Strata Control Technology

WOLLONGONG COAL LTD

Russell Vale Colliery: Subsidence Assessment for PC07-08 and PC21-25 Extraction Plan

WCRV5285

SCT Operations Pty Ltd PO Box 824 Wollongong NSW 2520 Australia
Phone: +61 2 4222 2777 Email: sctnsw@sct.gs Website: www.sct.gs
ABN 23 078 328 953

REPORT TO	Richard Sheehan Environmental and Approvals Manager Wollongong Coal Limited Russell Vale Colliery 7 Princes Highway CORRIMAL NSW 2518
TITLE	Russell Vale Colliery: Subsidence Assessment for PC07-08 and PC21-25 Extraction Plan
REPORT NO	WCRV5285_Rev3
PREPARED BY	Stephen Wilson Ken Mills
DATE	23 June 2021

Ken Mills
Principal Geotechnical Engineer

Report No	Version	Date
WCRV5285	Draft	9 April 2021
WCRV5285	1	30 April 2021
WCRV5285	2	2 June 2021
WCRV5285	3	23 June 2021

SUMMARY

Wollongong Coal Limited (WCL) owns the Russell Vale Colliery located approximately 9km north-northwest of Wollongong in the Southern Coalfield of New South Wales. WCL is preparing an Extraction Plan for bord and pillar mining in the Wongawilli Seam as required by development consent MP09_0013 for the Russell Vale Revised Preferred Underground Expansion Project. WCL commissioned SCT Operations Pty Ltd to forecast the likely subsidence effects, assess impacts from the planned mining, and prepare a subsidence assessment report to support the Extraction Plan application, specifically Condition C10(e) and part of Condition C10(f) of MP09_0013. This report presents the results of our assessment for the planned PC07-08 and PC21-25 bord and pillar panels and first workings required to access/service these panels and sub-panels.

Our assessment indicates vertical subsidence associated with the planned bord and pillar mining geometry is expected to be less than 100mm and generally imperceptible. Vertical subsidence of greater than 500mm is considered possible, but most unlikely, in isolated areas above Bulli Seam goaf areas not yet confirmed as collapsed and subsided. The potential for this additional subsidence exists irrespective of planned mining. These estimates are consistent with previous assessments (SCT 2019) and peer reviews (Hebblewhite 2020).

Impacts and consequences to natural, surface, and sub-surface features are expected to be negligible and imperceptible in the undeveloped bushland setting over most of the subject areas considered in this Extraction Plan subsidence assessment.

Impacts to Mount Ousley Road are expected to be minor and manageable with appropriate management plans and risk control measures in place following consultation and agreement with the asset owner. No perceptible subsidence effects or impacts are expected at the electricity transmission lines which are located well outside the area of mining planned and assessed in this report. Additional risk to public safety is expected to be negligible.

Notwithstanding the input of other specialists, impacts and consequences are expected to be compliant with the subsidence impact performance measures in the MP09_0013 conditions of consent.

Potential impacts from subsidence movements are not expected to constitute a principal hazard as defined by the *Work Health and Safety (Mines and Petroleum Sites) Regulation 2014* with the required management plans and other risk control measures to manage risks to the health and safety of workers and other persons from subsidence.

A subsidence monitoring program as required by MP09_0013, relevant guidelines and legislated standards and management measures that are appropriate for the planned mining method and subsidence expectations is recommended.

TABLE OF CONTENTS

PAGE NO

SUMMARY I

TABLE OF CONTENTS II

1. INTRODUCTION 1
2. CONCLUSIONS AND RECOMMENDATIONS 4
   - 2.1 Review of Subsidence Forecast Since Consent for RPUEP 4
   - 2.2 Subsidence Impact Performance Measures 5
   - 2.3 Performance Indicators 5
   - 2.4 Recommendations 5
3. SITE DESCRIPTION 6
   - 3.1 Site Overview 6
   - 3.2 Extraction Plan Assessment Areas 8
   - 3.3 Approvals Context 8
   - 3.4 Land Ownership and Land Use 9
   - 3.5 Mining Geometry 9
     - 3.5.1 Previous Mining 9
     - 3.5.2 Planned Mining 10
   - 3.6 Surface Features and Surface Infrastructure 12
     - 3.6.1 Natural Features 14
     - 3.6.2 Man-Made or Built Features 14
4. FORECAST SUBSIDENCE BEHAVIOUR 15
   - 4.1 Review of Previous Subsidence at RVE 15
     - 4.1.1 Vertical Subsidence 15
     - 4.1.2 Tilt and Strain 17
   - 4.2 Forecast of Subsidence Effects 19
     - 4.2.1 Vertical Subsidence 19
     - 4.2.2 Tilt and Strain 21
     - 4.2.3 Horizontal Movements 21
     - 4.2.4 Unconventional Subsidence Effects 22
     - 4.2.5 Risk of Pillar Instability 22
   - 4.3 Reliability and Accuracy of Subsidence Forecasts 28
   - 4.4 Comparisons with Previous Subsidence Forecasts and Consent Subsidence Performance Measures 29
     - 4.4.1 Basis for EP Subsidence Assessment 29
     - 4.4.2 Changes to Subsidence Parameters Since RPUEP Subsidence Assessment 30
     - 4.4.3 Recommendation for Performance Indicators 30

5. SUBSIDENCE IMPACT ASSESSMENT 31
5.1 Natural Features 31
5.1.1 Upland Swamps 31
5.1.2 Watercourses 32
5.1.3 Sandstone Formations 32
5.1.4 Surface Landform 33
5.1.5 Groundwater 34
5.2 Heritage Sites 34
5.3 Built Features and Infrastructure 35
5.3.1 Mount Ousley Road 35
5.3.2 Electricity Transmission Lines 36
5.3.3 Cataract Storage Reservoir 37
5.3.4 Access Road/Four-Wheel Drive Tracks 38
5.3.5 Survey Control Stations 38
5.4 Public Safety 39
6. SUBSIDENCE MONITORING 39
7. REFERENCES 42
APPENDIX 1 – THE EP/SMP APPLICATION GUIDELINES LIST OF SURFACE FEATURES TO BE CONSIDERED IN A SUBSIDENCE ASSESSMENT 45
APPENDIX 2 – SUBSIDENCE IMPACT PERFORMANCE MEASURES 48
APPENDIX 3 – RELIABILITY OF MINE PLAN RECORDS FOR RUSSELL VALE EAST 51
A3.1 Introduction 53
A3.2 Conclusions 54
A3.3 Mining Layouts and Method 55
A3.4 History of Surveying for and Drafting of Mine Plans in NSW 56
A3.4.1 Plan Area Overlap 59
A3.4.2 Record Tracings 59
A3.5 Correlation of Bulli Seam and Balgownie Seam Records 60
A3.6 Subsidence Monitoring for the Balgownie Seam Longwalls 61
A3.6.1 Multi-Seam Subsidence at Ashton Underground 62
A3.6.2 Multi-Seam Subsidence from the Balgownie Seam 64
A3.7 Other Investigations and Observations 68
A3.7.1 Boreholes 68
A3.7.2 Inspections 70
A3.7.3 Underground Mapping and Stress Observations 71
A3.8 Predicted and Actual Subsidence for Wongawilli Seam Longwalls 71

1. INTRODUCTION

Wollongong Coal Limited (WCL) owns the Russell Vale Colliery (RVC) located approximately 9km north-northwest of Wollongong in the Southern Coalfield of NSW. In accordance with development consent for the Russell Vale Revised Preferred Underground Expansion Project (RPUEP) MP09_0013, WCL is preparing an Extraction Plan (EP) for bord and pillar mining of the Wongawilli Seam in the multi-seam Russell Vale East (RVE) area of RVC. WCL commissioned SCT Operations Pty Ltd (SCT) to forecast the likely subsidence effects and assess impacts from the planned mining and prepare a subsidence assessment report to support the EP application. This report has been prepared to meet the requirements of Condition C10(e) and part of Condition C10(f) of MP09_0013 and provides revised predictions of potential subsidence effects and subsidence impacts for the planned PC07-08 and PC21-25 bord and pillar panels and first workings required to access/service these panels and sub-panels.

The report is structured to provide:

- Conclusions and recommendations including:
    - a review of subsidence forecasts since consent for RPUEP
    - assessment of expected compliance with subsidence impact performance measures in the MP09_0013 consent conditions
    - a review of performance indicators
    - recommendations for subsidence monitoring and subsidence management.
- A brief overview of the site, including a general description of significant surface features within the EP assessment areas (EP Areas) including those identified during the risk assessment undertaken for this EP application.
- Estimates of the subsidence effects expected within the EP Areas as a result of the planned mining including a review of previous subsidence experience at RVE.
- A description of the subsidence impacts expected to the various surface and sub-surface features and surface infrastructure located across the EP Areas resulting from the forecast subsidence movements for the planned mining.

Figure 1 shows a site plan of the existing and planned mining in the Wongawilli Seam and the EP Areas superimposed onto a 1:25,000 topographic map of the area. Secondary extraction areas of the overlying Balgownie and Bulli Seams are also shown. The subsidence assessment presented in this document is based on this plan. Variations to this plan would require reassessment of the subsidence potential.

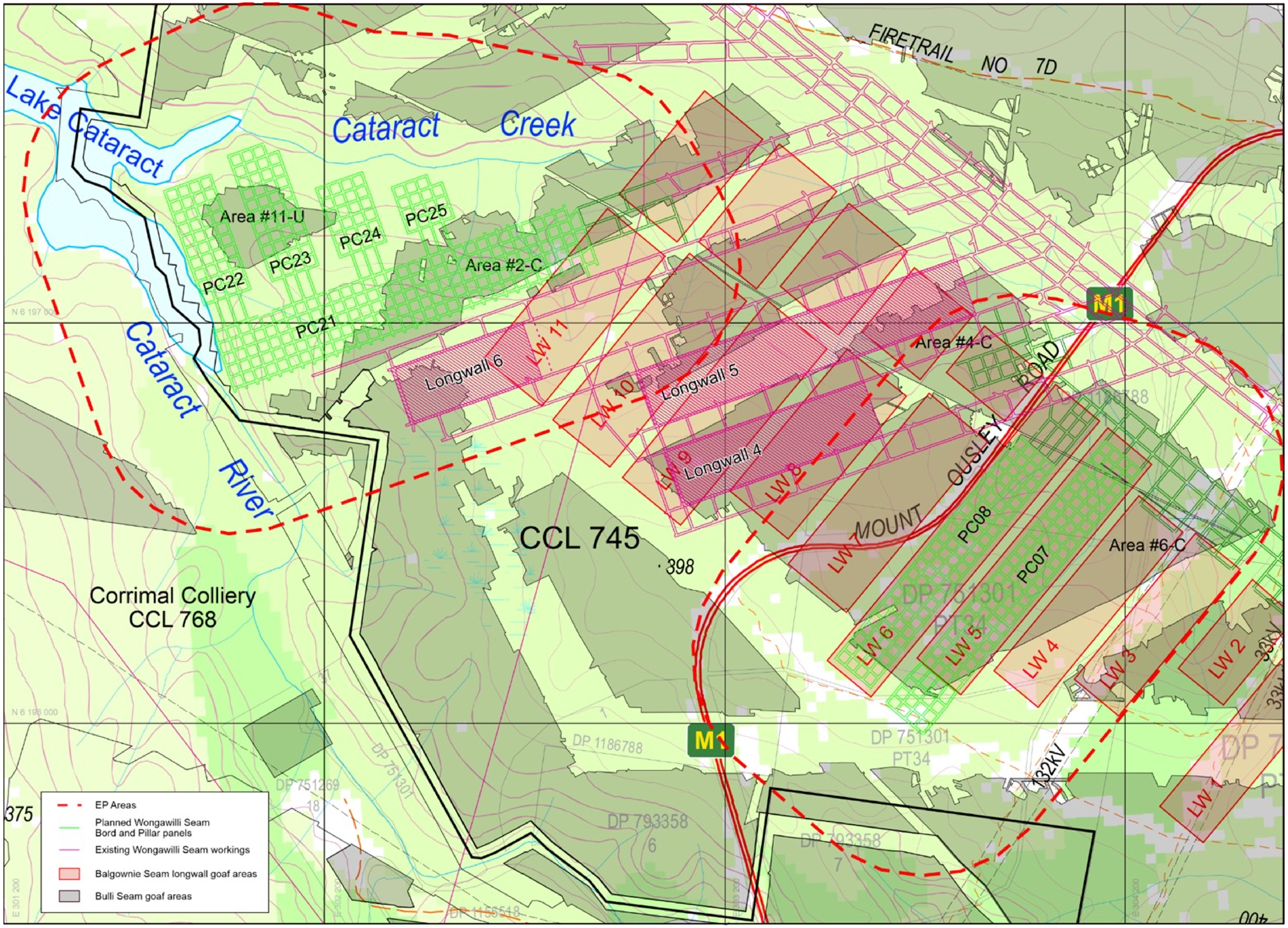


Figure 1: Site plan superimposed on 1:25,000 topographic map.

WCL is also planning to extract the remaining 25m of the approved panel length in Longwall 6 to recover the longwall face equipment. It is assumed that this mining will be undertaken in accordance with the previously approved EP for this panel. This matter is outside the scope of this report and as such, not discussed further.

This subsidence assessment includes considerations of a risk assessment conducted on 10 March 2021 for the planned mining, the “Guideline for Applications for Subsidence Management Approvals” and “Guidelines for the Preparation of Extraction Plans”.

The subsidence effects and impacts to surface features are assessed as required for an EP, but also in the context of the requirements under the *Work Health and Safety (Mines and Petroleum Sites) Regulation 2014* to manage risks to health and safety associated with subsidence. The information presented is intended to assist in:

- Determination of whether subsidence is or is not a principal hazard.
- Informing risk assessments and the development of control measures to manage or control risks to health and safety.
- Managing risks to health and safety associated with mining induced seismic activity.
- Improving co-operation and co-ordination of action, with respect to subsidence, between the mine operator and relevant persons conducting any business or undertaking that is, or is likely to be, affected by subsidence.
- Detailing the site characteristics, including relevant mining geometries, geological, hydrogeological or geotechnical conditions and potential impacts on relevant surface and sub-surface features to develop control measures to manage the risks from subsidence.
- Providing information about the land above or in the vicinity of the proposed mining that may be affected by subsidence.
- Managing the risks to the health and safety of workers and other persons from subsidence.

SCT has conducted research and investigations for the preparation of this EP additional since the RPUEP development consent was approved. This research has focused on the reliability of the Bulli Seam mine plan records and status of the goaf areas not yet confirmed as collapsed and includes additional information. The details of this research are presented in Appendix 3. The research and review of available data confirms the interpretation and assumptions made by SCT in previous assessments.

2. CONCLUSIONS AND RECOMMENDATIONS

Estimates of subsidence effects, primarily vertical subsidence, for the planned bord and pillar mining in this EP are consistent with previous assessments (SCT 2019) and peer reviews (Hebblewhite 2020).

Vertical subsidence is expected to be less than 100mm and generally imperceptible within the EP Areas. The IAPUM (2020) suggests allowance for subsidence of up to 300mm to cover possible reactivation of goafs in both the Bulli and Balgownie Seams. Vertical subsidence of greater than 500mm is considered possible, but most unlikely. If such subsidence were to occur, it would be expected in small, isolated areas within and near the edges of Bulli Seam goaf areas where remnant pillars not already collapsed may become unstable. This potential for additional subsidence greater than 100mm exists irrespective of planned bord and pillar mining in the Wongawilli Seam.

Subsidence impacts and environmental consequences from the planned bord and pillar mining are consistent with the subsidence impact performance measures in the MP09_0013 conditions of consent. The impacts and environmental consequences are expected to be negligible in the undeveloped bushland setting that exists over most of the EP Areas.

Impacts from planned bord and pillar mining to natural, surface, and sub-surface features are expected to be negligible. Impacts to the two upland swamps (CCUS1and CCUS5) above the planned mining are expected to be negligible.

Impacts to built features and infrastructure are expected to be minor and manageable with appropriate management plans and risk control measures in place. These management plans and risk control measures need to be developed in consultation and with the agreement of the asset owners and relevant stakeholders through risk assessments. Impacts to Mount Ousley Road are expected to be minor and manageable, consistent with previous experience. No perceptible subsidence effects or impacts are expected at the electricity transmission towers. These structures are located on the far side of substantial main heading pillars remote from proposed mining.

Additional risk to public safety is expected to be negligible.

Potential impacts from subsidence movements are not expected to constitute a principal hazard as defined by the *Work Health and Safety (Mines and Petroleum Sites) Regulation 2014* with the required management plans and other risk control measures to manage risks to the health and safety of workers and other persons from subsidence.

2.1 Review of Subsidence Forecast Since Consent for RPUEP

The EP process provides an opportunity to update subsidence forecasts and assessment of impacts based on additional information and understanding gained since consent was granted. The subsidence forecasts and assessment of impacts for the EP Areas assessed in this report has not changed from those provided to the IPC for final determination of the RPUEP. Subsidence effects forecasts are consistent with previous assessments (SCT 2019) and other peer or expert reviews.

Impacts are expected to be negligible or minor and manageable consistent with the previous assessment for the planned bord and pillar mining geometry.

2.2 Subsidence Impact Performance Measures

Our assessment indicates that impacts from the planned bord and pillar mining, with the required management plans and associated risk control measures in place, are expected to be compliant with the subsidence impact performance measures detailed in Table 6 and Table 7 of MP09_0013.

Table 6 requires negligible or no impacts, consequences, and other changes to natural and heritage features. Table 7 requires infrastructure and built features to remain safe and serviceable and if damaged, repaired or compensated for with negligible additional risk to public safety. Appendix 2 summarises the subsidence impact performance measures of the development consent conditions for MP09_0013.

The performance measure for mine workings to remain long-term stable and 'non-subsiding' is taken to apply to the planned first and second workings as the performance measure for vertical subsidence is a limit of not more than 300mm for all areas of the site affected by the development.

2.3 Performance Indicators

Conditions of MP09_0013 require detailed performance indicators for each of the subsidence impacts performance measures in Tables 6 and 7 to be included in relevant management plans. Most of the categories of subsidence impacts performance measures that require performance indicators are outside SCT's areas of expertise and so need to be set by other specialists given the forecast subsidence.

Performance indicators for subsidence effects can be set. We recommend performances indicators for multi-seam mining are set at greater than 20% above forecast values. With this margin, it is envisaged that natural variability will not trigger unnecessary reporting procedures for events of no practical consequence. For a non-caving mining method where the forecast vertical subsidence levels are low and an upper limit of 300mm has been set by experts in this field (IAPUM 2020) as a performance measure for swamps, values of 100mm and 250mm are considered appropriate to activate trigger action response plans (TARP) for the planned mining geometry in this EP. Similarly, 100mm additional closure from all mining in the Wongawilli Seam, including from Longwalls 4-6, is considered appropriate as a lower valley closure trigger with an upper level of 150mm following confirmation of the current measurement of valley closure from the final survey for Longwall 6.

2.4 Recommendations

We recommend subsidence monitoring for the planned bord and pillar mining shown in Figure 1 includes:

- A shift from previous conventional monitoring of subsidence lines to selected, continuous, high accuracy (GNSS) ground-based point measurements supported by broader scale, remote monitoring such as LiDAR.

- Retention of the existing conventional surveying techniques for the monitoring of Mount Ousley Road and closure across Cataract Creek.
- Monitoring of the electricity transmission lines.
- Underground geotechnical mapping as an indicator for the status of the overlying Bulli Seam goaf areas and the potential for additional subsidence.

Full details of recommendations for a subsidence monitoring program are presented in Section 6.

The management plans required by an EP under Condition C10 of MP09_0013 are expected to be suitable to manage the potential risks and impacts from subsidence effects expected for the planned bord and pillar mining shown in Figure 1.

Further recommendations for subsidence monitoring, the application of performance indicators, and for risk control measures to mitigate or remediate potential subsidence impacts are made throughout this report. These are presented in the context of each relevant management plan.

3. SITE DESCRIPTION

This section presents a description of the surface features within the EP Areas for PC07-08 and PC21-25 as well as other items of relevance to this subsidence assessment.

3.1 Site Overview

The surface within the EP Areas for PC07-08 and PC21-25 is located below the ridgeline between Cataract River and Cataract Creek valleys within the catchment for the Cataract Reservoir. The surface is mainly undeveloped bushland. Natural features include a section of the Cataract Reservoir within the Full Supply Level (FSL), watercourses including Cataract River, Cataract Creek and tributaries, upland swamps and sandstone outcrop formations. Major built features include the Mount Ousley Road (M1 Princes Motorway) and high voltage electricity transmission lines to the east of Mount Ousley Road.

The mine workings of RVC (previously known as South Bulli and NRE No1 Colliery) in the Bulli, Balgownie and Wongawilli Seams and sections of Bulli Seam workings at the adjacent Corrimal Colliery exist within the EP Areas. The Bulli Seam workings of South Bulli and Corrimal Collieries are separated by a 40m wide barrier of coal along the boundary of the mining leases.

Figure 2 shows the existing and planned workings in the Wongawilli Seam superimposed onto an aerial photograph with vegetation, watercourses, and land ownership details.

