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WOLLONGONG COAL

RESPONSE TO IAPUM ADVICE

Russell Vale Colliery Revised
Underground Expansion Project
MP09_0013

FINAL

November 2020

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Prepared by
Umwelt (Australia) Pty Limited
on behalf of
Wollongong Coal Limited

Project Director:	Barbara Crossley
Project Manager:	Gabrielle Allan
Technical Director:	David Holmes
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Newcastle

75 York Street
Teralba NSW 2284

T| 1300 793 267
E| info@umwelt.com.au

www.umwelt.com.au

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FINAL	Gabrielle Allan		Barbara Crossley	30/11/20

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1.0 Introduction

1.1 Background to Report

The Independent Advisory Panel on Underground Mining (IAPUM) was asked by the Independent Planning Commission (IPC) to provide advice on 8 specific questions which related to a number of issues raised during the NSW *Environmental Planning and Assessment Act 1979* assessment process for the Russell Vale Colliery Revised Underground Expansion Project MP09_0013 (the Project). These questions are set out below and the IAPUM advice dated November 2020 is attached as **Appendix A** to this Report.

> *1. In terms of the STC report and Dr Hebblewhite's peer review, are the risk and extent of the predicted subsidence impacts in the catchment reasonable? This needs to be considered in two scenarios:*
>
> *(i) that all the overlying Bulli Seam pillars have collapsed; and*
>
> *(ii) that some of the pillars have not collapsed.*
>
> *2. Is it likely that the Applicant will be able to develop a Mine Plan and Principal Hazard Management Plan that meets the requirements of the Resources Regulator and limits the level of subsidence to 100mm?*
>
> *3. Beyond a 100mm target what is likely to be the worst-case local subsidence scenario if residual pillars in the Bulli Seam collapse?*
>
> *4. Dr Gang Li has made comments and raised concerns relating to the local subsidence impacts and mine stability due to the possible existence of un-collapsed "marginally stable pillars". Are these concerns adequately addressed by the approach proposed by the Applicant and the guidance given in the Resource Regulator's Letter to Commission from Resources Regulator on 16 October, 2020?*
>
> *5. We note that the Resources Regulator has recommended that the applicant undertake investigations to identify and define the existence and distribution of any marginally stable pillars in the overlying Bulli Seam. Are there proven non-invasive methods available to determine the subsurface presence of voids either from existing surface access points or from underground prior to development commencing in sections of the mine which may undercut areas identified as 'unconfirmed' with respect to pillars in the Bulli Seam?*
>
> *6. To what extent should the status of any voids in sections of the old Bulli workings be determined before mining commences or is it appropriate to do this by measurement (and observation) of abutment stresses once mining commences?*
>
> *7. Is the claimed stability of the pillars in the current application likely to be realised given the ground conditions expected in the poorer quality coal remaining in the Wongawilli Seam above that part of the Wongawilli Seam that is proposed to be mined?*
>
> *8. Could any of the above matters be reasonably addressed through conditioning, and if so, how?*

The IAPUM Advice relied primarily on the material provided to it by the IPC however this information does not appear to have included the following most recent subsidence assessment reports, or the Recommended Conditions for the Project:

- SCT Report: *Russell Vale Colliery: Subsidence Assessment for Proposed Workings in Wongawilli Seam at Russell Vale East* dated 3 October 2019 (SCT Subsidence Assessment) (SCT 2019)

- Dr Bruce Hebblewhite Peer Review of the SCT Subsidence Report: *Report No. 1907/01.2 Peer Review – Russell Vale Colliery Subsidence Assessment Supplementary Summary Report* dated 12 October 2019 (Hebblewhite Consulting, 2019) and

- *Russell Vale Revised UEP Recommended Conditions* prepared by the NSW Department of Planning, Industry and Environment (DPIE) prepared as part of the DPIE Assessment Report (Recommended Consent Conditions).

The IAPUM Advice discusses both the adequacy of the proposed mine plan and risks of pillar failure and subsidence in relation to the proposed workings in the Wongawilli Seam together with the potential subsidence impacts associated with pillar failure in the overlying Bulli Seam workings.

The IAPUM specifically focussed its assessment on the potential impacts from subsidence impacts on Upland Swamps present above parts of the proposed workings. Their response acknowledges that there are a number of matters for which they didn't have access to relevant information and suggests clarification by the Proponent in relation to such matters. The IAPUM did not have the benefit of review of the Recommended Consent Conditions which include the requirement for the preparation of an Extraction Plan for all underground mining in the Bulli Seam undertaken as part of the Project. Notwithstanding, the IAPUM has acknowledged that:

> *The Panel concurs with SCT that it is very unlikely that there are pockets of pillars still standing in the 14 goaf areas identified in the SCT quantitative risk assessment report.*
>
> *The predictions of incremental vertical subsidence are considered soundly based and reasonable.*
>
> *… it seems implausible that an incremental strain of only 0.5 mm/m could initiate a catastrophic loss of a swamp*
>
> *In all but one case, the predictions of SCT (2020b) and the Panel of worst case outcomes for vertical surface subsidence agree to within 200 mm, as documented in Table 5. The one exception is highly unlikely to be realistic in the given conditions and not pursued further.*
>
> *… the Panel agrees with the Regulator [NSW Resource Regulator] that the identified risks can be suitably and appropriately managed post approval provided that appropriate inquiries and investigations are undertaken by the applicant to further identify and define the existence and distribution of the marginally stable pillars in the overlying Bulli Seam.*
>
> *If the IPC assesses these impacts to be tolerable and/or able to be managed to a tolerable level through approval conditions, the need to resolve most, if not all, the geotechnical uncertainties is removed.*

As acknowledged in the 16 October 2020 letter from the Resources Regulator to the IPC:

> *[T]he Resources Regulator's position remains that the identified risks can be suitably and appropriately managed post approval provided that appropriate inquiries and investigations are undertaken by the proponent to further identify and define the existence and distribution of the marginally stable pillars in the overlying Bulli Seam.*

This view is supported by the IAPUM Advice in its response to Question 4. Further discussion on the process of detailed mine design, management and monitoring is provided in **Section 3.0**.

1.2 Purpose of Report

This Report has been prepared to respond to the observations made in the IAPUM Advice and provide additional input to the consideration of the matters posed to the IAPUM as recommended by the IAPUM Advice. The Report also provides the IPC with further details regarding the application of the existing NSW regulatory regime to the proposed mining operations and how this regulatory framework and additional management measures proposed by the Proponent provide a high degree of confidence that the minimal level of impact predicted in the assessment documentation related to subsidence impacts can be achieved.

1.3 Structure of Response

Section 2.0 includes further discussion regarding the nature of the risk presented by the potential presence of remnant pillars in Bulli Seam goaf areas in terms of both likelihood and consequence of such pillar failure occurring. Additional information regarding the existence and distribution of marginally stable pillars is contained in the SCT Subsidence Assessment.

Section 3.0 of this Report provides further details of the regulatory regime and management measures that will apply to and be implemented for the proposed mining of the Wongawilli Seam at Russell Vale.

Section 4.0 provides a consolidated summary of the response to the questions posed to the IAPUM by the IPC and the IAPUM response to those question.

Appendix B to this Report includes a detailed technical response by SCT to specific observations made in the IAPUM Advice.

Appendix C includes additional observations from Dr Bruce Hebblewhite in relation to both the IAPUM observations and conclusions and the response provided by SCT.

Appendix D contains a summary of proposed subsidence monitoring measures to be implemented.

Appendix E contains a summary of predicted subsidence impacts from previous mining for relevant upland swamps.

2.0 Comments on Risks Associated with Subsidence

2.1 General comments on Bulli Seam Workings

The Bulli Seam at Russell Vale Colliery was initially mined using hand bord and pillar mining techniques from the 1890's through until pillar extraction became possible with improvements in mining technique and the arrival of mechanised mining (SCT, 2019). Within the Bulli Seam workings, some of the standing pillars associated with the main headings and original mining areas were extracted during the later stages of retreat.

The assessment documentation includes the phrases 'potential pillar instability', 'marginally stable pillars' and 'standing pillars' in relation to the Bulli Seam workings and there appears to be some confusion as to the meaning of these terms and their consideration in the SCT Subsidence Risk Assessment and SCT Subsidence Assessment, particularly as these phrases have been used interchangeably.

Appendix A, Section A1.1 of the SCT Subsidence Assessment includes a comprehensive discussion of past workings within the Bulli Seam and predicted impacts associated with these Seams. The following summarises the two different types of remnant pillars in the Bulli Seam considered in the Subsidence and risk assessments and these phrases will be used throughout this report and **Appendix B** and **Appendix C**.

2.1.1 Marginally Stable Pillars

The phrase 'marginally stable pillars' and discussion around 'potential pillar instability' relates to consideration of irregularly shaped bord and pillar workings adjacent to the Bulli Seam main headings. These are shown in Figure 16 of the SCT Subsidence Assessment (reproduced below in **Figure 2.1**). The SCT Subsidence Assessment includes the following commentary regarding these 'marginally stable pillars':

> *Similar workings were directly mined under by the Balgownie Seam longwall panels and it is clear from the underground inspection that these overlying pillars were destabilised in the area directly above the Balgownie Seam longwall goaf. Both these areas are shown in Figure 16* [refer to **Figure 2.1**]*. There did not appear to be any evidence that the footprint of instability extended significantly beyond the footprint of the underlying goaf, but it is considered possible that this potential may exist in some places where there are localised areas of standing pillars remaining.*
>
> *The formation of isolated roadways in the Wongawilli Seam is not expected to have potential to cause instability in these Bulli Seam pillars. There is no known evidence of this effect at the Russell Vale site. However, the possibility cannot be ruled out completely.*

While the terminology used is different, Section 2.3.3 of the SCT Subsidence Risk Assessment specifically considered the risk of subsidence associated with the failure of these pillars. The SCT Subsidence Assessment concludes in relation to these pillars:

> *These pockets of smaller pillars have potential to become unstable and collapse with some subsidence possible irrespective of any proposed mining in the Wongawilli Seam. Proposed mining is not expected to significantly affect their stability. The limited size of the pockets of standing pillars means that maximum surface subsidence is expected to be less than about 0.3-0.5m.*

There are no swamps located in the vicinity of these pockets and so the impacts to swamps of instability of these pockets of standing pillars is considered negligible even if instability were to occur at any time unrelated to proposed mining.

As is noted in the SCT Subsidence Assessment and the SCT Subsidence Risk Assessment, the dimensions and shape of these pillars are such that they have potential to become unstable and collapse (with some associated subsidence impacts) *irrespective* of the proposed mining in the Wongawilli Seam.

It is therefore important to recognise that the consequences of subsidence associated with the failure of these marginally stable pillars is almost certain to occur at some time in the future irrespective of whether or not the Project proceeds. The Project therefore does not cause the subsidence impacts that will arise from the eventual failure of these pillars (this is the result of historical mining which occurred prior to 1950), however the potential for the Project triggering the failure of these pillars cannot be ruled out.

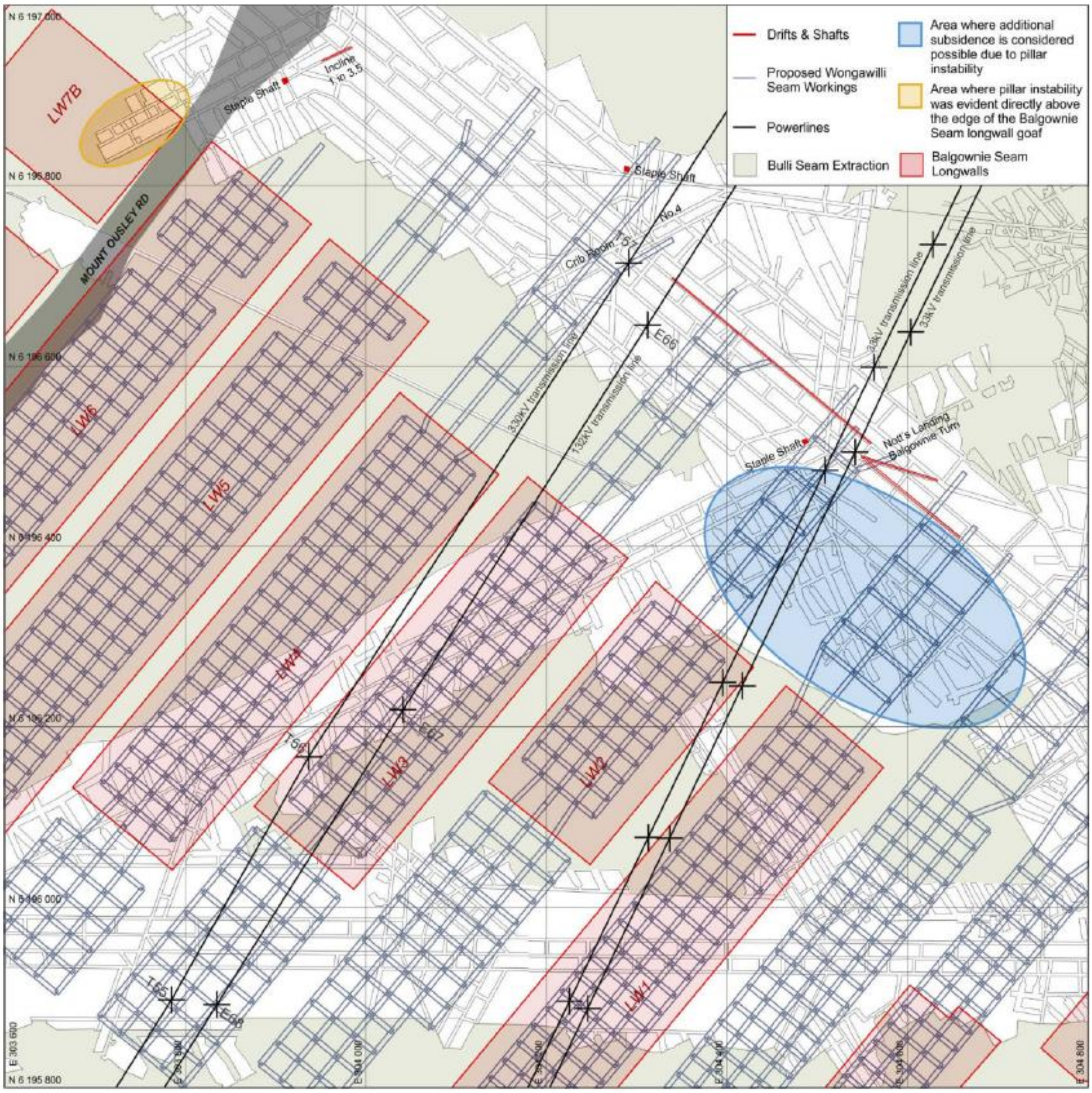

Figure 16: Plan showing areas of existing and potential pillar instability in overlaying Bulli Seam.

Figure 2.1 Marginally Stable Pillars

None of the marginally stable pillars are located below swamps nor is the failure of these pillars likely to impacts on any creeks, cliff lines or rockshelf features. As such, the environmental impacts of a failure of these pillars is likely to be negligible. These pillars are however located in close proximity to high voltage transmission line towers (refer to **Figure 2.1**) and the detailed mine design will need to have regard to the management of these features. This is discussed further in **Section 3.0**.

2.1.2 Standing Pillars

The use of the phrase 'standing pillars' in this Report relates to the potential for there to be remnant pillars or parts of pillars remaining within areas shown on the Bulli Seam record tracings as shaded (refer to black/grey areas in Figure 14 of the SCT Subsidence Assessment - reproduced in **Figure 2.2**) which have potential to fail. These areas are described in the SCT Subsidence Assessment as follows:

> *Where large areas have been shaded (refer to Figure 14) to represent the completion of mining, the detail of the Bulli Seam extraction is not available. These areas are likely to include different levels of mining ranging from solid coal, large standing pillars, standing pillars associated with Welsh bords, and goaf areas where there has been pillar extraction or the pillars have previously collapsed.*

These grey/black shaded areas correspond to the 14 'Bulli Seam goaf areas' considered in the SCT Subsidence Risk Assessment (SCT, 2020: refer to Figure 1 in the SCT Subsidence Risk Assessment – reproduced in **Figure 2.3**). Section 2.3.2 of the SCT Subsidence Risk Assessment (SCT, 2020a) describes these areas as follows:

> *Figure 1 shows fourteen large areas of Bulli Seam pillar extraction, referred to as Bulli Seam goaf areas. There is evidence available from subsidence monitoring and observation of roadway conditions in the Wongawilli Seam to confirm seven of these areas have fully collapsed with no potential for further subsidence. The seven collapsed goaf areas are numbered in Figure 1 as 1-7.*
>
> *It is almost certain that the other seven goaf areas (8-14) have also fully collapsed because the mining systems used in each are similar and the areas extracted are of similar size. Confirmation of collapse in all these areas would be reassuring for the sake of completeness. Proposed mining in the Wongawilli Seam would not change the potential for further subsidence from the Bulli Seam. This potential would exist irrespective of proposed mining. The benefit of knowing that all the Bulli Seam goaf areas have collapsed and fully subsided is that this risk could then be eliminated.*

Section 4.2.2.1 of the SCT Subsidence Risk Assessment (SCT, 2020a) provides further information regarding these areas:

> *The overburden depths in the Southern Coalfield are typically greater than 300m. At this depth, the abutment loads from a goaf are large enough to cause smaller pillars to become overloaded at the goaf edge. Pillars required to maintain a stable goaf edge at 300m need to be more than about 30-35m wide. Pillars of this size are large enough to either show on the mine record tracings or be too large to be at risk of becoming overloaded in the future. Their width to height ratio is nominally 14-16 and as such they continue to gain load carrying capacity as they become loaded and deform.*
>
> *The implication of this observation is that any pillar instability within a shaded area of goaf in the Bulli Seam is likely to cause pillar instability across the full shaded area. It is difficult to conceive of a pillar geometry that could involve a large area of standing pillars remaining stable for an extended period when surrounded by a goaf. The pillars have either already become overloaded and subsided, so they no longer present a hazard or are so large that they continue to gain load-bearing capacity as they deform and so no longer present a hazard.*

The ‘standing pillars’ referred to in this Report are those pillars that may (but are unlikely to) occur in Bulli Seam goaf areas 8-14 that were not designed to be long term stable and, in many cases, would be designed to fail as mining retreated from the area. Notwithstanding the expectation (and intention) that these pillars would fail, there is potential for some of these to remain in isolated areas of the Bulli Seam goaf areas 8-14. If present, these pillars would be largely surrounded by goaf material associated with the failure of surrounding pillars. Unlike the marginally stable pillars, the location of any standing pillars in the Bulli Goaf Areas cannot be determined from historical records and physical access to these areas is unavailable due to the goafing that has already occurred.

The eventual failure of these pillars is almost certain and all subsidence predictions have assumed that pillars in these areas have already collapsed, that is, predictions of cumulative subsidence impacts, tilts and strains have already considered the impacts associated with the failure of the pillars in these areas. This is acknowledged in the IAPUM Advice however, as correctly noted in the IAPUM Advice, if any pillars remain in Bulli seam Goaf Areas 8 to 14, features above these standing pillars may yet to experience the modelled levels of subsidence and the consequences associated with the almost certain subsidence that would occur when these standing pillars eventually fail.

SCT remain of the view that it is extremely unlikely that the proposed first workings below any of these standing pillars will further destabilise them however it is acknowledged that it cannot be entirely ruled out. However, as with the marginally stable pillars, the Project will not increase the consequences associated with these pillars failing (other than the predicted incremental subsidence associated with the proposed first workings) in that these consequences will eventually occur (if they haven’t already) irrespective of the Project proceeding. The Project could however bring the timing of these consequences forward if the works did result in destabilisation.

Figure 14: Plan showing extent of previous secondary extraction in Bulli Seam (black), Balgownie Seam (red) and Wongawilli Seam (grey) in the Application Area.

Figure 2.2 Areas of Secondary Extraction

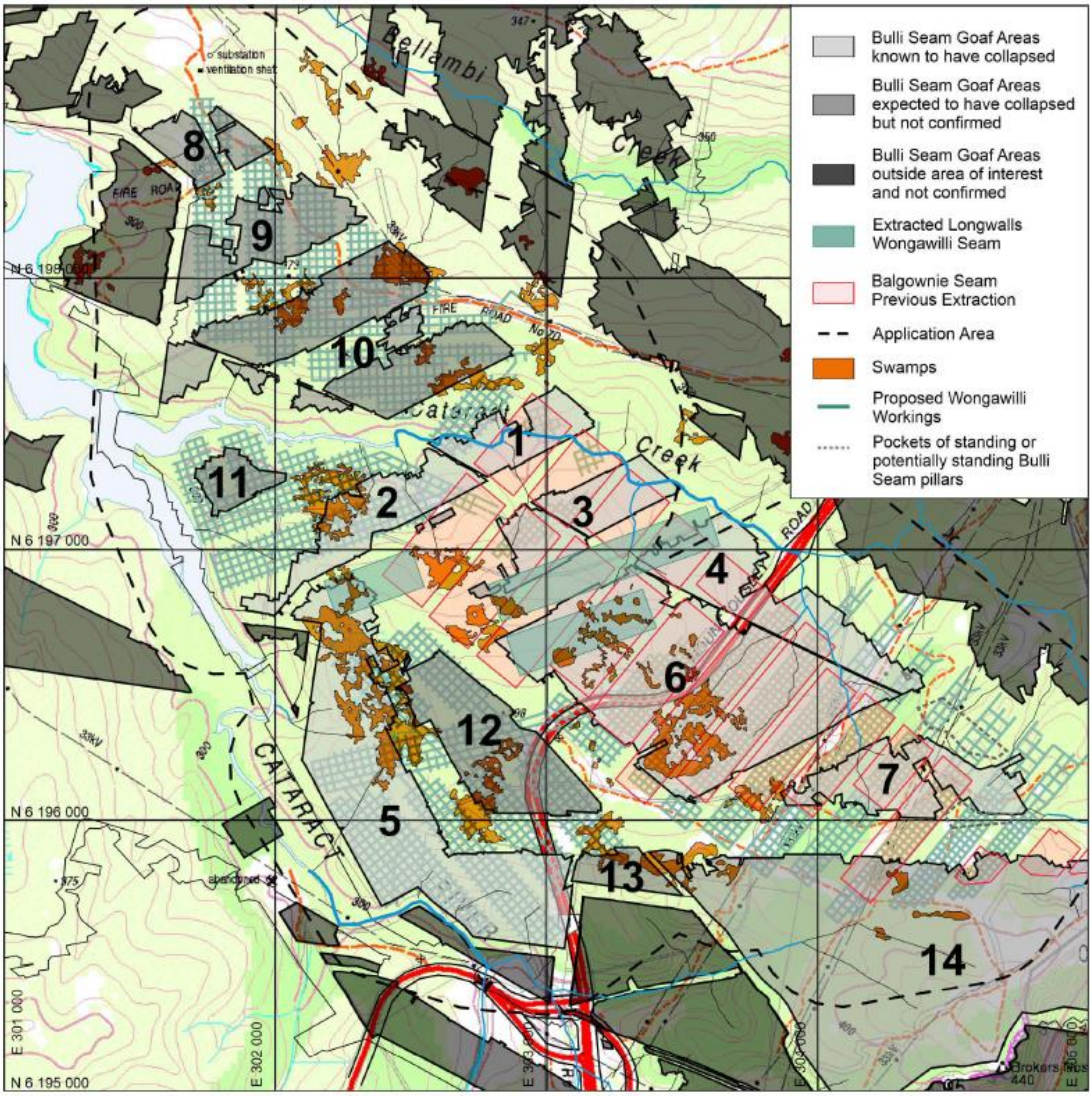

Figure 1: Plan showing location of swamps and proposed first workings in the Wongawilli Seam relative to previous secondary extraction in Bulli Seam (Grey), Balgownie Seam (Red) and Wongawilli Seam (Dark Green).

Figure 2.3 Goaf Areas Considered in SCT Subsidence Risk Assessment

© SCT, 2020a

2.2 Consequences of Standing Pillar Failure

As detailed in the SCT Subsidence Risk Assessment (SCT 2020a) and **Appendix B**, there is evidence available that confirms Bulli Seam Goaf Areas 1-7 have collapsed. This evidence is available directly through measurement of subsidence, borehole measurements or indirectly through observations of goaf edge abutment loading in underlying seams. In all seven of the goaf areas where evidence is available, the Bulli Seam pillars are confirmed as having been extracted or collapsed. The potential for further subsidence in these areas is limited to residual movements. Over the 80-90 years since mining was completed, any residual movements are expected to have occurred (SCT, 2020).

