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14 January 2020

Mr Paul Freeman
Team Leader - Resource Assessments
Department of Planning, Industry and Environment
GPO Box 39
Sydney NSW 2001

Dear Sir,

Russell Vale Colliery
Underground Expansion Project

We refer to the Independent Expert Scientific Committee (**ISEC**) advice dated 19 November 2019 in relation to the Wollongong Coal Limited (**WCL**) Russell Vale Underground Expansion Project (**UEP**).

The ISEC advice states the following:

> *The proponent states that there is a "negligible risk" of pillar failure (Umwelt, 2019, p. 9), but they have not quantitatively assessed the residual risks. If the likelihood of pillar failure is "extremely rare" (less than 0.01% per year; Australia Institute for Disaster Resilience, 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. However, if multiple assets are threatened or the likelihood increases, then the risks are of greater material concern.*

The ISEC advice requests that a quantitative assessment of the risks of pillar failure be prepared that includes an empirical analysis of mining failures since the 1880s, recognising the risks posed by mining a third seam under the already mined Bulli and Balgownie seams and quantify the potential magnitude and extent of impacts to water resources should these pillars be destabilised by the project.

The ISEC advice further states the following:

> *Accordingly, for the purposes of this advice, the IESC have considered two scenarios:*
>
> > *1. a "negligible risk" scenario (as assumed in the Revised Preferred Project Report (RPPR)) in which it is expected that the likelihood of pillar failure is less than 0.01% per year; and,*
> > *2. a "worse case" scenario in which the likelihood of pillar failure is materially greater than 0.01% per year.*
>
> *The decision as to which scenario is appropriate depends on the outcomes of the quantitative risk assessment, noted above, which is recommended to be undertaken and provided by the proponent. The responses below address both scenarios.*

WCL notes that the ISEC opinion is that if the likelihood of pillar failure is “extremely rare” (less than 0.01% per year) 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 ISEC advice references the likelihood level outlined within Table 10 of the *National Emergency Risk Assessment Guidelines* (Australia Institute for Disaster Resilience, 2015) of less than 0.01% as being approximate for “negligible risk”.

WCL engaged SCT Operations Pty Ltd (**SCT**) to undertake a quantitative assessment of the risks of pillar failure and a copy of that risk assessment is attached to this covering letter.

The SCT report concludes that the likelihood of the quantitative assessment as follows:

> *Our assessment indicates that the risk of “Catastrophic loss of a single swamp” due to subsidence impacts associated with proposed mining in the Wongawilli Seam is “very rare” or less than 1 in 10,000 years. The potential for further impact to water resources, including stored water, surface water and groundwater, from proposed first workings in the Wongawilli Seam is assessed as negligible.*

The “very rare” description, from Table 10, is for an annual exceedance probability at 0.01%.

On this basis, WCL concur with the SCT conclusions and supports that the IESC should adopt the position that the project should not be regarded as being of material concern.

WCL will provide further correspondence to address the other matters raised within the ISEC advice under the “Negligible Risk” scenario. WCL further notes that the majority of these matters raised can be adequately dealt within in the post approval stage, within the required detailed management plans.

If you have any questions or wish to discuss this matter in further detail, please contact me on 0404 972 746 or rbush@wcl.net.au

Yours sincerely,

Ron Bush
Group Environment and Approvals Manager
Wollongong Coal Limited

14 January 2020

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WCRV5111

Dear Ron

IESC 2019-108: QUANTITATIVE ASSESSMENT OF RISK OF PILLAR FAILURE IN RUSSELL VALE EAST AREA

1. INTRODUCTION

Wollongong Coal Limited (WCL) is planning 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. A review of this project by the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) at the request of the NSW Department of Planning and Environment concluded further work is required to quantify the potential risk to coastal upland swamps from pillar failure. WCL commissioned SCT Operations Pty Ltd (SCT) to provide a quantitative assessment of the risk of pillar failure causing catastrophic loss of a single coastal upland swamp within the project area. This report presents our quantitative assessment of this risk.

The report is structured to provide:

- a summary of the outcomes of the assessment
- an introduction to the specific hazards considered in this assessment and overview of the approach used for the assessment
- detail of the quantitative assessment of each of the specific hazards considered
- an assessment of the magnitude of potential impact to water resources.

2. OUTCOMES OF THE ASSESSMENT

Our assessment indicates that the risk of "catastrophic loss of a single swamp" due to subsidence impacts associated with proposed mining in the Wongawilli Seam is "very rare" or less than 1 in 10,000 years. The potential for further impact to water resources, including stored water, surface water and groundwater, from proposed first workings in the Wongawilli Seam is assessed as negligible.

We recommend, however, that several Bulli Seam goaf areas yet to be mined under are confirmed as subsided goaf areas by observing roadway conditions below Bulli Seam goaf edges during mining of proposed development headings in the Wongawilli Seam. These areas are expected to have subsided, but the presence of abutment loading would unequivocally demonstrate the goaf area has already subsided and that there is no risk of further subsidence. We note that experience at Russell Vale East, of swamps being mined under by pillar extraction in the Bulli Seam, indicates that there would still be no risk of "catastrophic loss of a single swamp" even in the unlikely event there was to be some unexpected further subsidence over these Bulli Seam goaf areas.

For Bulli Seam pillars to present a hazard to swamps, the pillars need to be still standing, be marginally stable so as to fail under the slightly modified stress state generated by proposed mining in the Wongawilli Seam, be strong enough to support abutment loads from surrounding extraction and small enough to be able to deform sufficiently to cause significant subsidence i.e. the pillar geometry would need large panels of pillars with width to height ratio less than about four. At overburden depths of more than about 250m, a pillar geometry that would meet these criteria is difficult to conceive of.

Pillars proposed to be formed in the Wongawilli Seam are quantitatively assessed using the UNSW pillar design approach (Galvin et al 1999), an internationally recognised approach, as less than 1 in 100,000 (0.001% ever and therefore less than 0.01% per year). On the scale used by the National Emergency Risk Assessment Guidelines (NERAG), this likelihood equates to "very rare".

The load-deformation characteristics of these large pillars is such that they continue to be able to support increasing load, even if loading exceeds their nominal pillar strength. Given this load-deformation characteristic, there is no potential for instability of such large pillars to cause subsidence that would pose any risk to upland swamps in the area.

