05, in Appendix E.

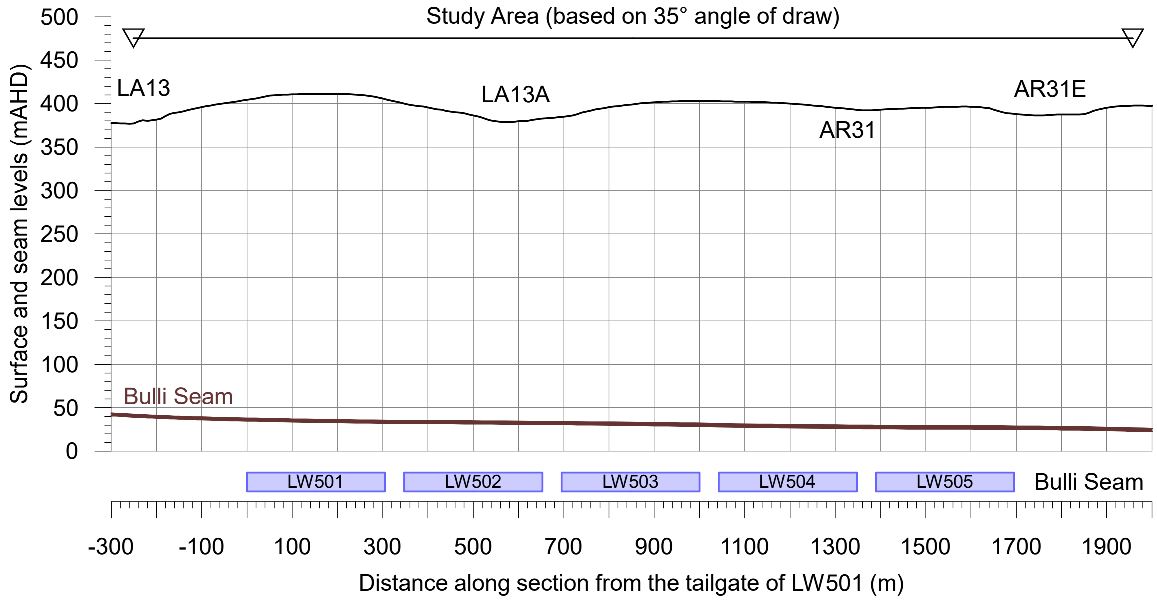


Fig. 0.3 Surface and seam levels along Cross-section 1 through the proposed LW501 to LW505

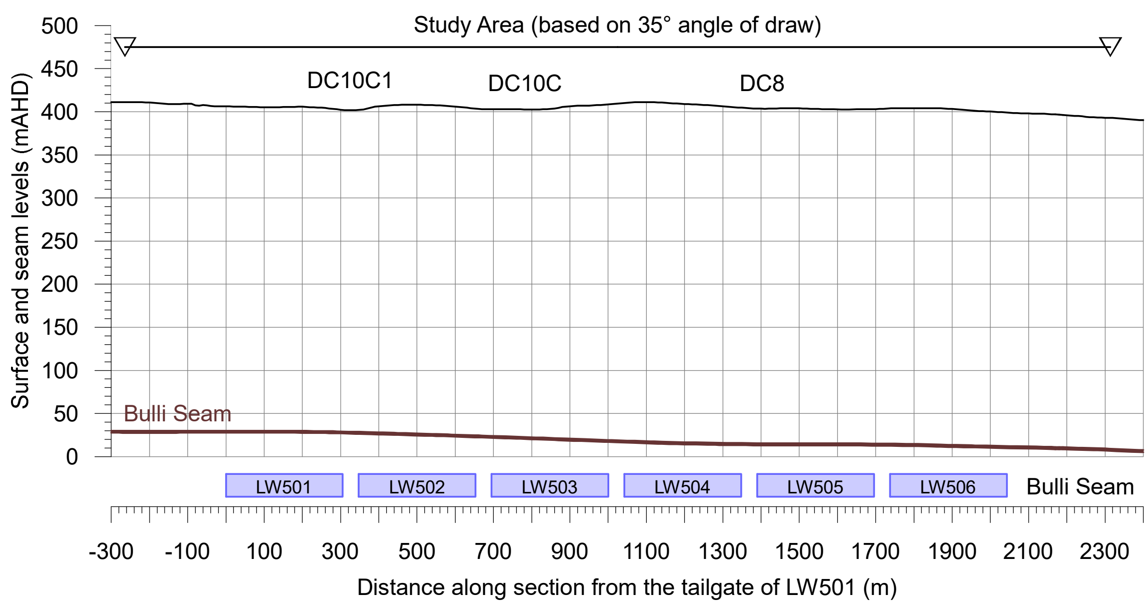


Fig. 0.4 Surface and seam levels along Cross-section 2 through the proposed LW501 to LW506

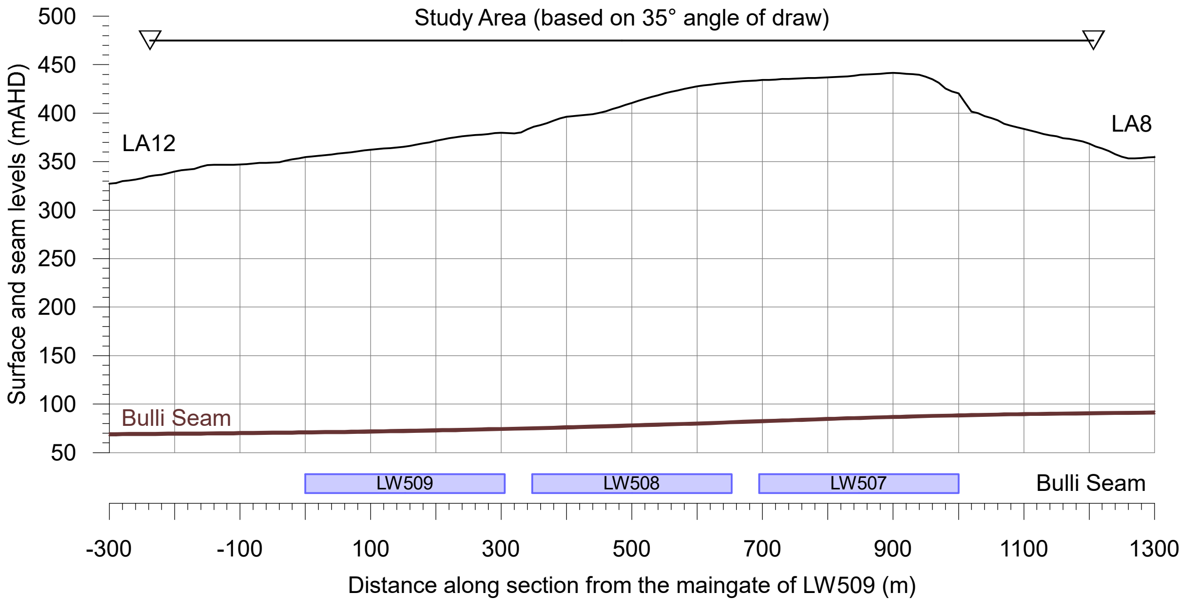


Fig. 0.5 Surface and seam levels along Cross-section 3 through the proposed LW507 to LW509

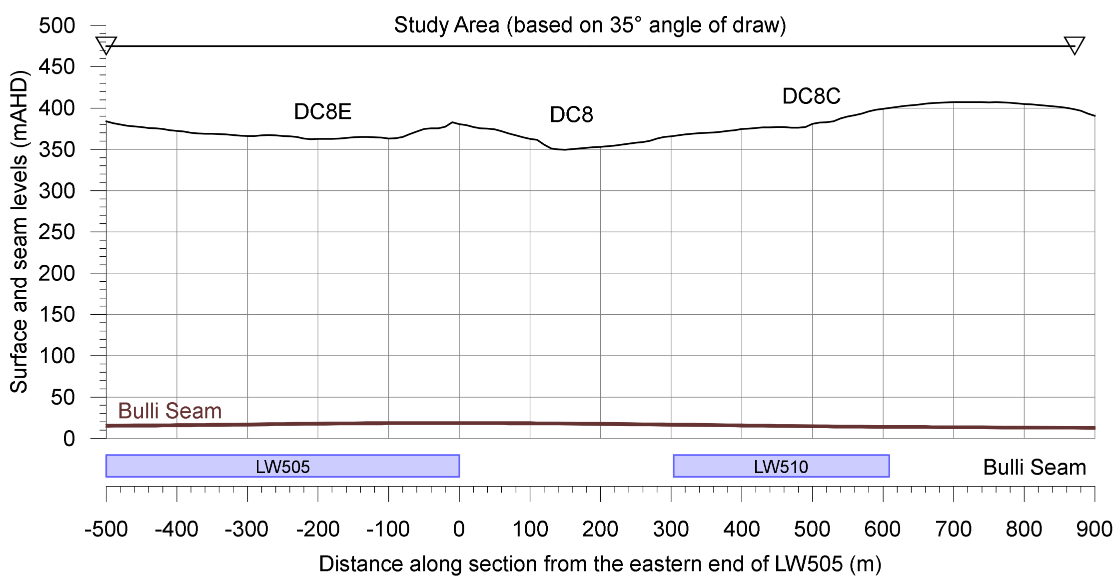


Fig. 0.6 Surface and seam levels along Cross-section 4 through the longwalls in Area 5

The Bulli Seam generally dips towards the north to north-east in Area 5 with an average grade of approximately 1 % (i.e. 1 in 100) within the proposed mining area. A north-south orientated syncline is located at the eastern ends of LW504 to LW506. The seam dip across the main axis of the syncline is up to approximately 1.5 % (i.e. 1 in 67).

Geological Details

The Dendrobium Mine is located in the southern part of the Sydney Basin. The landform is hilly and the region is crossed by the Avon River, the Cordeaux River and their associated creeks and tributaries.

The geology mainly comprises sedimentary sandstones, shales and claystones of the Permian and Triassic Periods which have been intruded by igneous sills. A typical stratigraphic section for the Dendrobium Mine is provided in Fig. 0.7 (Source: IMC).

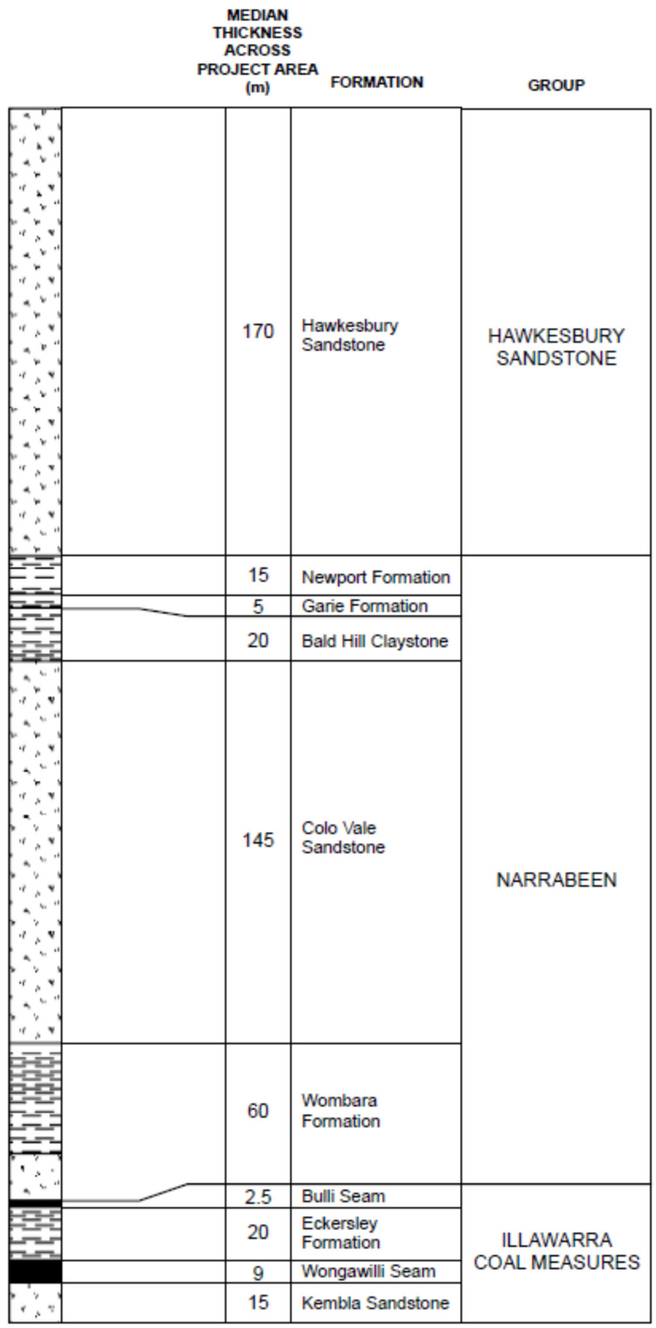


Fig. 0.7 Typical stratigraphic section for the Dendrobium Mine (Source: IMC)

The major sedimentary units at the Dendrobium Mine are, from the top down, the Hawkesbury Sandstone, the Narrabeen Group and the Illawarra Coal Measures. The Wianamatta Group is only present as a very limited overlying residual in localised areas.

Hawkesbury Sandstone is the largest member in the overburden, with an average thickness of approximately 170 m within Area 5 at the Dendrobium Mine. The Narrabeen Group contains the Newport Formation (sometimes referred to as the Gosford Formation), Garie Formation, Bald Hill Claystone, Colo Vale Sandstone (also referred to as Bulgo Sandstone), and the Wombarra Formation comprising Stanwell Park Claystone, Scarborough Sandstone, Wombarra Shale and Coalcliff Sandstone.

The Bulli Seam is the top unit in the Illawarra Coal Measures. The interval between the Bulli Seam and the Wongawilli Seam is known as the Eckersley Formation which consists of sandstones, shales and minor coal seams. The proposed longwalls are proposed to be extracted from the Bulli Seam.

The major claystone units are the Bald Hill and Stanwell Park Claystones that lie above and below the Colo Vale Sandstone and at the base of the Hawkesbury Sandstone. The Wombarra Shale will be located within the collapsed zone above the proposed longwalls.

The Dendrobium Mine sits at the southern end of the Nepean/Kurrajong Fault and Lapstone Monocline system. The area is therefore imprinted with the north-westerly trending structures that connect to these large-scale geological features to the north. The large north-west and north-north-west displacement faults are the primary deformational set in the area. However, these faults trend north-east in the coastal fault zone.

The geological structures identified at seam level are shown in Drawing No. MSEC1181-07.

Igneous sills have intruded into the coal seams in parts of Area 5. The inferred cinder zone in the Bulli Seam extends into the eastern end of the proposed LW501 and the southern end of the proposed LW510. The inferred cinder zone is also located adjacent to the western end of the proposed LW506 and the northern end of the proposed LW507.

There is a north-north-east to south-south-west trending fault that crosses the proposed LW501 to LW506 and LW508. There are dykes located north-west and south-east of the proposed mining area. The locations of these structures will be better defined through the ongoing investigations and the development of the first workings. A north-south orientated syncline is located at the eastern ends of LW504 to LW506.

A review was carried out on the effects of geological structures on the measured surface subsidence above LW9 to LW13 in Area 3B (MSEC, 2019). The available monitoring data suggest that there was no apparent increase in the subsidence measured in the mapped locations of the lineaments, minor faults and dykes. Similarly, there was no apparent increase in the subsidence measured along the minor seam folds (i.e. synclines and anticlines). There also does not appear to be an association between the observed surface impacts and the mapped lineaments, minor faults, dykes and minor seam folds.

IMC has advised that the surface lineaments, minor faults and dykes located above and near to the proposed longwalls in Area 5 are similar to those mapped in Area 3B. It is considered unlikely, therefore, that these structures would adversely affect the subsidence predictions and assessed impacts for the proposed longwalls.

There are no other major faults or other geological structures that have been identified within the extents of the proposed longwalls. The identification of geological structures in the area will be continually refined based on the ongoing investigations and the development of first workings. The proposed mining layout will be reviewed based on this updated geological information and, if required, will be modified to avoid the major geological features.

The surface lithology in the area can be seen in Fig. 0.8, which shows the proposed longwalls and the Study Area overlaid on the Geological Map *Bargo 9029-3-N*, which was published by the Department of Mineral Resources (DMR, 1988), now known as the NSW Resources Regulator. The surface lithology in Area 5 generally comprises Hawkesbury Sandstone (Rh), with localised areas of Quaternary Alluvium (Qs).