2.2.1 Potential Impacts on Upland Swamps

The IAPUM Advice has made specific reference to the existing predicted impacts to upland swamps presented in Table 3 of the IAPUM Advice in its assessment of likely impacts on upland swamps. At page 12 of the advice it states:

It is concluded that:

- *even allowing for those swamps overlying goaves where it is yet to be 'proven' that vertical subsidence has not been impeded by marginally stable pillars and, therefore, would be less than estimated in Table 3, the catastrophic loss of a swamp due to only 100 mm of incremental vertical subsidence is hardly credible. (It could be helpful and improve confidence in impact predictions for swamps if SCT, as the originators of Table 3, were to reproduce it having regard to the location of areas where vertical displacement would be less than estimated if there are still standing pillars in the Bulli Seam goaves.)*

- *based on historical performance, the failure of standing pillars in the Bulli Seam is extremely unlikely to result in catastrophic loss of a swamp (noting that the values for these swamps in Table 3 would need to be reduced accordingly if they are in fact located over pillars that are still standing).*

- *the additional amount of vertical subsidence that can be tolerated by the four swamps overlying both Bulli Seam workings and Balgownie Seam workings that are estimated to have already experienced around 10.5 mm/m tensile strain is unknown and, therefore, bord and pillar workings in the Wongawilli Seam beneath these areas need to be designed judiciously and conservatively in order to restrict vertical subsidence in the event of them becoming unstable.[8]*

  [Footnote 8: It was the high risk of reaching a swamp's tipping point (i.e. the point where the swamp can no longer function effectively as a swamp) due to a predicted incremental increase in tensile strain of 11 mm/m that caused the PAC to limit the extraction of LW 6 in the Wongawilli Seam to the western edge of swamp CCUS4 (DoP, 2014).]

Table 3 of the IAPUM Advice doesn't cover all swamps over the proposed first workings mine plan area and a number of swamps shown in Table 3 are not over the proposed mine workings area. **Appendix E** contains an updated list of upland swamps and the predicted cumulative subsidence and tensile strain impacts experienced at each of these swamps associated with mining in the Balgownie Seam and Bulli Seam. In total, there are 27 swamps located over the proposed first workings.

The IAPUM Advice noted that it would be helpful if maximum subsidence predictions in areas where pillars may still be standing could account for these pillars remaining. As noted in **Section 2.1** above and the SCT Subsidence Risk Assessment, in the absence of mining under the Bulli Seam goaf areas, it is not possible to identify where (if at all) any standing pillars may remain and therefore account for this in the subsidence predictions. The subsidence and tensile strain predictions therefore assume there are no standing pillars in any of the Bulli Goaf Areas. These predictions represent the maximum subsidence and tensile strain impacts that could occur if these standing pillars remain in the absence of further impacts associated with mining in the Wongawilli Seam.

The swamps within the vicinity of the proposed first workings are shown in **Figure 2.4**.

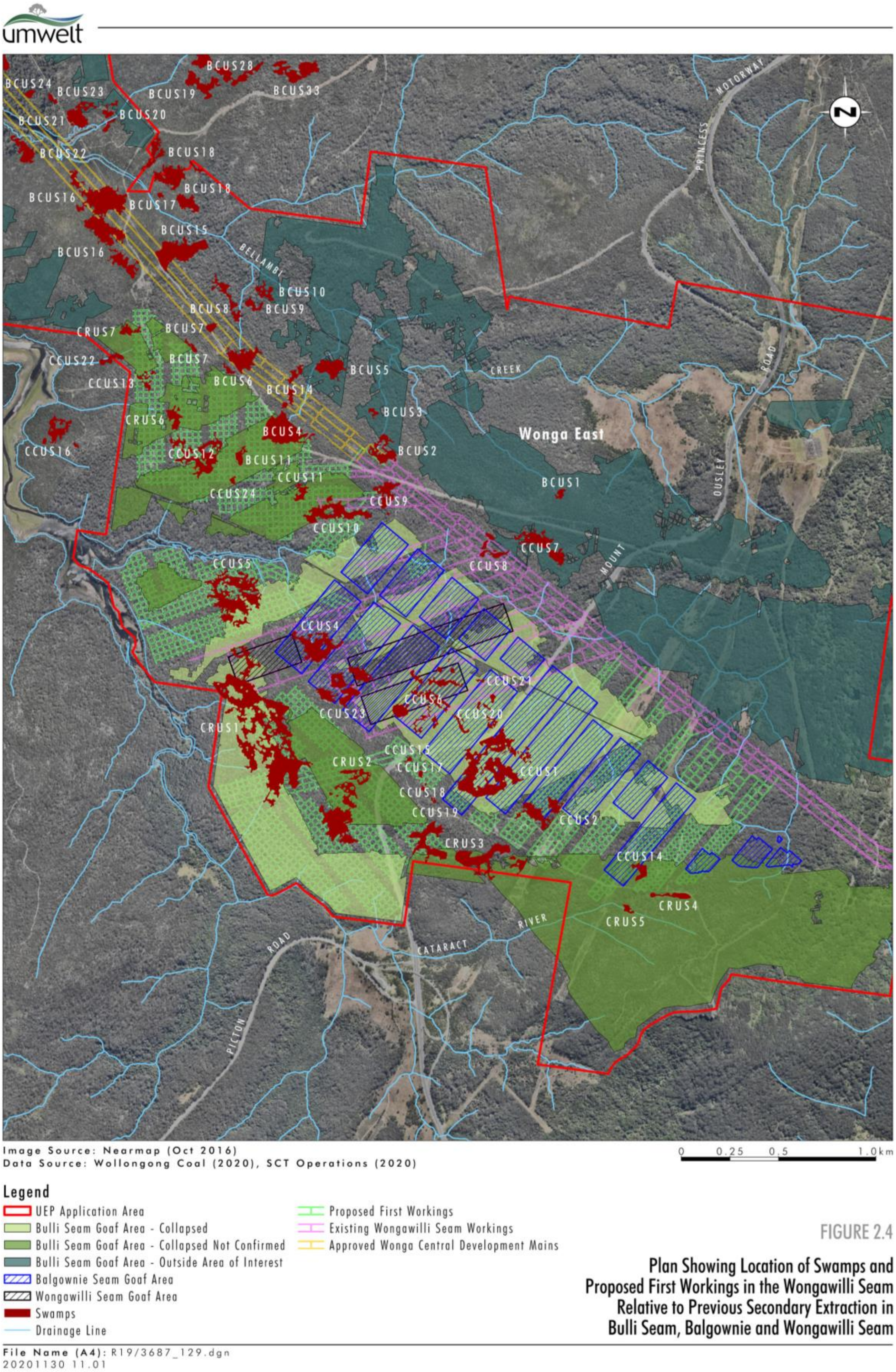

Figure 2.4 Upland Swamps Considered by IAPUM

Table 2.1 lists the 27 swamps which are located over areas of proposed first workings.

Table 2.1 Swamps over Proposed First Workings

Swamp	Bulli Seam Goaf Area	Potential for Standing Pillars Under Swamp	Located over Proposed First Workings	Max Predicted Subsidence - Bulli and Balgownie Seams (m)	Estimated Max Tensile Strain (mm/m)
CCUS1	Area 6	No	Yes	2	10.5
CCUS2	Edge Area 7	No	Yes	1.1	5.8
CCUS5	Pt Area 2	No	Yes	0.6	3.3
CCUS9	N/A	No	Yes*	0.1	0.5
CCUS10	Pt Area 10	No	Yes	0.2	0.9
CCUS11	Area 10	Yes	Yes	1.0	4.4
CCUS12	Part Area 10	Yes	Yes	0.5	2.1
CCUS13	Area 8	Yes	Yes	0.1	0.4
CCUS14	Area 14	Yes	Edge	1.2	6.5
CCUS15	N/A	No	Yes	0.2	0.9
CCUS17	N/A	No	Yes	0.1	0.5
CCUS18	N/A	No	Edge	0.1	0.5
CCUS20	Area 6	No	Yes	2.0	10.3
CCUS24	Edge Area 10	Yes	Yes	0.3	1.30
CRUS1	Pt Area 5	No	Part	0.5	2.5
	Edge Area 12	Yes	Yes		
CRUS2	Pt Area 12	Yes	Yes	0.6	4.3
CRUS3	Pt Area 13	Yes	Yes	0.6	3.1
CRUS6	Edge 9	Yes	Yes	0.1	0.40
CRUS7	Area 8	Yes	Yes	0.3	1.3
BCUS2	Nth of Mains	No	Yes#	0.5	2.6
BCUS3	Nth of Mains	No	Yes#	0.5	2.8
BCUS4	Area 10	Yes	Yes	0.6	3.1
BCUS6	Nth of Mains	No	Yes#	0.1	0.5
BCUS7	Edge Area 8	No	Edge	0.1	0.5
BCUS8	Nth of Mains	No	Yes#	0.1	0.5
BCUS11	Area 10	Yes	Edge	0.5	2.2
BCUS14	Nth of Mains	No	Yes#	0.5	1.0

* Headings only
# Mains Headings Only

2.2.1.1 Swamps with existing tensile stains >10 mm/m

The four upland swamps identified in the IAPUM Advice as already having experienced tensile strain impacts of over 10 mm/m (CCUS1, CCUS6, CCUS20 and CCUS21) are all located over Area 6 (refer to **Figure 2.4** and **Table E.1.1** in **Appendix E**). Area 6 is one of the Bulli Seam goaf areas confirmed as having been fully collapsed. Of these four swamps, neither CCUS6 and CCUS21 will be directly undermined by the proposed first workings in the Wongawilli Seam and are unlikely to experience any additional subsidence effects from the proposed mining.

The management of potential impacts on CCUS1 and CCUS 20 are discussed further in **Section 3.0**.

2.2.1.2 Swamps with existing tensile stains <10 mm/m

It is noted that not all of these swamp areas are located over the proposed first workings and 5 (BCUS2, BCUS 3, BCUS8 and BCUS14) are only located over areas of mains headings which are extremely unlikely to experience any observable subsidence impacts due to the large pillar size in mains headings. Accordingly, potential subsidence impacts associated with these swamps are not considered further other than to note that parts of the Bulli Seam north of the Mains heading is identified as being goaf and there remains potential for remnant standing pillars in these areas to collapse irrespective of the Project (the mains headings in the Wongawilli Seam do not undermine these Bulli Seam goaf areas). Accordingly, any subsidence impacts limits set for the Project and monitoring program must have regard to the potential for future subsidence impacts to arise in this northern area which is unrelated to the Project.

Of the remaining 22 swamps, 10 swamps are located over Bulli Seam goaf areas where there is evidence that all remaining pillars have fully collapsed. Potential subsidence impacts in these areas will therefore be limited to the subsidence associated with compression of the Wongawilli Seam Pillars. These incremental impacts are predicted to be between 30 and 100 mm (SCT 2019) with maximum impacts unlikely to exceed 140 mm even in the event of a collapse of pillars in the proposed first workings (SCT 2020). Based on the IAPUM Advice estimated predictions, the maximum additional subsidence (i.e. in addition to that specified in **Table 2.2**) that likely occur as a result of the Project at any of these 10 swamps is in the order of 150 mm based on the IAPUM Advice calculation which conservatively takes into account potential for additional goaf activation. With the possible exception of CCUS1 and CCUS 20 (refer to **Section 2.2.1.1**), it is, to use the language of the IAPUM Advice, implausible that the incremental tensile strains associated with this additional vertical subsidence could initiate a catastrophic loss of any of these swamps.

The 12 swamps which are wholly or partly located over both Bulli Seam goaf areas where there is potential for standing pillars to remain (Areas 8-14) and the proposed first workings in the Wongawilli Seam are listed in **Table 2.2**.

Table 2.2 Swamps over both proposed Wongawilli Seam Workings and Bulli Seam goaf areas 8-14

Swamp	Bulli Seam Goaf Area	Potential for Standing Pillars Under Swamp	Located over Proposed First Workings	Max Predicted Subsidence - Bulli and Balgownie Seams (m)	Estimated Max Tensile Strain (mm/m)
CCUS11	Area 10	Yes	Yes	1.0	4.4
CCUS12	Part Area 10	Yes	Yes	0.5	2.1
CCUS13	Area 8	Yes	Yes	0.1	0.4
CCUS14	Area 14	Yes	Edge	1.2	6.5
CCUS24	Edge Area 10	Yes	Yes	0.3	1.30
CRUS1	Edge Area 12	Yes	Yes	0.5	2.5

Swamp	Bulli Seam Goaf Area	Potential for Standing Pillars Under Swamp	Located over Proposed First Workings	Max Predicted Subsidence - Bulli and Balgownie Seams (m)	Estimated Max Tensile Strain (mm/m)
CRUS2	Pt Area 12	Yes	Yes	0.6	4.3
CRUS3	Pt Area 13	Yes	Yes	0.6	3.1
CRUS6	Edge 9	Yes	Yes	0.1	0.40
CRUS7	Area 8	Yes	Yes	0.3	1.3
BCUS4	Area 10	Yes	Yes	0.6	3.1
BCUS11	Area 10	Yes	Edge	0.5	2.2

While the incremental subsidence associated with the Project is unlikely to exceed 100mm (up to 150mm mm based on the conservative IAPUM estimates), the observed subsidence could be larger if standing pillars remained in the Bulli Seam goaf areas and these pillars failed during the life of the Project (up to 300mm in the event of an unlikely pillar failure based on IAPUM estimates). The observed subsidence at any of the swamps could not exceed the sum of the incremental subsidence (100mm) plus the maximum predicted subsidence levels as set out in **Table 2.2**. Any additional subsidence over the incremental subsidence predictions would be limited to localised areas around the failed standing pillar. As noted in the SCT response to the IAPUM Advice (**Appendix B**), the maximum extent of subsidence should any pillars still be present and fail during the life of the Project is likely to be lower than the IAPUM estimates.

As noted in **Section 2.1**, this additional subsidence associated with the standing pillars in the Bulli Goaf Areas is not caused by the Project but is rather an inevitable consequence of the mining previously undertaken in the former Bulli Seam Workings. Notwithstanding, even assuming such a pillar failure did occur during the life of the Project, it is considered extremely unlikely that these levels of subsidence would result in a catastrophic loss to upland swamps above these workings given that significantly higher impacts have occurred at other locations without any observable adverse impacts on these swamps. This conclusion is supported by the discussion on page 12 in the IAPUM Advice.

2.2.1.3 Summary of potential impacts to swamps

There are 27 swamps located above the proposed first workings. The predicted subsidence impacts on these swamps associated with subsidence due only to the proposed first workings in the Wongawilli seams is 100mm (SCT 2019). The IAPUM has estimated that slightly higher levels of subsidence of up to 150 mm could occur. Based on well-established principles, an incremental vertical subsidence of 100mm could be expected to result in an incremental tensile strain of up to 0.5mm/m (although, as discussed by SCT in **Appendix B**, this is likely to be conservative in the Russell Vale context). There are 10 swamps (including CCUS 1 and CCUS 20) for which this is the maximum likely extent of subsidence impacts.

With the possible exception of swamps CCUS1 and CCUS20, the IAPUM has indicated that "*it seems implausible that an incremental strain of only 0.5 mm/m could initiate a catastrophic loss of a swamp*." And "*the catastrophic loss of a swamp due to only 100mm of incremental vertical subsidence is hardly credible*." This conclusion would also extend to the incremental tensile strains associated with the additional 50mm of subsidence that the IAPUM conservatively assumed was possible. Consistent with the advice of the IAPUM, the design of bord and pillar workings below CCUS1 and CCUS20 will need to be designed judiciously and conservatively to restrict adverse impacts on these two swamps. It is noted that neither of these swamps are located over Bulli Seam goaf areas where there is any potential for standing pillars to remain. This is discussed further in **Section 3.0**.

12 swamps are located over Bulli Seam goaf areas where there are potential for standing pillars to remain. As noted in the IAPUM Advice:

> *The Panel concurs with SCT that it is very unlikely that there are pockets of pillars still standing in the 14 goaf areas identified in the SCT quantitative risk assessment report.*

Even where such a failure occurs during the course of the Project, or at some time in the future, this is an inevitable consequence of the former Bulli Seam workings in these areas as these pillars were never intended to remain standing for long periods of time (and hence the high degree of confidence expressed by both SCT and the IAPUM that it is unlikely that any such pillars remain).

Swamps located over Bulli Seam goaf areas 1-7 which are known to have fully collapsed have not experienced any catastrophic failure of ecological function. The predicted maximum vertical subsidence and tensile strains in all of the 12 swamps over Bulli Seam goaf areas 8-14 are lower than the maximum levels predicted and/or observed in Bulli Seam goaf areas 1-7. As noted by the IAPUM, based on the predicted maximum vertical subsidence and tensile strains predicted as being experienced at the 12 swamps:

> *based on historical performance, the failure of standing pillars in the Bulli Seam is extremely unlikely to result in catastrophic loss of a swamp.*

2.2.1.4 Impacts to groundwater and surface water systems

The groundwater impact assessment prepared by Geoterra (2020) and the uncertainty assessment undertaken by HydroAlgorithmics (2020) was based on modelling of fully collapsed Bulli Seam goaf areas. Should there be any standing pillar in these areas that fail during the life of the Project, the potential impacts associated with these failures has already been considered in the Groundwater and Surface Water cumulative impact assessment and sensitivity analysis.

2.2.1.5 Impacts to other sensitive features

Additional subsidence below cliff lines and under rock platforms and shelfs has the potential to cause cliff line instability and cracking of rock features. The predicted incremental vertical subsidence impact associated with the Project of up to 100mm (and a consequent 0.5mm/m tensile stain) are considered unlikely to result in any cliff line instability or additional observable surface cracking in rocks. Even the incremental impacts associated with an unlikely failure of a Wongawilli Seam Pillar (up to 140mm) is considered unlikely to have a significant impact on these surface features. Should there be any standing pillars in the Bulli Seam goaf areas which fail during the life of the Project, additional vertical subsidence and tensile cracking could be observed depending on the magnitude of the additional subsidence. Significant additional vertical subsidence could also cause cliff instability.

As noted above, any additional observed subsidence associated with the failure of standing pillars in the Bulli Seam goaf areas is largely inevitable irrespective of the project occurring due to the inherent instability. Accordingly, impacts to cliffs or rock shelves associated with standing pillar failure are a consequence of historic mining and not the Project even were they to occur during the life of the Project.

WCL will remain liable for rehabilitation of mining related impacts covered by the mining leases held by them and this includes liabilities associated with the former Bulli Seam Workings. Accordingly, the monitoring and management measures implemented as part of the Project will need to have regard to impacts associated with the potential failure of standing pillars in the Bulli Seam. This is discussed further in **Section 3.0**.

2.3 Consequences of Failure of Marginally Stable Pillars

The failure of marginal pillars will have similar levels of subsidence impacts (vertical subsidence, strains and tilts) to those predicted for standing pillars in the Bulli Seam goaf areas.

None of the marginally stable pillars are located below swamps nor is the failure of these pillars likely to impacts on any creeks, cliff lines or rockshelf features. As such, the environmental impacts of a failure of these pillars is likely to be negligible. These pillars are however located in close proximity to high voltage transmission line towers (refer to **Figure 2.1**) and the detailed mine design will need to have regard to the management of these features. The specific mine design and management process is discussed further in **Section 3.0**.

2.4 Subsidence Attributed to the Project

The IAPUM Advice quantifies both potential subsidence impacts associated with the proposed Wongawilli Seam workings as well as maximum subsidence impacts should standing pillars in Bulli Goaf areas also fail. As discussed above, while there is a potential for this maximum scenario to occur during the life of the Project, the eventual failure of any standing pillars in the Bulli Seam goaf areas is expected due to the nature of these pillars and the mining system used in these areas (SCT2019, SCT 2020a, SCT 2020b). As a result, the consequences of the subsidence associated with these Bulli Seam pillars is almost certain to occur irrespective of the Project.

While cumulative impacts are relevant to the overall assessment of the Project, the key issue to note is that the potential for additional subsidence impacts to arise during the course of the Project which are due to a failure of inherently unstable pillars in the Bulli Seam is an impact that would occur irrespective of the Project occurring.

Monitoring will necessarily pick up the cumulative impact of both the inevitable impacts of former workings and those associated with the Project. Where impacts occur due to either proposed or former workings, the Proponent, as the holder of the relevant mining leases, will have an obligation under the mining leases to undertake appropriate rehabilitation measures. However, from a compliance perspective, it is expected that specific performance measures will be set for the Project based on impact predictions and commitments. This is discussed further in **Section 3.0**.

3.0 Regulatory and Management Measures

3.1 Regulatory Framework

The two main approval processes which regulate the carrying out of underground mining activities which have potential to cause subsidence impacts are:

- development consent under the Environmental Planning and assessment Act including:
    - Extraction Plan (see for example Recommended Consent Condition C10)
    - performance measures (see for example Recommended Consent Condition C1 and C7)
    - rehabilitation and offsetting requirements (see for example Recommended Consent Condition B42 and C4, C4 and C6) C5)
    - monitoring and adaptive management processes (see for example Recommended Consent Condition C2, C3, monitoring requirements under the Extraction Management Plan)
- development and implementation of principal hazard management plans under the *Work Health and Safety (Mine and Petroleum Sites) Regulation 2014* (WHS Mining Regulation).

The Extraction Plans required under the terms of the Recommended Consent Conditions must be prepared in consultation with the Resources Regulator which also administers the WHS Mining Regulation. Extraction Plans must be approved by the Secretary of DPIE prior to the works covered by those Plans being undertaken. In practice, there is a close alignment between Extraction Plans prepared in accordance with the development consent and Subsidence Principal Hazard Management Plans.

In addition to the above the Ground and Strata Failure Hazard Principal Hazard Management Plan will also include specific procedures related to pillar design and strata control which are relevant to the long term stability of pillars such as proposed for the Wongawilli Seam. The Ground and Strata Failure Hazard Principal Hazard Management Plan will also include underground monitoring processes, including those discussed in **Appendix D**.

The efficacy of the WHS Mining Regulation process in managing subsidence related risks is emphasised in the Resources Regulator Letter of 16 October to the IPC which provides:

> *I confirm that the Resources Regulator's position remains that the identified risks can be suitably and appropriately managed post approval provided that appropriate inquiries and investigations are undertaken by the proponent to further identify and define the existence and distribution of the marginally stable pillars in the overlying Bulli Seam.*
>
> *…*
>
> *Further, it is our view that the NSW work, health and safety laws can be appropriately applied to manage risks to the health and safety of workers and other persons to deal with the above identified risks. In this respect, clause 24 of the Work Health and Safety (Mine and Petroleum Sites) Regulation 2014 reference to clause 3C(d) of Schedule 1, of the Regulation and requires the development of a principal hazard management plan in relation to subsidence. Notably, the subsidence PHMP requires consideration of the following when developing the control measures to manage the risks of subsidence:*
>
>> *"the existence, distribution, geometry and stability of significant voids, standing pillars or remnants within any old pillar workings that may interact with any proposed or existing mine workings"*

The views of the Resources Regulator are also supported by the IAPUM Advice response to Question 4 where it provides:

> *[T]he Panel agrees with the Regulator that the identified risks can be suitably and appropriately managed post approval provided that appropriate inquiries and investigations are undertaken by the applicant to further identify and define the existence and distribution of the marginally stable pillars in the overlying Bulli Seam.*
>
> *Further, the Panel supports the Regulator in its view that work health and safety laws can be appropriately applied through, int this matter, the development of a principal hazard management plan for subsidence.*

3.2 Proposed Monitoring and Management Measures

The Response to Second PAC Review Report (Umwelt 2019a) and Response to Submissions Reports A and B (Umwelt 2019c and 2019d) include a comprehensive suite of proposed monitoring and management commitments and strategies.

3.2.1 Subsidence Monitoring

Appendix D provides a summary of proposed subsidence monitoring to be undertaken as part of the Project prepared by SCT and includes the following:

- a description of the ongoing subsidence monitoring program within Wonga East (RVE) area.
- a description of the proposed subsidence monitoring program for the UEP.
- a description of any additional subsidence monitoring that may be required in order to identify and differentiate any additional subsidence from Bulli Seam goaf areas from impacts associated with the UEP.
- plans showing the location of monitoring and, as relevant, key features such as the seven Bulli Seam goaf areas yet to be confirmed as collapsed.
- a description of the process for confirming the status of the Bulli Seam goaf areas yet to be confirmed as subsided (noting specifically that this is an existing risk not related to, or exacerbated, by the project).
- a description of any specific subsidence management measures to be implemented for the UEP.
- a description of the process for reviewing and validating subsidence predictions.

