Appendix B

Subsidence Report

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Strata Control Technology

REPORT TO:

WOLLONGONG COAL

Update of Subsidence Assessment for
Wollongong Coal Preferred Project Report
Russell Vale No 1 Colliery

WCRV4263

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REPORT TO	David Clarkson Group Environment & Approvals Manager Wollongong Coal PO Box 281 FAIRY MEADOW NSW 2519
SUBJECT	Update of Subsidence Assessment for Wollongong Coal Preferred Project Russell Vale No 1 Colliery
REPORT NO	WCRV4263
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SUMMARY

Wollongong Coal (WC) is proposing to mine eight additional longwall panels in an area approximately 9km north-north-west of Wollongong in New South Wales referred to as the Wonga East mining area. After consideration of submissions from the community and government agencies to its earlier Underground Expansion Project Part 3A (Pt3A) application, WC (then Gujarat NRE) significantly modified the application in a proposal referred to as the Preferred Project Report (PPR). In 2013, Gujarat NRE commissioned SCT Operations Pty Ltd (SCT) to predict the subsidence likely to be caused by the proposed longwall panels recognising the influence of previous mining in the area and to assess the likely subsidence impacts in the PPR mining area. Subsidence predictions and an impact assessment were presented in SCT Report NRE14123 dated 24 September 2013 (SCT 2013) based on the data was available at the time.

Since the completion of SCT Report NRE14123, Longwall 5 has finished, further subsidence monitoring data particularly in relation to valley closure measurements has become available, additional field studies have been undertaken, and the initial report has been peer reviewed. This current report is an update of the earlier report with the main changes being inclusion of subsidence monitoring results to the end of Longwall 5, revision of the valley closure estimates, and identification of a sandstone formation downstream of CCUS4. Changes and clarifications recommended in the peer review have also been included.

Our assessment indicates that the subsidence impacts associated with the proposed PPR mining layout can be managed to a level consistent with impacts from previous mining in the area. Continued monitoring and adaptive management strategies are considered appropriate to manage these impacts in a holistic sense, but changes in panel length may be required to completely protect individual natural features identified as ecologically or aesthetically significant depending on the balance that is struck by government between coal resource recovery and surface impacts. Mitigation measures will be required to manage the impacts on high voltage power transmission lines.

Site Description

The PPR Assessment Area is located entirely within the headwaters of Cataract River in the catchment of the Cataract Metropolitan Water Supply Reservoir and predominantly within the catchment of Cataract Creek. The surface is mainly undeveloped bushland. Surface features include sections of rain forest in the valleys, a variety of upland swamps located mainly on the valley sides and numerous sandstone rock formations on the upper slopes associated with Hawkesbury Sandstone. Some archaeological heritage sites are located within this outcrop. Several first order tributaries of Cataract Creek have formed waterfalls where they flow over Hawkesbury Sandstone formations. The surface is traversed by the Mount Ousley Road and four high voltage power transmission lines. A telecommunications installation and the Illawarra Escarpment are located approximately 1km to the east of the proposed longwall mining area.

Coal has previously been mined in three seams at this site, the Bulli Seam, the Balgownie Seam 10m below, and the Wongawilli Seam a further 20m below that. The Bulli Seam was mined from the late nineteenth century through to the 1950's using a variety of mining systems including in the later stages mechanised pillar extraction. The Balgownie Seam was mined as one of the first longwall mining operations in Australia from 1970 through to 1982. The Wongawilli Seam has been mined by NRE with the first of two longwall panels commencing in April 2012. Within the PPR Assessment Area the overburden depth to the coal seams ranges 220-390m mainly as a result of variation in surface topography but also as a result of the strata dipping at between 1 in 25 and 1 in 30 to the west-north-west away from its outcrop on the Illawarra Escarpment.

The presence of this previous mining presents some challenges for future mining but also brings some advantages in terms of providing high confidence definition of the nature, location, and characteristics of geological structures, actual measurements of the subsidence behaviour of the overburden strata at the site during previous mining, and an extended baseline of some 60-100 years to study the recovery of natural features from previous subsidence impacts.

Prediction Methodology

The subsidence prediction methodology used in this assessment is based on previous subsidence monitoring experience at this site available from mining in the Bulli Seam (over longwall panels 6-8km to the west) and the Balgownie and Wongawilli Seams in the PPR Assessment Area. This data is considered to provide a strong basis for predicting subsidence above the proposed longwall panels, particularly when consideration is given to the mechanics of the subsidence processes involved, specifically the differences between sag subsidence over individual panels and elastic compression subsidence associated with elastic compression of the strata between panels. Tilts and strains are predicted using incremental subsidence and the approach forwarded by Holla and Barclay (2000). Maximum closure is predicted using the ACARP Method developed by Waddington and Kay (2002). Available monitoring data indicates that both approaches provide predictions that are conservative.

The approach to predicting subsidence movements that has been adopted is considered to be appropriate in the relatively complex mining environment that exists within the PPR Assessment Area especially now that there is actual subsidence data available from Longwalls 4 and 5 in the Wongawilli Seam to provide confirmation of behaviour when a third seam is mined.

The experience available from mining Longwalls 4 and 5 indicates that the subsidence behaviour is predictable albeit with somewhat different characteristics to subsidence over single seam mining operations. The main difference is that the overburden strata are more flexible as a result of the disturbance caused by previous mining. The bridging capacity across individual panels is reduced and sag subsidence in the middle of individual panels is thus greater than it would be above single seam operations.

Predicted Subsidence

Maximum subsidence over individual longwall panels in the Wongawilli Seam is predicted to range from 1.5m over the slightly narrower Longwall 7 through to 2.6m over Longwall 3 where the overburden depth is shallowest and there is overlying mining in both seams. Previous mining in the Bulli and Balgownie Seams is estimated to have caused up to about 1.9m of subsidence in some localised areas of the PPR east of the Mount Ousley Road but more generally cumulative subsidence in areas of previous mining has been in the range 0.3-1.3m.

There is considered to be some potential for pillar instability in the Bulli Seam to cause additional surface subsidence of up to about 0.5m in localised areas of marginally stable pillars when the proposed longwall panels are mined in the Wongawilli Seam. The area likely to be most affected by pillar instability is located at the northern end of Longwall 1 and although the area is relatively small compared to overburden depth, special consideration is required in this area to limit impacts on power transmission pylons located nearby.

Maximum tilts over individual longwall panels in the Wongawilli Seam are expected to range up to maxima of 24mm/m over Longwall 10 through to maxima of 51mm/m above Longwall 3. Although these maxima may occur anywhere in the panel, they are most likely to occur at panel edges in overlying seams and in areas of topographic change in gradient. More generally across the panel, systematic tilts are likely to be in the range 50-90% of the maximum values.

Maximum strains over individual longwall panels in the Wongawilli Seam are expected to range up maxima of 14mm/m over Longwall 10 to maxima of 31mm/m over Longwall 3. Although these maxima may occur anywhere within the panel, maximum tensile strains are most likely to occur at topographic high points and maximum compression strains are most likely to occur at topographic low points. More generally across the panel, systematic strains are likely to be 20-30% of the maximum values.

The predicted closures across Cataract Creek have been revised slightly from the earlier report. Total closures are predicted to range up to 300mm adjacent to the end of Longwall 5 and up to 290mm adjacent to the end of Longwalls 6 and 7. Closure across the second order southern branch of Cataract Creek upstream of the Mount Ousley Road crossing is predicted to reach 700mm. These closure estimates are recognised as being upper limit values because they are based on experience in deep gorges at high stress levels. Monitoring to date indicates closure movements of up to 49mm. These movements are less than 40% of the 135mm predicted for Longwall 5 only.

The following table summarises the subsidence that has occurred in the area of each longwall panel during mining in the Bulli Seam (estimated) and the Balgownie Seam (measured) as well as the subsidence that is predicted above each longwall panel from proposed mining in the Wongawilli Seam.

General Observations Above Individual Panels	Previous Bulli and Balgownie Seam Subsidence (m)	Predicted Additional Subsidence for PPR Wongawilli Seam (m) and Measured (in bold)	Predicted Tilt for PPR Wongawilli Seam (mm/m) and Measured (in bold)	Predicted Tensile Strain for PPR Wongawilli Seam (mm/m) and Measured (in bold)	Predicted Compressive Strain for PPR Wongawilli Seam (mm/m) and Measured (in bold)	Predicted Maximum Closure on Cataract Creek (mm) (Southern Tributary in Brackets – LW1-3)
Longwall 1	1.3	2.1	40	12	24	N/A (700)
Longwall 2	1.1	2.1	40	12	24	N/A (300)
Longwall 3	1.3	2.6	51	15	31	N/A (150)
Longwall 4	1.9	2.1 (**1.8**)	35 (**30**)	10.5 (**7.5**)	21 (**14**)	N/A
Longwall 5	0.9	1.9 (**1.8**)	36 (**16**)	10.8 (**6**)	22 (**12**)	300 (**49**)
Longwall 6	1.5	2.1	38	11	23	290
Longwall 7	1.2	1.5	28	8	17	290
Longwall 9	0.5	2.1	32	10	19	50
Longwall 10	0.6	1.6	24	7	14	30
Longwall 11	0.6	2.1	30	9	18	10

Movements outside the goaf edge (i.e. edge of each longwall panel) are expected to be similar to the movements observed beyond the goaf edges of Longwalls 4 and 5. Vertical movements of greater than 20mm are expected to be limited to within a distance of about 0.7 time overburden depth from the nearest goaf edge equivalent to an angle of draw of 35°. In areas where there is either solid coal or substantial coal pillars directly above the goaf edge, goaf edge subsidence is expected to be of the order of 100-200mm. In areas where there has been previous mining in both the overlying seams, vertical subsidence at the goaf edge is expected to increase up to 300-500mm and the goaf edge subsidence profile is expected to be more gradual outside the goaf edge and steeper directly over the panel.

Impact Assessment

The impacts of mining subsidence on surface features are considered in detail within the body of the report. These features include natural features such as Cataract Creek, Cataract River, upland swamps, sandstone cliff formations including the Illawarra Escarpment and some smaller sandstone outcrops where first order creeks have formed waterfalls, archaeological heritage features, and surface infrastructure including Mount Ousley Road, four high power transmission lines, Cataract Water Supply Reservoir, and a telecommunications installation on Brokers Nose.

Cataract Creek flows across the PPR Assessment Area. The PPR mine layout has been designed to avoid longwall extraction directly under the main channel of Cataract Creek and particularly the third and fourth order sections. An adaptive management strategy based on closure monitoring and cessation of longwall extraction if there is a likelihood of significant perceptible impacts becoming apparent is considered to be an effective method for managing the potential for subsidence impacts on Cataract Creek.

The valley closure measurements observed during mining of Longwall 5 are much less than predicted using the available methodology. The closure movements have occurred gradually and incrementally with mining allowing them to be predicted in advance with reasonable confidence. The more difficult challenge is determining the level of closure that is likely to cause impacts to the creek. Cataract Creek has previously been subsided up to 1.2m by mining Longwall 11 in the Balgownie Seam with closure of 350mm measured across Cataract Creek. This closure has not resulted in apparent impact, possibly because of the position of the creek in the stratigraphic section and the presence of Bald Hill Claystone in the base of the creek. There has been no perceptible impact from 49mm of closure associated with mining Longwall 5. An adaptive management scheme based on avoiding perceptible impacts is considered to be appropriate.

Cataract River is remote from the proposed mining in an area where there are not expected to be any perceptible impacts.

Biosis (2013) has mapped and described 33 separate upland swamps within the PPR Assessment Area. Many of these swamps have been previously mined under in both the Bulli Seam and Balgownie Seam. The proposed mining is not expected to cause significantly different impacts to those already experienced. It is considered that more work is required to determine the relationship between mining subsidence and the long term health of swamps. The extended baseline of subsidence impacts over 60-100 years in the Bulli Seam and 30-40 years in the Balgownie Seam provides a rare opportunity to study these effects. The development of a monitoring and review strategy involving relevant experts is recommended to manage mining impacts on these swamps. This process should include a review of the recovery of these features from previous impacts and the implication of this recovery for future swamp protection strategies.

CCUS4 has been identified as a significant swamp within the PPR mining area that drains via a first order watercourse. CCUS4 has previously been subsided 0.6-0.8m by mining in the Balgownie Seam without apparent impact. Proposed mining in the Wongawilli Seam is expected to cause up to 2.1m of additional subsidence. Impacts such as cracking of the sandstone base and surface water diversion are expected as a result of proposed mining.

There are numerous sandstone cliff formations located within the Hawkesbury Sandstone outcrop in the PPR Assessment Area. Most of these are less than 5m high. Some perceptible cracking on hard rock surfaces is expected to be apparent as a result of the proposed mining. Minor rock falls are expected on up to 5% of the length of sandstone cliff formations that are mined directly under. It is noted that there are a number of rock falls present across the site that can be attributed to previous mining impacts and others that have occurred naturally.

There are several locations where drainage lines and first order creeks flow over sandstone outcrops to form waterfalls following periods of heavy rain. Field inspections conducted since the previous report was prepared have identified the presence of several such features that were not apparent in original LiDAR surveys used to characterise the cliff formations because of their small size and the presence of downstream boulders.

Two of these features are approximately 7m high. However, only the feature at the downstream edge of CCUS4 is regarded as a semi-permanent waterfall. The others are either located on drainage lines that have no permanent flow or have been impacted by previous mining so that water emerges from the base of the rock formation during periods of low flow rather than flowing over it like a waterfall. Some impact from previous mining is apparent at each of these rock formations. Proposed mining is expected to cause further impacts including rock falls and cracking.

Nineteen Aboriginal heritage sites have been identified within the PPR Assessment Area. Some of these sites have potential to be impacted by rock falls caused by mining subsidence. A detailed assessment of these sites is presented in the body of the report and in Biosis (2013).

Mount Ousley Road is protected from direct mine subsidence by a horizontal distance from the nearest goaf edge equal to half overburden depth. Low levels of vertical subsidence of less than about 100mm in total are expected in the vicinity of Mount Ousley Road with up to approximately 40mm of this maximum having already occurred from mining Longwalls 4 and 5. These low level vertical movements are expected to be imperceptible for all practical purposes. Tensile cracking adjacent to the topographic high ground south of Cataract Creek and closure of up to a maximum of about 50mm is expected at the crossing of Cataract Creek. Some 11mm of closure was measured during mining of Longwall 5. There is considered to be no potential for significant horizontal movements to impact the Picton Road Interchange and no movements attributable to mining have been measured in the subsidence monitoring conducted to date.

There are four power transmission lines located in two corridors between Mount Ousley Road and the Illawarra Escarpment. All four lines were mined under by Longwalls 1 and 3 in the Balgownie Seam and potentially by late stage pillar extraction in the main heading pillars in the Bulli Seam although this latter mining may have preceded their construction. Subsidence movements predicted in the vicinity of four of the towers (two each on the 330kV and 132kV lines) are expected to be sufficient to require construction of cruciform bases to protect them from mining subsidence. T56 on the 330kV line will require a special design to accommodate the slight change in direction that occurs at this tower. Vertical subsidence of up to 2.1m and horizontal valley closure movements of up to 700mm are expected in the vicinity of some of the pylons.