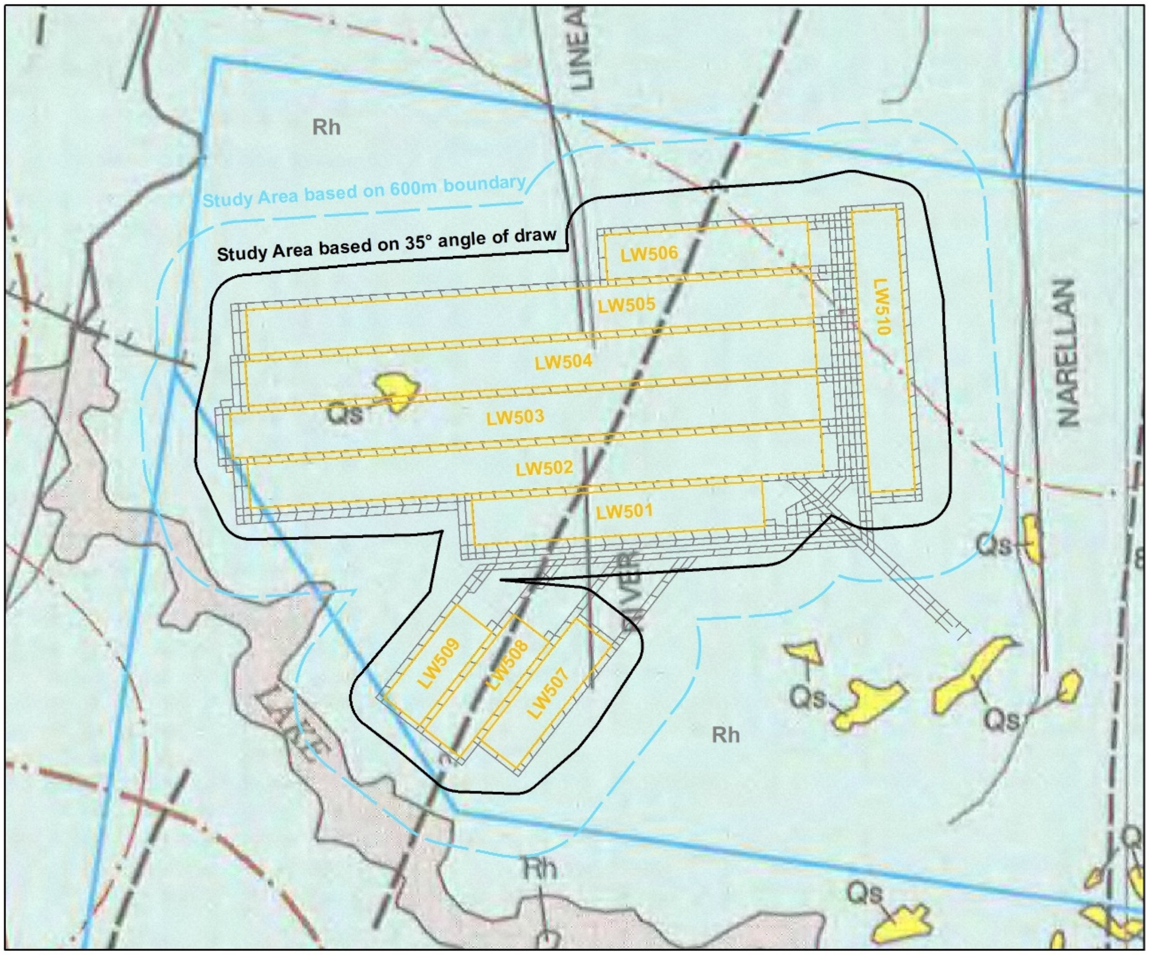


Fig. 0.8 The proposed longwalls overlaid on Geological Map *Bargo 9029-3-N* (DMR, 1988)

Definition of the Study Area

The *Study Area* is defined as the surface area that could be affected by the mining of the proposed longwalls in Area 5 at the Dendrobium Mine. The extent of the Study Area has been calculated by combining the areas bounded by the following limits:

- a 35° angle of draw from the extents of the proposed longwalls in Area 5;
- the predicted limit of vertical subsidence, taken as the 20 mm subsidence contour, resulting from the extraction of the proposed longwalls;
- features that could experience far-field or valley-related movements and could be sensitive to such movements; and
- the natural features located within 600 m of the extent of the longwall mining area, in accordance with Condition 8(d) of the Dendrobium Mine Development Consent.

The major natural and built features within the Study Area can be seen in the 1:25,000 topographic map of the area, published by the Central Mapping Authority (CMA), called *Avon River 9029-3-S*. The proposed longwalls in Area 5 and the Study Area have been overlaid on an extract of this CMA map in Fig. 0.9".

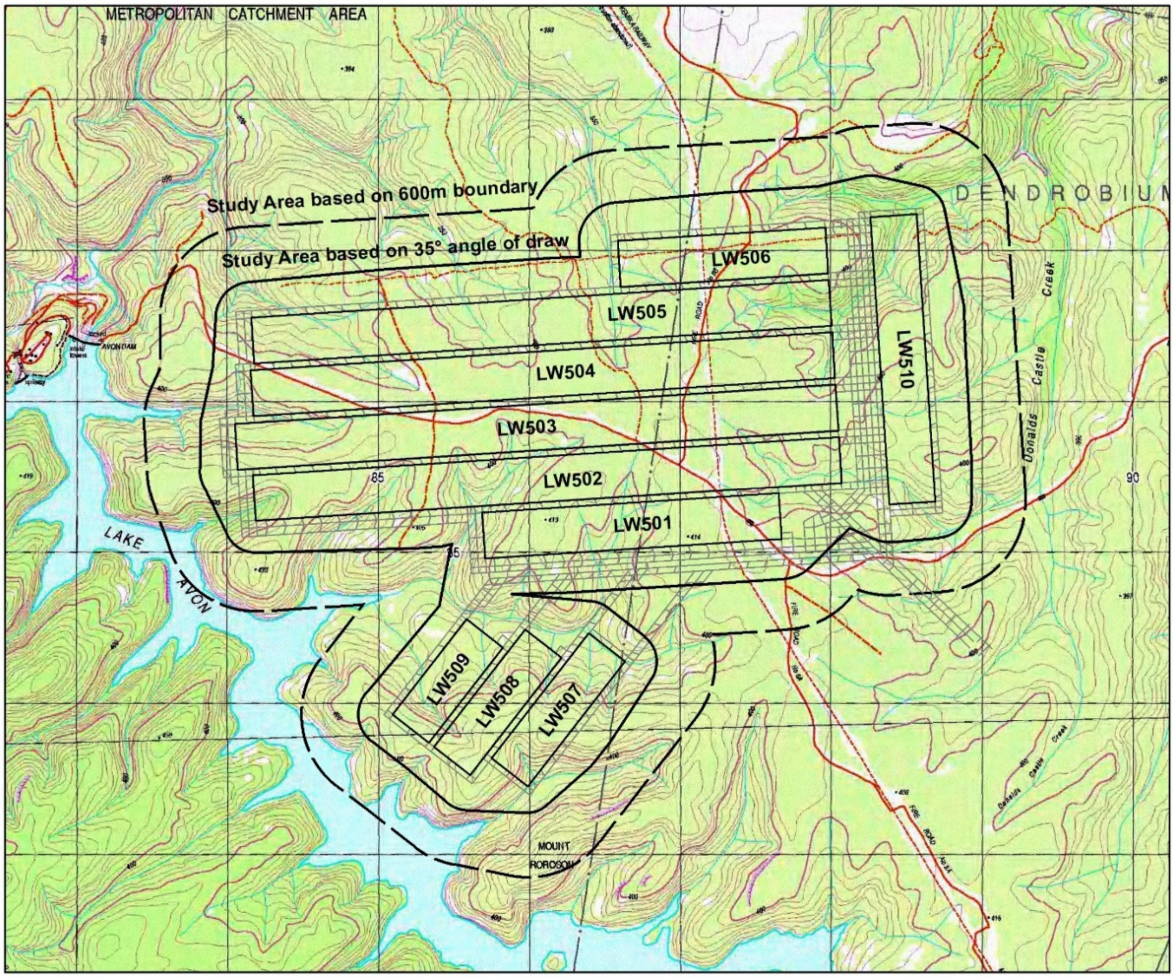


Fig. 0.9 Proposed longwalls overlaid on CMA Map *Avon River 9029-3-S*

The following acronyms are used to describe the major geological units in various reports, as follows:

- HBSS – Hawkesbury Sandstone
- NPFM – Newport Formation
- BACS – Bald Hill Claystone
- CVSS – Colo Vale Sandstone
- WBFM – Wombarra Formation.

2. REVIEW OF MSEC SUBSIDENCE REPORT

The following comments on the MSEC Report are provided in the order that issues appear in the report, with page numbers and section numbers quoted, where relevant. The Executive Summary is discussed at the end of this section of the peer review report and provides a basis for a summary of the overall subsidence assessment.

2.1 Section 1: Introduction

1) This section provides factual background information regarding the project and the characterisation of the mining location. Large sections of this Introduction have already been reproduced in section 1.2 above, and no further comment is required here, other than the specific geological comments below.

2) Pp 7-9, section 1.4: Geological Details – The major overburden geological units are described here and illustrated in MSEC Fig. 1.7. This is a very generic geological section for Dendrobium Mine as a whole, without specifying any particular location. Given that in the later discussion of expected subsidence, the predictions are based on calibration of the methodology with results from Area 3B, it would be useful in this current section if there was evidence provided, plus some discussion and comparison between the typical overburden geology over Area 3B, compared to that expected across and within Area 5 – if in fact, there are any expected differences. In particular, the presence and thickness of major strata units, especially the stiffer/stronger units, can have a significant impact on subsidence behaviour. If there are no appreciable differences, it would be useful to make a statement to that effect. In the event that there are any significant differences, their impact on subsidence predictions should be discussed and allowance made in the prediction values, discussed later in the report.

3) Pp 7-9, section 1.4: Geological Details – It is also noted that there is a north-north-east to south-south-west trending fault mapped across Area 5, impacting Longwalls 501 to 506. This is indicated on MSEC Figure 1.8, together with evidence of some other lineaments that cross the Study Area. Whilst it is reassuring that these different structures are understood to be similar to those encountered in Area 3B where the specific impact of the lineaments and other structures is said to have been minimal, with no apparent increases in subsidence or any adverse impact, it would be useful to give some consideration to the potential upper-bound of impact that such features could have, beyond that experienced in Area 3B, and how this might be assessed prior to, and during mining. It would also be useful to define the current knowledge of the fault across the area, in terms of range of throw expected, and any other specific features that may impact on geotechnical behaviour.

2.2 Section 2: Definition of the Extent of the Longwall Mining Area

1) Key elements of this section have already been included in the Background section (Section 1.2) above.

2.3 Section 3: Overview of Mine Subsidence and Prediction Methodologies

1) Pp 13-16, sections 3.1 to 3.4 – These sections provide a useful description of the different forms of subsidence, including both conventional, and non-conventional subsidence behaviour. This is considered to be an appropriate description. However, it would also be of assistance and provide greater clarity for readers not familiar with the terminology, to include a clear definition, and explanation of the differences between the terms *"subsidence effect"* and *"subsidence impact"*.

2) Pp 16-17, sections 3.5 and 3.6 – These sections describe the application of the Incremental Profile Method (IPM) for subsidence prediction, and its calibration using data obtained from Area 3B. The IPM was developed by MSEC, with industry support through the ACARP research program, over the past 20+ years – based on an extensive industry database of subsidence monitoring data, the largest source of which has been the NSW Southern Coalfields.

   It is my opinion, and that of most industry and subsidence experts, that the IPM is one of the most appropriate and well-proven empirical subsidence prediction methods available in Australia for coal mining subsidence prediction at the present time. It has been refined over the years to not only deal with conventional subsidence, with high levels of confidence, but also increasing confidence levels in predicting non-conventional subsidence effects.

   It is important to recognise that MSEC adopts a conservative approach in the use of the IPM, whereby predictions made represent an upper-bound of expected subsidence effects.

3) Pp 17-22, section 3.6: Calibration of the IPM – There is considerable discussion of the various tools used for calibration of the IPM based on experience from Area 3B in particular. Use of LiDAR is discussed, together with conventional ground monitoring data. It is reported that actual subsidence effects were found to be of the order of 30% greater than that predicted by the earlier IPM method. As a result, a re-calibration of IPM was conducted, to provide for this 30% increase in maximum subsidence, leading to the so-called MSEC792 version of the IPM. The results presented in Figures 3.3 to 3.6 of the MSEC Report provide a high degree of confidence in the re-calibrated IPM prediction technique, for the Area 3B results.

   Section 3.6.3 then discusses the application of the IPM to Area 5, noting that the different seam being mined (Bulli as opposed to Wongawilli) results in lower mining heights. MSEC state that they have adopted a conservative approach in still using the MSEC792 version of the IPM.

   It is then stated that the MSEC792 version produces a maximum subsidence value of 76% of seam thickness, and so the predictions have been downrated to a lower level to achieve a maximum subsidence value of 65% of seam thickness, which is considered reasonable. This equates to a 12% increase on the original IPM model, rather than the 30% incorporated in MSEC792.

   I fully understand what MSEC has done here and have no fundamental problems with it. However, the way it is described may be considered a bit confusing. Given that it is now a 12% rather than 30% upgrade on the original IPM, I believe MSEC should not state that they have used MSEC792 for Area 5. They have in fact used a new version (at 12%), which should be described with a new or unique name.

I also believe it is not in fact a genuine calibration of the model at this stage, but rather, a preliminary adjustment, to match a 65% upper bound for maximum subsidence. Whilst I have no objection to what has been done, and that this seems to be appropriate at this point in time, for an initial prediction of Area 5 subsidence, I would suggest that it is not a legitimate calibration yet. Such a calibration should occur at the earliest opportunity after mining has commenced in the first longwalls of Area 5, with further adjustments then applied for the remainder of Area 5, if necessary.

As noted in section 2.1, point 2 above, any impact of different geology in Area 5 should also be discussed here.

4) Pp 23–28, Section 3.7: Numerical Model – This section discusses a numerical model developed by MSEC for the Bulli Seam using the distinct element code, UDEC. Past experience with UDEC has confirmed that it is one of the most suitable numerical codes for replicating coal mine subsidence behaviour. The results presented in this section indicate very good correlation with the IPM results for Dendrobium Area 3B, which provide further reassurance regarding the use of both the IPM and the UDEC models. It is agreed that there is no need for further recalibration of the IPM model, based on the UDEC results. As noted in point 3 above, the next stage of IPM calibration should come once mining has commenced in Area 5.

5) Pp 28-29 Section 3.8: Mine Design based on Major Stream and Critical Stream Features – MSEC notes that all rivers and named streams are at least 600m from the closest mining, falling outside of the nominated 600m limit for the Study Area. The two named streams, Avon River and Donalds Castle Creek are at minimum distances of 900m and 700m away from the mining boundary. This degree of protection is considered adequate, and the conclusion of minimal subsidence effects or adverse impacts is accepted as reasonable. Other unnamed streams do exist over the mining Study Area, and there will be localised effects and impacts on these, as discussed subsequently.

2.4 Section 4: Maximum Predicted Subsidence Effects

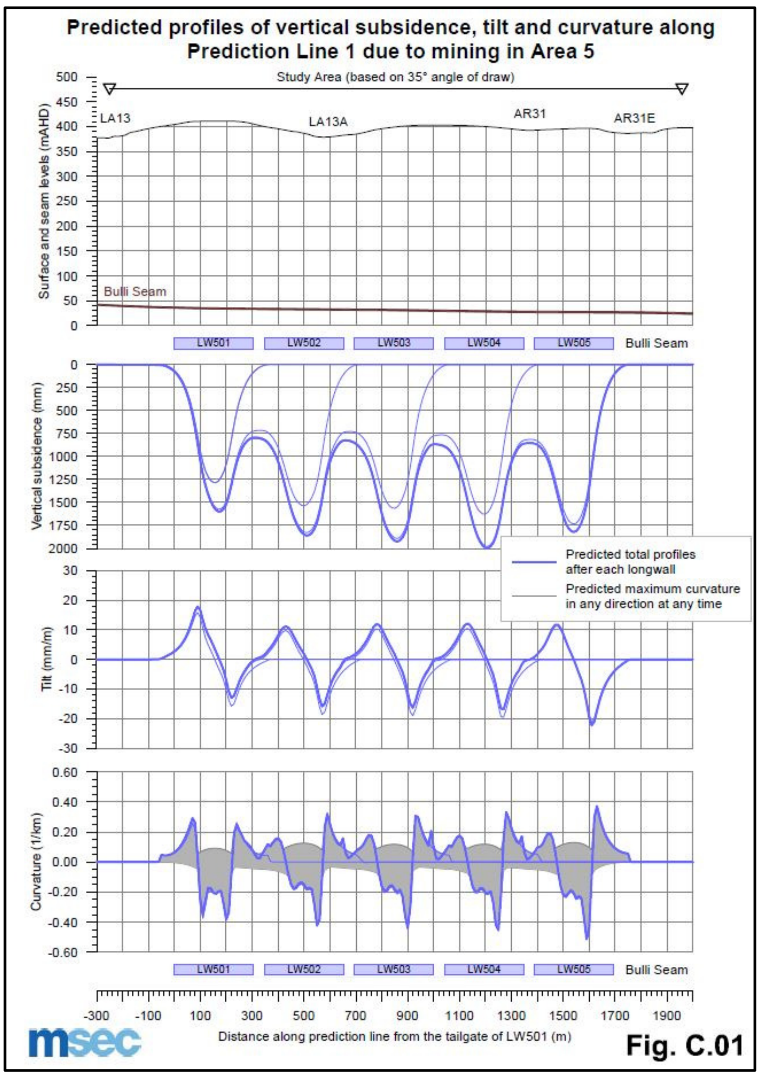
1) Subject to the previous commentary on the prediction methods used by MSEC, I am satisfied that the predicted subsidence effects reported by MSEC are reasonable, representing a conservative upper bound of expected magnitudes. I do not propose to comment on individual features or parameters, as reported by MSEC.