Additional monitoring of groundwater, surface water, and biodiversity values and well as targeted monitoring of cliff lines and other sensitive features will be detailed in specific management plans developed for these matters as part of both the extraction plans and general operations.

3.2.2 Subsidence Management

Specific management plans will be developed or existing plans updated to cover the proposed operations. Compliance with these management plans is a requirement under the development consent or WHS Mining Regulation. The existing Subsidence Management developed and approved for Longwall 6 will be applied to the remaining extraction associated with the removal of the longwall miner.

Extraction plans required under the development consent and managements plans required under the WHS Regulations will be developed for specific areas or panels of proposed first workings. These Extraction Plans, Subsidence Principal Hazard Management Plans and Ground and Strata Failure Hazard Principal Hazard Management Plans will include further details regarding:

- key risks associated with the mining of the specific are covered by the plan
- the specific monitoring to be undertaken for the first workings extraction areas covered by the management plan.
- management measures to be implemented through design features (e.g. pillar design)
- adaptive management measures to be implemented, and
- Trigger Action Response Plans related to the management of specific impacts or potential impacts which are identified through monitoring.

Under the proposed wording of the Recommended Consent Conditions, works requiring an extraction plan cannot be carried out unless the relevant plan is approved by the Secretary for the DPIE.

The Extraction Plan(s) and Subsidence Principal Hazard Management Plan(s) developed for the first workings potentially affecting swamps CCUS1, CCUS6, CCUS20 and CCUS21 will have specific regard to any updated subsidence, groundwater and swamp monitoring in the development of the mine plan below and in the vicinity of these swamps. The mine plan and monitoring in these areas will require careful consideration of cumulative impacts on these swamps and the potential for tensile strains to exceed thresholds that may present a risk to these swamps.

As recommended by the Resources Regulator in its letter of 16 October 2020, initial mining operations will also commence in panels to the west of the Mt Ousley Road to enable further investigation of marginally stable pillars to the east of Mount Ousley Road and any mine design or other considerations required to mitigate potential impacts to surface infrastructure (discussed in **Section 2.1.1**). The management of risks associated with these marginally stable pillars will be contained in the Extractions Plans, Subsidence Principal Hazard Management Plans and Ground and Strata Failure Hazard Principal Hazard Management Plan developed for the proposed mining in areas where these marginally stable pillars are contained.

As highlighted by the IAPUM Advice:

> *Bord and pillar mining as proposed in the Wongawilli Seam offers many advantages in these types of situations because it is flexible and amenable to rapid changes in mine layout to respond to changed mining conditions and risk profiles.*

This flexibility is important in that it enables mining operations (and associated economic benefits to the State) to quickly adapt to changed circumstances and continue operations in circumstances that may otherwise cause a suspension of operations for mini-wall or longwall mining operations.

Other management plans covering the broader operations will be developed or updated as necessary. These management plans will be revised periodically in response to annual reviews, TARP triggers and specific changes associated with management measures proposed in the more detailed extraction plans when approved.

4.0 Response to IPC Questions

4.1 Question 1

In terms of the STC report and Dr Hebblewhite's peer review, are the risk and extent of the predicted subsidence impacts in the catchment reasonable? This needs to be considered in two scenarios:

(i) that all the overlying Bulli Seam pillars have collapsed; and

(ii) that some of the pillars have not collapsed.

SCT concurs with the conclusions reached in relation to Question 1, especially given the limited information provided to the IAPUM. As the IAPUM states:

> *There is nothing particularly unique or abnormal about what is being proposed and that has not been done before and, apart from the matters noted already, the SCT report addresses the extent of the impacts adequately.*

4.2 Question 2

Is it likely that the Applicant will be able to develop a Mine Plan and Principal Hazard Management Plan that meets the requirements of the Resources Regulator and limits the level of subsidence to 100mm?

The 100mm limit used in the SCT Subsidence Risk Assessment was intended as a conservative guide to estimating the risk of vertical subsidence causing catastrophic loss of a single swamp and wasn't based on any specific risks to individual swamps. The mine plan has been specifically designed to meet this limit. Notwithstanding, given the experience of the IAPUM in determining swamp impacts, a higher value is accepted as more appropriate to use as a general performance indicator and for the development of Extraction Plans and Principal Hazard Management Plans for subsidence.

Management plans, including Extraction Plan and Principal Hazard Management Plan will be developed based on the specific conditions relevant to the plans including the specific circumstances of individual swamps.

The IAPUM has specifically acknowledged that the proposed pillar mining system is flexible and can be easily modified to respond to changes in loading and other circumstances allowing for more responsive adaptive management systems.

4.3 Question 3

Beyond a 100mm target what is likely to be the worst-case local subsidence scenario if residual pillars in the Bulli Seam collapse?

The SCT Response in **Appendix B** supplements the IAPUM Advice as follows:

> *The IAPUM indicate 1150mm of subsidence may be possible if failure is confined to remnant pillars in the Bulli Seam and, in the very unlikely scenario of pillar failure in the Wongawilli Seam, subsidence of up to 1300mm may be possible.*

The Bulli Seam mining height across most of the Russell Vale East area is approximately 2.2m. On the assumption that there are still standing pillars capable of supporting the 250-300m of overburden strata that would subsequently need to collapse to give rise to surface subsidence, a value of subsidence equal to 1150mm (50% of seam thickness) appears quite high. Even total extraction from longwall mining only causes 55%-65% of mining height. A maximum value of additional subsidence from collapse of standing pillars in Bulli Seam goaf areas is considered likely to be limited to less than 1m and probably significantly less than 1m if the collapse area is narrower than the overburden depth.

It should be recognised that the original figure that forms the basis for Figure 1 presented in the IAPUM report is slightly misleading in that the panel width (W) relates to the width of individual panels. This width is normalised when divided by overburden depth (H). However, the maximum subsidence normalised by dividing by mining height relates to the subsidence across multiple panels of width W, not just a single panel as drawn. It is very unusual to see surface subsidence above a single panel when the panel width is less than one third of overburden depth. The guidelines from the Reynolds Inquiry (Reynolds 1977) take advantage of this geometry to control subsidence below stored waters.

4.4 Question 4

Dr Gang Li has made comments and raised concerns relating to the local subsidence impacts and mine stability due to the possible existence of un-collapsed "marginally stable pillars". Are these concerns adequately addressed by the approach proposed by the Applicant and the guidance given in the Resource Regulator's Letter to Commission from Resources Regulator on 16 October, 2020?

The IAPUM Advice addresses this issue.

The commitment from WCL to commence operations to the west of Mt Ousley Road to enable mine design and management processes to be proven prior to mining below areas of marginally stable pillars is consistent with the recommendation of the Resources Regulator.

4.5 Question 5

We note that the Resources Regulator has recommended that the applicant undertake investigations to identify and define the existence and distribution of any marginally stable pillars in the overlying Bulli Seam. Are there proven non-invasive methods available to determine the subsurface presence of voids either from existing surface access points or from underground prior to development commencing in sections of the mine which may undercut areas identified as 'unconfirmed' with respect to pillars in the Bulli Seam?

The SCT response in **Appendix B** concurs with the IAPUM Advice on this issue. SCT also advise the following:

It would not be practical or necessary to drill holes across the entire area of Bulli Seam goafs. Other methods are likely to be more effective.

Mining conditions in the Wongawilli Seam are expected to provide clearer evidence of the presence of goaf edges in the Balgownie and Bulli Seams above. The presence of standing pillars in the Bulli Seam does not cause a sharp change in vertical stress, whereas mining below a goaf edge does cause a sharp change in vertical stress under the increased abutment loads generated by a large area of extracted pillars. The proposed method of confirming the collapse of pillars in the Bulli Seam from mining conditions encountered in the Wongawilli Seam is considered a practical and robust approach.

4.6 Question 6

To what extent should the status of any voids in sections of the old Bulli workings be determined before mining commences or is it appropriate to do this by measurement (and observation) of abutment stresses once mining commences?

SCT, as part of the preparation of their Subsidence Assessment (SCT2019) which wasn't part of the material provided to the IAPUM, had the opportunity to review detailed mine plans and recording tracings of the Bulli Seam mining and to inspect areas in the Bulli Seam, Balgownie Seam and Wongawilli Seam workings where there is interaction between seams. With the benefit of this additional background knowledge of the site, SCT concurs with the IAPUM assessment and response.

All currently available information indicates that the Bulli Seam goaf areas have almost certainly collapsed. The IAPUM Advice also acknowledges that it would be unlikely for any standing pillars to remain in these areas. Deteriorated mining conditions below the goaf edge when mining in the Wongawilli Seam will provide unequivocal confirmation of this expectation.

4.7 Question 7

Is the claimed stability of the pillars in the current application likely to be realised given the ground conditions expected in the poorer quality coal remaining in the Wongawilli Seam above that part of the Wongawilli Seam that is proposed to be mined?

The IAPUM refers to a description of the Wongawilli Seam roof strata being "weak coal/shale roof in a thick seam environment" (SCT 2019) contrasting with field monitoring data from AMIRA (1995) that supports the finding that Wongawilli Seam pillars are observed to generate confinement consistent with strong roof and floor conditions. This issue was specifically addressed in the updated Subsidence Assessment provided with the Response to Submissions Report B (see SCT, 2019a).

This issue is discussed further in **Appendix B** where it is noted that:

> "these two observations are not in conflict. Field monitoring experience supports the strength of Wongawilli Seam pillars as being consistent with pillars in strong roof and floor conditions despite the roof material comprising "weak coal/shale roof in a thick seam environment".

SCT further note in **Appendix B** in relation to this issue:

> *The stability of the Wongawilli Seam pillars will be critical to the maintenance of productive roadway conditions during mining. The pillars are large enough not to collapse suddenly. Any potential for them to become heavily loaded will become evident through rib and potentially roof deterioration. Such deterioration will significantly impact mining productivity. The mining system is flexible enough to allow modification to the layout as part of the ongoing adaptive mine management system proposed. There will be significant value to the mine in ensuring that pillars do not become heavily loaded and productive mining conditions are maintained.*

4.8 Question 8

Could any of the above matters be reasonably addressed through conditioning, and if so, how?

We note that the IAPUM were not provided with a copy of the Recommended Consent Conditions which include a comprehensive framework around the management of mining operations that have potential to cause subsidence impacts. The approach reflected in the Recommended Consent Conditions are consistent with the approval framework that has been successfully applied to underground mining operations in NSW (including the mining of Longwalls 4, 5 and 6 in the Bulli Seam at Russell Vale Colliery) for over 15 years.

The views expressed by the IAPUM Advice and the Resources Regulator that these matters can be managed through the existing and proposed regulatory framework are supported.

The SCT Advice in **Appendix B** provides further discussion on this point.

5.0 Summary

The Project has been designed to minimise subsidence impacts and the proposed first workings mine plan has had specific regard to the former workings in overlying seams. The SCT Subsidence Assessment (SCT, 2019) prepared for the Project has been prepared based on extensive monitoring data and observations from the Russell Vale Colliery as well as accepted pillar design principals such as the UNSW Pillar Design Methodology (Galvin et al., 1999).

WCL remain committed to the design and implementation of a first workings, long term stable mine plan that meets the performance criteria set out in Condition C1 of the Recommended Consent Conditions. The predicted incremental vertical subsidence impacts associated with the proposed first workings mine plan is up to 100mm (SCT 2019). The IAPUM Advice has provided a slightly more conservative assessment of potential impacts of up to 150 mm of vertical subsidence.

Additional subsidence impacts may be observed over the Bulli Seam goaf areas 8-14 in the unlikely event that standing pillars remain in localised areas in these goaf areas and fail during the life of the Project. Subsidence impacts associated with these pillar failures are assumed to have already occurred and have been factored into cumulative impact assessment considerations. To the extent that this risk is present, it is a pre-existing risk which applies irrespective of whether the Project occurs.

In terms of potential impacts on upland swamps which are present over some areas of the proposed first workings, tensile strains associated with subsidence are identified in the IAPUM Advice as being the key risk in terms of swamp functioning. To date, there is no evidence that historical mining below these swamps has caused any significant harm to the functioning of these swamps. The IAPUM have acknowledged that the incremental tensile strains associated with the proposed first workings (taking into account the predicted full extent of subsidence associated with the mining of the Bulli and Balgownie Seams) are unlikely to result in a catastrophic loss of any swamps, however they have advised that the mine design will need to have specific regard to the pre-existing conditions present at swamps CCUS1, CCUS6, CCUS20 and CCUS21. As also acknowledged in the IAPUM Advice, the flexible nature of bord and pillar mining systems means risks associated with the low level of predicted subsidence can be effectively managed to avoid significant risks, including in areas below the four swamps identified by the IAPUM as having larger pre-existing predicted higher levels of tensile strains and the marginally stable pillars.

The Recommended Consent Conditions (and particularly the requirement for the preparation of Extraction Plans to the satisfaction of the Secretary of DPIE) and the WHS Mining Regulation contain a detailed and proven regulatory process for the management of potential subsidence impacts associated with the Project.

6.0 References

Galvin N., Hebblewhite J.M, and Salamon B.K, M.D.G. 1999. University of New South Wales Pillar Strength Determinations for Australian and South African Conditions. Paper presented at the Second Int. Workshop on Coal Pillar Mechanics and Design., Vail, CO, 6-9 June 1999.

Geoterra/GES, 2020, Russell Vale Colliery Underground Expansion Project Russell Vale East First Workings Groundwater Assessment: Revised Assessment Report", dated 5 February 2020

HydroAlgorithmics Pty Ltd, "Russell Vale Colliery Underground Expansion Project – Groundwater Peer Review", dated 3 February 2020

Hebblewhite Consulting 2019 "Peer Review - Russell Vale Colliery Subsidence Assessment. Report: Supplementary Summary Report", No. 1907/01.2."

Hebblewhite Consulting 2020 "Peer Review - Russell Vale Colliery Assessment of Risk of Pillar Failure. Report No. 2003/03.5."

SCT 2014 "Update of Subsidence Assessment for Wollongong Coal Preferred Project Report Russell Vale No 1 Colliery" SCT Report WCRV4263, 18 June 2014.

SCT 2019. "Russell Vale Colliery: Subsidence Assessment for Proposed Wongawilli Seam at Russel Vale East" SCT Report UMW4609 3 October 2019.

SCT 2020a "IESC 2019-108: Quantitative Assessment of Risk of Pillar Failure in Russell Vale East Area" SCT Report WCRV5111 REV4 12 June 2020.

SCT, 2020b Response to Advice from Independent Advisory Panel for Underground Mining, SCT Letter Report WCRV5269 , 30 November 2020.

SCT, 2020c Response to Advice from Independent Advisory Panel for Underground Mining, SCT Letter Report WCRV5269 , 30 November 2020.

APPENDIX A

IAPUM Advice

INDEPENDENT ADVISORY PANEL FOR UNDERGROUND MINING

ADVICE RE:

RUSSELL VALE UNDERGROUND EXPANSION PROJECT

November 2020

EXECUTIVE SUMMARY

On 5 November 2020, the Independent Planning Commission (IPC – the '**Commission**') requested the advice of the Independent Advisory Panel for Underground Mining (IAPUM – the '**Panel**') in relation to predicted surface subsidence for the Russell Vale Underground Expansion Project. The Commission's request was framed in the form of eight questions and supported with relevant reference documents.

The crux of the matter relates to coal pillar system design in a multiseam mining environment and the risk of the catastrophic loss of a swamp presented by vertical surface subsidence. As aspects of the matter are technically complex, the Panel's advice is structured around first presenting some basic geotechnical principles relevant to understanding the issues. Risk, which is a combined measure of the consequences of an event and the likelihood that the event will occur, is then evaluated by considering each of these components separately and drawing conclusions. This approach informs the Panel's answers to the Commission's questions that conclude this advice.

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1. INTRODUCTION AND SCOPE OF WORKS

On 5 November 2020, the Independent Planning Commission (IPC – the '**Commission**') requested the advice of the Independent Advisory Panel for Underground Mining (IAPUM – the '**Panel**') in relation to predicted surface subsidence for the Russell Vale Underground Expansion Project. The Commission's request was framed in the form of eight questions and supported with the following documents:

1. Applicant's response to the advice, dated 15 June 2020, of the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development Advice (IESC)
2. SCT Report, dated 14 January 2020, titled IESC 2019-108: Quantitative Assessment of Risk of Pillar Failure in Russell Vale East Area. SCT Report No: WCRV5111 (SCT, 2020a)
3. Dr Hebblewhite's Peer Review Report, dated 7 April 2020, of SCT's 14 January 2020 report, (Hebblewhite Consulting, 2020a)
4. SCT's finalised report, dated 12 June 2020, titled IESC 2019-108: Quantitative Assessment of Risk of Pillar Failure in Russell Vale East Area. SCT Report No: WCRV5111_Rev 4 (SCT, 2020b)
5. Transcript of Verbal Submission by Dr Gang Li to the Commission, dated 13 October 2020; and
6. Resources Regulator's letter to the Commission, dated 16 October 2020.

The crux of the matter relates to coal pillar system design in a multiseam mining environment and the risk of the catastrophic loss of a swamp presented by vertical surface subsidence. Dr Ann Young and Em. Professor Jim Galvin have expertise in these areas and have prepared this advice.

Dr Young is a geomorphologist and environmental scientist with more than 40 years experience in sandstone terrain, with particular emphasis on upland swamps. She is author/co-author of books on sandstone landforms worldwide, Australian soils, environmental impact in Australia and upland swamps in the Sydney region. Dr Young has contributed to several public inquiries on mining in the Southern Coalfield and was peer reviewer for the 2014 Commonwealth Independent Expert Scientific Committee Report on Temperate Highland Peat Swamps on Sandstone.

Professor Galvin has some 45 years international experience in mining and geotechnical engineering that includes research and practical mining experience in multiseam mining, coal pillar design and subsidence engineering. He is one of the two principal developers of the internationally recognised UNSW coal pillar strength formulations (Salamon et al., 1996) that form the basis of the UNSW Pillar Design Methodology (Galvin et al., 1999) and to which some of the Commission's questions relate. Professor Galvin is familiar with Russell Vale from visiting it a number of times during his career and as a member of the Planning Assessment Commission Panel for the Russell Vale Colliery PAC determination for Preliminary Works Project – Commencement of Longwall 6 (MP 10_0046 MOD 2) (DoP, 2014).

This advice is structured around first presenting some basic geotechnical principles relevant to understanding the Panel's advice. Risk, which is a combined measure of the consequences of an event and the likelihood that the event will occur, is then evaluated by considering each of these components separately and drawing conclusions which inform the answers to the Commission's questions that conclude this advice.

Aspects of the matter are technically complex and the documentation provided to the Panel does not include a detailed account of all of these and how they have been addressed by the Applicant. Due to the short timeframe allocated to provide this advice, the Panel has been constrained in making further inquiries of stakeholders and sourcing additional information, which it would normally do. Nevertheless, the Panel considers that it is unlikely that additional information would impact materially on its responses to the questions posed by the IPC.

2. BASIC PRINCIPLES

2.1. PILLAR STABILITY

The Russell Vale Underground Expansion Project is premised on conducting bord and pillar mining in the Wongawilli Seam beneath existing bord and pillar and pillar extraction workings in the Bulli Seam and beneath longwall panels in some areas of the Balgownie Seam, some 5 to 10 m below the Bulli Seam and 20 m above the Wongawilli Seam. The stability of bord and pillar layouts is determined by the strength of the coal pillars left to support the superincumbent strata and the load (stress) acting on the coal pillars. The ratio of these two parameters is defined as the 'Factor of Safety'.

$$Factor\ of\ Safety = \frac{Pillar\ strength}{Pillar\ working\ stress}$$

The strength of the pillars is determined by five primary components which collectively constitute the 'pillar system'. These are:

- the in-seam element, which is generally referred to as 'the coal pillar';
- the pillar/roof interface(s);
- the immediate roof strata (typically within 10 m);
- the pillar/floor interface(s), and
- the immediate floor strata (typically within 10 m).

The interaction between these five components can be complex and require numerical analysis to assess, especially if the immediate floor and roof strata are not competent and homogenous. The bearing capacities of the immediate roof and floor strata must be sufficient to sustain the load acting through a coal pillar in order for the coal pillar to reach its maximum load carrying capacity. Low friction and/or cohesion interfaces in these strata can act as slip surfaces for the coal pillar to expand laterally and fail in tension rather than loading up in compression. Since the tensile strength of rock is typically 10 to 30 times less than its compressive strength, this behaviour can also result in a significant reduction in the load carrying capacity and stability of the pillar system.

Calculation of the pillar working stress is also complex and usually requires the use of analytical and/or numerical techniques. This is because the working stress acting on a pillar is a function of both the stiffness[1] of the coal pillar and the stiffness of the surrounding strata. Both of these are a function of elastic modulus of the rock mass, which cannot be changed, and geometry, which can be varied as part of mine design.

Against this background, uncertainty is associated with both the estimation of the strength of a coal pillar system and the estimation of the load acting on the coal pillar system. Consequently, this uncertainty flows through to the calculation of the factor of safety and the reliance that can be placed on this parameter. Two designs with the same factor of safety can have very different stability risk profiles, and conversely, two designs with the same risk profile can have very different factors of safety.

Two design approaches have been developed which allow this uncertainty to be quantified but, importantly, only for specific circumstances. These are founded on the power coal pillar strength formulation developed by Salamon & Munro (1966, 1967) on the basis of a South African database and

[1] Stiffness is the engineering term used to describe the relationship between load and displacement. It is a measure of the 'springiness' of the structure being loaded (Galvin, 2016).

its extension by Salamon et al. (1996) on the basis of an Australia database to produce both a power coal pillar strength formula and a linear coal pillar strength formula.[2]

The documentation under review relies on the application of the power pillar strength formula developed by Salamon et al. (1996), which has come to be known as the 'UNSW power pillar strength formula'. This formula is founded on a statistical analysis of both failed and unfailed coal pillar layouts (using the maximum likelihood method) for circumstances where the load acting on the pillars could be estimated with a relatively high degree of confidence and where case studies were confined to situations in which instability could be attributed to failure of the coal pillar element of the pillar system; that is, where the roof and strata were competent and unaffected by natural or mining-induced structural disturbances and not the initiating cause of the instability.

On the basis that the load acting on a pillar system at the time of failure was known reasonably accurately, geomechanically-based pillar strength formulations that gave the closest fit to the known pillar failure loads could be derived statistically. This approach also enabled the reliability of the (three) formulations to be quantified by correlating factor of safety with field performance, as shown in Table 1 for the two UNSW formulations.

Table 1: Statistical confidence levels associated with UNSW pillar design formulae (Galvin, 2016).

Probability of Failure	**Safety Factor**	
	UNSW Linear Formula	**UNSW Power Formulae**
8 in 10	0.84	0.87
5 in 10	1.00	1.00
1 in 10	1.30	1.22
5 in 100	1.40	1.30
2 in 100	1.53	1.38
1 in 100	1.62	1.44
1 in 1 000	1.85	1.63
1 in 10 000	2.09	1.79
1 in 100 000	2.42	1.95
1 in 1 000 000	2.68	2.11

Of particular relevance to this matter is that the approaches of Salamon and Munro (1967) and Salamon et al. (1996) do not predict the probability of stability on an annualised basis. Salamon et al. (1996) noted that:

> *In this and some previous publications on the matter (Salamon and Munro, 1967, 1966), the importance of pillar life was bypassed. This was achieved by the introducing (sic) a minimum period that must elapse before a layout is declared 'unfailed'. This approach recognises by implication that some of the unfailed cases will collapse in due course. This problem cannot be avoided altogether. No respectable pillar design method can guarantee permanent pillar stability.*[3]

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[2] The terms 'power' and 'linear' refer to the manner in which the effect of pillar width-to-height ratio on pillar strength is taken into account in a pillar strength formulation.
[3] Page 58, Salamon et al (1996)

These basic principles are relevant to the Russell Vale Underground Extension Project because the confidence that can be placed in the factors of safety and the corresponding probabilities of instability depends both on the accuracy of pillar load predictions and on the coal pillar element being the weakest element of the coal pillar system. Furthermore, the probabilities of instability cannot be equated to annualised probabilities, which was the form adopted in the IESC advice.