The formation of the proposed large pillars in the Wongawilli Seam is expected to cause minor surface subsidence; much less than 100mm and most likely less than 30mm. SCT does not have expertise in the health and well-being of upland swamps but understands that these low levels of subsidence have no potential to cause catastrophic loss of any single upland swamp.

The risk of further subsidence resulting from future pillar instability in the overlying seams is assessed as "very rare" for the Balgownie Seam and "unlikely" for the Bulli Seam.

Record tracings and mine plans for the Balgownie Seam indicate there are no areas of uncertain pillar stability in the Balgownie Seam located below coastal upland swamps. SCT (2019a) indicates there are eight identified upland swamps located over areas of extracted Balgownie Seam longwall panels. Subsidence monitoring conducted at the time of Balgownie Seam longwall extraction confirms that:

1) the overburden strata had fully subsided at the completion of mining in the Balgownie Seam

2) previous mining in the Bulli Seam had caused the swamps located above the mining area to subside to the fullest extent possible with no potential for further subsidence from Bulli Seam pillar instability.

The load-deformation characteristics of the large pillars formed in the Balgownie Seam for longwall mining effectively preclude further subsidence associated with pillar instability. The risk of further subsidence occurring below these swamps as a result of pillar instability in the Balgownie Seam is assessed as “very rare”.

Assessment of the long term stability of remnant coal pillars in the Bulli Seam can be separated into two parts, consideration of the stability of main heading pillars and the potential for further significant subsidence over fourteen previously extracted areas of the overlying Bulli Seam referred to as Bulli Seam goaf areas.

The main heading pillars are quantitatively assessed as long term stable based on their geometries and large pillar load-deformation characteristics. The risk of these pillars becoming unstable is assessed as “very rare” given their large size and the load-deformation characteristics of such large pillars.

The potential for further subsidence over the Bulli Seam goaf areas hinges on whether these extracted areas have already subsided. Evidence available from surface subsidence monitoring and underground observations indicates that there is quantitative information available to confirm the status of seven of the fourteen Bulli Seam goaf areas located within the project area. All seven of these Bulli Seam goaf areas are confirmed as having already subsided at the time they were formed or soon afterwards.

Once an extracted panel has subsided, the potential for additional pillar instability within that extracted panel is limited by several factors, particularly when the overburden depth is greater than about 250m as it is at Russell Vale East.

The abutment loading generated around the periphery of an extracted panel at greater than 250m overburden depth is so high that only large pillars can remain stable under abutment loading conditions. Small width to height ratio pillars become immediately overloaded and collapse during the subsidence event, effectively being consumed within the goaf area.

The caving processes within an extracted panel lead to the roof and floor horizons closing toward each other until the weight of overlying rock is able to be supported by the goaf. The space that was created by mining is filled by material from the roof and floor of the extracted seam and the ribs of any remnant coal. Remnant pillars attract load until they either collapse if small or deform if large, so much that the pillar ribs contact fallen material and build confinement. In both cases, the goaf comes into equilibrium.

Additional subsidence over the panel can be generated if the solid abutments are destabilised by, for instance longwall mining in the seam below, in which case, it is possible to recover latent subsidence as part of the subsidence caused by subsequent extraction. The formation of large pillars in the Wongawilli Seam would not be able to destabilise large pillars in the Bulli Seam.

The subsidence associated with pillar extraction in the Bulli Seam is likely to have occurred at the time of mining in the Bulli Seam. Subsidence monitoring data from the Balgownie Seam indicates that subsidence had certainly already occurred in those panels subsequently undermined by longwall panels in the Balgownie Seam.

There are seven of fourteen goaf areas that are yet to be confirmed as subsided. All are considered likely to have also subsided given the nature of the mining systems used is similar to the areas confirmed as having subsided. To eliminate any uncertainty, we recommend that confirmation of subsidence is provided during the period of proposed mining through observation of development roadway conditions driven below the edges of these extracted goaf areas. Abutment load can only be developed where there is a goaf edge surrounding an area of extracted coal; and for large goaf areas where subsidence has occurred.

For Bulli Seam pillars to present a hazard to swamps, the pillars would need to be still standing, be marginally stable so as to fail under the slightly modified stress state generated by proposed mining in the Wongawilli Seam, be strong enough to support abutment loads and small enough to be able to deform enough to cause significant subsidence i.e. large areas of pillars with width to height ratio less than about four. At overburden depths of more than 250m, a pillar geometry that would meet these criteria is difficult to conceive of, particularly within a panel that has subsided.

We note that an area of standing pillars in the eastern part of Russell Vale East at 230m overburden depth to the Bulli Seam is confirmed from underground observations as still standing. This area is referred to in various assessment reports in the context of impact to power infrastructure. There are no upland swamps in this area. The maximum subsidence able to be generated by the collapse of these pillars is estimated to be 300-500mm because of the limited extent of this panel relative to overburden depth.

The coastal upland swamps in the Russell Vale East area considered in this assessment are based on the swamps identified and recorded by Biosis (2013). These swamps are divided into some twenty groups, with eight of these swamps or groups of swamps regarded at that time as “significant”. Most of these swamps are located over or partly over extracted Bulli Seam goaf areas with most of these goaf areas confirmed as having already subsided. Most of the swamps in the Russell Vale East area have or are likely to have already experienced full subsidence from mining in the Bulli Seam with six or more groups of swamps also mined under by longwall panels in the Balgownie and Wongawilli Seams.

SCT understands that none of these swamps subsided only by mining in the Bulli Seam is considered to have suffered "catastrophic loss" despite experiencing estimated subsidence of up to 1m from mining in the Bulli Seam.

Based on this assessment, the risk of catastrophic loss of any of the coastal upland swamps located over Russell Vale East due to proposed mining is assessed to be "very rare".

The potential for further subsidence impact to water resources is negligible if, as expected, there is no further significant subsidence. In the unlikely event that any of the seven goaf areas in the Bulli Seam not previously subsided does become destabilised and subside during the period of proposed mining in the Wongawilli Seam, the impact on water resources would be similar and incremental to the impact caused by the seven goaf areas in the Russell Vale East area that are known to have subsided.

