Wollongong Coal Limited

Russell Vale Colliery

Underground Expansion Project

Response to the

Independent Expert Scientific Committee Advice

June 2020

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1 INTRODUCTION

The Russell Vale Colliery (**RVC**) is an existing underground coal mine located in Russell Vale, north of Wollongong in NSW that is owned and operated by Wollongong Coal Limited (**WCL**). RVC has been on 'care and maintenance' since 2015 and the current Project Approval applying to mining operations at RVC requires that no mining occur after 31 December 2015.

WCL is seeking Project Approval under the *Environmental Planning and Assessment Act 1979* (**EP&A Act**) to expand the mining operations at RVC. This ongoing application is referred to as the Underground Expansion Project (**UEP**).

The Revised Preferred Project Report and Response to Second PAC Review (**Revised Preferred Project Report**) for the Russell Vale Revised UEP was placed on public exhibition from 1 August to 29 August 2019.

A Submissions Report was prepared to address the key issues raised in the submissions received during the public exhibition period. The Submissions Report was provided in two separate reports, with Part A addressing all key issues raised, apart from groundwater and Part B addressing groundwater issues raised.

During the assessment process, additional information has been provided to DPIE in support of the UEP, which has been consolidated into a separate report (**Additional Information Response Report**).

2 INDEPENDENT EXPERT SCIENTIFIC COMMITTEE ADVICE

The Independent Expert Scientific Committee (**IESC**) on Coal Seam Gas and Large Coal Mining Development provides independent, expert, scientific advice to the Australian and state government regulators on the potential impacts of coal seam gas and large coal mining proposals on water resources.

The IESC was requested by DPIE to provide advice on the RVC UEP and the IESC provided advice within a report dated 19 November 2019 (**IESC November Advice**).

The IESC November Advice notes that the WCL's proposed bord-and-pillar (first workings only) extraction will greatly reduce the risk of subsidence compared with other subsurface mining approaches, such as longwall mining, and comments that first workings only by the UEP is strongly commended by the IESC.

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 the likelihood of pillar failure is less than 0.01% per year in accordance with the Australia Institute for Disaster Resilience Guideline (2015).

3 QUANTITATIVE ASSESSMENT OF RESIDUAL RISKS AND PEER REVIEW

3.1 SCT Report

WCL engaged SCT Operations Pty Ltd (**SCT**) to undertake a quantitative assessment of risk of pillar failure for the RVC UEP area.

SCT prepared a report on the quantitative assessment of the risk of pillar failure causing catastrophic loss of a single coastal upland swamp in the project area.

SCT reported the outcomes of the quantitative assessment of risk of pillar failure within the following report (**SCT January 2020 Report**):

> *"IESC2019-108: Quantitative Assessment of Risk of Pillar Failure in Russell Vale East Area", dated 14 January 2020. Report No. WCRV511.*

The SCT January 2020 Report is contained within **Appendix 1**.

The SCT January 2020 Report, concluded the following:

> *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.*

3.2 Peer Review

WCL engaged B K Hebblewhite Consulting to conduct an independent peer review of the SCT January 2020 Report.

The peer review is outlined within the following report (**Hebblewhite April 2020 Peer Review Report**):

> *Report No. 2003/03.3 Peer Review – Russell Vale Colliery Assessment of Risk of Pillar Failure, dated 7 April 2020.*

A copy of the Hebblewhite April 2020 Peer Review Report is contained within **Appendix 2**.

The Hebblewhite April 2020 Peer Review Report provided comments and suggestions for revision of the SCT January 2020 Report to improve the quantitative risk assessment undertaken and the resultant clarity of the risk assessment outcomes.

3.3 Revised SCT Report

SCT reviewed the peer review comments and suggestions outlined within the Hebblewhite April 2020 Peer Review Report and revised their report to address the matters raised.

SCT revised report (**SCT June 2020 Report**) is titled:

> *"IESC2019-108: Quantitative Assessment of Risk of Pillar Failure in Russell Vale East Area", dated 12 June 2020. Report No. WCRV511_4.*

A copy of SCT June 2020 Report is contained within **Appendix 3**.

The SCT June 2020 Report, provides the following assessment:

> *Our assessment indicates the likelihood of "catastrophic loss of a single swamp" from proposed mining in the Wongawilli Seam is "extremely rare" (less than 0.01%) over greater than 95% of the proposed mining area using the National Emergency Risk Assessment Guidelines (NERAG). In the remaining area, the probability is estimated to be 0.028% or "very rare" until goaf areas in the Bulli Seam are confirmed as collapsed, as they are expected to be. It is anticipated that the status of the unconfirmed Bulli Seam goaf areas will be easily confirmed by visual observation of roadway conditions as goaf edges are mined under. Once confirmed as collapsed, there will be no further credible source of subsidence impact to upland swamps and the likelihood will revert to "extremely rare" across the entire area*.

3.4 Supplementary Peer Review

A copy of the SCT June 2020 Report was provided to B K Hebblewhite Consulting to provide a summary of the SCT responses to the Hebblewhite April 2020 Peer Review Report.

A copy of the Supplementary Peer Review report dated 15 June 2020 is contained within **Appendix 4**.

The supplementary peer review report concludes with the following:

> *I am satisfied that the updated WCRV5111 Rev. 4 SCT Report has adequately responded to my substantive comments from the original peer review and that the conclusions reached are therefore considered appropriate and valid, based on the information available.*

APPENDIX 1

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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.

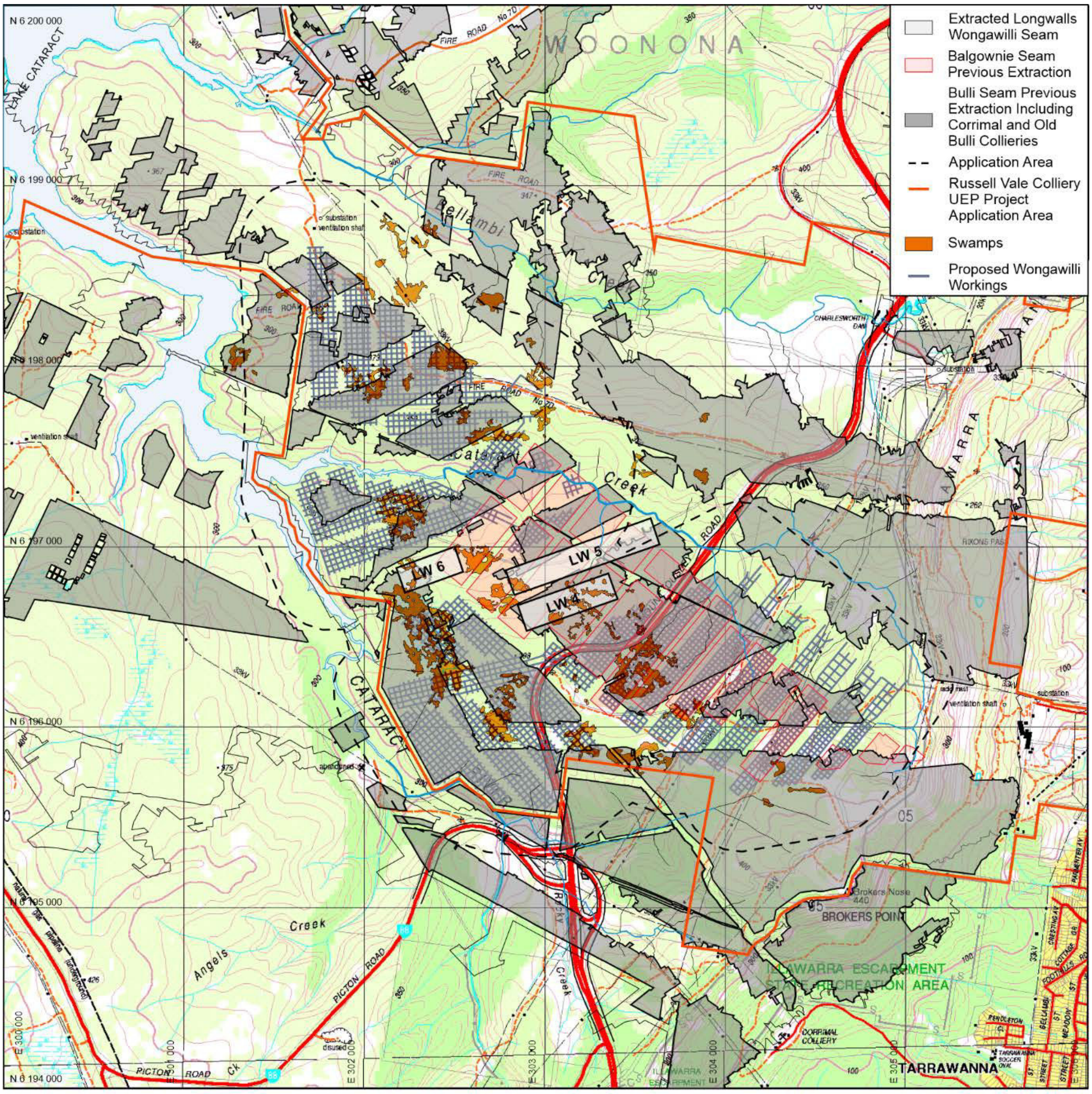

Figure 1: Plan showing location of swamps and proposed first workings in the Wongawilli Seam relative to previous secondary extraction in Bulli Seam (Grey), Balgownie Seam (Red) and Wongawilli Seam (Light Grey).

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).

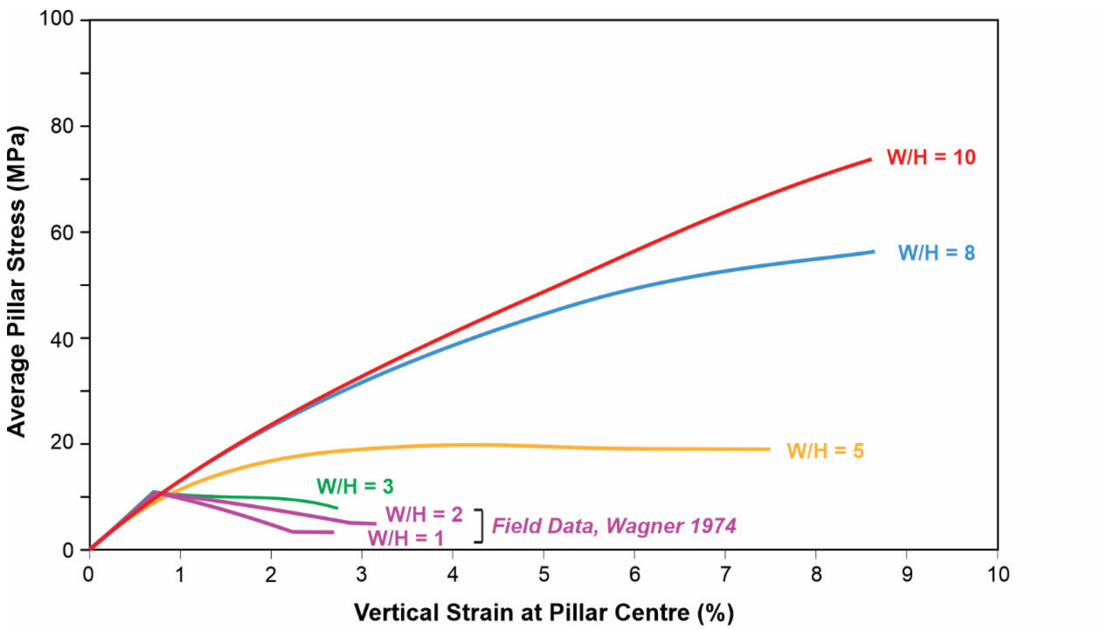

Figure 2: Pillar load/deformation characteristics for varying width/height ratios.