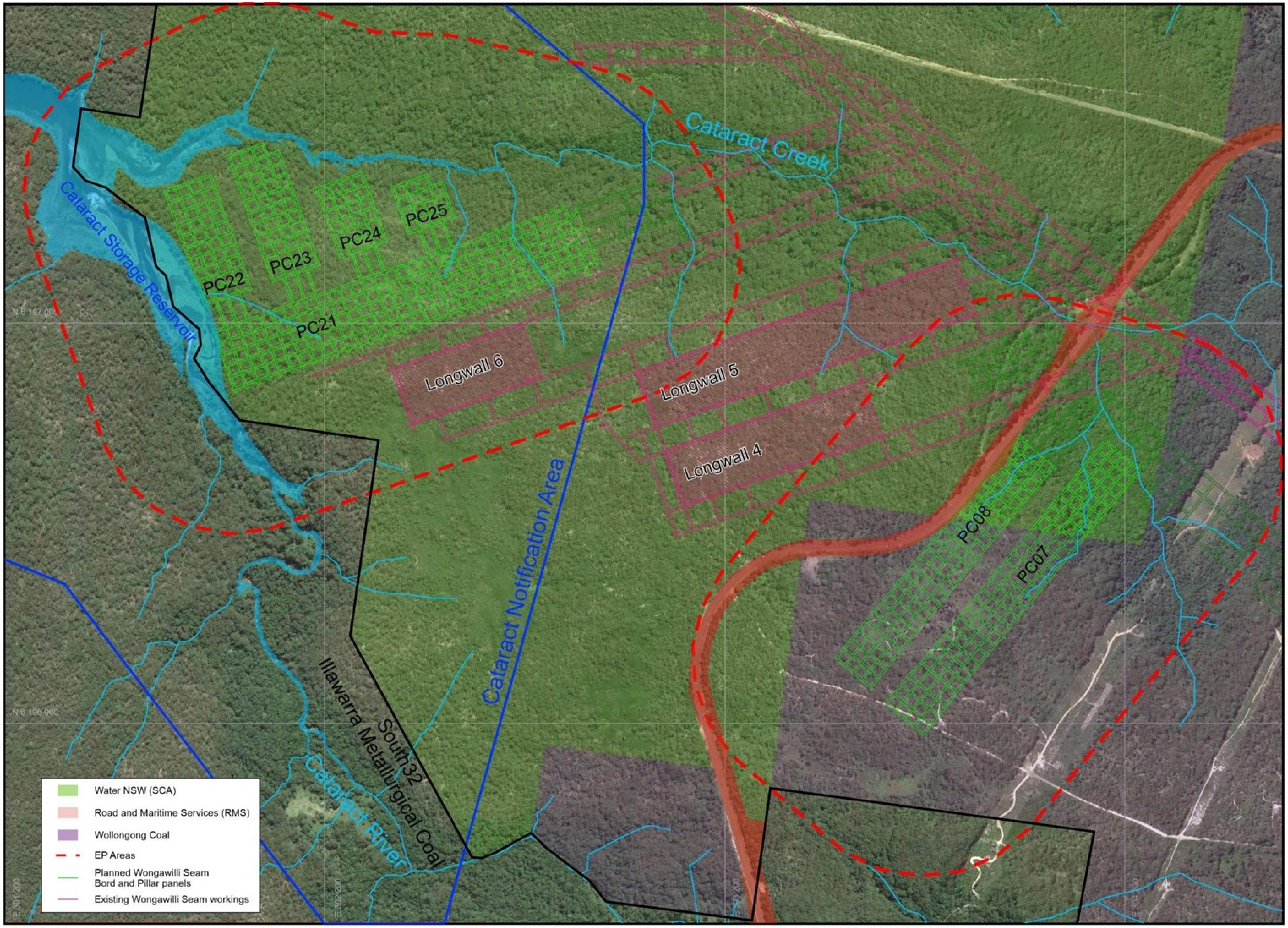


Figure 2: Site plan showing land ownership.

3.2 Extraction Plan Assessment Areas

The EP Areas for PC07-08 and PC21-25 shown in Figure 1 are considered conservative zones where all impacts from the planned mining would be expected to occur and are focus of the assessment of potential subsidence impacts.

The EP Areas are determined based on a distance of 350m, which is equal to or greater than the overburden depth to the Wongawilli Seam (equivalent to a 45° angle of draw), around the planned bord and pillar workings rather than the 35° angle of draw traditionally used for subsidence management plan application areas. The size of the EP Areas also includes consideration of coal barriers remaining in the Bulli Seam workings and incorporates the first workings required to access/service these panels and sub-panels. In this situation, EP Areas of this size are considered a conservative option for the identification of surface features and assessment of impacts to these features. Any subsidence related movements beyond the boundary of the EP Areas are expected to be imperceptible and generally insignificant for all practical purposes.

3.3 Approvals Context

The planned mining within the EP Areas for PC07-08 and PC21-25 is wholly within Consolidated Coal Lease 745 (CCL745).

WCL was granted development consent MP09_0013 under of the Environmental Planning and Assessment Act 1979 (EP&A Act) for the Russell Vale Revised Preferred Underground Expansion Project (RPUEP) by the Independent Planning Commission (IPC) of NSW in December 2020. Condition C10, Part 3 of MP09_0013, requires WCL to prepare an EP for all second workings to the satisfaction of the Secretary of the Department of Planning, Industry and Environment (DPIE).

Second workings are defined as the workings in the bord and pillar panels. These workings are intended to be a non-caving and non-subsiding mining method. The conventional industry definition for second workings involves secondary extraction of first workings or other areas of the coal seam where caving of the immediate seam roof and overburden strata, with the potential for subsidence of the surface, may be intentional.

As part of the EP requirements, the EP must:

- "Provide revised predictions of the potential subsidence effects, subsidence impacts and environmental consequences of the proposed mining covered by the EP, incorporating any relevant information obtained since obtaining the development consent."

- Describe the performance indicators that would be implemented to ensure compliance with the subsidence impact performance measures and manage or remediate any impacts and/or environmental consequences to meet the rehabilitation objectives of MP09_0013.

This report specifically addresses Section C10(e) and part of Section C10(f).

In addition to a subsidence monitoring program, MP09_0013 requires specific subsidence management plans and monitoring programs for Built Features, Water, Biodiversity, Swamps, Land, Heritage, Public Safety, as well as Trigger Action Response Plans and a Contingency Plan. These provide for the management of potential subsidence impacts and/or environmental consequences caused by the planned mining.

3.4 Land Ownership and Land Use

Figure 2 shows details of the land ownership within the EP Areas.

The surface within the EP Areas for PC07-08 and PC21-25 is owned by WCL, Water NSW (previously Sydney Catchment Authority) and Roads and Maritime Services (RMS). An adjacent area above the eastern area of Corrimal Colliery is owned by South32 - Illawarra Metallurgical Coal.

The EP Areas are wholly within the Metropolitan Special Area for the Sydney water catchment. This catchment area is a restricted area with no access for the general public and limited access for other persons.

3.5 Mining Geometry

This section provides details of the previous multi-seam mining in the Bulli, Balgownie and Wongawilli Seams at RVE relative to the planned mining of the Wongawilli Seam in the EP Areas for PC07-08 and PC21-25.

3.5.1 Previous Mining

Coal has previously been mined in three seams within the EP Areas, the Bulli Seam, the Balgownie Seam and the Wongawilli Seam.

The Bulli Seam was mined extensively at RVE from the late 1800's until circa 1950. This seam is also referred to in historical records as the Top, Upper or No1 Seam. The Bulli Seam thickness and mining height is approximately 2.2m.

The early mining layouts of the Bulli Seam were irregular compared to later mining methods. The layouts include the full evolution of hand-working bord and pillar methods from the early 'Welsh bords' technique that resulted in very wide roadways and very narrow pillars in "worked out" areas through to complete pillar extraction by hand. Hand-working techniques were superseded with the introduction of mechanised mining from the 1950's. There are areas of completed pillar extraction and large areas of standing coal pillars remaining as first workings. Some of these areas are under and around the FSL of the Cataract Reservoir. Reliable (accurate and complete) mine plan records (mine working plans and the record tracing copy) are available for areas of interest to this EP recognising that more detail is shown after 1931 when legislated standards required plans to be certified as accurate by a surveyor. Further detail of Bulli Seam workings is presented in Appendix 3.

The Balgownie Seam is approximately 10m below the Bulli Seam. The seam thickness is 1.2-1.3m but anecdotal and survey plan evidence indicates the actual mining height in later panels and on the longwall faces was increased to 1.5m by including some floor material. Most of the Balgownie Seam workings in RVE were mined with continuous miners and longwall methods from 1968 to 1982. Eleven longwall panels of various lengths and widths were extracted from 1970 to 1982.

The floor of the Wongawilli Seam is approximately 25m below the Balgownie Seam. The seam is approximately 10m thick but only the bottom 2-3m is economic due to coal quality. Three short longwall panels, 150m in width, were extracted between 2012 and 2015.

3.5.2 Planned Mining

Figure 3 shows the planned mining layout and contours of overburden depth to the mining horizon in the Wongawilli Seam assessed in this report.

The mining plan layout for this EP integrates with the existing Wongawilli Seam workings and consists of bord and pillar (non-conforming) workings in:

- two panels (PC07 and PC08) to the east of Mount Ousley Road
- one panel (PC21) and 4 sub-panels (PC22, PC23, PC24 and PC25) to the west of Mount Ousley Road adjacent to the Cataract Storage Reservoir
- and the first workings (conforming pillars) required for access and services, including ventilation, to the bord and pillar panels.

Conforming pillars are prescribed by *Work Health and Safety (Mines and Petroleum Sites) Regulation 2014* as having a minimum dimension of greater than one tenth of the thickness of cover (to the surface). These first workings pillars are designed to remain stable and 'non-subsiding' as required by MP09_0013 with large width to height ratios and factors of safety greater than 2.11 where a factor of safety of 2.11 implies a probability of instability of 1 in 1,000,000.

The layout avoids mining below the abutment load bearing (and subsidence controlling) Balgownie Seam chain pillars between longwall goafs. Limiting bord and pillar panels to five headings with barrier pillars between each panel and increasing pillar dimension near the major geological structures in the EP Areas (i.e. Dyke D8 and extension of Corrimal Fault at Wongawilli Seam horizon) is recommended. The risks to Cataract Reservoir from longwall mining through Corrimal Fault and Dyke D8 at RVE are assessed in SCT (2015).

PC07 and PC08 bord and pillar panels are positioned below Bulli Seam goaf Areas #4 and #6 and the goaf of Longwall 5 and Longwall 6 in the Balgownie Seam. These goaf areas are confirmed as collapsed (see Appendix 3). The Bulli Seam goaf areas are identified in SCT (2020a) using an identification number (ID#). PC07 and PC08 are separated by a barrier pillar of 54m (coal) in width positioned below the Balgownie Seam chain pillars.

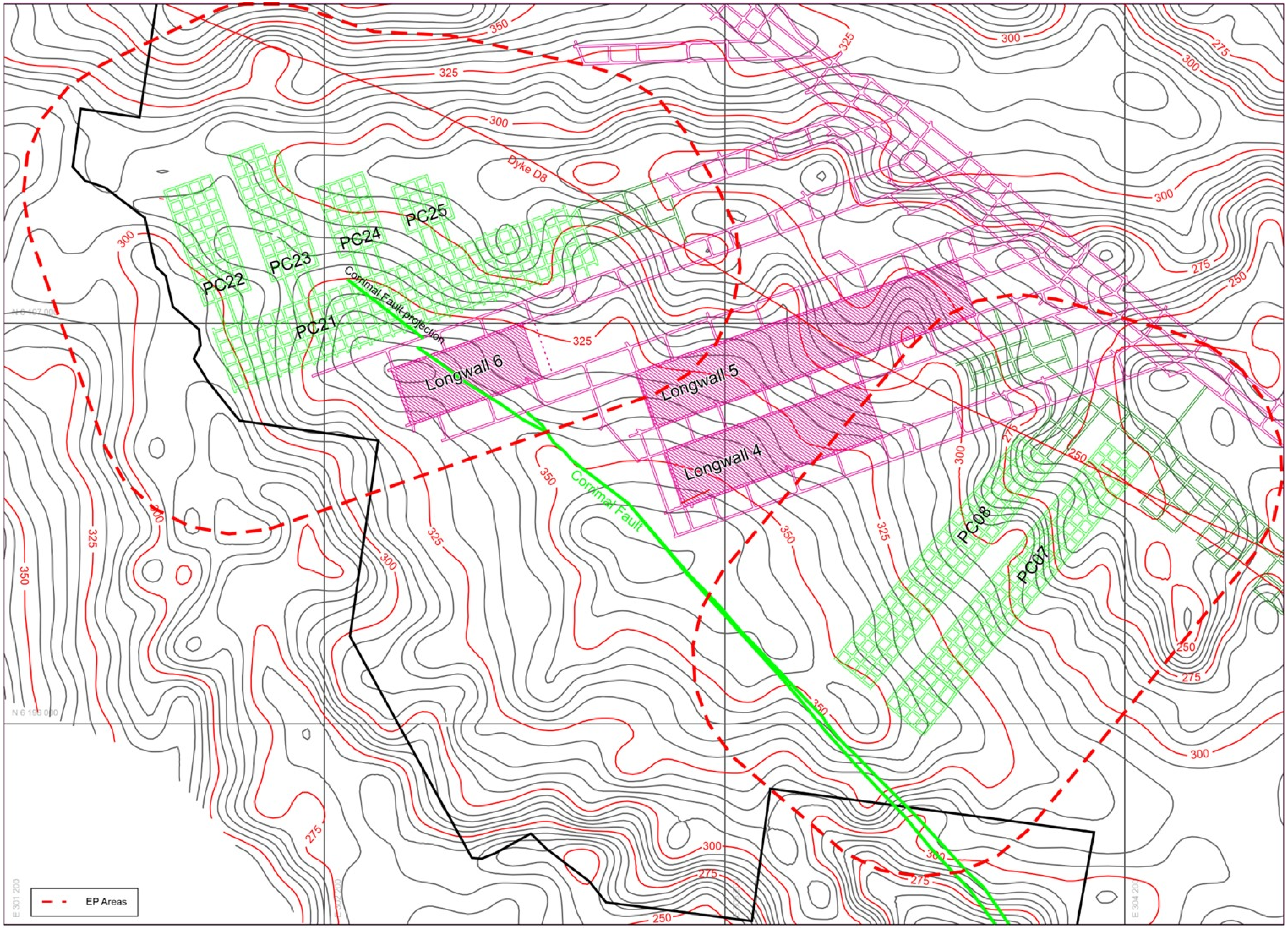


Figure 3: Contours of overburden depth to Wongawilli Seam mining horizon.

Pillar dimensions in PC07 and PC08 have been increased since approval for MP09_0013 was granted. The pillars are increased in size to accommodate full tributary load below the Balgownie Seam longwall goafs consistent with IAPUM (2020) assessment and IESC (2021) comments.

The coal dimensions increased from 19.5m to 22.5m for width and 19.5m to 24.5m for length to increase pillar strength and still maintain an offset from being directly below the Balgownie Seam chain pillar edges. These changes to the layout in PC07 and PC08 are for the pillars at an overburden depth of up to 330m.

In PC21 and PC22-25, the pillars are generally square in shape with minimum coal pillar dimensions of 24.5m. Longer rectangular barrier type pillars are incorporated into the three headings entries to the PC22-25 sub-panels. Three barrier pillars of 54m (coal) width separate the PC22-PC25 sub-panels.

The overburden depth ranges from approximately 250m to 350m for the PC07 and PC08 bord and pillar panels and first workings. The overburden depth ranges from approximately 280m to 340m for the PC21 and PC22-25 bord and pillar panels and first workings. The planned mining height is 2.4m for the non-conforming bord and pillar workings and 3.0m for the conforming first workings. These planned working sections of the Wongawilli Seam are at the base of the seam. All roadways are assumed to be at the maximum prescribed width of 5.5m.

As shown in Figure 1, most of PC21 and all of PC22-25 bord and pillar panels are located in areas where there is previous extraction in one seam only, mainly the Bulli Seam. Only a small area of PC21 is below Balgownie Seam Longwall 11 and in this area, the Bulli Seam has only been mined as first workings. Area #11 is the Bulli Seam goaf area located over PC22-24 and is yet to be confirmed as having subsided. Area #2 is located over the eastern area of PC21 and is confirmed as having subsided. Details of the pillar extraction areas on the mine working plans and copies of the recording tracings indicate the dates of mining in these two areas are similar. Dates of mining were 1942-1945 in Area #11 and 1943-1949 in Area #2.

3.6 Surface Features and Surface Infrastructure

Figure 4 shows the locations of surface features identified within the EP Areas for PC07-08 and PC21-25 during a risk assessment conducted on 10 March 2021. These features are described in this section.

The risk assessment team included environmental and subsidence specialists, and management personnel from WCL. The risks associated with subsidence impacts to the features identified within the EP Areas were considered in the context of the subsidence management requirements under the *Work Health and Safety (Mines and Petroleum Sites) Regulation 2014*.

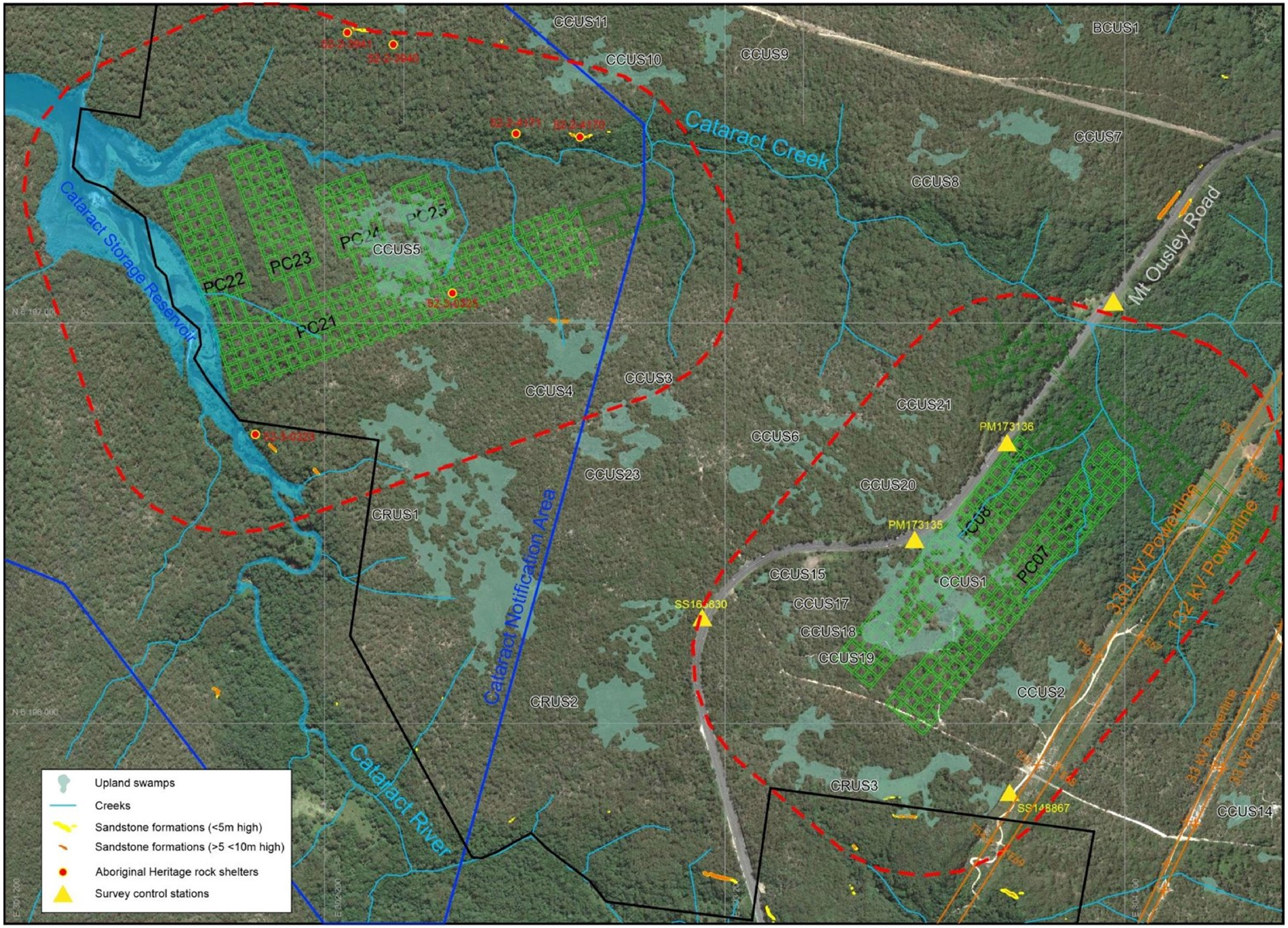


Figure 4: Surface features.

The NSW Department of Mineral Resources "Guideline for Applications for Subsidence Management Approvals" provides a comprehensive list of surface and sub-surface features to be considered in a subsidence assessment. With no such equivalent list included in the draft (Version 5 - unpublished) Department of Planning & Environment, NSW Trade & Investment – Division of Resources and Energy – "Guidelines for the Preparations of Extraction Plans" for EP applications, the SMP list has been used as a guide instead. A complete list of these items is provided in Appendix 1.

3.6.1 Natural Features

The major natural features within EP Areas for PC07-08 and PC21-25 are the Cataract River and Cataract Creek valleys and ridgeline between these features. The surface terrain is mainly undeveloped bushland.

First, second, third and fourth order streams, mainly in the Cataract Creek valley, cross the EP Areas but only first and second order tributaries of Cataract Creek and a first order tributary of Cataract River are located above the planned bord and pillar panels.

There are 16 upland swamps located partially or wholly within the EP Areas, but only two, CCUS1 and CCUS5, are above the planned bord and pillar panels. Swamp CCUS1 is above the planned PC07 and PC08 bord and pillar panels. Swamp CCUS5 is above the planned PC21, PC24 and PC 25 bord and pillar panel and sub-panels.