Pumping records from Russell Vale Colliery indicate that the inflow into the Russell Vale East area is less than 0.4Ml/day and rises after some months to 0.6Ml/day following periods of high rainfall (SCT 2019b). Most of this inflow is from up dip and through previously extracted longwall goafs in the Balgownie and Bulli Seams. The increment of impact to water resources in the unlikely event that one of the Bulli Seam goaf areas is still standing and subsequently subsides is considered to be negligible.

3. ASSESSMENT APPROACH

3.1 Background

The IESC (2019) provided advice to DPIE on the Russell Vale Colliery Underground Expansion Project. The IESC commended the approach of using first workings to greatly reduce the risk of subsidence compared with other approaches (e.g. longwall mining) but noted that the residual risks of pillar failure had not been quantitatively assessed. DPIE is seeking quantification of the residual risks relative to the 0.01% per year ("extremely rare") threshold detailed in the National Emergency Risk Assessment Guidelines (NERAG 2015).

Figure 1 shows a plan of the Russell Vale East project area superimposed onto a 1:25,000 topographic series map of the area. The locations of previous extraction in the Bulli, Balgownie and Wongawilli Seams are shown together with the proposed first workings in the Wongawilli Seam. The locations of coastal upland swamps identified by Biosis (2013) are also shown.

3.2 Approach

Notwithstanding the intent of the using NERAG to determine the residual risk relative to a guideline, NERAG appears to be more relevant to recurring human emergencies, such as flood risk, rather than the management of one-off environmental risks. Assessment of a one-off subsidence event does not appear to be suitably quantified on a scale of recurring annual probability. Particularly in the context of evidence that the Bulli Seam pillars extracted below upland swamps have already subsided.

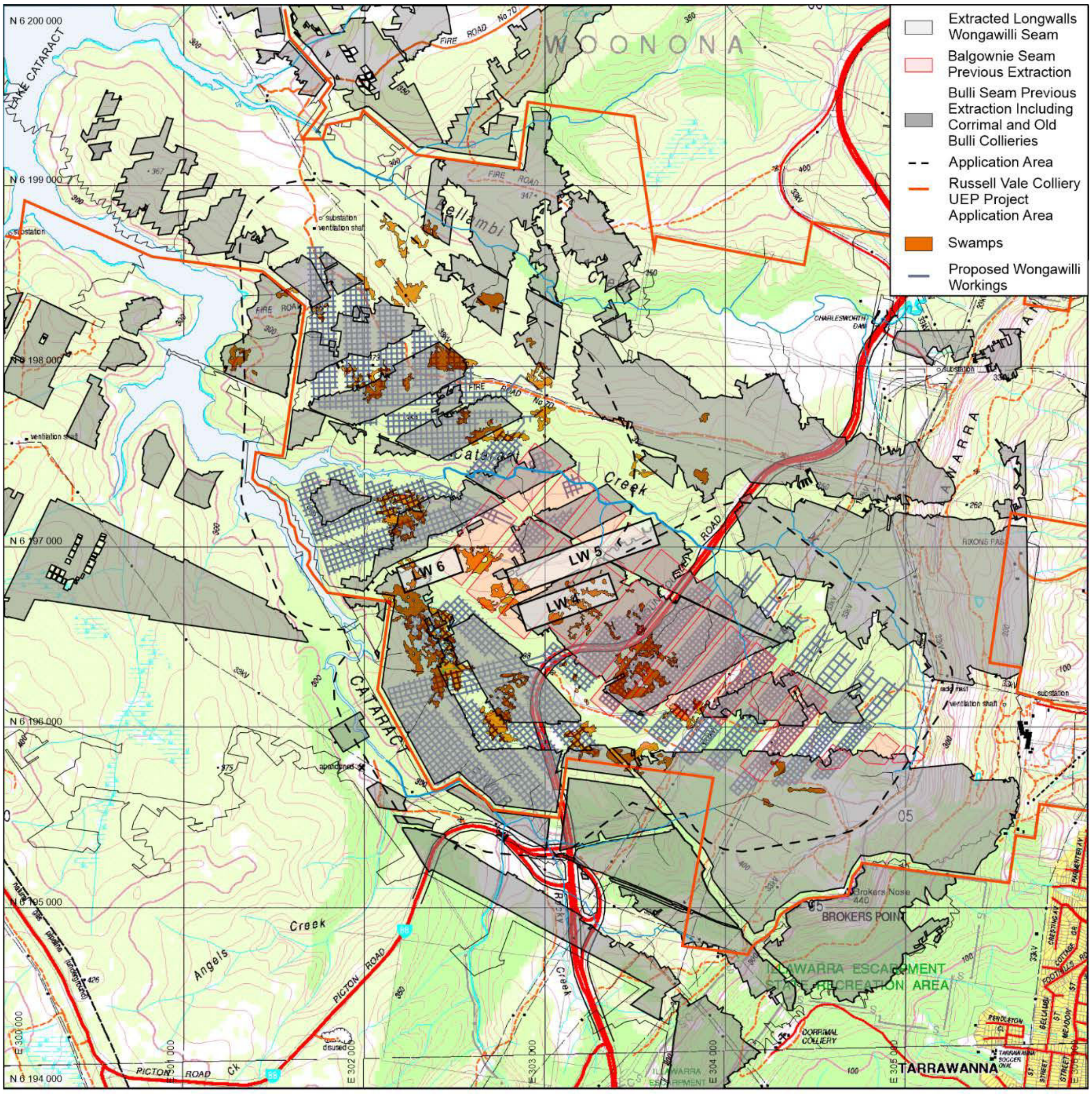

Figure 1: Plan showing location of swamps and proposed first workings in the Wongawilli Seam relative to previous secondary extraction in Bulli Seam (Grey), Balgownie Seam (Red) and Wongawilli Seam (Light Grey).

Gormley et al (2011) present Guidelines for Environmental Risk Assessment and Management developed and used in the United Kingdom to provide a "structured decision making process across government". The approach is based on identifying the hazards and then determining three factors contributing to the likelihood of a hazard being realised as an impact to receptors:

- the probability of the initiating event occurring
- the probability of exposure as a result of the initiating event
- the probability of the receptors being affected by that exposure.