2) The following is an extract from the MSEC Report, showing MSEC Table 4.4, which summarises the major subsidence parameters for the Area 5 prediction, relative to Areas 3A and 3B. In all cases, the Area 5 values are significantly lower, and hence, more benign.

   MSEC's Figure C-01 is also reproduced below to show a graphical representation of subsidence effects across a line extending over Longwalls 501 to 505 in Area 5.

Table 0.3 Comparison of maximum predicted total subsidence effects at the Dendrobium Mine

Layout	Mining area	Maximum predicted total conventional subsidence (mm)	Maximum predicted total conventional tilt (mm/m)	Maximum predicted total conventional hogging curvature (km^{-1})	Maximum predicted total conventional sagging curvature (km^{-1})
Existing and approved longwalls at the Dendrobium Mine	Area 3A	3000	40	1.0	1.0
	Area 3B	3600	50	1.4	1.4
Revised Layout (MSEC1181)	Area 5	2000	25	0.50	0.60



3) Pp 34-35, Section 4.6: Far-Field Movements – MSEC draws an appropriate conclusion that far-field horizontal movements will be experienced in association with mining in Area 5, but these are unlikely to result in adverse physical impacts generally, as they are usually associated with block movements and very low levels of strain. This general conclusion is accepted. However, MSEC makes the statement that the impacts of such movements are not expected to be significant *"except where they occur at large structures which are sensitive to small differential movements"*. Accepting this to be a valid statement, it would be useful for MSEC to advise where, if any, such structures exist, and what level of adverse impact might occur.

4) P36, Section 4.8: Surface Deformations – It is reported that surface deformations, and cracking in particular, are likely to be of similar or less magnitude than those for Areas 3A and 3B, and certainly less than those for Area 2. This is agreed.

2.5 Section 5: Maximum Predicted Subsidence Impacts for Natural Features

1) Similar to my opinion on the previous section regarding subsidence effects, I am satisfied that the predictions made by MSEC regarding impacts on natural features are reasonable, without discussing each one, or each type of feature individually. I repeat the comment made at the start of this peer review report, that it is not within my scope to comment on the acceptability or otherwise of the predicted impacts. That responsibility lies with others. However, I will draw attention to several points which warrant further priority attention.

2) P43, Section 5.3.2 – MSEC makes the point that conventional closures (conventional horizontal movements towards the centre of the mining void), are reported separately to the non-conventional valley-related closures, which generally occur only at the valley floor. However, it is understood that MSEC considers these in total, when considering the impact of all such closures.

3) P51, section 5.3.2 – It is noted by MSEC that *"the likelihood and extents of the assessed impacts on the first and second order streams due to the extraction of the proposed longwalls in Area 5, therefore, are expected to be less than that observed above the previously extracted longwalls in Area 3B"*. This is an important conclusion that provides a degree of reassurance regarding stream-based impacts.

4) Pp 60-65, Section 5.9 – This section discusses impact on swamps, both due to undermining, and adjacent mining. Whilst it is noted that the predicted number of swamps to be undermined is less under the revised Area 5 layout (compared to the original layout) and maximum predicted subsidence effects are unchanged, some of the effects and hence impacts are greater at individual swamps. MSEC then discusses swamp impact assessment. Whilst the technical descriptions of the expected subsidence impacts are accepted as reasonable, consideration of the nature of these impacts on swamp health and conditions warrants further consideration by someone with expertise in swamp impacts.

   MSEC makes a number of recommendations for the swamps, stating that they should be read in conjunction with reports from other project specialists. Such reading by other appropriate experts should give consideration to these MSEC recommendations, recognising that they are not intended to be impact-preventative, but informative.

2.6 Section 6: Maximum Predicted Subsidence Impacts for Built Features

1) Similar to my opinion on the previous sections regarding subsidence effects and impacts on natural features, I am satisfied that the predictions made by MSEC regarding impacts on built features are reasonable, without discussing each one, or each type of feature individually. I repeat the comment made at the start of this peer review report, that it is not within my scope to comment on the acceptability or otherwise of the predicted impacts. That responsibility lies with others. However, I will draw attention to several points which warrant further priority attention.

2) Pp 70-77, Section 6.3: Dams and Reservoirs – This section discusses predicted impacts on dams and reservoirs in the vicinity of the study area. The most significant feature for consideration is the Avon dam wall, at a distance of approximately 1,000m from the end of Longwalls 504 and 505. MSEC predicts far-field horizontal movements and potential valley closure at this location, with a magnitude of up to 10mm. MSEC recommends the development of appropriate monitoring and management strategies for the reservoirs and dam walls, including TARPs and a detailed assessment of the dam walls. It is further recommended that an independent review be conducted on the possible or expected impact of 10mm of valley closure on the actual dam wall structure.

3) Pp77-81, Section 6.4: Aboriginal Heritage Sites – MSEC has considered effects and impacts of subsidence on multiple heritage sites, both above the proposed longwall panels, and adjacent to them, but within the Study Area. This is once again a matter for specialist experts to determine the acceptability of any adverse impacts. MSEC has made predictions on subsidence, curvature and tilt. An assessment has also been made on the likelihood of fracturing through rockbars in stream beds containing heritage sites such as grinding grooves.

   It has been noted by MSEC that the mining of longwall panels will result in fracturing of exposed bedrock along the streams, which may or may not intersect any grinding grooves present. MSEC agrees that it is extremely difficult to assess the likelihood of such fracturing intersecting grinding grooves. They have made an assessment, based on past Southern Coalfield experience, that the likelihood of such impact on grinding groove sites directly above mining, is *"unlikely"*. However, the basis for this assessment is not discussed in any detail but must be regarded as dependent on many site-specific conditions and, as such, could involve a wide degree of uncertainty.

2.7 Executive Summary

1) The Executive Summary provides a useful summary of the wide range of subsidence effects and impacts predicted by MSEC to occur, as a result of the proposed longwall mining in Area 5. The above discussion has highlighted a number of issues associated with the prediction method used and its application to Area 5, together with some specific comments in relation to effects and impacts.

The following is a copy of the summary table of these effects and impacts, reproduced from Table 1 in the MSEC Executive Summary.

Table 1 Maximum predicted subsidence effects for the natural and built features based on the Previous and Revised Layouts

Feature type	Parameter	Name	Previous Layout (i.e. Previous Area 5 and Area 6)	Revised Layout (i.e. Revised Area 5)
Named streams	Total length of stream within 600 m of the longwalls (km)	Avon River	0.8	0.0
		Cordeaux River	1.4	0.0
		Donalds Castle Creek	3.3	0.0
		Wongawilli Creek	0.0	0.0
	Maximum predicted additional closure due to the longwalls (mm)	Avon River	200	30
		Cordeaux River	80	< 20
		Donalds Castle Creek	200	30
		Wongawilli Creek	< 20	< 20
Unnamed streams	Total length directly above the longwalls (km)	Third order	0.9	0.0
		First and second order	34	14
	Maximum predicted total closure due to the longwalls (mm)	Third order	1150	325
		First and second order	1000	750
Key stream features	Number located within the Study Area	-	45	15
	Maximum predicted total closure (mm)	-	700	300
Cliffs	Number located directly above longwalls	-	40	12
	Total length located directly or partially above longwalls (km)	-	2.2	0.8
	Maximum predicted total vertical subsidence (mm)	-	2000	1600
Rock outcrops and steep slopes	Maximum predicted total vertical subsidence (mm)	-	2450	2000
Upland swamps	Number directly or partially above longwalls	-	26	15
	Number within the 600 m boundary	-	46	22
	Maximum predicted total vertical subsidence (mm)	-	2300	1950
Dam walls	Minimum distance from the longwalls (km)	Avon Dam Wall	1.0	1.0
		Cordeaux Dam Wall	1.1	> 4
	Maximum predicted total closure (mm)	Avon Dam Wall	20	10
		Cordeaux Dam Wall	20	< 3
Aboriginal heritage sites	Number directly or partially above longwalls	Isolated finds	0	0
		Grinding groove sites	11	3
		Rock shelters	9	3
	Maximum predicted total vertical subsidence (mm)	Isolated finds	< 20	< 20
		Grinding groove sites	2150	1550
		Rock shelters	1650	1750

3. REVIEW OF WATERSHED REPORT – HEIGHT OF FRACTURING

This section of my peer review report is focused on one element of the Watershed Report, which addresses the topic of Height of Fracturing at Dendrobium, as indicated in the scope for this peer review (see section 1.1).

3.1 Background Discussion

Prior to providing specific review commentary on the relevant sections of the Watershed Report, it is considered to be valuable to repeat some general background discussion, as previously reported by me as part of my role in undertaking an independent review of results on this topic at the end of several longwall panels mined in Dendrobium Area 3B (Hebblewhite (2018, 2019, 2020a, 2020b, 2021). The following text has been extracted directly from those various Area 3B reports to DPIE.

Knowledge of the detailed nature of rock deformation and failure above any form of large-scale underground mining is always going to be limited to interpretation from a very incomplete set of data. It is extremely difficult, if not impossible, to directly measure the detailed nature of the rock failure, fracture networks and deformational behaviour above an extracted mining area. Limited techniques such as borehole extensometry can provide some evidence of relative or incremental deformation in the direction of the borehole (usually vertical). However, such data cannot assist below the horizon where full caving has caused major rotation and dislocation of rock blocks and effectively destroyed the instrumentation borehole. Above such a horizon, the data is only valid along the axis and in the direction of the borehole, and to the level of detail defined by the extensometer anchor spacing intervals.

Other direct measurement techniques include the use of either borehole inclinometers or Time Domain Reflectometry (TDR), both of which can assist with measuring shearing across the line of the instrumentation borehole, usually, but not always associated with bedding plane horizons. Coupled with an extensometer to provide movements in the borehole axis direction, the combination of extensometers and inclinometers, or TDR, provides a "coarse" level of deformation measurement along the axis of the instrumentation borehole. This direct borehole monitoring data can also be complemented by down-hole geophysical and caliper logging to provide further fracturing information along the axis of the borehole, together with various forms of borehole wall inspection or scanning devices. However, none of these different borehole techniques assist with detection of the laterally dispersed deformation and failure taking place away from the individual instrumentation boreholes. The result is therefore a very incomplete dataset that relies heavily on in-fill estimation and interpretation.

Why then is there a need for an improved knowledge of such regional deformation and failure above the mining location – in particular, above underground longwall mining panels? The answer can relate to a number of important issues:

(a) To consider the effect of mining taking place at one horizon on a higher horizon within the overburden (either mined previously, or planned to be mined in the future);
(b) To assist in developing predictive models for estimating surface subsidence;

(c) To develop an understanding of, and predictive model for the impact of underground mining on groundwater present within the overburden.

It is this third issue that has taken on increased importance in recent years and is the primary focus of this current and previous reviews. In fact, the reason for trying to define regions of fracturing above a longwall panel is not typically about defining the deformation and fracturing specifically, but actually about interpreting the impact of such deformation and fracturing on the groundwater regimes. Such information is also critical to the establishment of a "calibrated" groundwater model for the area.

Furthermore, at the present time, it is often the measurement of groundwater data which is used to infer the different fracture zones – so the whole argument becomes a circular one. We measure groundwater pressures and related data to infer overburden fracture zones in order to estimate groundwater impact levels and regions. Why not simply refer to the parameters we can measure – groundwater pressures and properties – rather than making arbitrary distinctions regarding the level of rock fracturing that is not clearly defined?

However, as a part of the scope for these various reviews of "height of fracturing" at Dendrobium, there has been a desire to assess a number of rock deformation and fracturing parameters in the overburden above longwall mining, specifically:

- The height of connective cracking (or fracturing);
- Extent of surface cracking;
- Potential connections with horizontal partings.

It is therefore important to have a clear understanding of what is meant by these terms and how they relate to each other and to the mining process.

Firstly, fracture patterns associated with overburden rock strata subjected to longwall mining can be extensive and quite variable, ranging from complete rock failure in the immediate caving zone above the coal seam, through to some level of near-surface tensile cracking within the subsidence impacted zones of curvature. It must be understood that these two extremities of the fracturing regime are normally isolated from each other, and subject to quite separate or independent mechanisms. It is simply not possible to fully analyse or characterise all fracture patterns throughout the overburden – either pre- or post-mining. It is considered more important to focus on what is commonly referred to as the *"height of connective cracking, or height of fracturing",* which is a widely-used term. The issue of surface cracking is also of interest, but as a separate fracture region within the overburden, as noted above.

Even the concept of height of fracturing is difficult to fully and accurately *"analyse and characterise"* and remains a subject of some debate amongst the geotechnical and hydrogeological community. However, it is accepted as being very important to gain a meaningful understanding and best-estimate analysis of such a region of fracturing and *"connective cracking"* within the overburden, using whatever practical means available.

It is important when discussing the height of fracturing zone to establish some common and consistent terminology. The actual nature of the fracturing above a longwall panel cannot be directly measured but can generally only be inferred from indirect observations and measurements, as discussed above. The conceptual model of the fracture zone has been discussed internationally by many authors through the use of a number of simplified conceptual models which describe a series of zones of different types of rock failure, fracturing and deformation above longwall panels.

On the basis of this form of conceptual model and definitions, the term *"height of fracturing"* is used to refer to the region of connective fracturing and structural deformation (bedding planes, joints etc) leading to increased permeabilities which will result in significant depressurisation of the strata. For this reason, groundwater pressure monitoring can be used as a means of detection of the upper limit of this fracturing zone, rather than relying on direct, but limited deformation and fracture monitoring, which, as discussed above, is extremely difficult.

On the basis of these concepts, several empirical prediction models have been developed in Australia to estimate height of fracturing based primarily on mining geometries (depth, panel width and mining height). Two such empirical models are the Tammetta and the Ditton models – both of which have been applied at a number of Southern Coalfield mines, and elsewhere.

Some important summary points to note in relation to the above concepts:

- These are concepts only, representing hypotheses regarding the nature of fracturing above an extracted longwall panel. They have been developed as conceptual artefacts, in order to describe the type of deformation and fracturing of the overburden strata, and how it is made up of different zones or different types and intensities of deformation and fracturing.
- These concept models have been developed based only on indirect or very incomplete data sets, be they data from geotechnical monitoring, groundwater monitoring or numerical and physical modelling.
- The gradation from one zone to another in any of these models, whilst appearing distinct within the concept diagrams, may well be quite gradual and transitional, rather than distinct boundaries, and may be highly impacted by localised geological factors such as specific strata units present, or other structural defects including bedding planes, joints and major structures (faults, dykes etc.).

Based on the above points, caution is urged in use of these model concepts, without significant qualification, and/or detailed analysis of the underpinning data. The breakdown of the overburden into distinct zones should only be regarded as an artefact or concept, to aid in understanding, rather than an exact definition of what is occurring in the ground.

It is further proposed that there should be a change in the terminology – for all of the reasons discussed above, relating to both the nature of the deformation and fracturing characteristics; as well as the means of measurement or estimation. For use of this concept for groundwater impacts, it is proposed that the term ***"height of depressurisation"*** be adopted in future, rather than the terms *height of fracturing*, or *height of connective cracking*. This proposed terminology is directly linked to the application of the term for groundwater purposes, as well as being directly linked to the means of measurement or estimation.

It is also noted that some authors are also making reference to this zone as a height of drainage. However, a caution is raised with such a term, which is discouraged. Whilst it is acknowledged that some increased level of free drainage will occur in this zone (to enable depressurisation to occur), the word drainage can sometimes be interpreted to refer to total dewatering, which is certainly not usually the case within the depressurisation zone. From a groundwater perspective, the height of drainage where complete dewatering is always expected would more commonly be associated with the immediate caving zone, directly above the extracted longwall panel.

Reference is also made to the IEPMC Report (2019) which acknowledged some important points raised in my previous reports and reported above – firstly, that the description of discrete zones within the overburden, as described by many of the height of fracturing conceptual models, is a misnomer, and in fact the extent of fracturing and the changes in fracturing and related strata permeability do not exist as step changes, but as gradational changes with fracturing occurring often beyond the so-called fractured zone, and is potentially connected cracking. A further important comment by IEPMC is: *"zones defining mining-induced rock deformation do not necessarily align with zones defining groundwater response to mining"*.

One further general point I would make here is to refer to the behaviour of shearing on bedding planes within the overburden, which is quite a common phenomenon associated with overburden behaviour above, and adjacent to longwall extraction. Whilst such shearing can be quite significant, in terms of shear deformation, the extent to which it contributes to any change in strata permeability is not well understood, and certainly cannot be assumed to occur, whenever such shearing occurs. Once again, terminology is important, and it is recommended that this type of behaviour be referred to as bedding plane shear, rather than the commonly used basal shear term, since it is not restricted to just the basal horizons of major strata units.

3.2 Review Commentary – Watershed Report

The sections of the Watershed Report that are directly relevant to the issue of "height of fracturing", or height of depressurisation, are section 3 (Mining Effects), and specifically, sections 3.1, 3.2 and 3.3. My review commentary on these sections follows. (Note: In my comment referencing below, I am referring to a "track-change" draft version of the Watershed Report, as provided to me, so page numbering may vary in different forms of the report).

1) P76, Section 3, para 2 – It is noted that data from the nearby Tahmoor Mine, which mines the Bulli Seam, has been reviewed by the authors to inform and support their conclusions in the development of a groundwater model. This is endorsed as a valuable initiative.