There are multiple sandstone formations located within the EP Areas, but none are greater than 5m high directly above the planned mining. There are no sandstone formations located within the EP Areas that would be described as cliffs by contemporary mining approval definitions.

3.6.2 Man-Made or Built Features

The major built features or infrastructure within the EP Areas for PC07-08 and PC21-25 are the Cataract Reservoir, the Mount Ousley Road and the 330kV and 132kV electricity transmission lines in the east. Other features include Aboriginal heritage sites, unsealed access tracks/fire roads, and survey control marks. No European or historical heritage features have been identified.

The planned mining for PC21 and PC22 bord and pillar panels is marginally below the FSL of the Cataract Reservoir at RL289.9m AHD in Cataract River and Cataract Creek.

All the planned mining in PC21 and PC22-25 bord and pillar panels and sub-panels is within the Notification Area around the Cataract Storage Reservoir administered by Dams Safety NSW (previously NSW Dams Safety Committee).

The section of Mount Ousley Road between Cataract Creek and the crest of the ridge to the south crosses the EP Area for PC07-08. The PC08 bord and pillar panel is immediately adjacent to the section of Mount Ousley Road that is above the chain pillar between Longwalls 6 and 7 in the Balgownie Seam.

A 330kV and a 132kV electricity transmission line are on the eastern edge of EP Area for PC07-08 but are not above the bord and pillar panels. The pylon structures that support the conductors of these powerlines are also not above any of the planned first workings in the EP Area for PC07-08.

Appendix 6 of MP09_0013 shows two Aboriginal heritage rock shelter sites located (52-3-0323 and 52-3-0325) within EP Area for PC21-25. The positions shown on this plan are inconsistent with previously assessments and recent ground-truthing field work confirms this plan is incorrect. Figure 4 shows the locations of six rock shelter sites (52-3-0323, 52-3-0325, 52-2-4170, 52-24171, 52-2-3940 and 52-2-3941) within the EP Area for PC21-25. Only one site (52-3-0325) located above Bulli Seam goaf Area #2 (confirmed as collapsed) is over the planned bord and pillar panels. No aboriginal heritage sites are located above the EP area for PC07-08.

Unsealed access road/four-wheel drive tracks cross the EP Area for PC07-08 on land owned by WCL and Water NSW. These tracks provide access to and along the high voltage powerline easements and to the telecommunications installation at Brokers Nose. These are not recognised fire roads.

Four permanent survey control marks have been identified within the EP Area for PC07-08. Three marks are along the edge of the Mount Ousley Road easement and one mark is on the southern edge of this EP Area in the 330kV and 132kV powerline easement.

Historical heritage features at the Russell Vale pit-top area and the Cataract dam wall are more than 1.5km and 9Km respectively from the planned bord and pillar panels and not expected to be impacted by the planned mining.

4. FORECAST SUBSIDENCE BEHAVIOUR

In this section, the subsidence movements expected above the planned PC07-08 and PC21-25 bord and pillar panels and within the EP Areas are estimated from experience of subsidence behaviour at RVC and elsewhere in the Southern Coalfield and NSW more generally.

4.1 Review of Previous Subsidence at RVE

This review is presented in the context of the advancements in understanding of the mechanics of multi-seam subsidence behaviour made since the last forecast for longwall mining at RVE was prepared in 2014. Back analysis of measured vertical subsidence profiles from mining in the Balgownie and Wongawilli Seams indicates behaviour consistent with this latest multi-seam understanding.

4.1.1 Vertical Subsidence

The only known records of subsidence effects associated with mining of the Bulli Seam are comments on historical plans regarding individual subsidence impacts. However, it is possible to estimate subsidence given the geometry of the panels mined and estimating the likely secondary extraction percentages.

The vertical subsidence for the Bulli Seam mining in RVE is estimated based on subsidence monitoring results and subsidence profiles from mining in the Bulli Seam further to the west above the T and W (200 and 300 Series) longwall panels at South Bulli Colliery and subsequent pillar extraction operations. Maximum vertical subsidence of up to 1.0m is estimated.

Monitoring of the subsidence from the Balgownie Seam longwalls was comprehensive for the period of mining. Each of the 11 longwalls mined between 1970 and 1982 had a longitudinal line along the whole length of the panel and three cross panel lines were also installed perpendicular across Longwalls 1-11.

The incremental vertical subsidence was monitored at regular intervals during panel retreat above the initial panels and less frequently during mining of the last few panels. Ground strains were only measured during the last panel; Longwall 11. The last subsidence surveys for the Balgownie Seam longwalls were completed in 1983.

Longwall 7 mined directly below Mount Ousley Road in 1976-77 where maximum subsidence of approximately 1.0m was measured. Sections of Mount Ousley Road were realigned coincidental with the period of active longwall mining. Subsidence impacts were managed as part of the realignment construction activities.

Observations from the database of subsidence monitoring for the Balgownie Seam longwalls indicate:

- The chain pillars and other areas of coal not mined by the longwall are evident in the subsidence profile.
- Incremental subsidence of approximately 75% (generally 65-85%) of mining height is evident in areas where secondary extraction in both the Bulli and Balgownie Seams has been undertaken.
- Subsidence occurred primarily within the footprint of the Balgownie Seam longwall panels.
- Goaf edge subsidence is greater and extends further where there is overlying Bulli Seam goaf.
- Incremental subsidence of greater than 90% of the Balgownie Seam mining height is evident where latent subsidence is recovered. Latent subsidence in this context is the subsidence associated with Bulli Seam mining that did not occur during mining of the Bulli Seam because of proximity to the edge of the panel. Maximum incremental subsidence of 1.42m was measured above Longwall 10 where latent subsidence from Bulli Seam pillars is likely to have been recovered. This subsidence represents 95% of the nominal 1.5m mining height.

Monitoring of subsidence from longwall mining in the Wongawilli Seam indicated maximum incremental vertical subsidence of 1.8m occurred over Longwalls 4 and 5 after Longwall 5 was mined. Incremental vertical subsidence over the short section of Longwall 6 mined to date is estimated at 0.72m. These values are consistent with and less than the forecast for these longwalls provided the subsidence assessment for the Preferred Project Report (PPR) longwall layout at RVE (SCT 2014).

Cumulative vertical subsidence can be estimated in the form of subsidence contours for mining in each seam. Figure 5 shows the estimated contours of cumulative subsidence for all three seams relative to swamps and the planned mining geometry.

Although mining has been conducted in three seams at RVE, there are only a few places where secondary extraction has occurred at the same location in all three seams. Total cumulative subsidence is not necessarily the addition of all the increments. The maximum cumulative vertical subsidence for all three seams is approximately 3.7m above Longwall 4 in the Wongawilli Seam at a location below parts of Swamp CCUS6.

Mills and Wilson (2017) present measurements and observations of the incremental and cumulative subsidence effects from longwall mining in two seams in a regular, parallel, offset geometry at a site in NSW. More recent monitoring to 2020 at this site confirms these earlier observations and interpretation and includes additional learnings for multi-seam subsidence from longwall mining in three seams.

4.1.2 Tilt and Strain

Detailed measurements of tilt and strain effects on the ground surface from mining subsidence are not available for the Bulli Seam mining and most of the Balgownie Seam longwalls. Incremental strains were measured for the mining of Longwall 11 in the Balgownie Seam. Incremental tilts and strains were measured for the mining completed in Longwalls 4-6 in the Wongawilli Seam.

Maximum strains over Longwall 11 were measured at the northern end of the panel were there has been pillar extraction in the Bulli Seam. Strains ranged from 3-4mm/m along the panel to peaks of 13-14mm/m in compression across the topographic low point of Cataract Creek and 8-9mm/m in tension on the slope beyond after vertical subsidence of 1.3-1.4m.

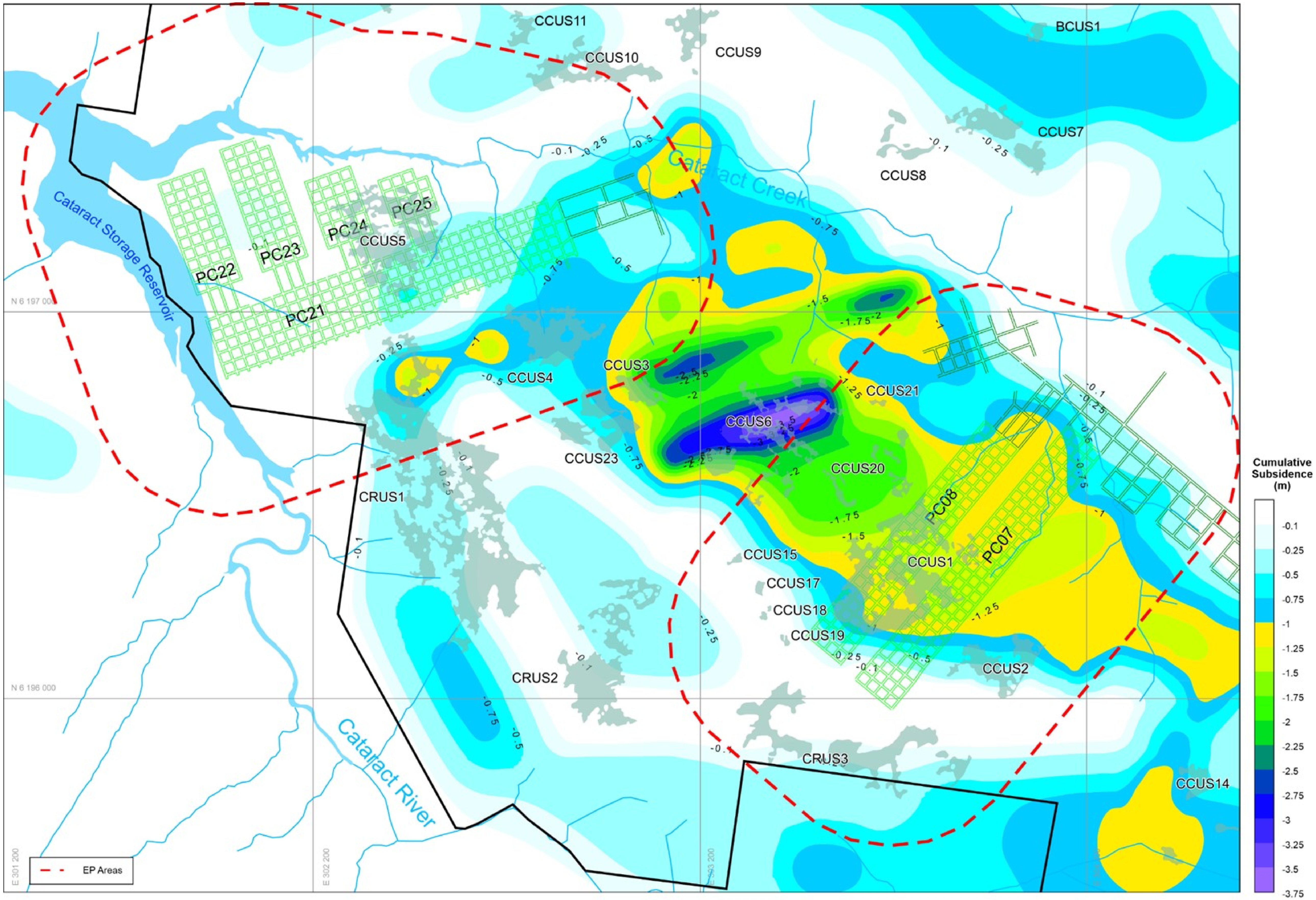


Figure 5: Estimate of existing cumulative subsidence relative to swamps.

The monitoring of incremental subsidence movements from the mining of Longwalls 4, 5 and 6 in the Wongawilli Seam indicates:

- Maximum tilt of 30mm/m in the RVE area was measured on the southern cross-panel line over Longwall 4 after mining Longwall 5. This maximum tilt was measured near the edge of Longwall 9 in the Balgownie Seam superimposed onto a goaf edge in the Bulli Seam. Maximum tilts measured elsewhere along Longwalls 4 and 5 were in the range of 10-25mm/m.

- Maximum tensile strain in the range 3-6mm/m.

- Maximum compressive strain of 12mm/m at the pillar and D8 Dyke over Longwall 5. Maximum compressive strains elsewhere along Longwalls 4 and 5 were in the range of 3-6mm/m.

Cumulative tilts and strains are not able to be derived, due to the limits of the database. However, Mills and Wilson (2017) present results that show that in areas remote from stacked goaf edges, the levels of permanent tilt and strain in multi-seam mining are similar or less than for single seam mining despite the greater vertical subsidence.

Cumulative values for tilt and strain are not necessarily the addition of the increments from each seam due to the general softening, or reduction in shear stiffness, of the overburden with each episode of subsidence. Transient and permanent levels of tilt and stain are much higher when a stacked goaf edge is formed and especially when the edge is undercut. At RVE, there are no stacked goaf edges of any significant length due to the irregular mining layouts in the three seams.

These observations suggest that tensile ground strains from previous mining are likely to be less than about 60% of values estimated and forecast in SCT (2014) for longwall mining of the PPR layout in RVE. This reduction is significant when considering cumulative effects including those from the planned bord and pillar mining.

4.2 Forecast of Subsidence Effects

In this section, the maximum subsidence effects for the primary subsidence parameters are estimated for the planned geometry shown in Figure 1.

4.2.1 Vertical Subsidence

Figure 6 shows contours for the estimated vertical subsidence expected at the completion of the planned bord and pillar panels in the EP Areas. Vertical subsidence from the mining of the planned bord and pillar panels is expected to be less than 100mm and generally less than 30mm within the EP Areas. These levels of subsidence are expected to be imperceptible for all practical purposes.

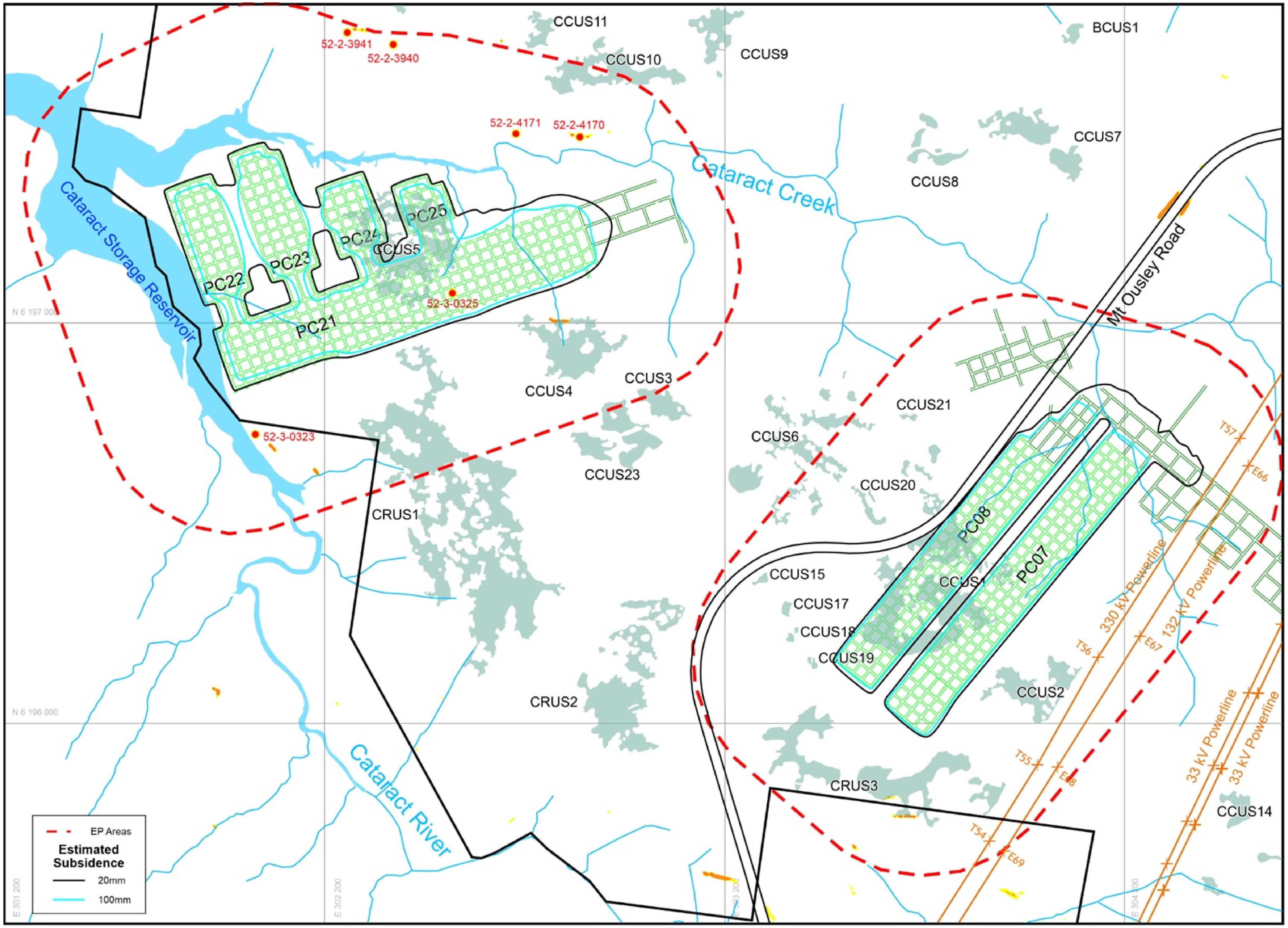


Figure 6: Estimated subsidence contours and surface features.

Vertical subsidence of greater than 500mm is considered possible, but most unlikely. If such subsidence were to occur, it would be expected in small, isolated areas at RVE near edges or below Bulli Seam goaf areas where any remnant pillars not already collapsed are destabilised. The IAPUM (2020) identify the potential for subsidence up to 300mm in some areas. The potential for this greater vertical subsidence exists because of subsidence associated with previous mining. This potential exists irrespective of planned mining, but additional subsidence of this magnitude would be considered a significant departure from the low levels of subsidence expected. Any such subsidence would be identified from LiDAR monitoring and investigated to better inform subsequent mining layouts.

A previously identified and inspected area of Welsh bords in the Bulli Seam adjacent to the main headings is outside the EP Area for PC07-08 and not expected to be affected by the planned mining. Although considered to be marginally stable based on pillar stability calculations, the pillars have been standing for 120 years. The expected 300mm subsidence associated with failure of these pillars would occur in a small area that would not affect surface infrastructure.

4.2.2 Tilt and Strain

The approach to estimate incremental tilt and strain levels outlined in Holla and Barclay (2000) for single seam mining in the Southern Coalfield indicates that for 100mm of vertical subsidence at 280m depth the following maximum values can be estimated:

- Tilt of less than 2.0mm/m.
- Tensile strain of approximately 0.5mm/m.
- Compressive strain of approximately 1.0mm/m.

Mills and Wilson (2017) found that in areas of multi-seam mining remote from stacked edges, incremental tilt and strain are not necessarily increased by greater vertical subsidence, so the Holla and Barclay (2000) approach is likely to give a conservative estimate of the strains and tilts.

Changes to the surface from these low-level values of tilt and strain are expected to be generally imperceptible.

Any changes in the small areas where additional subsidence does develop are also expected to be generally imperceptible and less than the tilt and strain levels already experienced at the site over a wide area.

4.2.3 Horizontal Movements

Systematic horizontal ground movements from vertical subsidence are expected to be generally imperceptible. However, ongoing low-level horizontal movements of the southern slope down to Cataract Creek are expected to continue irrespective of the planned mining.

These movements are a legacy of the previous mining at the site, including early Bulli Seam mining, the Balgownie Seam longwalls and the mining of Longwalls 4 and 5 in the Wongawilli Seam more recently.

These horizontal movements are expected to continue to cause horizontal strains that increase cracking at the top of the ridge line, cause minor cracks in the slope and cause minor compression at the Cataract Creek crossing point.

4.2.4 Unconventional Subsidence Effects

No significant unconventional subsidence movements are expected from the planned mining. Valley closure movements are expected but far-field movements from stress relief in the overburden strata are not envisaged.

Ongoing low-level valley closure movements are expected irrespective of the planned mining.

The current incremental closure at Cataract Creek from the Wongawilli Seam mining is approximately 60mm. This incremental closure is expected to remain well below the 150mm threshold set for the previously approved longwall mining in the Wongawilli Seam.

Any far-field horizontal movements from stress relief in the overburden strata are expected to have already occurred from the previous secondary extraction mining in the Bulli and Balgownie Seams and to a lesser extent, in the Wongawilli Seam. The planned mining in the Wongawilli Seam involves a non-caving method so additional far-field horizontal movements are not expected.

4.2.5 Risk of Pillar Instability

In this section, the existing coal pillars at RVE and pillars to be formed by the planned mining in this EP are assessed for stability and convergence at seam level that may result in subsidence at the surface.

The basis of the assessment is the University of NSW pillar design formulae (UNSW 1999) and consideration of width to height ratios, roof and floor properties, potential loading scenarios in the multi-seam environment and factors of safety. The Australian and South African failed pillars database developed by UNSW does not contain any cases where the factor of safety is greater than 1.5 for a width to height ratio of 5. Both these parameters are less than for the planned pillars in this EP.

The UNSW approach recognises that:

- Stable bord and pillar workings result in minimal surface subsidence.
- The design of stable pillars requires consideration of the strength of the 'pillar system' and the load that will be acting on the pillar system.