The probability of the occurrence of an event can be expressed as a fraction from 0.0 to 1.0. Events that are unlikely will have a probability near 0, and events that are likely to happen have probabilities near 1. The probability of the hazard occurring (receptor being affected by the initiating event) is the product of the probability of these three factors.

Both approaches are used in this assessment.

3.3 Hazard Identification

The specific hazards addressed in this assessment are:

- pillar failure causing "catastrophic loss of a single swamp"
- potential impacts to water resources.

The only significant impact on water resources would occur in the event of pillar instability causing a further subsidence event, so the focus of the assessment is on the risk of pillar failure. The magnitude of impacts to water resources is considered separately and found to be negligible.

Three seams of coal have been mined in the area of interest, so the initiating events capable of causing significant surface subsidence are considered to include:

1) failure of proposed pillars in the Wongawilli Seam
2) failure of existing pillars in the Balgownie and Bulli Seam without proposed mining (existing residual risk)
3) failure of existing pillars in the Balgownie and Bulli Seam with proposed mining assuming some interaction with proposed Wongawilli Seam mining.

The stability of the proposed pillars in the Wongawilli Seam is considered in SCT (2019a) but not in the context of a risk framework. The UNSW pillar design approach allows the risk to be assessed based on international experience. This approach is used to assess the stability of the proposed Wongawilli Seam pillars and finds that the probability of failure is less than 1 in 100,000 (0.001% ever and therefore less than 0.01% per year).

The geometry of the pillars in the Bulli Seam are not able to be defined with sufficiently confidence for a robust quantitative assessment based on their geometry. The quantitative assessment is instead based on confirming that all the Bulli Seam goaf areas have already subsided and are therefore already long-term stable.

The influence of the proposed mining on the stability of the proposed pillars is the difference between the existing residual risk and the risk of pillar stability associated with proposed mining in the Wongawilli Seam. If the Bulli Seam goaf areas have already subsided, there is no residual risk and no risk of further subsidence associated with proposed mining in the Wongawilli Seam.
The potential magnitude and extent of impacts to water resources, should pillars be destabilised, is quantified based on existing inflow rates and the pathways for flow.

4. QUANTITATIVE RISK ASSESSMENT

4.1 Pillar Stability Assessment for Proposed Wongawilli Seam Pillars

In this section the stability of the proposed pillars is quantitatively assessed in a probability framework using the University of New South Wales (Galvin et al 1999) pillar design approach with context provided by the coal pillar design guidelines presented in Gale and Mills (1994). The bulk of this assessment was presented in SCT (2019a) but this earlier assessment was not presented in a risk based framework.

Pillars proposed to be formed in the Wongawilli Seam are found to be large enough for them to have no potential to become unstable and fail. The risk of individual pillar failure is assessed using the UNSW pillar design approach, an internationally recognised probability based approach, as less than 1 in 100,000 (0.001% ever and therefore less than 0.01% per year). The deformation characteristics of the proposed pillars are such that they continue to be able to carry increasing load even if loading exceeds their nominal pillar strength, so the risk of pillar instability is further reduced.

Using the NERAG approach, the likelihood of pillar instability is assessed as less than "very rare".

Using the Gormley et al (2011) approach, the probability of a subsidence event caused by pillar failure in the Wongawilli Seam is estimated to be 8.5×10^{-7} (0.000085%) and low enough to be regarded as negligible for all practical purposes.

4.1.1 Deformation Characteristics of Coal Pillars

The strength and deformation characteristics of coal pillars are described in this section. The discussion presented shows how pillars of the size of those proposed to be formed at Russell Vale East continue to gain load carrying capacity as they deform so there is no potential for collapse or load shedding at failure.

Coal pillars derive their strength from two independent sources: cohesion and friction.

- Cohesive strength can be thought of as the strength that is derived from the chemical bonds that hold the fabric of the coal together. These bonds are variable in strength. The typical average in situ strength of most Australian coals is found to be approximately 6MPa. The cohesive strength of the bonds does not change significantly with external confinement. Once the bonds are broken, the material strength is lost and cannot be regained.

- Frictional strength can be thought of as the strength that is derived from confinement, much like the strength developed in sand. Frictional strength is zero without confinement but increases quickly with confinement at a rate of about 3-5MPa for every 1MPa of confinement. Frictional strength is effectively independent of cohesive strength and is retained even when the chemical bonds that generate cohesive strength have been broken. Frictional strength is much less variable than cohesive strength but its reliance on confinement means that it is sensitive to the geometry of the pillar and the strength characteristics of the roof and floor strata through which confinement is generated.

Figure 2 shows the pillar stress/strain relationship for pillars with width to height ratios from 1 to 10 (Gale and Mills 1994). The two components, cohesive strength and frictional strength, contribute to the different pillar behaviour observed for different sized pillars in strong roof and floor conditions. Pillar behaviour in the Wongawilli Seam is observed to be more consistent with strong roof and floor conditions allowing frictional strength to develop (Gale and Mills 1994).