2) P76, Section 3.1 – Watershed discusses the commonly defined fracturing zones above longwall extraction, including the caved zone directly above the extracted coal horizon or goaf; and the surface cracking zone. Between these two zones is a zone commonly referred to as a *"constrained zone" within which fracturing is minimal and permeability remains relatively low"*. This concept of such a zone is accepted as appropriate, although caution is recommended on the general point that potential movement of water through the strata does not just rely on fracturing but can also occur on deformed bedding planes (near-horizontal) and deformed or open joints (near-vertical).

Watershed then makes the important statement (which is consistent with my previously reported experience in Area 3B) that *"At Dendrobium, the longwall geometry is such that a constrained zone is likely not present"*. This statement is totally endorsed based on previous experience at Dendrobium, with the implication that the height of depressurisation can extend to well within the Hawkesbury Sandstone, if not to the surface.

3) P77, Section 3.1 – Discussion is then provided on the various forms of conceptual model available, noting the more recent work by Adhikary & Poulson (2021), in addition to the earlier work by Tammetta, Ditton & Merrick, and others. It is importantly noted here that the terms or definitions used by the authors of these various models differ, explaining some of the variations in outcomes. It is noted, for example, that Tammetta refers to a *"height of desaturation"*, or more correctly, a height of complete depressurisation (which aligns with my earlier terminology recommendation). In contrast, Ditton & Merrick refer to a *"zone of continuous cracking (A Zone)"*, which is not necessarily the same as the Tammetta height and may not be the most appropriate definition, in isolation, in terms of inferring groundwater behaviour – see my earlier introductory discussion.

4) P80, Section 3.1 – Watershed then makes the further comment that the authors of the various conceptual models emphasise that *"seam to surface fracturing does not imply seam to surface connection"*. Whilst I accept that this quote may be a direct reflection of the work of these various authors, the statement itself is rather simplistic and could be misconstrued. It is all about the extent and degree of connectivity of fracturing, PLUS the all-important other deformation and opening of structures such as joints and bedding planes (regardless of fractures). I do, however, accept that there can be regions of fracturing within all geological units from seam to surface, without them necessarily being connected.

5) P80, Section 3.1 – An important observation is made here concerning post-mining compression and reconsolidation of fractured overburden strata, resulting in a positive impact on some groundwater storage horizons within the overburden. Using gas drainage data, figures are quoted for permeability reductions averaging 65% in the caved zone over a period of months, post-mining. These figures illustrate the concept of compression and reconsolidation, although the actual numbers would not be applicable to water permeability in the higher horizons.

   This is a very important factor, in relation to groundwater recovery, albeit that the time period involved for any significant recovery is likely to be years rather than months. However, early signs from post-mining monitoring over Area 3B are very encouraging, indicating some degree of storage recovery at various horizons in the upper sections of the overburden. This has been commented on in my previous Area 3B review reports, and is discussed again, later in this review.

   Evidence of this was provided by Watershed, earlier in their report, presented in Figure 2-19, which is reproduced below, for information. The areas where this behaviour has been observed are indicated by upward blue arrows on the boreholes, and shaded areas of inferred saturated strata. Evidence shows increasing regions of groundwater recovery, and some isolated perched aquifers within the Hawkesbury Sandstone, with some evidence extending down to and just through the Bald Hill Claystone also. The effect of time is also evident, with more evidence of this recovery above the older longwall panels, mined between 2014 and 2017.

It is understood that this diagram represents late 2021 data.

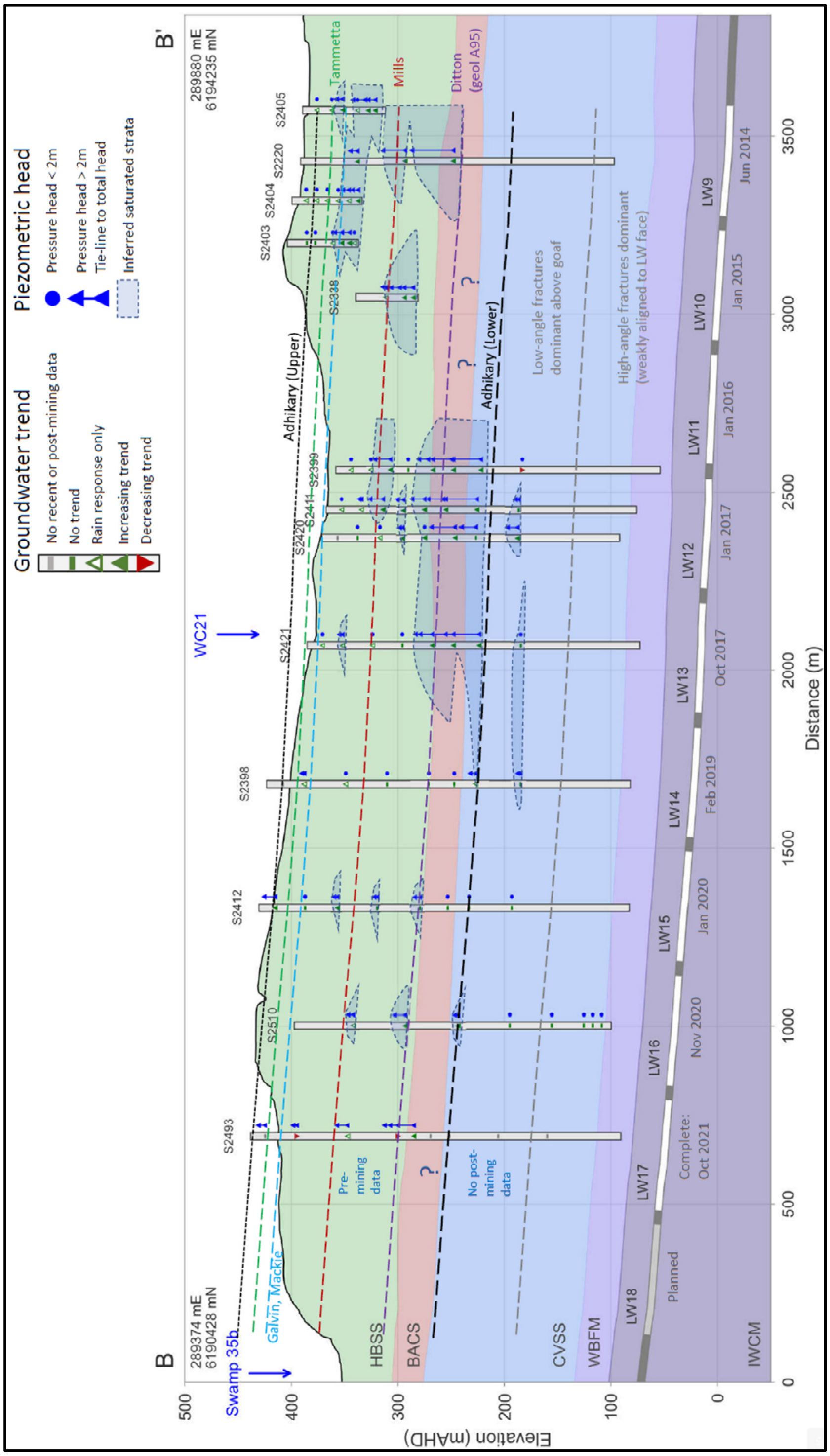


Figure 0-1 Groundwater pressure profile for Area 3B (over-goaf bores)

6) P81, Section 3.2.1 – This section discusses the results obtained from post-mining boreholes over Areas 3A and 3B. Figure 3-2 from the Watershed Report is reproduced below, to illustrate the data obtained from both a pre-mining and post-mining borehole over the centre of a longwall panel, in this case Longwall 14. The data presented includes caliper and fracture logging, permeability and groundwater levels.

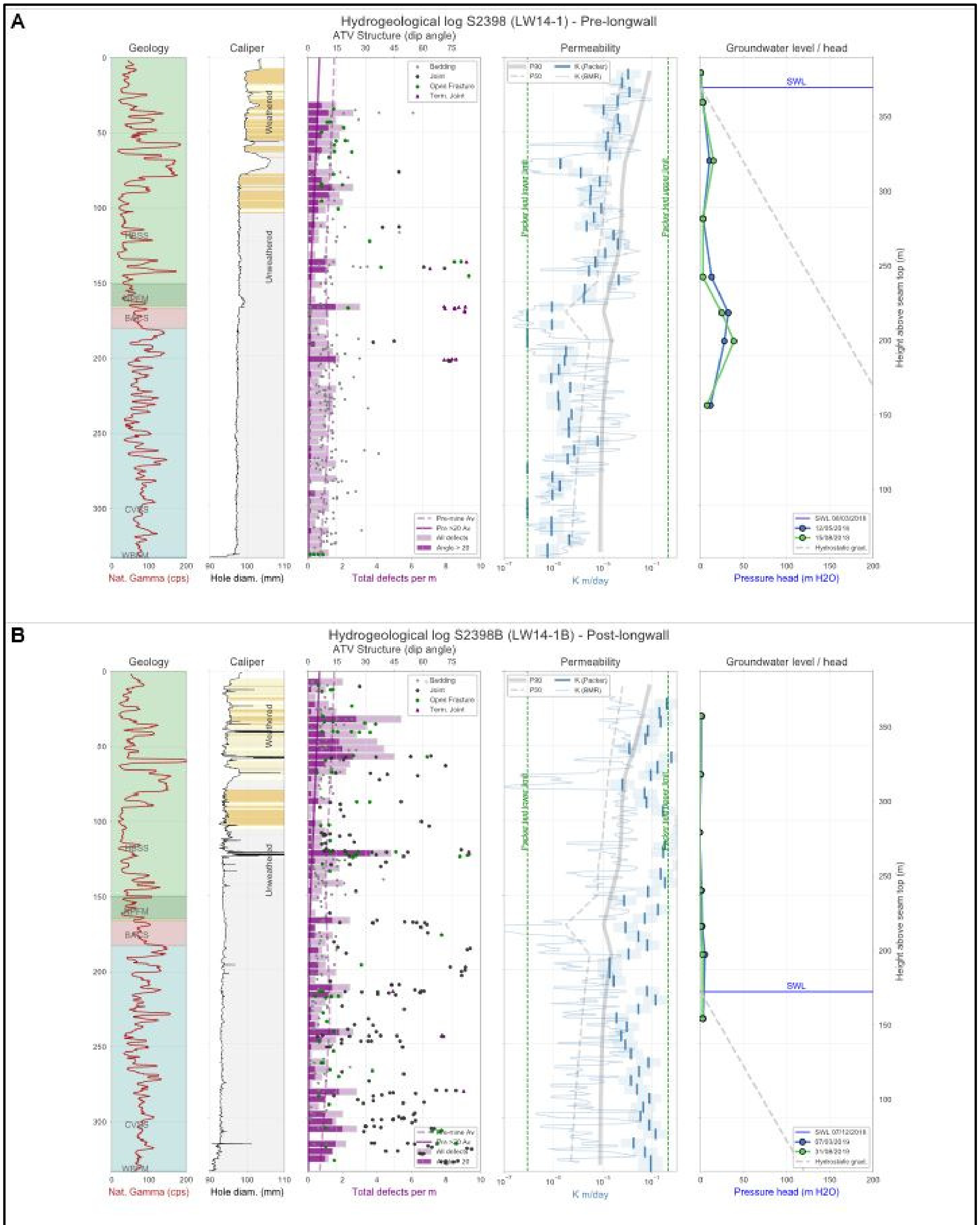


Figure 3-2 Pre- and post-mining conditions above Longwall 14 (boreholes S2398 and S2398B)

The main conclusions reported here are all supported, based on my previous review of such work, and are as follows:

- All holes drilled above extracted longwall panels exhibit significant permeability increases through to the surface (2 to 3 orders of magnitude).
- Mining-induced fracturing extends through to the surface, but with a reducing intensity for the higher-angled fractures.
- Ratio of vertical to horizontal permeability decreases with height above the goaf; whereas horizontal permeability is elevated throughout all strata.
- VWP monitoring indicates strata depressurisation developing well ahead of mining.
- Complete depressurisation of the HBSS is recorded in most holes drilled above the goaf.
- Piezometers installed after mining have recorded evidence of groundwater recovery at some horizons, including perched water, primarily between the upper CVSS and the lower HBSS – occurring above longwalls mined at least three or more years previously.
- Based on these results, the conclusion already reported, is that *"fracturing (and groundwater depressurisation) following mining extends to the surface in Areas 3A and 3B"*.

7) P84, Section 3.2.1 – On the basis of the above conclusions, and the last point (above), in particular, Watershed rightly states that *"this aspect of the observations is consistent with the empirical model of depressurisation put forward by Tammetta (2013)"*. I support this interpretation, which is in line with my previous conclusions in review of Area 3B data, that the Tammetta model provides the best estimate of initial depressurisation after mining.

However, Watershed then refers to a definition given by Tammetta in relation to the depressurised zone, stating that *"This zone is severely disturbed and is completely drained of groundwater during caving. It is subsequently unable to maintain a positive pressure head. It will behave as a drain while the mine void is kept dewatered"*. This statement, taken at face value, is at odds with the above reported experience in Area 3B where some level of groundwater recovery is experienced over time, including the establishment of some perched aquifers within the so-called zone of depressurisation.

I have not independently verified the above quotation from Tammetta, or the source or context of this statement. However, accepting it for what it is, Watershed is inferring that the Tammetta model is therefore inconsistent with the Area 3B data. Using the above definition, I agree. However, I do not step away from the primary conclusion that, setting aside this specific definition of behaviour, the Tammetta model does produce a useful estimate of the height of depressurisation, at least in the immediate timeframe after mining.

What it does not assist with is any determination of the time-dependant behaviour of the various groundwater horizons. In fact, none of the current conceptual models explicitly attempt to model or define a time-dependent relationship with regard to groundwater recovery, as is now being observed. Watershed has also considered the more recent work of Adhikary and Poulson, who also define a range of heights of fracturing. Within the definitions used in the Ditton & Merrick model, their model does indirectly address this issue by predicting a height of genuinely connected fracturing, below which, by definition, groundwater recovery would not be possible at any subsequent time period (whenever the mine void is dewatered). But such a prediction is not as appropriate for the immediate, post-mining depressurisation height, as predicted by Tammetta.

The reality is therefore that a number of conceptual models should be considered for different purposes, giving recognition both to the immediate post-mining effects and impacts, as well as the time-dependent groundwater recovery. Different parameters should be chosen accordingly, to reflect the different time-dependent conditions.

8) P84, Section 3.2.1 – Brief mention is made of the shallow, surface cracking regime, by reference to other mines such as Metropolitan and Tahmoor. It is stated that the depth of such mining-induced surface fracturing is typically 8-10 times mining height, which for the Bulli Seam is 2m –2.5m, resulting in a fracturing depth in the range of approximately 15m – 25m. This conclusion is consistent with my experience and understanding.

9) Pp 85-86, Section 3.2.2 – Discussion of groundwater flow, remote from the mining area, includes reference to TDR results since 2015 in Area 3B confirming single or multiple bedding plane shear horizons in four out of five monitored locations, at distances several hundred metres remote from the active longwall. It is noted that packer test results from such locations do not support a model of these shear planes being *"the primary potential groundwater pathways in off-goaf areas"*. This is an encouraging conclusion, although it would be useful to see some results presented to support this statement and demonstrate the range and variability of such flow pathways, and the associated extent of shear deformation, to identify (a) how consistent such bedding plane shear flow behaviour is, or not, and (b) if there is any relationship between flow magnitude and shear deformation magnitude (albeit that this is not always possible to measure with TDR alone).

10) Pp 86-93, Section 3.3 – Watershed now applies the data interpretation around heights of fracturing and depressurisation to the development of a site-specific groundwater model for Dendrobium Mine. This is an appropriate and very useful approach to take and will result in a powerful model for future consideration of the impacts of mining in Area 5 – taking into account the various observations and commentary on the different heights, as discussed above.

On the basis of the above data conclusions and interpretations, it is correctly noted that *"groundwater impact models must account for restricted vertical drainage above a specified height threshold and recovery of groundwater levels in overlying strata"*.

Watershed has concluded that gradational boundaries should be specified between the various conceptual zones above mining, with the Ditton & Merrick (A Zone) height of vertically connected cracking being a useful definition for the base of the constrained zone, but that depressurisation in the initial instance, will still occur above this horizon immediately post-mining (as per the Tammetta height). It is noted that there is not a significant difference in height between Ditton & Merrick and Tammetta for Area 5.

Figure 3-7 is reproduced below, from the Watershed Report, illustrating the results of the various models for various height parameters above Area 5. This shows both the Ditton & Merrick and Tammetta heights reporting into the base of the HBSS across Area 5, (i.e., above the marked Bald Hill Claystone horizon), although not connecting with the base of the surface fracturing zone (in contrast to the same calculations for Areas 1 to 3).