Generally, with the pillar system parameters remaining constant, vertical subsidence decreases as the width to height ratios of pillars increases. For pillars with width to height ratios of greater than about 8 in strong roof and floor strata, the load bearing capacity of the pillars can increase beyond the nominal strength, so the pillars become 'stronger' by a process referred to as 'strain hardening'. Some small convergence or deformation of the pillar occurs during this process.

The IAPUM (2020) advises the maximum probability of instability of 1 in 1,000,000 for all mine workings minimises (almost eliminates) the likelihood of pillar instability developing. A probability of failure of 1 in 1,000,000 equates to a factor of safety of 2.11.

Figure 7 shows the details of the existing Bulli and Balgownie Seam workings and the existing and planned mining in the Wongawilli Seam relative to the EP Areas.

4.2.5.1 Wongawilli Seam Pillars

The planned Wongawilli Seam pillars are assessed as long-term stable.

It is recognised that pillar width to height ratio and pillar strength are sensitive to the mining height of the surrounding roadways. Where the width to height ratio is small, pillar strength and factors of safety reduce significantly with only small increases in mining height. The coal pillars in the PC07-08 bord and pillar panels are planned to have a minimum width of 22.5m and be 24.5m long. SCT understands that the mining height is planned to be 2.4m and maximum roadway width is 5.5m. These pillars have a width to height ratio of greater than 9. Pillar stability is assessed on this basis.

Strong roof and floor conditions typical of the Wongawilli Seam are expected. Assuming full tributary overburden load, these pillars have a factor of safety of greater than 2.11 at depths up to 330m. There is no experience in Australia or South Africa of pillars in this geometry failing when the factor of safety is 2.11.

Assuming full tributary load for workings below Longwall 5 and 6 in the Balgownie Seam is considered conservative based on the observations of load on the adjacent Balgownie Seam chain pillars inferred from subsidence profiles, observed mining conditions below these pillars and the experience of drilling a borehole referred to as RV16 from surface to the Wongawilli Seam for groundwater monitoring.

RV16 shown on Figure 7, was drilled down through the collapsed Bulli Seam goaf, through the Balgownie Seam chain pillar between Longwall 5 and 6 and down the Wongawilli Seam floor at approximately 320m depth. Fragments of timber were encountered at the Bulli Seam mining horizon indicating the presence of previous mining activity, but the Bulli Seam mining horizon was observed to be completely compressed. This borehole was not cased through the strata above the chain pillar but was observed to support more than 300m of water head indicating the Bulli Seam mining horizon was tightly compressed.

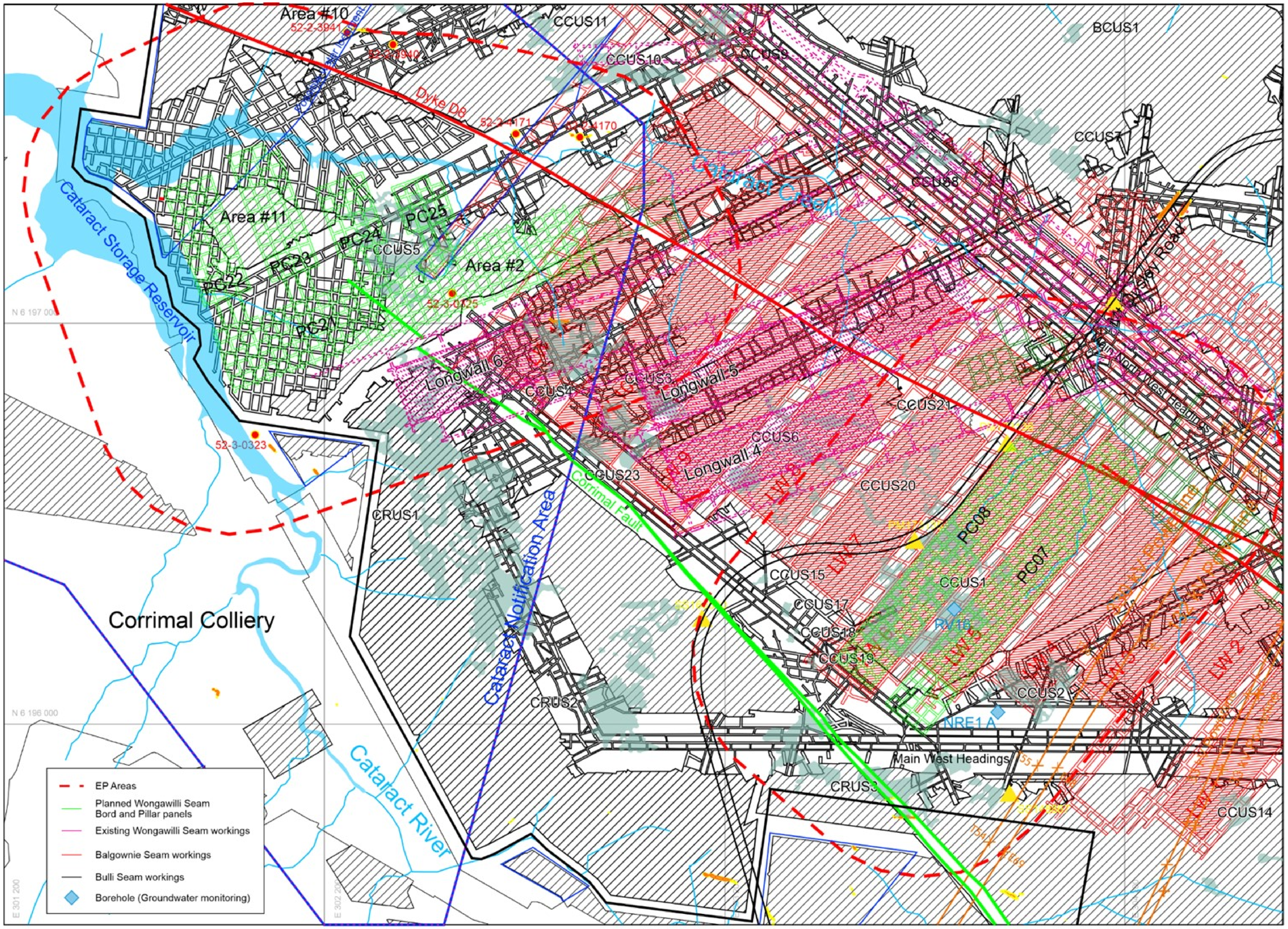


Figure 7: Workings in Bulli and Balgownie Seams with existing and planned workings in Wongawilli Seam.

The coal pillars in the PC21 and PC21-25 bord and pillar panels are planned to be a minimum size of 24.5m wide and 24.5m long. SCT understands that the mining height is to be 2.4m and maximum roadway width 5.5m. The minimum sized pillars have a width to height ratio of greater than 10. Pillar stability is assessed on this basis.

Strong roof and floor conditions typical of the Wongawilli Seam are expected. Assuming full tributary overburden load, these pillars have a factor of safety of greater than 2.11 for the maximum 335m depth above these panels.

The potential for perceptible subsidence should pillars become overloaded and deform over time is significantly reduced by limiting the panels to five headings and incorporating a barrier greater than 50m wide between panels. This strategy isolates individual panel width to approximately 125m at depths of 280-340m.

4.2.5.2 Balgownie Seam Pillars

The existing Balgownie Seam pillars are assessed as long-term stable after consideration of the status and the potential for interactions from the planned Wongawilli Seam mining.

The existing Balgownie Seam coal pillars above or adjacent to the planned bord and pillar panel within the EP Areas range in width from a minimum of 25m to 40m or larger. These pillars have width to height ratios of greater than 16 to greater than 26 for a mining height of 1.5m and greater than 19 to greater than 30 for a seam thickness of 1.3m.

4.2.5.3 Bulli Seam Pillars

The potential for any remnant pillars in the Bulli Seam goaf areas to become destabilised and result in additional subsidence has been identified and considered in the forecast of subsidence effects.

Most of the planned bord and pillar panels in the PC07-08 EP Area are below Bulli Seam goaf areas and Balgownie Seam longwall panels. Detailed mine workings plan and record tracings are available for the two Bulli Seam goaf areas referred to as Area#4 and Area#6. Subsidence profiles from longwall mining in the Balgownie Seam, inspections of the Balgownie Seam goaf edge at the Bulli Seam horizon and experience from mining the Wongawilli Seam below these areas confirm that Bulli Seam pillars above Balgownie Seam longwall goafs are collapsed as would be expected with full extraction less than 10m below the Bulli Seam horizon.

The planned PC21 and PC22-25 bord and pillar panels are located below two areas of Bulli Seam goaf and some first workings. The edges and some of the goaf area above PC21 (identified as Area #2 in SCT 2020a) have already been confirmed as collapsed from the Balgownie Seam subsidence profiles and from experience of difficult mining conditions in the Wongawilli Seam below the edge of this goaf area. A second area of Bulli Seam goaf above the planned PC22-25 bord and pillar sub-panels (identified as Area #11 in SCT 2020a) is not confirmed as collapsed and subsided because there has not been any Balgownie or Wongawilli Seam mining at this location.

In Area #2, secondary extraction of the pillars that form this goaf area was undertaken between 1943 and 1949 according to the original mine working plan and record tracing copy. There are some small pillars shown as not mined. These remnant pillars are unlikely to be standing as they are generally less than 10m wide and 15m long surrounded by secondary extraction at a depth of 285m. These pillars have lower width to height ratios and are expected to have collapsed at the time of secondary extraction in the Bulli Seam because of the high abutment loads generated by the secondary extraction process.

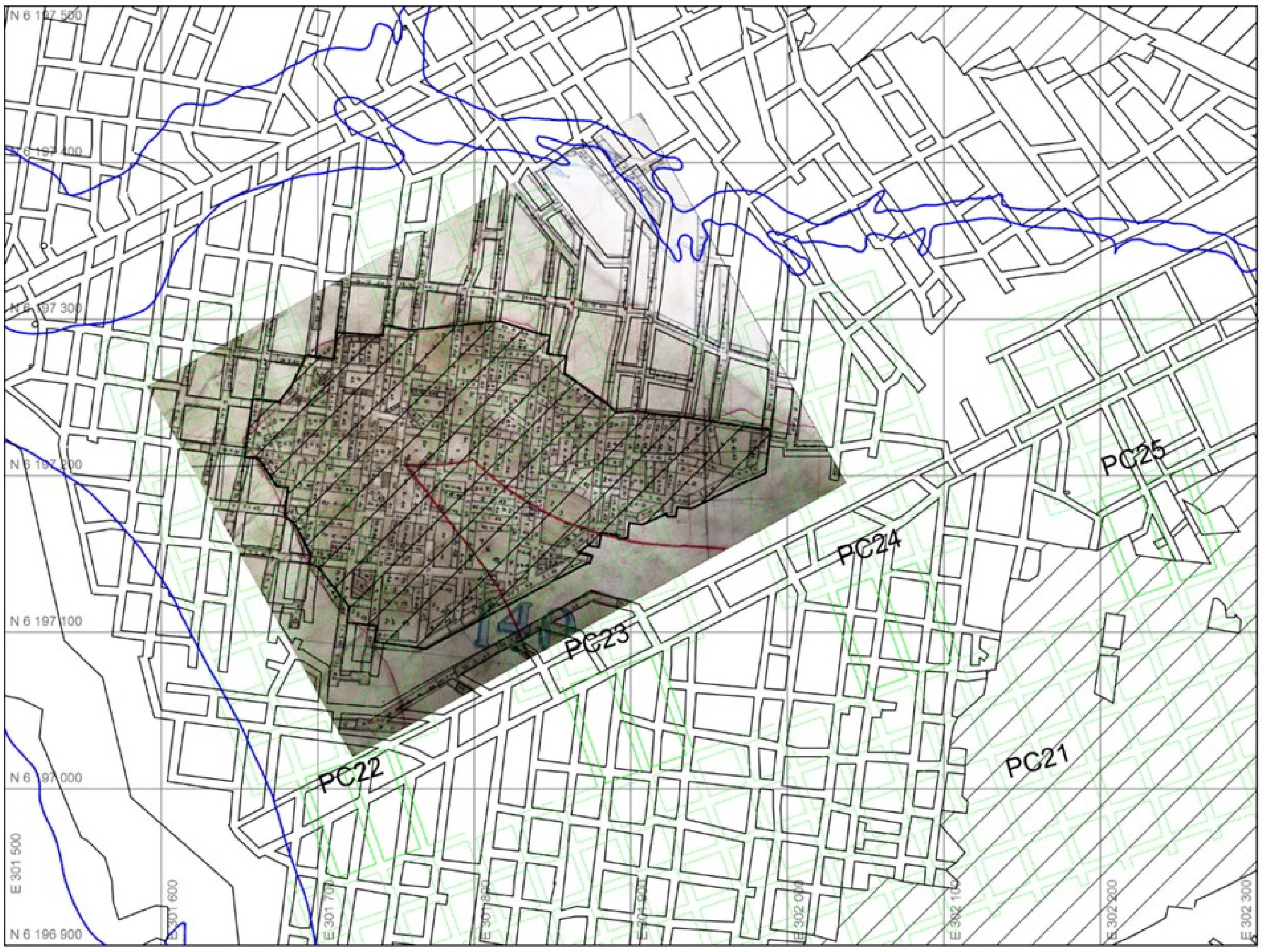
In Area #11, the original mine working plan and record tracing copy indicate the secondary extraction of the first workings pillars was undertaken from 1942 to 1945. Care was taken to show the extraction of pillars and sections of pillars to the limit for secondary extraction around the FSL of Cataract Reservoir allowed at that time. Only two small remnant pillars are shown as not mined, but these are likely to have collapsed at the time of secondary extraction because they are less than 8m wide and 10m long and surrounded by secondary extraction at a depth of 280m. Figure 8 shows sections of the mine working plan and the record tracing copy for Area # 11 demonstrating the reliability of the Bulli Seam records. These are two hand-drawn plans drafted at different times, updated at different intervals, and using different depictions for secondary extraction. Similar records are available for Area #2.

The potential for additional subsidence above these two Bulli Seam goaf areas cannot be eliminated, but this potential exists irrespective of the planned mining and the planned mining is not expected to cause a significant change at the Bulli Seam mining horizon. In the unlikely event that remnant pillars are still standing and were to collapse at the time of mining the Wongawilli Seam below, additional subsidence is expected to be less than 300mm over an area with a radius of approximately 50m.

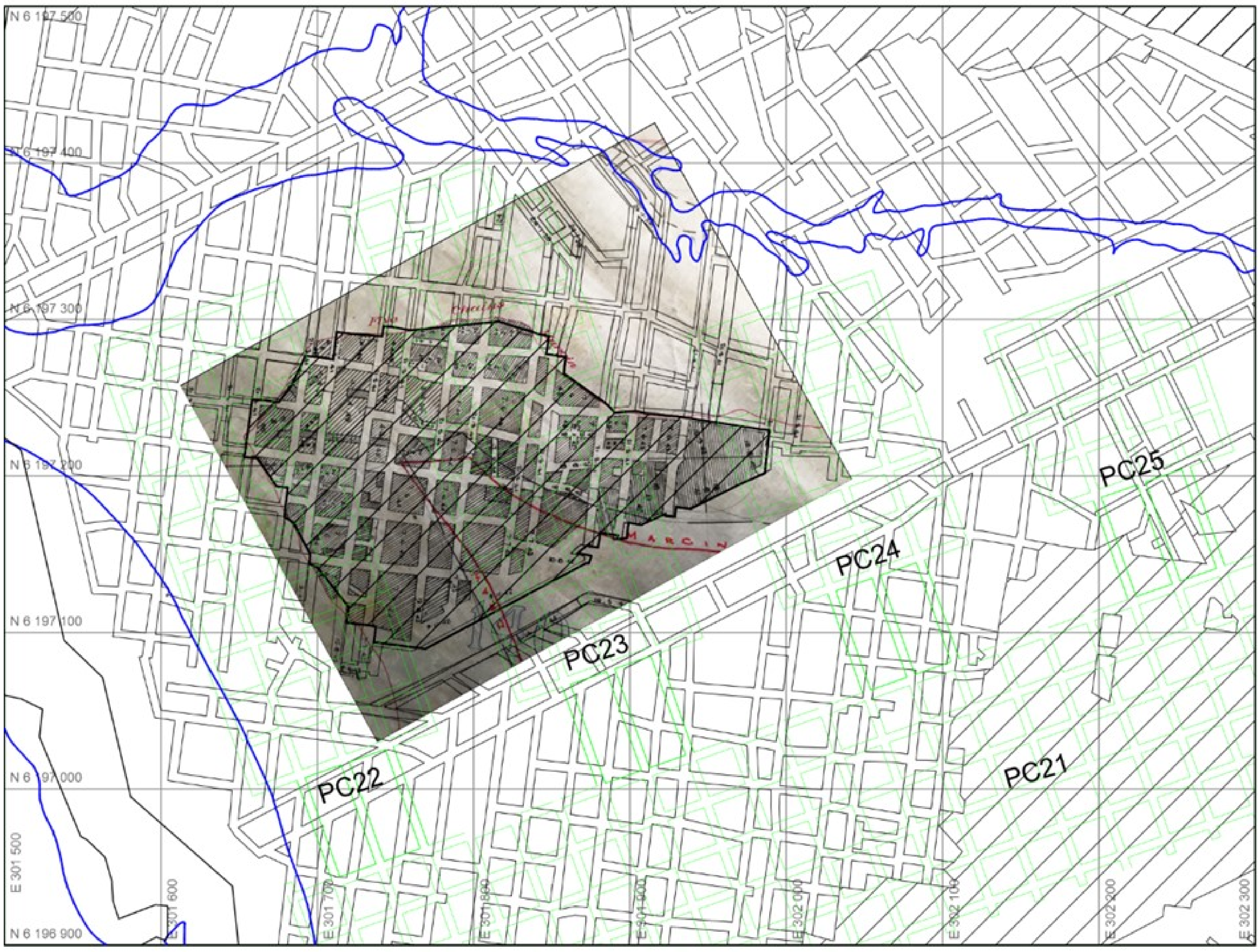
The Bulli Seam first workings layout in the vicinity of planned bord and pillar panels in the PC21-25 EP Area consists of two heading panels and sub-panels. The pillars in the first workings are expected to remain long-term stable because of their large width to height ratios and high factors of safety against instability.

The two parallel headings are separated by long, narrow pillars ranging in width from 12m to 17m. The pillars are typically rectangular in shape with the length being more than 1.5-2.0 times greater than width. Flanking the narrow two heading panels and sub-panels are wider pillars, typically 20m to 30m wide. There is one section of main headings with 10m wide pillars flanked by pillars 40m to 50m wide. Some irregular shaped pillars, including triangular pillars, were formed where the sub-panels intersect the main headings. The width to height ratios for the standing pillars in the PC21-25 EP Area range from generally greater than 5 to greater than 13 and are typically around 9.

Where there are more cut-throughs and smaller pillars, the pillars typically range in width from 17m to 20m and are marginally longer than wide. The depth at this location is approximately 280m. Assuming these pillars are square in shape, are 2.2m high and surrounded by 6m wide roadways, the factor of safety ranges from 1.67 to 2.22 for strong roof and floor conditions typical for the Bulli Seam.



a) Mine working plan of Bulli Seam goaf Area #11.



b) Record tracing of Bulli Seam goaf Area #11.

Figure 8: Example of Bulli Seam mine plan records.

There are some areas where there are narrow (12m) pillars. The 12m wide pillars are generally about 24m long and flanked on both sides by pillars at least 24m wide. Assuming the unlikely scenario that the 12m pillars cannot carry any load, the tributary load of the overburden above these narrow pillars would then be required to be carried by the larger flanking pillars to maintain equilibrium. In this scenario the factor of safety for the 24m square pillars is estimated as greater than 2.8. A greater stability is derived for the 10m wide pillars flanked by pillars at least 40m in width.

Some of the Bulli and Balgownie Seam workings located above the planned bord and pillar panels in the PC21-25 EP Area are likely to be flooded. Assessment of pillar stability for the geometry in both seams indicates that the pillars are expected to remain stable without any reduction in load due the minimal buoyancy effects of the water. That is, if the water is removed to render the inrush hazard harmless, overall stability of pillars in the overlying seams is unlikely to be affected.

4.3 Reliability and Accuracy of Subsidence Forecasts

Maximum vertical subsidence in a single seam mining environment is naturally variable by about 15% for any given panel geometry and overburden depth. In a multi-seam situation, the variability is somewhat greater particularly given the sensitivity of subsidence to the interaction between mining geometries in each seam. For multi-seam mining, performance indicators of 20% greater than maximum forecast values are recommended to provide an alert that subsidence is not tracking as expected while avoiding unnecessary triggering of insignificant events associated with natural variation.

Guidelines for Subsidence Management Approvals recommend assessing impacts at 1, 1.5, 2 or 2.5 times the maximum values forecast for subsidence parameters or 5 times where subsidence is forecast at less than 150mm.

The limited extraction and limited width of individual panels relative to overburden depth makes it difficult for instability in the Wongawilli Seam to cause greater than 100mm of surface subsidence. Maximum convergence at seam level would be 440mm before the roadways became filled (assuming no bulking). The limited panel width and significant depth means that maximum subsidence at the surface would be less than 100mm if the Wongawilli Seam pillars were to totally collapse.

Instability of the overlying Bulli Seam would be possible in those areas where no subsidence has occurred previously. There is potential for up to 1m of subsidence from instability in the overlying Bulli Seam, this potential exists irrespective of any further mining activity. The surface terrain in the general vicinity has historically experienced subsidence of this magnitude and greater following mining in the overlying Bulli and Balgownie Seams. In a bushland environment, such levels of subsidence are barely perceptible.