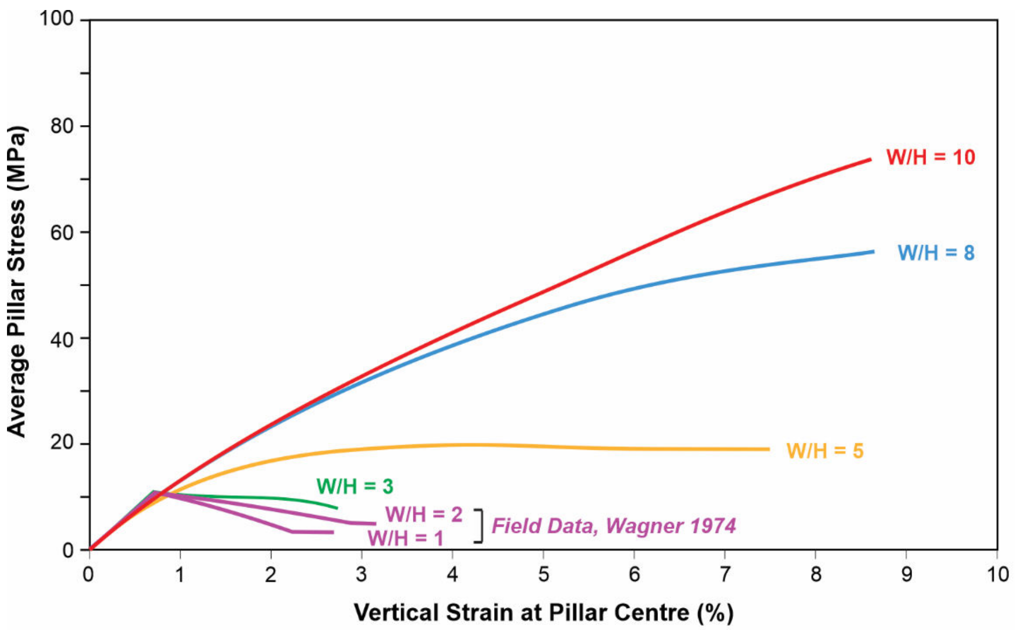

Figure 2: Pillar load/deformation characteristics for varying width/height ratios.

Small pillars with a width to height of less than about three have a slender geometry that is unable to generate any significant confinement within the core of the pillar until all the cohesive strength has been exhausted and the pillar has collapsed. Their strength is clearly apparent as the point at which cohesive strength is lost and this strength varies with the variability of cohesive strength. Estimating pillar strength is a process that involves characterising the variability of cohesive strength. Probabilistic approaches have been found to be effective when the applied load is limited by design relative to the average strength.

Larger pillars with a width to height ratio of greater than about eight in strong roof and floor conditions develop most of their strength from confinement provided to the core of the pillar by the frictional resistance of failed coal around the pillar edges. The variability in strength associated with the variability of cohesive strength is not a significant component of the strength of large pillars. Instead their strength is a function of the geological setting and the confinement that this setting provides to the core of the pillar.

Pillars with a width to height ratio between three and eight in strong roof and floor conditions show pillar deformation behaviour that is transitional between pillars that initially increase in strength and then lose strength as they deform, to pillars that maintain the same strength after they have reached peak load and on to pillars that, continue to increase in strength and load carrying capacity as they deform.

4.1.2 Pillar Loading in the Wongawilli Seam

For the purposes of a quantitative assessment of pillar stability, pillar loading is determined as the maximum weight of overburden strata at 380m overburden depth.

It is recognised that in multi-seam workings where, overlying seams have been partially or fully extracted, the vertical loads are not necessarily uniform and may become locally redistributed as a result of the overlying mining. The variations are expected to change from reduced loads under sections of goaf areas, to full tributary area loading below areas of regular, first workings pillars, to elevated loading under chain pillars between the extracted Balgownie Seam longwall panels, or under abutment pillars and barrier pillars in both the Balgownie and Bulli Seams. These loading scenarios have been observed previously at Russell Vale East as locally elevated stress conditions in underground roadways in the Wongawilli Seam.

Pillars in the proposed layout for the Wongawilli Seam have minimum width to height ratios in the range of 8-10. Such pillars are large enough that although they may become more heavily loaded, their stress-strain characteristics (as shown in Figure 2) are such that their load carrying capacity continues to increase.

Pillar loading based on maximum weight of overburden is considered appropriate to use for a quantitative assessment of pillar stability given that the local variation in loading at the level of the Wongawilli Seam occurs over a distance that is much less than the overburden depth (ranging 250m to 380m). Any local variations in pillar deformation due to the variable loading conditions is effectively averaged out by the overburden strata given that individual pillars continue to build load-bearing capacity as they deform and become more heavily loaded.

4.1.3 Wongawilli Seam Pillar Stability Assessment

The proposed pillars are expected to continue to gain load carrying capacity as they deform (as shown in Figure 2). In this circumstance, there isn't a critical "strength" value that represents a point of maximum load carrying capacity. Roadway deformation continues but the pillar load carrying capacity continues to increase. In this context, a factor of safety approach is not very useful. Nevertheless, it is helpful to consider their nominal strength using traditional pillar design approaches.

The nominal strengths of the 25m and 30m square pillars and 2.4m mining height indicated by the Galvin et al. (1999) approach are 22MPa and 30MPa respectively. The nominal strengths indicated by the Bieniawski approach are 21MPa and 26MPa respectively.

As discussed in the previous section, estimation of the pillar loading is more difficult because loading is expected to vary with overburden depth and relativity to previous mining in the overlying seams. Maximum credible worse case loading is used for the pillar stability assessment.

Under the extracted Balgownie Seam longwall panels where the 25m square pillars are located, maximum loading is expected to be reduced by the presence of the overlying extraction. As an upper limit, maximum loading is not expected to exceed the weight of the maximum overburden depth. The maximum overburden depth to the Wongawilli Seam in the areas of previous Balgownie Seam longwall extraction is estimated to be 350m. Tributary area loading on the 25m square pillars is estimated to reach a maximum of 14MPa. The 25m square pillars are therefore expected to be relatively lightly loaded compared to their nominal 21-22MPa strength.

Under areas in the Bulli and Balgownie Seam where there has been little or no nearby extraction, the maximum overburden depth is 380m. Maximum tributary area loading on 30m square pillars is estimated to be less than 15MPa. The 30m square pillars are therefore expected to be relatively lightly loaded compared to their 26-30MPa nominal strength.

The risk of individual pillar failure under the weight of 380m of overburden strata is assessed using the UNSW pillar design approach as less than 1 in 100,000 (0.001% ever and therefore much less than 0.01% per year).

Using the NERAG approach, the likelihood of pillar instability is determined to be "very rare".

There is potential for higher and lower loads to be carried locally by some pillars adjacent to areas of full extraction in the overlying seams. Even if the load calculations underestimate the actual loading, increased loads would cause the large pillars proposed to have greater load carrying capacity as they deform. Under these circumstances, the roadways may become more difficult to develop but there is no potential for the pillars to collapse or for subsidence to increase suddenly as a result of such a collapse.

In areas where the Bulli Seam has been extracted, vertical loading is expected to be less than tributary area loading and so the 30m square pillars are more lightly loaded than indicated above.

