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.

TABLE OF CONTENTS

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).

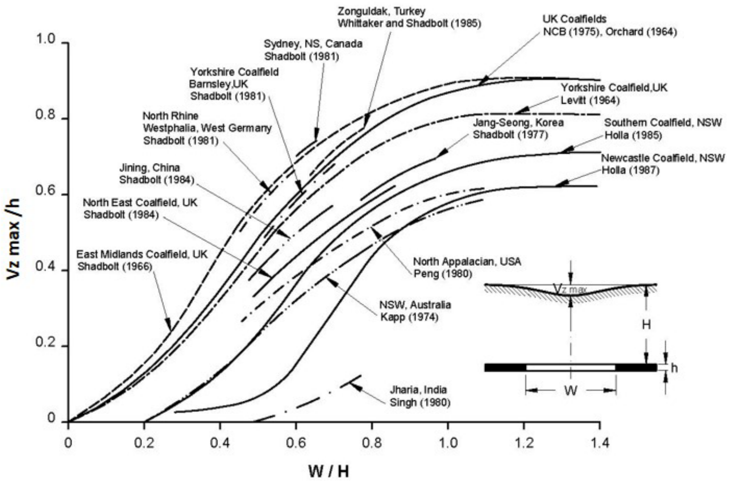

Figure 1: Influence of extraction panel width-to-depth ratio, W/H, on maximum vertical surface displacement, $V_{z\,max}$, expressed as a fraction of mining height, h, for isolated total extraction panels (adapted by Galvin (2016) from Whittaker and Reddish (1989)).

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)