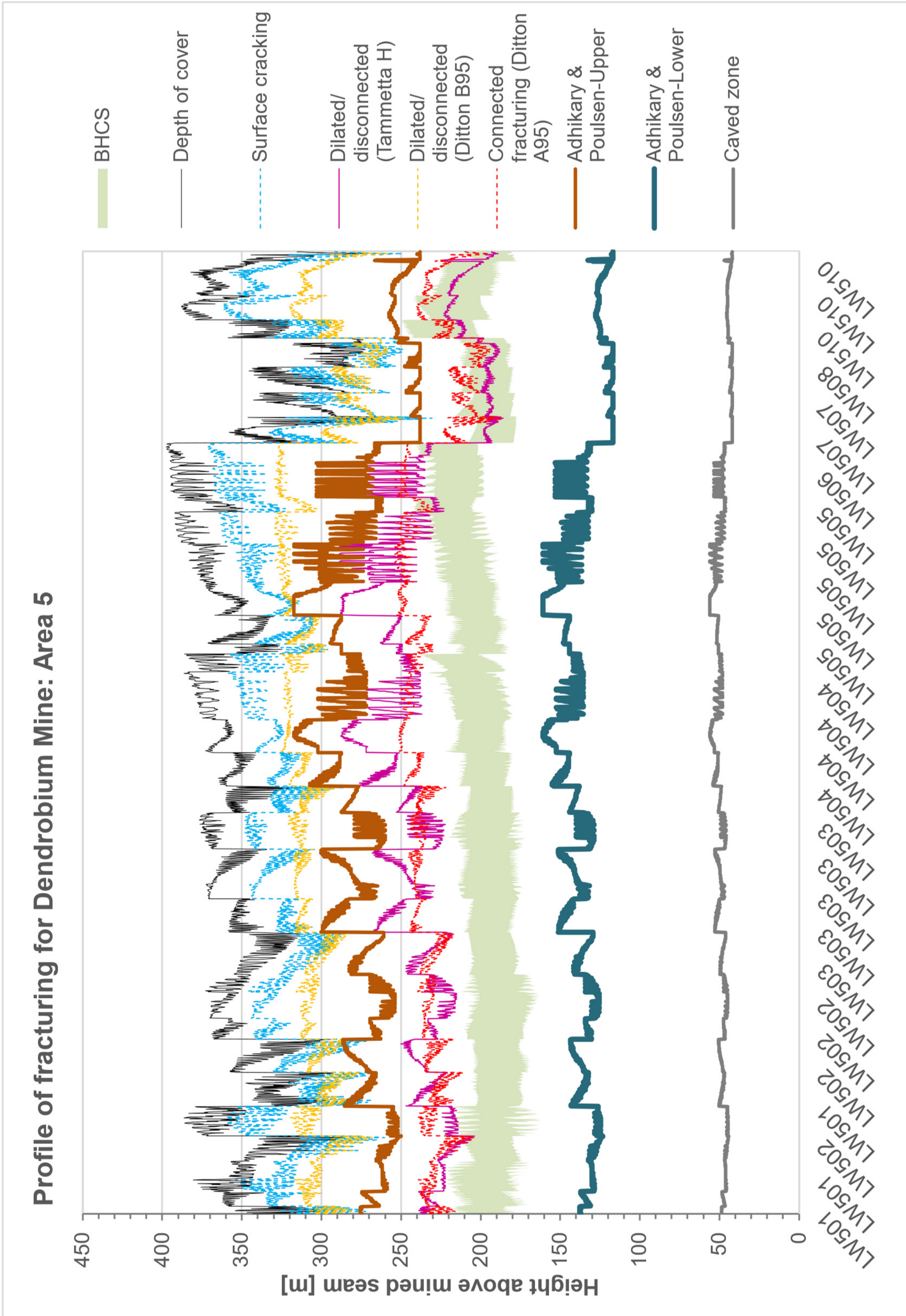


Figure 0-2 Profile illustrating estimated height and mode of fracturing in Area 5

11) Pp93, Section 3.3.1 - Further to the above model development, Watershed draws a conclusion, which I fully support at this stage of the project, stating *"For conservatism, and without other evidence, the DFZ is assumed to extend above the connected fracture zone to the surface cracking zone across much of Dendrobium, including in Area 5. In general, this is supported by considering the maximum of the Ditton B95, Tammetta H, Adhikary-upper (orange, purple and green lines respectively)"*. (Note: DFZ is undefined in the Report, which should be rectified – understood to be Disconnected Fracture Zone).

Bruce Hebblewhite
18 February 2022

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NSW Dept of Planning (2008). Impacts of underground coal mining on natural features in the Southern Coalfield- Strategic review.

APPENDIX A

Attached is a summary Curriculum Vitae for the author of this report, Bruce Hebblewhite. Bruce has worked within the Australian mining industry from 1977 to the present time, through several different employment positions. Throughout this period, he has been actively involved in all facets of mining industry operations. In addition, he has visited and undertaken consulting and contract research commissions internationally in such countries as the UK, South Africa, China, Indonesia, New Zealand, Turkey, Canada, Chile, Namibia, Austria, USA and Kazakhstan. For the majority of his 17-year employment period with ACIRL Ltd he had management responsibility for ACIRL's Mining Division which included specialist groups working within both the underground and surface coal mining sectors, and the coal preparation industry– actively involved in both consulting and research in each of these areas.

In his most recent permanent employment position with The University of New South Wales, Bruce was involved in academic management, undergraduate and postgraduate teaching and research, and contract industry consulting and provision of industry training and ongoing professional development programs – for all sectors of the mining industry – coal and metalliferous, both national and international.

Both past substantive employment positions required regular visits, inspections and site investigations throughout the Australian mining industry, together with almost daily contact with mining industry management, operations and production personnel.

On his retirement from UNSW at the end of December 2020, Bruce was appointed as a Professor Emeritus to UNSW Sydney (an ongoing honorary appointment).

Throughout his consulting career which continues to the present time, Bruce has maintained contacts with the mining industry and mining profession and an ongoing connection with the School of Minerals & Energy Resources at UNSW Sydney and is involved in a number of ongoing industry research projects.

The following summary points further highlight some aspects of his career which are considered to have particular relevance to his current consulting activities:

- Educated in the discipline of Mining Engineering at UNSW, with a BE (Hons 1) in 1974.

- PhD obtained in the UK (1977) in the field of underground mining rock mechanics whilst working for Cleveland Potash in N Yorkshire.

- Obtained a business management Graduate Diploma from Uni of New England in 1991 - Graduate Diploma program run by the Australian Institute of Company Directors (AICD).

- A 45-year professional career of engagement with the Australian mining industry, the first 17 years of which was exclusively focused on the black coal mining industry.

- This career long engagement comprised a range of diverse roles in provision of consulting, research, contract and training/educational services.

- Regular engagement throughout this career with all levels of industry, from senior executives to mine managers, technical services staff, direct production supervisors (deputies) and mine/face production workers.

- Provision, as author, of several hundred consulting and research reports provided to industry, government and other third parties.

- Consulting roles have included:
    - participation in, and/or peer review of mine feasibility studies
    - a range of other independent peer reviews
    - peer reviews focused on underground mine geomechanics and related mine subsidence
    - development of, and review of mining systems and layouts
    - underground mine planning and design studies
    - participation in, and facilitation of risk assessments (management/operational)
    - review of mine management systems and management plans
    - numerous expert witness contracts in relation to mine injury accidents
    - major accident investigations
    - management of a directional long-hole drilling contracting service
    - management and direction of an exploration technology contracting business.

- Educational (academic) roles have included:
    - overall leadership of the Mining Engineering educational program at UNSW
    - establishment and leadership of the national Mining Education Australia program
    - leadership of national and international mining engineering curriculum reviews
    - course leadership in Mining Systems courses (undergraduate)
    - course development/leadership in Mining Processes & Systems course (p/graduate)
    - guest lecturing into course on Contracts and Contractors in Mining Industry (p/grad)
    - guest lecturing into Mining Industry Management course (undergraduate).

SUMMARY CURRICULUM VITAE

Bruce Kenneth Hebblewhite

Consultant Mining Engineer & Principal, ***B K Hebblewhite Consulting***

DATE OF BIRTH 1951

NATIONALITY Australian

QUALIFICATIONS
1973: Bachelor of Engineering (Mining) (Hons 1) School of Mining Engineering, Uni. of New South Wales
1977: Doctor of Philosophy, Department of Mining Engineering, University of Newcastle upon Tyne, UK
1991: Diploma AICD, University of New England

PROFESSIONAL MEMBERSHIPS; APPOINTMENTS; AWARDS & SPECIAL RESPONSIBILITIES

Fellow - Australasian Institute of Mining and Metallurgy
Member - Australian Geomechanics Society
Member – Society of Mining and Exploration Engineering (SME), USA
Member - International Society of Rock Mechanics (President – Mining Interest Group (2004 – 2011))
Emeritus Member - Society of Mining Professors (SOMP) (President (2008/09); Council Member (2006 -2018; 2020 - present); Secretary-General (2011-2018))
Executive Director – Mining Education Australia (July 2006 – December 2009)
Chair, Governing Board – Mining Education Australia (2015)
Member, Branch Committee – AusIMM Sydney Branch (2017-2019)

Expert Witness assisting Coroner: Coronial Inquest (2002-2003): 1999 North Parkes Mine Accident.
Chair: 2007-2008 Independent Expert Panel of Review into Impact of Mining in the Southern Coalfield of NSW (Dept of Planning & Dept of Primary Industries).
Expert Witness assisting NSW Mines Safety Investigation Unit – Austar Mine double fatality, April 2014.
Member (2012 – 2019): Scientific Advisory Board, Advanced Mining Technology Centre, Uni. of Chile.
Trustee (2013 – 2020): AusIMM Education Endowment Fund.
Member (2020 – present): Independent Advisory Panel for Underground Mining, NSW Dept of Planning, Industry & Environment (DPIE).
2012 Syd S Peng Ground Control in Mining Award (SME (USA)) – *"in recognition of his long and distinguished career conducting research, providing instruction and applying practical solutions in the field of ground control"*.
2017 Ludwig Wilke Award (Society of Mining Professors) – *"for his pioneering work as a researcher, his accomplishments as a global educator, and his leadership and vision as Secretary-General of the Society of Mining Professors (SOMP)"*.
2017 Rock Mechanics Award (SME (USA)) – *"for his significant contribution as an educator, researcher and consultant in rock mechanics and ground control"*.
2020 AusIMM Institute Medal – "*for contributions to the mining industry and profession through education, research and training"*.
2021 – Professor Emeritus, University of New South Wales

PROFESSIONAL EXPERIENCE

1995 - present	B K Hebblewhite Consulting Consultant Mining Engineer & Principal
2014 – 2020	University of New South Wales, School of Minerals & Energy Resources Engineering (formerly School of Mining Engineering) Professor of Mining Engineering (p/t)
2003-2014	University of New South Wales, School of Mining Engineering Head of School and Research Director, (Professor, Kenneth Finlay Chair of Rock Mechanics (to 2006); Professor of Mining Engineering (from 2006))
2006 – 2009	Mining Education Australia (a national joint venture between UNSW, Curtin University of Technology, The University of Queensland & The University of Adelaide) Executive Director (a concurrent appointment with UNSW above).
1995-2002	University of New South Wales, School of Mining Engineering Professor, Kenneth Finlay Chair of Rock Mechanics and Research Director, UNSW Mining Research Centre (UMRC)
1983-1995	ACIRL Ltd, Divisional Manager, Mining - Overall management of ACIRL's mining activities. Responsible for technical and administrative management of ACIRL's Mining Division covering both research and consulting activities in all aspects of mining and coal preparation.
1981-1983	ACIRL Ltd, Manager, Mining - Responsibility for ACIRL mining research and commissioned contract programs.
1979-1981	ACIRL Ltd, Senior Mining Engineer - Assistant to Manager, Mining Research for administrative and technical responsibilities. Particularly, development of geotechnical activities in relation to mine design by underground, laboratory and numerical methods.
1977-1979	ACIRL Ltd, Mining Engineer Project Engineer for research into mining methods for Greta Seam, Ellalong Colliery, NSW. Also, Project Engineer for roof control and numerical modelling stability investigations.
1974-1977	Cleveland Potash Ltd, Mining Engineer and Department of Mining Engineering, University of Newcastle-upon-Tyne, UK - Research Associate. Employed by Cleveland Potash Limited to conduct rock mechanics investigations into mine design for deep (1100m) potash mining, Boulby Mine, N Yorkshire (subject of Ph.D. thesis).

SPECIALIST SKILLS & INTERESTS

- Mining geomechanics
- Mine design and planning
- Mining methods and practice
- Mine safety and training
- Mine system audits and risk assessments
- Mining education and training

Dendrobium Groundwater Model Review

Date:	21 March 2022
Project name:	Dendrobium EES
Project no:	IA258800
Attention:	Chris McEvoy
Company:	South32:
Prepared by:	Brian Barnett
Document no:	1

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Background

This memorandum includes my review of the report entitled South32 Illawarra Metallurgical Coal, Dendrobium Mine Extension Project (DMEP), Groundwater Assessment, March 2022 prepared by Watershed HydroGeo (the Report). The Dendrobium Coal Mine is located inland of Wollongong in the Southern Coalfield of New South Wales and is bordered by a number of existing and former mines.

My review is aimed at providing an independent assessment of the groundwater model in relation to the expectations and requirements of the Australian Groundwater Modelling Guidelines and more generally whether the work meets current industry standards and reasonable regulator and stakeholder expectations.

I am a hydrogeologist and groundwater modeller with more than forty years of consulting industry experience. My qualifications and experience are summarised in an attachment to this memorandum.

- I believe I am suitably independent as I:
- Have no pecuniary interest in the project.
- Have never worked for the proponent either as an employee or consultant.
- Have never worked or collaborated with the proponent's specialists (Watershed HydroGeo), other than in a peer review capacity.
- Have never worked on another nearby project that may have material cumulative impacts with the Dendrobium Mine, other than in a peer review capacity.

My review is aimed at assessing the groundwater modelling that has been undertaken to support the environmental impact assessment of the project. Accordingly, I have focussed on those aspects of the conceptualisation and modelling that may influence the simulation of drawdown and flux impacts on the surface and groundwater resources (including water supply reservoirs), and the environmental assets they support. To this end, I understand that the Mine is in close proximity to water storage reservoirs (namely the Avon, Cordeaux and Nepean Reservoirs) managed by WaterNSW and used to supply municipal water to the Illawarra and Sydney. The appropriate simulation of the groundwater interactions with the reservoirs themselves and with the tributary creek and streams that discharge to these reservoirs has been a key aspect of my review.

As a result of my initial review of an earlier version of the Report, there were a number of issues raised as to how the work was reported, and these have been addressed by the author. My comments pertained to the following:

- Improving the clarity of the modelling objectives as presented in Section 1.3.
- Presentation of drawdown contours.
- Providing further justification and clarity on the choice of boundary conditions assigned to the edges of the model domain.
- Clarifying the use of the SFR Package to simulate stream-aquifer exchange.
- Clarifying the justification for recharge assumptions used in climate change scenarios.
- Adding water balance impacts extracted from the entire model domain as reported in Section 6.4.
- Providing additional details of the predicted changes to the water balance.
- Clarification of drawdown results presented in Section 6.6.4.
- Providing further justification for conclusions presented in Section 7.

Objectives

The work described in the Report is aimed at providing inputs to an Environmental Impact Statement (EIS) for environmental approvals for the Area 5 extension. Specific objectives of the work are to quantify groundwater inflows to the mine and to assess the associated changes in groundwater level and fluxes with focus on those that are expressed in the near-surface environment.

It is noted that the work is also aimed at addressing issues raised through earlier approvals consideration as summarised by the New South Wales Independent Planning Commission in 2021[1]. To this end, the work is aimed at:

- Reducing uncertainty regarding the reliability of predicted catchment-wide water losses including those from minor watercourses,
- Improving the understanding of potential water quality impacts of the project,
- Addressing mine closure planning.

The impacts are required to be expressed in terms of both incremental (those due to the proposed Area 5 expansion) and cumulative effects (those due to the Area 5 expansion combined with other Dendrobium operations and with other nearby mines). These objectives are addressed through the development and use of a groundwater flow model of the Dendrobium and surrounding mines. The Report provides a detailed description of the conceptualisation, calibration and use of the numerical groundwater flow model.

Conceptualisation

The area has been mined over a considerable period of time and this has led to a wealth of geological and hydrogeological knowledge accompanied by a significant database of groundwater and surface water observations that illustrate current conditions and previous responses to historic mining activities. The report includes an excellent summary of the available data and draws reasonable conclusions regarding the key components of the hydrogeological conceptualisation of the model. To this end, the experience obtained from Dendrobium and other nearby mines is a key issue that is particularly relevant to the Confidence Level

[1] IPC NSW 2021. Dendrobium Extension Project SSD 8194. Statement of Reasons for Decision. S O'Connor and F Hann dated 5 February 2021. https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=SSD-8194%2120210204T205914.818%20GMT

Classification. In other words, when a model can draw on a large and validated data set for conceptualisation and is located in an area where there is a long and detailed history of the type of development simulated in the predictive scenarios then the model's predictive capability is enhanced and confidence in those predictions is increased.

In Chapter 3, the Report includes a detailed review of longwall subsidence effects including detailed discussions of the height of fracturing above the goaf, investigations and evidence of fracturing above the historically mined longwall panels at Dendrobium, comparison of various empirical fracturing models at Dendrobium, the risks to the WaterNSW water supply reservoirs and potential water quality impacts that may occur or be exacerbated by fracturing at Dendrobium.

Model Design

The model has been developed in the MODFLOW-USG software package using a combination of Voronoi and rectangular shaped elements to provide local refinement in areas of interest and to allow a precise replication of the geometry of the longwall panels and other mine infrastructure. The model domain measures approximately 30 km in the east-west direction and about 35 km in the north-south direction. It is a large model domain and the boundary conditions assigned to the edges of the model are sufficiently remote from that the effects of mining at Dendrobium are unlikely to impact on the calibration or predictive scenarios (also refer to the discussion on predictive scenarios in this review).