Under Bulli Seam and Balgownie Seam abutment areas, there is potential for higher vertical loading to develop where the weight of overburden strata is concentrated locally. The area over which abutment loading is concentrated is unlikely to be significantly greater than one or perhaps two pillars so the effect of this concentrated loading is expected to be relatively localised by comparison with the overburden depth.

Measured and inferred vertical abutment load distributions from longwall panels are expected to provide an upper limit on the pillar load concentrations around extracted pillar panels. The maximum abutment loading from a 200m longwall panel on a 30m wide pillar located at the goaf edge is estimated for 350m deep using the approach described by Mills (2001) as being 350MN/m or 17MPa distributed over a 24.5m square pillar.

Including the pre-mining vertical stress and allowing for dispersion of vertical load through the 30-40m of interburden between the Bulli Seam and the Wongawilli Seam gives a total pillar load in the range 20-25MPa. This loading is greater than the 20MPa level where first workings are likely to become difficult to mine in a thick coal seam environment but is still less than the 26-30MPa nominal strength of 30m square pillars (measured centre to centre), again recognising that this nominal strength is of no practical significance for large pillars that gain load-bearing capacity as they deform.

Using the Gormley et al (2011) approach, the probability of a subsidence event caused by pillar failure in the Wongawilli Seam is estimated as follows to be 8.5×10^{-7}:

$$
\begin{aligned}
P &= P_{\text{initiating event}} \times P_{\text{exposure}} \times P_{\text{receptor affected}} \\
&= 0.0001 \times 0.7/4.2 \times 0.05 \\
&= 8.5 \times 10^{-7} \ (0.000085\%)
\end{aligned}
$$

Where the $P_{\text{initiating event}}$ is based on the UNSW pillar design approach, P_{exposure} is based on the area of swamps above Russell Vale East divided by the total project area, and $P_{\text{receptor affected}}$ assumes that one swamp of the twenty or so swamps located over Russell Vale East suffers a catastrophic loss if subsided by less than 1m noting that none of the swamps are recognised to be catastrophically impacted by mining in the Bulli Seam alone. This probability of impact is regarded as low enough to be insignificant for all practical purposes.

4.2 Pillar Stability Assessment for Pillars in Overlying Seams

DPIE is seeking a quantitative assessment of the risk of pillar failure to cause catastrophic loss of any single swamp. The ISEC indicates that the assessment should include empirical analysis of mining failures in the area since the 1880's and should recognise the risks posed by mining a third seam under the already mined Bulli and Balgownie Seams.

The mine plans and record tracings of historical workings in the Bulli Seam in the Russell Vale East area are considered reliable enough to show where large pillars and main headings are located and where coal extraction has been maximised using the mining systems available at the time (shaded areas). The record tracings are not considered accurate enough to support a robust quantitative pillar stability assessment based purely on the geometry of individual pillars.

The quantitative assessment of risk to coastal upland swamps is instead based on consideration of the current state of the Bulli Seam workings and the potential for instability of these workings to be a hazard for overlying coast upland swamps.

4.2.1 Balgownie Seam Mining

Record tracings of mining in the Balgownie Seam indicate there are no areas of uncertain pillar stability in the Balgownie Seam located below coastal upland swamps. There are six identified upland swamps located over areas of extracted Balgownie Seam longwall panels. Subsidence monitoring conducted at the time of longwall extraction (shown in Figure 17 of SCT 2019a) confirms that all these swamps were fully subsided and there is no potential for further subsidence to occur below these swamps.

The subsidence monitoring also provides insights into the status of the Bulli Seam pillars above. The Bulli Seam pillars overlying the Balgownie Seam longwalls are indicated by subsidence monitoring and underground inspection to have been completely destabilised. Any standing pillars located 5-10m above an extracted longwall mining horizon could not be other than completely destabilised as a result of that subsequent longwall mining.

4.2.2 Bulli Seam Mining

Bulli Seam coal has been mined in the Southern Coalfield for approximately 170 years with mining at Russell Vale East over more than 130 years. The Bulli Seam was mined in the Russell Vale East area up until the early 1950's using pick and shovel mining techniques. Record tracings of the area indicate three distinct areas of mine workings:

- large barriers protecting the main heading pillars
- areas of cross-hatching where coal was extracted to the fullest extent possible using the mining techniques available at the time
- areas of larger pillars individually defined.

The main heading barriers are typically in the range 120m to 150m wide measured goaf edge to goaf edge. The pillars in these barriers are large enough that there is no potential for them to fail. They are typically 35-45m wide in a 2.2m coal seam. There is no potential for these pillars to collapse or subside further irrespective of any further first workings developed in the Wongawilli Seam.

The issue of uncertainty for future subsidence relates to those areas of the Bulli Seam shown as goaf areas. There is detail showing the date of mining and the geometry for most of these areas on mine plans and record tracings.

If remnant pillars have already collapsed in these hatched goaf areas, the surface has already subsided. In this case, there is no potential for further pillar instability, further subsidence or further impact to surface swamps irrespective of any proposed first workings in the Wongawilli Seam. The record tracings indicate that there are no large intermediate barriers within the hatched areas. Each can therefore be treated as a single goaf area.

If these workings have not already subsided there may still be a risk of additional subsidence and there remains the potential for this further subsidence in the Bulli Seam to present a risk to coastal upland swamps. Available evidence indicates that seven hatched goaf areas in the Bulli Seam have already fully subsided and therefore pose no further hazard. It is also likely that the other seven goaf areas have also subsided, but the status of these goaf areas needs to be confirmed.

Methods available to determine if there are large areas of standing pillars in old goaf areas include:

1) review of the mining systems and consideration of the abutment loading

2) observation of Bulli Seam goaf edges

3) review of subsidence monitoring from mining in other seams – the collapse of overlying pillars in the Bulli Seam would be evident as significantly greater subsidence

4) observation of abutment loading under the edges of barrier pillars when mining in lower seams – abutment loads would not be perceptible unless a caved goaf has formed.

All these methods indicate that areas indicated on the mine plans and record tracings as goaf have already collapsed with no potential for future instability with or without the first workings in the Wongawilli Seam.