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}:

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

$$= 0.0001 \times 0.7/4.2 \times 0.05$$

$$= 8.5 \times 10^{-7}\ (0.000085\%)$$

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

Ken Mills
Principal Geotechnical Engineer

6. REFERENCES

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SCT 2019a. "Russell Vale Colliery: Subsidence Assessment for Proposed Wongawilli Seam at Russel Vale East" SCT Report UMW4609 to Umwelt (Australia) Pty Ltd dated 3 October 2019.

SCT 2019b. "Russell Vale Colliery: 2018 Update of Water Balance Estimation" SCT Report WCRV4929 to Wollongong Coal dated 4 April 2019.

APPENDIX 2

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7 April 2020

Report No. 2003/03.3
Peer Review – Russell Vale Colliery Assessment of Risk of Pillar Failure

Attn: Mr Ron Bush, Group Environment and Approvals Manager

1. BACKGROUND

A previous independent review was undertaken for Wollongong Coal of the subsidence assessment carried out by SCT Operations Pty Ltd (SCT) in relation to the proposed future workings at Russell Vale Colliery. That previous review considered the Subsidence Assessment Report No. UMW4609, dated 10 July 2019, and V2 of the same report, dated 3 October 2019 prepared by SCT. The outcome of that review was reported in my Report No. 1907/01.2, dated 12 October 2019.

A further independent peer review has now been commissioned by Wollongong Coal, following a request from the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC). The IESC was requested by the NSW Department of Planning, Industry and Environment (DPIE) to offer advice on the Russell Vale Revised Underground Expansion Project submitted by Wollongong Coal, to inform their consideration of the proposal.

The IESC issued a notification on 19 November 2019 (Ref. IESC 2019-108) that stated, in relation to this current issue, that:

> *"an independent peer review be completed to ensure that pillar designs are conservative according to leading practices of mine design and that the implications for surface and hydrological systems are adequately considered. This independent review should be based on the most comprehensive local and international databases of pillar failure that are currently available".*

In a subsequent notification by IESC, Ref. IESC 2020-112, dated 5 March 2020, the IESC noted that advice had been provided to DPIE on 3 December 2019 in relation to the current revised mine plan, and further recommended that:

> *“a quantitative risk assessment of the risks of pillar failure be done and independently peer-reviewed by a recognised expert in multi-seam geomechanical stability. This recommendation was made to provide greater confidence in the proponent’s assertion that pillar failure was so unlikely that there was no need to collect baseline ecological data or monitor for potential impacts on overlying water-dependent assets…”.*

Subsequent to this 3 December 2019 request, Wollongong Coal commissioned SCT to undertake a further assessment of the risk of pillar failure associated with the proposed workings. This work was reported by SCT as Report No. WCRV5111, dated 14 January 2020, in a report titled: *“IESC2019-108: Quantitative Assessment of Risk of Pillar Failure in Russell Vale East Area”.*

The specific questions asked by the IESC in relation to this issue of pillar stability were noted in their Advice Note (Ref. IESC 2020-112), dated 5 March 2020, as follows:

Question 1: Does the quantitative assessment of risk of pillar failure satisfy the IESC that there is a “negligible risk” of pillar failure associated with the Project?

1. The advice provided by the IESC on 3 December 2019 to the Department of Planning, Industry and Environment recommended a quantitative assessment of the risk of pillar failure and that it should be independently reviewed by a recognised expert in multi-seam geomechanical stability. This review is yet to be done. The IESC recommends that the regulator make their decision, based on the results of this review once conducted.

2. This review should consider, but not be limited to, issues outlined below.

   a. Given the proposed project utilises non-conforming pillars, further information and justification is required of the proposed pillar design including pillar loading and the width to height ratio of 8 – 10.

   b. The quantitative assessment provided has highlighted that there is still uncertainty about future subsidence in the Bulli Seam goaf areas and that there remains a potential risk of additional subsidence in the Bulli Seam in seven of the 14 goaf areas whose status has not been confirmed by the proponent (SCT 2020, p. 14). Furthermore the exact locations of the seven goafs, where subsidence is possible, in relation to the Coastal Upland Swamps has not been clearly defined by the proponent; this information is critical to determine the risk from the potential subsidence.

2. SCOPE OF WORK

This current report provides the independent review of the risk of pillar failure in the proposed Wongawilli Seam workings, based on the assessment conducted by SCT and reported in their January 2020 Report, as referenced in Q1 above (points 1 and 2), from the IESC (5 March 2020).

2.1 Documentation Provided

The following documents were provided by Wollongong Coal Ltd for the purposes of conducting this peer review:

- SCT Report No. WCRV5111, dated 14 January 2020, titled: *"IESC2019-108: Quantitative Assessment of Risk of Pillar Failure in Russell Vale East Area"* prepared by Ken Mills.
- IESC 2019-108: Russell Vale Colliery Underground Expansion Project Advice, dated 19 November 2019.
- IESC 2020-112: Russell Vale Colliery Underground Expansion Project Advice, dated 5 March 2020.
- Wollongong Coal Ltd letter to DPIE, dated 14 January 2020, providing DPIE with copy of above SCT Report.

2.2 This Report

I offer the following comments on the above SCT risk of pillar failure report, on the basis of my relevant professional qualifications, experience and background (see Summary CV in Appendix A). My background relevant to this project includes association with a number of different coal mining projects across NSW and internationally – from various perspectives, including mine design and audit on behalf of coal companies; and consulting/review studies on behalf of government and agencies (e.g. NSW Dept of Planning, Dept of Primary Industry and Dams Safety Committee); an earlier such study being as Chair of the Independent Expert Panel of Review into *"Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield"* (jointly for the NSW Dept of Planning & Dept of Primary Industry, 2006-2008).

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

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

This report is structured in the form of some relevant background information; followed by specific comments provided on the SCT Report.

In relation to this report commentary, specific comments are provided in the order they appear in the report text, and not in any order of priority or importance (with the exception of comments on the Outcomes of the Assessment section (section 2 on page 1), which are provided at the end of this review report). Some review comments are quite minor in significance and are provided more in the form of an observational comment rather than a major criticism.

It should be noted that this review is focused on risk of pillar failure and related impacts which may include influence on groundwater parameters. However, detailed assessment of groundwater, swamps or related hydrogeological factors is outside of the scope for this report and is not included.

In line with the DPE Peer Review Guidelines, for the purposes of transparency, I declare that I have had previous associations with SCT as an organisation, and some members of their staff, as individuals, in the following manner:

- Participation in various joint/collaborative research and consulting projects, and subsequent jointly authored publications.
- Conduct of previous independent peer reviews of SCT reports for government authorities and other third parties.

3. COMMENTARY ON SCT REPORT

3.1 Preliminary Comments – Risk Assessment

Prior to offering specific review comment on the SCT January 2020 report, I would like to offer some more general comments on the principles of risk assessment, and how these should be applied when considering the risk of pillar failure.

The IESC is seeking an assessment of the risk of pillar failure, and in the IESC 2019-108 notification, has referenced the National Emergency Risk Assessment Guidelines (NERAG) published by the Australian Institute for Disaster Resilience in 2015. IESC states:

> *"If the likelihood of pillar failure is "extremely rare" (less than 0.01% per year, Australian 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 IESC subsequently uses the terms *"negligible risk"* scenario, where the likelihood of pillar failure is less than 0.01% per year; and a *"worst case"* scenario in which the likelihood of pillar failure is materially greater than 0.01% per year.

The terminology of requiring risk to be assessed as extremely rare, or negligible is considered appropriate, and there are valid and internationally acceptable quantitative means of making such an assessment. However, I do not consider it appropriate to apply a "disaster resilience" risk approach to the pillar failure scenario. Such an approach is used to assess the likelihood or expected frequency of <u>repeat</u> events, such as floods, bushfires, cyclones etc. Considering the risk on a yearly basis is obviously highly relevant when trying to determine the likelihood of such major disasters occurring on a repeating basis.

However, in the case under consideration, the risk is being assessed of the failure of a designed structure or system – in this case a mine plan containing panels of pillars and barriers. Failure of such a system does not occur on a repeating basis, but if it does occur, it only occurs once. Risk assessment of such a design should be based on assessing the likelihood or probability of such a one-off failure within the lifecycle or life expectancy of the pillar system, as designed. This can be done, as outlined below, with a probability of failure determined, and a number assigned accordingly.

For example, if a system of pillars is designed to be stable for the life of the mine (say 20 years), the assessment of the risk of failure might use a design figure of 1 in 10,000 as being a design failure likelihood (this is an illustrative number only, for the purposes of this explanation). A likelihood of 1 in 10,000 could also be expressed as 0.01%. This means there is a 1 in 10,000 (or 0.01%) likelihood of failure during the 20-year life of the pillar system. Whilst one could attempt to convert this to an annualised risk level, such a derivation is not particularly meaningful and is not recommended. (I would stress that these figures used here are illustrative only).

As quoted above, the IESC has requested that this independent review should be based on a comprehensive local and international database of pillar failures. In following such a request, the above recommended approach to risk of pillar failure, linked to such databases, should be adopted, rather than a disaster frequency methodology. Appropriate pillar databases and risk-based methodologies are discussed further, in context, within the report commentary below.

3.2 Specific Comments on SCT Report

1. P1, section 1 – SCT is correctly responding to the request of IESC, in quoting their scope of work as being to provide *"a quantitative assessment of the risk of pillar failure causing catastrophic loss of a single coastal upland swamp"*. I would question the appropriateness of such a scope, given that these are two quite distinctly different issues, and it is recommended that they would more appropriately be considered separately, rather than in the one assessment. The first is the risk of a pillar system failure, which can be quantitatively assessed. The second consequential assessment is whether such a pillar failure, even if it were to occur, would lead to catastrophic loss of a swamp, taking into account the likely mode of any such pillar system failure. This is a separate question that may be more difficult to assess, at least in the same quantitative sense. The wording in the scope almost implies that a pillar failure will automatically lead to such a catastrophic loss. Such an implication is challenged. Perhaps the scope should have been more correctly worded as *"… pillar failure that may lead to catastrophic loss.…"*.

2. On the basis of these comments, it is recommended that SCT considers carrying out and reporting these two assessments separately, or at least drawing out clearly differentiated discussion and outcomes, prior to reaching an overall conclusion covering the combined assessment. It is considered that information is provided in the SCT report addressing both issues, but it may be helpful to highlight them separately before presenting the final outcome.

3. P5, section 3.2 – SCT provides similar commentary to that offered in section 3.1 above, raising questions as to the suitability or relevance of using the NERAG disaster resilience style of annualised risk assessment. They have proceeded on the basis of using such a system of annualised risk, to comply with their instructions, but as noted above, this is not considered appropriate for consideration of the risk of failure of a system of mine pillars.

4. P7, section 3.2 - SCT has then identified a UK-based environmental risk assessment system (Gormley, 2011) that is considered to be more appropriate, and have subsequently made calculations based on this approach, which may be more relevant, especially when considering the risk of consequential swamp loss (as opposed to pillar failure). Alternative, more appropriate pillar failure risk assessment tools are discussed at a later point in the report.