The main surface features likely to be impacted are upland swamps. The probability of such an event causing loss of a swamp is assessed as “very rare” using the National Emergency Risk Assessment Guidelines (SCT 2020a) and “extremely rare” once Bulli Seam pillars are confirmed as having previously collapsed during the period of active mining. SCT understands that the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) considers these risks to be tolerable.

4.4 Comparisons with Previous Subsidence Forecasts and Consent Subsidence Performance Measures

Condition C10, Part 3 of MP09_0013, requires WCL to prepare an EP for all second workings. The EP must:

- “Provide revised predictions of the potential subsidence effects, subsidence impacts and environmental consequences of the proposed mining covered by the EP, incorporating any relevant information obtained since obtaining the consent.”

- “Describe in detail the performance indicators that would be implemented to ensure compliance with the performances measures in Tables 5 and 6 (sic) and manage or remediate and impacts and/or environmental consequences to meet the rehabilitation objectives in Table 4 (sic).”

We note that Tables 4, 5 and 6 referred to above have been renumbered in the document as Tables 5, 6 and 7.

This section provides details of:

- The scope of the subsidence assessment for this EP.

- Changes to the subsidence effects forecast since the subsidence assessment (SCT 2019) for the RPUEP was prepared.

- Recommendations for performance indicators for subsidence effects consistent with the subsidence performance measures of the consent.

4.4.1 Basis for EP Subsidence Assessment

The mining plan layout and mining sequence for this EP has been revised from that approved by development consent MP09_0013. This subsidence assessment is for the mining layout shown in Figure 1 and described in detail in Section 3.5.2.

A conservative approach to subsidence forecasts has been adopted for the purpose of impact assessment and compliance thresholds.

4.4.2 Changes to Subsidence Parameters Since RPUEP Subsidence Assessment

The subsidence assessment for the RPUEP was presented in SCT (2019). This assessment was peer reviewed (Hebblewhite 2019a and 2019b). Since then, further information on potential subsidence impacts was sought by the IPC, NSW Department of Planning Industry and Environment (DPIE) and the Australian Government Department of Agricultural, Water and the Environment. Advice was also sought from the IESC and the IAPUM to inform the NSW and Federal Government approval processes for the proposed mining.

The IESC (2019) advice to DPIE concluded further assessment was required to quantify the potential risk to coastal upland swamps from pillar failure. SCT (2020a) responded to this risk assessment requirement. IAPUM (2020) responded to a request for advice from the IPC on the risk assessment for upland swamps and the forecast of subsidence effects more generally with reference to estimated subsidence effects at upland swamps presented in SCT (2014) for the longwall mining proposed at that time.

IAPUM (2020) suggests an upper limit of 300mm for vertical subsidence as a threshold for significant impact to swamps as compared to the more conservative 100mm subsidence used by SCT (2020a) for the quantitative risk assessment. The IPC has included 300mm as a subsidence performance measure in the consent conditions for MP09_0013.

SCT's assessment of the likely maximum subsidence of less than 100mm has not changed, but the maximum subsidence considered tolerable by upland swamps has increased from 100mm to 300mm on the advice of the IAPUM.

4.4.3 Recommendation for Performance Indicators

Most of the categories of subsidence impacts performance measures that require performance indicators are outside the SCT's area of expertise and need to be determined by other specialists.

SCT typically recommends performance indicators for subsidence effects that are generally 20% above the maximum values forecast so that natural variability does not trigger unnecessary reporting procedures for events of no practical consequence. For the non-caving mining method planned where the forecast vertical subsidence levels are low and the upper limit of 300mm has been set as a performance measure, values of 100mm and 250mm are considered appropriate to activate trigger action response plans (TARPs) for the planned mining geometry in this EP.

Similarly, 100mm additional closure from all mining in the Wongawilli Seam, including from Longwalls 4-6, is considered appropriate as a lower valley closure trigger with an upper level of 150mm consistent with the EPBC 21014/7259 approval conditions for the first 400m of Longwall 6. These trigger levels need to be confirmed based on the measurement of valley closure from the final survey for Longwall 6.

5. SUBSIDENCE IMPACT ASSESSMENT

In this section, the potential subsidence impacts are assessed for the various surface features located within the EP Areas for PC07-08 and PC21-25.

5.1 Natural Features

Natural features considered in this section comprise upland swamps, watercourses, sandstone formations and steep slopes, surface landform and groundwater more generally. Figure 4 shows the locations of these surface features.

5.1.1 Upland Swamps

Upland swamps CRUS1, CRUS3, CCUS1, CCUS2, CCUS3, CCUS4, CCUS5, CCUS6, CCUS10, CCUS15, CCUS17, CCUS18, CCUS19, CCUS20, CCUS21 and CCUS23 are located partially or wholly within the EP Areas, but only CCUS1 and CCUS5 are above the planned bord and pillar panels. No significant impacts are expected to any of these features from the planned mining based on specialist advice from the IAPUM. Consequences are expected to negligible in the context of previous impacts.

Sections of the planned PC07 and PC08 bord and pillar panels are below CCUS1 Swamp. Maximum incremental vertical subsidence from the mining in these panels is expected to be much less than 100mm. Tensile strain of 0.5mm/m and tilt of less than 2mm/m is expected from 100mm of vertical subsidence. No significant impacts are expected to CCUS1 Swamp based on specialist advice provided by IAPUM (2020). Parts of CCUS1 Swamp are estimated to have already experienced up to 0.7m vertical subsidence from the mining in the Bulli Seam and 0.8m of subsidence was measured during the mining of the Balgownie Seam longwalls. The total 1.5m subsidence is less than the 2m used in SCT (2014) to estimate maximum strain and tilt values associated with previous mining. For reference, parts of the nearby CCUS6 Swamp are estimated to have experienced up to 3.7m of vertical subsidence from the previous mining in all three seams.

The experience presented in Holla and Barclay (2000) indicates maximum tensile strain of 7.9mm/m and tilt of 26.3mm/m would be expected for 1.5m of subsidence. The actual levels of tilt and strain for most areas of the swamps are likely to be much less than the maximum predictions with the maxima only occurring in small areas where sections of the swamp coincide with the fringes of the subsided areas.

PC21 and PC24-25 bord and pillar panels and sub panels are located below part of CCUS5 Swamp. Parts of this swamp are also located over areas of existing first workings and part of Bulli Seam goaf Area #2. The potential for additional subsidence above some of Area #2 cannot be completely eliminated, but this potential exists irrespective of the planned mining. In the unlikely event that remnant pillars are still standing and were to collapse, additional subsidence is expected to be less than 300mm over an area with a radius of approximately 50m. Parts of CCUS5 Swamp that are confirmed as fully subsided are likely to have already experienced vertical subsidence from the mining in the Bulli Seam of up to 0.6m with associated maximum tensile strain of 3.3mm/m and maximum tilt of up to 11mm/m.

Maximum incremental subsidence from planned mining of PC21 and PC24-25 bord and pillar panels is expected to be less than 100mm. Maximum tensile strains of approximately 0.5mm/m and tilt of less than 2mm/m are expected. Any changes to the surface from the levels of tilt expected are unlikely result in flow patterns that would significantly increase erosion within a swamp. No significant impacts are expected to CCUS5 Swamp based on specialist advice provided by IAPUM (2020

5.1.2 Watercourses

First, second, third and fourth order streams cross the EP Areas but only first and second order tributaries of Cataract Creek and a first order tributary of Cataract River are located above the planned bord and pillar panels. No significant additional subsidence impacts are expected to these watercourses. Impacts and consequences are expected to be negligible in the context of previous impacts.

First and second order tributaries of Cataract Creek, remote from the main channel, traverse the surface above PC07 and PC08. Incremental vertical subsidence of up to 100mm with low-levels of tilt and strain is expected along these tributaries from the planned bord and pillar mining. No significant additional impacts are expected.

Two first order tributaries of Cataract Creek cross over PC21 and a first order tributary of Cataract River crosses above PC21 and PC22. The two first order creeks above PC21 flow from swamps CCUS4 and CCUS5 down the steeper terrain to Cataract Creek. The first order creek above PC21 and PC22 flows into Cataract River. There are no creeks above Bulli Seam goaf Area #11.

The two first order creeks that cross PC21 are likely to have been previously subsided by approximately 0.2m and up to 0.8m from secondary extraction in the Bulli and Balgownie Seams, respectively. Maximum incremental subsidence from the mining in this panel is expected to be less than 100mm with low levels of tilt and strain. No significant additional impacts are expected.

The first order tributary of Cataract River is above first workings in the Bulli Seam and unlikely to have experienced any substantial vertical subsidence in the past. Incremental vertical subsidence of up to 100mm with low-levels of tilt and strain is expected from the mining of PC21 and PC22.

No significant impacts are expected to watercourses from any additional cracking or erosion from the low levels of subsidence effects forecast.

5.1.3 Sandstone Formations

There are no definitions for cliffs and steep slopes included in the consent conditions of MP09_0013. For the purposes of this assessment cliffs are defined as sandstone formations or rock faces greater than 10m high, consistent with contemporary definitions and steep slopes are defined as extended slopes, that are not sandstone formations, with an average slope of greater than 1 in 1.

There are several sandstone formations within the EP Areas. These are all less than 10m high. There are no sandstone formations greater than 5m in height above the planned bord and pillar panels. There are no areas above the planned bord and pillar panels considered to be steep slopes.

No significant, additional impacts to sandstone outcrop formations (including Aboriginal heritage rock shelter sites) or instability of steeper ground is expected from the low level subsidence effects forecast. Impacts and consequences are expected to be negligible in the context of previous impacts.

Subsidence warning signs, restricting access where possible, and regular inspections before and after active mining in Land and Heritage Management Plans are considered appropriate measures to monitor and limit exposure to potential subsidence impacts.

The nearest cliff to the EP Areas is Brokers Nose on the Illawarra Escarpment, more than 1.3km from PC07. No impacts from the planned mining are expected at Brokers Nose. The Illawarra Escarpment and Brokers Nose are protected from any pillar run potential by the barriers of solid coal remaining in the Bulli Seam on either side of the Main West Headings and the unworked panel to the east of Longwall 1 in the Balgownie Seam and the larger coal pillars of the main headings in all three seams. The coal barrier pillars adjacent to the Main West and Main Northwest Headings are those used as the eastern boundary for the additional subsidence management area in the subsidence management plan approval for the Wongawilli Seam Longwalls 4 and 5.

The battered road cuttings for Mount Ousley Road located on the northern side of the Cataract Creek are outside the EP Areas and more than 500m from PC07. No perceptible impacts to these features are expected from the planned mining.

5.1.4 Surface Landform

Ongoing low-level horizontal movements of the slope on the south side of Cataract Creek, a legacy of the previous mining on site, are expected to continue irrespective of the planned mining. This movement is likely to result in small increases in tensile cracking along the topographic high point, the crest/ridgeline between the Cataract River and Cataract Creek valleys, minor cracks on the slope and valley compression closure across Cataract Creek.

Inspection of the main channel of Cataract Creek indicates that there is almost no physical disturbance to the rock strata in the bed of the creek despite previous mining activity in three seams. Geological mapping indicates that this section of the creek flows across outcrops of the Bald Hill Claystone and Bulgo Sandstone immediately below it. These strata units appear more tolerant of valley closure movement than Hawkesbury Sandstone.

This level of impact to the creek may change in the future regardless of any further mining. The basal shear plane is at limiting equilibrium (on the verge of moving) as a legacy of previous longwall mining. Only very small changes, such as changes in pore pressure caused by high intensity rainfall events, are required to cause further movement.

The main impacts from this ongoing movement are closure of the pavement, compression of the culverts at Cataract Creek and stretching at the top of the ridge to the south. These impacts and management measures are discussed in Section 5.3.

5.1.5 Groundwater

The planned first workings and bord and pillar mining in the Wongawilli Seam below existing Bulli and Balgownie Seam workings are not expected to significantly alter the current groundwater regime. The overburden strata is already depressurised to various heights from the previous secondary extraction mining. Groundwater levels are expected to respond more to weather patterns than to the planned mining. Any additional impacts to groundwater are expected to be negligible and limited to only in the immediately vicinity of the Wongawilli Seam.

5.2 Heritage Sites

In this section, the potential subsidence impacts to Aboriginal heritage features located within the EP Areas are assessed. There are no historical heritage items in or within the vicinity of the EP Areas.

Figure 4 shows the locations of six rock shelter sites (52-3-0323, 52-3-0325, 52-2-4170, 52-24171, 52-2-3940 and 52-2-3941) within the EP Area for PC21-25. No aboriginal heritage sites are located above the EP Area for PC07-08.

Of the six sites, only 52-3-0325 is located over the planned bord and pillar panels. This rock shelter with art and deposit is located above PC21 and has already been mined under by the workings in the Bulli Seam but not the Balgownie Seam. Site 52-3-0325 is positioned above the already confirmed as collapsed Bulli Seam goaf Area #2 where approximately 0.3m of subsidence is estimated to be occurred.

In this location, the site is expected to experience less than 100mm of vertical subsidence and corresponding level of compressive strain from the mining in PC21. No significant impacts to this detached boulder type feature are expected at this location. Any impacts and consequences are expected to be negligible in the context of previous impacts.

Site 52-3-0323 is located above a solid coal barrier pillar in the Bulli Seam workings of Corrimal Colliery. The barrier pillar is approximately 120m wide below the FSL of the Cataract Reservoir. Previous subsidence at this site is estimated at less than 0.1m. This location is more than 100m from PC21. No perceptible subsidence effects or impacts are expected at this location from the planned mining in the EP Area for PC21-25.

Sites 52-2-4170 and 52-2-4171 are located on the northern side of Cataract Creek above first workings in the Bulli and Balgownie Seams. Previous subsidence at these sites is estimated at less than 0.1m. These locations are more than 150m from PC21 on the northern side of Dyke D8. No perceptible subsidence effects or impacts are expected at these locations from the planned mining in the EP Area for PC21-25.

Sites 52-2-3940 and 52-2-3941 are located further north on the edge of the EP Area beyond the extent of the Balgownie Seam workings. Site 52-2-3940 is located above Bulli Seam first workings where previous subsidence is estimated at about 0.1m. Site 52-2-3941 is located above the edge of Bulli Seam goaf Area#10 where previous subsidence is estimated at approximately 0.2m. Both these sites are more than 300m from PC24 on the northern side of Dyke D8. No perceptible subsidence effects or impacts are expected at these locations from the planned mining in the EP Area for PC21-25.

Subsidence warning signs, restricting access where possible, and inspections before and after active mining as detailed in the Heritage Management Plan (HMP) are considered appropriate measures to monitor and limit exposure to potential mining related hazards during the planned mining in the EP Area for PC2125.

5.3 Built Features and Infrastructure

Built features are shown in Figure 4. Public utilities identified within the EP Areas or in positions with potential to be affected include: Mount Ousley Road, the Cataract Storage Reservoir and overhead electricity transmission lines. Minor infrastructure is limited to unsealed access road/four-wheel drive tracks and survey control stations. There are no public amenities, farmland and facilities, industrial, commercial and business establishments, residential establishments, or items of architectural significance.

5.3.1 Mount Ousley Road

Mount Ousley Road (or M1 Princes Motorway) traverses the EP Area for PC07 and PC08 from the Cataract Creek crossing in the north to the ridgeline between Cataract River and Cataract Creek in the south. The planned PC07 and PC08 bord and pillar panels are immediately adjacent to a section of the road easement that was realigned soon after being impacted by subsidence from Longwall 7 in the Balgownie Seam. As well as the developments for PC07 and PC08, two underground access roadways are planned to pass below Mount Ousley Road remote from PC07 and PC08.

Vertical subsidence of approximately 30mm is expected from the planned mining. This level of subsidence is expected to be generally imperceptible and of a similar magnitude to the subsidence experienced on the road alignment during the nearby mining of Wongawilli Seam longwall panels. The difference between the planned mining and the earlier longwall mining is that there will no longer be any large-scale subsidence below the adjacent terrain. Horizontal movements associated with the planned mining will therefore be much less than the small ongoing movements associated with longwall mining. The magnitude and rate of these movements has not been measured since longwall mining ceased but will be determined when the first surveys are conducted as required within the existing Built Features Management Plan (BFMP) for the Mount Ousley Road.

Impacts to the road pavement, culverts and cuttings/embankments are expected to be minor and manageable within the existing risk control measures and the subsidence management plans currently in place. Subsidence monitoring required within the Built Features Management Plan (BFMP) required by the EP for the Mount Ousley Road in consultation with NSW Roads and Maritime Services (RMS) is expected to be appropriate to manage subsidence impacts to Mount Ousley Road. It is envisaged the BFMP would be developed through consultation and agreement with the asset owner to the required standards and the process would include a risk assessment conducted to relevant standards,

Impacts to the pavement surface include tension cracks at the crest/ridgeline and on the slope down to Cataract Creek and a compression hump at the Cataract Creek crossing. The potential for this closure to impact the safety of road users was previously identified and actioned by the installation of a slot across the pavement surface to mitigate the hazard of closure from horizontal movements.

Impacts to the culverts for the creek from ongoing closure movements are expected to be minor, manageable, and repairable if required. Impacts to embankments from small differential movements are expected to generally be insignificant but repairable if required. No perceptible impacts to cuttings are expected as these features are remote from the planned mining.

5.3.2 Electricity Transmission Lines

There are four overhead electricity transmission lines to the east of Mount Ousley Road. These comprise a 330kV and 132kV powerline in the same easement and two 33kV powerlines further to the east. The 330kV and 132kV powerlines owned by TransGrid and Endeavour Energy, respectively are located at the east of the PC07-08 EP Area. These powerlines are more than 150m to the east of the planned PC07 and 08 bord and pillar panels. The pylon structures that support the conductors of these powerlines are also not above any of the planned first workings in the EP Area for PC07-08.

No perceptible subsidence effects or impacts from the planned mining are expected at the towers, however, consultation with the asset owners and monitoring of the structures during the period of active mining in the PC07-08 EP Area consistent with the BFMP is recommended. It is envisaged the BFMP would be developed through consultation and agreement with the asset owners to the required standards and the process would include a risk assessment conducted to relevant standards.

Research from aerial photography indicates the 330kV and 132kV powerlines were constructed between 1951 and 1961, after the Bulli Seam extraction but before Longwall 3 in the Balgownie Seam was mined in 1972.

Towers T54 and E69 were constructed above a Bulli Seam goaf area mined circa 1914. Towers T55 and E68 are located above the Bulli Seam solid coal barrier on the southern side of the Main West Headings. Towers T56 and E67 are above Longwall 3 in the Balgownie Seam. Towers T57 and E66 are located above the main heading pillars of the Bulli Seam (Main Northwest Headings) and Balgownie Seam and above solid coal adjacent to the main headings in the Wongawilli Seam. The coal barrier pillars adjacent to the Main West and Main Northwest Headings are those used as the eastern boundary for the additional subsidence management area in the subsidence management plan approval for the Wongawilli Seam Longwalls 4 and 5.

The two towers above Longwall 3, Towers T56 and E67, have experienced significant subsidence movements since their construction. Maximum subsidence of 1.3m was measured above the centre of Longwall 3. The towers are located near the panel edges. T56 is estimated to have experienced 0.6-0.8m of vertical subsidence and E67 is estimated to have experienced 1.0m of vertical subsidence. We understand neither tower was replaced following these subsidence movements suggesting that the four legs of each tower are located within the same block of sandstone strata. Cracks are reported to have occurred nearby supporting this hypothesis. Any further subsidence would be expected to localise on the existing fractures (cracks) formed during mining of the Balgownie Seam. The tower legs are all anchored to the same block of sandstone so that the structural integrity of the tower is protected. Nevertheless, Towers T56 and E67 are expected to require a structural engineering review as part of a risk assessment prior to any future mining.

Towers T54, T55, T57, E66, E68 and E69 are not expected to have previously experienced significant subsidence movements by virtue of their position, timing of construction and the protection provided by the remaining coal barriers, but are expected to be included in the risk assessment before any future mining.

5.3.3 Cataract Storage Reservoir

All planned mining in the PC21 and PC22-25 EP Area is within the Notification Area for Cataract Storage Reservoir. The planned mining layout includes mining up to directly below the FSL of the reservoir. The revised mining plan for the EP is expected to require consent from Dams Safety NSW (DSNSW) and the approval of the Chief Inspector of Coal Mines.

The expected subsidence effects and impacts from the planned mining within the Notification Area are expected to be tolerable to Dams Safety NSW. Any changes to water quantity flowing into the mine are expected to be negligible and no additional conductive cracking is expected. No changes to water quality are expected.

A detailed risk and engineering assessment consistent with DSNSW guidelines is expected to be required before any further mining within the Notification Area is conducted. The mining consent/approval is expected to require a detailed underground mine water balance measurement system to be implemented and maintained. The underground mine water balance monitoring system is expected to be effective as a guide to any unexpected inflows from the reservoir. The underground mine water balance reviewed in SCT (2021) indicates that there is no significant flow from the reservoir into the mine workings.

5.3.4 Access Road/Four-Wheel Drive Tracks

Several unsealed access road/four-wheel drive tracks cross the edge of the PC07-08 EP Area. These access roads are on land owned by WCL and Water NSW and entry to these roads is controlled by locked gates. These tracks provide access from the crest/ridgeline on Mount Ousley Road, to and along the high voltage powerline easements, and to the telecommunications installation at Brokers Nose. These are not recognised fire roads but may be used for bushfire control purposes.