Most of the coastal upland swamps in the Russell Vale East area have been previously mined under in the Bulli Seam and previously subsided by more than 1m. Mining in the Bulli Seam alone does not appear to have led to catastrophic loss of any swamps. In the unlikely event that any of the remaining seven unconfirmed Bulli Seam goaf areas are still standing and able to subside, the subsidence is unlikely to be as large or to have greater impact on the surface as subsidence that has already occurred below the swamps that are known to have been previously subsided.

4.2.2.1 Mining Systems

The evolution of coal mining layouts for the bord and pillar method in NSW (and indeed elsewhere in the world) was by a process of trial and error with local 'rules of thumb' dictating the width of first workings pillars, bord (roadway) width and at different times, mining or pillar heights. Some of these dimensions were prescribed for the first time or varied by legislation in response to significant accidents or incidents (both in Australia and worldwide) including recognition of the influence of increasing depth of mining on pillar stability. There is evidence of pillar crushes or creeps occurring during the period of active mining and soon after mining was complete.

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.

4.2.2.2 Underground Observation of Bulli Seam Goaf Edges

Direct observation of the Bulli Seam goaf edges is not typically possible. Where goaf edges shown as hatched areas on the record tracings are accessible from underground, a goaf is observed to have formed.

There is one area referred to in Figure 16 of SCT (2019a) that shows an area of standing pillars represented as individual pillars on the record tracings. This area of pillars is still standing and accessible. The area of standing pillars is approximately 80m wide at 240m deep (a width to depth ratio of 0.3). The area is surrounded by a barrier of solid coal 30-40m wide. If pillars in this panel were to collapse, surface subsidence would be limited to less than 300-500mm by the narrow panel width. There are no coastal upland swamps in this area, but the area represents an example of a mining system that was used at the mine and may be present elsewhere.

Comment is made in SCT (2019a) that "there is some potential for pillar stability to lead to subsidence, potentially of the order of 1-2m, should the pillars collapse over a large enough area". While theoretically possible, further review of the geometries required to generate this level of subsidence indicates that, in circumstances where a large enough area of pillars could exist to produce subsidence of this magnitude, the pillars would not be stable under goaf edge loading and would already have collapsed. If a goaf has formed anywhere in the vicinity of an extensive area of standing pillars, the potential for further subsidence would be low.

4.2.2.3 Review of Subsidence Monitoring during Longwall Extraction

Longwall mining in the Balgownie and Wongawilli Seams provide an opportunity to find if the shaded areas in the overlying Bulli Seam had already subsided prior to longwall mining. If pillars in the Bulli Seam directly above a longwall panel were still standing, they would certainly be destabilised by longwall mining. Additional subsidence associated with this destabilisation would then be observed in the subsidence profile. The subsidence profiles from the extensive Balgownie Seam monitoring data and the more recent subsidence monitoring for the Wongawilli Seam longwalls indicate that the magnitude of subsidence observed is consistent with the Bulli Seam pillars having already subsided prior to longwall mining. There is no indication in the subsidence monitoring of further subsidence due to collapse of any pillars in Bulli Seam goaf areas during longwall mining.

Subsidence monitoring beyond the goaf edge of longwall mining provides another indicator of whether the Bulli Seam pillars have already collapsed. If the Bulli Seam pillars were still standing and of marginal stability, the extra abutment loading from longwall mining would cause them to become overloaded and collapse leading to additional subsidence beyond the goaf edge. There is no evidence of such behaviour around the goaf edges of the Balgownie or Wongawilli Seam longwall panels.

These observations imply that Bulli Seam goaf areas had already fully subsided before longwall mining. These goaf areas are therefore now long-term stable.

4.2.2.4 Abutment Loading Observations

When coal is extracted, the weight of overburden strata is transferred from directly above the extracted area onto the solid coal or standing pillars around the perimeter of the extracted area. At 250-380m overburden depths, the abutment load at the goaf edge is typically 2-3 times the background load. When mining in the seams below, this additional abutment load is evident as a deterioration in the roadway conditions experienced.

Abutment loading is not evident when standing pillars are formed because the weight of overburden strata is still substantially carried by the standing pillars and therefore more uniformly distributed. The presence of deteriorating roadway conditions below Bulli Seam goaf edges is consistent with any standing pillars having already collapsed and subsidence having already occurred.

Multiple roadways mined in the Wongawilli Seam to form longwall gateroads and main headings have passed below goaf edges in the Bulli Seam. Roadway conditions are observed to deteriorate significantly in these areas indicating that abutment loads are present. The implication of these observed abutment loads is that the Bulli Seam goaf area has already subsided.

Although there are seven goaf areas in the Bulli Seam that cannot currently be confirmed as subsided, the 100% confirmation of subsidence in seven other goaf areas where confirmation has been possible, indicates that all goaf areas are likely to have subsided at the time of Bulli Seam mining.

On this basis, Bulli Seam goaf areas where subsidence is currently unconfirmed could be confirmed as subsided by observing the roadway conditions as the goaf edges are mined under. Where there is clear evidence of abutment loading, subsidence of the Bulli Seam goaf areas would be confirmed. The observation of abutment loading in the Wongawilli Seam roadways below goaf edges in the Bulli Seam would be confirmation that all pillars in the goaf have collapsed and there is no potential for further subsidence.

4.3 Quantification of Potential to be Impacted

To assess the probability of any upland swamp being impacted by the proposed mining is the product of:

- the probability of the proposed mining initiating a subsidence event
- the probability of the upland swamps being exposed to that subsidence event
- the probability of the swamps being impacted by the subsidence.

These probabilities are quantified in this section.

4.3.1 Probability of Initiating Event

There is considered to be no potential for the first workings in the Wongawilli Seam to destabilise large pillars in the Bulli or Balgownie Seams.

There may be potential for first workings in the Wongawilli Seam to cause pillar instability of remnant Bulli Seam pillars if marginal pillars are still standing. If remnant pillars are confirmed as having already been destabilised, there is no potential for further destabilisation and therefore no potential to impact surface swamps.

All seven panels where the status of the pillars can be confirmed independently from subsidence monitoring or other means are confirmed as having fully subsided. The other seven panels where the status of the pillars is unknown are also expected to have subsided given the same or similar mining systems were used in all the Bulli Seam goaf areas of interest.