2.2. SURFACE SUBSIDENCE

As the width, W, of an excavation increases relative to its depth, H, below surface, the stiffness of the superincumbent strata progressively reduces and the strata sags into the excavation to result in increasing surface subsidence. This is illustrated in Figure 1. At the relatively shallow depths associated with Russell Vale Colliery, this process involves the immediate roof caving into the mine workings, with bulking of the fallen material causing the cave to ultimately choke and so limit the height of caving into the roof. The remaining overburden fractures and sags, decreasing in severity with distance above the excavation, and ultimately reporting as vertical subsidence of the surface (surface subsidence).

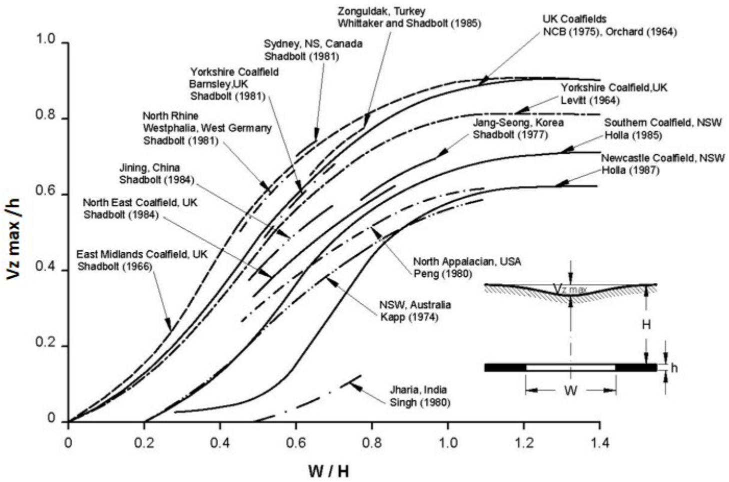

Figure 1: Influence of extraction panel width-to-depth ratio, W/H, on maximum vertical surface displacement, $V_{z\,max}$, expressed as a fraction of mining height, h, for isolated total extraction panels (adapted by Galvin (2016) from Whittaker and Reddish (1989)).

For all other factors remaining constant, the magnitude of vertical surface subsidence in a single seam mine depends on the mining method. Bord and pillar workings (as proposed in the Wongawilli Seam) cause the least amount of subsidence because the percentage areal extraction associated with them is least and because, unless the failed coal pillars have a small width-to-height ratio, they do not uniformly ‘flow’ into the roadways but retain a core which provides ongoing resistance against subsidence. Pillar extraction workings (which already exist in the Bulli Seam) result in more subsidence because the percentage areal extraction is much higher. However, although this mining method is classified as a ‘total extraction’ method, it usually results in coal being left in the goaf in a variety of forms of remnant pillars and as broken coal on the ground and this unrecovered coal impedes subsidence. Longwall mining achieves total extraction in the mining horizon and, consequently, results in the greatest subsidence.

In many coal mining countries, including Australia, maximum vertical subsidence at the surface arising from the total extraction of a single seam is typically of the order of 50 to 65% of the extracted height. Of importance in this matter, however, is that extraction of subsequent seams results in proportionally greater subsidence, variously reported to be of the order of 90 to 100% of the incremental extracted height (Galvin (1981), Schumann (1993), Li et al. (2010) and others). This is believed to be due to either or both enhanced caving of the superincumbent strata of the second seam extracted and reconsolidation of the goaf of the first seam extracted.

These basic principles are relevant to the Russell Vale Underground Extension Project in respect of the coal pillar loads used in the design of the Wongawilli Seam workings; surface subsidence predictions should the proposed bord and pillar workings in the Wongawilli Seam become unstable; and Dr Gang Li's concerns as to the state of stability of existing workings in the Bulli Seam and the potential for vertical surface subsidence to be more than predicted.

2.3. STRESS DISTRIBUTION IN MULTISEAM WORKINGS

At low values of mining panel width-to-depth ratio, W/H, a large proportion of the overburden bridges across the excavation even though the immediate roof may have fallen and resulted in the workings becoming choked off. This results in a large component of the weight of the undermined overburden being transferred to the abutments of the panel, thus generating what is referred to as 'abutment load' or 'abutment stress'. As panel width-to-depth ratio continues to be increased, a point is ultimately reached where the overburden stiffness reduces to zero and the full weight of overburden strata above the centre of the panel once again acts on the floor of the excavation. However, because the overburden does not cave vertically around the abutments of the panel but rather cantilevers out over the panel, the panel abutments are still subjected to elevated levels of stress. These elevated stress levels extend down into the floor strata. Two potential implications of this for the stability of underlying workings are that 1) the roof of the underlying workings could be fractured, and 2) the load acting on the pillars in the underlying workings could be variable, depending on their location relative to the workings in overlying seam(s).

Reasons for these basic principles being relevant to the Russell Vale Underground Extension Project include that SCT (2020b) reports that elevated stress levels are evident in the Wongawilli Seam due to past pillar extraction workings in the Bulli Seam, *'with roadway conditions observed to deteriorate significantly in these areas indicating that abutment loads are present adjacent to the goaf edge'*.[4] SCT proposes that these conditions can be used to determine whether pillars in the Bulli Seam have already failed. The proposed mine layout in the Wongawilli Seam is based on reducing pillar size under the goaves of total extraction panels in the Balgownie Seam, on the basis that vertical load at floor level in this upper seam is less than full overburden load.

[4] SCT (2020b), page 8

3. ADVICES OF OTHERS

The documentation provided to the Panel and the IPC's questions are primarily concerned with matters arising out of advices provided to the IPC by the IESC and by the Principal Subsidence Engineer for the Resources Regulator.

3.1. IESC ADVICE

The Panel has had regard to the advice provided to the Department by the IESC because the two SCT reports provided as reference documents for preparing this advice (SCT, 2020a, 2020b) and the peer reviews of both these reports (Hebblewhite Consulting, 2020a, 2020b) were prepared in an endeavour to satisfy that advice. Elements of the IESC's advice that are of particular relevance in this matter (extracted from the Applicant's response to the IESC's advice) are:

> *The IESC November Advice notes that WCL's Revised Preferred Project Report states that there is a "negligible risk" of pillar failure, but that this risk has not quantitatively assessed the residual risks.*
>
> *The IESC November Advice states that if the likelihood of pillar failure is "extremely rare" (less than 0.01% per year in accordance with the Australia Institute for Disaster Resilience Guideline (2015) and does not result in the catastrophic loss of a single swamp, then the IESC would not regard this proposal as being of material concern.*
>
> *The IESC November Advice notes that the legacy mining environment requires a quantitative assessment of the risks of pillar failure that is independently reviewed by a recognised expert in multi-seam geomechanical stability. The assessment should include an empirical analysis of mining failures in the area since the 1880s and should recognise the risks posed by mining a third seam under the already mined Bulli and Balgownie seams. The assessment should also quantify the potential magnitude and extent of impacts to water resources should these pillars be destabilised by the project. Without such an assessment, a "negligible risk" cannot be fully ascribed.*
>
> *The IESC November Advice states that "negligible risk" is expected that [sic] the likelihood of pillar failure is less than 0.01% per year in accordance with the Australia Institute for Disaster Resilience Guideline (2015).*

The intent of the IESC advice is sound but the manner in which the IESC proposes that it is addressed is not practically achievable and does not fully reflect contemporary principles of subsidence engineering and stability assessment. This has complicated the assessment of what is already a complex matter from a subsidence engineering perspective. Further complexity is added by the manner in which SCT (2020b) has attempted to address the issues raised by the IESC and this is reflected in some of the IPC's questions. Consistent with risk management principles, the IESC's advice has two components; one focused on consequence of coal pillar system failure and the other on likelihood of coal pillar system failure. The Panel has addressed the IESC advice and other matters relevant to answering the Commission's question by considering each of these components in turn in the next two chapters.

3.2. PRINCIPAL SUBSIDENCE ENGINEER'S CONCERNS

In his oral presentation to the IPC on 13 October 2020, Dr Gang Li, Principal Subsidence Engineer for the Resource Regulator, expressed concern that first workings in the Wongawilli Seam could cause instability of any areas of standing pillars in the Bulli Seam and that the presence of any such workings needed to be confirmed ahead of mining. Dr Li referred to subsidence measurements over LW 4 and LW 5 in the Wongawilli Seam that he considered to be substantially higher than predicted. He interpreted this as a strong indication that there had been standing pillars and open voids in the overlying Bulli Seam workings.

4. CONSEQUENCE OF SURFACE SUBSIDENCE

The report *Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield: Strategic Review* (the Southern Coalfield Report, DoP (2008)) drew a distinction between subsidence effects, subsidence impacts and subsidence consequences. The concept is now embedded in subsidence engineering in NSW, with the three subsidence factors being defined as:

- **Effect -** the nature of mining-induced deformation of the ground mass. This includes all mining-induced ground movements such as vertical and horizontal displacements and their expression as ground curvatures, strains and tilts.
- **Impact -** any physical change caused by subsidence effects to the fabric of the ground, the ground surface, or a structure. In the natural environment these impacts are, principally, tensile and shear cracking of the rock mass, localised buckling of the strata and changes in ground profile.
- **Consequence -** any change caused by a subsidence impact to the amenity, function or risk profile of a natural or constructed feature. Some consequences may give rise to secondary consequences. For example, the redirection of surface water to the subsurface through mining-induced fractures may be a primary consequence for water inflow to a reservoir and result in secondary consequences for ecology.

This concept has supported a change in approach to mine approvals in that the focus is no longer on the accuracy of predictions of subsidence effects but rather on designating acceptable subsidence impacts.

In this matter, vertical surface subsidence and ground strain induced by curvature of the ground surface as it subsides into the subsidence trough are ‘subsidence effects’. Cracking beneath swamps is a ‘subsidence impact’, while changes in soil moisture content and species composition in swamps are ‘subsidence consequences’.

The IESC has not defined what constitutes *‘catastrophic loss of a single swamp’*. Based on experience in the Sydney Basin Biogeographic Region, the Panel associates catastrophic loss with a reduction in the capacity for a swamp to retain its water table and soil moisture that is so severe as to cause the swamp flora species to be replaced by species representative of dry heath or woodland. This process is exacerbated by bushfires since dry swamps and their organic-rich sediments are susceptible to very hot burns, as evident by the fires in the Western Coalfield late last year (see, for example Keith et al. (2020)). The Panel is not aware of this degree of consequence having been experienced over the workings of Russell Vale Colliery in the more than 130 years that the mine has been in operation.

Rather, it appears that in the area of this proposal (the Wonga East area of Russell Vale Colliery), mining operations in the Bulli and Balgownie Seams have not resulted to date in adverse consequences for swamps that can be linked unequivocally to mining impacts. Three reasons postulated for this outcome in previous approval processes (e.g. DoP (2014)) are:

1. The magnitude of the subsidence impacts, principally tensile cracking, are not sufficient to cause a significant change in swamp moisture content.
2. Loss of swamp water through tensile cracks is compensated for by (high) rainfall on the escarpment.
3. If the swamps have had vertical drainage increased due to undermining, the mix of flora species in the swamps has changed over the decades to adapt to the modified soil moisture conditions and gone unnoticed due to a lack of monitoring; the sub-communities may have altered (for example, from cyperoid heath to banksia thicket) but still are within the Coastal Upland Swamp Ecological Community.

In endeavouring to address the IESC's advice, SCT (SCT, 2020b) has advised that:

> *'SCT has expertise in assessing pillar stability and potential; for surface subsidence but does not have expertise in assessing factors that affect the health of swamps. Our quantitative assessment assumes subsidence of less than about 100mm would not cause catastrophic loss of any swamp. In the probability assessment, 1 in 100 swamps subject to 100mm of subsidence are assumed to suffer catastrophic loss. We understand from discussion with experts on swamp impacts and experience of historic mining below swamps in the Southern Coalfield that these assumptions are conservative.'*[5]

Hence, SCT's assessment of risk is based on both an assumed correlation between a subsidence effect (100 mm of vertical subsidence) and a subsidence consequence of catastrophic proportions and on an assumed probability of the number of times this amount of vertical subsidence will result in the catastrophic outcome. The Panel assumes that SCT's selection of 100 mm of vertical subsidence is based on this being about the maximum level of vertical subsidence that SCT predicts will result from a stable bord and pillar layout in the Wongawilli Seam.

A limitation with the SCT approach is that subsidence consequences are a function of cumulative subsidence effects and not incremental increases in subsidence effects. In this case, the consequences of a 100 mm increase in vertical subsidence can be expected at some stage to be relative to how much vertical subsidence has already occurred.

In order to assess the implications of the SCT approach to endeavouring to conform to the advice of IESC, the Panel has had regard to subsidence effects associated with multiseam mining in the past at Russell Vale Colliery.[6] Figure 2 shows the location and nature of workings in each of the three seams extracted to date and Figure 3 shows the location of overlying swamps. The following summary characterises these mining operations. Because monitoring was very limited at the time of extracting the top two seams, subsidence effects due to mining in these seams can only be estimated and there is variability in estimates between the various reports that contain this information.

- Bulli Seam: Bord and pillar first workings and extensive secondary pillar extraction in the period circa 1890 to 1950. Typical extraction height 2.2 m. Estimated maximum vertical subsidence of 1 m.
- Balgownie Seam: Located some 5 to 10 m below the Bulli Seam. Longwall mining circa 1970 to 1982. Typical extraction height 1.5 m. Estimates of maximum vertical subsidence range up to 1 m.
- Wongawilli Seam: Located some 20 m below the Balgownie Seam. Longwall mining in area of interest undertaken 2012 to 2014 and confined to the extraction of longwall panels LW 4, LW 5 and LW 6. Extraction height 2.4 m but could be up to 2.8 m. Predictions of subsidence effects for these three panels and measurements of these effects at the time that LW5 was still being extracted are recorded in Table 2.

[5] Page 2 of (SCT, 2020b)
[6] Some of this information was produced during the PAC's 2014 determination in regard to LW6 at Russell Vale (DoP, 2014)

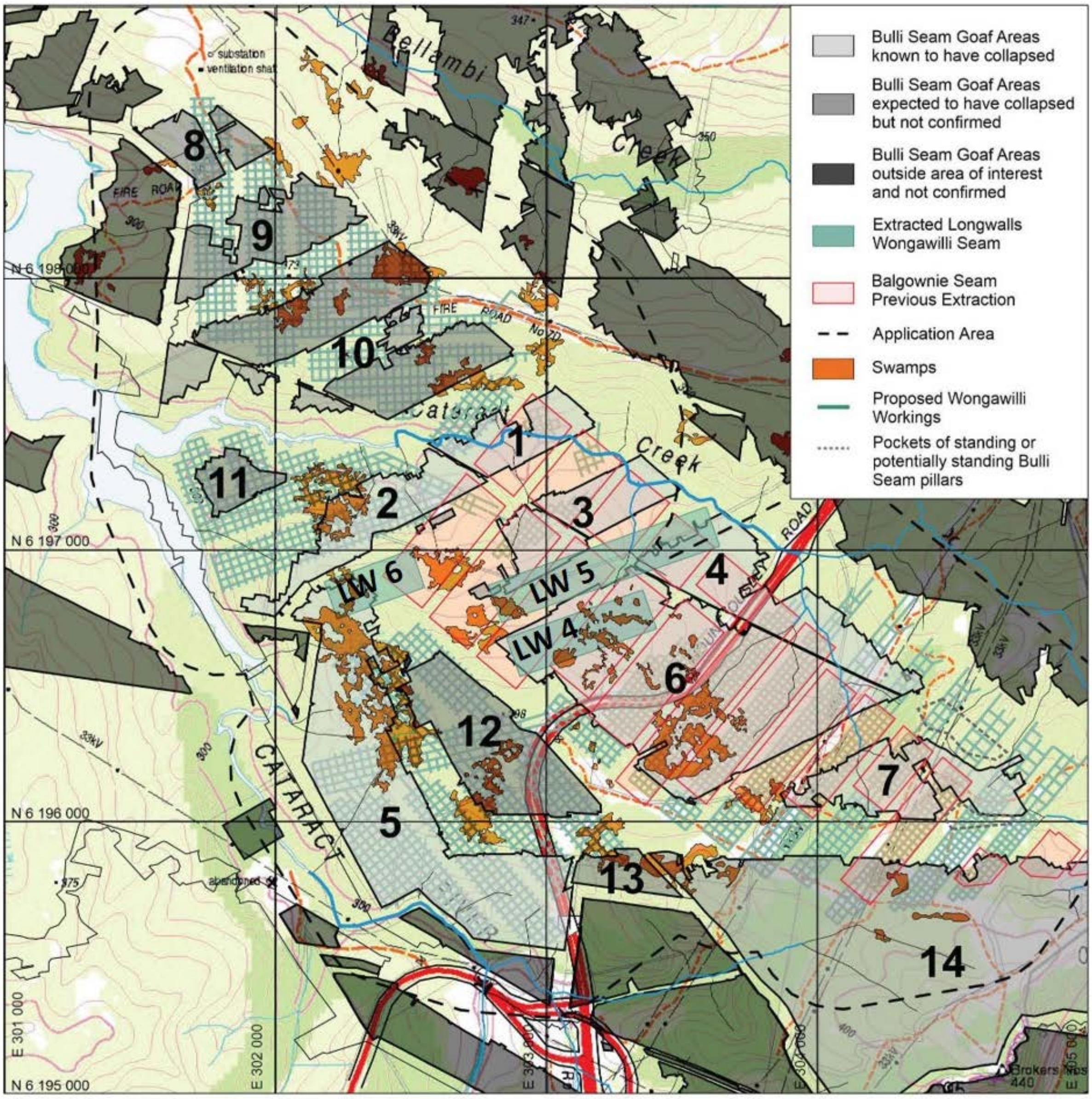

Figure 1: Plan showing location of swamps and proposed first workings in the Wongawilli Seam relative to previous secondary extraction in Bulli Seam (Grey), Balgownie Seam (Red) and Wongawilli Seam (Dark Green).

Figure 2: Location and nature of workings in each of the three seams at Russell Vale, sourced from SCT (2020b) and annotated to identify longwall panel numbers in the Wongawilli Seam.

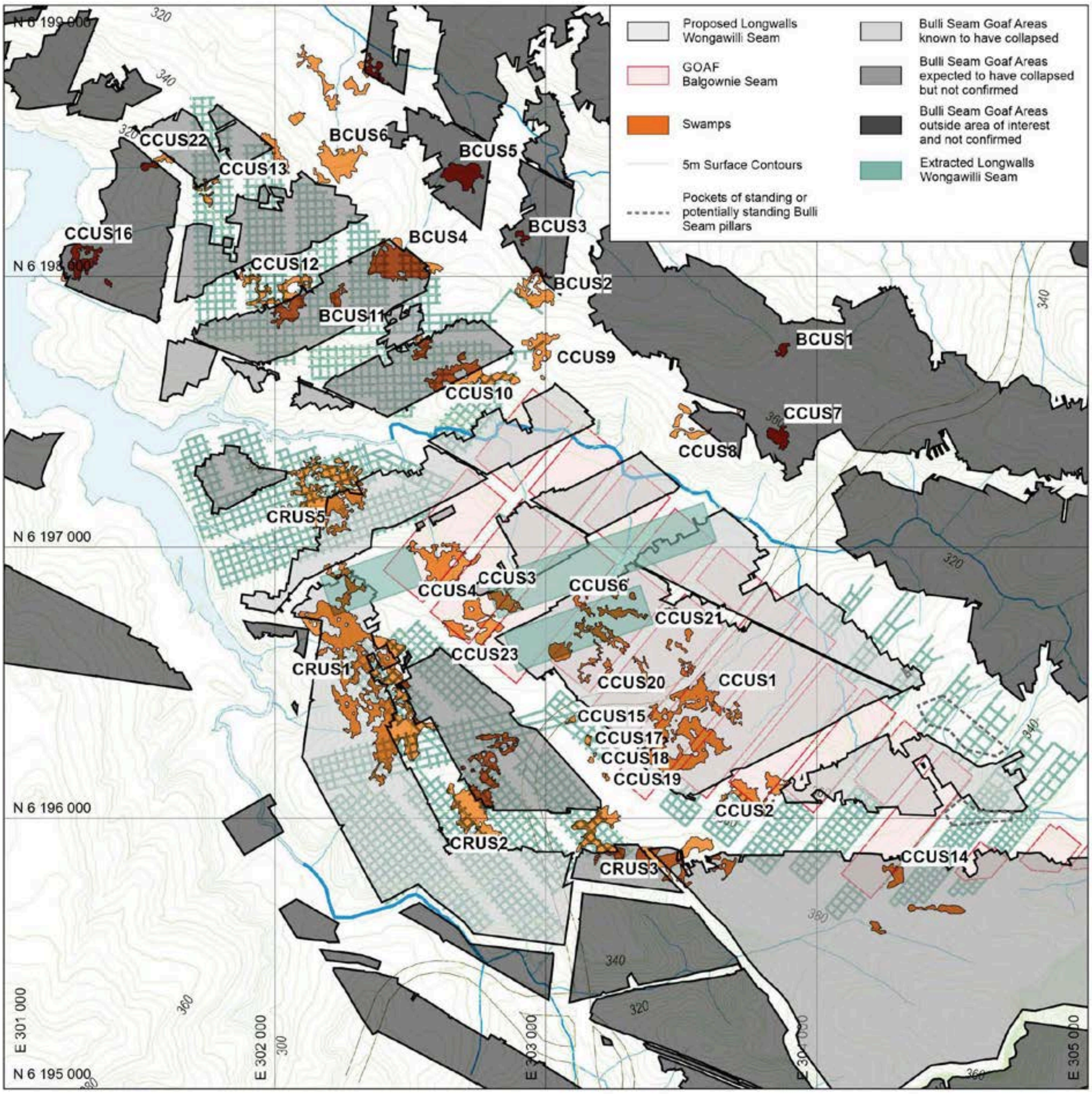

Figure 3: Identification and location of swamps in area of interest (SCT, 2020b) .

Table 2: Estimates of cumulative subsidence effects due to mining operations in the Bulli and Balgownie Seams and predicted (and some measured) subsidence effects associated with extracting LW 4, LW 5 and LW 6 in the Wongawilli Seam (AECOM, 2014).

Table 2 – Predicted Subsidence for the Russell Vale Colliery Underground Expansion Project (LW4, LW5 and LW6)

Subsidence Parameter	Long Wall Panel		
	LW4	LW5	LW6
Overburden depth to Wongawilli Seam (m)	300	265	285
Previous Bulli and Balgownie Seam subsidence (m)	1.9	0.9	1.5
Predicted subsidence for Wongawilli Seam (measured data) (m)	2.1 (1.6)	1.9 (1.5*)	2.1
Predicted tilt for Wongawilli Seam and (measured data) (mm/m)	35 (30)	36 (16*)	38
Predicted tensile strain for Wongawilli Seam and (measured data) (mm/m)	10.5 (7.5)	10.8 (4.5*)	11
Predicted compressive strain for Wongawilli Seam and (measured data) (mm/m)	21 (14)	22 (14*)	23
Predicted maximum closure on Cataract Creek (Southern Tributary) (mm)	N/A	210 (20*)	400

*Mining in progress at the time of the assessment (SCT, 2013)

Table 3 records estimated cumulative effects at specific swamps due to past mining in the Bulli and Balgownie Seams. Together, Table 2 and Table 3 provide a basis for assessing SCT's assumptions that subsidence of less than about 100 mm would not cause catastrophic loss of any swamp[7] and that 1 in 100 swamps subject to 100 mm of subsidence will suffer catastrophic loss.

Table 3: Estimated cumulative subsidence effects at specific swamps (SCT, 2014).