No additional subsidence effects or impacts are expected to be perceptible from the planned mining. Regular inspections during active mining, and timely remediation are considered appropriate management measures in the unlikely event of any impacts or changes to the surface being observed. Including these measures in the Land and Public Safety Management Plan is recommended.

5.3.5 Survey Control Stations

There are four survey control stations within the EP Area for PC07-08. Permanent marks PM173136, PM173135 and state survey mark SS165830 are positioned along the Mount Ousley Road easement from north the south. State survey mark SS14867 is positioned in the south of the EP Area some 200m to the east of PC07.

State survey marks are designed to be stable reference points. Ground movements caused by mining subsidence have potential to move the position of these marks. Reference to a mark displaced by mining subsidence could, in certain circumstances, have significant consequences. All four marks are likely to have been disturbed by the previous and ongoing subsidence movements at RVE. Although the subsidence movements at these marks from planned mining are expected to be of low magnitudes, subsidence impacts nevertheless need to be managed.

A BFMP that includes a process to manage impacts to survey marks is recommended. A practical way to manage subsidence impacts from mining on survey control stations is to notify the asset owner to temporarily decommission marks that may be affected. Once the subsidence effects have taken place and the position of marks known to have stabilised, the horizontal and vertical position of the marks are re-established, and they are returned to service with revised coordinates and height.

5.4 Public Safety

The only potential risk to public safety associated with the planned mining is expected to be from impacts to Mount Ousley Road and the electricity transmission lines.

Any potential impacts to Mount Ousley Road and risks to public safety are expected to be manageable within a BFMP developed in consultation with RMS. A BFMP like that used successfully to manage impacts for the previous longwall mining in the Wongawilli Seam is expected to be suitable.

Planned mining is not expected to cause perceptible subsidence effects or impacts to the powerlines, so no additional risk to public safety is expected. However, including monitoring of the powerlines during the period of active mining in a BFMP is considered an appropriate risk control measure for this infrastructure.

A Public Safety Management Plan (PSMP) that includes reference to the risk control measures for public safety in the BFMP and Land and Heritage Management Plan is recommended.

6. SUBSIDENCE MONITORING

Subsidence monitoring is recommended to manage operational, personal, and public safety risks and to address the specific requirements of MP09_0013 conditions including those detailed in the subsidence monitoring program.

The aim of this monitoring is to:

- Provide data to assist with the management of the risks associated with subsidence.
- Confirm the status of Bulli Seam goaf areas.
- Validate subsidence forecasts.
- Provide a basis to analyse the relationship between the forecast and actual subsidence effects and impacts including any environmental consequences.
- Ensure compliance with subsidence performance measures.
- Inform adaptive management process for compliance with performance measures.
- Collect sufficient baseline data for future mining applications.
- Enhance general understanding of subsidence behaviour at RVE.

An overview of the recommended monitoring approach to satisfy these aims is presented here. The full details are provided in a revised subsidence monitoring program required by Condition C10 (g) (i) of MP09_0013, relevant guidelines and legislated standards.

Conventional subsidence monitoring is not suitable to confirm the low levels of subsidence expected in the bushland environment at RVE. The requirement to minimise disturbance to the bushland conflicts with the need to develop a well-controlled survey network for subsidence monitoring in the steep terrain above the site.

A continuous, high-accuracy ground-based array of monitoring points combined with a broad-area remote monitoring system is considered the best option. The high-accuracy ground-based points are planned to be located at suitable locations above planned mining and on adjacent high-value infrastructure to confirm the low-level ground movements expected. Broad-area remote monitoring is planned across the entire area to check for unexpected movements, particularly any that may be associated with instability of remnant pillars in Bulli Seam goaf areas.

A commercially available GNSS (GPS) system can be installed at single points over the mining panels and in or on specific natural or built features. The location in three dimensions of these points can be continuously monitored and made available on the internet in real time to interested parties. To be effective, the units require clear access to the sky for GNSS signals, mobile phone coverage, and solar power. The GNSS units can continuously record position in three dimensions to better than ±10mm accuracy. The units can be programmed to provide a record of positioning data to track trends and trigger levels can be set to alert of any exceedances.

Installing these units at suitable locations above the initial panels, adjacent to the Mount Ousley Road and on adjacent electricity pylons is recommended. The number and spacing of GNSS units and the frequency of LiDAR surveys needs to be confirmed in consultation with the supplier of the units and the infrastructure owners.

Broad-area monitoring could be undertaken using airborne LiDAR (Light Detection and Ranging) or dInSAR (satellite based differential synthetic aperture radar).

LIDAR is expected to produce surveys with a tolerance of ±150mm, potentially resulting in up to 300mm difference between two surveys. Pre-mining surveys exist already and could be re-flown at regular intervals during mining to confirm there have been no subsidence events associated with instability of the Bulli Seam workings.

Satellite monitoring using dInSAR is expected to be accurate to a few centimetres on hard surfaces, but experience indicates it tends to be affected by ground cover vegetation. The dInSAR monitoring could provide deformation updates (changes to the surface topography) annually for instance or more regularly if required.

Continuation of the existing systems of closure monitoring across Cataract Creek including closure slot monitoring on the Mount Ousley Road pavement, culvert surveys and survey closure monitoring at four cross-sections is recommended. Monitoring of the Picton Road interchange bridge is not considered necessary, and this monitoring could be discontinued in consultation with RMS. Periodic ground surveys and inspections of the relative positions of individual legs of powerline towers is recommended with a program developed in consultation with the asset owners.

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

Underground geotechnical mapping of changes to the observed vertical and horizontal stress conditions, around the edges of the areas shown as goaf on the original Bulli Seam mine working plans and record tracing copies, is expected to be a strong indicator of the status of Bulli Seam goafs. There are currently seven Bulli Seam goaf areas that are likely to have collapsed but there is no direct evidence to confirm this collapse. Underground observations of roadway condition in the Wongawilli Seam are considered a reliable technique to confirm these areas have collapsed. Once all seven areas are confirmed as collapsed, the scale of the broad-area monitoring could be reduced.

The proposed mining method is flexible compared to longwall mining and easily adaptable to unexpected or unfavourable mining conditions. Adaptive management practices including TARPs would allow for immediate changes to the mining layout in response to changes in mining conditions, risk profiles and potential impacts.

In addition to incident reporting (e.g. a TARP exceedance), the 'Guidelines for the Preparation of Extraction Plans' requires subsidence impact reporting on a bi-monthly (every two months), six-monthly and annual basis. Subsidence effects monitoring results are required in the annual report.

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

Clause 67 (2), requires:

b) monitoring of subsidence to be conducted, including monitoring of its effects on relevant surface and subsurface features

c) any investigation of subsidence and any interpretation of subsidence information is carried out only by a competent person.

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

7. REFERENCES

DMR 1998 – NSW Department of Mineral Resources – Gretley Information & Retraining Seminar – November 1998

Hebblewhite 2019a "Peer Review – Russell Vale Colliery Subsidence Assessment (SCT Report UMW4609, 10 July 2019)" B.K. Hebblewhite Consulting Letter Report No. 1907/01.1 - 6 September 2019.

Hebblewhite 2019b "Peer Review – Russell Vale Colliery Subsidence Assessment - Supplementary Summary Report". B. K. Hebblewhite Consulting Letter Report No. 1907/01.2 – 12 October 2019.

Hebblewhite 2020a "Peer Review – Russell Vale Colliery Assessment of Risk of Pillar Failure" B.K. Hebblewhite Consulting Letter Report No. 2003/03.3 - 6 April 2020.

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

Holla, L. and Barclay, E. 2000, "Mine Subsidence in the Southern Coalfield, NSW, Australia" NSW Department of Mineral Resources, ISBN 0 7313 9225 6.

IAPUM 2020 "Advice Re: Russell Vale Underground Expansion Project" - Independent Advisory Panel for Underground Mining – November 2020.

IESC 2019 "Advice to decision maker on coal mining project - IESC 2019-108: Russell Vale Colliery Underground Expansion Project (MP09_0013) – Expansion" Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development – 19 November 2019.

IESC 2021 "Advice to decision maker on coal mining project - IESC 2020-0120: Russell Vale Colliery Revised Underground Expansion Project, NSW (EPBC 2020/8702) – Expansion" Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development – 8 February 2021.

Kapp, W.A. 1982, A review of subsidence experience in the Southern Coalfield of New South Wales, in State of the art of ground control in longwall mining and mining subsidence (editors Chugh, Y.P. and Karmis, M.) SME of AIME, New York, p167-182

Li G., Steuart P. and Paquet, R. 2007 "A Case Study on Multi-Seam Subsidence with Specific Reference to Longwall Mining Under Existing Longwall Goaf" Proceedings of 7th Triennial Conference on Mine Subsidence - University of Wollongong N.S.W – 26 & 27 November 2007 pp 111-125.

Li G, Steuart P, Paquet R, and Ramage R 2010 "A Cast Study on Mine Subsidence Due to Multi-Seam Longwall Extraction" Proceedings of Second Australasian Ground Control in Mining Conference - Sydney N.S.W. 23-24 November 2010 pp 191-200.

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

MSEC 2007 "General Discussion on Systematic and Non Systematic Mine Subsidence Ground Movements" - Revision A - August 2007

SCT 2013 "Subsidence Assessment for Gujarat NRE Preferred Project Russell Vale No 1 Colliery" SCT Report NRE14123 to Gujarat NRE Coking Coal Limited dated 24 September 2013.

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

SCT 2015 "Assessment of Corrimal Fault and Dyke D8 at Russell Vale East as Risks to the Stored Waters of Cataract Reservoir" SCT Report WCRV4466A - 19 August 2015.

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

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

SCT 2020b "Response to Advice from Independent Advisory Panel for Underground Mining" SCT Letter Report WCRV5269_ Rev1 – 29 November 2020.

SCT 2021 "Russell Vale Colliery: Review of Underground Mine Water Balance" SCT Report WCRV5053 dated 22 April 2021.

SG 2011 "Management of subsidence risks associated with Wongawilli Seam extraction with particular focus on Wongawilli East – Area 2" Seedsman Geotechnics Pty Ltd Report to Gujarat NRE No1 Colliery dated July 2011.

SG 2012a "Subsidence associated with Wongawilli Seam extraction at NRE No 1 Colliery" Seedsman Geotechnics Pty Ltd Letter Report GNE-136.docx to Dr C. Harvey dated 20 July 2012.

SG 2012b Seedsman Geotechnics Pty Ltd letter report to C Harvey, Gujarat NRE, dated 19 November 2012, reference GNE-141.docx.

Staunton J.H. 1998 "Report of the formal investigation under Section 98 of the Coal Mines Regulation Act 1982" Gretley Inquiry Report to Minister of Mineral Resources and Fisheries dated June 1998

UNSW 1999 - Galvin, J M, Hebblewhite, B K and Salamon, M D G, 1999. UNSW coal pillar strength determinations for Australian and South African mining conditions, in Proceedings Second International Workshop on Coal Pillar Mechanics and Design, Pittsburgh, NIOSH IC9448.

APPENDIX 1 – THE EP/SMP APPLICATION GUIDELINES LIST OF SURFACE FEATURES TO BE CONSIDERED IN A SUBSIDENCE ASSESSMENT

Table A1: The EP/SMP Application Guidelines List of Surface Features to be Considered in a Subsidence Assessment

Natural Features	Within EP Area	Relevant Section
1) Catchment areas and declared Special Areas;	Y	*3.1, 3.4*
2) Rivers and creeks;	Y	*3.6.1, 5.1.2*
3) Aquifers, known groundwater resources;	Y	*3.6.1, 5.1.5*
4) Springs;	N	
5) Sea/lake;	N	
6) Shorelines;	N	
7) Natural dams;	N	
8) Cliffs / pagodas;	Y	*3.6.1, 5.1.3*
9) Steep slopes;	Y	*3.6.1, 5.1.3*
10) Escarpments;	N	
11) Land prone to flooding or inundation;	N	
12) Swamps, wetlands, water related ecosystems;	Y	*3.6.1, 5.1.1*
13) Threatened and protected species;	Y	
14) National parks;	N	
15) State conservation areas;	N	
16) State forests particularly areas zoned FMZ 1, 2 and 3;	N	
17) Natural vegetation;	Y	*3.1, 3.6.1*
18) Areas of significant geological interest, and	N	
19) Any other feature.	N	
Public Utilities		
1) Railways;	N	
2) Roads (all types);	Y	*3.6.2, 5.3.1*
3) Bridges;	N	
4) Tunnels;	N	
5) Culverts;	Y	*5.1.4, 5.3.1*
6) Water/gas/sewerage pipelines;	N	
7) Liquid fuel pipelines;	N	
8) Electricity transmission lines (overhead/underground) and associated plants;	Y	*3.6.2, 5.3.2*
9) Telecommunication lines (overhead/underground) and associated plants;	N	
10) Water tanks, water and sewage treatment works;	N	
11) Dams, reservoirs and associated works;	Y	*3.6.2, 5.3.3*
12) Air strips,	N	
13) Any other infrastructure items.	N	
Public Amenities		
1) Hospitals	N	
2) Places of worship	N	
3) Schools	N	
4) Shopping centres	N	
5) Community centres	N	
6) Office buildings	N	
7) Swimming pools	N	

Public Amenities	**Within EP Area**	**Relevant Section**
8) Bowling greens	**N**	
9) Ovals and cricket grounds	**N**	
10) Racecourses	**N**	
11) Golf courses	**N**	
12) Tennis courts	**N**	
13) Any other amenities considered significant	**N**	
Farm Land and Facilities		
1) Agricultural utilisation or agricultural suitability of farmland;	**N**	
2) Farm buildings / sheds;	**N**	
3) Gas and / or fuel storages;	**N**	
4) Poultry sheds;	**N**	
5) Glass houses;	**N**	
6) Hydroponic systems;	**N**	
7) Irrigation systems;	**N**	
8) Fences;	**N**	
9) Farm dams;	**N**	
10) Wells, bores, and	**N**	
11) Any other feature.	**N**	
Industrial, Commercial and Business Establishments		
1) Factories;	**N**	
2) Workshops;	**N**	
3) Business or commercial establishments;	**N**	
4) Gas and / or fuel storages and associated plants;	**N**	
5) Waste storages and associated plants;	**N**	
6) Buildings, equipment and operations that are sensitive to surface movements;	**N**	
7) Surface mining (open cut) voids and rehabilitated areas;	**N**	
8) Mine infrastructure including tailings dams and emplacement areas, and	**N**	
9) Any other feature considered significant.	**N**	
Areas of Archaeological and/or Heritage Significance	**Y**	
Items of Architectural Significance	**N**	
Permanent Survey Control Marks	**Y**	*3.6.2, 5.3.5*
Residential Establishments	**N**	
1) Houses;	**N**	
2) Flats / Units;	**N**	
3) Caravan parks;	**N**	
4) Retirement/aged care villages;	**N**	
5) Associated structures such as workshops, garages, on-site waste water systems, water or gas tanks, swimming pools and tennis courts, and	**N**	
6) Any other feature considered significant.	**N**	

APPENDIX 2 – SUBSIDENCE IMPACT PERFORMANCE MEASURES

Feature	Performance Measures
Watercourses	

Watercourses, including Cataract River, Cataract Creek and associated	• Negligible subsidence impacts or environmental consequences including
	  ○ Negligible diversion of flows or changes in the natural drainage behaviour of pools.
	  ○ Negligible increase in waters cloudiness.
	  ○ Negligible increase in bank erosion and
	  ○ Negligible increase in sediment load

Water Supply	
Cataract Reservoir	• Negligible leakage from reservoir • Negligible reduction in water quality of reservoir • No connective cracking between the reservoir surface and the underground workings
Land	
Cliffs, steep slopes and rock face features	• Negligible environmental consequences (including subsidence induced rockfalls, displacement or dislodgement of boulders or slabs or fracturing)
Swamps	
Upland swamps identified in the figure in Appendix 5	• Negligible environmental consequences including negligible change to the structural integrity of the bedrock base or any controlling rockbar of swamp.
Biodiversity	
Threatened species, threatened populations, or endangered ecological communities	• Negligible environmental consequences
Heritage Sites	
Aboriginal heritage sites identified in the figure in Appendix 6	• Negligible subsidence impacts and environmental consequences • Negligible loss of heritage value
Historic heritage sites identified in the figure in Appendix 7	• Negligible subsidence impacts and environmental consequences • Negligible loss of heritage value
Other Aboriginal and historic heritage sites	• Negligible subsidence impacts and environmental consequences • Negligible loss of heritage value

Feature	Performance Measures
Mine workings	
First workings and Second workings	• To remain long-term stable and non-subsiding
Key Public Infrastructure	
M1 Princes Motorway (formally known as Mount Ousley), electricity transmission lines and towers (330kV, 132kV, 2x33kV) and telecommunications line	• Always safe and serviceable • Damage that does not affect safely or serviceability must be fully repairable and must be fully repaired.
Other Infrastructure	
Access roads, fire trails and other public infrastructure and built features	• Always safe. • Serviceability should be maintained wherever practicable. • Loss of serviceability must be fully compensated. • Damage must be fully repairable and must be fully repaired or else replaced or fully compensated.
Public Safety	
Public Safety	• Negligible additional risk
Vertical Subsidence	
All areas of the site affected by the development	• Vertical subsidence limit of not more than 300mm

APPENDIX 3 – RELIABILITY OF MINE PLAN RECORDS FOR RUSSELL VALE EAST

The planned mining at Russell Vale East (RVE) is in an area where previous mining has occurred in two overlying seams. Staunton (1998) stressed in the formal investigation report into the accident that occurred at Gretley Colliery how additional care is required to understand the potential for seam interaction effects when mining in the vicinity of previous workings. He found it is incumbent on the mine manager and mine surveyor to undertake research into the adequacy of the plans of previous mining to enable identified hazards to be managed safely. These findings have subsequently been translated in the legal requirements detailed in the WHS (Mines and Petroleum Sites) Regulations 2014.

This appendix presents our research into the reliability of Bulli Seam mine plan records. This research is undertaken from the perspective of residual risk for greater than predicted subsidence from unstable pillars remaining as undocumented remnant pillars in areas depicted as goaf or as marginally stable pillars identified on the mine working plan. The research is for the greater RVE area but with more focus on the areas associated with the EP for PC07-08 and PC21-25 including areas where the Balgownie Seam longwalls were extracted. The research does not include consideration of inrush from overlying seams, which SCT understands will be addressed separately by Wollongong Coal and is outside the scope of the work described in this document.

SCT has expertise in geotechnical and multi-seam subsidence engineering as well as over 40 years' experience in mine surveying and drafting. These skills have been applied directly and indirectly to researching the reliability of the mine plan records for RVE. We believe the findings of the research to be true and accurate, but we note that this research does not obviate the responsibilities of the mine manager and mine surveyor under the WHS (Mines and Petroleum Sites) Regulation 2014. An independent review of the data by the mine manager and mine surveyor is recommended.

This document details the research conducted and the basis for the conclusions reached. The research includes:

- Examination of detailed mine plans held by:
  - Wollongong Coal
  - Department of Mineral Resources
  - University of Wollongong Library - Archives
  - Wollongong City Library – Local Studies
  - Other historical groups

- Consideration of subsidence measurements conducted during mining of the Balgownie Seam longwall panels with insight provided by multi-seam mining at Ashton Underground Mine.

- Drilling of multiple holes, from underground and the surface, to confirm the location and status of overlying workings.

- Visual inspections of underground workings in the two overlying seams.

- Observation of seam interaction effects associated with mining in the Wongawilli Seam.

- Consideration of pillar sizes required to maintain stability under the overburden loads, goaf edge loading and chain pillar loading from overlying seams and the potential for these to contribute to a pillar run.

The integrity of the mine plans is improved because the three seams of mining are all within the same colliery and the mine records for the areas of interest are complete throughout the period of mining.

The research has been conducted for the RVE area in its entirety. The eastern area of interest to the current EP is located almost entirely below Balgownie Seam goaf where subsidence records are available and sensitive infrastructure to the east is protected from multi-seam interaction by solid coal pillars associated with main heading developments. The western area of interest to the current EP is located remote from sensitive surface infrastructure. The interaction issues associated with the broader area of the RVE will be addressed in subsequent EP's with the benefit of subsidence information gathered by the planned mining in the current EP areas. The sequence of mining the western area first is expected to provide further confirmation of ground behaviour.

A3.1 Introduction

There have been many references during the UEP environmental impact assessment process to the reliability of the historical mine plan data for RVE and the risk resulting from any uncertainty and assumptions based on poorly defined or unknown information. Reliability, in this situation, refers to accuracy, completeness and the somewhat subjective, percentage of extraction of the coal seam depicted by the drafting standards of the plans.

SCT has expertise in geotechnical and multi-seam subsidence engineering as well as experience in mine surveying and drafting and have been indirectly or directly involved in research into the reliability of the mine plan records at RVE since 2010. The initial investigations were into the origin and transformation process for the creation of the digital (electronic) plans for the Bulli and Balgownie Seam used in the management of daily operations, for mine planning and subsidence prediction and assessment purposes. The results of these initial investigations were presented to Dams Safety NSW (previously Dams Safety Committee - DSC) and Roads and Maritime Services (RMS - previously Roads and Traffic Authority - RTA) prior to the commencement of longwall mining in the Wongawilli Seam adjacent to Mount Ousley Road and the Cataract Storage Reservoir.

Our research indicates that the Balgownie Seam records are of a high quality and reliability having been drafted or converted to the standards of the 1976 survey and drafting instructions for coal mine surveyors. These records provide relevant information regarding mining heights and implications for the inferred status of the overlying Bulli Seam workings from interpretations of the subsidence monitoring conducted for the Balgownie Seam longwalls.