Nevertheless, until this confirmation is available, the pillars are assumed to still be standing and capable of being destabilised. The status of pillars in the seven panels where status is unknown can be confirmed by observing roadway conditions under the goaf edge.

The probability of first workings in the Wongawilli Seam causing instability of any standing pillars in the Bulli Seam is estimated to be less than 0.01 (1%). Approximately 5km of longwall gateroad pillars were mined in the Balgownie Seam 5-10m below remnant Bulli Seam pillars panels. Subsidence monitoring shows that none of these gateroad developments caused instability in the Bulli Seam pillar panels above suggesting the interaction effects were not enough to destabilise overlying pillars 5-10m above.

The probability of an initiating event, the formation of first workings in the Wongawilli Seam, causing further subsidence in the Bulli Seam goaf areas is either:

$$P_{\text{pillar instability}} = 0.01 \times 0.0 = 0.00 \text{ or } 0\%$$

(if the goaf areas are confirmed as having already subsided),

or

$$P_{\text{pillar instability}} = 0.01 \times 0.5 = 0.05 \text{ or } 5\%$$

(for those goaf areas that have not subsided, assuming all unconfirmed Bulli Seam goaf areas have not subsided).

4.3.2 Exposure to Event

Figure 1 shows the locations of the coastal upland swamps in the Russell Vale East area relative to the proposed mining area in the Wongawilli Seam and existing workings in the Bulli and Balgownie Seams. Locations where the Bulli Seam workings are indicated as being collapsed either by subsidence monitoring or abutment loading are also shown.

The total area of proposed mining is approximately 4,200,000m^2. Within this total area, the area covered by recognised swamps is approximately 710,000m^2 (17% of the total proposed mining area). The area within the total mining area where Bulli Seam goaf areas are confirmed as already subsided by one or other methods is approximately 1,500,000m^2 (36%). The area within the total mining area where there are not yet any direct methods to confirm subsidence within the Bulli Seam goaf is approximately 1,200,000m^2 (29%).

The area of swamps located in areas where subsidence in Bulli Seam goaf areas has yet to be confirmed is approximately 200,000m^2 (4.8% of the total project area and 28% of total area of swamps). The other 72% of swamps have already been subsided by previous mining with maximum subsidence ranging from 1m up to approximately 3.6m.

The probability of exposure of any particular swamp to a subsidence event is estimated to be 0.28 being 28% of the total area of swamps located over potential subsidence areas.

4.3.3 Probability of Impact

SCT does not have expertise in assessing the significance or otherwise of any given quantum of subsidence to a swamp. The impacts to swamps from previous mining based on the magnitude of subsidence is used as a guide instead.

The panels where swamps are located above areas of unconfirmed pillar stability range in width from 230m to 310m. The overburden depth ranges from 270m to 350m. The panel width to depth ratio ranges from 0.63 to 1.1. If the pillars in the widest panel were to collapse, full subsidence would be limited by the width of the panel. For full extraction, maximum subsidence in very wide panels is typically recognised to be less than 65% of seam thickness. At a panel width to depth ratio of 1.1, maximum subsidence of 55% of effective seam thickness is a more reasonable maximum. The maximum extraction ratio is estimated to be about 70%.

Maximum subsidence resulting from a pillar instability is thus estimated to be:

$$\text{Max subsidence} = 0.55 \times 0.7 \times 2.2\text{m}$$

$$= 0.85\text{m}$$

This level of subsidence is consistent with estimates of historical Bulli Seam subsidence presented in SCT (2019a). Swamp CCSU1 located to the east of Mount Ousley Road has been subjected to up to 1m of subsidence from mining in the Bulli Seam and a further 1.2m of subsidence from mining in the Balgownie Seam for a total subsidence of approximately 2.2m. Most other swamps have likely been subject to subsidence of less than 1m. SCT is not aware of any swamps located over Bulli Seam goaf areas (where there has been no longwall mining in the Balgownie or Wongawilli Seams) that would be regarded as having suffered “catastrophic loss”. The potential for other swamps to suffer “catastrophic loss” as a result of less than 0.85m of subsidence is estimated to be less than 0.1 (10%).

4.3.4 Probability of A Single Swamp Being Impacted

The probability of an initiating event causing impacts to any single swamp is calculated as the product of the probability of the initiating event, the probability of exposure and the probability of impact.

If all the Bulli Seam goaf areas are, or can be, confirmed as already having subsided the probability of mining Wongawilli Seam pillars causing “catastrophic loss of a single swamp” is estimated to be:

$$P_{\text{loss of swamp}} = 0.00 \times 0.28 \times 0.1 = 0.00\ (0\%)$$

(if all goaf areas are confirmed as having already subsided), or

$$P_{\text{pillar instability}} = 0.01 \times 0.28 \times 0.1 = 0.00028\ (0.028\%)$$

(if goaf areas cannot be confirmed as having already subsided).

The estimated probability of impact is either zero if all the goaf areas can be confirmed as having subsided or 0.028% if not. The NERAG assessment guidelines rate a likelihood of less than 0.1% as being "very rare", so the likelihood of impact to swamps is assessed as "very rare".

5. Impact to Water Resources

The potential for further subsidence impact to water resources is zero if, as expected, there is no further significant subsidence. In the unlikely event that any of the seven goaf areas in the Bulli Seam has not previously subsided and does become destabilised and subside during the period of proposed mining in the Wongawilli Seam, the impact on water resources would be similar and incremental to the impact caused by the seven goaf areas in the Russell Vale East area that are known to have already subsided.

Pumping records from Russell Vale Colliery indicate that the inflow into the Russell Vale East area is less than 0.4Ml/day and rises after some months to 0.6Ml/day following periods of high rainfall (SCT 2019b). Most of this inflow is from up dip where the Bulli Seam has been mined at shallow depth below the escarpment and through previously extracted longwall goafs in the Balgownie and Bulli Seams.

The incremental impact to water resources in the unlikely event that one of the Bulli Seam goafs areas is still standing and subsequently subsides is expected to be less than 0.02Ml/day. The likelihood of this impact occurring is determined to be "unlikely" based on the NERAG scale. On this basis, the risk of impact to water resources is considered negligible.

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

Yours sincerely

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