Cumulative Subsidence at the Completion of Bulli and Balgownie Seam Mining

Swamp	Subsidence Used (m)	Overburden Depth (m)	Max Tensile Strain (mm/m)	Max Comp Strain (mm/m)	Max Tilt (mm/m)
CCUS1	2	285	10.5	21.1	35
CCUS2	1.1	285	5.8	11.6	19
CCUS3	1.1	300	5.5	11.0	18
CCUS4	0.9	290	4.7	9.3	16
CCUS5	0.6	272	3.3	6.6	11
CCUS6	2	285	10.5	21.1	35
CCUS7	1	270	5.6	11.1	19
CCUS8	0.1	270	0.6	1.1	2
CCUS9	0.1	293	0.5	1.0	2
CCUS10	0.6	280	3.2	6.4	11
CCUS11	1	340	4.4	8.8	15
CCUS12	0.5	355	2.1	4.2	7
CCUS13	0.1	335	0.4	0.9	1
CCUS14	1.2	275	6.5	13.1	22
CCUS15	0.2	325	0.9	1.8	3
CCUS16	0.5	300	2.5	5.0	8
CCUS17	0.1	325	0.5	0.9	2
CCUS18	0.1	325	0.5	0.9	2
CCUS19	0.1	325	0.5	0.9	2
CCUS20	2	290	10.3	20.7	34
CCUS21	2	280	10.7	21.4	36
CCUS22	0.5	317	2.4	4.7	8
CCUS23	0.9	310	4.4	8.7	15
CRUS1	0.5	300	2.5	5.0	8
CRUS2	0.6	210	4.3	8.6	14
CRUS3	0.6	295	3.1	6.1	10
BCUS1	1	270	5.6	11.1	19
BCUS2	0.5	285	2.6	5.3	9
BCUS3	0.5	265	2.8	5.7	9
BCUS4	0.6	295	3.1	6.1	10
BCUS5	0.5	273	2.7	5.5	9
BCUS6	0.1	308	0.5	1.0	2
BCUS11	0.5	335	2.2	4.5	7

[7] SCT (2020b) states that '*the probability of a swamp being catastrophically impacted by subsidence of 100 mm is considered very low given that these swamps have all been subsided by Balgownie Seam and Bulli Seam mining by more than 1m and up to 3.7m*'. The figure of 3.7 m corresponds to maximum subsidence after the extraction of the Wongawilli Seam. Presumably, 3.7 m should read 2m.

It is common in subsidence engineering to associate the onset of tensile cracking with a tensile strain of 0.5 mm/m. Once fractures are initiated, further extension of the ground surface tends to be concentrated at these fracture sites. That is, strain is no longer uniformly distributed. In virgin conditions, the impact of a tensile strain of 0.5 mm/m is most likely to result in a hairline fracture, in which case it is of little consequence to the integrity of an overlying swamp. Thereafter, incremental strain is most likely to cause existing cracks to become wider and deeper, until a tipping point is reached where the width and depth of the crack/s (the subsidence impact) have serious negative consequences for the moisture retaining capacity of that portion of a swamp overlying the fracture/s.

It can be concluded from both predicted and measured vertical subsidence and tensile strain values recorded in Table 2 and Table 3 that in the case of longwall mining in the Wongawilli Seam, 100 mm of incremental vertical subsidence resulted in an incremental increase in maximum tensile strain of around 0.5 mm/m. The database concerning surface subsidence behaviour above bord and pillar workings comprised of high width-to-height ratio coal pillars, as now proposed for the Wongawilli Seam, is very limited and the corresponding maximum tensile strain induced by a 100 mm increment in those circumstances in unknown but likely to be less than for longwall mining. The Panel's advice is based on assuming that 100 mm of vertical surface subsidence induced by bord and pillar workings in the Wongawilli Seam will cause around a 0.5mm/m increase in tensile strain. It should be confirmed by a subsidence prediction specialist that it is at least conservative (that is, it overpredicts rather than underpredicts tensile strain).

Insight into the significance on the integrity of the swamps overlying Russell Vale Colliery of an increase in tensile strain of 0.5 mm/m can be gauged from Table 3, which is based on the assumption that there are no pockets of marginally stable pillars still standing in the Bulli Seam goaves. The table shows that the estimated cumulative tensile strains due to workings in both the Bulli Seam and the Balgownie Seam range from 0.4 mm/m to 10.7 mm/m, with 17 of the 33 swamps estimated to have experienced more than 3 mm/m tensile strain, and with 4 of these estimated to have experience more than 10 mm/m tensile strain. As there are no reports of subsidence having had negative consequences for any of these swamps, it seems implausible that an incremental strain of only 0.5 mm/m could initiate a catastrophic loss of a swamp. The tabulated results suggest that, based on site specific historical performance, at least two-thirds of the swamps could still tolerate ten times this much incremental strain without suffering negative consequences other than possibly a change in species mix, which cannot be excluded from having occurred in the past.

It is concluded that:

- even allowing for those swamps overlying goaves where it is yet to be 'proven' that vertical subsidence has not been impeded by marginally stable pillars and, therefore, would be less than estimated in Table 3, the catastrophic loss of a swamp due to only 100 mm of incremental vertical subsidence is hardly credible. (It could be helpful and improve confidence in impact predictions for swamps if SCT, as the originators of Table 3, were to reproduce it having regard to the location of areas where vertical displacement would be less than estimated if there are still standing pillars in the Bulli Seam goaves.)
- based on historical performance, the failure of standing pillars in the Bulli Seam is extremely unlikely to result in catastrophic loss of a swamp (noting that the values for these swamps in Table 3 would need to be reduced accordingly if they are in fact located over pillars that are still standing).
- the additional amount of vertical subsidence that can be tolerated by the four swamps overlying both Bulli Seam workings and Balgownie Seam workings that are estimated to have already experienced around 10.5 mm/m tensile strain is unknown and, therefore, bord and pillar workings in the Wongawilli Seam beneath these areas need to be designed judiciously and conservatively in order to restrict vertical subsidence in the event of them becoming unstable.[8]

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[8] It was the high risk of reaching a swamp's tipping point (i.e. the point where the swamp can no longer function effectively as a swamp) due to a predicted incremental increase in tensile strain of 11 mm/m that caused the PAC to limit the extraction of LW 6 in the Wongawilli Seam to the western edge of swamp CCUS4 (DoP, 2014).

5. LIKELIHOOD OF SURFACE SUBSIDENCE

5.1. PILLAR DESIGN FOR WONGAWILLI SEAM

The Applicant's response to the IESC advice relies on the UNSW power pillar strength formulation and the correlation between likelihood of pillar stability and factors of safety for this formulation, shown in Table 1. This approach is premised on the coal pillar being the weakest element in the pillar system and on knowing the pillar load reasonably accurately. In respect of coal pillar strength, SCT (2020b) does not include consideration on the impact that abutment stress may have had on the structural integrity of the roof, coal pillar and floor strata in the Wongawilli Seam. This may have been addressed elsewhere as mine design is not the primary focus of this SCT report. This should be confirmed if reliance is to be placed on the predictions of likelihood of pillar stability when utilizing the UNSW power pillar strength formula.

Additionally, the peer review by Hebblewhite Consulting (2020a) of SCT (2020a) noted that:

> *'SCT makes reference to 1994 work in support of the data presented in Figure 2, showing w/h ratio pillars of 8 and 10 continuing to increase in their load-carrying capacity. Further in support of this position, the statement is made that "pillar behaviour in the Wongawilli Seam is observed to be more consistent with strong roof and floor conditions allowing frictional strength to develop". This may well be the case based on the evidentiary data from 1994, but a further explanation of this claim should be provided here, given that in the 2019 Subsidence Assessment Report, SCT referenced the fact that the Wongawilli Seam roof was not strong. SCT stated in that report: "despite Wongawilli Seam workings being characterised as having a weak coal/shale roof in a thick seam environment …" (SCT 2019, page 22).'* [9]

Subsequently, Hebblewhite Consulting (2020b) concluded that SCT (2020b) has adequately responded to substantive comments. The manner in which the important point noted above has been responded to is not apparent from reading SCT (2020b).

The design of the bord and pillar workings for the Wongawilli Seam has been based on two pillar sizes, which SCT refers to as 30 m pillars and 25 m pillars. 30 m pillars are proposed throughout the Wongawilli Seam other than under the goaves of the longwall panels in the Balgownie Seam and under two small areas of standing pillars in the Bulli Seam, where 25 m pillars are proposed.

SCT's reference to coal pillars as being either 30 m pillars or 25 m pillars (SCT, 2020b) is based on the centre distance between the coal pillars; that is, it is the sum of half the roadway width on one side of a pillar, the actual pillar width and half of the roadway width on the other side of the pillar. Although SCT qualifies this in its report (SCT, 2020b), it is not the form most often used to define pillar width. The peer reviewer made the point that the solid pillars are actually 24.5 m square and 19.5 m square, respectively (Hebblewhite Consulting, 2020a).

The analysis of stability undertaken by SCT for the nominal 24.5 m square and 19.5 m square pillars is based on a maximum overburden depth to the Wongawilli Seam of 380 m. The Panel regards this as a conservative approach since, as reference to Table 2 shows, there are areas where overburden depth is considerably less.

SCT (2020b) reports[10] that the 30 m pillars (i.e. 24.5 m square pillars) have a (UNSW power formula) factor of safety of 2.09 and that this indicates that the probability of failure is less than 1 in 100,000. In fact, as reference to Table 1 shows, the probability of failure is only marginally less than 1 in 1,000,000. However, analysis undertaken by the Panel for 24.5 m wide pillars surrounded by 5.5 m wide roadways

[9] Page 17, last paragraph of peer review report
[10] Page 15

returns a factor of safety of 2.12 and, hence, a probability of failure is actually less than a 1 in 1,000,000 threshold.

While a conservative approach has been taken in basing these calculations of pillar stability on maximum depth of cover load, they do not take account of abutment load around the goaves of pillar extraction workings in the Bulli Seam and longwall panels in the Balgownie Seam. SCT cites visual changes in the condition of workings in the Wongawilli Seam induced by abutment stress as a means of confirming that goaf areas in the Bulli Seam, some 25 to 30 m above, have collapsed. However, no indication of the magnitude of these elevated stresses is given in the documentation under review. Rather than taking the additional pillar loading into account in pillar stability calculations, SCT accounts for it in the following manner:

> *'Pillars in the proposed layout for the Wongawilli Seam have minimum width to height ratios in the range of 8-10. These pillars are large compared to the variations in loading. They are also large enough that although one pillar may become more heavily loaded, their stress-strain characteristic (as shown in Figure 4) allow load to be redistributed to other adjacent pillars without any loss of loading bearing capacity.'*

This approach contrasts with standard approaches to the design of bord and pillar first workings abuting goaves, as reflected for example in Salamon and Oravecz (1976), Galvin and Hebblewhite (1995) and Galvin (2016). Sound bord and pillar design requires explicit and site-specific consideration to pillar loading. The Panel is not aware of whether this is planned to be the case if the Russell Vale Expansion Project is approved.

Additional uncertainty is associated with the 19.5 m square pillars beneath the Balgownie Seam longwall panels. It appears that SCT (2020b) has misreported the loading on these pillars as 6.3 MPa when, based on SCT's assumptions, it is actually of the order of 10.3 MPa. This has not carried over to SCT's calculation of a (UNSW power formula) factor of safety of 2.11, which it reports as a probability of failure of less than 1 in 100,000 when, as reference to Table 1 shows, it also qualifies as a probability of failure of less than 1 in 1,000,000.

The Panel has concerns regarding the loading assumptions on which the SCT stability assessment is based for the 19.5 m square pillars. It appears that pillar width has been reduced under the goaves of the Balgownie Seam longwall panels in the belief that due to the limited width, W, of these panels in comparison to their depth below surface, H, full overburden load is not transferred to the floor of the longwall panels and, hence onto the pillars in the Wongawill Seam. If this is the case, the concept does not appear to have regard to the reduction in the stiffness of the overburden due to caving, fracturing and subsidence and, therefore, its capacity to tranfer load to panel abutments of total extraction workings in the overlying Bulli Seam.

Based on the layout of mine workings shown in Figure 1, the lateral extent (W) of collapsed workings in Area 6 is much greater than their depth below surface (H). Consistent with the subsidence engineering principles shown in Figure 1, the floor of the Bulli Seam over most of Area 6 should therefore be subjected to full cover load. In turn, longwall mining in the Balgownie Seam will result in caving of the 5 to 10 m parting to the floor of the Bulli Seam and, thus, should result in the full cover load being transferred to the floor of the Balgownie Seam. This contrasts with the pillar stability analysis reported by SCT which is based on the pillars in the Wongawilli Seam only having to support some 65% of the overburden load. If the 19.5 m square pillars are subjected to full overburden load, their factor of safety drops to 1.4, corresponding to around a 2 in 100 likelihood of pillar failure, which is some 2000 times greater than for 24.5 m square pillars.

Should the load estimated by SCT for the 19.5 m square pillars turn out to be reasonable, further consideration then needs to be given to the size of these pillars. This is because that portion of the full overburden load that does not act on the floor of the Balgownie Seam workings has had to have been transferred to the panel abutments, including the chain pillars between the Balgownie Seam longwall panels. This increase in abutment stress creates a pressure bulb beneath the chain pillars that extends vertically and laterally into the floor strata, in a similar manner to that which is reported to exist beneath the flanks of the pillar extraction goaves in the Bulli Seam. Reference to Figure 2 shows that the 19.5 m square pillars in the Wongawilli Seam abut the sides of the chain pillars in the Balgownie Seam. Hence, these pillars will be subjected to additional abutment load.

SCT (2020b) goes on to state that:

> *'Allowing for abutment loads from Bulli Seam goafs adjacent to the main heading pillars, the most heavily loaded 25 m [19.5 m square] pillars in the Wongawilli Seam are still not as heavily loaded as their nominal strength.'*

Caution is required with this approach. There is no accurate formula for determining pillar strength. The probabilities of failure correlated in Table 1 are a measure of the reliability of the respective pillar strength formula derived from back-analysis of field performance and only relate to situations where pillar load is known reasonably accurately. They show, for example, that even when pillar load is only 80% of the predicted UNSW power pillar strength (that is, FoS = 1/0.8 = 1.25), nearly 1 in every 10 panels of pillars can be expected to fail.

The preceding discussion leads the Panel to conclude that pillar size should not be reduced from 24.5 m to 19.5 m under longwall panels in the Balgownie Seam unless based on site-specific studies that include reliably estimating pillar load.

5.2. PROBABILITY ASSESSMENT

The IESC advice sets a probability threshold that is expressed in terms of an annualised probability of pillar failure and equated in accordance with the Australian Institute for Disaster Resilience Guideline (2015) (AIDRG) to an event that is 'extremely rare'. SCT (2020b) expresses the view that the approach suggested by the IESC '*appears to be more relevant to recurring human emergencies such as flood risk, rather than the management of one-off environmental risks such as potential subsidence impacts to swamps.*' The peer reviewer recommends that the risk assessment of a pillar design should be based on assessing the likelihood or probability of such a one-off failure within the life cycle of life expectancy of a pillar system and gives an example based on a 20 year life of mine.

In this matter, however, the pillar system is required to remain permanently stable. Its life expectancy is indefinite. Therefore, the Panel considers that the concept of annualised probability is appropriate and notes that it does find application in other facets of geotechnical engineering as reflected, for example, in the Guideline for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Planning developed by the Australian Geomechanics Society (Australian Geomechanics Society, 2007).

However, while the application of annualised probability to coal pillar system stability is appropriate in theory, international attempts to apply it to coal pillar systems have been unsuccessful. This is because the size of the pillar failure database (including the international database) is too small to enable meaningful annualised probabilities to be derived (Galvin (2016)).

The IESC advice also makes reference to undertaking an empirical analysis of mining failures in the Russel Vale area since the 1880s. While this is a sensible approach in theory, it is also not practical to execute. This is because, as is usually the case, records of these types of events were not made and/or retained in the mining industry up until a few decades ago.

SCT have made best endeavours to overcome these limitations by utilising the probabilities of failure derived by Salamon et al. (1996) for the UNSW power pillar strength formula. These probabilities are based on the failure of panels of pillars, and not individual pillars. This has implications for the stability analysis presented in SCT (2020b) and based on the following equation:

$$P = P_{initiating\ event}\ x\ P_{exposure}\ x\ P_{receptor\ affected}$$

In applying this equation, SCT have set the probability of the initiating event to be 1 in 100,000. This was derived from the analysis reviewed in the previous section of this Panel advice. Since this probability relates to the likelihood of the failure of a single panel of pillars, it should more correctly be multiplied by the number of panels that could potentially fail.

Probability of exposure has been calculated on the basis of the proportion of total surface area over pillars of a given width that is occupied by swamps, rather than their location relative to past and proposed mining panels as shown in Figure 3. The SCT approach is effectively an averaging approach since it does not have regard to site-specific factors such as the location of individual swamps relative to profiles of surface subsidence, the physical characteristics of swamps, the amount of subsidence and tensile strain to which they have already been subjected (see Table 3) and to individual vulnerability. As such, the approach is not consistent with a contemporary approach to the risk management of swamps whereby, in these types of circumstances, each swamp would be risk assessed on its own merits. If the probability equation is to be persevered with, it would be more appropriate to assess the probabilities of both the initiating event and exposure on a mining panel by mining panel basis.

The value for the probability of a receptor being affected is based on SCT's assumption that 1 in 100 swamps could be catastrophically impacted by (incremental) vertical displacement of 100 mm. For reasons noted earlier, although conservative, this is not considered realistic.

6. MAGNITUDE OF SURFACE SUBSIDENCE

6.1. SUBSIDENCE CONTRIBUTION FROM BULLI SEAM WORKINGS

The proposed bord and pillar mining in the Wongawilli Seam underlies 14 areas where pillar extraction has been undertaken in the Bulli Seam. SCT (2020b) reports that seven of these areas, numbered 1 to 7 in Figure 2, are confirmed as 'subsided'.[11] It goes on to state that

> *'There is evidence available from subsidence monitoring and observation of roadway conditions in the Wongawilli Seam to confirm seven of these areas have fully collapsed with no potential for further subsidence.'*[12]

Reference to Figure 2 shows that these seven areas have been undermined by longwall mining in the Balgownie Seam, some 5 to 10 m below the Bulli Seam. The Panel interprets the SCT statement to mean that the subsidence measured as a result of longwall mining in the Balgownie Seam confirms that the workings were already in a collapsed state prior to longwall mining in the Balgownie Seam.

The Panel agrees that based on the evidence present in SCT (2020b) and additional information relevant to Dr Li's concerns, the pillar extraction panels in the Bulli Seam had collapsed prior to mining in the Balgownie Seam. However, SCT goes further in stating that the areas have **fully collapsed** with **no potential** for further subsidence. Ground engineering is characterized by pervasive uncertainty and these are bold statements, especially when dealing with caved ground that contains voids and has the potential to undergo further consolidation with the passage of time and mining-induced changes in the stress field.

In relation to the remaining seven areas, SCT states that:

> *'Proposed mining provides the opportunity to confirm the status of the Bulli Seam goaf. Deterioration of roadway conditions consistent with the presence of abutment loading when goaf edges are mined under in the Wongawilli Seam would unequivocally demonstrate each goaf area has already collapsed and that there is no risk of further subsidence.'*[13]
>
> and
>
> *'The observation of abutment loading in the Wongawilli Seam roadways below goaf edges in the Bulli Seam would bring certainty that all pillars in the goaf have collapsed and there is no potential for future subsidence.'*[14]

Similarly, the Panel is in general agreement that the visual signs of abutment loading would indicate that the overlying Bulli Seam workings have caved (goafed) but, once again, it cautions against concluding that there is **no risk** of further subsidence. The Panel does not concur that the observation of abutment loading would bring **certainty**, let alone in regard to **all pillars in the goaf** having collapsed. The detection of signs of abutment stress is not a guarantee that all pillars have collapsed, let alone fully collapsed.

SCT is of the view that:

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[11] SCT (2020b), Table 1.
[12] SCT (2020b), page 4.
[13] SCT (2020b), page 2.
[14] SCT (2020b), page 23

'Proposed mining in the Wongawilli Seam would not change the potential for further subsidence from the Bulli Seam'[15]

and

'If the Bulli Seam goaf areas have already subsided, there is no residual risk of further subsidence associated with proposed mining in the Wongawilli Seam'[16]

The Panel does not fully support this view. This is because although pillars may have failed in the Bulli Seam, pressure bulbs can still be present under remnant portions of partially extracted pillars in the goaf and these can be expected to extend into Wongawilli Seam, just as abutment stress does. The formation of bord and pillar workings has the potential to disturb these pressure bulbs, especially if they are located above roadways, and so cause reactivation of the goaf leading to further subsidence. The magnitude and extent of the additional subsidence is dependent not only on the area occupied by the remnant pillars but also on how much load and how far load is redistributed as a result of disturbing remnant pillar/s. However, given the considerable depth of mining, any additional convergence is expected to be barely detectable as surface subsidence in most cases.

6.2. ESTIMATED MAXIMUM INCREMENTAL VERTICAL SUBSIDENCE

There are a number of components that can contribute to vertical surface subsidence above the proposed Wongawilli Seam mining panels at Russell Vale Colliery, the principal ones being:

1. Compression of the pillar system and also roof and floor strata somewhat remote from the pillar system in response to the additional load placed on this strata when coal is removed to form roadways (bords) and when the pillars are subjected to additional abutment load in the vicinity of goaf edges. SCT (2020b) does not provide insight into the calculation of this potential contribution to surface subsidence but it does appear to acknowledge it in the statement that *'there is no potential for mining these [25m and 30m pillars] to cause surface subsidence of more than a few tens of millimetres.*[17] Numerical modelling that includes provision for taking abutment loads into account would aid in confirming the reasonableness of this estimate.
2. Punching of the coal pillars into the roof or floor strata. This has not been explicitly addressed in SCT (2020b) but may have been elsewhere. It may or may not make a contribution to surface subsidence.
3. Yielding of the coal pillars and further ongoing convergence determined by their post-yield behaviour. In this matter, SCT contends that the coal pillars will undergo strain hardening to result in an increase in their load carrying capacity. The Panel concurs. SCT states '*that assuming all pillars were to fail and all roadways were to become completely filled with coal without any bulking – an extreme case used for the purpose of illustration – maximum subsidence would still be less than 140 mm.*'[18] SCT does not explain how it arrived at the value of 140 mm. The Panel questions the value since, for 19.5 m square pillars, this extreme case would result in a convergence of 940 mm at seam level. Based on subsidence behaviour in the Southern Coalfield, surface subsidence could be expected to be somewhere in the range of 40 to 60% of this convergence, or 375 to 560 mm. In any event, this extreme case is unrealistic. There are very few points of reference for failed pillars of the size proposed for Russell Vale Colliery. One useful case relates to the Crandall Canyon disaster where 2.44 m high roadways converged about 300 mm over an area of some 50 acres following a dynamic pillar failure event (Gates et al., 2008). When allowance is made for the fact that Crandall Canyon Coal Mine was around twice as deep as Russell Vale

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[15] SCT (2020b), page 4
[16] ***page 12
[17] Page 15, last paragraph.
[18] Page 16, 2nd paragraph.

Colliery, surface subsidence of the order of 100 to 150 mm at Russell Vale Colliery does not seem to be an unreasonable estimate.

4. Yielding of standing pillars in the Bulli Seam. SCT (2020b) acknowledges that there is a possibility that bord and pillar first workings in the Wongawilli Seam could cause instability of any standing pillars in the Bulli Seam. It estimates the probability of this to be less than 1% but does not explain how it arrived at this figure. If this situation arises, history shows that it could result in an increase in maximum vertical subsidence of the order of 1 m.

5. Reactivation of existing goaves. Given that there is a possibility that bord and pillar first workings in the Wongawilli Seam could cause instability of any standing pillars in the Bulli Seam then there must also be a possibility the Wongawilli Seam workings could cause some reactivation of overlying goaves in the Bulli Seam and the Balgownie Seam. The amount of incremental vertical surface subsidence that could result from this behaviour is unknown to the Panel. However, given that surface subsidence due to total extraction longwall mining in a multiseam situation is some 10 to 15% greater than in a single seam situation, it seems reasonable to expect that reactivation of goaves caused by interactions with bord and pillar first workings would not cause more than one to two percent increase in subsidence. Based on Table 2, this equates to 10 to 20 mm in areas where only the Bulli Seam has been totally extracted and 20 to 40 mm where both the Bulli Seam and the Balgownie Seams have been totally extracted.

When the contribution of all these components except pillar punching of the roof and floor strata (or bearing capacity failure) is summed, it can be concluded that, based on a 2.4 m mining height in the Wongawilli Seam:

1. Stable bord and pillar first workings in the Wongawilli Seam are unlikely to result in more than 150 mm of surface subsidence in areas where there are no standing pillars in the Bulli Seam.
2. Unstable bord and pillar first workings in the Wongawilli Seam are unlikely to result in more than 300 mm of surface subsidence in areas where there are no standing pillars in the Bulli Seam.
3. Stable bord and pillar first workings in the Wongawilli Seam could result in up to 1150 mm of surface subsidence in areas where failure of standing pillars in the Bulli Seam is induced.
4. Unstable bord and pillar first workings in the Wongawilli Seam could result in up to 1300 mm of surface subsidence in areas where failure of standing pillars in the Bulli Seam is also induced.