The 33kV single and double pole structures are relatively tolerant of subsidence movements and because these structures are located more than 60m outside of the footprint of the longwall panels no protection measures are considered necessary, although a monitoring regime is nevertheless recommended.

The Cataract Water Storage Reservoir is not expected to be impacted by the proposed mining. The Full Supply Level (FSL) for the reservoir including the section that extends up Cataract Creek is protected from the nearest longwall goafs by a nominal horizontal distance of greater than 203m at 290m overburden depth (equivalent to 0.7 times overburden depth or an angle of draw of 35°). Vertical subsidence at the FSL is expected to be less than about 20mm.

Geological structures within the PPR Assessment Area are well defined because of the previous mining that has occurred in the overlying Bulli Seam over a large area and the overlying Balgownie Seam in a more limited area. The only geological structure that extends through to the proposed longwall panels in the PPR Assessment Area and the reservoir is Dyke D8. The horizontal distance along the dyke from the end of Longwall 10 to the FSL is approximately 560m at an overburden depth of 320m at the FSL. There is considered to be no potential for proposed mining to intersect the stored waters directly.

There are a number of small pre-existing Bulli Seam mining areas where, due to the legislative standards of the day, pillar extraction was permitted within the 0.7 times depth protection zone around the FSL. There does not appear to be any direct connection between the reservoir and the mining horizon through these mining areas. Although their presence appears to reduce the effectiveness of the 0.7 times depth barrier between the FSL and the proposed mining somewhat, particularly for mining of Longwalls 7 and 9, the pathway for seepage from the reservoir to the mine is likely to be predominantly along horizontal shear planes at or just below the level of the valley. This pathway is not expected to interact with the pre-existing Bulli Seam mining areas. As a result, there is not considered to be any potential for these existing Bulli Seam mining areas to significantly reduce the effectiveness of the 0.7 time depth barrier.

The Illawarra Escarpment at Brokers Nose and the telecommunications infrastructure located on it are protected by a horizontal distance of approximately 1km from the nearest point on Longwall 1. No ground movements or any perceptible impacts are expected in this area as a result of the proposed mining.

Management Strategies

The subsidence management strategies recommended include continuation of the upgrade to subsidence monitoring technique that has been ongoing since the start of Longwall 4. This upgrade has included measuring subsidence movements in three dimensions, increasing the resolution of valley closure monitoring, and establishing more reliable GPS based survey control points.

Ongoing management and review of subsidence impacts to Mount Ousley Road by a technical committee headed by the asset owner is considered suitable to manage the potential for any future impacts on the road and associated infrastructure. This approach was used successfully for managing the impacts from Longwalls 4 and 5. The half depth barrier used to substantially protect the road alignment provides a relatively high level of protection. Some consideration to remedial work to prevent water ingress into minor tension cracks that have formed is recommended to protect the road sub-base.

To manage potential impacts on the power transmission towers prior to mining Longwalls 1-3, it is recommended that a technical committee be formed with representatives from the colliery, the power utility companies, the Mine Subsidence Board, and government regulators. Several of the power transmission towers are likely to require the construction of cruciform bases to allow them to remain structurally stable during mining, a process that usually requires a significant lead time.

The Dams Safety Committee (DSC) is a statutory body with legal powers to manage mining to protect the stored waters in Cataract Reservoir. The colliery has been working with the DSC for many years and it is considered that the management process that has been adopted in the past continues to be appropriate. The 0.7 times depth (approximately 200m) stand-off from the FSL is the primary control for protecting the stored waters of Cataract Reservoir and this stand-off is expected to provide a high level of protection notwithstanding the presence of previous extraction in the Bulli Seam.

The detail of monitoring of swamps, cliff formations, heritage sites, and creek biota is beyond the scope of this report and has been addressed in other specialist's reports. However, it is recommended that one or more technical committees are formed to design monitoring programs that not only review the changes that may be associated with proposed mining but also take the opportunity to review the longer term impacts from previous mining in the same area. Ideally these technical committees would include external expertise from the community where appropriate so that monitoring programs are targeted, appropriate, can be ongoing, and are transparent to all stakeholders.

Response to Submissions to UEP Pt3A and Original PPR

A range of submissions were received in response to the Underground Expansion Project Pt3A (Pt3A). These submissions were received prior to the PPR amendments and while the PPR amendments have addressed many of the issues raised, a number of these issues are worth discussing in the context of the PPR design and how they have driven the changes that have been made to the design and the design process. There have also been submissions to the PPR itself. The response to this second group of submissions is included in an appendix to this report with the report itself updated to address the issues raised.

The subsidence prediction technique used in the original UEP Pt3A has been updated to reflect the subsidence monitoring data available from Longwalls 4 and 5. The revised approach is based on using the available data to provide insight into the subsidence mechanics and continuing to develop this understanding recognising the various subsidence processes involved. Although there is somewhat greater uncertainty for subsidence predictions in a multi-seam environment, the available data indicates that the behaviour observed is repeatable and consistent with the mechanics of the subsidence processes as currently understood.

There are a number of geological structures located in the general area of the proposed mining, but only one dyke (D8) is considered to be significant in the context of the proposed mining. The others are located away from the areas of mining and are not considered to have any significant potential to be affected by mining. A significant benefit of the previous mining activity is that the dykes and faults through the area are very well defined by previous mining activity.

The potential in the Bulli Seam for pillar instability and latent subsidence (where full subsidence has not occurred during previous mining) has been recognised as having some potential to cause additional subsidence at the northern end of Longwall 1 and this area is requires special consideration prior to mining Longwall 1. Other areas where there may be a similar potential are more difficult to identify because the mine records for the period of mining may be incomplete or inaccurate due to the survey and drafting standards of that time. The significance of any additional surface subsidence that may result is considered to be low, especially in terms of additional impacts to major surface infrastructure above the impacts expected.

The prediction of valley closure, upsidence, and far-field movements is recognised as being only approximate. Offsets that have been designed into the revised mine layout are aimed to avoid mining directly under the main channel of Cataract Creek to provide a buffer against closure related impacts and this protection is supported by Wollongong Coal's commitment to stop the longwalls short if closure movements become likely to cause unacceptable impacts.

There is considered to be no potential for the proposed mining to impact on the Illawarra Escarpment and in particular the section of Hawkesbury Sandstone outcrop at Brokers Nose. It should be recognised that there is always potential for cliff falls to occur naturally as part of the ongoing erosion processes.

The subsidence monitoring systems being used at Wollongong Coal have been upgraded from two dimensional surveying techniques used during the initial stages of mining Longwall 4 through to full three dimensional monitoring with an improved GPS survey control network.

Adaptive management strategies are being practiced by Wollongong Coal. Examples include the significant revision to the mine layout represented by the PPR and the use of closure monitoring across Cataract Creek to control the length of Longwalls 5, 6 and 7.

TABLE OF CONTENTS

PAGE NO

1. INTRODUCTION

Wollongong Coal (WC) is proposing to mine eight additional longwall panels in an area approximately 9km north-north-west of Wollongong in New South Wales referred to as the Wonga East mining area. After consideration of submissions from the community and government agencies to its earlier Underground Expansion Project Part 3A (Pt3A) application, WC (then Gujarat NRE) significantly modified the application in a proposal referred to as the Preferred Project Report (PPR). In 2013, Gujarat NRE commissioned SCT Operations Pty Ltd (SCT) to predict the subsidence likely to be caused by the proposed longwall panels recognising the influence of previous mining in the area and to assess the likely subsidence impacts in the PPR mining area. Subsidence predictions and an impact assessment were presented in SCT Report NRE14123 dated 24 September 2013 (SCT 2013) based on the data was available at the time.

Since the completion of, Longwall 5 has finished, further subsidence monitoring data particularly in relation to valley closure measurements has become available, additional field studies have been undertaken and cliff formations identified, and the initial report has been peer reviewed. This current report is an update of the earlier report with the main changes being inclusion of subsidence monitoring results to the end of Longwall 5, revision of the valley closure estimates, and identification of several rock formations not identified in the original PPR assessment. Changes and clarifications recommended in the peer review have also been included.

The report is structured into three parts:

The first part, Section 2, describes the site, the background to the project and the rationale for the mining layout in the Preferred Project showing changes to the geometry compared to the earlier Pt3A application, the geological setting, and an overview of the surface features.

The second part, Sections 3 to 7, describes the previous mining activity, the past and future subsidence including available monitoring data from mining in one, two, and three overlying seams, a description of the subsidence prediction methodology and a discussion of the accuracy and level of confidence that can be placed in the predictions, estimates of subsidence for the proposed mining based on the data currently available, an assessment of likely subsidence impacts on each of the surface features including a review of past impacts and the threats that previous mining activity still has for unpredictable subsidence behaviour. In the last section, a range of strategies to manage the subsidence impacts expected are presented and discussed.

The third part, Section 8, presents a response to submissions to the earlier Part 3A application where these responses remain relevant to the PPR and a response to the more recent submissions provided for the initial PPR report.

2. SITE DESCRIPTION

This section is structured to provide an overview of the site, background to the PPR and the Assessment Area and changes since the Underground Expansion Project Pt3A application, a review of surface ownership, an overview of the main surface features and the geological setting.

This site description section is presented primarily to provide context for the subsidence assessment. More detail of specific aspects of various features such as the geological setting, the flora and fauna, surface features such as swamps and cliffs, archaeological and other heritage sites, and surface and groundwater interactions is presented in other specialist reports associated with the project.

2.1 Site Overview

Figure 1 shows the location of the PPR Assessment Area superimposed on a 1:25,000 topographic series map. Detail of the surface contour available from LiDAR (Laser Interferometric Detection and Ranging) imagery flown since the production of the 1:25,000 series topographic series map has been used to refine the location of surface watercourses, particularly Cataract Creek. These watercourses have been coloured on the basis of their stream order using the approach described in the Strategic Review into Impacts of Underground Coal Mining on Natural Features in the Southern Coalfields (NSW Department of Planning 2008). The longwall panels discussed in this report and shown in Figure 1 include Longwalls 4 and 5 in the Wongawilli Seam both of which have already been mined.

The Assessment Area is located entirely within the headwaters of Cataract River and the Cataract Reservoir and predominantly within the catchment of Cataract Creek. The surface is mainly undeveloped bushland. Surface features include sections of rain forest in the valleys, a variety of upland swamps located mainly on the valley sides and numerous sandstone rock formations on the upper slopes associated with Hawkesbury Sandstone outcrop. The surface is traversed by the Mount Ousley Road and four high voltage power transmission lines.

2.2 Project Background

Gujarat NRE purchased the colliery in December 2004. In February 2014, Gujarat NRE formally changed its name to Wollongong Coal. In this report, the company is referred to as Wollongong Coal (WC) except in relation to events that occurred prior to the formation of WC. Similarly the NRE No 1 Colliery has been renamed Russell Vale Colliery.

Russell Vale Colliery is located near Russell Vale in the Illawarra region of New South Wales (NSW). Extensive underground mining has been undertaken within the colliery holdings dating from the late nineteenth century. However, a substantial volume of high quality coking coal resources remains along with some potential thermal coal resources.

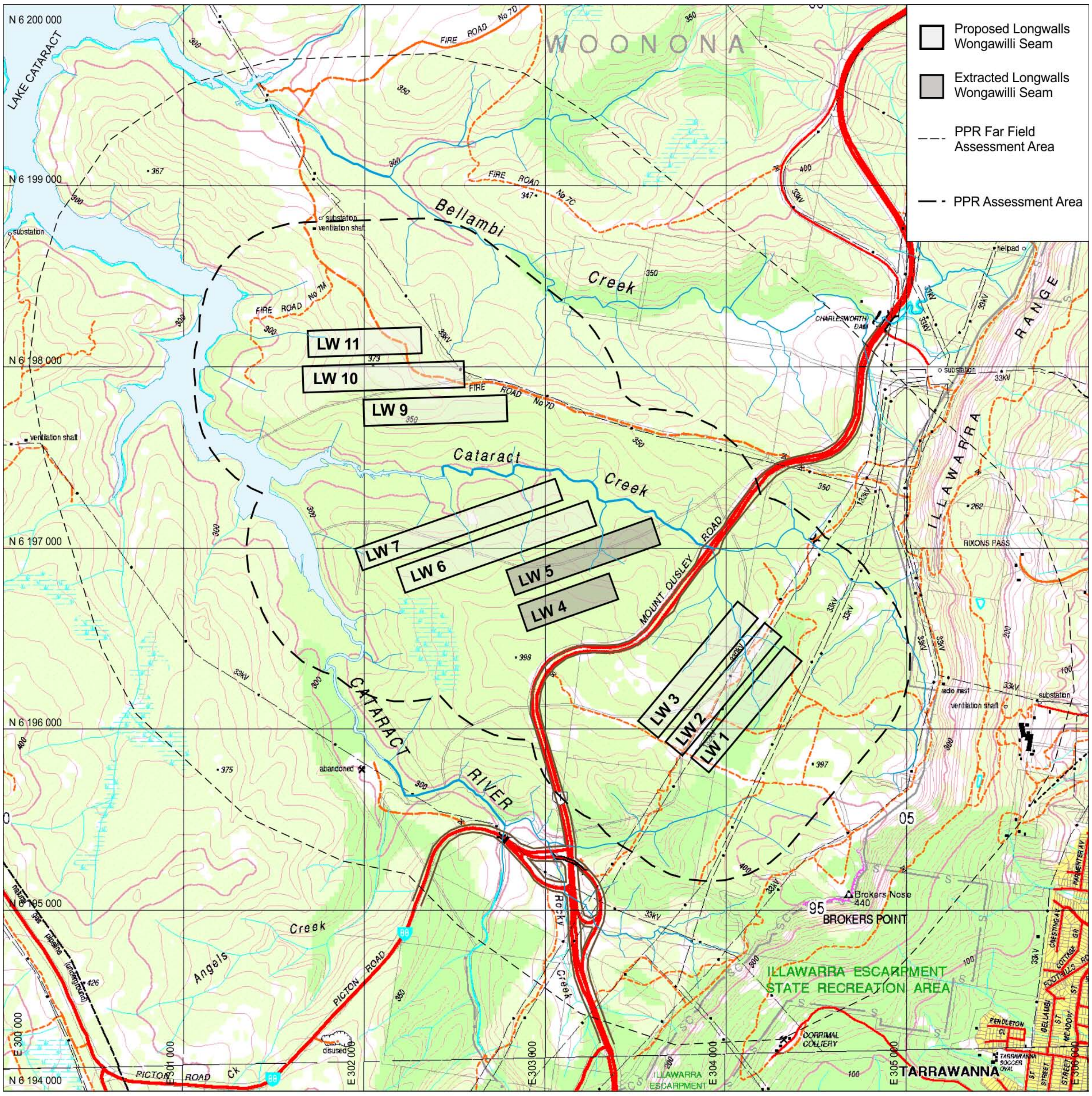


Figure 1: Plan showing location of PPR Assessment Area and proposed longwall panels superimposed onto a 1:25,000 topographic series map with creek alignments update based on LiDAR imaging of the ground surface.