5. P7, section 3.3 – SCT highlights three quite distinct scenarios that represent hazards associated with pillar failure. These are:

   (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.

6. These three categories of pillar failure hazard are valid and appropriate and were each discussed by SCT in their 2019 subsidence assessment. It is important that the current review considers both (1) and (3), and notes (2), but there needs to be acknowledgement that the scenario put forward in (2) is totally independent of any proposed mining in the Wongawilli Seam and as such, should not be considered as part of any current review of the Wollongong Coal proposal.

7. P7, section 3.3 – SCT now refers to the internationally recognised UNSW Pillar Design Procedure which was developed in the 1990s and has an extensive Australian pillar system database underpinning it; together with cross-referencing and close correlation with a far larger pillar database from South Africa. One of the quite unique features of the UNSW system is that it is a risk-based pillar failure prediction tool, assigning a quantitative likelihood for pillar failure

for a regular system of pillars (not single pillars in isolation), over the lifetime of the pillars (not an annualised risk figure). This likelihood figure is derived from a high-level statistical analysis of the underlying pillar database. Such a pillar database and risk-based failure prediction tool is considered to satisfy the criteria previously outlined by the IESC. (I need to declare an interest at this point, being one of the project research team that developed the UNSW Pillar Design Procedure, and a co-author of the relevant publication(s) cited by SCT).

8. At the foot of p7, it is stated that by using this procedure, the probability of failure for the proposed Wongawilli Seam pillars is less than 1 in 100,000. A more detailed analysis of these calculations is addressed later, but such a probability of failure could quite reasonably be considered to be extremely rare, posing negligible risk – using the wording of the IESC.

9. P8, section 3.3 – SCT rightly notes here that the geometry of the Bulli Seam pillars makes a quantitative analysis more difficult, but draws on evidence previously discussed that indicates that all of the Bulli Seam goaf areas have already subsided and have therefore reached a point of long-term stability, and do not pose a risk of further collapse leading to any further significant subsidence events, regardless of future mining in the Wongawilli Seam.

10. For completeness, it would be helpful to include a paragraph at this point regarding the Balgownie Seam pillars (these are discussed elsewhere but should be referenced here in a similar summary manner to the reference to Bulli Seam pillars).

11. P8, section 4.1 – This section again makes reference to the use of the UNSW system to assess the Wongawilli Seam pillars and quotes an outcome of pillar failure probability (or likelihood) being less than 1 in 100,000. This figure is discussed further when section 4.1.3 is reviewed.

    The discussion also refers to the ongoing deformational behaviour of such pillars (width:height (w/h) ratios of 8 and greater) which means that even under such further deformation of the pillars the risk of pillar instability is further reduced. A separate analysis of the pillars using the Gormley approach also concludes that the probability of a subsidence event caused by pillar failure is negligible.

12. Pp8-10, section 4.1.1 – This section discusses the likely deformational behaviour of a range of different w/h sized pillars under increasing loading conditions. This discussion was also included and reviewed as part of the 2019 subsidence assessment review. The principle that the "post-failure" load-deformation curves for increasing w/h ratio pillars tends to flatten out, and at a certain point could potentially increase the load-carrying capacity as deformation continues is accepted as valid and reasonable. Although it is noted that the specific behaviour of certain pillar systems and particular ratios may vary from this. What is clear and accepted is that these larger w/h ratio pillars are not likely to fail in any brittle or catastrophic manner, leading to any regional strata collapse – even when they reach a loading level equivalent to the theoretical strength calculated by methods such as the UNSW system. They may not necessarily continue to increase in load-carrying capacity, but they are unlikely to shed significant load, and therefore would demonstrate a quasi-stable form of ongoing deformation or yielding, while maintaining their load carrying ability.

    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).

13. Pp10-11, section 4.1.2 – This section discusses the range of loading conditions that may apply to Wongawilli Seam pillars, which may vary depending on whether they are under the protection of an overlying goaf, or exposed to abutments from overlying pillars in localised areas. SCT adopts a pillar system loading mechanism based on full cover load for a quantitative risk analysis, stating that localised variations will be smoothed out through the intervening interburden. This is considered to be a reasonable approach.

14. P11-12, section 4.1.3 – This section contains the more detailed quantitative analysis of pillar stability and risk of pillar failure for the different systems of pillars in the proposed Wongawilli Seam workings. The discussion here tends to move between both the 25m square pillars and the 30m square pillars, making it difficult to follow which pillar systems are being considered. It would be helpful to carry out this analysis separately for each different sized set of pillars. Further comment can be provided once greater clarity is provided on the various pillar systems and their locations on the mine plan.

    (In carrying out such an analysis, it is important to distinguish between pillar centreline dimensions (as these are understood to be) and actual pillar widths of solid coal, which for this system of mining would be one roadway width, or 5.5m narrower. Thus, the 25m pillars (centre to centre) are 19.5m solid pillars; and the 30m pillars (centre to centre) are 24.5m pillars).

15. P13 and following, section 4.2 – This section considers stability of pillars in the overlying seams, using historical records as a basis for assessment. There is no reason to question the evidence presented here, which relies on historical pillar records plus interpretation of subsidence monitoring data.

    In particular, the discussion regarding Bulli Seam workings refers to seven goaf areas where the data confirms that full subsidence has already occurred. However, a further seven areas remain subject to question as to their status and should be further investigated. It would be helpful if SCT provided plans showing specific locations for each of these fourteen goaf areas, and the seven, in particular, that are under some doubt, including the location of any swamps overlying them.

16. P15, section 4.2.2.1 – SCT is discussing the likelihood of sections of standing pillars within goaf areas in the Bulli Seam. It is stated that *"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".* This statement and conclusion is not unreasonable, although it is not possible to definitively rule out long-term, time dependent failure of some such pillars, particularly in smaller, more isolated regions within a goaf. The SCT conclusion is considered an extremely likely one, given the circumstances described. However, SCT goes on to note a small area of standing pillars that could pose a risk to overlying strata and surface features (no swamps involved), albeit a very localised effect, if it were to occur. Further discussion of this issue (on top of page 16) could benefit from greater clarification.

17. P16, section 4.2.2.3 – Discussion of the impact of longwall mining in the Balgownie Seam on pillars in the overlying Bulli Seam is considered valid and the conclusions reached as appropriate.

18. P16, section 4.2.2.4 – The discussion on the types of abutment loading beneath different forms of overlying mining conditions is reasonable, although could benefit from some additional explanation and greater clarity, regarding the conclusions that can be derived when encountering deteriorating Wongawilli Seam roadway conditions beneath Bulli Seam goaf edges.

19. P17, section 4.2.2.4 – The further discussion regarding confirmation of the status of seven of the Bulli Seam goaf areas is again discussed and would benefit from greater clarification of the abutment evidence that would be obtained and the interpretation of it.

3.3 Discussion of Section 2: Outcomes of the Assessment

1. As discussed in the previous section, it would be more helpful to make a clearer distinction between the risk of pillar failure, and the risk of consequential catastrophic loss of a swamp. SCT has claimed that the risk of a catastrophic loss of a swamp due to workings in the Wongawilli Seam is less than 1 in 10,000 years. The basis for this figure is not clear. Whilst a quantitative analysis can and has been applied to pillar failure; it is not as easy to apply to catastrophic loss of a swamp. This requires further justification, or greater clarity of explanation.

2. There is a need for confirmation of the status (and evidence of location, relative to swamp positions) of the Bulli Seam goaf areas.

3. Discussion of the interpretation of abutment loading evidence in Wongawilli roadways warrants further clarification.

4. The quantitative analysis of Wongawilli Seam pillars as having a probability of failure of less than 1 in 100,000 using the UNSW Pillar Design Procedure requires further analysis and clarification/explanation (see section 3.2, point 14 above).

5. It is noted that the formation of large pillars in the Wongawilli Seam is expected to result in much less than 100mm subsidence. This conclusion is reasonable. The implication for the health of swamps is a separate question for other experts to interpret, but the SCT understanding that such levels should not result in any swamp loss appears reasonable.

6. The conclusion that risk of further subsidence from future pillar instability in the Balgownie Seam assessed as very rare; and Bulli Seam assessed as unlikely, is considered reasonable, based on the available evidence.

7. The overall conclusion that the risk of catastrophic loss of any of the coastal upland swamps located over the proposed mining areas due to the proposed mining is assessed to be “very rare” is a reasonable conclusion – subject to satisfactory response to a number of points requiring greater clarity or explanation, as noted in this report.

Bruce Hebblewhite

APPENDIX A

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

In his current employment position with The University of New South Wales, Bruce Hebblewhite is involved in undergraduate and postgraduate teaching and research, and contract industry consulting and provision of industry training and ongoing professional development programs – for all sectors of the mining industry – coal and metalliferous.

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

Disclaimer

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

SUMMARY CURRICULUM VITAE

Bruce Kenneth Hebblewhite

(Professor, Chair of Mining Engineering),
School of Minerals & Energy Resources Engineering, The University of New South Wales, &

Consultant Mining Engineer

DATE OF BIRTH 1951

NATIONALITY Australian

QUALIFICATIONS
1973: Bachelor of Engineering (Mining) (Hons 1) School of Mining Engineering, Univ. of New South Wales

1977: Doctor of Philosophy, Department of Mining Engineering, University of Newcastle upon Tyne, UK
1991: Diploma AICD, University of New England

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

Expert Witness assisting Coroner: Coronial Inquest (2002-2003): 1999 Northparkes Mine Accident
Chair: 2007-2008 Independent Expert Panel of Review into Impact of Mining in the Southern Coalfield of NSW (Dept of Planning & Dept of Primary Industries)
Expert Witness assisting NSW Mines Safety Investigation Unit – Austar Mine double fatality, April, 2014.
Member (2012 – present): Scientific Advisory Board, Advanced Mining Technology Centre, Uni. of Chile.
Trustee (2013 – present): AusIMM Education Endowment Fund
2012 Syd S Peng Ground Control in Mining Award – by SME (USA).
2017 Ludwig Wilke Award for contribution to international mining research and education (Society of Mining Professors).
2017 SME Award for Rock Mechanics (presented at 2018 SME Annual Meeting in Minneapolis, USA in Feb 2018).
2020 AusIMM Institute Medal – for contributions to the mining industry and profession through education, research and training.

PROFESSIONAL EXPERIENCE

2014 – present	University of New South Wales, School of Minerals & Energy Resources Engineering (formerly School of Mining Engineering) Professor of Mining Engineering (p/t)
1995 - present	Principal Consultant - B K Hebblewhite Consulting

2003-2014	University of New South Wales, School of Mining Engineering Head of School and Research Director, (Professor, Kenneth Finlay Chair of Rock Mechanics (to 2006); Professor of Mining Engineering (from 2006))
2006 – 2009	Mining Education Australia (a national joint venture between UNSW, Curtin University of Technology, The University of Queensland & The University of Adelaide) Executive Director (a concurrent appointment with UNSW above).
1995-2002	University of New South Wales, School of Mining Engineering Professor, Kenneth Finlay Chair of Rock Mechanics and Research Director, UNSW Mining Research Centre (UMRC)
1983-1995	ACIRL Ltd, Divisional Manager, Mining - Overall management of ACIRL's mining activities. Responsible for technical and administrative management of ACIRL's Mining Division covering both research and consulting activities in all aspects of mining and coal preparation.
1981-1983	ACIRL Ltd, Manager, Mining - Responsibility for ACIRL mining research and commissioned contract programs.
1979-1981	ACIRL Ltd, Senior Mining Engineer - Assistant to Manager, Mining Research for administrative and technical responsibilities. Particularly, development of geotechnical activities in relation to mine design by underground, laboratory and numerical methods.
1977-1979	ACIRL Ltd, Mining Engineer Project Engineer for research into mining methods for Greta Seam, Ellalong Colliery, NSW. Also Project Engineer for roof control and numerical modelling stability investigations.
1974-1977	Cleveland Potash Ltd, Mining Engineer and Department of Mining Engineering, University of Newcastle-upon-Tyne, UK - Research Associate. Employed by Cleveland Potash Limited to conduct rock mechanics investigations into mine design for deep (1100m) potash mining, Boulby Mine, N Yorkshire (subject of Ph.D. thesis).