The extreme (and unrealistic) case is associated with total seam convergence in the Wongawilli Seam due to pillars punching the roof and/or floor strata, in which case incremental vertical subsidence is unlikely to exceed 550 mm in areas where there are no standing pillars in the Bulli Seam and 1600 mm where failure of standing pillars in the Bulli Seam is induced.

It might be argued that some of these values are overestimated by 50 to 150 mm. However, it must be remembered that subsidence prediction is not a precise science and very susceptible to localized changes in ground conditions and that some allowance should be made in recognition that ground engineering is characterized by pervasive uncertainty.

6.3. PRINCIPAL SUBSIDENCE ENGINEER'S CONCERNS

The concerns raised by Dr Gang Li in his presentation to the IPC on 13 October 2020 regarding the potential for first workings in the Wongawilli Seam to destabilise any areas of standing pillars in the Bulli Seam, and the need to confirm the presence of Bulli Seam workings ahead of mining are considered by the Panel to be important and relevant and to warrant assessment. Dr Li referred to vertical subsidence measurements over LW 4 and LW 5 of 1.77 m and 1.75 m, which he considered to be substantially higher than predicted. He interpreted this as a strong indication that there had been standing pillars and open voids in the overlying Bulli Seam workings.

The End of Panel Report for LW 5 (Wollongong Coal, 2014) sheds light on Dr Li's concerns. It records that the Subsidence Management Plan (SMP) predicted a maximum vertical subsidence of 1.4 m and that the exceedance of this value triggered a red trigger level exceedance. Presumably, Dr Li would have been notified of that exceedance. However, the End of Panel Report then goes on to advise that the predicted maximum vertical subsidence was revised to 1.9 m in the Preferred Project Report (for LW 6), which reflects the values record in Table 2 of this Panel advice. One effect of that revision is that measured maximum vertical subsidence over LW 5 has gone from being 28% greater than predicted to 6% less than the revised prediction.

Table 4 summarises subsidence factors (being vertical subsidence expressed as a percentage of extraction height) for LW 4 and LW 5. The high factors (68% and 75%) based on the revised predictions indicate that the subsidence predictions have taken account of the reduce stiffness of the overburden. This addresses another of Dr Li's concerns. Furthermore, SCT was commissioned in 2013 to provide the revised subsidence predictions. As (SCT, 2020b) maintains that prior to extracting the longwall panels in the Balgownie Seam, the pillars in the Bulli Seam had already collapsed, this is significant. This is because it provides further confidence that the collapse of standing pillars is not required in order to generate the elevated levels of vertical subsidence. Rather, these levels of elevated subsidence can result above areas where pillars have already failed in the Bulli Seam.

Table 4: Comparison between subsidence factors for LW 4 & LW 5 at Russell Vale Colliery (derived from Wollongong Coal (2014) and (AECOM, 2014))

	LW 4	LW 5
Initial Predicted Subsidence/Extraction Height		50%
Measured Subsidence/Extraction Height	63%	63%
Revised Predicted Subsidence/Extraction Height (Table 2)	75%	68%

7. RESPONSE TO COMMISSION'S QUESTIONS

7.1. QUESTIONS 1 TO 7

1. *In terms of the SCT report and Dr Hebblewhite's peer review, are the risk and extent of the predicted subsidence impacts in the catchment reasonable? This needs to be considered in two scenarios:*

   i. *that all the overlying Bulli Seam pillars have collapsed; and*

   ii. *that some of the pillars have not collapsed.*

   Generally

   - The Panel presumes, on the basis of the information provided to it, that the question is confined to subsidence impacts on swamps.
   - Given the challenges associated with sourcing data to satisfy the IESC's advice regarding quantifying the probability of the catastrophic loss of a swamp triggered by the instability of the proposed workings in the Wongawilli Seam, limitations associated with the alternative approach adopted, and the appropriateness of the input data to that approach, the Panel considers that considerable uncertainty is associated with predicted probabilities (Refer to Sections 4 and 5).
   - The Panel has reservations about the pillar loads used in arriving at 19.5 m square pillars beneath the longwall panels in the Balgownie Seam. It is possible that this load may have been underestimated, in which case the probability of instability of these pillars could be considerably higher than predicted. If pillar instability is intolerable, it would be judicious not to reduce pillar size from 24.5 m to 19.5 m under longwall panels in the Balgownie Seam until the pillar loading environment under these longwall panels has been confirmed from mining experience (Refer to Section 5)
   - The predictions of incremental vertical subsidence are considered soundly based and reasonable. In recognition of the pervasive uncertainty that characterises geotechnical engineering, it would be judicious to include an allowance in the predictions for conditions and situations that are unknown in advance of mining and to not be dogmatic as to the certainty of geotechnical states of stability and what can and cannot occur, especially in and around old mine workings and goaves.
   - Based on the limited information provided to the Panel, it appears that an objective subsidence impact assessment has not been undertaken for swamps. Rather, a limit has apparently been placed on a subsidence effect (being incremental vertical subsidence) that has no direct relationship to its impact on swamps. Nevertheless, that approach is likely to be conservative; that is, swamps are able to tolerate a level of incremental vertical subsidence.
   - The Panel questions the merits of a blanket 100 mm limit on incremental vertical surface subsidence and wonders if it would not be more sensible and practical to determine tolerable incremental vertical subsidence on a swamp-specific basis that has regard to how much vertical displacement is likely to have already occurred at each swamp. Such an approach is more in line with contemporary subsidence impact assessment and may assist greatly in addressing concerns relating to whether there are still pockets of standing pillars in the goaves of the Bulli Seam – it may simply not matter in most (if not all) cases – and deliver lower risk outcomes.

   i

   - The Panel has nothing to add. There is nothing particularly unique or abnormal about what is being proposed and that has not been done before and, apart from the matters noted already, the SCT report addresses the extent of the impacts adequately.

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- But for the apparent constraint of 100 mm on incremental vertical subsidence, there is also nothing particularly unique or abnormal about what is being proposed and the conditions under which it is being undertaken. One can never be entirely sure of the state of goaves in old workings and cannot rely on the completeness or accuracy of what is shown on mine plans.
- The Panel concurs with SCT that it is very unlikely that there are pockets of pillars still standing in the 14 goaf areas identified in the SCT quantitative risk assessment report.
- Notwithstanding this, the Panel concurs with the peer reviewer that endeavours should be made to confirm that there are no standing pillars in the goaves. This is for reasons relating to managing operational risks as well as for managing subsidence impacts.
- The information provided to the Panel gives no insight into the options available should pillars still be found to be standing in the goaves. It could prove very difficult to identify the presence of the pillars sufficiently ahead of mining operations to prevent mining impacting on their state of stability and, thus, on not exceeding 100 mm of incremental subsidence.

2. *Is it likely that the Applicant will be able to develop a Mine Plan and Principal Hazard Management Plan that meets the requirements of the Resources Regulator and limits the level of subsidence to 100mm?*

- Given the pervasive uncertainty associated with geotechnical engineering and based on the information supplied to the Panel, the achievement of this value could be marginal on occasions. (Refer to Section 6.2).
- For reasons noted in addressing Question 9, it would be judicious to specify a higher limit.

3. *Beyond a 100mm target what is likely to be the worst-case local subsidence scenario if residual pillars in the Bulli Seam collapse?*

- ~1150 mm if failure is confined to remnant pillars in the Bulli Seam.
- ~1300 mm if failure also involves pillars in the Wongawilli Seam. This is possible but very unlikely.
- (Refer to Sections 6.1and 6.2)

4. *Dr Gang Li has made comments and raised concerns relating to the local subsidence impacts and mine stability due to the possible existence of un-collapsed "marginally stable pillars". Are these concerns adequately addressed by the approach proposed by the Applicant and the guidance given in the Resource Regulator's 'Letter to Commission from Resources Regulator on 16 October, 2020'?*

- It has been established in Panel advice (see Section 6.3) that Dr Li's concerns regarding elevated levels of vertical subsidence arise out of subsidence predictions that did not properly account for increased subsidence in a multiseam mining situation; that is, subsidence had been under-predicted rather than excessive for a multiseam situation. This deficiency appears to have been overcome by appointing SCT to undertake subsidence predictions.
- Nonetheless, this explanation does not diminish the validity of Dr Li's concerns. The risk could still potentially exist in other areas of the mine.
- The applicant proposes to identify the presence of unfailed pillar workings in the Bulli Seam on the basis of an absence of abutment stress in the Wongawilli Seam. This is considered feasible but the information provided to the Panel is too limited for it to determine if it will cover all situations (the only mine plan which the Panel has is that which constitutes Figure 2

of this advice and it is does not contain the necessary information to inform further comment). The concept should be subjected to a risk assessment.

- The Panel is not in possession of all the material that the Resource Regulator notes in its response to this issue (for example, the conditions recommended by the Department). Nonetheless, the Panel agrees with the Regulator that the identified risks can be suitably and appropriately managed post approval provided that appropriate inquiries and investigations are undertaken by the applicant to further identify and define the existence and distribution of the marginally stable pillars in the overlying Bulli Seam.
- Further, the Panel supports the Regulator in its view that work health and safety laws can be appropriately applied through, int this matter, the development of a principal hazard management plan for subsidence.

5. *We note that the Resources Regulator has recommended that the applicant undertake investigations to identify and define the existence and distribution of any marginally stable pillars in the overlying Bulli Seam. Are there proven non-invasive methods available to determine the subsurface presence of voids either from existing surface access points or from underground prior to development commencing in sections of the mine which may undercut areas identified as 'unconfirmed' with respect to pillars in the Bulli Seam?*

   - If non-evasive means that there is to be no disturbance of the strata, then the Panel is not aware of any proven methods other than, given the right conditions as apparently exist in the Wongawilli Seam, visual observations as proposed by the applicant. Otherwise, one is effectively searching for pillars and roadways (only portions of which may still open) somewhere within an environment that is extremely disordered and chaotic. Unless the standing pillars are close to the abutment of goaves, non-invasive methods are extremely unlikely to penetrate the debris and make sense of the chaos. A point of reference in this regard is activities associated with searching for and recovering persons and equipment buried in goaf falls.
   - If non-evasive does not preclude the drilling of boreholes and the use of borehole cameras then, in theory, it is technically feasible to locate marginally stable pillars in goaf environments. However, the depth of the Bulli Seam and the nature of the topography will almost certainly exclude extensive drilling from surface. Drilling from the Wongawilli Seam is an option but success is very likely to depend on 1) having a reasonable idea of the location of the target pillars, and 2) being able to drill near vertical holes which, in turn, is likely to require at least some roadway development beneath the target zone; that is, a degree of undercutting.

6. *To what extent should the status of any voids in sections of the old Bulli workings be determined before mining commences or is it appropriate to do this by measurement (and observation) of abutment stresses once mining commences?*

   - In order to provide a properly informed answer, the Panel would need to be supplied with mine plans for both old mine workings and the proposed workings in the Wongawilli Seam. However, for reasons noted in answering Question 5, it is very unlikely that the status of voids can be determined in the Bulli Seam workings other than by interpreting visual observations of ground conditions in the Wongawilli Seam. The Panel does not have sufficient information to form a view on how fail safe that approach may be. However, if one is relying on the absence of abutment stress as an indicator of standing pillars in the Bulli Seam, careful consideration would need to be given to if this could be detected in time for the Wongawilli Seam workings not to have already had an adverse impact on the state of stability of the standing pillars.
   - This is not a unique situation. For example, mines which work beneath water bodies can be required to drill ahead to prove that no direct hydraulic connections exist to the water body. Bord and pillar mining as proposed in the Wongawilli Seam offers many advantages in these types of situations because it is flexible and amenable to rapid changes in mine layout to respond to changed mining conditions and risk profiles.

- It is not uncommon for bord and pillar first workings to take place in seams that have old workings in various and unknown states of stability above them, and for the lower seam workings to be impacted by abutment stress from the old workings in the upper seam.

7. *Is the claimed stability of the pillars in the current application likely to be realised given the ground conditions expected in the poorer quality coal remaining in the Wongawilli Seam above that part of the Wongawilli Seam that is proposed to be mined?*

- The Panel has no information in regard to this issue. The only insight it has into it is the query raised by Professor Hebblewhite in his peer review of the January 2020 version of the SCT report (being (SCT, 2020a)), viz

> *SCT makes reference to 1994 work in support of the data presented in Figure 2, showing w/h ratio pillars of 8 and 10 continuing to increase in their load-carrying capacity. Further in support of this position, the statement is made that "pillar behaviour in the Wongawilli Seam is observed to be more consistent with strong roof and floor conditions allowing frictional strength to develop". This may well be the case based on the evidentiary data from 1994, but a further explanation of this claim should be provided here, given that in the 2019 Subsidence Assessment Report, SCT referenced the fact that the Wongawilli Seam roof was not strong. SCT stated in that report: "despite Wongawilli Seam workings being characterised as having a weak coal/shale roof in a thick seam environment …" (SCT 2019, page 22).*[19]

- The Panel does not have any evidence and if and how this query was addressed.
- The issue is very important for designing stable pillars, no matter what design procedure is adopted for this purpose. Experience attests to pillar system strength being significantly reduced when the roof or floor strata are weak and/or comprise laminated strata (reference, for example, Peng (1978) and Wagner (1980)).
- The issue is also very important if the probabilities of pillar stability developed by Salamon et al. (1996) are to be relied upon since these were developed specifically for situations where pillar instability is due to failure of the coal pillar element and not to failure of the roof or floor strata.

7.2. QUESTION 8

8. *Could any of the above matters be reasonably addressed through conditioning, and if so, how*?

With or without a 100 mm incremental vertical subsidence limit in place, it might appear attractive and reasonable to require a mine operator to adopt a blanket maximum probability of instability of 1 in 1,000,000 for all mine workings in order to minimise (almost eliminate) the likelihood of a pillar instability developing in the first place. The choice of a pillar design methodology is one for the mine operator, who would only be required to demonstrate to the satisfaction of the Regulator that the design does not exceed the designated likelihood of instability.

However, while this approach does have considerable merit in theory, it is almost certainly unworkable in all situations in practice because a probability of instability cannot be assigned to all the individual components that go to make up a pillar system, let alone to how two or more may interact to cause pillar instability. As such, it would constitute an approval condition that could not be uniquely defined and confirmed as having been satisfied.

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[19] Page 17, last paragraph of peer review report

An alternative approach which does factor in issues raised in the preceding questions and caters for unknowns is to base project conditioning on one or more clearly measurable worst-case outcomes. In the circumstance specific to Russell Vale Colliery, this outcome could quite possibly be incremental vertical subsidence. The logic and foundations for the concept are detailed in the following subsections to assist the Commission in assessing its merits.

7.2.1.Subsidence Effects

1. In single seam mining operations, stable bord and pillar workings result in minimal surface subsidence.

2. The design of stable bord and pillar workings requires consideration to be given both to the capacity (strength) of the 'pillar system' to sustain load and to the load that will be acting on the pillar system.

3. The pillar system comprises the in-seam coal pillar, its contact surfaces with the immediate roof and floor strata, and the immediate roof and floor strata.

4. The stability of the coal pillar system is a function of:

   i. The width-to-height ratio, w/h, of the coal pillars. Pillar strength increases with increasing confinement to the pillar core which, in turn, increases as pillar width increases and decreases as pillar height is increased.

   ii. The nature of the immediate roof and floor strata.

      a. The bearing capacity of the roof and the floor strata must be sufficient to sustain the peak pillar load.

      b. Low friction/cohesion materials and parting planes in the roof or floor strata limit the amount of confinement provided to the pillar core and, thus, also the peak strength of the coal pillar.

   iii. The stability of the roof strata above the bords. Roof falls result in an increase in the effective height of the coal pillars, leading to a reduction in pillar strength.

5. The geomechanical properties that influence the stability of the pillar system can deteriorate over time and, therefore, the stability of bord and pillar workings can be time dependent.

6. In situations where the coal pillar element is the weakest component of the coal pillar system, the pillar width-to-height ratio is the primary variable that determines pillar strength.

7. For all other factors (parameters) remaining constant, as pillar width-to-height ratio increases

   i. vertical surface subsidence over unfailed bord and pillar mining decreases.

   ii. the maximum possible vertical surface subsidence that can occur over failed workings decreases. This is because the percentage extraction of coal is lower, meaning that there is comparatively less void space available to accommodate seam convergence before the workings become choked off.

8. At pillar width-to-height ratios greater than about 8 to 10:

   i. It is generally not possible in most practical situations (where maximum bord width is restricted to the order of 6 m) for bord and pillar first workings to be able to generate the loads require to exceed the peak load carrying capacity of the coal pillars. Some pillars or portions of pillars also need to be extracted (secondary extraction) in order to generate the high loads required to initiate yielding.

ii. After reaching its yield point, a coal pillar will behave in a manner referred to as 'strain hardening' whereby the pillar will continue to accept load when subjected to further convergence (strain), with each increment of convergence causing the pillar to generate a higher resistance to the next increment of convergence. That is, the pillar becomes 'stronger' with increasing seam convergence and has a greater resistance to further convergence.

9. The calculation of the load acting on a pillar system is also complex (except for one special situation which does not apply to Russell Vale Colliery) and there is a range of uncertainty associated with the outcomes.

10. Additional complexity and uncertainty is associated with the prediction of the load acting on pillar systems in multiseam situations, especially when the workings in each seam are not based on the same mining method and not superimposed, as in the case of the Russell Vale Extension Project.

7.2.2. Application to Russell Vale Colliery

1. A range of uncertainties associated with the prediction of pillar system stability are noted in the documentation provided to the IEPUM and reflect the complexity associated with mine design in the circumstances. For example, uncertainties are associated with estimates of pillar system load and the nature of the immediate roof strata.

2. A considerable amount of time and resources could be devoted to addressing these geotechnical uncertainties without any guarantee of resolution or improved confidence in the mine design. This is not unusual in mining geomechanics, which is characterised by pervasive uncertainty.

3. A pragmatic way to deal with this uncertainty is to base impact assessment on worst case predictions of subsidence effects.

4. In all but one case, the predictions of SCT (2020b) and the Panel of worst case outcomes for vertical surface subsidence agree to within 200 mm, as documented in Table 5. The one exception is highly unlikely to be realistic in the given conditions and not pursued further.[20] The 200 mm difference is associated with allowances by the Panel for possible reactivation of goaves in both the Balgownie Seam and the Bulli Seam. The Panel's predictions are utilised for the purpose of this logic tree but should not be adopted by the IPC without seeking input from the Applicant as to their reasonableness.

5. If the IPC assesses these impacts to be tolerable and/or able to be managed to a tolerable level through approval conditions, the need to resolve most, if not all, the geotechnical uncertainties is removed.

[20] It is noted in the IAPUM draft advice of 16/11/2020

Table 5: Predicted Worse Case Vertical Surface Subsidence

Situation	SCT (mm)	IAPUM (mm)
Unstable Wongawilli Seam bord and pillar workings only	30 to 100	300
Unstable Wongawilli Seam bord and pillar workings and destabilisation of standing pillar in the Bulli Seam	1100	1300

7.2.3.Impact Assessment for Swamps

7.2.3.1.Foundation

1. Vertical surface displacement, changes in surface tilt, and tensile and compressive strain are all subsidence effects which can impact swamps. However, tensile strain is the most critical impact as it can induced cracking of the base of swamps that has the potential to reduce soil moisture and groundwater levels in the swamps.

2. Table 2and Table 3and featured in the PAC's 2014 determination of the length of LW 6 to manage subsidence impacts on swamps. Table 3 is based on estimates of subsidence effects at each swamp in the area of interest due to previous mining in the Bulli Seam and Balgownie Seam. The locations of the swamps are shown in Figure 3. It is the IAPUM's understanding that the estimates were based on there being no areas of standing pillars in the Bulli Seam. (This should be confirmed by the Applicant.)

3. Based on Table 2 and Table 3 of this advice, it can be deduced that each incremental increase in vertical subsidence of 100 mm results in an incremental increase in tensile surface strain of about 0.5 mm/m. (This should be confirmed by the Applicant.)

4. It is reported in a range of documentation produced by the Applicant that swamps do not appear to have suffered adverse consequences that can be linked unequivocally to mining impacts.

5. Table 3 lists four swamps that have been subjected to estimated tensile strains of around 10.5 mm/m. A total of eight swamps have been subjected to tensile strains estimated to be in excess of 5 mm/m.

6. As a point of reference, swamp CCUS4 was a particular point of focus in the PAC's 2014 determination of the length of LW 6. The swamp lies predominantly over LW 6 as shown in Figure 3, the extraction of which was predicted to result in a maximum increase in incremental tensile strain of 11 mm/m. The 2014 PAC concluded that

   'The Commission recognises the uncertainty regarding the potential impacts to CCUS4 and the risks associated with those impacts, from mining beneath this swamp. Any previous impacts to the swamp's integrity are unknown, and as a result the risk of reaching the swamp's tipping point, (i.e. the point where the swamp can no longer function effectively as a swamp) is high.

In the circumstances, the Commission considers a cautious approach should be adopted. That is to limit extraction of LW6 to the western edge of CCUS4 to allow monitoring and data collection of any changes in the swamp. Monitoring should include hydrological changes. The monitoring results would provide empirical information for the assessment and prediction of the extent of changes to CCUS4 and formulation of adaptive management plan if mining is to proceed through the whole of LW6.'

7. The Panel is unaware of the outcomes of the recommended monitoring. The following advice needs to take these outcomes into account and be tested against them.

8. The Panel suggests that, should the project be approved, the IPC give consideration to a consent condition based on an upper limit of incremental vertical subsidence. Framing a consent condition on a subsidence effect, especially vertical displacement, is something that one tries to avoid in contemporary approval processes because subsidence effects do not always have a relevant or reliable relationship to the subsidence impact that needs to be managed. However, on this occasion there does appear to be a reasonably reliable relationship between incremental vertical displacement and incremental tensile strain, which is turn, can be expected to have a relationship to the frequency, width and depth of cracking beneath swamps. But, in the case of swamps, the problem with basing performance measures on the characteristic of mining-induced cracking or tensile strain is that they are not suited to being measured. Hence, the reversion to incremental vertical subsidence.

9. The determination of consent conditions should have regard to the outcomes of monitoring over LW 6.

7.2.3.2. No Standing Pillars in the Bulli Seam

1. A maximum incremental vertical subsidence of 100 mm (corresponding to an incremental; strain of ~0.5 mm/m) would be consistent with not exceeding the predictions presented in SCT (2020b) but leaves little opportunity for unplanned deviations, which are a feature of geotechnical engineering. On the other hand, the Panel's upper limit of 300 mm (~1.5 mm/m) may be generous.
2. Based on historical performance and geotechnical considerations, the Panel considers it very unlikely that such small changes could result in an impact of catastrophic proportions.
3. It seems reasonable to expect that the four swamps which have already experienced more than 10 mm/m tensile strain would be most vulnerable to being negatively impacted by an increase in strain (but it would be judicious to seek confirmation that the characteristics of some other swamps do not make those swamps more vulnerable). The IPC could consider a consent condition that requires that 1) these four swamps are not subjected to any further vertical subsidence, or 2) no more than 'x' mm of vertical further incremental vertical subsidence, where 'x' is <300 mm, and perhaps of the order of 100 mm.
4. Otherwise, consent conditions could allow for a fixed amount of incremental vertical subsidence of all other swamps. Whatever value the IPC chooses, monitoring to verify that this limit does not result in unacceptable impacts to swamps should be undertaken and provisions made to reduce the limit accordingly. If the IPC were to specify a lower end value of 100 mm, the same process could be applied to have the value increased in future, if need be.

7.2.3.3. Standing Pillars in Bulli Seam

1. The Panel is unaware if there are particular locations where standing pillars are more likely to be found in the Bulli Seam. The Applicant is relying on the absence of abutment stress to identify the presence of standing pillars. It needs to be established if there are areas where the absence of abutment stress is the norm, in which case standing pillars may not be detected by visual observation underground.

2. If pillars are still standing and swamps are located within their area of influence, then the estimates of subsidence effects for these swamps presented in Table 3 need to be discounted. It would be remarkable if all those swamps not overlying the Balgownie Seam and listed as having subsided one or more metres had, in fact, not subsided and, therefore, are creating a misleading impression of the tolerance of swamps to subsidence in this particular geographical setting.
3. With the resolution of Dr Li's concerns, the Panel is unaware of any evidence that suggests there could still be pillars standing in the Bulli Seam. However, this is not sufficient reason to dismiss the possibility.
4. At this point in time, all that the Panel can advise in dealing with this specific issue is to include provisions for 1) offsetting subsidence impacts on swamps, and 2) for requiring all significant exceedances of predicted subsidence effects, including outside areas containing swamps, to be investigated with a view to informing mine design going forward.