The colliery holding includes a number of sub leases between WC and surrounding mine operators, including Consolidated Coal Lease (CCL) 745, Mining Purposes Lease (MPL) 271 and Mining Lease (ML) 1575 and covers a total area of approximately 6,973 hectares (ha).

Originally, NRE intended to expand its Wongawilli Seam operations in two stages. Stage 1 plans were included in the Preliminary Works Pt3A that was approved on 13 October 2011 allowing some first workings coal extraction and surface facility upgrades. On 24 December 2012, the Preliminary Works Part 3A was modified to allow the extraction of Longwalls 4 and 5 and the development of Maingate 6.

The original Stage 2 application known as the Underground Expansion Project Pt3A was lodged with the DPI on 12 August 2009 and contained an application to extract eleven longwalls in the Wonga East area and seven longwalls in the Wonga West area along with surface facilities upgrades to allow production of up to 3Mtpa for up to 20 years. Since that time the application has been progressing through the Major Project approvals process and was placed on Public Exhibition on 18 February 2013.

As a result of the submissions received on the application, NRE made the decision to substantially revise the application to facilitate the approval process and allow continuity in operations. Due to the scope of the changes, the New South Wales Department of Planning and Infrastructure (DPI) requested NRE to prepare a Preferred Project Report for the revised Underground Expansion Project Pt3A.

The Preferred Project report outlines the revised Underground Expansion Project which has been reduced to a 5 year interim stage project, with extraction of eight longwalls in the Wonga East area and upgrading of surface facilities to manage an extraction rate of up to 3Mtpa ROM coal per annum. The original Wonga West longwall extraction is planned to be reviewed and resubmitted to DPI as a separate application at a later time.

2.3 PPR Assessment Area

Taking account of the various submissions received, the longwall panels in the PPR have been designed recognising the following constraints:

- The constraints of the mine lease.
- Geological constraints including the Corrimal Fault in the south, dyke D8, silling (an igneous intrusion within the seam) in the north, and coal quality considerations and its impact on mining height.
- Mining constraints associated with the need for main headings in the north and the legacy of previous mining extent and geometry.
- Surface subsidence constraints including:

- o Avoiding longwall extraction within 0.7 times depth (equivalent of 35° angle of draw) of the full supply level (FSL) of Cataract Reservoir including the section of the reservoir that extends up Cataract Creek.

- o Avoiding mining directly under the third and fourth order sections of Cataract Creek.

- o Minimising impacts on Mount Ousley Road to tolerable levels by remaining beyond approximately half depth (equivalent to 26.5° angle of draw) from the road easement.

- o Significant upland swamps

These constraints are illustrated in Figure 2 together with the PPR layout and the original layout proposed for the Underground Expansion Project Pt3A application. In the PPR, Longwall 8 has been left out, most of the panels have been shortened, Longwall 7 has been narrowed, and six of the panels (Longwalls 1-3 and 9-11) have been rotated in order to remain within the constraints described above. The only constraints that were not able to be completely accommodated within the realignment were the upland swamp known as CCUS4 including a 7m high waterfall on the downstream edge of CCUS4 located on a first order tributary flowing from the swamp, a small part of upland swamp CRUS1 located above Longwall 6, and a small part of upland swamp CRUS5 located above Longwall 7.

The PPR Assessment Area has been defined as an area that extends to a horizontal distance of 600m from the outside edge of any of the proposed longwall panels including Longwalls 4 and 5 (NSW Department of Planning 2008). A second far field assessment area extending to 1.5km outside the proposed longwall panels has been used to include significant features such as the Illawarra Escarpment, the power pylons at changes of direction, and the bridges of the Picton Road Interchange that while remote from mining are within the area where far-field horizontal movements may occur.

Longwall 4 and 5 are included in the assessment area and this subsidence assessment because:

- Although they were mined under a different regulatory process, they are nevertheless within the purview of the current mining area and it is appropriate to assess their impacts in this context.

- The levels of subsidence measured were significantly higher than predicted using the single seam subsidence prediction methodology used for the original assessments and therefore reassessment is considered appropriate.

- The measured subsidence movements and impacts provide a gauge of the accuracy of the prediction methodology and impact assessments.

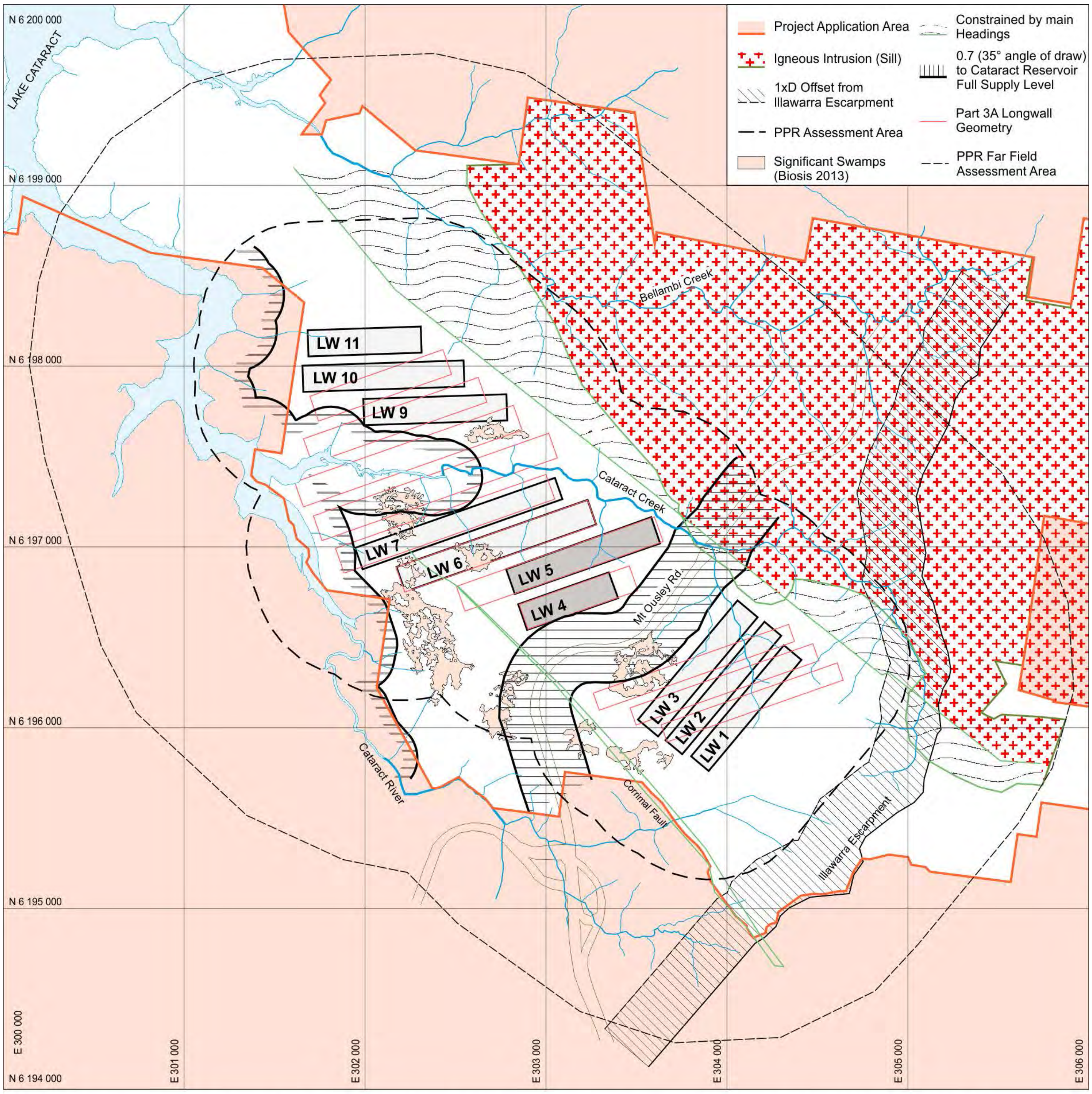


Figure 2: Plan showing the design constraints (lease, geological, mining, and surface protection) as the basis for the PPR mine layout design.

2.4 Surface Ownership

Figure 3 shows the surface ownership within the PPR Assessment Area. Most of the area is within the Metropolitan Special Area for Cataract Water Supply Reservoir. The surface area above the catchment is administered by the Sydney Catchment Authority (SCA). The stored waters of Cataract Reservoir are also administered by the Dams Safety Committee (DSC). A large part of the area to the east of Mount Ousley Road and small areas to the west are owned by WC. The easement for the Mount Ousley Road and an area northeast of the Picton Interchange within the Assessment Area is owned and administered by the Roads and Maritime Services (RMS).

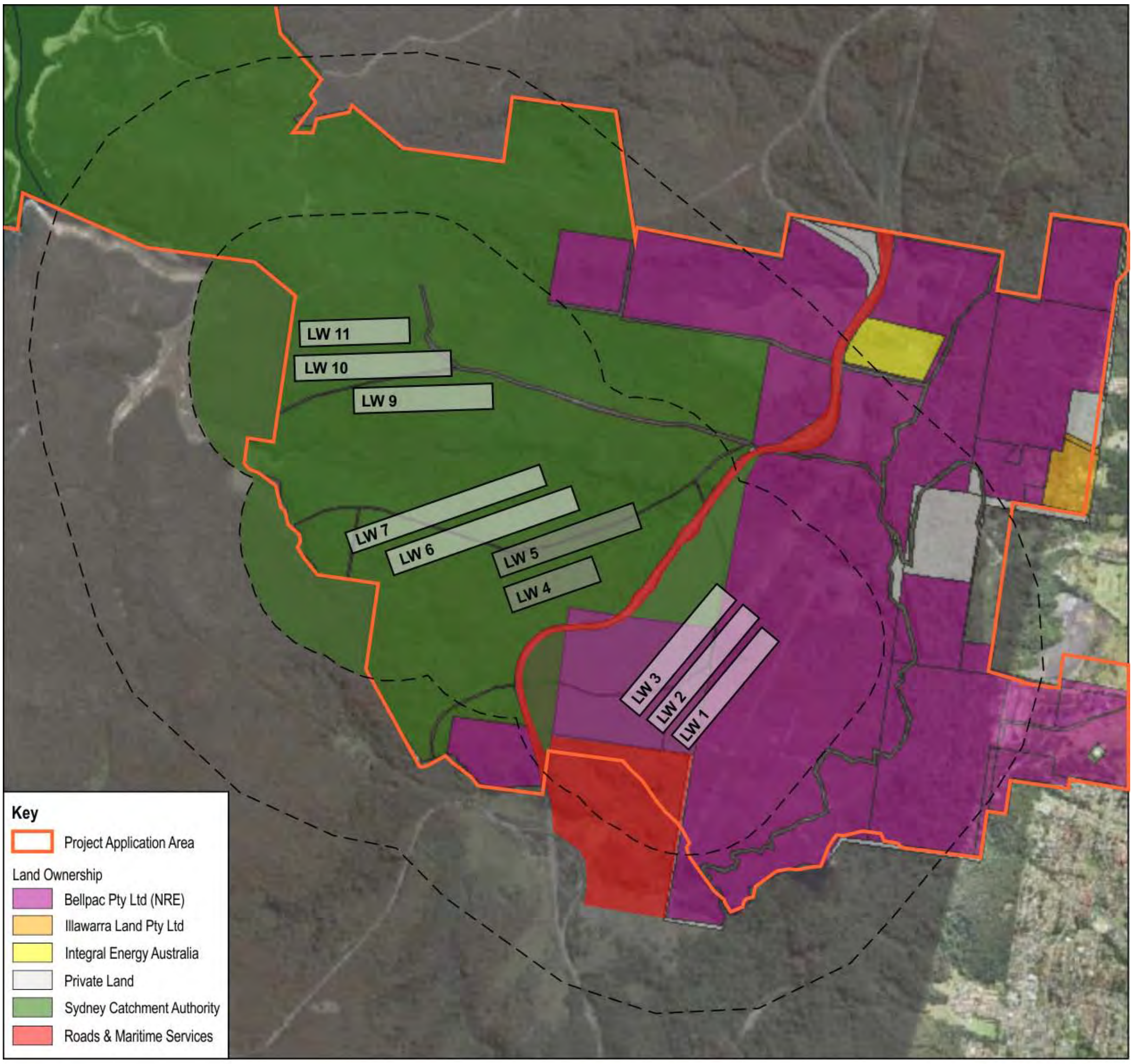


Figure 3: Plan showing land ownership within PPR Application Area. (Diagram modified from Figure 1.5 of EA from Environmental Resources Management Drawing Number 0079383s_EA_GIS013_RO.mxd dated 22/9/10).

2.5 Surface Infrastructure

Major infrastructure within the Assessment Area includes the Mount Ousley Road and four high voltage power lines to the east that cross the area. The location of this infrastructure is shown on the topographic map in Figure 1.

Mount Ousley Road (recently renamed the M1 Princes Motorway) is a major four lane highway connecting New South Wales largest and third largest cities. This road is administered by Roads and Maritime Services (RMS). The interchange with the Picton Road is located to the south outside the Assessment Area but within the 1.5km far field assessment area. This interchange includes a concrete bridge and several drainage culverts.

Mount Ousley Road was constructed as a defence route during 1942 with duplication of the highway commencing in 1965 reaching Picton Road from the south in 1979 (OzRoads 2012). A major deviation at Cataract Creek was opened in 1980. The northbound carriageway on Mount Ousley Road at Cataract Creek was last resurfaced in 2009 with the surface expected to last 10-12 years (Vecovski 2012). The southbound carriageway was last resurfaced in 2003 and resurfacing of this section is expected within 5-6 years.

There are four power transmission lines located within the Assessment Area, a 330kV transmission line owned and maintained by Transgrid, a 132kV transmission line located alongside that is owned and maintained by Endeavour Energy and two 33kV transmission lines and associated infrastructure owned and maintained by Endeavour Energy. There are also two more 33kV lines and sub-station infrastructure located outside the Assessment Area but within or just outside the 1.5km far field assessment area. One of these line services colliery infrastructure.

There is a telecommunications installation located adjacent to the Illawarra Escarpment at Brokers Nose. This facility is approximately 980m from the goaf edge of Longwall 1. The site is outside the PPR Assessment Area but within the far field assessment area.