SPECIALIST SKILLS & INTERESTS

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

APPENDIX 3

Strata Control Technology

WOLLONGONG COAL: RUSSELL VALE

IESC 2019-108: Quantitative Assessment of Risk of Pillar Failure in Russell Vale East Area

WCRV5111_REV 4

Mining Research and Consulting Group

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Title IESC 2019-108: Quantitative Assessment of Risk of Pillar Failure in Russell Vale East Area

Report No WCRV5111_Rev 4

Prepared By Ken Mills

Date 12 June 2020

Ken Mills
Principal Geotechnical Engineer

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SUMMARY

Wollongong Coal Limited (WCL) plans to mine coal from the Wongawilli Seam at Russell Vale Colliery near Wollongong in NSW by forming large pillars in an area east of Cataract Reservoir known as Russell Vale East. 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 was 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 this specific risk. This report is an update of letter report (SCT 2020) peer reviewed by B.K. Hebblewhite Consulting (2020) to address points raised in the peer review and provide greater clarity.

Our assessment indicates the likelihood of "catastrophic loss of a single swamp" from proposed mining in the Wongawilli Seam is "extremely rare" (less than 0.01%) over greater than 95% of the proposed mining area using the National Emergency Risk Assessment Guidelines (NERAG). In the remaining area, the probability is estimated to be 0.028% or "very rare" until goaf areas in the Bulli Seam are confirmed as collapsed, as they are expected to be. It is anticipated that the status of the unconfirmed Bulli Seam goaf areas will be easily confirmed by visual observation of roadway conditions as goaf edges are mined under. Once confirmed as collapsed, there will be no further credible source of subsidence impact to upland swamps in the proposed mining area and the likelihood will revert to "extremely rare" across the entire area.

The pathway for "catastrophic loss of a single swamp" requires several independent processes to occur; pillar collapse in any one of the three seams, surface subsidence to result from such a collapse and catastrophic loss of a swamp to result from the subsidence. Our quantitative risk assessment indicates the probability of catastrophic loss of swamps (P) for the various pillar groups and mining horizons are:

1) Areas of 30m x 30m pillars in Wongawilli Seam: $P = 3\text{x}10^{-9}$
2) Areas of 25m x 25m pillars below Balgownie longwalls: $P = 4\text{x}10^{-9}$
3) Other areas of 25m x 25m pillars (2 easternmost panels): $P=1\text{x}10^{-7}$
4) Balgownie Seam pillar instability: P=0.00
5) Bulli Seam main heading pillars: P=0.00
6) Bulli Seam goaf areas
    a. if collapsed (7/14 confirmed): P=0.00
    b. unconfirmed and standing: $P=2.8\text{x}10^{-4}$ (existing risk)
7) Pockets of standing pillars: P= 0.00 (no swamps nearby).

The potential for further impact to water resources, including stored water, surface water and groundwater, is assessed as negligible.

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1. Introduction

Wollongong Coal Limited (WCL) plans to mine coal from the Wongawilli Seam at Russell Vale Colliery near Wollongong in NSW by forming large pillars in an area east of Cataract Reservoir known as Russell Vale East. 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 was 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 this specific risk. This report is an update of letter report (SCT 2020) peer reviewed by B.K. Hebblewhite Consulting (2020) to address points raised in the peer review and provide greater clarity.

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 assessment of each of the specific hazards considered
- an assessment of the magnitude of potential impact to water resources.

2. Summary of Assessment Outcomes

Our assessment indicates the likelihood of "catastrophic loss of a single swamp" from proposed mining in the Wongawilli Seam is "extremely rare" (less than 0.01%) over greater than 95% of the proposed mining area using the National Emergency Risk Assessment Guidelines (NERAG). In the remaining area, the probability is estimated to be 0.028% or "very rare" until goaf areas in the Bulli Seam are confirmed as collapsed, as they are expected to be. Once these areas are also confirmed as collapsed, the likelihood of further impact reverts to "extremely rare" across the entire area. Monitoring the condition of proposed first workings roadways under Bulli Seam goaf edges is recommended as a basis to confirm these Bulli Seam goaf areas are collapsed.

The potential for further impact to water resources, including stored water, surface water and groundwater, is assessed as negligible.

The pathway for "catastrophic loss of a single swamp" requires several independent processes to occur:

1) pillars to collapse in any one of the three seams mined in the Russell Vale East area
2) surface subsidence to result from such pillar collapse
3) catastrophic loss of a swamp to occur as a result of subsidence.

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.

Table 1 shows the three processes that would need to occur to lead to catastrophic loss of a swamp and the probability of these occurring.

Most of the swamps in the Russell Vale East area have been mined under previously by pillar extraction in the Bulli Seam causing subsidence up to 1m. Some of these swamps were also subsided by longwall mining in the Balgownie Seam in the early 1980s causing additional subsidence of 0.6-1.0m and some more recently by longwall mining in the Wongawilli Seam causing additional subsidence of up to 1.7m.

2.1 Pillar Stability and Subsidence Potential of Proposed Mining in the Wongawilli Seam

Two sizes of pillars are proposed to be formed in the Wongawilli Seam; square pillars formed at 30m by 30m centres (30m pillars) and square pillars formed at 25m by 25m centres (25m pillars). Areas of 30m pillars are located outside the footprint of Balgownie Seam longwall panels. Areas of 25m pillars are mainly located below Balgownie Seam longwall panels where vertical load is significantly reduced except for two panels at the eastern margin on the mining area.

A quantitative assessment using the UNSW pillar design approach (Galvin et al 1999), an internationally recognised approach, indicates the 30m pillars at 380m deep have a less than 1 in 100,000 (0.001%) probability of failure. On the scale used by the NERAG Guidelines for recurring events, a scale that IESC requested be used, this likelihood is “extremely rare”. The likelihood of pillar failure would be even less frequent than “extremely rare” given that pillar failure would not be a recurring event.

A quantitative assessment using the same approach indicates:

- a probability of failure of less than 1 in 100,000 for the 25m pillars located below extracted Balgownie Seam longwall panels where vertical load is reduced due to the overlying extraction
- a probability of failure of less than 1 in 1,000 on average for 25m pillars in the two panels on the eastern margin not located below extracted Balgownie Seam longwall panels.

Table 1: Hierarchy of Probabilities Leading to Swamp Impacts

Pillar Collapse Potential	Consequential Subsidence	Impact to Swamps
Wongawilli Seam		
30m x 30m UNSW 1 in 100,000 of "failure" Collapse not credible W/H=10	Less than 100mm and likely less than 30mm	No perceptible impact Probability of Catastrophic Loss of Swamp = $3x10^{-9}$
25m x 25m under goaf UNSW 1 in 100,000 of "failure" Collapse not credible W/H=8	Less than 100mm and likely less than 30mm	No perceptible impact Probability of Catastrophic Loss of Swamp = $4x10^{-9}$
25m x 25m in eastern panels UNSW 1 in 1,000 of "failure" Collapse not credible W/H=8	Less than 100mm and likely less than 30mm	No swamps directly over these panels Probability of Catastrophic Loss of Swamp = $1x10^{-7}$
Balgownie Seam		
Main Heading Pillars UNSW 1 in 100,000 Collapse not credible W/H=20	Subsidence of nominally 30mm has already occurred. No further subsidence expected because not mining under mains.	No perceptible impact P = 0.00[1]
Longwall Chain Pillars UNSW 1 in 100,000 Collapse not credible W/H=20	Subsidence of 0.6-1.0m in 1980s No further subsidence expected because mining under the goaf	No additional impact P = 0.00[1]
Bulli Seam		
Main Heading Pillars Collapse not credible W/H>8	Subsidence of nominally 30mm has already occurred. No further subsidence.	No additional impact P = 0.00[1]
Pillar Extraction Areas (Bulli Seam Goaf) Existing risk that is unlikely based on 7/14 areas confirmed as subsided.	Existing risk not changed by proposed mining. Subsidence up to 1m if not collapsed.	Subsidence of swamps by Bulli Seam mining has already occurred without apparent impact P= 0.00 in areas known to have collapsed P = 0.00028 in seven remaining areas
Pockets of Standing Pillars Existing risk of collapse	Limited areas too small to cause significant subsidence (max 500mm)	No swamps in areas of pockets so no risk to swamps P=0.00

[1] Assumes that swamps are not impacted by up to 100mm of subsidence.

2.2 Pillar Stability and Subsidence Potential of Existing Balgownie Seam Mine Geometry

The risk of further subsidence occurring below any swamps as a result of pillar instability in the Balgownie Seam is assessed as "extremely rare". Record tracings and mine plans for the Balgownie Seam indicate there are no areas in the Russell Vale East Area where Balgownie Seam pillars might be unstable. Pillars are either main heading pillars or chain pillars. The mining height is less than 1.5m. Proposed mining in the Wongawilli Seam is designed to avoid mining directly below Balgownie Seam chain pillars. There is no potential for proposed mining in the Wongawilli Seam to destabilise pillars in the Balgownie Seam. The main heading pillars are long term stable. The chain pillars are heavily loaded but supported on both sides by collapsed goaf.

2.3 Pillar Stability and Subsidence Assessment of Existing Bulli Seam Mining Geometry

The risk of further subsidence occurring below any swamps as a result of pillar instability in the Bulli Seam is assessed as "rare", but this risk exists irrespective of any further mining and is not changed significantly by the proposed mining. The risk of any swamps being impacted by such subsidence is discussed in Section 2.4 as being zero if the Bulli Seam goaf has collapsed and "very rare" until they are confirmed as collapsed.

Record tracings and mine plans for the Bulli Seam indicate there are three types of mining geometry: main heading pillars, large areas of pillar extraction and small pockets of standing pillars. The stability assessment requires a different approach for each area.

2.3.1 Bulli Seam Main Heading Pillars

The main heading pillars are surrounded by significant coal barriers and there is no potential for these to become destabilised by proposed mining in the Wongawilli Seam. There is no potential for further subsidence in areas above these main heading pillars.

2.3.2 Bulli Seam Goaf Areas

Figure 1 shows fourteen large areas of Bulli Seam pillar extraction, referred to as Bulli Seam goaf areas. There is evidence available from subsidence monitoring and observation of roadway conditions in the Wongawilli Seam to confirm seven of these areas have fully collapsed with no potential for further subsidence. The seven collapsed goaf areas are numbered in Figure 1 as 1-7.

It is almost certain that the other seven goaf areas (8-14) have also fully collapsed because the mining systems used in each are similar and the areas extracted are of similar size. Confirmation of collapse in all these areas would be reassuring for the sake of completeness. Proposed mining in the Wongawilli Seam would not change the potential for further subsidence from the Bulli Seam. This potential would exist irrespective of proposed mining. The benefit of knowing that all the Bulli Seam goaf areas have collapsed and fully subsided is that this risk could then be eliminated.