The model includes 17 layers that represent the regolith cover, overburden and inter-burden (mostly sandstones) and coal seams that are present above and immediately below the Wongawilli Coal Seam which is the seam mined by most of the other mines in the area. The proposed Dendrobium Area 5 Mine will target coal in the shallower Bulli seam.

The model features a detailed network of head dependent boundary conditions that represent the water storage reservoirs and the influent streams that replenish the reservoirs. Many of the major streams are simulated using the MODFLOW SFR Package that represents the interaction between the surface water and groundwater with streamflow routing used to ensure that recharge from stream seepage is limited by the amount of water in the stream. The reservoirs are simulated with the conventional MODFLOW RIV package in which the groundwater exchange fluxes are calculated from the simulated gradient between the specified reservoir water level and the simulated groundwater heads in neighbouring cells. The approach and implementation of the RIV and SFR Packages are considered appropriate for the project objectives.

Mining is simulated by the progressive activation of drain cells in the coal seams within the longwall panels with concurrent changes in hydraulic properties defined in the MODFLOW TVM Package and activation of stacked drains above the panel. The method simulates the increased hydraulic conductivity and storage of the coal seam, goaf, connected fracture zone above the goaf and the near surface cracking zone that occur as a longwall panel is mined and subsequently collapses. Similar methods have been adopted successfully for the simulation of longwall mining throughout many of Australia's coal basins and I consider it to be an appropriate approach at Dendrobium. The unavoidable drawback in applying this approach is that there are numerous assumptions as to the degree and extent of fracturing and permeability enhancement that occurs during mining. In this instance, the modeller has provided a comprehensive assessment of the phenomena, evidence obtained from previous mining operations at Dendrobium and neighbouring mines and provides justification for the assumptions adopted.

Calibration

The model has been calibrated in transient mode by simulating the period 2000 to 2021 with mining at Dendrobium and neighbouring mines included. Calibration involved comparing model simulations of historic mining to the following data sets:

- Observed groundwater heads in the local Dendrobium monitoring bore network and to regional, DPIE monitoring bores,
- Measured mine inflows,
- Changes in surface water flows inferred from historic stream gauging records.

This is comprehensive calibration data set that, in my opinion, includes a high level of parameter information and provides constraints over the model parameters in calibration. Comparisons between measured and simulated hydrographs in nested piezometers illustrate a mixture or relatively good and relatively poor matches. This outcome is common in calibrations of groundwater models in coal mining environments and reflects the dramatic changes in hydraulic head and saturation that occur close to the mining operations and the extreme heterogeneity and complexity of the coal seam hydrogeological environment. Irrespective of the above-mentioned challenges, the reported matches to the observed calibration data are compelling and suggest that the model provides a good representation of a broad range of measured groundwater and surface water responses. Indeed, the reported calibration to changes in surface water flows caused by historic mining stands out as an exceptionally strong feature of the calibration rarely seen in similar models.

Predictive Scenarios

Predictive scenarios were run for the period 2021 to 2200 with proposed mining completed in 2039. Four base scenarios were simulated as follows:

- Scenario A is the null case and includes no mining operations,
- Scenario B includes historic and approved future operations at all neighbouring mines and no mining of the Dendrobium Mine,
- Scenario C includes all historic and approved future operations at the Dendrobium Mine and neighbouring mines.
- Scenario D includes all historic and approved future operations including the proposed operation of Dendrobium Area 5.

Cumulative and incremental impacts are calculated by taking the differences between model predicted fluxes and heads in relevant scenarios; Scenario D minus Scenario A to estimate the cumulative impacts and Scenario D minus Scenario C to estimate the incremental impacts of Area 5 mining.

While the changes in permeability and storage brought about by the mining and collapse of longwall panels has been implemented in the predictive models in a progressive manner that follows the planned mining schedule, I note that the model does not include a similar dynamic increase in stream bed conductance parameter at the time the near surface cracking is expected. I understand that the use of a time constant stream bed conductance has been adopted because the standard MODFLOW TVM package used to implement time varying material properties does not offer the bed conductance as a property that can be changed during a model run. To account for this problem, the model has been formulated with post mining stream bed conductance values to ensure a conservative outcome. In other words, predictive scenarios B, C and D include an assumption that the groundwater exchange fluxes with water courses above the longwall panels are enhanced by cracking and disturbance of stream bed sediments for the duration of the model run. While I believe the implementation of dynamic changes in bed conductance values to account for the effects of mining would improve the representation of mining impacts, I am comfortable that the approach provides reasonable predictions for EIS purposes because:

1. The model includes an over-estimate of the exchange fluxes between surface water and groundwater prior to mining and includes the best estimate of the exchange fluxes thereafter.
2. Increases in hydraulic conductivity implemented in shallow formations at the time of mining are applied to the model cells that host the stream boundary condition. This will lead to increased groundwater surface water exchange fluxes similar to those expected when the stream bed is disturbed by mining induced cracking. In other words, the model includes increases in hydraulic conductivity that may produce similar effects to those expected when the stream bed conductance term is increased.

Table 6-4 indicates that the mining of Area 5 is predicted to result in about 4.16 ML/d of groundwater on average being taken out of the aquifer through inflows to the mine. The predicted incremental impacts caused by the groundwater inflows to the Area 5 mine include:

- An average loss of water in the water reservoirs of about 1.2 ML/d consisting of 0.07 ML/d of net reduction in direct groundwater inflows and a further loss of 1.13 ML/d in net baseflow in streams that replenish the reservoirs.
- An average 1.08 ML/d of reduction in evapotranspiration that may reflect a loss of water available to GDE's including terrestrial vegetation due to the mining of Area 5.
- An average of about 1.88 ML/d of water released from storage through increased drawdown associated with the groundwater inflows to the mine.

I note that the impacts described in Section 6.4 are calculated as the average change in modelled fluxes over the approximate period in which Area 5 is assumed to be mined (2025 to 2040) and there will be times when the predicted impacts exceed the average. Reference to the predicted time series groundwater inflows to the Area 5 Mine presented in Figure 6-1 provides an indication of when the highest levels of incremental and cumulative impact can be expected. Time series plots of predicted impacts on the water storage reservoirs are presented in Figure 6-10 and clearly demonstrate the dynamic nature of the predicted impacts. The reported approach and outcomes provide a good representation of the predicted incremental impacts of Area 5 on groundwater fluxes throughout the model domain.

The predicted cumulative impacts are more difficult to interpret because the simulations include the impacts of neighbouring mines, some of which are in the mining phase and others in post-mining recovery. Results presented in Table 6.4 indicate an average inflow to all mine workings (not just those at Dendrobium Mine) between 2025 and 2040 of about 20.9 ML/d and this leads to the following impacts:

- An average reduction of water stored in the reservoirs of about 3.7 ML/d consisting of 0.4 ML/d of net increase in direct groundwater inflows to the reservoirs combined with a net loss of about 4.1 ML/d in baseflow in streams that replenish the reservoirs.
- 10.3 ML/d of reduced evapotranspiration.
- An average of about 8.7 ML/d of water added to storage through groundwater head increases associated with groundwater recovery following mine closure.
- An average of 15.5 ML/d net increase in groundwater exchange across the model edges. This outcome suggests that some of the neighbouring mines are close to the model boundaries and that cumulative impacts are anticipated to occur outside the model domain.

Because the model predictions include a significant response at the model boundaries, some impacts are expected to occur beyond the boundaries of the model. It is clear from Table 6-4, that the impacts caused by Dendrobium Area 5 are fully expressed within the model domain and the location of the other Dendrobium workings suggest that the impacts from mining these areas are also fully expressed within the model domain. While I am happy that the model provides a full accounting of cumulative impacts within the model domain, additional cumulative impacts are expected to occur outside the model domain and it is most likely that these impacts arise from other, neighbouring mines, especially Tahmoor and Appin, which are closer to model boundaries.

Predicted changes in groundwater heads are presented in the Report in Section 6.6.1 to 6.6.5. as:

- predicted hydrographs (groundwater head plotted against time) at key locations,
- groundwater level contours in various hydrogeological units at four different times included in Appendix J,
- depth to watertable maps at various times in the past and future,
- maximum groundwater drawdown contour maps that show the maximum difference between Scenario D minus Scenario B for all model nodes at any time during the simulation.
- Predicted drawdown at existing groundwater extraction wells within the model domain.

Potential water quality impacts in the long term post-mining period are assessed in Section 6.10. Table 6-13 details an assessment of contaminant fluxes, estimated in grams/day, calculated from modelled groundwater fluxes and measured concentrations of various metals in groundwater. The analysis suggests negligible water quality impacts on groundwater discharging to the Avon Reservoir and its upstream catchment.

Uncertainty Analysis

The Report describes a predictive uncertainty analysis that aligns with the *"Scenario analysis with subjective probability assessment"* as defined in Middlemis and Peeters, 2018[2]. Seven uncertainty scenarios were defined that include perturbations to key model input parameters. The method is considered subjective in that it relies on the modellers understanding of the potential variability in a particular parameter that can be reasonably accommodated within the constraints of the calibration. In this regard it does not provide the rigorous assessment of parameter uncertainty that may be expected from a stochastic modelling approach with Bayesian probability quantification. The adopted approach has the benefit that it can be undertaken on a large complex model that takes a long time to run. It represents the simplest approach to uncertainty analysis recommended by Middlemis and Peeters, 2018.

The results of the uncertainty analysis are not reported separately but are included in the results reported for the basic scenarios as error bars (for example Figure 6-2 shows error bars around the estimated mine inflow rates, leakage from reservoirs on Figure 6-10 and potential long-term discharge rates at the portals on Figure 6-16). The uncertainty model results have also been used to produce minimum and maximum 2 m drawdown contours included in Figures 6-7 and 6-8. These contours have been obtained from an analysis of the maximum and minimum drawdown predicted in each of the uncertainty scenarios in every model calculation node. I note that the description of Figures 6-7 and 6-8 in the Report text and on the figures themselves may be confusing as the deterministic uncertainty scenarios are referred as *"the scenarios"* and the distinction between these simulations and the mining scenarios A, B, C and D is not clear.

[2] Middlemis, H and Peeters, LJM, 2018. *Uncertainty Analysis – Guidance for groundwater modelling within a risk management framework*. A report prepared by the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment and Energy, Commonwealth of Australia 2018.

Assessment against Australian Groundwater Modelling Guidelines criteria

Question	*Yes/No*	*Comment*
1. Are the model objectives and model confidence level classification clearly stated?	Yes	Confidence level should be elevated to take account of the knowledge gained from experience mining and modelling in the area.
2. Are the objectives satisfied?	Yes	
3. Is the conceptual model consistent with objectives and confidence level classification?	Yes	
4. Is the conceptual model based on all available data, presented clearly and reviewed by an appropriate reviewer?	Yes	
5. Does the model design conform to best practice?	Yes	No dynamic increase in river bed conductance. Model domain not large enough to capture all cumulative impacts.
6. Is the model calibration satisfactory?	Yes	Calibration includes history matching of measured heads, groundwater inflows and stream depletion. An excellent example of maximising the value of the available data.
7. Are the calibrated parameter values and estimated fluxes plausible?	Yes	
8. Do the model predictions conform to best practice?	Yes	Refer to comment in Item 5 above. Shortcomings are not expected to significantly impact on the Dendrobium predictions and are expected to be conservative.
9. Is the uncertainty associated with the predictions reported?	Yes	Analysis based on *scenario analysis with subjective probability assessment*.
10. Is the model fit for purpose?	Yes	

Peer review findings

The groundwater assessment and supporting groundwater modelling work described in the Report have been carried out in a professional and rigorous manner and meet or exceed current industry standards. The modelling work has been completed in line with the Guiding Principles included in the Australian Groundwater Modelling Guidelines and I have not identified any fundamental flaws in the work, both in terms of the approaches and assumptions that have been adopted and the interpretation of the outcomes.

While I understand that the cumulative impacts of all the simulated mining operations are not fully expressed within the model domain and that some impacts will be *"exported"* to areas surrounding the model. I am confident that these exported impacts do not arise from mining at Dendrobium but from other mines located near the model boundaries. I am also confident that the impacts caused by operation of the Dendrobium Mine and the proposed Dendrobium Area 5 Mine are fully expressed in the existing model.

I have also noted that increased stream bed conductance expected to result from longwall panel collapse are implemented at the start of the calibration and predictive scenario models. I am confident that this compromise in detail will result in a conservative outcome in that the model will over-estimate the predicted impacts.

As with all numerical groundwater models, the Dendrobium Model includes uncertainties associated with the parameters, underlying assumptions and simplifications of the underground environment and the changes that will occur as mining progresses. These uncertainties need to be considered when using the predictions obtained from the model. Irrespective of the issues noted above, I have concluded that the model is fit for the purpose of impact quantification and assessment.

Attachment – Curriculum Vitae
Brian Barnett

Qualifications:
Bachelor of Engineering (Civil), University of Auckland

Relevant Experience:
Jacobs Group (Australia) Pty Ltd. (Prior to December 2013 SINCLAIR KNIGHT MERZ, AUSTRALIA)

May 2000 to present

Senior Hydrogeologist and Geothermal Reservoir Engineer SKM, Melbourne, Australia.

Responsible for groundwater modelling and geothermal studies. Major projects include:

- ***Australian Groundwater Modelling Guidelines. National Water Commission.*** Project manager and principal contributor to the Australian Groundwater Modelling Guidelines. The document, published in June 2012, is widely recognised as providing the benchmark industry standard in groundwater modelling.
- ***Lihir Gold Mine. Newcrest Mining Ltd.* Pit Cooling Project.** From mid-2018 to late 2019 Brian Barnett participated in the Pit Cooling Alliance as an independent peer reviewer of geothermal modelling and hydrogeology investigations. The work included attendance at three monthly workshops (each of five days duration) in which the latest findings were presented and discussed and critically reviewed. The work ended in late 2019 with the submission of the Pit Cooling Pre-feasibility Study.
- ***Lihir Gold Mine, MBIR. Newcrest Mining Ltd.*** Brian Barnett is currently a member of the ITRP (Independent Technical Review Panel) for a project aimed at identifying potential slope stability risks at the Lihir Gold Mine. The work commenced in September 2020 and is scheduled to be completed in mid-2021. Jacobs role is to bring specialist geothermal and hydrogeology expertise to the ITRP role of guiding and

reviewing external Subject Matter Experts assessing all aspects of slope stability in the mine.

- ***Frieda River Mine Dewatering Investigations. Xstrata Copper.*** Groundwater modelling of a proposed copper mine in Papua New Guinea. Groundwater models were used to estimate the dewatering pumping requirement for the mine and to provide an assessment of the environmental impacts that may accompany mine dewatering.
- ***New Acland Coal Mine***. ***New Hope Group.*** Developed a groundwater model of the New Acland Coal Mine to assist with gaining environmental and industry approvals for expanding coal mining operations. The model was used to predict the likely future inflows to the mining pits and to assess potential impacts that may arise from the inflows and associated drawdown in groundwater heads. The work has included expert witness appearance in recent Queensland Land Court proceedings.
- ***Wards Well Coal Mine. BMA***. Supervising the modelling of an underground coal mine in Queensland. The model includes time varying material properties that represent deformation of formations above long wall mine panels.
- ***Kulwin Mineral Sands Mine Dewatering Investigations. Iluka Resources Ltd.*** Detailed numerical groundwater models were developed to help design the mine dewatering system. Investigations were aimed at depressuring the local groundwater system to expose the mineral sand deposits to allow dry mining of the resource. The models paid particular attention to vertical flow processes in and around the deposit and hence incorporated multiple (27 layers in total) horizontal layers.
- ***Pardoo Iron Ore Mine Dewatering Investigations. Atlas Iron.*** Groundwater models were developed in the FEFLOW numerical modelling code to estimate the mine dewatering requirements of an iron ore mine in the Pilbara region of Western Australia.
- ***Millstream Aquifer Groundwater Model. DOW.*** Groundwater modelling of an inland aquifer in the Pilbara area of Western Australia. The aquifer is used for municipal water supply purposes and the project was aimed at helping to determine sustainable extraction rates from the aquifer. A principal constraint on future development is the requirement to protect and maintain iconic groundwater dependent river pools and springs
- ***Northern Murray Basin Environmental Effects Statement. Iluka Resources Ltd.*** Preparation of a water management report that formed part of the EES for the Kulwin and WRP deposits in the Northern Murray Basin Project. Work included the development of regional groundwater flow models to assess environmental impacts of dewatering and water disposal.
- ***Mine dewatering for Murray Basin Titanium Ltd for the Wemen Mineral Sand Mine.*** Numerical groundwater models were formulated and calibrated in order to help optimise a dewatering plan for a mineral sand deposit in Northern Victoria. The models were also used to assess the likely impacts of dewatering and associated water disposal on the Murray River.
- ***Mine water management consultant for Murray Basin Titanium Ltd for the Prungle Mineral Sand Mine.*** Responsibilities included the development of numerical groundwater models to assist in designing a groundwater supply scheme to provide water

for a dredge mining operation in Northern Victoria. Investigations also included the assessment of groundwater extraction and disposal on local and regional surface water and groundwater resources.