2.6 Natural Features

Major natural features and natural resources in the area include the Illawarra Escarpment and the upper parts of Lake Cataract that forms part of the Sydney's water supply catchment. The Illawarra Escarpment is located some 800-900m east of proposed Longwall 1 and outside the PPR Assessment Area but within the far field assessment area. Approximately one third of the Assessment Area and sections of five longwall panels are located within the DSC Cataract Notification Area (revised in 2013).

There are numerous natural swamps identified within the Assessment Area. The nature and distribution of these swamps are described in detail in associated specialist reports (Biosis 2013).

There are numerous sandstone cliff formations located within the Hawkesbury Sandstone outcrop in the PPR Assessment Area. Most of these are less than 5m high. Some perceptible cracking on hard rock surfaces is expected to be apparent as a result of the proposed mining. Minor rock falls are expected on up to 5% of the length of sandstone cliff formations that are mined directly under. It is noted that there are a number of rock falls present across the site that can be attributed to previous mining impacts and others that have occurred naturally.

There are several locations where drainage lines and first order creeks flow over sandstone outcrops to form waterfalls following periods of heavy rain. Field inspections conducted since the previous PPR assessment was prepared have identified the presence of several such features that were not apparent in original LiDAR surveys used to characterise the cliff formations because of their small size and the presence of boulders immediately downstream.

Two of these features are approximately 7m high. However, only the feature at the downstream edge of CCUS4 is regarded as a semi-permanent waterfall on a first order watercourse. The others are either located on drainage lines that have no permanent flow or have been impacted by previous mining so that water emerges from the base of the rock formation during periods of low flow rather than flowing over it like a waterfall. Some impact from previous mining is apparent at each of these rock formations. Proposed mining is expected to cause further impacts including rock falls and cracking.

2.7 Heritage Features

Several Aboriginal heritage sites have been identified within the Assessment Area. These sites are mainly associated with rock shelters in sandstone cliff formations and grinding groove sites on upland sandstone outcrops. One of the shelter sites appears to have been impacted by instability of the associated sandstone overhang either as a result of previous mining in the Bulli Seam or as a result of tree root invasion and natural erosion processes.

2.8 Geological Setting

In this section, an overview of the geological setting is presented as context for the subsidence assessment. The geological setting is described in more detail in Clark (2013) but several of the key diagrams are reproduced here.

Within the Assessment Area, the strata dip at between 1 in 25 and 1 in 30 to the west-north-west from outcrop on the Illawarra Escarpment.

Figure 4 shows a plan of the geological formations that outcrop at the surface and the geological structure that exists at the Wongawilli Seam level and at the surface. Hawkesbury Sandstone is present on the surface over most of the Assessment Area. The Bald Hill Claystone that underlies the Hawkesbury Sandstone outcrops in Cataract Creek and its tributaries.

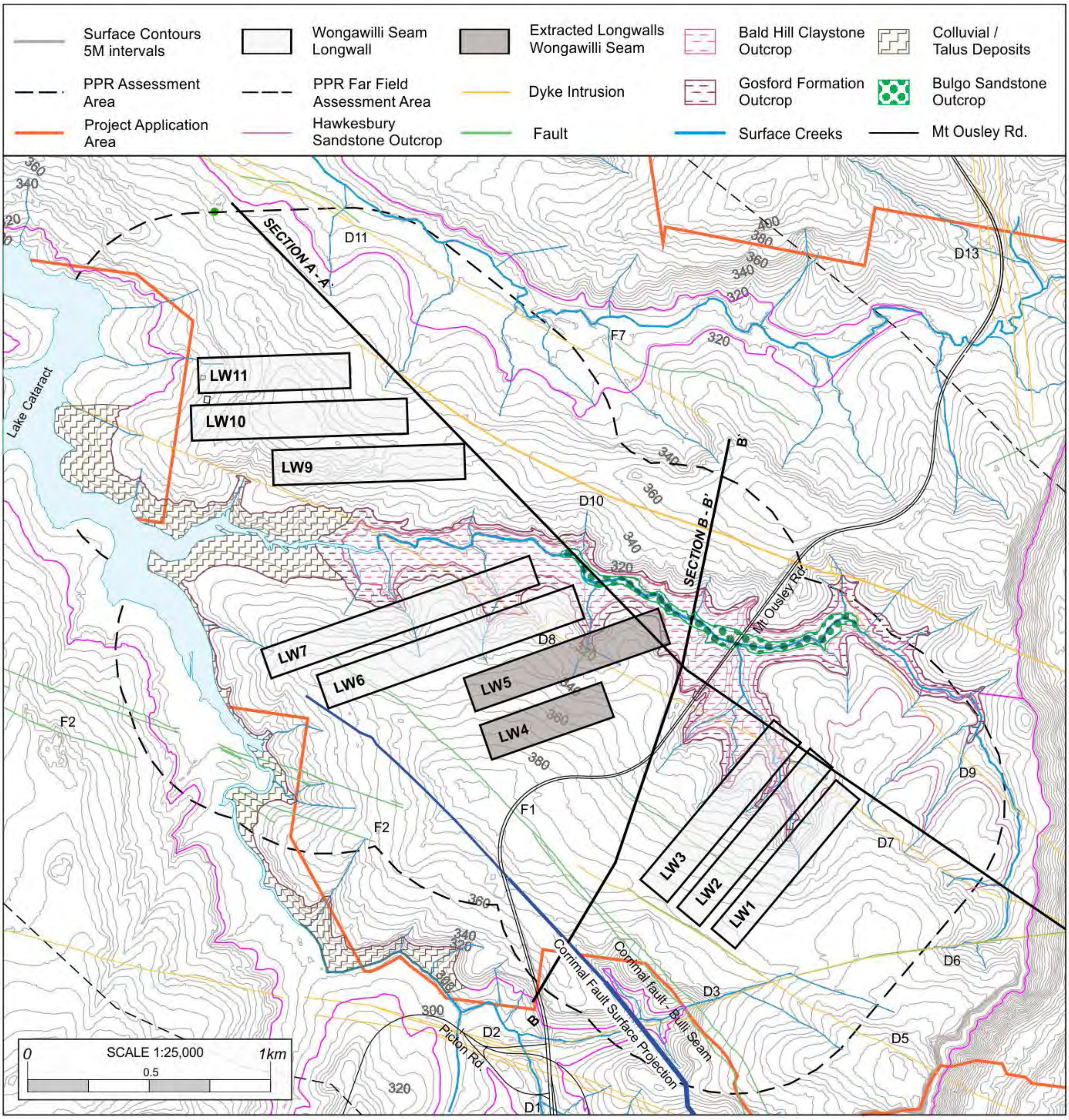


Figure 4: Plan showing geological outcrop at the surface and the location of major geological structures. (reproduced from Figure 11 of Clark 2013).

The Bulgo Sandstone that underlies the Bald Hill Claystone outcrops along the main channel of Cataract Creek on both sides of Mount Ousley Road.

Figure 5 shows a cross-section through the Assessment Area extending from south to north in the vicinity of Mount Ousley Road drawn at natural scale. This section shows how Cataract Creek has cut down through the stratigraphy near the top of the anticlinal structure (an upward or arch shaped fold in the geological strata) that exists in this area.

2.8.1 Coal Seams

The three coal seams that have been mined at the colliery are all located within the Illawarra Coal Measures.

The Bulli Seam is the uppermost of the three seams and averages about 2.2m in thickness across the Assessment Area. Figure 6 shows the layout of the Bulli Seam workings and the geological structure in the Bulli Seam (reproduced from Clark 2013).

The Balgownie Seam is located on average about 10m below the floor of the Bulli Seam ranging from 5m to 14m across the Assessment Area. Figure 7 shows the layout of the Balgownie Seam workings and the geological structure in the Balgownie Seam. The Balgownie Seam is approximately 1.2m thick, but anecdotal evidence from miners who worked the seam and subsidence monitoring indicates that the mining height may have been up to 1.5m on the longwall faces to accommodate the mining equipment. It is understood the additional height was gained by mining the immediate floor strata.

The Wongawilli Seam is located approximately 20m below the Balgownie Seam and ranges in thickness from 7.7m to 11.9m, but the lower 2.6-2.8m is the best quality. It is this section that is planned to be targeted by proposed longwall extraction. The development roadways are mined to a greater height for operational reasons. Figure 8 shows a plan of the geological structure at the Wongawilli Seam level reproduced from Clark (2013) and modified to include the Wongawilli Seam floor contours.

The floor of the Wongawilli Seam has an elevation of approximately RL 80mAHD at the north eastern corner of Longwall 1 and an elevation of approximately RL-25mAHD at the north western corner of Longwall 11. The dip of the seam between these two points is, for practical purposes, constant.

2.8.2 Geological Structures

The geological structure in each seam is shown in Figures 6-8. The major geological structures of interest in the area are igneous sills and dykes and the Corrimal fault. The vertically continuous structures are evident in the Bulli and Balgownie Seam and in the geomorphology on the surface. The position of these features is considered to be well defined as a result of the underground exposures.

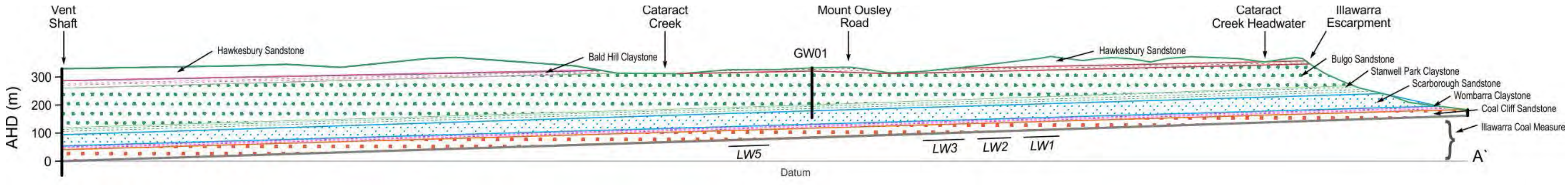


Figure 5a: Section A - A` West - East geological section through PPR Application Area.

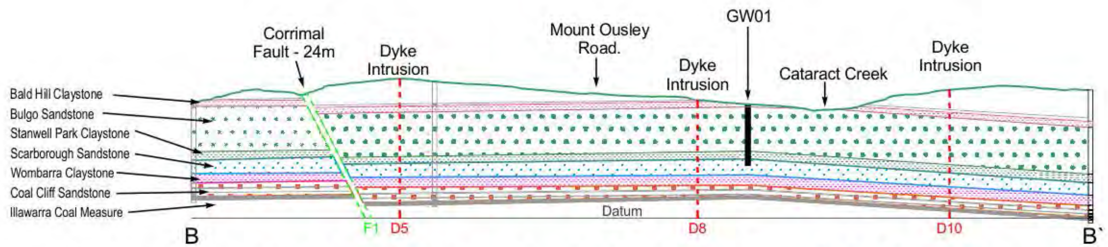


Figure 5b: Section B - B` South-North geological section through PPR Application Area.
(reproduced from Figure 12 of Clark 2013).

Note: Vertical scale is the same as the horizontal scale.
Refer to Figure 4 for section locations.

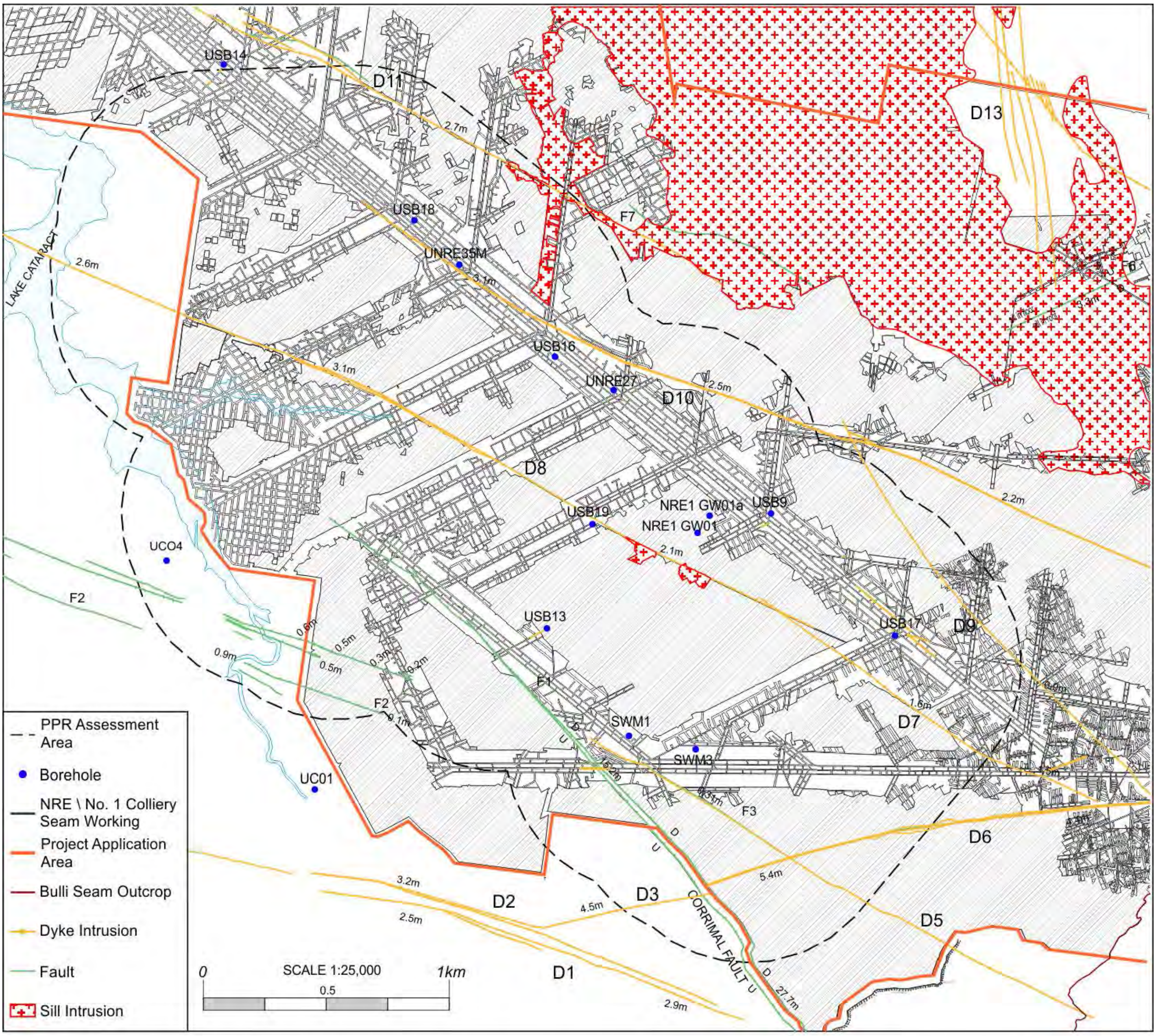


Figure 6: Plan showing geological structures and the extent of mining in the Bulli Seam level. (reproduced from Figure 14 of Clark 2013).