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. In the unlikely event that no abutment loading is observed, the significance of the existing risk to swamps from the historic mining could be assessed and appropriate monitoring installed.

2.3.3 Bulli Seam Standing Pillars

Records tracings and mine plans of the Bulli Seam show there are two pockets of small width to height ratio pillars located within or adjacent to main heading pillars. These are shown in Figure 1. One area of standing pillars was inspected from underground, the other is identified as standing from the mine plans but its status is not known following mining in the Balgownie Seam because the area is inaccessible.

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

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

2.4 Impacts to Swamps

The coastal upland swamps in the Russell Vale East area identified and recorded by Biosis (2013) are regarded as swamps of interest to this assessment. 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 the swamps subsided by previous mining suffered “catastrophic loss” despite experiencing estimated subsidence of up to 1m from the Bulli Seam, additional subsidence of up to 0.6-1.0m from mining in the Balgownie Seam in the early 1980s and further subsidence of up to 1.7m from recent longwall mining in the Wongawilli Seam.

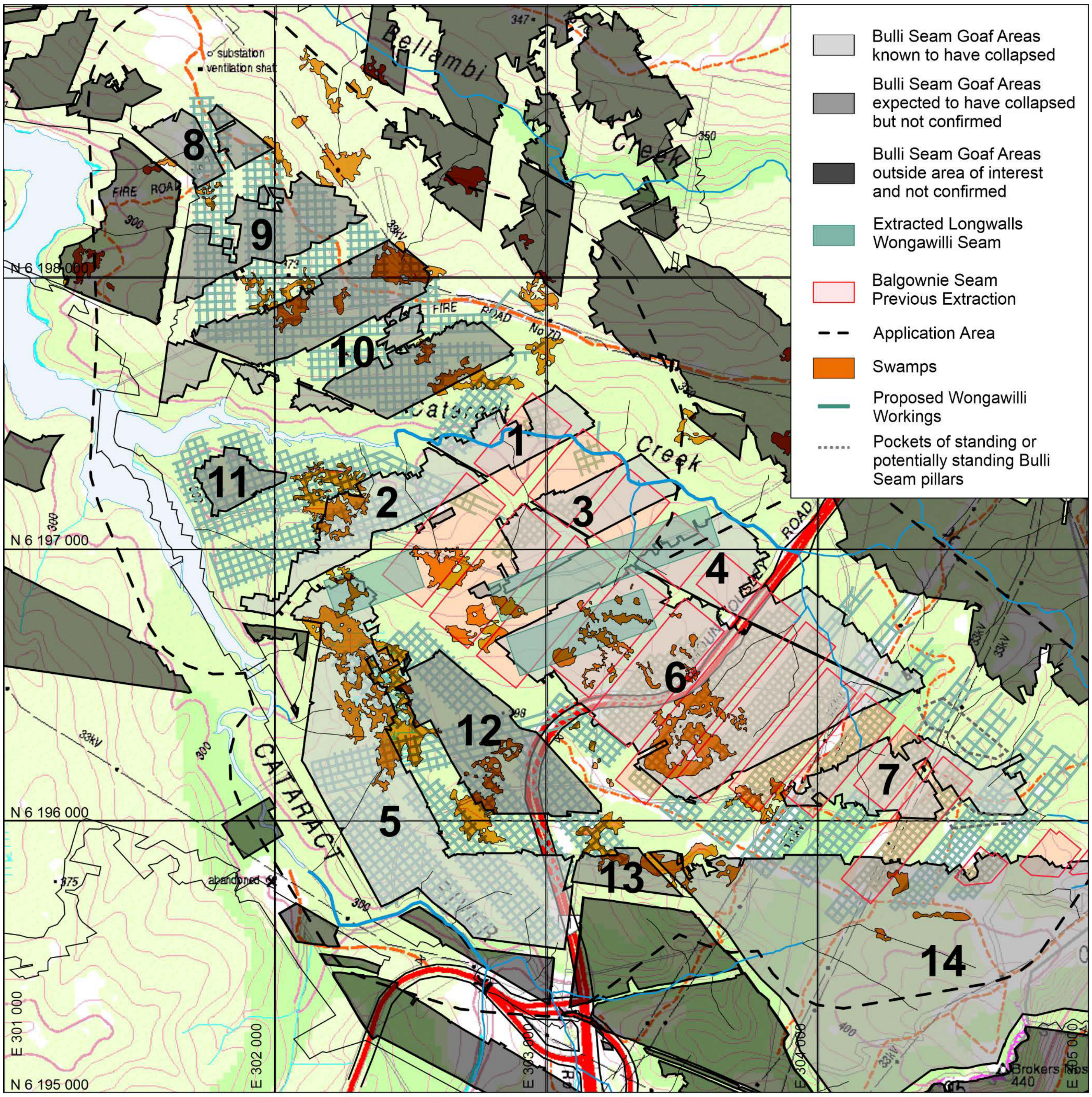

Figure 1: Plan showing location of swamps and proposed first workings in the Wongawilli Seam relative to previous secondary extraction in Bulli Seam (Grey), Balgownie Seam (Red) and Wongawilli Seam (Dark Green).

Based on this experience alone, 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 "extremely rare".

Table 1 summarises the probability of further subsidence of 100mm and most likely less than 30mm from proposed mining in the Wongawilli Seam causing catastrophic loss of any single swamp in this area. These probabilities are small and risk of catastrophic loss of a single swamp is assessed as "very rare".

2.5 Impacts to Water Resources

The potential for further subsidence to impact water resources is negligible if, as expected, there is no further significant subsidence. In the very unlikely event that any of the seven goaf areas in the Bulli Seam not previously subsided does subside – irrespective of any 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 Seam and pillar extraction in the Bulli Seam.

The increment of impact to water resources in the highly unlikely event that one of the Bulli Seam goaf areas is still standing and subsequently subsides is expected to be negligible given the impact of surrounding and adjacent goaf areas that are known to have collapsed.

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).

The locations of previous extraction in the Bulli, Balgownie and Wongawilli Seams are shown in Figure 1 together with the proposed first workings in the Wongawilli Seam. The Bulli Seam goaf areas are numbered. Those goaf areas confirmed by independent observations as collapsed and fully subsided, numbered 1-7, are shown in lighter shading. The goaf areas numbered 8-14 are those located in the area of interest that are expected to have collapsed but are not independently confirmed as such. The unnumbered goaf areas shaded a darker shade of grey are not confirmed as collapsed but are outside the area of interest. An outline of the coastal upland swamps identified by Biosis (2013) are also shown.

Figure 2 shows the locations of the coastal upland swamps numbered in accordance with the numbering system adopted by Biosis.

Figure 3 shows contours of the magnitude of the combined subsidence experienced to date from mining in all three seams.

Proposed mining is expected to cause maximum subsidence of 100mm and most likely less than 30mm. Most of the swamps have already experienced subsidence much greater than 100mm. From a practical perspective, proposed mining in the Wongawilli Seam is most unlikely to cause significant impact to any swamps.

3.2 Approach

The intent of the quantitative risk assessment is to determine the residual risk of impact to the swamps. The NERAG approach suggested by the ISEC 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.

Table 2 summarises the NERAG thresholds in the risk range of interest that have been used in this assessment.

Table 2: NERAG Likelihood Categories

<table>
<tr><td>Probability</td><td colspan="2">0.1%</td><td colspan="2">0.01%</td><td>0.001%</td></tr>
<tr><td>Average Recurrence</td><td colspan="2">1 in 1000</td><td colspan="2">1 in 10,000</td><td>1 in 100,000</td></tr>
<tr><td>Likelihood</td><td>Rare</td><td colspan="2">Very Rare</td><td colspan="2">Extremely Rare</td></tr>
</table>

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.

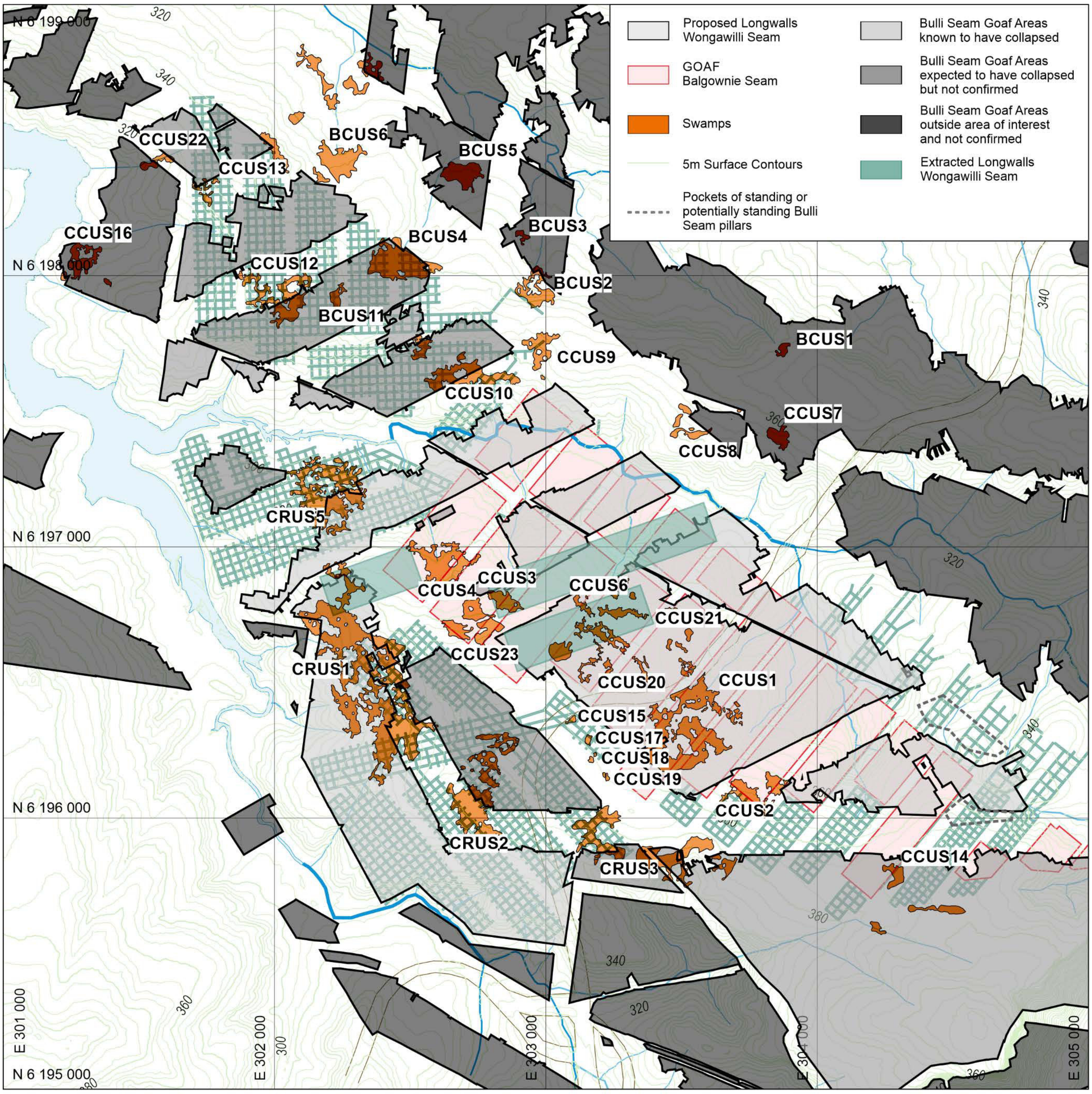

Figure 2: Location of Upland Swamps relative to historic and proposed mining.