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APPENDIX B

SCT Response to IAPUM Advice

SCT Operations Pty Ltd
ABN 23 078 328 953
www.sct.gs

HEAD OFFICE
Cnr Kembla & Beach Streets Wollongong NSW 2500 Australia
PO Box 824 Wollongong NSW 2520 Australia
Telephone +61 2 4222 2777 Fax: +61 2 4226 4884
Email: sctnsw@sct.gs

BRISBANE OFFICE
Telephone 0428 318 009 (international +61 428 318 009)
Email: p.cartwright@sct.gs

BENDIGO OFFICE
Telephone: +61 3 5443 5941
Email: s.macgregor@sct.gs

29 November 2020

Devendra Vyas
Project Manager
Wollongong Coal Ltd
PO Box 281
FAIRY MEADOW NSW 2519

WCRV5269_Rev 1

Dear Devendra

RESPONSE TO ADVICE FROM INDEPENDENT ADVISORY PANEL FOR UNDERGROUND MINING

Wollongong Coal Limited (WCL/Applicant) plans to mine coal from the Wongawilli Seam at Russell Vale Colliery near Wollongong in NSW by forming large pillars in an area east of Cataract Reservoir known as Russell Vale East. On 5 November 2020, the Independent Planning Commission (IPC) assessing the mining proposal requested the advice of the Independent Advisory Panel for Underground Mining (IAPUM/Panel) in relation to predicted surface subsidence for the Russell Vale Underground Expansion Project (UEP). WCL commissioned SCT to review the IAPUM advice and provide a technical response to the various issues raised. This letter report presents SCT's response to the IAPUM advice.

The report is structured to provide an overview of the key points of the IAPUM findings, considerations relating to the assessment approach used by SCT and a review of Section 7 of the IAPUM response to eight specific questions posed by the IPC.

1. OVERVIEW OF KEY POINTS

Key points to draw from the IAPUM's comments are:

> *The Panel concurs with SCT that it is very unlikely that there are pockets of pillars still standing in the 14 goaf areas identified in the SCT quantitative risk assessment report.*
>
> *The predictions of incremental vertical subsidence are considered soundly based and reasonable.*
>
> *… it seems implausible that an incremental strain of only 0.5 mm/m could initiate a catastrophic loss of a swamp.*
>
> *In all but one case, the predictions of SCT (2020b) and the Panel of worst case outcomes for vertical surface subsidence agree to within 200mm, as documented in Table 5. The one exception is highly unlikely to be realistic in the given conditions and not pursued further.*

> *... the Panel agrees with the Regulator [NSW Resource Regulator] that the identified risks can be suitably and appropriately managed post approval provided that appropriate inquiries and investigations are undertaken by the applicant to further identify and define the existence and distribution of the marginally stable pillars in the overlying Bulli Seam.*
>
> *If the IPC assesses these impacts to be tolerable and/or able to be managed to a tolerable level through approval conditions, the need to resolve most, if not all, the geotechnical uncertainties is removed.*

The IAPUM note at the beginning of the advice, and SCT concurs, that:

> *Aspects of the matter are technically complex and the documentation provided to the Panel [IAPUM] does not include a detailed account of all of these and how they have been addressed by the Applicant [WCL].*

Most of the issues raised by the IAPUM relate to technically complex aspects of:

- pillar behaviour in the short and longer term
- surface subsidence in a multi-seam environment
- interaction of this subsidence with swamps, many of which have been previously subsided much more than the maximum expected from the proposed mining.

SCT has considered and assessed all these issues at various stages. However, the IAPUM has not been provided with all the information relating to the various assessments undertaken and has not had the opportunity to discuss the technically complex issues relating to these various assessments with SCT. The IAPUM notes:

> *Nevertheless, the Panel considers that it is unlikely that additional information would impact materially on its responses to the questions posed by the IPC.*

Some misunderstandings have crept into the discussion and further clarification of these aspects would remove some of the concerns expressed by the IAPUM. The nature of this response as a public document, the technical complexity of the subject matter, and the timeframe available to respond do not allow all the various issues to be fully explored and discussed. This document focuses instead on those issues which are materially significant to the eight questions asked by the IPC. SCT would welcome the opportunity to further address any outstanding aspects in a meeting with the IPC and IAPUM if and when necessary.

2. SCT Assessment Approach and Related Considerations

SCT took a deliberately conservative approach in assessing the risk of "catastrophic loss of a single swamp" in SCT (2020) because of the importance of this issue to the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) for which the assessment was made and the broader community.

The IAPUM has identified several areas where a more appropriate, but less conservative approach is justified and SCT agrees with the IAPUM findings but recognises the need to be conservative in these situations. The areas identified by the IAPUM as suitable to adopt a less conservative approach include:

- Adopting a threshold of 300mm of vertical subsidence for significant swamp impacts is accepted as more credible than 100mm. The 100mm threshold was adopted as being clearly conservative in the absence of detailed assessments of individual swamps; such assessments were beyond the scope of the risk assessment undertaken for the IESC and presented in SCT (2020).

- Using a less conservative probability of failure table with the latest UNSW pillar design is accepted. The probability of failure table presented by the authors of the original UNSW pillar design formula was used in the assessment. This table of probabilities is more conservative than the more recent version of the table for the latest UNSW pilar design formula.

The IAPUM also identify areas where they are uncertain of the detail and suggest a more conservative approach. These include:

- Estimates of pillar loading under the Balgownie Seam goafs. There is no doubt that abutment loads will be concentrated on the Balgownie Seam chain pillars. It follows that loading on pillars directly below the goaf will therefore be reduced to some extent. The loading used in the pillar calculations below the Balgownie is based on SCT's experience of monitoring pillars loads and understanding overburden caving behaviour. The proposed mining will offer the opportunity to measure these loads directly and inform short-term panel design considerations in a timely manner. In the absence of such measurements, SCT considers the approach used to estimate load is reasonable. If the pillar loading is found to be higher than expected, the mining system is flexible enough to allow pillar sizes to be increased as required.

- The IAPUM refers to a description of the Wongawilli Seam roof strata being "weak coal/shale roof in a thick seam environment" (SCT 2019) contrasting with field monitoring data from AMIRA (1995) that supports the finding that Wongawilli Seam pillars are observed to generate confinement consistent with strong roof and floor conditions. These two observations are not in conflict. The monitoring experience and other field monitoring experience supports the strength of Wongawilli Seam pillars as being consistent with pillars in strong roof and floor conditions despite the roof material comprising "weak coal/shale roof in a thick seam environment".

The IAPUM identifies some differences of approach. These include:

- Estimating pillar loading and matching it against pillar strength. The IAPUM state: "*Caution is required with this approach.*" SCT agrees with the premise of this statement. The approach adopted in SCT (2020) is based on field measurements of abutment load, consideration of subsidence behaviour and a range of other considerations developed over 30 years of SCT working in the underground coal industry. It has been found to be conservative when matched to the UNSW pillar strength estimates. The approach takes account of several other effects not included in the UNSW approach. Nevertheless, integration with the UNSW approach is helpful because of the broad industry acceptance of the UNSW approach and the links to a probability-based assessment.

Other considerations relevant to the discussion include:

- The proposed pillar mining system is flexible and can be easily modified to respond to changes in loading and other circumstances allowing for more responsive adaptive management systems.

- WCL's plan to undertake a comprehensive subsidence monitoring program, even though surface subsidence is expected to be largely imperceptible in a bushland setting and only reliably measurable with high accuracy survey techniques.

- WCL's plan to initially mine in areas where it will be possible to determine the effectiveness of the mining system, the ability to detect goaf edge abutment loading and immediate surface subsidence without impacting swamps or infrastructure and other built features.

The IAPUM states in the opening section of their report that:

> *The crux of the matter relates to coal pillar system design in a multi-seam mining environment and the risk of the catastrophic loss of a swamp presented by vertical surface subsidence.*

SCT concurs with this statement, but there is some additional information that is relevant to the discussion.

- The probability of "catastrophic loss of a single swamp" is assessed as "very rare", but this probability exists irrespective of whether the project goes ahead.

- The potential for pillar instability in existing Bulli Seam goaf areas to cause further subsidence hinges on whether these goaf areas have collapsed or not. All available information indicates that these goaf areas have indeed collapsed but there is not yet definitive proof for half of the fourteen goaf areas relevant to project.

There is evidence available in seven of the fourteen Bulli Seam goaf areas relevant to the project that confirms these seven areas have collapsed. This evidence is available directly through measurement of surface subsidence, borehole measurements and indirectly from underground experience of goaf edge abutment loading in underlying seams. In all seven of the goaf areas where evidence is available, the Bulli Seam pillars are confirmed as having been extracted or collapsed. The potential for further subsidence in these areas is limited to residual movements. Over the 80-90 years since mining was completed, any residual movements are expected to have occurred.

Pillars were extracted using similar mining techniques in the other seven Bulli Seam goaf areas, but there has not been any subsequent mining in seams below these areas or other investigations to confirm their status. The proposed mining is expected to provide the opportunity to confirm these pillars have also been extracted and subsidence has already occurred. It is noted that three (#8, 9 and 11) of the seven Bulli Seam goaf areas not yet confirmed as collapsed do not have substantial areas of swamps above them.

3. Review of IAPUM Response to Specific IPC Questions

The IAPUM response to questions asked of it by the IPC are reviewed in this section.

3.1 Question 1

In terms of the SCT report and Dr Hebblewhite's peer review, are the risk and extent of the predicted subsidence impacts in the catchment reasonable? This needs to be considered in two scenarios:

> i. *that all the overlying Bulli Seam pillars have collapsed; and*
> ii. *that some of the pillars have not collapsed.*

SCT concurs with the conclusions reached in relation to Question 1, especially given the limited information provided to the IAPUM. As the IAPUM states:

> *There is nothing particularly unique or abnormal about what is being proposed and that has not been done before and, apart from the matters noted already, the SCT report addresses the extent of the impacts adequately.*

By way of clarification, the 100mm blanket limit on incremental vertical subsidence was for the express purpose of providing a conservative limit suitable to use in a probability assessment recognising that SCT does not have or claim to have expertise relating to swamps. Notwithstanding the merits of such an approach, the concept of providing a swamp-specific limit for each swamp was outside the scope of the probability assessment requested by the IESC.

3.2 Question 2

Is it likely that the Applicant will be able to develop a Mine Plan and Principal Hazard Management Plan that meets the requirements of the Resources Regulator and limits the level of subsidence to 100mm?

The 100mm limit was intended as a conservative guide to estimating the risk of vertical subsidence causing catastrophic loss of a single swamp. Given the experience of the IAPUM in determining swamp impacts, a higher value is accepted as more appropriate to use as a general performance indicator and for the development of Principal Hazard Management Plans for subsidence.

3.3 Question 3

Beyond a 100mm target what is likely to be the worst-case local subsidence scenario if residual pillars in the Bulli Seam collapse?

The IAPUM indicate 1150mm of subsidence may be possible if failure is confined to remnant pillars in the Bulli Seam and, in the very unlikely scenario of pillar failure in the Wongawilli Seam, subsidence of up to 1300mm may be possible.

The Bulli Seam mining height across most of the Russell Vale East area is approximately 2.2m. On the assumption that there are still standing pillars capable of supporting the 250-300m of overburden strata that would subsequently need to collapse to give rise to surface subsidence, a value of subsidence equal to 1150mm (50% of seam thickness) appears quite high. Even total extraction from longwall mining only causes 55%-65% of mining height. A maximum value of additional subsidence from collapse of standing pillars in Bulli Seam goaf areas is considered likely to be limited to less than 1m and probably significantly less than 1m if the collapse area is narrower than the overburden depth.

It should be recognised that the original figure that forms the basis for Figure 1 presented in the IAPUM report is slightly misleading in that the panel width (W) relates to the width of individual panels. This width is normalised when divided by overburden depth (H). However, the maximum subsidence normalised by dividing by mining height relates to the subsidence across multiple panels of width (W), not just a single panel as drawn. It is very unusual to see surface subsidence above a single panel when the panel width is less than one third of overburden depth. The guidelines from the Reynolds Inquiry (Reynolds 1977) take advantage of this geometry to control subsidence below stored waters.

3.4 Question 4

Dr Gang Li has made comments and raised concerns relating to the local subsidence impacts and mine stability due to the possible existence of un-collapsed "marginally stable pillars". Are these concerns adequately addressed by the approach proposed by the Applicant and the guidance given in the Resource Regulator's 'Letter to Commission from Resources Regulator on 16 October, 2020'?

SCT concurs with the IAPUM.

3.5 Question 5

We note that the Resources Regulator has recommended that the applicant undertake investigations to identify and define the existence and distribution of any marginally stable pillars in the overlying Bulli Seam. Are there proven non-invasive methods available to determine the subsurface presence of voids either from existing surface access points or from underground prior to development commencing in sections of the mine which may undercut areas identified as 'unconfirmed' with respect to pillars in the Bulli Seam?

SCT concurs with the IAPUM.

It would not be practical or necessary to drill holes across the entire area of Bulli Seam goafs. Other methods are likely to be more effective.

Mining conditions in the Wongawilli Seam are expected to provide clearer evidence of the presence of goaf edges in the Balgownie and Bulli Seams above. The presence of standing pillars in the Bulli Seam does not cause a sharp change in vertical stress, whereas mining below a goaf edge does cause a sharp change in vertical stress under the increased abutment loads generated by a large area of extracted pillars. The proposed method of confirming the collapse of pillars in the Bulli Seam from mining conditions encountered in the Wongawilli Seam is considered a practical and robust approach.

3.6 Question 6

To what extent should the status of any voids in sections of the old Bulli workings be determined before mining commences or is it appropriate to do this by measurement (and observation) of abutment stresses once mining commences?

SCT has had the opportunity to review detailed mine plans and recording tracings of the Bulli Seam mining and to inspect areas in the Bulli Seam, Balgownie Seam and Wongawilli Seam workings where there is interaction between seams. SCT concurs with the IAPUM assessment and response.

All currently available information indicates that the Bulli Seam goaf areas have almost certainly collapsed. Deteriorated mining conditions below the goaf edge when mining in the Wongawilli Seam will provide unequivocal confirmation of this expectation.

3.7 Question 7

Is the claimed stability of the pillars in the current application likely to be realised given the ground conditions expected in the poorer quality coal remaining in the Wongawilli Seam above that part of the Wongawilli Seam that is proposed to be mined?

As discussed in Section 2, the IAPUM refers to a description of the Wongawilli Seam roof strata being "weak coal/shale roof in a thick seam environment" (SCT 2019) contrasting with field monitoring data from AMIRA (1995) that supports the finding that Wongawilli Seam pillars are observed to generate confinement consistent with strong roof and floor conditions. These two observations are not in conflict. Field monitoring experience supports the strength of Wongawilli Seam pillars as being consistent with pillars in strong roof and floor conditions despite the roof material comprising "weak coal/shale roof in a thick seam environment".

The stability of the Wongawilli Seam pillars will be critical to the maintenance of productive roadway conditions during mining. The pillars are large enough not to collapse suddenly. Any potential for them to become heavily loaded will become evident through rib and potentially roof deterioration. Such deterioration will significantly impact mining productivity. The mining system is flexible enough to allow modification to the layout as part of the ongoing adaptive mine management system proposed. There will be significant value to the mine in ensuring that pillars do not become heavily loaded and productive mining conditions are maintained.

3.8 Question 8

Could any of the above matters be reasonably addressed through conditioning, and if so, how?

In SCT's experience, management of subsidence outcomes is most convincingly managed by measuring subsidence effects and, in systems where it is possible to measure impacts, measurement of impacts on the surface features of interest.

Empirical evidence (Holla and Barclay 2000) confirms that an increase of 100mm of subsidence would be expected to cause tensile strains of up to approximately 0.5mm/m.

Conditioning on the basis of incremental subsidence is easiest to do because subsidence can be measured precisely, unambiguously and accurately across large areas and at specific points using a range of reliable technologies. Derivative effects such as tilt and strain tend to be more difficult to measure. The systems required to make these derivative measurements also tend to be more intrusive.

Actual levels of tilt and strain for most areas of any swamps are likely to be less than the maximum predictions based on Holla and Barclay (2000). Elevated tensile strains are only expected around the fringes of subsided areas. Mills and Wilson (2017) present measurements and observations of incremental and cumulative subsidence effects from longwall mining in two seams. These measurements provide understanding of the mechanics of multi-seam subsidence. More recent monitoring in three seams confirms the earlier understanding developed for two seams.

This understanding indicates that except directly above stacked goaf edges – one goaf edge directly above another in an overlying seam – the levels of permanent tilt and strain in multi-seam mining are similar or less than for single seam mining despite the greater vertical subsidence. Cumulative values for tilt and strain are not increments from each seam. General softening of the overburden with each episode of subsidence means the cumulative tilts and strains are also softened. Tilt and strain are much higher over stacked goaf edges, but there are no stacked goaf edges at Russell Vale East due to the irregular mining layouts in the three seams.

Measurements of incremental subsidence available from Longwall 11 in the Balgownie Seam and Longwalls 4, 5 and 6 in the Wongawilli Seam are consistent with this softening behaviour. Maximum incremental tensile strain at the shallower northern end of Longwall 11 were measured as 8mm/m after incremental vertical subsidence of 1.3m. Incremental tensile strain over Longwalls 4, 5 and 6 were in the range of 3-6mm/m after incremental vertical subsidence of 1.8m. Actual tensile ground strains are expected to be no more than 60% of those predicted in earlier reports.

If you have any queries or require further clarification of any of the issues raised, please don't hesitate to contact me.

Yours sincerely

Ken Mills
Principal Geotechnical Engineer

4. References

AMIRA 1995, Gale W.J. & Mills K.W. Coal Pillar Design Guidelines P351 Report to AMIRA, January 1995.

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Mills, K. and Wilson, S. 2017. "Insights into the Mechanics of Multi-Seam Subsidence from Ashton Underground Mine" In proceedings of the 17th Coal Operators' Conference, University of Wollongong, 8-10 February 2017, pp51-66.

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SCT 2014 "Update of Subsidence Assessment for Wollongong Coal Preferred Project Report Russell Vale No 1 Colliery" SCT Report WCRV4263, dated 18 June 2014.

SCT 2019. "Russell Vale Colliery: Subsidence Assessment for Proposed Wongawilli Seam at Russel Vale East" SCT Report UMW4609, dated 3 October 2019.

SCT 2020 "IESC 2019-108: Quantitative Assessment of Risk of Pillar Failure in Russell Vale East Area" SCT Report WCRV5111 REV4, dated 12 June 2020.

APPENDIX C

Peer Review of SCT Response to IAPUM Advice

B.K. HEBBLEWHITE B.E.(Min.) PhD
Consultant Mining Engineer

B K Hebblewhite Consulting
ABN 85 036 121 217

5 Plant St
BALGOWLAH NSW 2093
AUSTRALIA
Mobile: +61 (0) 417 267 876
Email: hebble@bigpond.com

29 November 2020

Report No. 2003/03.6
Peer Review – Response to IAPUM Advice – Russell Vale Colliery

Supplementary Summary Report

Attn: Mr David Holmes, Principal Environmental Consultant - Approvals & Policy, Umwelt Australia Pty Ltd
Cc: Mr Devendra Vyas, Project Manager, Wollongong Coal Ltd

Introduction

The Independent Advisory Panel on Underground Mining (IAPUM) was asked by the Independent Planning Commission (IPC) to provide advice on eight specific questions which related to a number of issues raised during the NSW *Environmental Planning and Assessment Act 1979* assessment process for the Russell Vale Colliery Revised Underground Expansion Project. The IAPUM provided a report dated November 2020 containing a discussion of issues related to the project, and specifically containing responses to these eight questions, as listed below:

> *1. In terms of the STC report and Dr Hebblewhite's peer review, are the risk and extent of the predicted subsidence impacts in the catchment reasonable? This needs to be considered in two scenarios:*
> *(i) that all the overlying Bulli Seam pillars have collapsed; and*
> *(ii) that some of the pillars have not collapsed.*

2. Is it likely that the Applicant will be able to develop a Mine Plan and Principal Hazard Management Plan that meets the requirements of the Resources Regulator and limits the level of subsidence to 100mm?

3. Beyond a 100mm target what is likely to be the worst-case local subsidence scenario if residual pillars in the Bulli Seam collapse?

4. Dr Gang Li has made comments and raised concerns relating to the local subsidence impacts and mine stability due to the possible existence of un-collapsed "marginally stable pillars". Are these concerns adequately addressed by the approach proposed by the Applicant and the guidance given in the Resource Regulator's Letter to Commission from Resources Regulator on 16 October 2020?

5. We note that the Resources Regulator has recommended that the applicant undertake investigations to identify and define the existence and distribution of any marginally stable pillars in the overlying Bulli Seam. Are there proven non-invasive methods available to determine the subsurface presence of voids either from existing surface access points or from underground prior to development commencing in sections of the mine which may undercut areas identified as 'unconfirmed' with respect to pillars in the Bulli Seam?

6. To what extent should the status of any voids in sections of the old Bulli workings be determined before mining commences or is it appropriate to do this by measurement (and observation) of abutment stresses once mining commences?

7. Is the claimed stability of the pillars in the current application likely to be realised given the ground conditions expected in the poorer quality coal remaining in the Wongawilli Seam above that part of the Wongawilli Seam that is proposed to be mined?

8. Could any of the above matters be reasonably addressed through conditioning, and if so, how?

Wollongong Coal, together with their consultants – Umwelt and SCT Operations – have reviewed the IAPUM report, and specifically the IAPUM response to the eight questions, including a number of recommendations made by IAPUM to IPC as well as questions raised seeking further information or clarification.

The purpose of this supplementary letter report is to provide a brief, over-arching independent comment on the responses prepared by Wollongong Coal, through both Umwelt and SCT. I can confirm that I had the opportunity to participate in an online discussion with these three parties (Wollongong Coal, Umwelt and SCT) on 25th November, comprising a discussion of the IAPUM Report. I have subsequently been provided with the following two documents:

- SCT Report WCRV5269, dated 27 November 2020, titled: "*Response to Advice from Independent Advisory Panel for Underground Mining"* (received 29.11.2020).

- Umwelt Draft Report, dated November 2020, titled: *"Response to IAPUM Advice"* (received 29.11.2020).

I do not intend to deal with all of the detailed points raised in either the IAPUM Report or the above two responses. I will offer some brief summary observations and an independent professional opinion with regard to these responses.

I confirm that my role as an independent peer reviewer in relation to this project has been undertaken and presented in line with the NSW Department of Planning and Environment's Peer Review Guideline (draft) (2017).

For the purposes of transparency, I make the following declarations:

- I have had no direct involvement in the planning or design of the Russell Vale Colliery Extension Project, other than as providing independent peer review.
- I have been involved in a number of projects involving collaborative work (both of a research and consulting nature) with SCT Operations, over many years, both as an independent consultant, and also through my role at UNSW.
- I am appointed as a member of the Independent Advisory Panel on Underground Mining (IAPUM), subject to appointment to specific projects as required from time to time. Under Conflict of Interest provisions of the IAPUM, I am excluded from any IAPUM role in relation to the Russell Vale Project, by reason of my previous and current independent peer review responsibilities.

Summary Comments

Firstly, I wish to concur with opinions expressed in all of the reports under consideration, that being - that the issue being reviewed, associated with subsidence effects and impacts due to multi-seam mining – is a particularly technically complex issue, and will never be resolved in a totally definitive or black and white form of resolution. It involves considerable degrees of uncertainty, together with some significant levels of interaction between the different seams and surface features. The situation is further complicated by the age of some of the earlier higher seam workings and a lack of detail in relation to some of the mining conditions that may exist after many years.

Having said this, I believe that the earlier studies undertaken by SCT on behalf of Wollongong Coal have addressed the issues involved with an appropriate level of investigation and analysis. I believe that this analysis provides a significant degree of confidence in their design approaches and their recommendations for dealing with the ongoing uncertainties, where they exist.

It is noted by both SCT and Umwelt that the IAPUM was not provided with all of the background documentation for the project. This has led to IAPUM rightly raising some concerns, simply by way of lack of information. Nevertheless, on the basis of other information available to them, IAPUM has drawn some quite appropriate conclusions in many of their responses to the IPC questions raised.

I would particularly like to draw attention to just a few specific issues that I wish to offer further comment on.