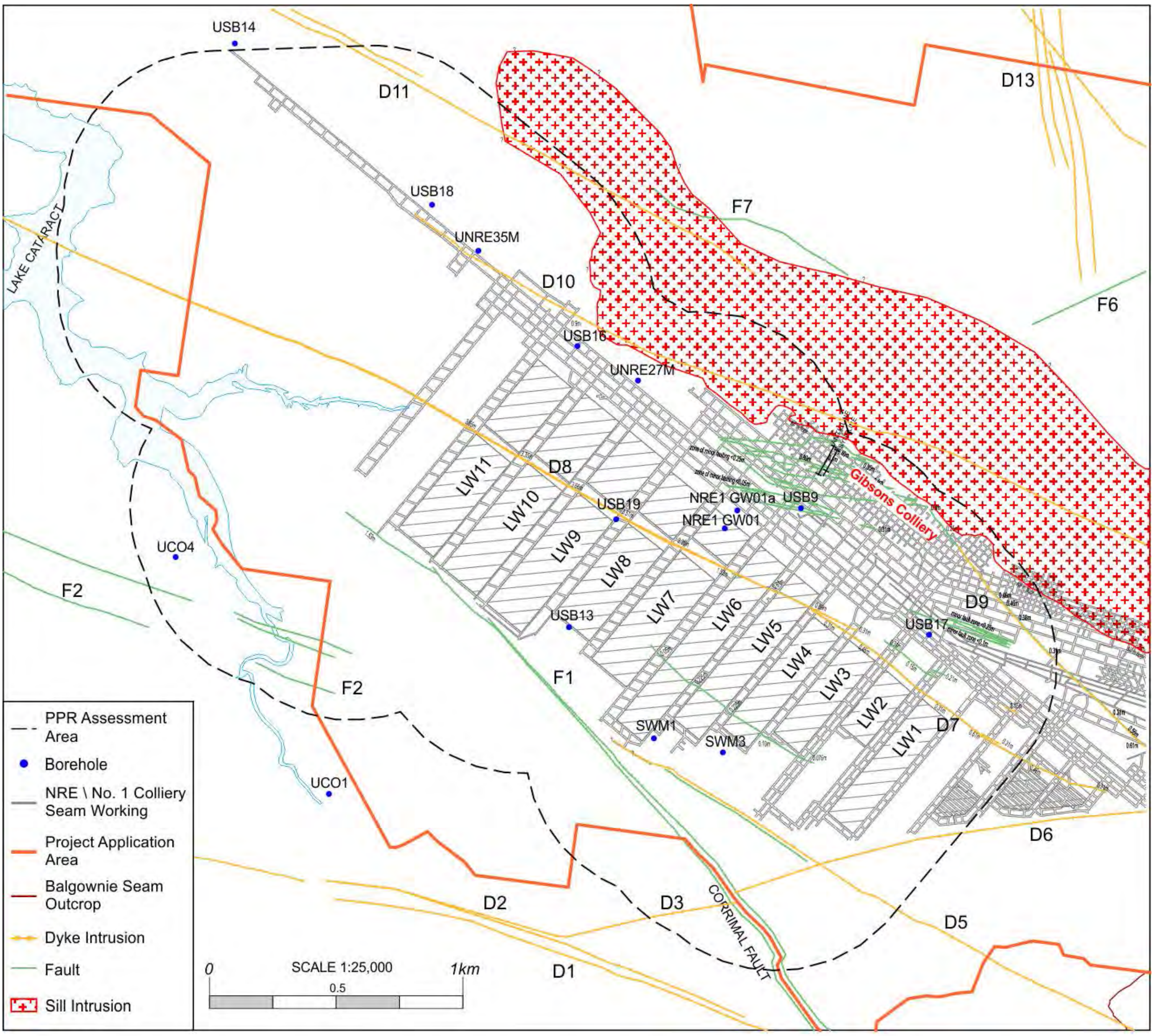


Figure 7: Plan showing geological structures and the extent of mining in the Balgownie Seam level. (reproduced from Figure 15 of Clark 2013)

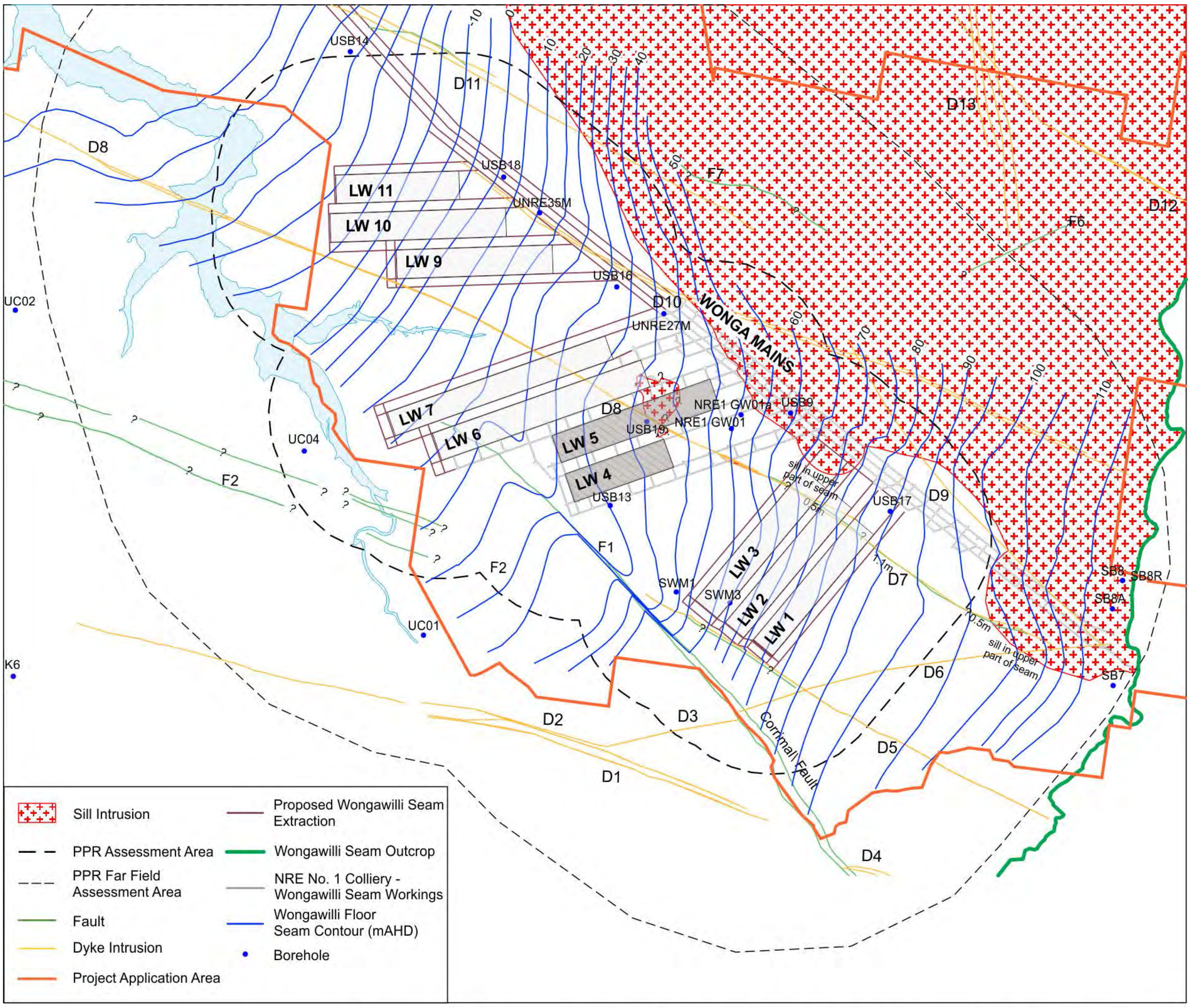


Figure 8: Plan showing geological structures in the Wongawilli Seam (reproduced from Figure 17 of Clark 2013) and floor contours of the Wongawilli Seam based on floor contours in the Bulli Seam.

An igneous sill has intruded into the Wongawilli Seam to the north of the main headings and the coal in this area is cindered and unsuitable to mine. A sill forms when molten igneous rock is injected under pressure into the host strata causing it to fracture hydraulically. When the in situ stresses at the time of injection are such that the lowest stress is vertical, the hydraulic fracture that forms is oriented horizontally. The injected rock then cools to form a horizontal layer of intruded rock within the host rock.

Several dykes exist within the Assessment Area with most having a west-north-west east-south-east orientation. Dykes are the vertical equivalent of sills and form when the lowest in situ stresses at the time of injection is one of the horizontal stresses. The resulting hydraulic fracture opens against this lowest stress cutting across the host strata to form an intrusion that is vertically and laterally continuous often for many kilometres in length. The dykes that have formed in the Southern Coalfield are generally less than a few tens of centimetres thick in the general strata but often increase in thickness at coal seam level where the in situ stresses are less. Dykes are usually hard to mine, dilute the coal product, cause damage to the mining equipment, and tend to be avoided where possible.

The site constraints within the Assessment Area mean that several of the proposed longwall panels will need to mine through Dyke D8. This dyke has been previously encountered in the Bulli Seam and Balgownie Seam workings and its trace is apparent in the geomorphology on the surface indicating that it is vertically continuous to the surface.

Figure 9 shows a photograph of Dyke D8 at Wongawilli Seam level where it was intersected on the longwall face at a shallow angle making it appear thicker than it actually is. Dyke D8 is approximately two metres thick in this area and fractured. Although the dyke appeared damp at the time of inspection (21/6/13), the coal seam to either side also appeared similarly damp. This dampness is considered likely to be a result of dust suppression water sprays on the longwall shearer. There did not appear to be any significant seepage flow emanating from the dyke consistent with experience at almost all other dyke intersections in the Southern Coalfield.

The only major geological fault within the Assessment Area is the Corrimal Fault (F1) which extends in a north-west south-east orientation in the southern part of the Assessment Area. This fault was intersected in the overlying Bulli Seam but the longwall panels in the Balgownie Seam did not extend far enough south, although some of the headings extended to the fault and the associated dyke D5. The fault is also apparent in the surface geomorphology and so its location and characteristics are well defined. The fault diminishes to the northwest and has become insignificant as a series of minor features with total displacement of about 1m where it is intersected by the gateroads for Longwall 6 in the Wongawilli Seam (Cartwright 2014).

Other faults in the general area, the Rixons Pass Fault, the Woonona Fault, and F2 are remote from the proposed mining and are not considered likely to affect mining or to be affected in any significant way by the proposed mining.

Figure 9: Dyke D8 exposed in the face of Longwall 5 on 21 June 2013. (Note this dyke was intersected at a shallow angle so the dyke appears thicker than it is).

2.8.3 Overburden Depth

Figure 10 shows a plan of the overburden depth to the Wongawilli Seam. The overburden depth ranges from 250m above Longwalls 2 and 3 in the northern part below the southern tributary of Cataract Creek through to 390m above the central part of Longwalls 10 and 11.

The overburden depth range for individual longwall panels is shown in Table 1. The ratios of panel width to depth range from 0.37 to 0.60. In previously unmined terrain, low levels of subsidence would be expected above each individual panel with the overall maximum subsidence controlled by elastic compression of the chain pillars between panels. However, subsidence monitoring data from the recently mined Longwalls 4 and 5 and from the Balgownie Seam longwall panels indicates that the presence of overlying mine workings has the effect of softening the overburden strata so that its bridging capacity (shear stiffness) is reduced thereby increasing the maximum subsidence above each individual panel to the higher magnitudes of subsidence that have been observed. This effect is discussed in more detail in the following sections.

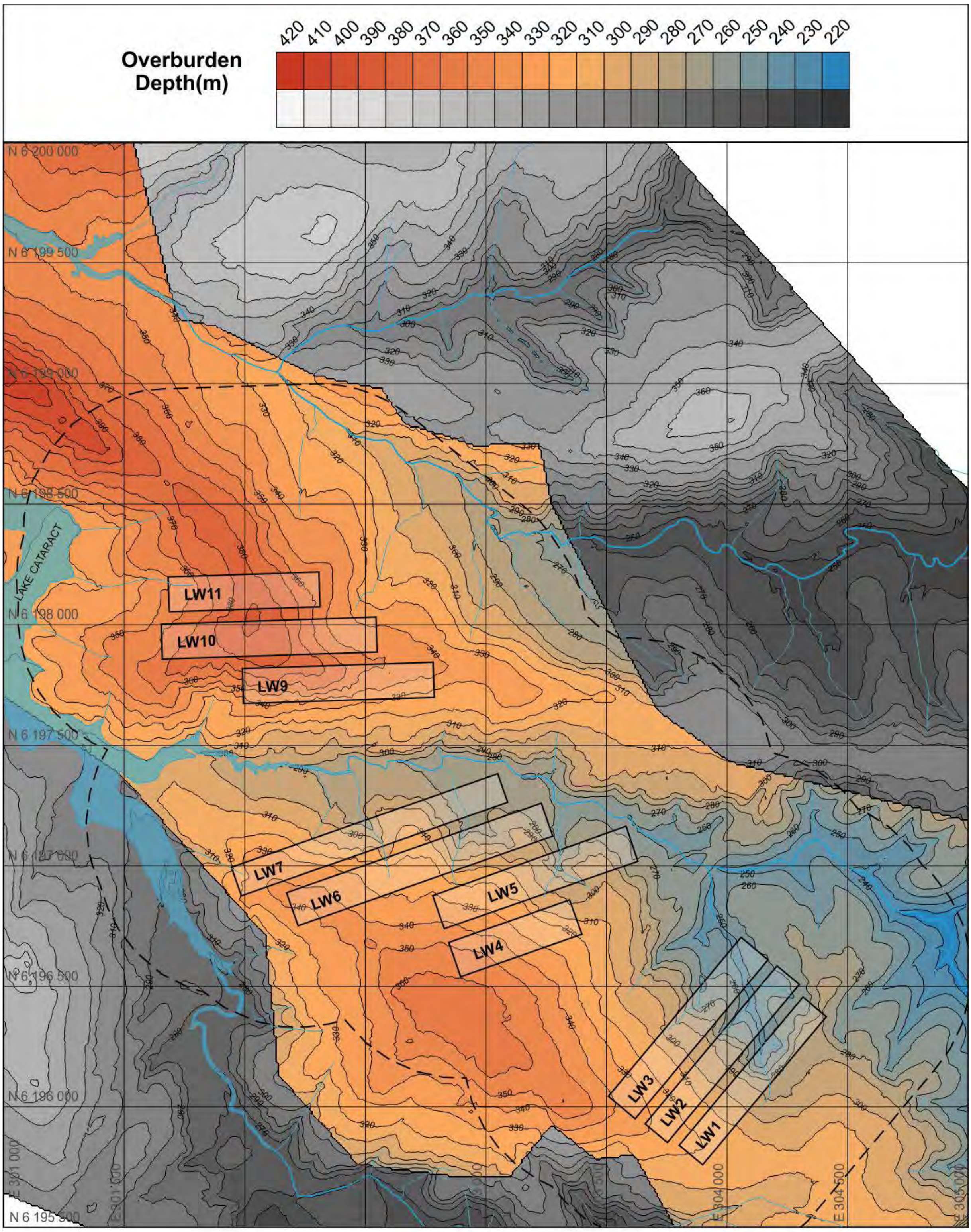


Figure 10: Depth of Overburden to the Wongawilli Seam.