Our research is based on review of the mine workings plans (original and redrafted versions) held by WCL, the recording tracing hand drawn copies of the plans (from circa 1948), a plan from 1903 and annual production plans for the years 1911, 1912, 1913, 1916, 1917 held in the University of Wollongong library archives and the recently discovered (May 2021) mine working plan held by the AusIMM – Illawarra Branch – Mineral Heritage sub-committee. This mine working plan, in combination with the others held by WCL, provides the details, missing on some later mine working plans and the record tracings, for mining within all the Bulli Seam areas shown as goaf above or in the vicinity of the planned bord and pillar mining in the Wongawilli Seam at RVE.

Observations from subsidence monitoring, borehole drilling and other investigations are included.

This appendix is structured to include relevant points in background information on:

- The evolution of mining layouts in NSW.
- The history of surveying for and drafting of mine plans.
- The correlation of Bulli Seam records with Balgownie Seam records.
- A review of the Balgownie Seam vertical subsidence measurements in the context of latest understanding of the mechanics of multi-seam subsidence.
- Details of other investigations into or observations of the status of the Bulli Seam workings.

The appendix provides a review of the mine plans for accuracy, completeness and percentage extraction or likelihood of remnant pillars in goaf areas that may affect subsidence outcomes.

A3.2 Conclusions

Our research indicates that the detail of the historical Bulli Seam and Balgownie Seam mining is now available for all areas of interest to the currently planned Wongawilli Seam mining in RVE. The complete details for the goaf areas recorded at the time of mining can be pieced together by combining all information shown on the from the mine workings and record tracings. The interpretation and assumptions made by SCT in previous assessments of pillar stability at RVE are consistent with this detail.

Our review of the available evidence indicates the Bulli Seam records are accurate, complete and the only remaining uncertainty is in the percentage extraction as shown by the drafting standards. This uncertainty is common for all historical mine plans and reflects the ‘artistic licence’ of the surveyors and draftsmen of the day. This artistic licence is still common practice in pillar extraction mining using continuous miners including the depiction of stook ‘X’ in Wongawilli system mining.

It is not considered practical to drill boreholes across the entire area of Bulli Seam goafs to confirm the status of each of these areas. This view is also recognised by the IAPUM (2020). Other methods are likely to be more effective. Geotechnical mapping of mining conditions in the Wongawilli Seam is expected to provide clear evidence of the presence of goaf edges in the Balgownie and Bulli Seams and any load bearing remnant pillars remaining in the Bulli Seam goaf areas.

The subsidence monitoring data from the Balgownie Seam longwall mining indicates consistent incremental vertical subsidence. The variation in subsidence is less than 200mm and within the variability expected for multi-seam mining. Natural variability, latent subsidence and changing incremental subsidence as a percentage of seam mining height with each successive seam mined are recognised to contribute to variability. There are no significant variations in magnitude or irregularities in subsidence profiles that would indicate collapse or progressive failure (pillar run) of standing pillars over a substantial area.

Substantially higher than predicted subsidence from the mining of Longwalls 4 and 5 in the Wongawilli Seam is consistent with under-prediction of subsidence for these panels. Consistent with the IAPUM (2020) advise our research indicates the issue stems from under-prediction of subsidence levels rather than excessive subsidence for the multi-seam mining geometry in Longwalls 4 and 5. Almost all the Bulli Seam areas above Longwalls 4 and 5 had been previously undermined by Longwalls 8-10 in the Balgownie Seam. There is no potential for standing pillars and open voids to remain in the Bulli Seam above Longwalls 8-10 in the Balgownie Seam prior to the mining Longwalls 4 and 5 in the Wongawilli Seam.

A3.3 Mining Layouts and Method

Coal mining in NSW has been undertaken for approximately 220 years in the Newcastle area and for around 170 years in the Southern Coalfield with mining at RVE for more than 130 years.

The evolution of coal mining layouts for the bord and pillar method in NSW 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. Local anecdotal evidence indicates pillar crush or creeps did occur. It appears minor events may have been a regular occurrence and as such are not well documented.

The first workings of the early Bulli Seam mining in RVE (and at the adjacent Old Bulli and Corrimal mines) using hand working methods were developed to maximise coal recovery percentages. These workings date from circa 1860 and 1870. The method has been referred to as “Welsh Boards” and consisted of long narrow driveages (bords) that were progressively widened out leaving narrow pillars of coal between adjacent bords. The bords were widened to about 8 yards (7.3m) with pillars as small as 4 yards (3.7m) wide between the bords. The smallest pillars had width to height ratios of less than 2. There are large areas of these bords and pillars in the earliest workings of South Bulli (including Bellambi), Old Bulli and Corrimal mines.

Some of the narrow pillars have then been removed by a secondary extraction process and are shaded or cross-hatched and labelled as “pillars extracted”, “coal extracted” or “pillared”. Other areas are shown as remaining with notations of “bords worked” or “worked ground”, “old workings and falls” and “fallen bords”. Presumably, the latter comments refer to the areas becoming unstable and inaccessible for secondary extraction, effectively sterilising the coal remaining in the narrow pillars.

Following a significant pillar failure accident in the 1880’s (in the Newcastle coalfield) and subsequent government inquiry and royal commission into mining conducted in the 1890’s, it was recommended that bord and pillar mining systems be adjusted to increase pillar widths to 8-16 yards. The methods and systems of working were still not extensively prescribed, and it is likely these would have overseen by government mines inspectors allowing some tolerance on local ‘rules of thumb’.

As the mining advanced, the mining layouts reflect a change to larger first pillars and the option of a more systematic or controlled secondary extraction process.

The first mention of losses, or sterilizing, of coal from methods or systems of working is in a 1941 amendment to the 1912 Coal Mines Regulation Act (CMRA). This is likely a reference to the impacts from unstable mining geometries and potential pillar failure or pillar run or pillar creep events.

The CMRA 1912 was amended in 1964 after the 1960 mining disaster at Coalbrook Colliery in South Africa involving the collapse of substantial areas of pillars. These amendments to the CMRA 1912 included maximum roadway widths being restricted to 6 yards and minimum pillars widths were prescribed as 8-26 yards, based on depth, with widths of 12-18 yards more typical for the depths at RVE. Mining heights were also restricted to 14 feet without the consent of the Minister. These dimensions were converted to metres in a 1974 amendment to the CMRA 1912 and this prescription for pillar widths and percentage extraction at various depths remained in place until the 1984 Regulations were introduced to support the CMRA 1982. It is noted that the 1982-84 legislation removed the prescription controlling mining heights.

Large areas of small pillars in the early Bulli Seam workings at RVE have either been removed by the secondary extraction of coal between roadways (bords), are expected to have deformed (collapsed) by abutment loading or been destabilised (collapsed and subsided) by secondary extraction in the Balgownie Seam below. Any small pillars with low w/h ratios around the perimeter of areas shown on plans as extracted (or “worked out”) are likely to have collapsed at or around the time of secondary extraction of the Bulli Seam, or if in the vicinity of the Balgownie Seam panels then, during the time the secondary extraction in the Balgownie Seam was undertaken.

A3.4 History of Surveying for and Drafting of Mine Plans in NSW

An appreciation of the reasons mine plans were prepared and the standards for reporting are helpful in the interpretation of the mine working plans and record tracings and other information recorded on mine plans.

The information on early mine working plans were recorded for two main reasons: first, to provide operational (production) needs of the mine and second to comply with NSW legislation. This legislation was aimed at both workplace health and safety and public safety.

Extensive historical research and re-education of the coal mining industry on the accuracy and reliability of mine plans was undertaken in 1998 to comply with the recommendations from the Gretley Disaster Inquiry (DMR1998). The following passage summarises the key points considered appropriate to this assessment.

- The first coal mining by European settlers in NSW is believed to have started in the late 1790's. In the Illawarra district, the first legal mining started in the 1840's.

- The first legislated requirement to accurately record mine workings on a plan was in 1902.

- The requirement to preserve mining plans was first introduced in 1931 when the plan of abandonment at the cessation of mining at a site was to be sent to the Mines Department for future reference.

- Plans were not required to be certified as accurate by a surveyor until 1931.

- The requirement for certificates of competency for mining surveyors was not introduced until 10 years later in 1941.

- Amendments to the 1912 NSW Coal Mines Regulation Act (CMRA) enforcing the Record Tracing concept (a second accurate copy of mine working plan information) were gazetted in 1947.

- While the requirement to keep plans and copies in safe keeping was then in place, the actual standards for surveys and the drafting methods for depiction of the workings and associated information, was still missing. This meant that many adjacent mines had different coordinate systems and height datums as well as different ways of showing the same type of mining method.

- Previous amendments to the 1912 CMRA had provided for 'the general rate and direction of dip of the strata', but the requirement to record detailed information for reduced levels of the seam floor and geological features in the workings were not introduced into legislation until during the 1950's with further amendments in the early 1970's.

- The first attempt to set uniform standards for surveying and drafting practices was in 1968, but it was not until 1976 that the comprehensive Surveying and Drafting Instructions for Coal Mine Surveyors were published.

- These instructions and the introduction of the Integrated Survey Grid (ISG) for NSW brought into place standard practices for systems including coordinate grids, height datums, scales of plans, the plan area and orientation (with no overlap) and as well as the requirement for a separate plan (or series of plan sheets) for each seam worked.

This summarises the evolution of hand-drawn plans. All of the earliest plans at mines were drafted by hand. Sometimes these were on large scroll type natural drafting medium (linen or cloth) or 'film' type medium suitable for tracing. There were many plans kept for operational and statutory requirements, that were invariably drawn by different individuals, at various scales and were not necessarily traced from previous plans.

- Since the surveying and drafting instructions and ISG were implemented, opportunities for further inconsistencies to develop have arisen through the advent of Computer Aided Drafting (CAD) and conversion to digital records, as well as the transformation from state to national (and international) coordinate systems for mapping.

- The current surveying and drafting standards for the digital Mine Survey Plan (no longer mine working plan and record tracing) in NSW are now contained within the Surveying and Drafting Direction for Mining Surveyors 2020.

This summary of the development of mine plans and record keeping indicates that there are likely to be differences across the database of information in the type of information presented, the level of detail, the completeness, and the accuracy of that information. Prior to 1977 there is a standard, prior to 1948 a different standard with a significant change in 1931. As a warning, users should be more suspicious of plans of mine workings abandoned prior to 1947 that have been stamped "Record Tracing" by the Department of Mines. These plans may not have been compiled to the standard expected of a record tracing.

From 1931, with the legal requirement to certify as accurate the quarterly (3 monthly) working places surveys, regular datelines for all mined areas appear on the plans for the first time. Prior to 1931, there are some workings dated but because it was not a legislated requirement, there is often inconsistency in the frequency of date notations. A change in the detail recorded in response to the 1931 legislative change is clearly apparent in the later mine working plans for South Bulli and the adjacent mines.

It has also been recognised through experience, that different surveyors (and mining companies) have different interpretations of legal requirements. The compliance with standards may have been enforced through auditing by the local mines inspectorate. This auditing may have been infrequent. Poor compliance often resulted in opportunities to collect data being lost due to mining progress making worked–out areas inaccessible. The nature of some mining methods precludes the possibility of retrofitting newer legislated standards for recording information in previously mined areas.

There are two key points in the evolution of mine plan standards relevant to this research. The first point is the extension of the plan area as the early mining areas expanded and the overlap for each plan area as additional mine working plans were created. The second point is the introduction of record tracings.

A3.4.1 Plan Area Overlap

The overlap issue stems from extending the mine plan areas as the mine expands in a sometimes irregular manner and a new plan is created to cover the new mining area. The new mining area may have changed from the previous intentions in size or direction based on more working places for greater production, unexpected geological features, change to leases or other factors. These plans could be physically large (commonly up to 1.8m wide and 5m long) with a large scale of 1:1584 (1 inch equals 2 chains) to capture more detail clearly. In this instance, it was typical for the new plan created not to show all the detail in the overlap section of the plans as all plans were drafted by hand. It was common practice to outline an area of secondary extraction with a polygon and a notation of “pillars extracted” or “goaf” (or similar) to reduce the amount of work in creating the new plan. Afterall, the detail was already recorded on the older plan.

However, some of the mine plan detail for the earlier mining could be lost as the older plans physically deteriorate, are misplaced, or destroyed.

A3.4.2 Record Tracings

The introduction of record tracings, circa 1948, as an accurate copy of the mine working plan information for safe keeping, resulted in the mine working plan information, including some areas where there as a lack of information, being duplicated. The record tracings do not necessarily include all information from all the mine working plans produced over the life of the mine.

The creation of record tracings appears to have been a massive undertaking at some larger mines at that time. This is seen in the standard of plans deemed to be record tracings. Some are clearly new plans drafted to satisfy the legislated requirements while others appear to be plans already in existence at the mine that have been designated as a ‘record tracing’.

The original record tracings for RVE are new plans created to satisfy the legislation. However, these record tracings, as a copy of the mine working plans, include some of the polygons of ‘goaf’ areas without all the detail for workings prior to 1931.

The manual redrafting of the Bulli and Balgownie Seam workings at RVE to the standard of the 1976 Surveying and Drafting Instructions including ISG coordinates and reduced levels on AHD 1971 datum, are the basis of the digital CAD files currently in use. The mine working plans and record tracings, in ISG format, appear to be scaled and orientated tracings of some original mine working plans and the original record tracings. These ISG plan area sheets have been converted to the MGA94 coordinate system and stitched together to provide the current digital plan drawings. The lack of detail in some of the ‘goaf’ polygons for areas mined prior to 1931 remains but the missing detail is available in the format of the original mine working plans including the mine working plan uncovered in May 2021.

A3.5 Correlation of Bulli Seam and Balgownie Seam Records

Research into the history of the Balgownie Seam mining at South Bulli Colliery has been undertaken to investigate any previous interactions or commonality that may have relied on the accuracy of the position of the Bulli Seam workings. Mining systems such as ventilation, coal transport and labour and materials transport are shown to have been linked between the seams via several drifts and staple shafts near the outcrop in the eastern section of the mine. Further historical research has also revealed that the hazard of inrush from the overlying Bulli Seam workings, appears to have been dependant on the correlation of the workings in both seams. This inrush hazard was effectively managed by the sequencing of the mining operations in conjunction with a series on inter-seam boreholes to drain the ponded water and allow the mine atmosphere to be tested. Most of these boreholes were drilled from first workings roadways to first workings roadways in the overlying seam.

It is noted that the information uncovered, and the resulting interpretations are consistent with the previous assumptions and conclusions reached from assessments for both mine water balance and pillar run (creep) potential during the UEP - PPR subsidence and groundwater studies conducted by SCT. The following section outlines the background and a summary of the water management measures successfully employed for the retreating longwall faces of the Balgownie Seam mining.

The initial area of the Balgownie Seam selected for longwall mining in the late 1960's was directly below an extensive goaf area in the Bulli Seam with bord and pillar workings dating from around 1910 to the 1930's that was suspected to be partially flooded due to the evidence of underground water flows that were able to be observed and the extent of the workings and dip of the seam depicted on the mine plans of the area.

The shape and volume of this water lodgement was controlled by an unmined barrier of coal known as the 'No7 left' or 'No7 SW" (southwest)' pillar off the Main North-West Headings, with the overflow from No7 left district being handled by the mine dewatering system. Sufficient survey information was available to permit the floor contours within the goaf area to be plotted with reasonable accuracy. Due to the safety concerns and the legislated requirements at that time, it was intended to dewater the Bulli Seam workings at a rate that would keep the vertical boundary of the water level at least 200m from the longwall faces. An early attempt to lower the water levels in the Bulli Seam via pumping infrastructure installed and advanced as required at this horizon was quickly abandoned due to the difficulties of reconstituting and maintaining access to the previously worked-out areas. Instead, inter-seam boreholes were drilled from the Balgownie Seam development panels. As a result of the large volumes of accumulated water (and recharge rate) against to No7 left barrier and the required timeframes, the development workings were sequenced to provide progressively lower access points to the inferred ponded water lodgements while maintaining safety for the development units and continuity of longwall operations.

From close inspection of the mining dates, it appears that in some instances the development panel faces were stopped for up to 12 months at a time while the drilling and draining rendered the overlying inrush hazard harmless. In some cases, it seems that this process was then repeated after only a short distance of panel advance due to the geometry of the Bulli Seam layouts compared to the Balgownie Seam longwall panel alignments, seam gradients and the potential risks. The mine working plans and the record tracings for the Balgownie Seam detail a total of seven boreholes sites with eight boreholes (one site with two parallel boreholes). Records from other sources indicate that eight borehole sites where established (including three sites with two parallel boreholes each) with one borehole attempt unable to successfully hit the intended target. The reason provided for this failure seems feasible. It is not suggested that it was due to the accuracy of the Bulli Seam mine plans.

The possibility has been considered that other boreholes failed to hit the target may not be documented on plans. However, the success of this dewatering program is in part due to the availability of accurate plans of the Bulli Seam workings, significantly the position of the first workings roadways developed prior to 1931. These 75mm diameter boreholes were drilled over a period of almost five years from 1973 to 1978 in an area covering Longwalls 6 to 11 of the Balgownie Seam and were estimated to have drained 890ML from the Bulli Seam workings. Although the interburden thickness between the Bulli and Balgownie Seams is only about10m, the drilling distances were up to 115m in length because of the targeted inclination and direction of the boreholes. Given the borehole steering and surveying technology of that time it is likely that it would have been difficult to achieve the planned outcomes to an accuracy of a few metres necessary to intersect roadways in the overlying seam.

WCL have also drilled inter-seam boreholes between 2009 and 2015 for inrush prevention purposes. These boreholes were drilled from the Wongawilli Seam to both the Balgownie and Bulli Seam during the development and secondary extraction of Longwalls 4, 5 and 6. The boreholes drained overlying water lodgements, that have accumulated after longwall mining in the Balgownie Seam, and in Bulli Seam areas outside the Balgownie Seam longwall footprint. This drilling program for hazard reduction further confirmed the accuracy of the Balgownie and Bulli Seam mine plans to within a few metres and their relativity to the Wongawilli Seam workings.

A3.6 Subsidence Monitoring for the Balgownie Seam Longwalls

In this section, insights into the status of the Bulli Seam goaf areas provided by the subsidence monitoring for the Balgownie Seam mining are discussed.

The incremental vertical subsidence measured for the mining of the Balgownie Seam longwalls is reviewed in the context of the advancements in understanding of the mechanics of multi-seam subsidence behaviour made since 2014.

Monitoring of subsidence from the Balgownie Seam longwalls was comprehensive for the period of mining. Each of the 11 longwalls mined between 1970 and 1982 had a longitudinal line along the whole length of the panel and three perpendicular cross-panel lines were also installed across Longwalls 1-11.

The incremental vertical subsidence was monitored at regular intervals during panel retreat above the initial panels and less frequently during mining of the last few panels. Ground strains were only measured during the last panel; Longwall 11. The last subsidence surveys for the Balgownie Seam longwalls were completed in 1983.

Maximum vertical subsidence in a single seam mining environment is naturally variable by about 15% for any given panel geometry and overburden depth. In a multi-seam situation, this variability is typically greater due to the sensitivity of subsidence to the interaction between mining geometries in each seam.

A3.6.1 Multi-Seam Subsidence at Ashton Underground

Mills and Wilson (2017) present measurements and observations of the incremental and cumulative subsidence effects from longwall mining in two seams in a regular, parallel, offset geometry at the Ashton Underground mine in the Hunter Valley of NSW. More recent monitoring of additional panels in the second seam up to 2020 at this site confirms the earlier observations and interpretation for two seams and includes additional learnings for multi-seam subsidence from longwall mining in three seams.

The key points from the Ashton observations applicable to this assessment of the Balgownie Seam monitoring are summarised here.

The Ashton site is unique when compared to other multi-seam sites for several reasons including:

- Longwall panels are all mined in a regular, parallel, offset layout with substantial remaining chain pillars. In the multi-seam area mined to date, all longwalls are of the same width and all chain pillars are of similar width.

- Gradually increasing overburden thickness toward the west, so that the overburden depth increases with each subsequent panel. Initial panel geometry in the upper seam is supercritical transitioning to near-critical width to the west.

- Longwall panels with different starting and finishing positions and goaf edge geometries enable a range of mining scenarios to be studied.

- Modern, reliable mine plan records.

- No areas of irregular pillar extraction (bord and pillar mining)

- No potential for small remnant pillars (or ‘stooks’) to fail and contribute to risk of pillar run or pillar creep.

For the longwalls mined to date in the upper two seams:

- All longwall voids are 216m wide and all inter-panel chain pillars are 24m wide.
- Mining heights for each seam are similar at 2.5m ±0.3m.
- Interburden thickness is 35-40m.
- Panels are offset by 60m.

The monitoring data allows the mechanics that drive the magnitude and the distribution of subsidence movements in the multi-seam environment at the site to be determined. Effects such as:

- difference in behaviour between overburden strata that is undisturbed by previous mining and strata that has already been subsided (disturbed or modified)
- recovery of latent subsidence from the overlying seam
- the effects of stacked goaf edges
- the effect of mining direction on subsidence above stacked goaf edges.

Analysis and interpretations of the Ashton data, where the mining layouts are regular and mechanics of subsidence behaviour are easily identified, indicates:

- Subsidence from multi-seam mining is more complex than for single seam mining, but the mechanics of overburden behaviour in response to mining are consistent. The incremental vertical subsidence profiles, with prominent latent subsidence areas, are regular and repeatable and as such, predictable once the various interactions and geometry effects are recognised and considered.
- Some conventional single seam concepts such as angle of draw and subcritical-supercritical width are less meaningful for multi-seam mining due to the subsequent behaviour of the disturbed (or modified) ground beyond the first episode of subsidence.