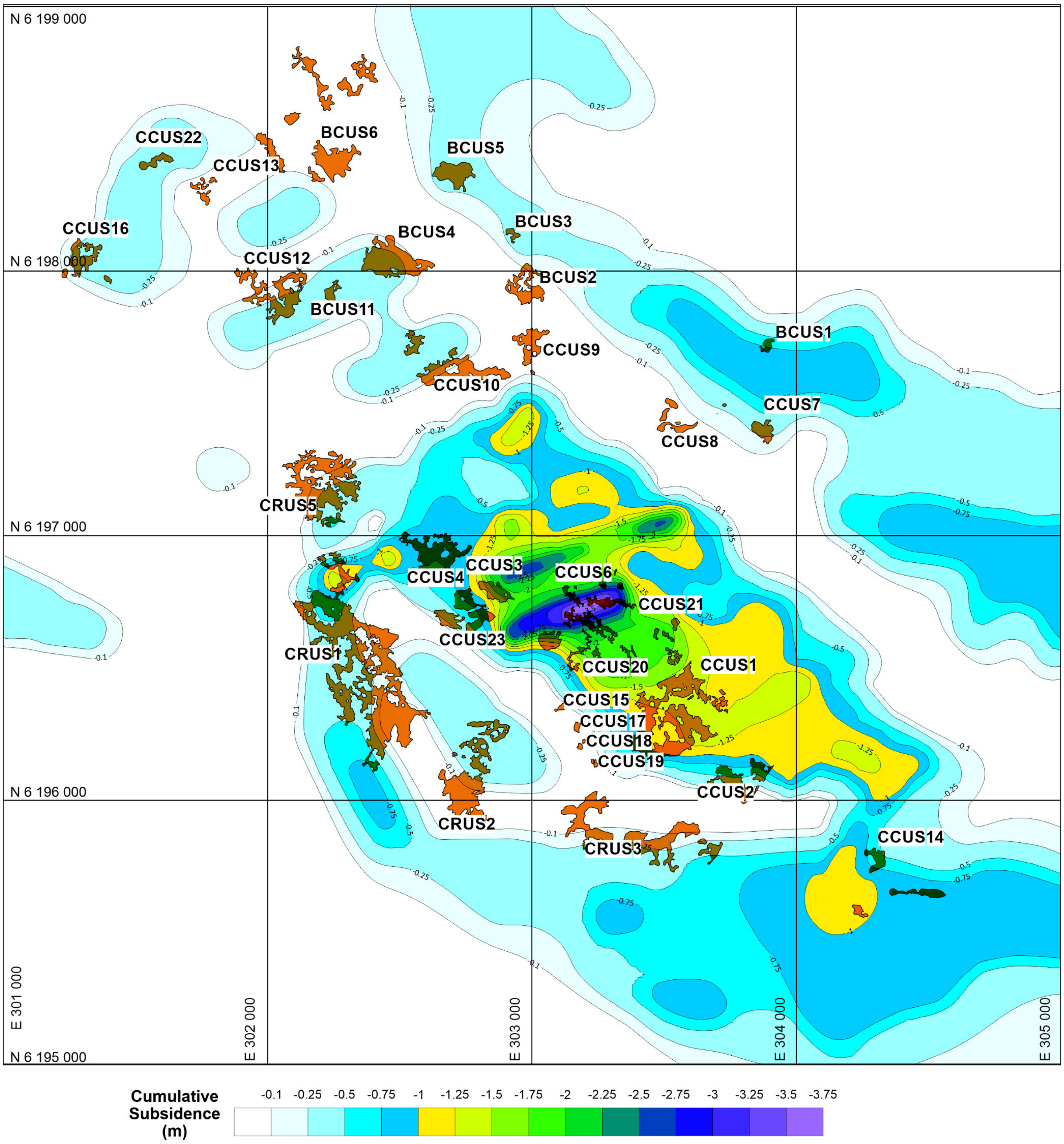

Figure 3: Cumulative subsidence for previous mining in all three seams.

Given the large width to height ratio of pillars proposed in the Wongawilli Seam, the only possible source of further subsidence is from Bulli Seam goaf areas located below upland swamps. These goaf areas are almost certainly already subsided, but only half of them can be independently confirmed as having subsided. The risk of any of the rest causing subsidence is a risk that exists irrespective of any proposed mining. It is anticipated that the status of the unconfirmed Bulli Seam goaf areas will be easily confirmed by visual observation of roadway conditions as goaf edges are mined under and in that case, there will be no further credible source of risk to upland swamps in the proposed mining area.

In the context of the swamps as Russell Vale East, a quantitative assessment that meaningfully characterises future subsidence risks is challenging. Most of the swamps have experienced significant subsidence in the past without apparent catastrophic loss. The imperceptibly low levels of subsidence expected from proposed mining is very small by comparison with subsidence already experienced. The approach outlined by Gormley et al. has been used to assess the risks as objectively as possible.

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%) for most of the pillars and 1 in 1,000 for two panels of

25m pillars on the eastern margin of the proposed mining area not located below swamps.

The geometry of the pillars in the Bulli Seam are not able to be defined with enough confidence for a robust quantitative assessment to be 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 Balgownie Seam pillars are well defined and large enough for there to be no potential for instability and subsidence.

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 Wongawilli Seam 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 terminology relating to pillar behaviour and pillar design formulae are examined.

Two sizes of pillars are proposed to be formed in the Wongawilli Seam; square pillars formed at 30m by 30m centres (30m pillars) and square pillars formed at 25m by 25m centres (25m pillars). Areas of 30m pillars are located outside the footprint of Balgownie Seam longwall panels. Areas of 25m pillars are mainly located below Balgownie Seam longwall panels where vertical load is significantly reduced. Two eastern panels of 25m pillars at the eastern margin on the mining area are located outside the footprint of overlying Balgownie Seam goaf.

The stability of each of these areas are considered separately.

4.1.1 Deformation Characteristics of Coal Pillars

The strength and deformation characteristics of coal pillars are described in this section.

Coal pillars derive their strength from two independent sources: cohesion and friction (Mills 2019).

- 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. The cohesive strength of coal is variable and can be characterised using a probability based approach.

- Frictional strength can be thought of as the strength that is derived from confinement. 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 shear strength characteristics of the roof and floor strata that enable confinement to be generated.

Figure 4 shows the pillar stress/strain relationship for pillars with width to height ratios from 1 to 10 (Gale and Mills 1994, Mills 2019). 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 monitoring field studies reported in detail in Gale and Mills (1994) indicate that large Wongawilli Seam pillars develop frictional strength consistent with the roof and floor conditions being able to support the confinement developed.

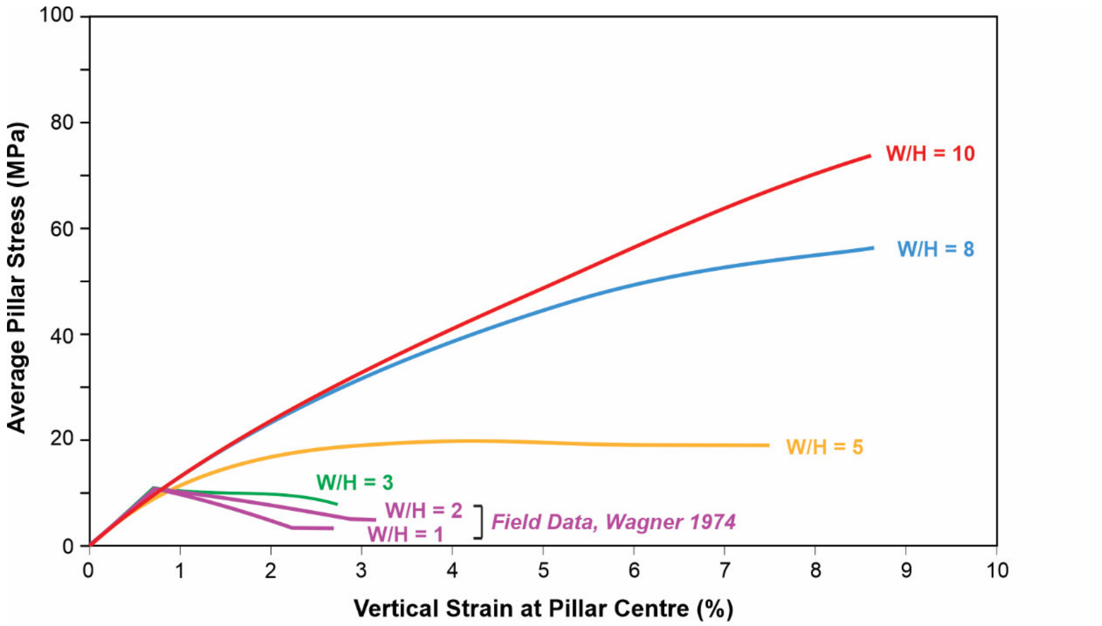

Figure 4: Pillar load/deformation characteristics for varying width/height ratios.

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. The strength of small pillars is clearly apparent as the point at which cohesive strength is lost and collapse occurs.

Given that the strength of small pillars varies with the variability of cohesive strength, designing stable pillars involves limiting the applied load to less than an estimated strength with sufficient margin to accommodate any variability. A probabilistic approach such as the UNSW approach provides an effective strategy for estimating pillar strength based on field experience of collapsed and stable pillars and using this experience to provide a statistically quantifiable margin against the potential for pillar collapse.

The UNSW approach has also been found to be effective for designing pillars with larger width to height ratios, but for slightly different reasons. For large width to height ratio pillars the outcomes of exceeding a nominal failure load are not as catastrophic as they are for small width to height ratio pillars. As large pillars are loaded, they continue to gain load bearing capacity at the expense of deteriorating conditions in the adjacent roadways. The concept of "failure" is more relevant to the condition of adjacent roadways rather than the concept of pillar collapse. This difference is significant in the context of subsidence control.

Large 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. When large pillars become heavily loaded, the roadways around the pillar progress towards becoming unserviceable

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

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. 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 characteristics (as shown in Figure 4) allow load to be redistributed to other adjacent pillars without any loss of loading bearing capacity.

Pillar loading based on maximum depth of overburden is considered appropriate to use for a quantitative assessment of pillar stability. Local variation in loading at the level of the Wongawilli Seam occurs over a distance that is much less than the overburden depth. Overburden depth in the proposed mining area ranges 250-380m. Any local variations in pillar deformation due to the variable loading conditions is effectively averaged out.

4.1.3 Wongawilli Seam Pillar Stability Assessment

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

Average loading on the 30m pillars at the maximum 380m overburden depth is estimated to be 14MPa. The ratio of nominal pillar strength to average load is 2.09. The probability of failure indicated by the UNSW pillar design approach is less than 1 in 100,000. The potential for “failure” of these pillars is assessed as “extremely rare” on the NERAG scale.

Average loading on the 25m pillars located below Balgownie Seam goaf is estimated from consideration of the goaf loading geometry to range up to a maximum of 6.3MPa, equivalent to an overburden depth of 250m. The ratio of nominal pillar strength to average load is 2.11 and the probability of failure indicated by the UNSW pillar design approach is less than 1 in 100,000. The potential for “failure” of these pillars is assessed as “extremely rare” on the NERAG scale.