Table 1: Overburden Depth Range

Longwall Panel	Panel Width (m)	Overburden Depth Range (m)	Width on Depth Ratio
1	131	255-320	0.41-0.51
2	125	255-330	0.37-0.49
3	150	250-340	0.44-0.60
4	150	300-360	0.42-0.50
5	150	265-345	0.43-0.57
6	150	270-345	0.43-0.55
7	131	270-340	0.39-0.49
9	150	330-380	0.39-0.45
10	150	335-390	0.38-0.45
11	150	350-385	0.39-0.43

3. PREVIOUS MINING ACTIVITY

A unique characteristic of the PPR Assessment Area is the presence of previous mining activity in two other seams in geometries that are unrelated to proposed mining in the third seam. Figure 11 and Figures 6-8 show the extent of previous mining in the Bulli Seam and Balgownie Seam within the PPR Assessment Area.

This previous mining provides a number of opportunities that are not usually available in single seam mining applications but also brings a number of differences as well. Geological structure and seam contour are much better known as a result of previous mining activity than would normally be possible for single seam mining.

Previous mining activity provides an opportunity to examine the mining impacts over timeframes of 50-100 years for the Bulli Seam and 30-40 year for the Balgownie Seam mining. The subsidence movements associated with the earlier mining have been estimated for the Bulli Seam and measured for the Balgownie Seam providing a baseline of impact experience and recovery that is not typically available.

The ongoing nature of the mining operation at NRE No 1 Colliery provides the opportunity to inspect the mine workings in the Bulli Seam and the Balgownie Seam to better understand the nature of the potential interactions between seams and the potential for pillar instability particularly in the Bulli Seam to cause unexpected additional subsidence. In preparation for this report, a site visit was made on 21 June 2013 to inspect the workings in all three seams.

Subsidence monitoring data available from mining in the Balgownie Seam and more recently from two longwall panels in the Wongawilli Seam is available and this provides a basis for predicting future subsidence behaviour. This data indicates that while there are some significant differences in behaviour compared to single seam mining, the multi-seam behaviour is predictable and occurs predominantly within the bounds of the panel being mined and the chain pillar to the previous panel. This data and observations of previous impacts indicate that the impacts of future mining are likely to be similar in nature to the impacts that have already occurred.

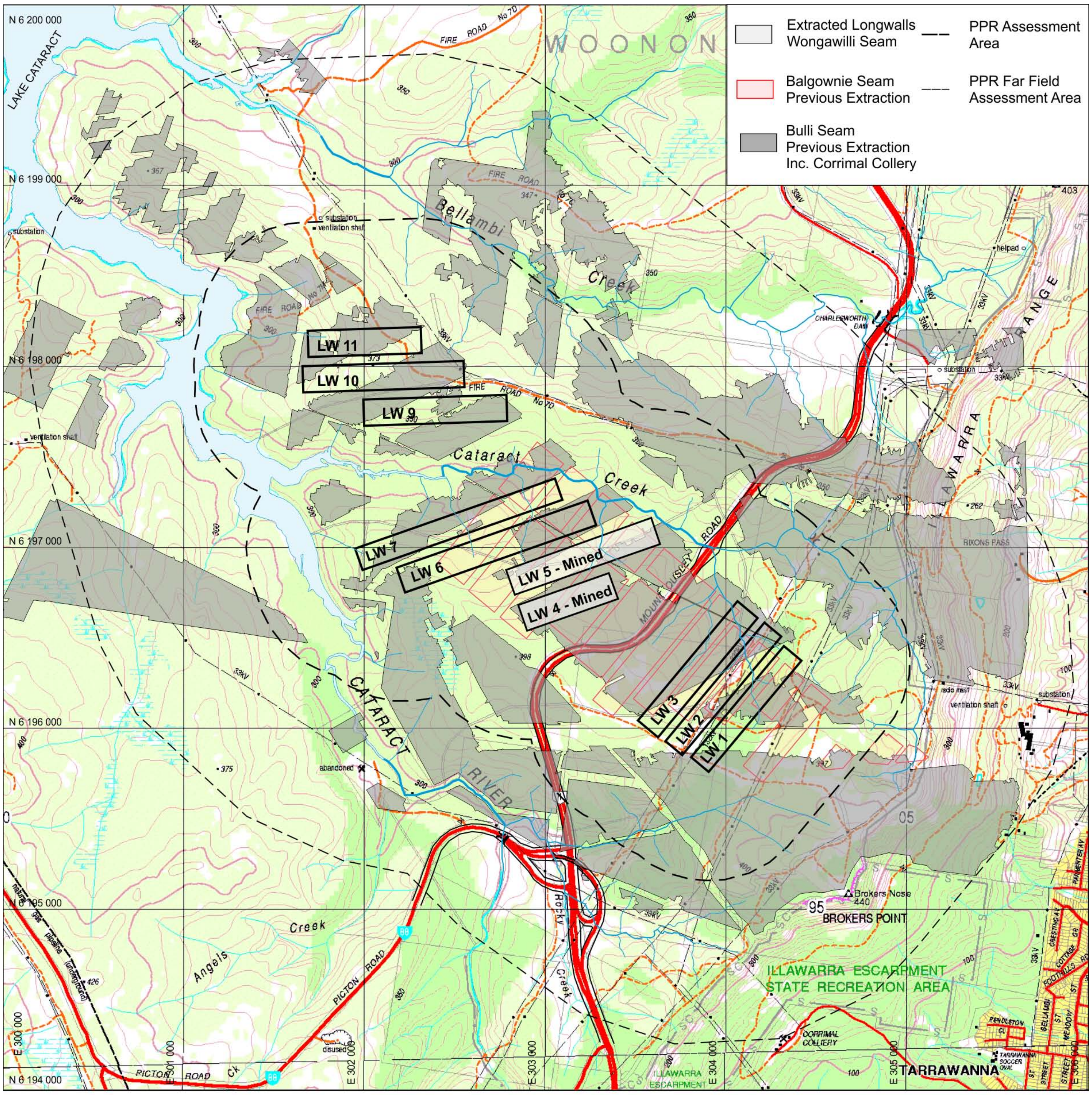


Figure 11: Plan showing extent of previous extraction in Bulli Seam (black) and Balgownie Seam (red) in the PPR Application Area.

The available subsidence monitoring data indicates that there is some softening of the goaf edge subsidence in areas where overlying seams have been mined but the effect is a second order effect and of relatively little significance in terms of subsidence impacts.

3.1 Bulli Seam Workings and Associated Subsidence

The Bulli Seam was mined initially using hand bord and pillar mining techniques from the 1890's through until pillar extraction became possible with improvements in mining technique and the arrival of mechanised mining. Some of the standing pillars associated with the main headings and original mining areas were extracted during the later stages of retreat. Mining in the Bulli Seam within the PPR Assessment Area had effectively finished by the 1950's. Areas of pillar extraction in Corrimal Colliery immediately to the south are also included in the estimation of subsidence from the Bulli Seam because they fall within the Assessment Area.

There are no known records of subsidence monitoring for the period of mining in the Bulli Seam. However, it is possible to estimate the levels of subsidence that are likely to have occurred given the geometry of the panels mined and estimating the likely extraction ratios.

Figure 12 shows contours of the surface subsidence interpreted as being caused by pillar extraction operations in the Bulli Seam. This subsidence has been 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 and subsequent pillar extraction operations.

An underground site inspection conducted on 21 June 2013 showed that there are existing bord and pillar workings alongside the Bulli Seam main headings that are likely to be destabilised if mined directly under in the Wongawilli Seam. Similar workings were directly mined under by the Balgownie Seam longwall panels and it is clear from the underground inspection that these overlying pillars were destabilised in the area directly above the Balgownie Seam longwall goaf as shown in Figure 13. There did not appear to be any evidence that the footprint of instability extended significantly beyond the footprint of the underlying goaf, but it is considered possible that this potential may exist in some places where there are localised areas of standing pillars.

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

The downward movements that occurred during Balgownie Seam mining and were observed on the surface as subsidence provide a basis to differentiate these shaded areas where they have been directly mined under by the Balgownie Seam longwall panels. Small pillars that have been mined under by the Balgownie Seam longwall panels are considered to have almost certainly

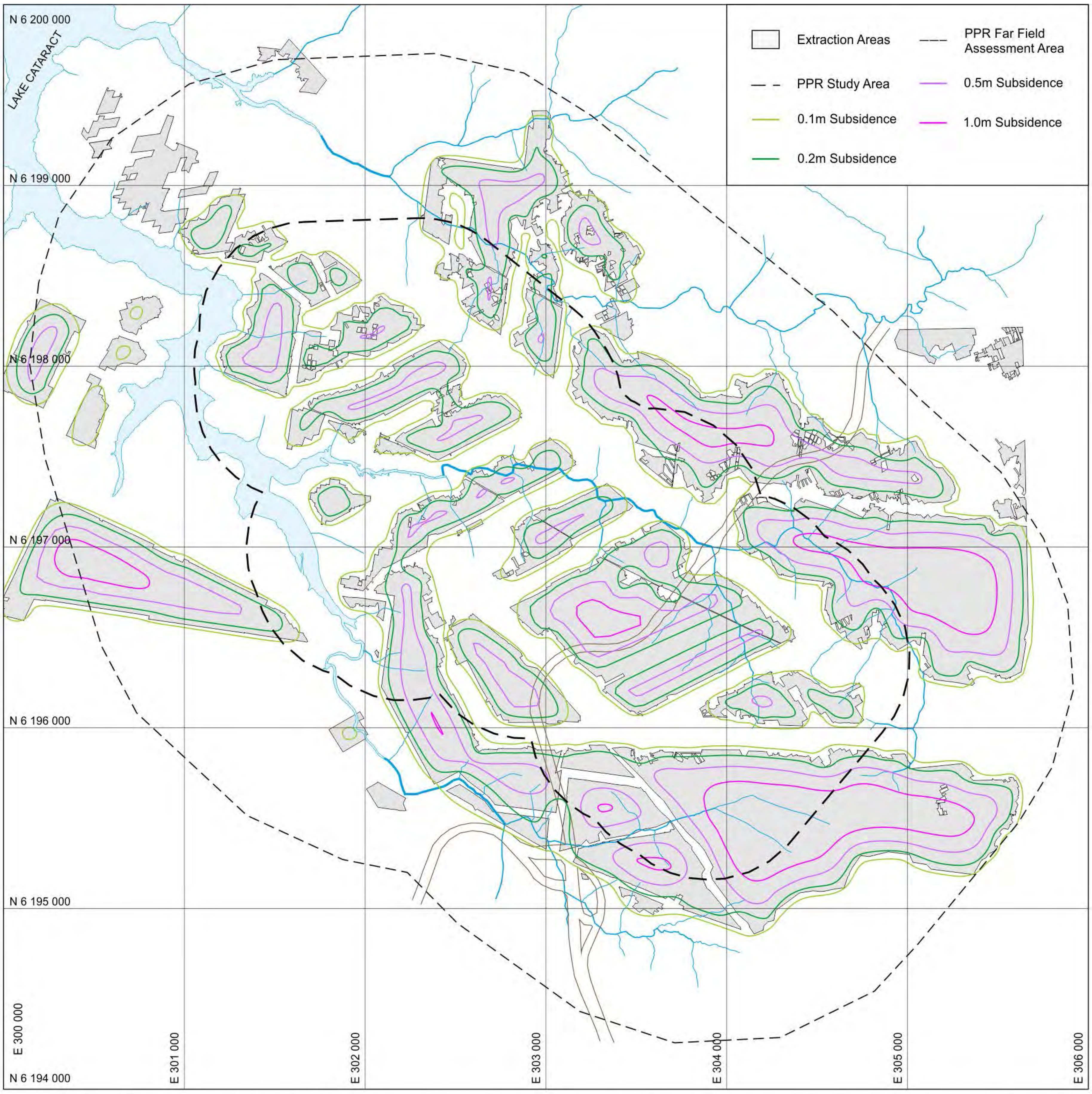


Figure 12: Plan showing estimated subsidence movements likely to have been associated with pillar extraction operations in the Bulli Seam.

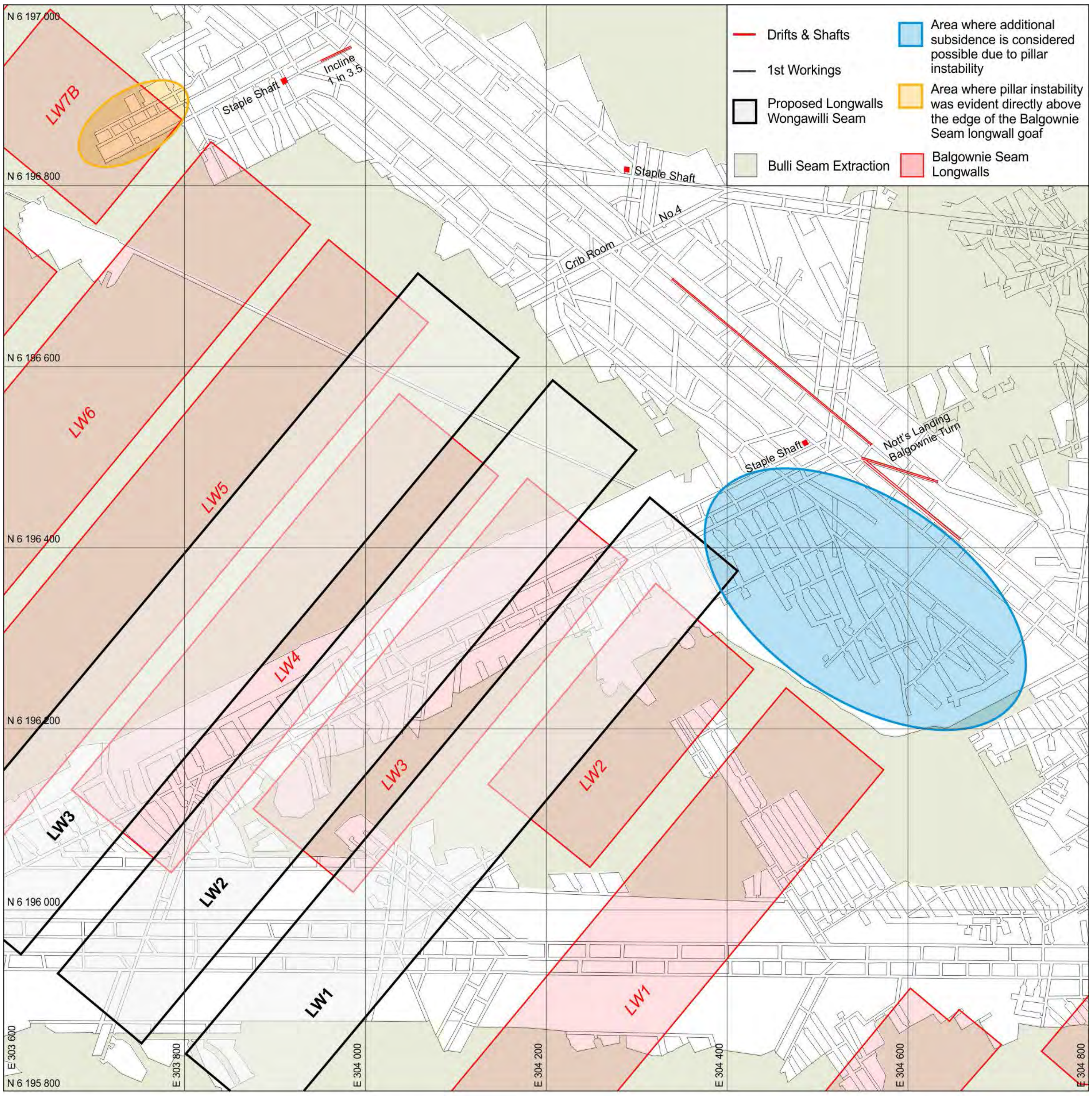


Figure 13: Plan showing areas of pillar instability in overlaying Bulli seam caused or possibly caused by mining in seams below.

been destabilised during the 1-1.5m downward movement that would have occurred as the pillars were mined under. Subsidence monitoring above the Balgownie Seam longwall panels shows areas where there has been some additional subsidence consistent with pillar instability, areas where there has been additional consolidation of an existing Bulli Seam goaf, and areas where there has been either no mining in the Bulli Seam or the Bulli Seam pillars are large enough to behave like solid coal.