- ***Murray Darling Basin Sustainable Yields Project. CSIRO.*** Groundwater modelling team leader for a major project covering groundwater resources in Queensland, New South Wales, Victoria and South Australia. SKM was contracted by CSIRO in 2007 to undertake the groundwater resource assessment for the entire Murray Darling Basin. The project involved the numerical modelling of all major fresh water aquifers in the basin. Twelve finite difference numerical models were run for the study. Results were used to quantify the available groundwater resources of the basin and to assess the impacts of future climate change and impacts of groundwater development on river flows.
- ***Northern Sewer Project, Groundwater Models.*** Groundwater flow models were developed for the NSP1 and NSP2 sewer tunnels in north Melbourne. The models were used to assess inflows into the tunnels and to determine the likely impacts of groundwater drawdown on the aquifer and on the associated loss of base flow to local streams and rivers. Models were constructed to assess both the construction and operational phases.
- ***Lindsay River Groundwater Modelling. DNRE Victoria.*** Development of a three dimensional finite element groundwater model of the aquifers within the Lindsay River Anabranch of the Murray River. The model was developed in the FEFLOW modelling code and is being used to design a salt interception scheme.
- ***Numerical Water Trade Models. Mallee CMA Victoria.*** Project manager and leader of modelling team to develop, calibrate and run predictive scenario models for the Nangiloc Colignan and Wemen irrigation areas in northern Victoria. Models were aimed at quantifying the impact on salinity in the River Murray associated with the trading of irrigation water.
- ***South East Queensland Effluent Reuse Study – Darling Downs.*** Brisbane City Council. The impacts associated with future use of treated effluent for irrigation in the Darling Downs was investigated through the development and calibration of large scale three dimensional groundwater flow and solute transport models. Impacts under investigation included changes in groundwater head, changes in the groundwater interaction with rivers and streams and the water quality changes in the aquifer.
- ***Lake Toolibin Groundwater Modelling. CALM WA.***   A three dimensional finite difference groundwater model was formulated to assess the dewatering performance of a network of pumping bores designed to reduce groundwater heads beneath Lake Toolibin. The project is aimed at minimising salinisation of the lake by reducing groundwater discharge through the lake bed.
- ***Barwon Downs Groundwater Modelling. Barwon Water, VIC.*** This project involved the development and calibration of a large three dimensional finite difference groundwater flow model to assess the safe long term yield from the Barwon Downs borefield. Models were calibrated over a thirty year period of observation and were run in predictive mode for 100 years.

KINGSTON MORRISON LIMITED, AUCKLAND

1997 to May 2000

In July 1999, Kingston Morrison Ltd joined the Sinclair Knight Merz Group.

- **Senior Geothermal Reservoir Engineer.** Responsible for all aspects of geothermal reservoir assessment and well testing. Also responsible for all hydrogeological investigations and groundwater modelling.

SUMIKO CONSULTANTS COMPANY LIMITED, TOKYO, JAPAN

1991 to 1997:

Geothermal Reservoir Engineering Manager. Responsible for the enhancement of geothermal reservoir engineering and mineral resource evaluation capabilities in Sumiko Consultants through the acquisition of reservoir and well bore simulation codes and the application of geostatistical methods and software.

GEOTHERMAL ENERGY NEW ZEALAND LIMITED (GENZL), AUCKLAND

1981 to 1991:

Reservoir Engineer. Responsible for all geothermal reservoir engineering studies including extended assignments in Indonesia, Kenya and Japan.

HAWKES BAY REGIONAL WATER BOARD

1979 to 1981:

Groundwater Engineer. Duties included the investigation of hydraulic and chemical characteristics of aquifers in the Hawkes Bay region and the preparation of resource management plans.

Report Final

GHG Calculation and Mitigation Measures Peer Review

Client	South32
Site	Dendrobium Mine Extension Project (Area 5)
Date	14 Mar 2022
Doc No.	SOUTH6082-01

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Version management

Process	Name	Date	Version
Author	Felipe Palominos	10 Feb 2022	3
Peer Review By	John Pala	15 Feb 2022	3
Draft Issued To	Chris McEvoy	15 Feb 2022 / 4 Mar 2022	3 / 4
Final Review By	John Pala	11 Mar 2022	6
Final Issued To	Chris McEvoy	14 Mar 2022	8

Contents

EXECUTIVE SUMMARY

The Dendrobium Mine Extension Project (the Project) requires an Environmental Impact Statement (EIS) to be prepared and submitted. As part of this submission, South32 have been requested to address the Planning Secretary's Environmental Assessment Requirements (SEARs), including items related to greenhouse gas (GHG) emissions for the development.

Palaris have been engaged to undertake an independent peer review of the greenhouse gas emission estimates and emission reduction measures, particularly targeting fugitive emissions from the project, addressing the following SEAR:

"*An independent peer review of the greenhouse gas emission estimates and emission reduction measures, particularly targeting fugitive emissions from the development*".

The peer review has targeted:

- The data sources used for the estimation of fugitive emissions (Scope 1 and Scope 2)
- The methodology employed to estimate Scope 1 and Scope 2 emissions and compliance to relevant NGER guidelines
- The integration of the proposed mining schedule for the calculation of fugitive emissions
- The proposed GHG emission reduction measures and their suitability to implementation.

The peer review aims to follow the general principles of carbon accounting outlined in Brohe, 2016 which include:

- Relevance – Appropriate definition for the boundaries of GHG emissions
- Completeness – All emission sources within the organisational and operational boundaries should be reported
- Consistency – In methods of calculation and presentation of data
- Transparency – Information should be transparent
- Accuracy – Data accuracy can be improved by adhering to prescribed GHG calculation methods.

All areas reviewed have been assessed in comparison to the information Palaris has previously reviewed or developed. Each assessment is presented in a table that employs a traffic light system, as shown below:

Traffic Light	Description
🟢	Used in the Project
🟠	Not currently used in the project, estimated from other operations, or identified as a potential improvement
🔴	Not considered for the Project (from the data made available for the peer review)
⚫	Not applicable

Emission Estimates

It has been found that overall, the most common sources of emissions from an underground coal mine have been employed in the calculation of GHG emissions.

The data sources used for the calculations are relevant and have been used in a manner that is logical, repeatable, and auditable.

The calculations appear to have been carried out in accordance with the relevant legislation including:

- National Greenhouse and Energy Reporting Act 2007
- National Greenhouse and Energy Reporting (Measurement) Determination 2008
- National Greenhouse Account Factors 2021.

Reduction Measures

The GHG emission reduction measures proposed by the Project are consistent with what is being applied across underground coal mines in Australia. Gas pre and post drainage is planned for the Project, with captured methane sent to flares for combustion.

Given Ventilation Air Methane (VAM) abatement technology in Australia is more difficult than gas drainage and gas destruction technologies due to the infancy of the technology, higher relative capital costs and large land requirements. Capturing methane into a reticulation system that would otherwise report to the ventilation stream and destructing it is currently the most efficient and practical means to reduce fugitive emissions from underground coal mines.

Gas liberated from the surrounding strata / seams from longwall mining is identified as the major emission stream for the Project, with the Wongawilli Seam the primary gas source. Longwall gas management proposed for the Project is designed with post drainage levels to meet planned production rates and maintaining gas levels within the ventilation stream below statutory requirements, as is common across the industry.

Increasing the planned post drainage level beyond the minimum requirements or pre-drainage of the Wongawilli Seam (which has been identified by S32 as an opportunity) would be the primary driver to facilitate further reductions of fugitive emissions from the Project.

Other opportunities identified by Palaris for consideration to further reduce Scope 1 GHG emissions for the Project could include:

- Capturing of emissions (subject to viability) from legacy sealed areas (outside Project footprint), which include sealed goafs and any areas that will be sealed in the future
- Use of alternative fuels (e.g., Bio-diesel) in surface and UG equipment. Suitability of fleet, availability of fuel source and compliance with particulate matter standards would need to be assessed.

1 EMISSIONS REVIEW

The guidance reference material available from the Clean Energy Regulator (NGER, 2021) provides a reasonable guide to assist with the identification and quantification of emission sources from underground coal mines. The identification and quantification of sources can be a subjective process, as such, a peer review is a beneficial tool to assist with the completeness and accuracy of the estimates.

1.1 Data Sources

It is Palaris' experience that data used to inform GHG emission estimates for underground coal mines varies significantly across operations within Australia, particularly around fugitive emissions. A combination of historical emissions/consumption and exploration data characterised for the gas reservoir is the most appropriate relating to the extraction of coal and fuel consumption.

Regarding Scope 2 emissions for an established site, historical data with future projections would be appropriate to estimate energy use.

The data sources used to inform the Project's GHG emission estimates have been assessed and are shown Table 1.1. Palaris is in agreeance with the nature of the data sources used.

Table 1.1 Assessment of Data Sources

Data Source	Use in A5	Comment
Gas reservoir characterisation (GRC)	🟢	▪ Developed by Palaris for the original Environmental Impact Statement (EIS) mine plan ▪ Adjusted by South32 to reflect the new mine plan ▪ Based on exploration borehole data.
Site specific ventilation models	🟢	▪ Used as part of the longwall emission estimate to calculate post drainage capture efficiency requirements.
Actual gas management and emissions data	🟠	▪ No data is available for the Project as the Project has not commenced ▪ Observed data from other Bulli (BU) Seam operations has been employed.
Actual productivity data	🟢	▪ Actual longwall production data for Dendrobium Area 3B (A3B) used to calculate longwall emissions.
Emission zoning	🟢	▪ Developed based on areas of representative gas emission profiles for each longwall block.
Mine production schedule	🟢	▪ Emission zones used in conjunction with the latest mine production schedule.

Data Source	Use in A5	Comment
Actual fuel consumption data	🟢	▪ A diesel intensity factor (kl/tonne) was derived from the 2021 diesel consumption and corresponding ROM production for the mine, Cordeaux site, Coal Preparation Plant (CPP) and Kemira Valley stockpile and train load out (TLO) facility ▪ A diesel intensity factor (kL/tonne) for locomotives was derived using a fuel consumption rate for locomotives (4.03 l/kt-km). The kt-km per annum was estimated using the approximate travel distance from the mine to the CPP and the forecast ROM coal production for each year. A return trip was also calculated for empty wagon ▪ Diesel consumption for product coal and coal wash transport (by truck) estimated from reported fuel consumption for articulated trucks (l/km) and estimated travel distance. Number of trips for yearly tonnage based on an average payload of 32.4 tonnes.
Actual electricity usage data	🟢	▪ An electricity intensity factor (kWh/tonne) was derived from the 2021 electricity use and corresponding ROM production.
Actual gas consumption data	🟠	▪ There was no data available for the coal dryer as it is currently not operational ▪ The emissions were estimated using textbook values for gas requirements and emission factors for natural gas fired boilers.

1.2 Emissions Stream Identification & Estimates

There are multiple streams of emissions to consider in a GHG estimate. For an underground coal mine, Palaris identifies the emission streams for Scope 1 and Scope 2 emissions to be as per Table 1.2.

This dissemination of emission streams is based on available literature and Palaris' experience in order to better understand the source, quantify in reconciliation processes and assess options to capture and mitigate. Since fugitive emissions make up the bulk of emissions within Scope 1 and 2, they are the main focus of the review.

Table 1.2 Palaris' Interpretation of Scope 1&2 Emission Streams for an UG Coal Mine

Scope 1	Scope 2
Gas captured in pre-drainage and post-drainage process	Electricity consumption not generated on site
Development rib emissions	
Emissions from longwall extraction	
Emissions from sealed goafs in active mining area	
Emissions from legacy goaf areas	
Emissions from fuel combustion (extraction, transport, CPP process and on-site electricity generation)	
Post mining emissions (e.g., coal stockpiles)	

The method used to estimate the emissions across the Project's life breaks down the mining schedule into several milestones, categorised by longwall extraction and the different emission zones within each longwall block. The total emissions from all sources (m^3/week) were determined for the period up to each milestone. This emission factor was then assigned to the relevant period (in weeks) from the mining schedule to determine the total yearly emissions.

The emission estimates from each stream were assessed in comparison to the Palaris database for emission sources. The assessment is shown in Table 1.3.

Palaris is in agreeance with the identification of emission streams and the estimation method employed for the Project. It is noted that emissions from legacy areas at Dendrobium Mine outside the proposed underground Project Area have been excluded from the estimate as they form part of the existing Dendrobium Mine, which would continue to operate under a separate Development Consent to the Project. Once the Project is operational, allowances for these emissions are recommended in the overall accounting of greenhouse gas emissions from the Dendrobium Mine (that is, the existing operations and the Project) to avoid under-estimating of emissions from the Mine.

Table 1.3 Assessment of Emission Estimates

Emission Stream	A5 Inclusion	Data Source (s)	Estimation Method Employed	Comment
Gas pre-drainage	●	▪ Gas reservoir characterisation document	▪ Mass balance based on virgin gas content and estimated residual gas content prior to mining (3.5 m^3/t) ▪ Drill patterns used in calculation based on areas requiring pre-drainage prior to each mining milestone used in the calculations	▪ Palaris employs a similar method to calculate gas captured in pre-drainage ▪ Mass balance used for total volume of gas.
Development Mining	●	▪ Gas reservoir characterisation document	▪ Rib emissions outlined in GRC were used ▪ Development areas used for each milestone were based on the mining schedule	▪ Palaris employs a similar method to calculate rib emissions from development.
Longwall Mining	●	▪ Gas reservoir characterisation document ▪ Long term ventilation modelling ▪ Actual gas management data (Appin) ▪ Actual production data (Dendrobium A3B)	▪ Specific gas emission (SGE) value (m^3/t) from GRC was corrected to the current mine plan and different emission zones identified ▪ The SGE value for each zone was allocated to the relevant tonnes from the production schedule ▪ Gas streams separated into ventilation stream and gas drainage stream based on statutory gas limits	▪ Palaris employs a similar method for calculating longwall emissions, combining different emission zones and associated SGE's with the production schedule.
Gas post drainage	●	▪ SGE value calculated for emissions from longwall mining	▪ Post drainage requirements for each emission zone used was calculated based on maintaining ventilation gas levels below statutory gas limits	▪ Palaris employs a similar method to determine post drainage requirements to meet planned production rates and maintain ventilation gas levels below statutory limits.

Emission Stream	A5 Inclusion	Data Source (s)	Estimation Method Employed	Comment
Outbye sealed areas (within the active mining area)	●	▪ Observed gas make data from outbye parts of an active mining area (Appin)	▪ An allowance has been made, increasing as more goafs are created ▪ Commencing through the extraction of the 2nd longwall block at 200 l/s of mixed gas increasing with each longwall block to a maximum of 700 l/s of mixed gas	▪ The allowances made represent between 9 - 32% of the total emissions from the mine ▪ This is comparable with what has been observed in other operations.
Fuel Combustion (Diesel)	●	▪ Actual fuel consumption data ▪ Fuel consumption rate for locomotives	▪ An intensity factor (kl/tonne, l/km) was determined ▪ The kl/tonne factor was multiplied by the planned yearly tonnes ▪ The total km's travelled were calculated from the planned yearly tonnes and multiplied by the l/km factor	▪ Palaris agrees with the use of an intensity factor for fuel consumption based on actual data.
Fuel Combustion (Gas) for coal dryer	●	▪ Textbook values for energy requirements and emissions	▪ Calculated using textbook values ▪ Gas requirement of 900 kilojoules per kilogram of coal ▪ Emission factors for natural gas fired boilers	▪ Palaris agrees with the use of textbook values for this estimate.
Electricity use	●	▪ Actual electricity consumption data	▪ An intensity factor was derived from actual electricity consumption and ROM tonnes mined (kWh/Tonne) ▪ The intensity factor was applied to the planned yearly ROM tonnes	▪ Palaris agrees with the use of an intensity factor for electricity use based on actual data.

1.3 Conversion of Emissions to Tonnes CO_2e

1.3.1 Calculation Method

An audit of the GHG calculations was carried out against NGER (Measurement) Determination 2008 (Compilation 13, July 21) with a focus on the fugitive emissions as a result of mining and flaring of gas.

The conversion calculations for Scope 1 and Scope 2 emissions appear to have been carried out in accordance with the NGER (Measurement) Determination 2008.

Table 1.4 Calculation Method for Each Emission Source

Emission Source	Relevant NGER Section	Calculated according to NGER	Comment
Gas pre-drainage	Section 3.15, Method 2	🟢	▪ Conversion factors used for CO_2 and CH_4 as per section 3.6.
Development Mining	Section 3.6, Method 4	🟢	▪ Conversion factors used for CO_2 and CH_4 as per section 3.6.
Longwall Mining	Section 3.6, Method 4	🟢	▪ Conversion factors used for CO_2 and CH_4 as per section 3.6.
Gas post drainage	Section 3.15, Method 2	🟢	▪ Conversion factors used for CO_2 and CH_4 as per section 3.6.
Outbye sealed areas (within the active mining area)	Section 3.6, Method 4	🟢	▪ Conversion factors used for CO_2 and CH_4 as per section 3.6.
Residual (post mining) fugitive emissions	Section 3.17, Method 1	🟢	▪ Conversion factors used for CO_2 and CH_4 as per section 3.6.
Diesel combustion for transport purposes	Section 2.41, Method 1	🟠	▪ Calculations not supplied ▪ Spot check carried out indicates calculation appears to have followed Method 1.
Gas combustion from use of coal dryer	Section 2.20, Method 1	🟠	▪ Calculations not supplied ▪ Spot check carried out indicates calculation appears to have followed Method 1.
Electricity use	Section 7.2, Method 2	🟠	▪ Calculations not supplied ▪ Spot check carried out indicates calculation appears to have followed Method 2.