The maximum overburden depth above the two panels of 25m pillars located outside the Balgownie Seam goaf footprint at the eastern margin of the proposed mining area is 320m. The estimated average load on these pillars is 13MPa. The ratio of nominal pillar strength to average load is 1.65 and the probability of failure indicated by the UNSW pillar design approach is approximately 1 in 1,000. The potential for “failure” of these pillars is assessed as borderline between “rare” and “very rare” on the NERAG scale.

Allowing for abutment loads from Bulli Seam goafs adjacent to the main heading pillars, the most heavily loaded 25m pillars in the Wongawilli Seam are still not as heavily loaded as their nominal strength. These more heavily loaded pillars are surrounded by similar sized pillars carrying less load and capable of sharing any surplus load.

Recognising the load bearing characteristics of large width to height ratio pillars such as the 25m and 30m pillars proposed and the narrowness of each pillar panel relative to overburden depth, there is no potential for mining these pillars to cause surface subsidence of more than a few tens of millimetres.

None of the 25m or 30m pillars proposed are loaded to more than their nominal strength. They continue to develop load carrying capacity as they are loaded so collapse is not possible and significant subsidence is also not possible. Both the 25m and 30m pillar geometries proposed are therefore expected to remain stable over the long term.

A further protection against subsidence is provided by the narrow panel widths. These are the order of 1/3 overburden depth. For panels of this width, maximum surface subsidence is expected to be evenly distributed and limited to less than about 0.1 times the effective mining height at seam level. Assuming that 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 140mm. Allowing for bulking of coal material as it fails, maximum subsidence would be less than 100mm and likely less than 30mm.

4.1.4 Swamp Impact Assessment from Wongawilli Seam Pillars

The probability of a subsidence event caused by failure of Wongawilli Seam pillars causing catastrophic loss of a swamp can be quantitatively estimated using the Gormley et al (2011) approach.

4.1.4.1 Swamps above 30m Pillars

The probability of pillar failure for the 30m pillars is estimated to be 1 in 100,000 using the UNSW pillar design approach. Failure of one of these pillars is estimated to cause subsidence at the surface of less than 100mm. The area of swamps located above areas of proposed 30m pillars is approximately 0.8km^2 of a total 2.3km^2. The area of the swamps themselves is a much less than 0.8km^2 but the area used for impact assessment purposes includes a 50m zone around each swamp to be conservative. The probability of a swamp being catastrophically impacted by subsidence of 100mm is difficult to estimate. An assumption of 1 in 100 is used for the calculation. This proportion is considered conservative given no swamps are known to have been catastrophically impacted by mining subsidence less than 100mm.

The probability of catastrophic loss of a swamp above the 30m pillars at Russell Vale East is estimated to be:

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

$$= 0.000001 \times 0.8/2.3 \times 0.01$$

$$= 3\times10^{-9}\ (0.0000003\%)$$

Where the $P_{\text{initiating event}}$ is based on the UNSW pillar design approach, P_{exposure} is based on the area of swamps above the 30m pillars divided by the total areas of 30m pillars, and $P_{\text{receptor affected}}$ assumes that one swamp in 100 suffers catastrophic loss if subsided by 100mm.

4.1.4.2 Swamps above 25m Pillars Within Balgownie Seam Footprint

The probability of pillar failure for the 25m pillars located below the Balgownie Seam longwall footprint is estimated as 1 in 100,000 using the UNSW pillar design approach. Failure of one of these pillars is estimated as likely to cause surface subsidence of less than 100mm. The area of swamps located above areas of proposed 25m pillars is approximately 0.7km^2 of a total 1.5km^2. The area of the swamps themselves is a much less than 0.7km^2 but the area used for impact assessment purposes includes a 50m zone around each swamp to be conservative. The probability of a swamp being catastrophically impacted by subsidence of 100mm 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. An assumption of 1 in 100 is used for the calculation. This proportion is considered very conservative given none of the swamps are known to have been catastrophically impacted by previous mining subsidence of 1m or more.

The probability of catastrophic loss of a swamp above the 25m pillars located below Balgownie Seam longwalls at Russell Vale East is estimated to be:

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

$$= 0.000001 \times 0.7/1.5 \times 0.01$$

$$= 4\times10^{-9}\ (0.0000004\%)$$

Where the $P_{initiating\ event}$ is based on the UNSW pillar design approach, $P_{exposure}$ is based on the area of swamps above the 25m pillars divided by the total area of 25m pillars, and $P_{receptor\ affected}$ assumes that one swamp in 100 suffers catastrophic loss if subsided by 100mm.

4.1.4.3 Swamps above 25m Pillars Outside Balgownie Seam Footprint

The probability of pillar failure for the 25m pillars located below the Balgownie Seam longwall footprint is estimated as 1 in 1,000 using the UNSW pillar design approach. Failure of one of these pillars is estimated as likely to cause surface subsidence of less than 100mm. There are no swamps located above areas of proposed 25m pillars outside Balgownie Seam longwall panels, but there are two small areas located nearby. The area of swamps exposed to subsidence of 100mm is estimated to be 1% of the total area of the two panels. An assumption of 1 in 100 is used to estimate the number of swamps impacted by subsidence of 100mm.

The probability of catastrophic loss of a swamp above the 25m pillars located outside of Balgownie Seam longwalls at Russell Vale East is estimated to be:

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

$$= 0.001 \times 0.01 \times 0.01$$

$$= 1\times10^{-7}\ (0.00001\%)$$

Where the $P_{initiating\ event}$ is based on the UNSW pillar design approach, $P_{exposure}$ is based on the area of swamps near the 25m pillar panels outside the Balgownie Seam longwall footprint, and $P_{receptor\ affected}$ assumes that one swamp in 100 suffers catastrophic loss if subsided by 100mm.

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 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 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 5 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
- pockets of pillars individually defined.

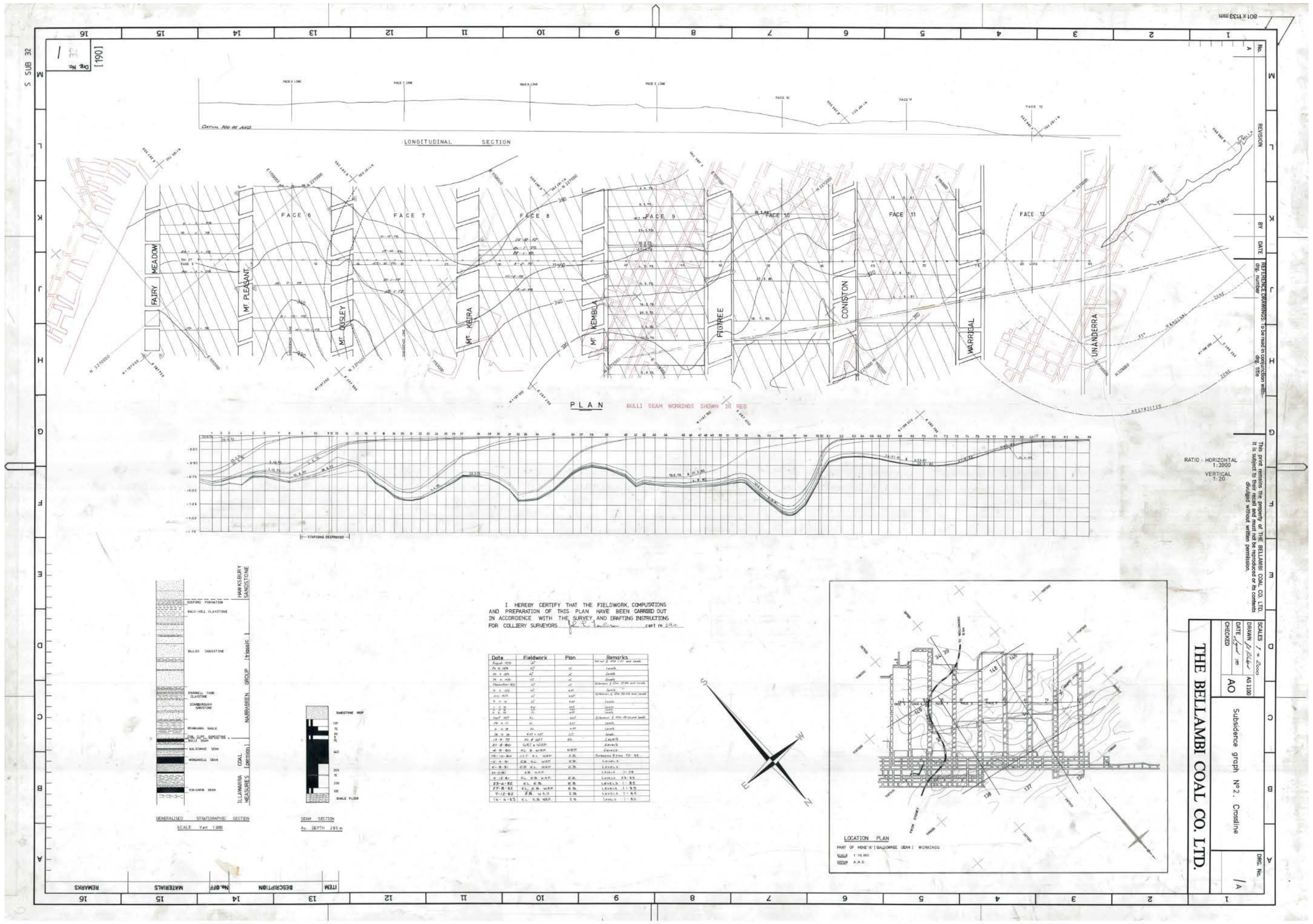

Figure 5: Example of subsidence monitoring of Balgownie Seam longwall panels.

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, numbered 1 to 7 in Figure 1, have already fully subsided and therefore pose no further hazard. It is also likely that the other seven goaf areas, number 8-14 in Figure 1, 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 as shown in Figure 1. 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 as subsidence that has already occurred below 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.

One of the areas shown as a pocket of standing pillars in Figure 1 is 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 narrowness of the 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 peaks at 2-3 times the pre-mining vertical stress near the goaf edge and tapers back to this level over a distance equal to about half overburden depth. 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. Deteriorating roadway conditions below Bulli Seam goaf edges indicates the presence of a collapsed goaf.

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 adjacent to the goaf edge. The implication of these observed abutment loads is that the Bulli Seam goaf area has already collapsed and fully subsided.

There are seven goaf areas in the Bulli Seam that cannot currently be confirmed as subsided. These are numbered in Figure 1 as 8-14. There is a strong likelihood that these areas collapsed as they were mined because the same mining systems were used in these areas as in similar areas that are known to have collapsed.

Bulli Seam goaf areas where subsidence is currently unconfirmed could be confirmed as collapsed and subsided by observing the roadway conditions as the goaf edges are mined under in the Wongawilli Seam. The sharp rise in vertical stress that occurs at a goaf edge in an overlying seam has been evident whenever roadways in the Wongawilli Seam have mined under such a goaf edge. 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 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 could be 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 where abutment loads are present.

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:

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

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

or

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

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

4.3.2 Exposure to Event

Figures 1 and 2 show 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.

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 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 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 from destabilisation of Bulli Seam pillars is assessed as being "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.

6. References

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SCT 2019b. "Russell Vale Colliery: 2018 Update of Water Balance Estimation" SCT Report WCRV4929 to Wollongong Coal dated 4 April 2019.