The Bulli Seam subsidence estimates shown in Figure 12 include refinements based on the ground behaviour observed during longwall mining in the Balgownie Seam. Although it is not possible to interpret the characteristics of some of the other large Bulli Seam goaf areas that have not been directly mined under in the Balgownie Seam, these other large goaf areas are remote from the areas where the PPR longwall panels are proposed.

The detail of the Bulli Seam pillars is available in some areas close to the main headings as shown in Figure 13. The site visit to this area indicated that additional subsidence due to pillar instability would be possible in the area shown if Longwall 1 was extended to its full length although surface subsidence may be relatively small given the narrowness of the panel at an overburden depth of 270m. Any additional subsidence would have potential to impact on pylons on the two 33kV power transmission lines and this potential is addressed in the impact assessment for these structures.

The issue of a “pillar run” in the Bulli Seam was raised in the Pt3A submissions. As indicated above, there is considered to be potential for a classical “pillar run” associated with pillar instability, but the geometries in the Bulli Seam and the evidence from previous mining in the Balgownie Seam make it unlikely that such an event would extend more than a few hundred metres from the goaf edge (i.e. the extent of the panel of standing pillars). The subsidence from such an event would be limited to low levels of less than a few hundred millimetres maximum due to the narrow panel width of standing pillars small enough to be destabilised and would be limited to only those areas where there are small standing pillars that have not previously been mined under in the Balgownie Seam.

The terms “pillar run” and “pillar creep” have been used in some of the submissions to describe the phenomenon that is perhaps better described as “stress redistribution” because of the relatively smaller ground movements involved, typically less than 100mm. As one area is subsided, pillars become more heavily loaded, and compress slightly causing lateral migration of low level subsidence movements well beyond the limits of subsidence normally associated with single seam mining. This phenomenon is particularly common where panels are relatively narrow compared with overburden depth and surface subsidence is controlled mainly by elastic compression of the pillars between panels.

A similar process can also occur for horizontal movements as horizontal stresses are redistributed and dilation of subsiding strata causes horizontal movement in a downslope direction. Again the ground movements tend to be small second order movements that may cause perceptible low level cracking on hard surfaces such as sealed roads especially adjacent to topographic high points, but such movements are usually not significant because they tend to be of small magnitude and occur over large areas.

3.2 Balgownie Seam Workings and Associated Subsidence

Figure 7 shows the extent of the Balgownie Seam workings. There are eleven longwall panels extending to the south of the main headings. Apart from development headings, the remaining coal was recovered from three small areas of pillar extraction in the east and more recently as a panel of pillars formed up as first workings against the sill in the north.

Longwall mining in the Balgownie Seam started in September 1970 at Longwall 1 and finished on 27 May 1982 at Longwall 11. The first six panels were located east of the current Mount Ousley Road alignment and ranged in width from 141m to 145m. The last five panels were located west of Mount Ousley Road and ranged in width from 185m to 189m. These later panels were split into two parts either side of the D8 Dyke. These longwalls mined directly below the road alignment.

3.2.1 Vertical Subsidence

Surface subsidence was monitored along the centreline of each of the eleven longwall panels and on three cross-lines. The vertical subsidence was monitored at regular intervals during panel retreat above the initial panels and less frequently during mining of the last few panels. Surface strains were also measured during the last panel.

Figure 14 shows an example of the subsidence measured on the second cross-line that extends from the centre of Longwall 5 to the solid coal west of Longwall 11. The characteristics of the subsidence measured that are of relevance to this assessment are:

- The chain pillars are clearly evident in the subsidence profile with 0.5m to 0.75m of subsidence directly over these pillars.
- Coal left in the Balgownie Seam around the dyke is clearly evident as reduced surface subsidence.
- The maximum sag subsidence in the centre of each panel is reduced in areas where the panels are narrower (0.2m in narrow panels compared to 0.5m above the wide panels).
- The sag subsidence is more in areas where the Bulli Seam has been extracted.
- The subsidence is greatest (1.42m) over Longwall 10 in an area on the fringe of Bulli Seam goaf where full subsidence during mining of the Bulli Seam was prevented by the presence of solid abutment coal or marginally stable pillars were destabilised.
- Surface subsidence occurred primarily within the geometry of the Balgownie Seam longwall panels.

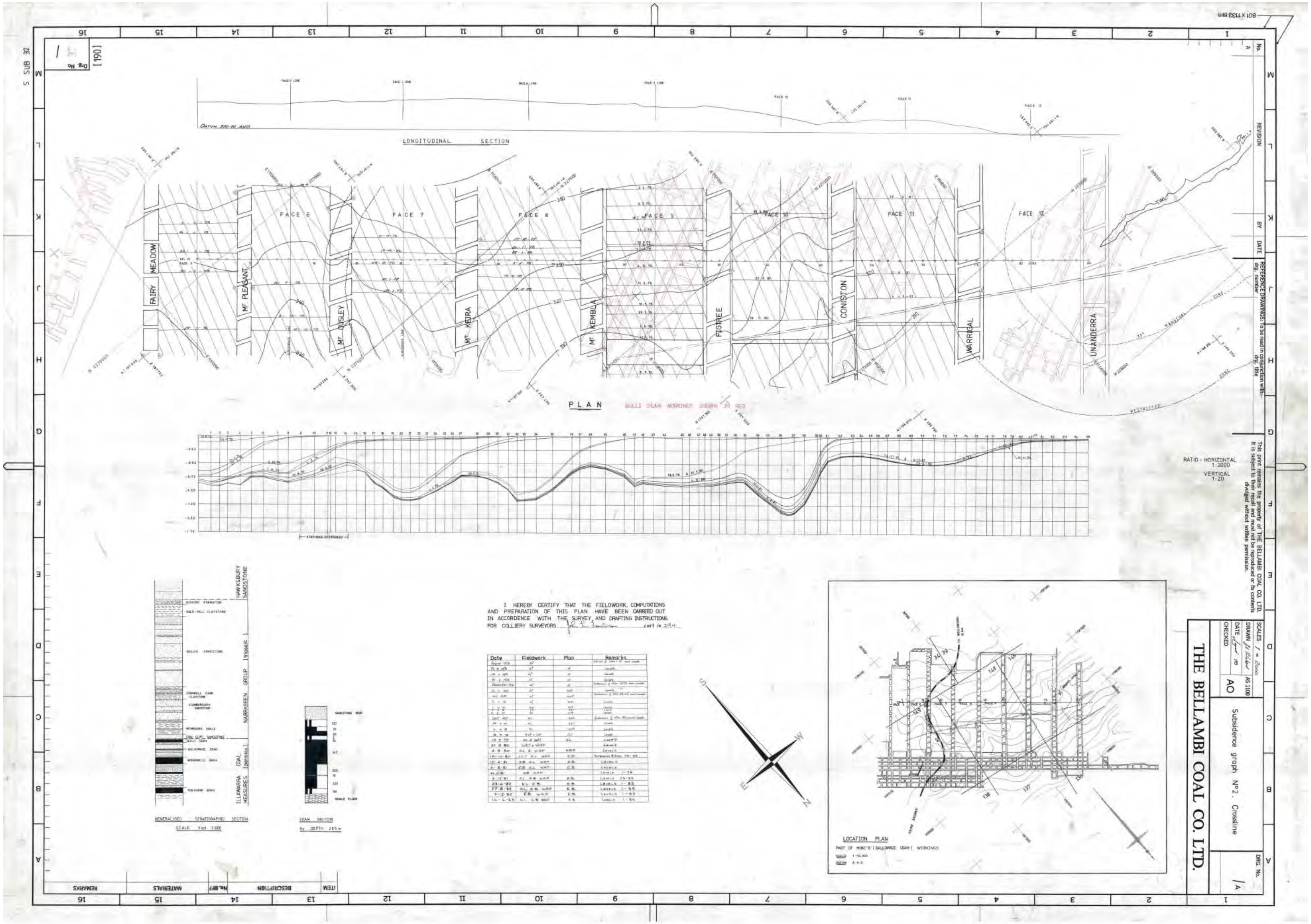


Figure 14: Example of subsidence monitoring of Balgownie Seam longwall panels.

- The goaf edge subsidence is greater and extends further when there is overlying Bulli goaf, but this effect is a second order effect.

These different characteristic behaviours have been considered for each of the subsidence lines and the maximum subsidence observed is able to be used to characterise the condition of the Bulli Seam goaf above.

Figure 15 shows the maximum subsidence observed for each of the longwall panels. The different areas can be divided up as shown in Table 2 based on where there are pillars and goaf in the two seams.

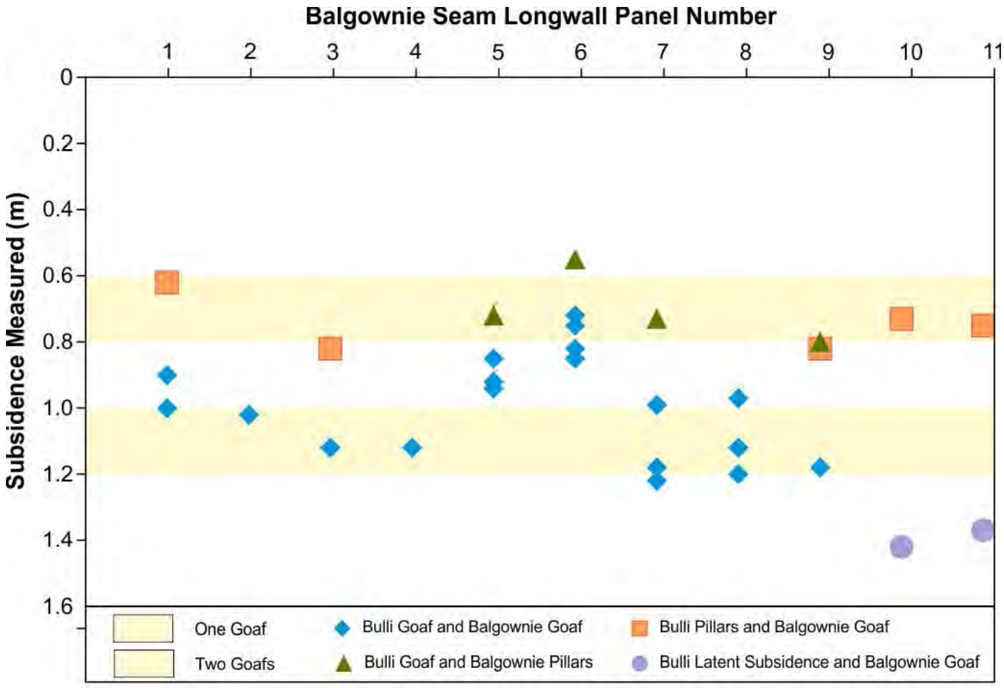


Figure 15: Maximum subsidence observed for each longwall panel in the Balgownie Seam.

Table 2: Subsidence Observed in Different Conditions

	Bulli Seam Pillars	Bulli Seam Goaf	Unstable Bulli Pillars
Balgownie Seam Pillars	Low level subsidence (<0.2m)	0.6-0.8m	Low level (<0.2m)
Balgownie Seam Goaf	0.6-0.8m	1.0-1.2m	1.4m

In areas where there are Balgownie chain pillars and pillars in the Bulli Seam, the subsidence directly over the chain pillars is less than 0.2m. In areas where there are pillars in one seam and extraction in the other seam, surface subsidence is between 0.6m and 0.8m. Where there has been extraction in both seams, the maximum incremental subsidence is in the range 1.0m to 1.2m – i.e. approaching 80% of the nominal mining height of the second seam mind.

In areas where there is clearly potential for either latent subsidence because the Bulli Seam goaf is narrow and bridging (such as the zone of high subsidence associated with mining Longwall 11 in the Balgownie Seam) or along a goaf edge where full subsidence has not been able to develop during mining the first seam (such as the high subsidence zone associated with mining Longwall 10 in the Balgownie Seam), the incremental subsidence reaches 1.4m and is of the order of 100% of the mining height of the second seam mined.

The 1.4m of subsidence observed in these circumstances is likely to have a component of destabilisation of standing pillars in the Bulli Seam caused by mining in the Balgownie Seam. Up to 0.7m of subsidence would be expected from mining below pillars in the Bulli Seam plus an additional 0.8m subsidence in the Bulli Seam of about 30% of the 2.2m mining height given an extraction ratio of about 30%. The total subsidence would therefore be about 1.5m and of the same magnitude as the subsidence observed.

Figure 16 shows the subsidence measured during mining the Balgownie Seam based on interpolation of the subsidence monitoring data. This data represents the incremental subsidence associated with mining the Balgownie Seam given that all the Bulli Seam subsidence had already occurred prior to the subsidence pegs being installed.

Maximum subsidence is 1.42m and 1.33m over Longwalls 10 and 11 respectively but in most of the areas, subsidence over the longwall goafs is in the range 0.6m to 1.2m.