Although not directly applicable at RVE, due to the irregular mining geometries (including an absence of stacked goaf edges) and reduced interburden thickness, the key points of relevance to the Balgownie Seam monitoring data for vertical subsidence parameters from the two seams of mining at Ashton are:

- In general background areas (away from overlying pillar edges), incremental subsidence is approximately 75% (72-83%) of the seam mining height. This percentage reduced with subsequent panels where depth increased, and a more critical width behaviour was observed.
- Where latent (extra) subsidence is recovered from near the edges of the overlying pillars where the supporting effect to the overburden from the pillars is lost, incremental subsidence of approximately 90% (up to 92%) of the seam mining height was measured. This percentage was also observed to reduce in subsequence panels. Although the magnitude of latent subsidence is not a function of the lower seam mining height. In the case of Ashton, this additional, 15% was about 300mm for a 2.5m mining height in the overlying seam.
- This greater incremental subsidence, as a percentage of mining height, is due to the softening of the overburden strata or a reduction in shear stiffness with each episode of subsidence which reduces the bridging or spanning and overhang ability of the overburden and results in wider and steeper subsidence troughs.

It should be noted:

- Depending on the overlying geometry and where any latent subsidence is released, the latent subsidence component may not necessarily increase the maximum value in the subsidence profile.

- Where longwall extraction in the second seam starts below a goaf, subsidence at this goaf edge is greater and the angle of draw increases. Minor subsidence is seen to extend out the next load bearing pillar in some cases. The angle of draw around the outermost panel edge remains largely unchanged.

A3.6.2 Multi-Seam Subsidence from the Balgownie Seam

Figure A3.1 shows the Balgownie and Bulli Seam workings with the 11 longitudinal and 3 cross-panel subsidence monitoring lines and measured vertical subsidence profiles.

This section details our review of the Balgownie Seam subsidence data. Previous reports by others have stated the incremental vertical subsidence was equivalent to or greater than mining height (Kapp 1982, Holla and Barclay 2000 and MSEC 2007). Our research does not indicate this.

The Balgownie Seam longwalls are of two different widths with either two-heading or three-heading gateroad panels. The seam thickness is approximately 1.3m.

The voids for Longwalls 1-6 are approximately 143m wide with tailgate chain pillars widths in two heading or three heading layouts of approximately 17m or 26m.

Anecdotal evidence (personnel communication with operators) indicates the mining height was equal to seam thickness for Longwalls 1-6 and was increased to greater than seam thickness in Longwalls 7-11 after new longwall face equipment was purchased. One of the 'run-of-face' longwall supports used in these later panels is on display in a park on the Princes Highway at Russell Vale.

Voids for Longwalls 7-11 are approximately 189m wide and chain pillars are approximately 40m wide. These panels are in two sections as they step around a dyke structure referred to as Dyke D8 leaving a section of coal on either side of the dyke. The ISG mine plan records indicate mining heights in gateroads were greater than seam thickness. The detailed roof and floor RL information for the gateroads shows heights of 1.5-2.0m. Anecdotal evidence indicates mining height on the longwall face was at least 1.5m, achieved by mining the carbonaceous shale below the seam floor.

For Longwalls 1-6, individual panels are subcritical in a single seam context. The average overburden depth ranges 250-280m. The panel width to depth ratio is 0.51-0.58. In a single seam context, maximum subsidence of 30-40% of the mining height or up to approximately 0.5m would be expected over these early longwalls. However, in the multi-seam environment up to 75% of the mining height or approximately 1.0m would be expected with any latent subsidence being additional. These estimates exclude natural variation for single and multi-seam subsidence.

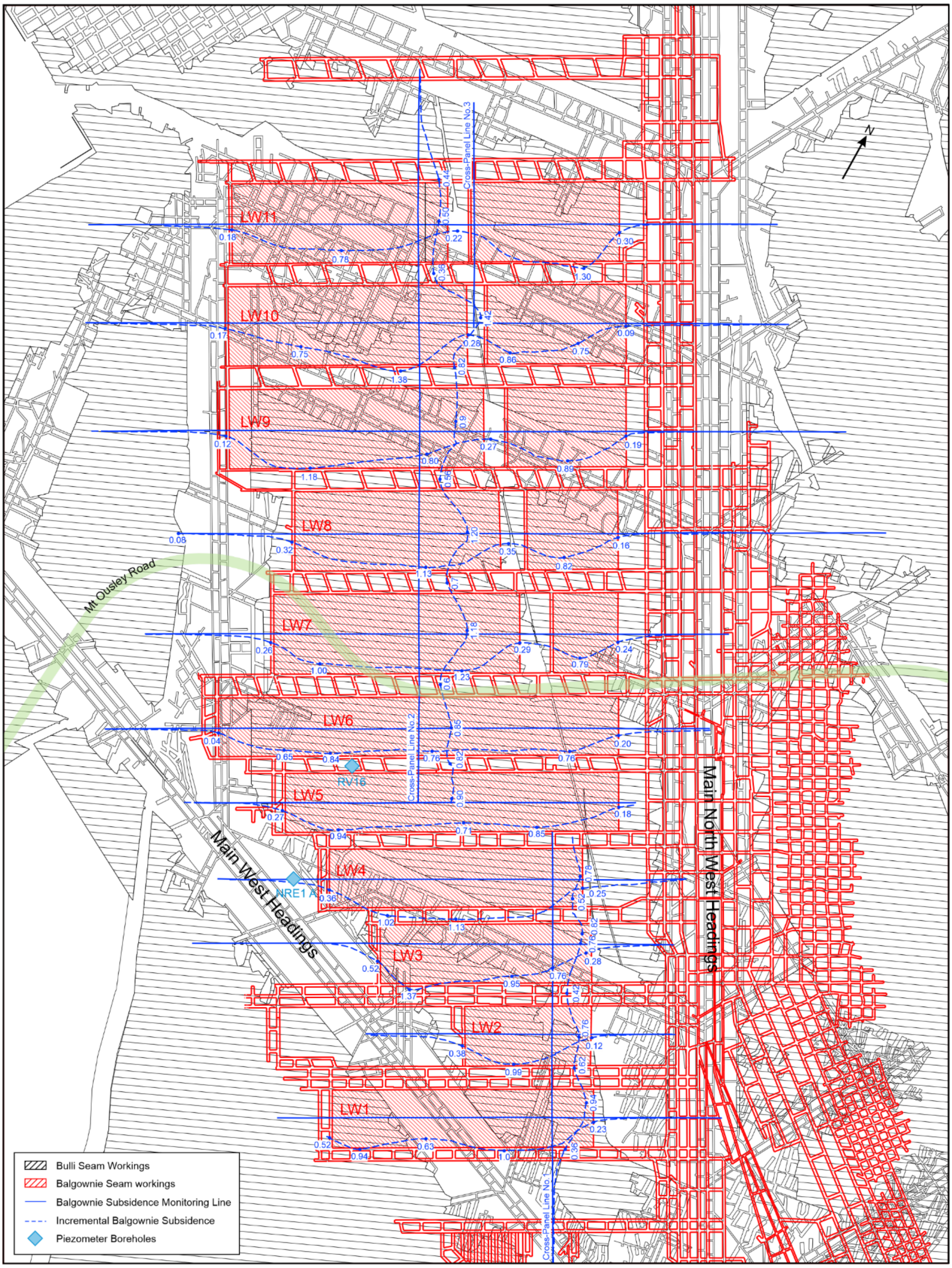


Figure A3.1: Incremental Subsidence measured for Balgownie Seam Longwalls.

For the wider Longwalls 7-11, the mining geometry is also subcritical in single seam terms. The average overburden depth ranges 275-280m. The panel width to depth ratio is 0.67-0.69. In a single seam context, maximum subsidence of about 45% of the mining height or approximately 0.7m would be expected over these later longwalls. However, in the multi-seam environment up to around 75% of the mining height or up to 1.2m could be expected excluding any latent subsidence. These estimates exclude natural variation.

Table 1 shows details of the actual incremental subsidence measured on the longitudinal monitoring lines above Longwalls 1-6 and Longwalls 7-11. The maximum subsidence shown was measured between 6 months and 9 years after individual panels were mined.

Table1: Balgownie Seam Incremental Vertical Subsidence on Longitudinal Lines

Longwall	Goaf Edge at panel start	Maximum	Estimated Latent	Minimum over large Bulli pillars	Goaf Edge at panel finish
LW1	0.52 (below goaf)	1.00	-	0.63	0.23 (near Bulli goaf edge)
LW2	0.38 (below goaf)	0.99	-	-	0.12 (near dyke)
LW3	0.5.2 (below goaf)	1.30 (includes latent)	0.3	0.76	0.28 (below goaf)
LW4	0.36 (below Bulli pillars)	1.13 (includes latent)	0.1		0.25 (below goaf)
LW5	0.27 (near goaf edge)	0.94	-	-	0.18 (below goaf)
LW6	0.04 (below Bulli pillars/solid)	0.84	-	-	0.20 (below goaf)
LW7	0.26 (near goaf edge)	1.23	-	-	0.24 (below goaf)
LW8	0.32 (below goaf)	1.13	-	-	0.16 (below Bulli pillars)
LW9	0.12 (below Bulli pillars/solid)	1.18	-	0.80	0.19 (below goaf)
LW10	0.17 (below Bulli pillars/solid)	1.38	0.25	0.75	0.09 (below Bulli pillars/solid)
LW11	0.18 (below Bulli pillars/solid).	1.30	-	0.78	0.30 (below goaf)

The data from the long-panel lines indicates consistent vertical subsidence behaviour. The variation in subsidence for similar geometry and locations is less than 200mm. This range is within expectation for multi-seam mining including considerations for natural variability, latent subsidence and incremental subsidence as a percentage of second seam mining height. Significantly, there are no variations in magnitude or irregularities in subsidence profiles that would be consistent with collapse of standing pillars over a substantial area or any form of 'pillar run' (widespread destabilisation of pillars).

Tables 2 and 3 show details of the actual incremental subsidence measured on the cross- panel monitoring lines No1 and No2 above Longwalls 1-4 and Longwalls 5-11, respectively.

Table 2: Balgownie Seam Incremental Vertical Subsidence Cross-Panel 1

Subsidence (m)							
Goaf Edge	LW1	Chain pillars (3 hdgs)	LW2	Chain pillars (3 hdgs)	LW3	Chain pillar (2 hdgs)	LW4
0.36 (below Bulli pillars)	0.94 (below Bulli pillars)	0.62 (below Bulli pillars)	0.76 (below Bulli solid/pillars)	0.42 (below Bulli solid/pillars)	0.82 (below Bulli solid/pillars) Includes 0.1 latent	0.52 (below goaf)	0.78

Table 3: Incremental Vertical Subsidence (m) on Cross-Panel Line No2

Subsidence (m)											
LW5	Chain pillar	LW6	Chain pillar (wider)	LW7 (wider)	Chain pillar (wider)	LW8 (wider)	Chain pillar (wider)	LW9 (wider)	Chain pillar (wider)	LW10 (wider)	Chain pillar (wider)
0.90 (below goaf	0.82 (below goaf	0.85 (below goaf)	0.6 (below goaf)	1.18 (below goaf)	0.70 (below goaf)	1.20 (below goaf)	0.56 (below goaf)	0.90 (below Bulli pillars)	0.82 (near Bulli pillars) includes 0.1 latent	1.42 (near Bulli pillars) includes 0.3 latent	0.36

The vertical subsidence is consistent with expectations for the Balgownie Seam geometry and confirms the status of the overlying Bulli Seam workings.

Comparing the subsidence measured on the long and cross lines and considering the line position relative to panel edges, the values on cross-panel lines agrees with the long-panel data to within 100mm.

The subsidence monitoring data from the long-panel and cross-panel lines indicates that, in the vicinity of the monitoring lines:

- Areas above and immediately adjacent to the Balgownie Seam longwalls are collapsed and fully subsided.

- Areas of Bulli Seam shown as goaf were collapsed prior to mining of the Balgownie Seam longwalls. These areas include remnant pillars in the Bulli Seam identified on mine plans.

- In isolated areas, smaller pillars located above the panel edge are observed to soften the subsidence profile. Their status prior to mining the Balgownie Seam longwalls cannot be determined so it is possible that pillar instability was caused by the Balgownie Seam longwalls, but the effect is limited in magnitude and extent.

A3.7 Other Investigations and Observations

Other investigations that indicate the status of the Bulli Seam workings include the drilling of surface to seam boreholes, underground inspections of accessible Bulli Seam workings identified on the mine plans with potential to be marginally stable if not already collapsed and subsided, and observations of elevated vertical stress conditions in the Wongawilli Seam below the edges of overlying goaf areas.

A3.7.1 Boreholes

A surface to seam borehole referred to as RV16, was drilled in 2014 to investigate the status of the Bulli Seam goaf area as part of groundwater monitoring. This borehole was positioned to drill through the Bulli Seam horizon, through the Balgownie Seam chain pillar between Longwalls 5 and 6 and down to the floor of the Wongawilli Seam. Some wood fragments, but no coal, were recovered in core from the depth where the Bulli Seam was expected. This uncased borehole was able to maintain a 300m head of water during drilling and piezometer installation but the piezometric profile indicates a downward hydraulic gradient toward the mine.

The observations in this borehole confirm the Bulli Seam is extracted and the roof strata has collapsed at this location.

The collapsed status of the Bulli Seam at the location of RV16 is consistent with the mining detailed in the recently discovered mine working plan and in the annual production plans from 1913, 1916 and 1917. These plans indicate the Bulli Seam was extracted at this location within the larger area that is now depicted as 'goaf' on other mine workings plans and record tracings. Extraction of the Bulli Seam and collapse of the strata above the Bulli Seam is also consistent with the subsidence profiles from the Balgownie Seam mining along the cross-panel monitoring line that traverses the longwalls panels adjacent to this location.

Figure A3.2 shows the extent of mining in the Bulli Seam in the vicinity of location of RV16 from the 1916 yearly plan and the mine working plan for this area. A later mine working plan which also includes this area shows that additional pillar extraction to the west was undertaken in 1944.

a) Position of Borehole RV16 relative to Bulli Seam workings on plan from 1916.

b) Position of Borehole RV16 relative to Bulli Seam workings on mine working plan to 1932.

Figure A3.2: Position of Borehole RV16 relative to Bulli Seam records.

Borehole NRE1A provides confirmation of the existence of the Bulli Seam barrier pillar adjacent to the Main West Headings. NRE1A is a groundwater monitoring borehole, drilled in 2009. The hole is positioned above the Bulli Seam coal barrier and outside the Balgownie Seam mining footprint. The hydrostatic piezometric pressure profile at this location indicates there has not been any drawdown at this location consistent with the strata above the barrier pillar being intact and likely compressed by abutment loading from the surrounding goaf areas.

A3.7.2 Inspections

An underground inspection of two areas of Bulli Seam workings identified from mine plans as potentially unstable and were still accessible was conducted by SCT in June 2013.

An area of Welsh bords adjacent to the Main North West Headings (main headings) to the east of Mount Ousley Road have been described as marginally stable, a pocket of standing pillars with potential to become unstable and collapse with some subsidence is possible, and an area where additional subsidence is considered possible due to pillar instability.

Research indicates the roadways (bords) in this area were mined from1899-1901. These roadways were driven adjacent to an area with a similar layout where the bords were mined and the pillars extracted during the 1890's. The earlier workings were developed, and the pillars extracted, up to a dyke. Subsequent longwalls in the Balgownie Seam (Longwalls 1 and 2) mined below the earlier area of pillar extraction and stopped short of the dyke.

The remaining Welsh bords are separated from the Bulli Seam pillar extraction area and Longwalls 1 and 2 by a barrier of solid coal on one side and the barrier of coal adjacent to the main headings on the other side.

Although inspected and considered "marginally stable" at the time, assessment of this remaining section of Welsh bords indicates that the smallest pillar shown on mine plans has a width to height ratio of five, a factor of safety of 1.4 and a probability of instability of 2 in 100.

The smaller pillars are adjacent to larger pillars and together with the surrounding barrier coal may explain why these pillars are still standing some 120 years after being formed. Nevertheless, these pillars are not considered long-term stable and an estimate of the potential subsidence should these pillars collapse or be destabilised into the future indicates maximum vertical subsidence is expected to be less than 0.3-0.5m due to the width of this area of standing pillars and the depth below the surface. Any additional subsidence would be over a small, isolated area where there are no surface features sensitive to subsidence movements.

A second area of pillars identified on the Bulli Seam mine plans directly to the west of Mt Ousley Road were also inspected. Although shown as unmined, these pillars were undermined by Longwall 7B in the Balgownie Seam. This area is described as an area where pillar instability was evident directly above the edge of the Balgownie Seam longwall goaf.

Observations from the inspection were consistent with expectation and indicate the Bulli Seam horizon was completely collapsed and subsided forming part of goaf from the floor of the Balgownie Seam horizon approximately 10m below. A similar situation is expected in all areas of the Bulli Seam undermined by the Balgownie Seam longwalls.

A3.7.3 Underground Mapping and Stress Observations

There are many places in the Wongawilli Seam at RVE where the overlying goafs have elevated the vertical and horizontal stresses resulting in difficult mining conditions. The change in stress results from loads generated around the abutments of secondary extraction areas or from remnant pillars within secondary extraction areas. These areas of increased stress are associated with both Bulli and Balgownie Seam goafs with the Balgownie generally dominating the Bulli Seam due to the proximity to the Wongawilli Seam mining horizon. However, there are clear examples of difficult conditions adjacent to the Bulli Seam goaf edges, including the in main headings, Maingate 6 Panel transport road and Tailgate 9 Panel where the continuous miner was buried.

Elevated stress levels are expected to provide a strong indication of the status of the overlying Bulli Seam goaf areas. There are currently seven Bulli Seam goaf areas that are likely to have collapsed but there is no direct evidence from subsidence monitoring or observations from mining below to confirm this collapse. Underground observations of roadway conditions in the Wongawilli Seam are considered a reliable technique to confirm these areas have collapsed and subsided.

A3.8 Predicted and Actual Subsidence for Wongawilli Seam Longwalls

The original subsidence predictions for the Wongawilli Seam longwalls in RVE for the UEP were undertaken by Seedsman Geotechnics Pty Ltd (SG). These predictions and updates were subsequently used for modification to the Preliminary Works Project (PWP) approval to allow secondary extraction of Longwalls 4 and 5 and in applications for a Subsidence Management Plan (SMP) for these two panels.

An initial report (SG 2011) discusses the potential for reduced bridging capacity of the overburden after multi-seam mining but predicts a low-level of vertical subsidence of 0.2m over the majority of Longwall 4 and up to 1.2m over Longwall 5. It is noted that the lengths of Longwalls 4 and 5 were shortened several times after SG (2011).

The predictions for vertical subsidence were revised (SG 2012a) after the first subsidence survey for Longwall 4 during the extraction of this panel. Maximum vertical subsidence of 1.2m was predicted for both Longwalls 4 and 5 based on what was measured above Longwall 4 at that time of the first survey and the assumption that there is a reduction in spanning capacity of the overburden strata due to previous subsidence associated with the overlying Bulli and Balgownie goaf areas.

The prediction for vertical subsidence in the SMP for Longwall 5 (SG 2012b) was revised again to 1.4m after mining of Longwall 4 was complete and subsidence for this first Wongawilli Seam panel was measured.

The actual incremental subsidence measured over Longwall 4 after mining in this panel was 1.4m. This incremental subsidence increased to 1.8m after the mining of Longwall 5 with compression of the inter-panel chain pillar and strata above and below the pillar. Maximum incremental subsidence measured over Longwall 5 at the completion of this panel was also 1.8m.

SCT were engaged in 2013, during the mining of Longwall 5, to provide predictions of subsidence effects and assessment of impacts for the longwall mining proposed at RVE in a revised longwall layout referred to as the UEP-Preferred Project Report (PPR). An initial report was prepared in 2013 which included predictions for Longwalls 1-7 and Longwalls 9-11. The length, widths and orientations of longwalls were changed, and the Longwall 8 panel was removed in the PPR layout.

SCT (2013) presents vertical subsidence predictions for Longwalls 4 and 5 of 2.1m and 1.9m, respectively, based on the method for predicting multi-seam subsidence from longwall mining suggested in Li et al (2007 and 2010). The Li et al method considers the mechanics of the modified overburden similar to the subsequent experience from Ashton Underground Mine.

The adoption of the Li et al method, which is based on the combined extraction height in each seam, provided a conservative estimate of the actual maximum incremental subsidence for Longwalls 4 and 5 in the Wongawilli Seam. The actual incremental subsidence of 1.8m represents about 60% of the mining height which is not excessive for multi-seam mining and consistent with the irregular geometry relative to the overlying Balgownie Seam chain pillars, dyke pillar, and areas of larger Bulli Seam pillars. The areas of maximum subsidence appear to be associated with latent subsidence near the overlying Balgownie Seam longwall edges.

The IAPUM (2020) advise states "*concerns regarding elevated levels of vertical subsidence arise out of subsidence predictions that did not properly account for increased subsidence in a multiseam mining situation; that is, subsidence had been under-predicted rather than excessive for a multiseam situation. This deficiency appears to have been overcome by appointing SCT to undertake subsidence predictions*".

The IAPUM (2020) reference relates to SG (2011) where SG had chosen not to comply with the direction of the Sydney Catchment Authority (now Water NSW) to use the Li et al method at that time.