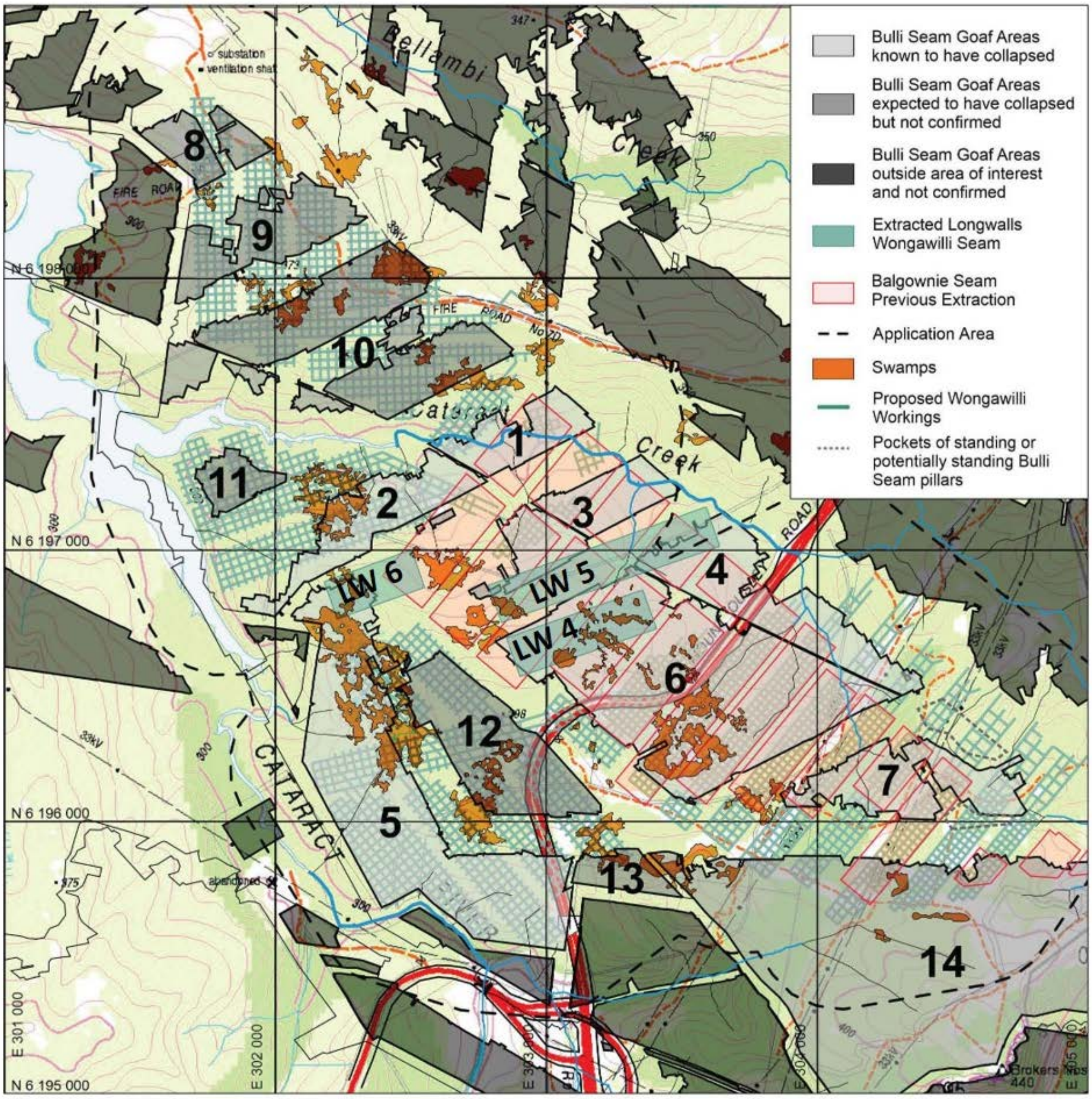

Figure 1: Plan showing location of swamps and proposed first workings in the Wongawilli Seam relative to previous secondary extraction in Bulli Seam (Grey), Balgownie Seam (Red) and Wongawilli Seam (Dark Green).

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.

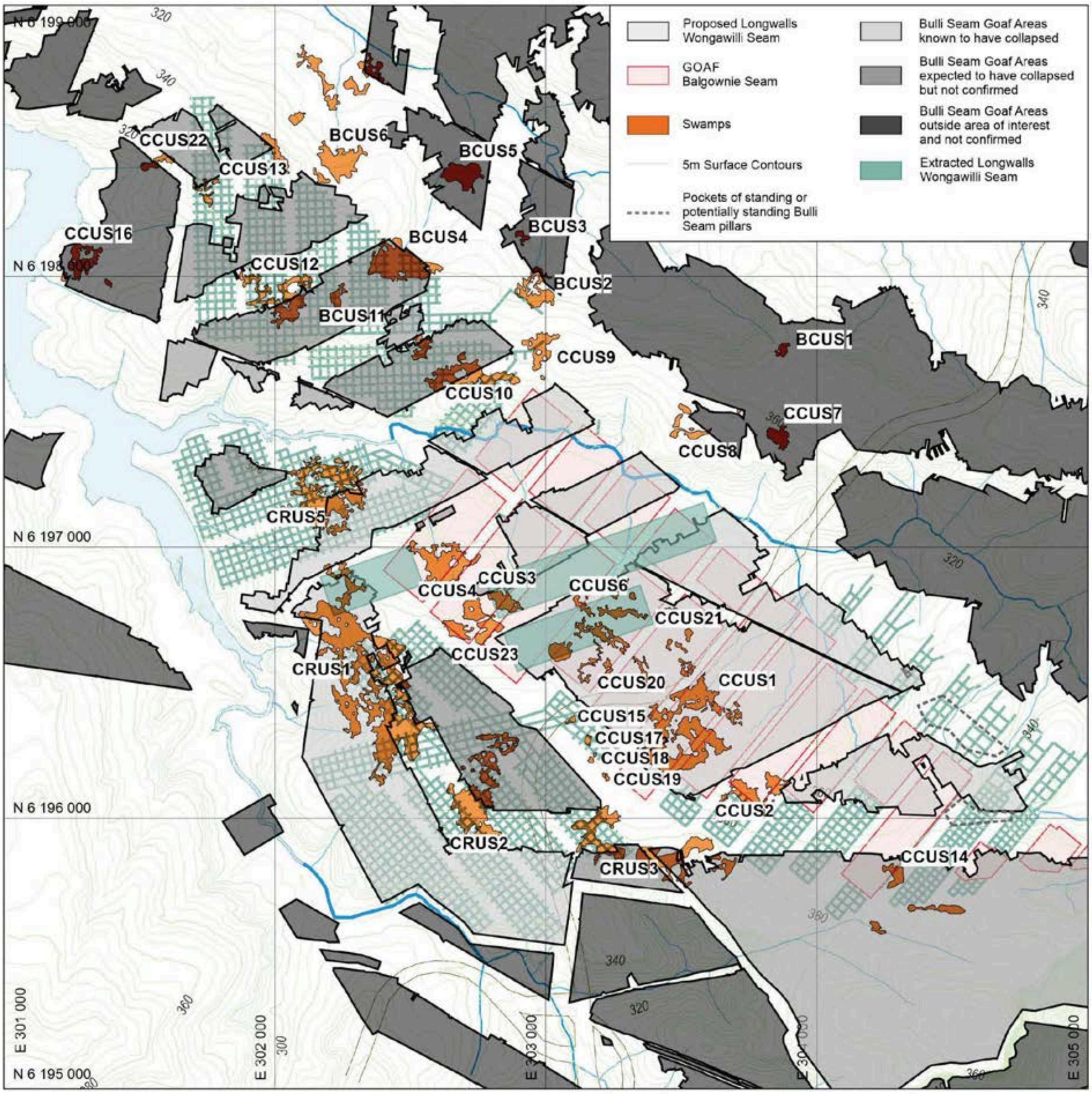

Figure 3: Identification and location of swamps in area of interest (SCT, 2020b) .

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]

[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

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[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.

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   - 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.

[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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