Firstly, is the issue of the small group of potentially marginally stable pillars in one section of the old Bulli Seam bord and pillar workings. These are discussed and highlighted in section 2.1.1 of the Umwelt response and the associated mine plan provided, where the pillars in question are shaded in a blue ellipse.

It is important to understand and I seek to emphasise that any potential for future instability of these pillars is considered to be totally independent of any proposed new Wongawilli Seam workings. Even if no Wongawilli Seam workings were to proceed in this region, there is a small risk associated with future failure of these pillars, but it is totally independent of the Russell Vale Expansion Project. The second point to make about these pillars, is that it is understood that there are no significant swamp areas on the surface above these pillars.

The second issue that I wish to add a comment on relates to the mining conditions likely to be experienced beneath the old Balgownie Seam goaf areas or longwall panels. This is one of the technical issues that cannot be totally defined in advance. IAPUM is right to raise some concerns about the anticipated levels of stress that might act on Wongawilli Seam pillars beneath these goaf areas. However, SCT has also drawn on considerable experience of previous multi-seam mining conditions and monitoring and observations, to support their expectation of some degree of stress reduction or shadowing on these underlying pillars, resulting in lower levels of pillar loading. The reality of pillar loading levels will only be known once mining commences in the area.

The important points to make in response to this issue, as has been stated by SCT in their response report, is that firstly, there is no practical, comprehensive and reliable method of pre-determining the state of the overlying goaf areas and hence the underlying stress levels. Observation in the development headings within the Wongawilli Seam will provide the best means of assessing abutment loading conditions and degrees of stress protection or otherwise. Secondly, the proposed bord and pillar mining system is an extremely flexible type of mining where changes can be made to panel layouts at quite short notice, in response to observed conditions. In particular, detailed panel layouts (and pillar dimensions in particular) will be able to be modified in response to these abutment stress observations at the time. This, together with a formalised geotechnical observation and monitoring regime, should be a key feature of the ongoing, risk-based operational adaptive management plan to be adopted by Wollongong Coal. Such an adaptive management plan is critical to the success of this proposed mining system and is also critical to managing the extent of any potentially adverse impacts as a result of mining.

The third point I would like to briefly comment upon is to simply endorse the recommendation of the IAPUM regarding the increase in the threshold level of acceptable incremental vertical subsidence to 300mm, from the more conservative 100mm currently adopted, when considering significant swamp impacts.

Beyond these specific issues where I have chosen to add further reinforcement to what has already been said by both SCT and Umwelt, I am comfortable that the responses by both SCT and Umwelt have adequately and appropriately addressed the issues raised by IAPUM, and this should provide further confidence to the IPC in considering this proposed project, going forward.

Bruce Hebblewhite

Disclaimer

Bruce Hebblewhite is employed as a Professor within the School of Minerals & Energy Resources Engineering, at The University of New South Wales (UNSW). In accordance with policy regulations of UNSW regarding external private consulting, it is recorded that this report has been prepared by the author in his private capacity as an independent consultant, and not as an employee of UNSW. The report does not necessarily reflect the views of UNSW and has not relied upon any resources of UNSW.

APPENDIX D

Summary of Subsidence Monitoring for Russell Vale Underground Expansion Project

29 November 2020

SCT Operations Pty Ltd
ABN 23 078 328 953
www.sct.gs

HEAD OFFICE
Cnr Kembla & Beach Streets Wollongong NSW 2500 Australia
PO Box 824 Wollongong NSW 2520 Australia
Telephone +61 2 4222 2777 Fax: +61 2 4226 4884
Email: sctnsw@sct.gs

BRISBANE OFFICE
Telephone 0428 318 009 (international +61 428 318 009)
Email: p.cartwright@sct.gs

BENDIGO OFFICE
Telephone: +61 3 5443 5941
Email: s.macgregor@sct.gs

Gabrielle Allan
Manager – Planning and Assessment NSW
Umwelt (Australia) Pty Ltd
75 York St
TERALBA NSW 2284

WCRV5268_Rev1

Dear Gabrielle

SUMMARY OF SUBSIDENCE MONITORING FOR RUSSELL VALE UNDERGROUND EXPANSION PROJECT

1. INTRODUCTION

Wollongong Coal Limited (WCL) is proposing to mine the Wongawilli Seam in the Russell Vale East (RVE) area of Russell Vale Colliery (RVC) located approximately 9km northwest of Wollongong as part of the Russell Vale Revised Underground Expansion Project (UEP). Umwelt Australia Pty Ltd (Umwelt) are the lead environmental consultant managing the UEP approval process under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and the NSW *Environmental Planning and Assessment Act 1999* (EP&A Act).

WCL commissioned SCT Operations Pty Ltd (SCT) to assist Umwelt by preparing a consolidated summary of subsidence monitoring for the UEP to inform both the EPBC Act and EP&A Act approval assessment processes.

Umwelt have specifically requested:

1) A description of the ongoing subsidence monitoring program within Wonga East (RVE) area.
2) A description of the proposed subsidence monitoring program for the UEP.
3) A description of any additional subsidence monitoring that may be required in order to identify and differentiate any additional subsidence from Bulli Seam goaf areas from impacts associated with the UEP.
4) Plans showing the location of monitoring and, as relevant, key features such as the seven Bulli Seam goaf areas yet to be confirmed as collapsed.
5) A description of the process for confirming the status of the Bulli Seam goaf areas yet to be confirmed as subsided (noting specifically that this is an existing risk not related to, or exacerbated, by the project).
6) A description of any specific subsidence management measures to be implemented for the UEP.
7) A description of the process for reviewing and validating subsidence predictions.

This letter report provides our preliminary advice and recommendations for these items in consideration of the recommended conditions of approval issued by the NSW Department of Planning, Industry and Environment (DPIE) for the UEP and the NSW regulatory process for underground mining under the *Workplace Health and Safety (Mine and Petroleum Sites) Regulation 2014*.

2. ADVICE AND RECOMMENDATIONS

This advice has been compiled based on our site knowledge and experience from previous site visits in recent years. No specific surface inspections have been undertaken to assess the status of vegetation and other features that may impact the practicality of the suggested monitoring.

2.1 Description of the ongoing subsidence monitoring program

The existing subsidence monitoring program (SMP) for Russell Vale East was prepared in 2015 as required by the Extraction Plan (EP) for Longwall 6 (365m) under MOD2 to the Russell Vale Preliminary Works Project (10_0046).

This existing SMP covers all of Longwall 6 and Longwall 7 based on the mining plan layout being assessed for the UEP application at that time. That is, the Preferred Project Report (PPR) layout with Longwalls 1-3 east of Mt Ousley Road, Longwalls 6 and 7 west of Mt Ousley Road and east of Cataract Creek, and Longwalls 9-11 west of Cataract Creek. Ultimately, only the first 365m of LW 6 was approved.

The EP for Longwall 6 (365m) includes subsidence management plans for Groundwater, Stream, Biodiversity, Upland Swamp, Heritage, Built Features Electricity Transmission Lines and Public Safety over the total length of Longwalls 6 and 7. The monitoring in the SMP for Longwalls 6 and 7 overlaps with that in several of these management plans including the Built Features and Electricity Transmission Lines plans. The subsidence management plans and SMP include reporting and trigger action response plan (TARP) details to manage the impacts from subsidence.

The existing SMP is based on conventional ground measurements of subsidence effects and visual inspections of impacts. No airborne or satellite-based survey techniques are included. Under this SMP, WCL are responsible for surveys on the conventional monitoring lines established along the centrelines (longitudinal) of Longwalls 6 and 7 with three main cross-panel (transverse) lines and a line along the edge of Mt Ousley. The lines generally have pegs at approximately 20m spacings. Other measurements include valley closure across Cataract Creek, crack-meters at the closure slot in Mt Ousley Road, tilt meters on powerline towers and measurements by fixed prism shots of the geometry of the bridge at the Picton Road interchange.

The frequency of surveys is generally pre and post mining for each longwall panel or more frequent based on the likelihood of movements and level of consequence.

For the mining of the first 365m of Longwall 6, additional short lines along the edge of upland swamp CCUS4 were installed and regularly surveyed.

Review of the monitoring of Mt Ousley Road conducted by Roads and Maritime Services (RMS) under the Built Features Management Plan (BFMP) for Longwalls 6 and 7 is overseen by a technical committee of experts. The monitoring includes continuous measurements at the closure slot, weekly pavement inspections and periodic inspections and measurements of other infrastructures sensitive to subsidence movements.

This SMP was prepared on the basis of the expected subsidence behaviour from longwall mining with forecasts for maximum incremental subsidence effects of 2.1m vertical subsidence, tilt of 38mm/m, strain of 23mm/m and 290mm of valley closure across Cataract Creek.

No changes are proposed to Longwall 6 relative to that which was approved under MOD2 to the Russell Vale Preliminary Works Project (10_0046) and EPBC2014/7259. The extraction of the remaining 25 metres approved for mining and the removal of the longwall mining equipment would be undertaken in accordance with the existing approved SMP. This would include the post mining survey of subsidence effects.

The existing SMP is not considered appropriate for the first workings development or bord and pillar mining method proposed by the Revised Preferred Project (RPP) plan with the expected low-magnitude subsidence movements and low risk of significant impacts and consequences.

2.2 Description of the proposed subsidence monitoring program for UEP

With the reduced subsidence effects and impacts expected from the proposed mining method and mining plan layout, a shift from the existing conventional monitoring techniques in the difficult surveying environment above RVE, is recommended. A full-time (continuous) high accuracy ground based system, backed up by accurate aerial or satellite based remote sensing on a regular basis, is considered a better way to measure the expected low-magnitude movements from the proposed Wongawilli Seam mining and possibly larger movements from the collapse of any marginally stable pillars remaining in the Bulli Seam.

The basis of the recommended monitoring for ground and some built features involves the installation of a series of continuous GNSS (GPS) units at single points over the mining panels and on specific infrastructure with regular Interferometric Synthetic Aperture Radar (InSAR) deformation monitoring. The use of airborne LIDAR (Light Detection and Ranging) is also available however is not recommended because, without extensive survey control points on the ground, LIDAR is expected to produce surveys with a tolerance of ±200mm, resulting in up to potentially 400mm difference between two surveys.

These proposed methods are expected to provide more accuracy than the existing conventional monitoring where overall survey control and peg to peg accuracy is reduced by surface constraints and limits on vegetation clearing. The suggested methods are also expected to be cost-effective as the need for conventional ground surveys is reduced. The actual cost would depend on the number of GNSS units deployed and the frequency of InSAR data processing. The number of GNSS units and the frequency of InSAR surveys would be confirmed during preparation of the SMP under the EP for the RPP.

Some existing systems for the monitoring on Mt Ousley Road and closure across Cataract Creek would be retained. These include closure slot monitoring on the pavement. The review of the monitoring of the Picton Road interchange bridge would be conducted in consultation with asset owner (RMS). Some periodic ground surveys at base of the powerline towers are also likely to be retained.

The GNSS units can record the 3D position (XYZ coordinates) continuously to less than ±10mm accuracy. The units could be programmed to provide a record of positioning data on say a daily basis, tracking trends and be set to alert at any exceedance of trigger levels or thresholds.

InSAR could provide deformation updates (changes to the surface topography) at weekly intervals, if required, or longer intervals, depending on mining progress. For example, on a two-monthly, six-monthly or annual timeframe.

2.3 Description of any additional subsidence monitoring

This section describes additional subsidence monitoring that may be required in order to identify and differentiate any additional subsidence from Bulli Seam goaf areas from impacts associated with the UEP.

The proposed GNSS and InSAR survey techniques are expected to be able to identify the subsidence effects in all areas above and adjacent to the proposed Wongawilli Seam first workings, including Bulli Seam goaf areas yet to be confirmed as collapsed.

Once monitoring is established, any additional subsidence effects above Bulli Seam goaf areas over or in close proximity to the active Wongawilli Seam operations are likely to be attributed to the mining of the Wongawilli Seam regardless of the timing of the additional subsidence. It is not considered possible to unequivocally separate those subsidence effects that may involve interaction between the proposed and previous mining and those that may have occurred coincidentally. However, it could be concluded that any observed subsidence levels significantly in excess of that which could reasonably be expected from mining in the Wongawilli Seam are attributable to additional subsidence effects from Bulli Seam goaf areas.

Subsidence impacts are expected to be able to be assessed and quantified based on subsidence movements measured by the proposed survey techniques.

2.4 Plans showing the location of monitoring

This section describes the location of monitoring and, as relevant, key features such as the seven Bulli Seam goaf areas yet to be confirmed as collapsed.

Figure 1 shows the concept of the GNSS units installed for routine monitoring of three continuous miners (CM) forming first workings in the Wongawilli Seam and the Bulli Seam goaf areas yet to be confirmed as collapsed where swamps are located above the proposed workings. The configuration shown assumes one CM unit is operating west of Longwall 6, one CM unit is mining east of Longwall 4 and one CM unit is mining at the eastern edge of the proposed mine plan area. It is recognised that three of the seven goaf areas (#8, 9 and 11) not confirmed as collapsed do not have any substantial areas of swamps above them and would not necessarily be monitored with a GNSS unit but would still be covered by the proposed InSAR technique.

The number of the GNSS units in operation at any one time, the timing of their installation and the locations would be based on consideration of the number of CM units operating, mining sequence and direction, and proximity to sensitive surface features. The timing and location of units would be especially important when mining towards sensitive surface features (i.e. upland swamps, specifically those swamps above Bulli Seam goaf areas not yet confirmed as collapsed) to provide early warning of any increasing subsidence prior to mining below the goaf edges and allow time for any adaptive management practices that may be required to manage impacts.

The GNSS units are flexible with regard to their location but do require a degree of 'open sky' to access visible satellites. The units are portable and reusable so they can be leap-frogged forward as panels advance, moved to the next panel or returned to previous installation points if required.

Similar units are currently installed and operating successfully at a number of mine sites in NSW and Queensland.

2.5 Process for confirming status of Bulli Seam goaf

This section describes the process for confirming the status of the Bulli Seam goaf areas yet to be confirmed as subsided. Any risk associated with potential subsidence in these areas currently exists and is not related to, or exacerbated, by the project.

As shown in Figure 1, it is intended to monitor subsidence movements above areas where it is possible there may be:

- remnant standing pillars remaining in the Bulli Seam
- the pillars have not yet been confirmed as collapsed
- and the overburden strata is not yet confirmed as fully subsided.

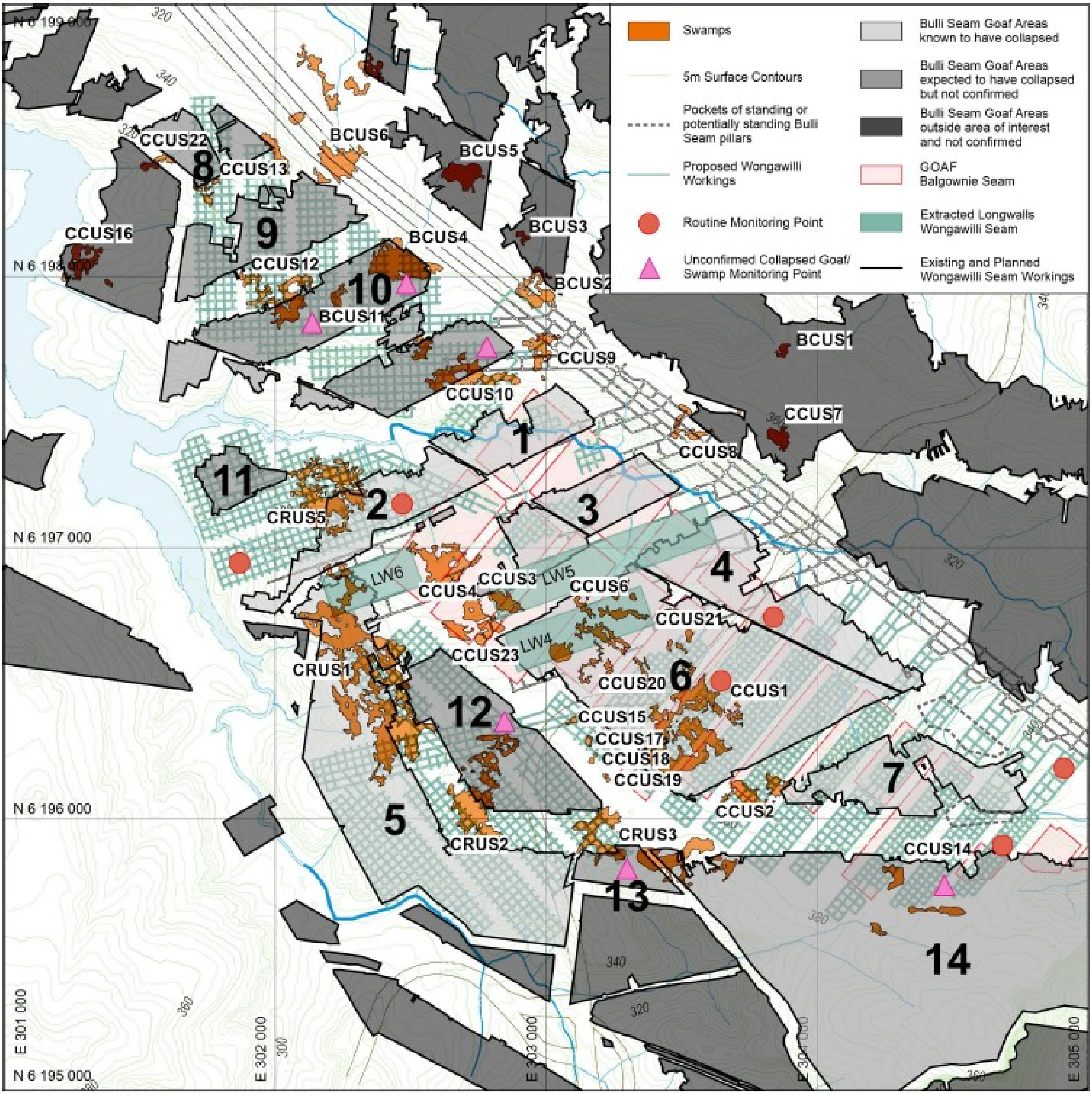

Figure 1: Concept of GNSS monitoring points relative to existing goaf areas and swamp locations.

Underground geotechnical mapping of changes to the observed vertical and horizontal stress conditions, around the edges of the areas shown as goaf on the original Bulli Seam mine plans and record tracings, is expected to be a strong indicator of the status of these areas.

As benchmarks, there are several examples, but three in particular, of areas still currently accessible in RVE where the interaction of an overlying goaf edge with tell-tale signs and impacts of changes to the vertical (and horizontal) stress were experienced.

Evidence of an example from another local mine where the same situation occurred of mining first workings in the Wongawilli Seam up to and then below a Bulli Seam pillar extraction area with significant changes in mining conditions, is also available.

2.6 Subsidence management measures

This section describes specific subsidence management measures to be implemented for the UEP.

The proposed subsidence monitoring survey techniques are expected to provide early warning of the potential for any subsidence effects and impacts greater than forecast.

The proposed mining method is flexible compared to longwall mining and easily adaptable to unexpected or unfavourable mining conditions.

In this case, the use of adaptive management practices including TARPs would allow for immediate changes to the mining layout in response to changes in mining conditions, risk profiles and potential impacts.

Coordinated managements plans for environmental monitoring and inspections that include TARPs associated with regular subsidence observations are expected to be effective in managing the actual subsidence impacts and any consequences.

2.7 Validation processes

This section describes the process for reviewing and validating subsidence predictions.

In addition to incident reporting (e.g. a TARP exceedance), the draft (unpublished) "Guidelines for the Preparations of Extraction Plans" issued by the Department of Planning & Environment, NSW Trade & Investment – Division of Resources and Energy, require subsidence impact reporting on a bi-monthly (every two months), six-monthly and annual basis.

The SMP required under an EP for the RPP is expected to include, amongst other things, provisions to ensure the mine operator manages risks to health and safety associated with subsidence as required by Clause 67 of *Work Health and Safety (Mines and Petroleum Sites) Regulation 2014.*

Clause 67 (2), requires monitoring of subsidence to be conducted, including monitoring of its effects on relevant surface and subsurface features, and any investigation of subsidence and any interpretation of subsidence information is carried out only by a component person.

On this basis, it is suggested that subsidence effects and impacts are reviewed and validated for compliance with forecast by a component person and reported at the end of a panel (or significant milestone in mining of the underground layout) and/or annually as a minimum.

If you have any queries or would like further clarification of any of these issues, please don't hesitate to contact us.

Yours sincerely

Stephen Wilson
Mine Planner

Ken Mills
Principal Geotechnical Engineer

3. References

SCT 2019. "Russell Vale Colliery: Subsidence Assessment for Proposed Workings in Wongawilli Seam at Russel Vale East" SCT Report UMW4609 - 3 October 2019.

SCT 2020 "IESC 2019-108: Quantitative Assessment of Risk of Pillar Failure in Russell Vale East Area" SCT Report WCRV5111_REV4 – 12 June 2020.

APPENDIX E

Predicted Subsidence Impacts at Swamps from Balgownie and Bulli Seam Workings

Table E.1.1 Summary of Existing Impacts on Swamps – Balgownie and Bulli Seam Working

Swamp	Bulli Seam Goaf Area	Potential for Standing Pillars Under Swamp	Located over Proposed First Workings	Max Predicted Vertical Subsidence – Bulli and Balgownie Seams (m)	Estimated Max Tensile Strain - (mm/m)
CCUS1	Area 6	No	Yes	2	10.5
CCUS2	Edge Area 7	No	Yes	1.1	5.8
CCUS3	Edge Area 3	No	No	1.1	5.5
CCUS4	N/A	No	No	0.9	4.7
CCUS5	Pt Area 2	No	Yes	0.6	3.3
CCUS6	Area 6	No	No	2.0	10.5
CCUS7	Nth of Mains	Yes	No	1.0	5.6
CCUS8	N/A	No	No	0.1	0.6
CCUS9	N/A	No	Yes*	0.1	0.5
CCUS10	Pt Area 10	No	Yes	0.6	3.2
CCUS11	Area 10	Yes	Yes	1.0	4.4
CCUS12	Part Area 10	Yes	Yes	0.5	2.1
CCUS13	Area 8	Yes	Yes	0.1	0.4
CCUS14	Area 14	Yes	Edge	1.2	6.5
CCUS15	N/A	No	Yes	0.2	0.9
CCUS16	N/A	N/A	No	0.5	2.5
CCUS17	N/A	No	Yes	0.1	0.5
CCUS18	N/A	No	Edge	0.1	0.5
CCUS19	N/A	No	No	0.1	0.5
CCUS20	Area 6	No	Yes	2.0	10.3
CCUS21	Area 6	No	No	2.0	10.7
CCUS22	Pt area 8	Yes	No	0.5	2.4
CCUS23	N/A	No	No	0.9	4.4
CCUS24	Edge Area 10	Yes	Yes	0.3	1.30
CRUS1	Pt Area 5	No	Part	0.5	2.5
	Edge Area 12	Yes	Yes		
CRUS2	Pt Area 12	Yes	Yes	0.6	4.3
CRUS3	Pt Area 13	Yes	Yes	0.6	3.1
CRUS6	Edge 9	Yes	Yes	0.1	0.40
CRUS7	Area 8	Yes	Yes	0.3	1.3
BCUS1	Nth of Mains	Yes	No	1	5.6
BCUS2	Nth of Mains	No	Yes*	0.5	2.6
BCUS3	Nth of Mains	No	Yes[#]	0.5	2.8
BCUS4	Area 10	Yes	Yes	0.6	3.1
BCUS5	Nth of Mains	Yes	No	0.5	2.7

Swamp	Bulli Seam Goaf Area	Potential for Standing Pillars Under Swamp	Located over Proposed First Workings	Max Predicted Vertical Subsidence – Bulli and Balgownie Seams (m)	Estimated Max Tensile Strain - (mm/m)
BCUS6	Nth of Mains	No	Yes#	0.1	0.5
BCUS7	Edge Area 8	No	Edge	0.1	0.5
BCUS8	Nth of Mains	No	Yes#	0.1	0.5
BCUS11	Area 10	Yes	Edge	0.5	2.2
BCUS14	Nth of Mains	No	Yes#	0.2	1.0

* Headings only

Mains Headings Only

umwelt
Environmental & Social Consultants

Newcastle | Perth | Canberra | Brisbane | Sydney | Orange

T| 1300 793 267 E| info@umwelt.com.au www.umwelt.com.au