SCT 2020 "IESC 2019-108: Quantitative Assessment of Risk of Pillar Failure in Russell Vale East Area" Letter report WCRV5111 to Ron Bush dated 14 January 2020.

APPENDIX 4

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15 June 2020

Report No. 2003/03.5
Peer Review – Russell Vale Colliery Assessment of Risk of Pillar Failure
Supplementary Summary Report

Attn: Mr Ron Bush, Group Environment and Approvals Manager

Introduction

Wollongong Coal was provided with my original peer review report, No. 2003/03.3, dated 7 April 2020. That original peer review considered the Report No. WCRV5111, dated 14 January 2020, titled: *"IESC2019-108: Quantitative Assessment of Risk of Pillar Failure in Russell Vale East Area"*, prepared by SCT Operations Pty Ltd.

It is understood that my review report was forwarded to SCT for their consideration. Subsequently, SCT has produced the latest updated version of their report, WCRV5111, Rev. 4, dated 12 June 2020. This report has been updated in the light of comments contained in my original peer review and others.

The purpose of this Supplementary Report (No. 2003/03.5) is to provide a summary of the SCT responses to my original review, which should be read in conjunction with this supplementary, summary report.

Risk Assessment Background

Prior to addressing the specific commentary contained in my original report, I will repeat section 3.1 from my original report, which sets out some context to what I consider to be an appropriate means of addressing the risk of pillar failure. The inclusion of these background comments is not a criticism of SCT, but rather a proposition for an alternative approach to that prescribed by the Scope assigned to SCT. All of my commentary and review is based on adopting this proposed approach to pillar failure risk assessment – hence the point of repeating it here, for emphasis and clarity:

> *"Prior to offering specific review comment on the SCT January 2020 report, I would like to offer some more general comments on the principles of risk assessment, and how these should be applied when considering the risk of pillar failure.*
>
> *The IESC is seeking an assessment of the risk of pillar failure, and in the IESC 2019-108 notification, has referenced the National Emergency Risk Assessment Guidelines (NERAG) published by the Australian Institute for Disaster Resilience in 2015. IESC states:*
>
> > *"If the likelihood of pillar failure is "extremely rare" (less than 0.01% per year, Australian 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 IESC subsequently uses the terms "negligible risk" scenario, where the likelihood of pillar failure is less than 0.01% per year; and a "worst case" scenario in which the likelihood of pillar failure is materially greater than 0.01% per year.*
>
> *The terminology of requiring risk to be assessed as extremely rare, or negligible is considered appropriate, and there are valid and internationally acceptable quantitative means of making such an assessment. However, I do not consider it appropriate to apply a "disaster resilience" risk approach to the pillar failure scenario. Such an approach is used to assess the likelihood or expected frequency of <u>repeat</u> events, such as floods, bushfires, cyclones etc. Considering the risk on a yearly basis is obviously highly relevant when trying to determine the likelihood of such major disasters occurring on a repeating basis.*
>
> *However, in the case under consideration, the risk is being assessed of the failure of a designed structure or system – in this case a mine plan containing panels of pillars and barriers. Failure of such a system does not occur on a repeating basis, but if it does occur, it only occurs once. Risk assessment of such a design should be based on assessing the likelihood or probability of such a one-off failure within the lifecycle or life expectancy of the pillar system, as designed. This can be done, as outlined below, with a probability of failure determined, and a number assigned accordingly.*
>
> *For example, if a system of pillars is designed to be stable for the life of the mine (say 20 years), the assessment of the risk of failure might use a design figure of 1 in 10,000 as being a design failure likelihood (this is an illustrative number only, for the purposes of this explanation). A likelihood of 1 in 10,000 could also be expressed as 0.01%. This means there is a 1 in 10,000 (or 0.01%) likelihood of failure during the 20-year life of the pillar system. Whilst one could attempt to convert this to an annualised risk level, such a derivation is not particularly meaningful and is not recommended. (I would stress that these figures used here are illustrative only).*
>
> *As quoted above, the IESC has requested that this independent review should be based on a comprehensive local and international database of pillar failures. In following such a request, the above recommended approach to risk of pillar failure, linked to such databases, should be adopted, rather than a disaster frequency methodology. Appropriate pillar databases and risk-based methodologies are discussed further, in context, within the report commentary below".*

Summary Comments

These comments refer to and adopt the comment numbering system used by me in the original peer review report (see section 3.2 and 3.3 of my Report No. 2003/03.3).

Section 3.2

1. SCT Scope – See above background comments. Further to this, SCT has now clearly indicated the combined impacts that would be required for there to be a catastrophic loss of an upland swamp. It is very clearly pointed out that there would need to be a combination of:
   - A region of pillar failure.
   - An excessive level of surface subsidence resulting from such a pillar failure.
   - An adverse impact on the swamp due to the excessive subsidence event.

   The SCT Report is primarily focused on the first two of these factors, and this review is specifically tasked with considering the first factor.

2. See response to comment 1 above.

3. See previous commentary in original report, and above background, regarding the preferred and more appropriate means of assessing pillar failure risk – which has been adopted by SCT.

4. See 3 above.

5. For noting – especially emphasising that scenario (2) is independent of any future mining proposal and is an existing risk factor.

6. See 5 above.

7. Re recommended use of the UNSW Pillar Design Procedure for an appropriate quantitative means of assessing risk of pillar system failure.

8. It is noted here that a UNSW-determined probability of failure of less than 1 in 100,000 is considered to be at least consistent with the IESC use of the terminology of "extremely rare" or "negligible risk".

9. Bulli Seam pillars – this was adequately dealt with previously, subject to further comment below, regarding Bulli Seam goaf areas.

10. Balgownie Seam pillars – addressed later in the SCT report, confirming there are no areas of concern with regard to Balgownie Seam pillars standing beneath overlying swamp areas.

11. Reference to quantitative pillar failure risk assessment – this is discussed in more detail and clarity in SCT section 4 and is addressed under comment 14, below.

12. Post-failure pillar performance for large width:height ratio pillars – noted. Same commentary as previously provided (refer to SCT section 4.1.1).

13. Wongawilli Seam pillar loading – Section 4.1.2 notes that maximum overburden depth is reasonable to use for pillar loading and stability assessment – as stated previously. However, this is varied in the subsequent analysis – see 14 below.

14. Wongawilli pillar system stability assessment (SCT Section 4.1.3) – This section provides the main quantitative analysis of the risk of failure of the proposed Wongawilli pillar systems. It provides greater clarity than previously reported, in distinguishing between the different pillar systems under consideration. As noted previously, it is important to appreciate that where SCT

is referring to 30m and 25m square pillars, these are centre-to-centre pillar dimensions. The actual solid pillar widths are 24.5m and 19.5m respectively, as previously noted.

Analysis of the 30m pillars using the UNSW system reveals a pillar strength of 30 MPa; average pillar loading for full cover depth of 14 MPa, resulting in a Factor of Safety of 2.09 and a probability of failure of well below 1 in 100,000 (actually closer to 1 in 1,000,000). (Figures subject to minor, insignificant rounding errors).

The 25m pillar systems are then considered in two separate analyses. For the 25m pillar panels that are located entirely beneath the overlying Balgownie Seam longwall panel goaf areas, the pillar loading has been calculated on the basis of a reduced cover load, equivalent to a depth of 250m, which under pre-mining conditions represents a vertical stress of 6.2 MPa. Regardless of the statement made by SCT in section 4.1.2 concerning use of maximum overburden depth for pillar loading and stability assessment, which is at odds with the calculations now reported, this reduced figure is considered to be more appropriate for the pillar panels beneath these known longwall goaf areas where there would be an undoubted level of stress reduction.

Analysis of the 25m pillars in the panels beneath the goaf areas using the UNSW system reveals a pillar strength of 22 MPa; average pillar loading for a reduced cover depth of 10 MPa, resulting in a Factor of Safety of 2.14 and a probability of failure of well below 1 in 100,000 (actually closer to 1 in 1,000,000).

The second set of 25m pillar panels relates to two isolated panels at the eastern end of the mining area which do not fall under the protection of Balgownie Seam goaf areas. Full overburden cover load of 320m is used for their analysis.

Analysis of these two outlier panels of 25m pillars using the UNSW system reveals a pillar strength of 22 MPa; average pillar loading for full cover depth of 13 MPa, resulting in a Factor of Safety of 1.67 and a probability of failure of approximately 1 in 2,000.

Apart from minor rounding differences in the calculations, the SCT calculations now presented are reasonable and accurately reflect the application of the UNSW Pillar Design Procedure, leading to predictions of probability of failure, within the indefinite life of the pillar systems, of well below the 1 in 100,000 threshold, being very rare, or negligent, using the IESC (NERAG) terminology. The only exception to this level of negligible risk relates to two eastern panels of 25m pillars, where the risk of failure is slightly greater, at 1 in 2,000, or “rare” or “unlikely” as interpreted by SCT. It is understood that there are no swamps located above these two panel locations.

The remainder of the discussion on pillar stability assessment presented by SCT is considered valid and appropriate.

15. to 19. These remaining comments addressed the issue of stability of pillars in the overlying seams, and the condition of 14 Bulli Seam goaf areas. SCT has now provided far greater clarity with regard to the goaf areas, providing a numbered plan (Figure 1) showing all of the goaf locations relative to both mining panels and surface swamps. The seven goaf areas where there remains some uncertainty about their condition are noted as goaf numbers 8 to 14. SCT asserts that it is likely that these goaf areas have also fully subsided, as have 1 to 7, but further confirmation of this status is needed – to be established by mining conditions whilst undermining.

Section 3.3 (Overall Summary Outcomes – SCT Section 2)

1. The SCT report now makes a much clearer distinction between pillar system failure; major subsidence event; and subsequent swamp impact. Given that these factors all must coincide to result in the catastrophic loss of a swamp due to pillar failure, and hence their probabilities are compounded, then since the stability of the Wongawilli Seam pillar systems located beneath the swamps has been determined to be less than 1 in 100,000 (and in fact, much closer to 1 in 1,000,000), then the risk of such pillar system failure combined with a subsequent major subsidence event and catastrophic swamp impact is considered to be extremely rare/negligible.

2. Bulli Seam goaf areas (relative to swamp locations) is now clearly provided.

3. It is noted that the risk of Bulli Seam pillar failures impacting on surface swamps does exist, albeit considered rare, independent of any proposed future mining. However, it is noted that the proposed Wongawilli Seam mining is unlikely to change this risk – a position that is accepted.

4. The Wongawilli Seam pillar system failure analysis has now been provided, using an internationally recognised pillar stability assessment database (UNSW PDP) and has concluded that the risks of Wongawilli Seam pillar failure beneath swamp areas is extremely rare/negligible. There are two pillar panels towards the eastern edge of the lease that constitute a slightly higher risk, but it is understood that there are no swamps overlying these panels. It is considered unlikely, even if a pillar failure were to occur on these two outlier panel areas, that it would result in any significant subsidence impact, as a result of the relatively large width:height ratios of the pillars which would result in considerable post-failure strength and overburden support.

5. to 7. The previous comments remain valid and reflect an acceptable position taken by SCT.

Overall Conclusion

I am satisfied that the updated WCRV5111 Rev. 4 SCT Report has adequately responded to my substantive comments from the original peer review and that the conclusions reached are therefore considered appropriate and valid, based on the information available.

Bruce Hebblewhite