1.3.2 National Greenhouse Accounts Factors

The emission factors, global warming potential (GWP) factors and energy content factors used were reviewed against the National Greenhouse Accounts (NGA) Factors document (August 2021).

The factors used for the calculations of Scope 1 and Scope 2 emissions appear to be in accordance with the NGA document.

Table 1.5 Factors Used in Calculations

Factor	NGA Reference	Used in A5	Value (s)	Comment
Global Warming Potential Factors:				
CH_4	Table 32	●	28	
CO_2	Table 32	●	1	
Energy Content Factors (by activity and scope)				
Natural gas distributed in a pipeline	Table 2	●	39.3×10^{-3} GJ/m^3	
Coal mine waste gas that is captured for combustion	Table 2	●	37.7×10^{-3} GJ/m^3	
Diesel oil for stationary energy purposes	Table 3	●	38.6 GJ/kL	
Diesel oil for Transport energy purposes	Table 4	●	38.6 GJ/kL	
Emission Factors (by activity and scope)				
Natural gas distributed in a pipeline	Table 2	●	CO_2 CH_4 N_2O 51.4 0.01 0.03 (Kg CO_2-e/GJ)	
Coal mine waste gas that is captured for combustion	Table 2	●	CO_2 CH_4 N_2O 51.9 4.6 0.3 (Kg CO_2-e/GJ)	
Diesel oil for stationary energy purposes	Table 3	●	CO_2 CH_4 N_2O 69.9 0.1 0.2 (Kg CO_2-e/GJ)	

Factor	NGA Reference	Used in A5	Value (s)	Comment
Diesel oil for Transport energy purposes	Table 4	●	CO_2 CH_4 N_2O 69.9 0.1 0.4 (Kg CO_2-e/GJ)	
Post mining activities associated with gassy underground mines	Table 7	●	0.019 t CO_2-e/t raw coal	
Electricity supplied by the grid for NSW and ACT	Table 5	●	0.79 kg CO_2-e/kWh	

2 REDUCTION MEASURES REVIEW

Through industry experience and involvement with several decarbonisation projects Palaris has developed a database of emission reduction measures (ERM) specific to Scope 1 and Scope 2 emissions for underground coal mines. The emission reduction measures are described below:

Scope 1 Reduction Measures

i. Pre-draining of the target mining seam

This allows for controlled capture of high purity gas prior to mining that can be reticulated for treatment or utilisation.

ii. Pre-draining of adjacent seams (above and below the target seam)

Allows for controlled capture of higher purity gas (and potentially higher volume) prior to mining that can be reticulated for treatment or utilisation. This has the potential to reduce the longwall gas emissions during extraction reporting to the ventilation stream.

iii. Use of a post-drainage gas capture system for longwall extraction

Allows to capture gas emissions resulting from longwall mining as the strata is relaxed and gas is released from other coal seams and strata. Gas purity can be compromised as ventilation air is more likely to be introduced to the gas reticulating system.

iv. Increase of post drainage capture efficiency (PDCE)

Once a system is in place, and the gas sources and fracture mechanisms of the longwall strata are understood, this can be achieved through the use of targeted gas drainage holes or increased hole density. The technical viability of this option varies from mine to mine, particularly in areas where a surface based drainage system is not possible.

v. Gas capture from sealed goaf areas

Capturing gas from the goaf environment in the active mining area and legacy areas prevents it from being released to the atmosphere through the ventilation stream and it allows for the gas to be treated and/or utilised. It has been found that this component of emissions can be as little as ~10 – 20% for newer mines and up to ~ 60% of the total ventilation emissions, for more established mines with a large legacy footprint.

This abatement option requires studies to identify viability at each individual site, as the goaf environment may not be of a suitable concentration to allow capture and reticulation.

vi. Use of a vacuum extraction plant

To maintain effective suction on the underground gas pipe range to ensure the underground gas is safely extracted to the surface where it can then be utilised or destructed.

vii. Flaring of gas captured

Either using fixed or mobile flares. The function of a flare is to destruct the methane (CH_4) captured as part of the gas drainage process (pre and/or post drainage). This method of gas destruction is commonly used throughout Australian mines. Typically, suppliers aim for 99.7% destruction of all CH_4.

viii. Electricity generation using a gas fired power station

The function of a gas fired power station is to convert the methane extracted from the mine into electricity and potentially offset electricity costs where possible. Specially designed gas gensets are available in numerous capacities to accommodate the predicted amount of the gas feed throughout the mine life.

ix. Gas Separation and Enrichment Technology

Potential application in low CH_4 environments. It involves the extraction of a portion of gas out of the gas pipeline, removing most or all the carbon dioxide (CO_2), and injecting high purity gas back into the main pipeline downstream to increase the overall CH_4 concentration and allowing the gas to be treated and/or utilised.

These technologies include Pressure Swing Absorption, Amine Gas Sweetening and Membrane Separation Technology. None of these technologies are currently being used in the Australian underground coal industry.

x. VAM Abatement Technology

The potential application of ventilation air methane (VAM) abatement technology in Australia is more difficult than gas drainage and gas destruction technologies due to the infancy of the technology, higher relative capital costs and large land requirement. The current technology involves an exothermic oxidation of low concentrations of CH_4 to form CO_2 and water vapour.

There are currently no active commercial applications of VAM technology in underground coal mines within Australia.

xi. Use of Bio-diesel or Alternative Low Carbon Fuel Options

Biofuels are said to be carbon-neutral because the carbon dioxide that is absorbed by the plants is equal to the carbon dioxide that is released when the fuel is burned. This means it does not release any additional carbon dioxide into the atmosphere (as is reflected in the emission factors in the NGA document). The use of biofuels would require a study to ensure compatibility with the mining equipment.

Scope 2 Reduction Measures

i. Power purchase agreements (PPA)

Under a Corporate PPA, electricity buyers agree to buy power and/or Large Generation Certificates from a renewable energy project (currently solar or wind farms) at a fixed price over a longer-term. Reporting for use of renewable electricity is not required.

2.1 Assessment of Reduction Measures

From the documentation made available to Palaris the emission reduction measures proposed by South32 for the Project have been compared to the database outlined above. Findings are shown in Table 2.1.

Table 2.1 Assessment of Reduction Measures

ERM	Use in A5	Comment
Pre-drainage of target seam	🟢	▪ BU Seam has been identified as requiring pre-drainage to manage emissions during mining in areas where virgin gas contents exceed 3.5 m^3/t.
Pre-drainage of adjacent seams	🟠	▪ Adjacent seams, namely Wongawilli (WW) Seam is not currently identified as pre-drainage target ▪ Identified as an optimisation opportunity by South32 ▪ Trials and studies would be required to determine the feasibility of pre draining the Wongawilli seam at the site.
Post-drainage for LW	🟢	▪ Post drainage system consists of sub-vertical holes ▪ Proposed system efficiencies range from ~3 – 69%.
Increased PDCE	🔴	▪ Current post drainage system is designed to ensure ventilation stream gas levels remain below statutory limits, not to capture as much gas as possible as the design objective ▪ The viability and feasibility of increasing PDCE using existing technology would need to be investigated once operational experience in the gas environment in Area 5 is obtained.
Sealed goaf gas capture	🟠	▪ There is no allowance for gas capture from adjacent goafs within the project area ▪ Studies would be required to assess if this would be viable for the site ▪ Identified as an optimisation opportunity for Area 5 by South32.
Use of vacuum plant	🟢	▪ A gas extraction plant is proposed as part of the abatement technologies.
Flaring of gas captured	🟢	▪ Flaring of gas is proposed.

Electricity generation	●	▪ Variable nature of volume and quality of gas in A5 (content ranges from 2 – 10 m^3/t and composition ranges from 40 – 90% CH_4) ▪ Short overall mining life of the domain (~7.5 years) ▪ Identified as an unviable option due to the reasons above.
Gas enrichment technology	●	▪ N/A – Gas concentration is rich in CH_4. This technology is only applicable for high CO_2 concentrations.
VAM abatement technology	●	▪ There are currently no active commercial applications of VAM technology in underground coal mines in Australia ▪ Pilot plant being trialled at Appin Mine in conjunction with CSIRO, with planning underway for a commercial scale trial.
Use of Bio-diesel or Alternative Low Carbon Fuel Options (E.g., Bio-diesel, hydrogen, electricity)	● (red)	▪ Not captured as part of the emissions reduction plan ▪ Emissions from diesel combustion represent a small portion of the total GHG emissions for the project ▪ A study would be required to assess the suitability of the fleet, the availability and use of alternative fuels and the compliance of the fuels to particulate matter thresholds underground.
Power purchase agreement	● (orange)	▪ Not captured as part of the emissions reduction plan ▪ Identified as an optimisation opportunity by South32.

The GHG emission reduction measures proposed by the Project are consistent with what is being applied across underground coal mines in Australia and it has been estimated that they will reduce emissions by approximately 31% over the life of the Project.

A number of optimisation opportunities have been discussed and identified in Table 2.1.The viability and feasibility of each would need to be determined though studies and site-specific trials which will be subject to different time scales (e.g., pre-draining of the Wongawilli Seam is likely to be a lengthy process). The implementation of feasible options would further reduce GHG emissions for the project.

The proposed mitigation measures, in addition to the optimisation opportunities (the feasibility of which needs to be determined via further studies during the operation of the Project), would result in GHG emissions being minimised "as far as practicable".

2.2 Opportunities within the Project Area

Opportunities identified by Palaris to consider for further reduction of Scope 1 GHG emissions for the Project include:

(Noting that further studies would be required to determine if they are reasonable and feasible for the Project)

i. Increased recovery of longwall emissions reporting to ventilation stream

The Wongawilli Seam has been identified as a major source of emissions to longwall mining. Increased recovery of Wongawilli Seam gas could be in the form of either gas pre-drainage targeting the Wongawilli Seam (recognised by S32 as an opportunity) or via increasing the post drainage effort. The feasibility of this option will be dependent on conditions identified once development in Area 5 is undertaken. It is therefore reasonable to identify this as an opportunity at this stage of the project and not as an inclusion in the base case emissions estimations.

ii. Use of alternative fuels (e.g., Bio-diesel)

The use of Biodiesel or a Biodiesel blend (typically ranging from 2 – 50% Biodiesel) would assist in the reduction of GHG emissions from the combustion of fuel. As an example, the use of a 50% biodiesel blend would reduce emissions from the combustion of fuel by ~49%. The use of biofuels would require a study to ensure compatibility with the mining equipment and diesel particulates standards. It is important to note that emissions from diesel combustion represent a small portion of the total GHG emissions for the project.

2.3 Opportunities Outside the Project Area

i. Capture of emissions from legacy sealed areas

Although outside of the Project footprint, in order to reduce emissions reporting to the ventilation stream for the totality of the mine, capturing gas from legacy sealed areas may be an option to investigate further.

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S32 (2), Russell Thomas, A5 Gas Estimate, Spreadsheet, companion to S32 (1)

S32 (3), Daniel McCarthy, A5 Gas Estimate Applied to EIS Schedule 220207, Spreadsheet, supplied as calculations for fugitive emissions, developed from S32 (2)

S32 (4), Daniel McCarthy, Internal Memorandum “Dendrobium Mine Extension Project - Greenhouse Gas Emission Forecast”, 15 February 2022

S32 (5), South32, Internal Memorandum “Mitigation Strategy_Issue (RES01128053)_Revised.docx”, received 10 February 2022

Felipe Palominos

BEng (Civ) (Hons), Dip UG CoalMineMngt, Class 3 Cert Mine Deputy NSW.

Felipe is a Civil and Mining Engineer that brings 17 years of technical, operational and leadership experience in underground and open cut mines across the coal and limestone industries in Australia and Latin America as well as in civil and mining engineering consultancies. He has a passion for problem solving and brings a positive, solution-oriented approach to work. Felipe has extensive experience in mine planning and optimisation with involvement in underground ventilation and exploration drilling. His experience with gas management includes exposure to gas drainage at several gassy operations, both from surface and underground drilling programs as well as ventilation design and estimation of GHG fugitive emissions. His career in the resources industry has included roles as a senior mining engineer, mine deputy, drilling coordinator, project manager, acting technical services manager and gas & ventilation consultant.

Expertise

- Mine Optimisation
- Mine Design & Planning
- GHG Fugitive Emissions Assessment
- Gas Emission & Management Assessment
- Feasibility Studies

Felipe's Track Record

- Felipe and his team delivered an increase in NPV of $815M for a project in Queensland's Bowen Basin. The technical aspects of the asset included high gas levels, low permeability and high stress due to depth of cover.
- He has been involved in several due diligence, concept and feasibility studies as a technical expert in mine design and innovation including the conceptual design of a reject emplacement strategy for UG coal mines which negates the need for surface reject emplacement areas.
- Felipe has undertaken extensive benchmarking of gas management strategies across the Australian underground coal mining industry in various coal basins.
- He has been involved in a number of benchmarking studies investigating GHG abatement strategies used in underground coal mines across Australia.
- Felipe was the primary gas consultant for a project involving the estimation of GHG fugitive emissions for 8 of the gassiest mines in Australia. The project required the determination of a baseline for each asset as well as the identification and quantification of options for abatement.
- Felipe has been extensively involved in gas emission evaluation, gas management, reservoir modelling and estimating GHG fugitive emissions assessment and reviews for numerous mines and projects.

John Pala

BEng (Mining), Mine Manager's Cert of Comp

John's deep operational experience, underpinned by his strong commercial acumen, has delivered results for our clients world-wide and established him as a trusted advisor in the resource industry for many years. With close to 40 years in the resource industry, John's approach extends beyond the traditional role of a mining consultant. Combining 20 years of technical, operational and senior management experience on mines sites which provides him with a deep understanding of how to successfully run mining operations, with 20 years of leading a successful mining consultancy business, John has overseen over 3000 consulting projects completed across 40 countries. John delivers value through his unrelenting focus on understanding the material project risks, capitalising on opportunities, unearthing project optionality, and maximisation returns. His insight brings an astute perspective and a discerning clarity to any project he is involved in. His advice has consistently ensured our clients make an insightful and informed decision about the viability of their project.

Expertise

- Strategic Reviews
- Due Diligence
- Feasibility Studies
- Independent Expert Advice
- Asset Optimisation & Performance

John's Track Record

John has led over 50 strategic, operational, and business improvement reviews where the total of annual operational savings is over $1 billion. This is only overshadowed by the cost of optimisation projects, which is tenfold in terms of profit/margin impacts, that he has helped achieved for his clients.

Having acted for both buyers and sellers of assets, John has led due diligence teams in the evaluation of a broad range of assets, in many commodities across 40 international geographies. With involvement in over 200 due diligence projects in the past 20 years, John has a very robust and deep understanding of project 'value drivers'. He has worked with both national and international mining companies, as well as international financial institutions, and JV participants.

He is the industry "go-to" person for independent reviews, asset valuations, and technical economic evaluations to support the acquisition, optimisation, rationalisation, merger, and disposal of mining assets.

John has led over 30 feasibility studies and provided technical directorship over an additional 30 studies, bringing together all of the elements required for a successful project delivery, including processing, rail, and port. An extension of the studies process is project optimisation, and John has led teams in over 500 mine design and optimisation projects internationally.

His 20+ years of experience in undertaking all levels of feasibility studies, from greenfield projects and brownfield expansions for both open pit and underground mines, offers a unique guarantee to our clients – to help them "mine smarter." John has an unparalleled mix of operational experience and internal industry insight, backed by our up to date benchmarking performance data.

Eugene Yurakov

PhD, MSc (MinEng), MAusIMM

With more than 35 years in the resources industry, including 24 years providing specialist consultancy services in Australia, Eugene has established himself as an industry leader. Eugene has extensive experience in gas content testing support, gas drainage system maintenance and assessment, gas content/composition testing, gas emission evaluation and control, gas management, reservoir modelling, coal mine gas production assessment and greenhouse gas (GHG) fugitive emissions assessment. He also has extensive experience in the stability of coal and rocks using polymeric resin injection, coal seam electromagnetic energy applications for stress and gas dynamic activity assessment, biotechnology of coal mining, and design and testing of mining equipment.

Expertise

- Gas Reservoir Definition
- Gas Emission & Management Assessment
- Gas Reservoir Modelling
- Coal Mine Methane Production Assessment
- GHG Fugitive Emissions Assessment

Eugene's Track Record

- Eugene has extensively managed gas emission evaluation, gas management, reservoir modelling, and estimating GHG fugitive emissions assessments for numerous operations and projects.
- Recently, Eugene has led the development of an audit tool to review the areas of geology, gas reservoir characteristics, gas drainage design, and capital and operating cost estimations for clients.
- He was significantly involved from the initiation in the development of Moranbah Gas Project (exploitation of coal bed methane (CBM) reserves) which delivered gas to the Townsville Power Station.
- Eugene has provided extensive advisory services for the gas content testing development for underground mines and associated GHG emissions.
- He was also heavily involved in the development of guidelines for the implementation of NGER Method 2 for open cut coal mining fugitive GHG emissions reporting.