3.2.2 Horizontal Strains and Tilts

Maximum strains measured over Longwall 11 ranged from 3-4mm/m along the panel to peaks of 14mm/m in compression across the topographic low point of Cataract Creek and 9mm/m in tension on the slope beyond. For the maximum subsidence of 1.4m and an overburden depth to the Balgownie Seam of 260m at this location, the strain peaks measured indicate a relationship between maximum strain and maximum subsidence of:

$E_{max} = 500\ S_{max} / D$ for systematic strains and

$E_{max} = 1500\text{-}2500\ S_{max} / D$ for non-systematic strains associated with valley closure and steep topography.

These compare reasonably with the peak strain subsidence relationships presented by Holla and Barclay (2000) for the Southern Coalfield which indicate:

$E_{max\ tensile} = 1500\ S_{max} / D$
$E_{max\ compressive} = 3000\ S_{max} / D$
$Tilt_{max} = 5000\ S_{max} / D$

for peak strains and tilts that include non-systematic strains and tilts associated with valley closure and steep topography. The peak compressive strains tend to be apparent in topographic low points and the tensile strains tend to be more apparent at the start of panels in ground sloping in the same direction as mining, and along topographic high points such as ridges.

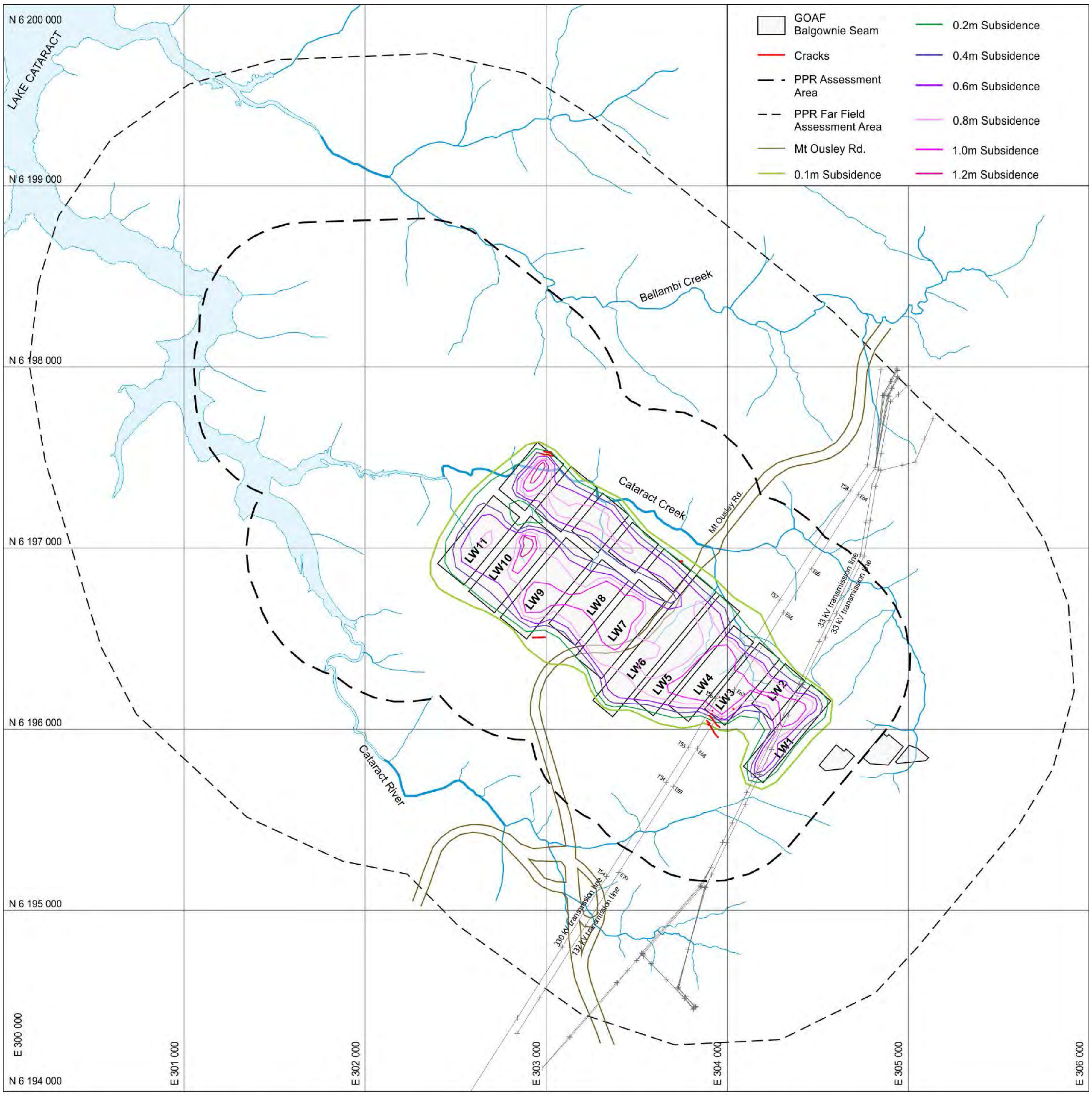


Figure 16: Contours of subsidence measured above the Balgownie Seam longwall panels.

Table 3: Comparison of Measured and Calculated Upsidence

Balgownie Longwall Panel	Distance from End of Panel (m) (positive over goaf)	Incremental Upsidence Indicated (mm) (not necessarily peak)	Overburden Depth (m)	Maximum Subsidence (m)	Calculated Upsidence for each panel individually (mm)
3	170	130	230	1.1	70
4	30	210	230	1.1	100
5	0	80	230	0.8	100
6	-75	30	240	0.8	120
8	-106	80	240	0.9	130
9	-30	120	250	0.9	110
10	20	100	260	0.9	100
11	116	100	260	1.4	90

3.2.3 Valley Closure and Upsidence

The 14mm/m compressive strain peak measured across Cataract Creek on the centreline of Longwall 11 was measured between pegs spaced 18m apart. Compressive strain of 4mm/m was measured between the next two pegs spaced 15m apart. These measurements imply a total closure across the creek of about 310mm.

The ACARP method for estimating valley closure developed by Waddington and Kay (2002) indicates the incremental valley closure for Longwall 11 as being of the order of 200-300mm and is therefore consistent with the closure measured during mining of Longwall 11. The agreement is relatively close between measured and calculated even though the geometry associated with the short longwall panels is irregular and well outside the database of experience on which the ACARP method is based.

Valley closure at other locations is also evident as upsidence in the subsidence profiles that extend across Cataract Creek. Table 3 summarises the upsidence measured as well as the incremental upsidence calculated for each longwall panel to allow direct comparison with the upsidence measured for each longwall panel during mining of that panel.

Upsidence measurements shown in Table 3 are made at the peg locations. The pegs are 15-20m apart while the upsidence tends to peak over a distance of only a few metres. The location of the pegs may not necessarily coincide with the peak upsidence, so the measured upsidence is considered to be a lower bound estimate of the maximum upsidence that occurred. The measurements made during mining of the Balgownie Seam longwall panels indicate that Cataract Creek has already sustained upsidence in the range 100-200mm from this mining with some additional upsidence likely to have occurred during mining in the Bulli Seam.

The ACARP method for estimating upsidence for single seam mining operations indicates upsidence and valley closure that are consistent with the values measured. This method appears likely to still be relevant for estimating upper bound upsidence and valley closure for future mining activity in the Wongawilli Seam even in a multi-seam mining environment.

3.2.4 Total Cumulative Subsidence

Figure 17 shows the total cumulative subsidence estimated by adding together the estimated subsidence from the Bulli Seam and the measured subsidence from the Balgownie Seam using Surfer and a 10m by 10m grid spacing. The locations of surface features that have or may have been impacted by subsidence from this previous mining are also shown. The proposed and previously mined longwall panels in the Wongawilli Seam are also shown for reference purposes.

The total cumulative subsidence associated with mining both the Bulli Seam and Balgownie Seam is an estimate because the Bulli Seam subsidence was not measured. The total subsidence is nevertheless useful as an indicator of maximum subsidence when interpreting subsidence impacts from previous mining activity.

Maximum cumulative subsidence is approximately 1.9m in the area above Longwalls 7 and 8 in the Balgownie Seam just to the west of the Mount Ousley alignment on the slope to the south of Cataract Creek. More generally the cumulative subsidence is in the range 0.3-1.3m.

3.3 Historical Mining Impacts

While it is not possible to completely separate the impacts from previous mining in the Bulli Seam from the impacts associated with previous mining in the Balgownie Seam in areas where both have been mined, it is nevertheless helpful to review the impacts that have occurred previously as a basis for estimating the likely impacts of future mining.

These impacts are most evident as rock falls and surface cracking on hard rock surfaces and changes in the character of stream channels such as upsidence cracking, iron staining, and sediment infilling in areas where the stream bed has been subsided. Other features where evidence of impacts is not so apparent include Mount Ousley Road, the power transmission lines, and natural features such as swamps and other vegetation.

3.3.1 Surface Cracks

Surface cracking is documented on subsidence plans prepared during and after mining of the Balgownie Seam longwall panels. The cracks reported are mainly located near the start of Longwall 3 in the open terrain of the power transmission line easement.

These cracks are located near the start of the longwall panel on a topographic ridge in an area where the combination of systematic horizontal movements at the start of the panel and horizontal movements in a downslope direction would be expected and are commonly observed. Similar cracks are likely to have occurred at other locations but most of these would be in bushland locations where they would be difficult to detect.

For instance, a linear depression opened up near the southern corner of Longwall 4 in the Wongawilli Seam during mining of Longwall 5. This depression is considered to be associated with subsidence cracking. The

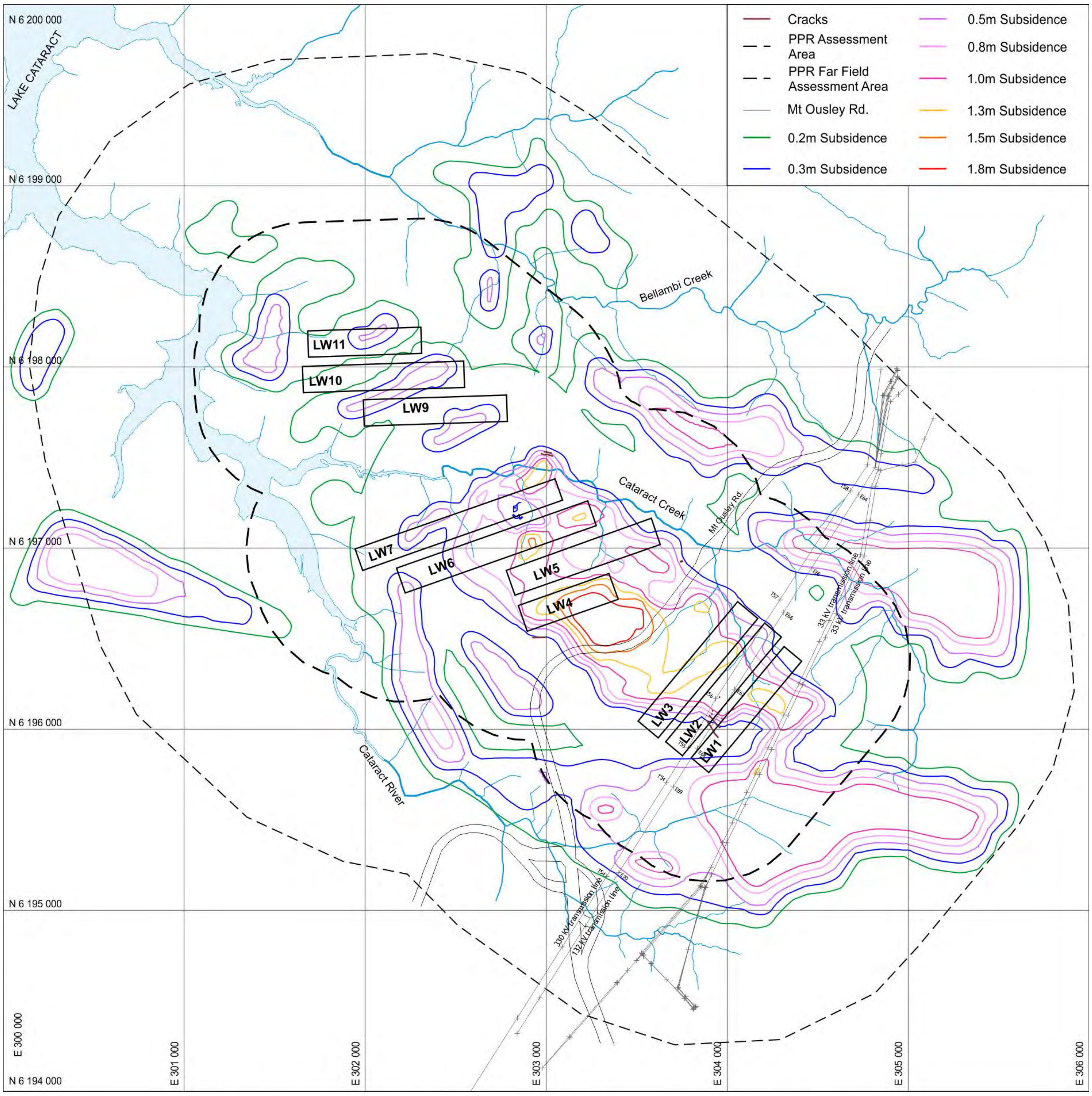


Figure 17: Contours of cumulative subsidence for the Bulli Seam and the Balgownie Seam.

depression and associated crack are located in an area where the goaf edges in all three seams are superimposed. The area is also near the top of the ridge between Cataract Creek and Cataract River where horizontal ground movements are expected to concentrate surface cracks. The ground displacement indicated by this crack is of the order of 700mm but subsidence monitoring indicates that only a small part of this movement occurred during recent mining of Longwall 5 when the crack was first noticed. The implication of these measurements is that the crack developed during previous mining but was disguised below the soil and had been substantially infilled by soil material over the period since it formed.

Inspections conducted in association with cracking on the Mount Ousley Road show that there are a series of tension cracks and minor sinkholes evident along the northern side of the ridgeline between Cataract River and Cataract Creek. These cracks are locally aligned with the direction of one of the principal joint directions in the Hawkesbury Sandstone

3.3.2 Rock Falls

An inspection of cliff formations across the PPR Assessment Area conducted during the original subsidence assessment program informed by LiDAR interpretation indicated that there are several rock falls that are considered to be attributable to mining subsidence from both Bulli Seam and Balgownie Seam mining activity. These rock falls are small in volume and are barely discernable from natural rock falls that have occurred in the general area over the period since mining was completed.

A recent inspection of sandstone cliff formations on the southern side of Cataract Creek indicated the presence of several rock falls and subsidence cracks associated with previous mining.

A sandstone formation immediately downstream of CCUS4 showed evidence of previous mining impacts in the form of cracking and a section of overhanging cliff that had toppled over. The nature of the fracturing is consistent with mining induced subsidence from the Balgownie Seam longwall panels.

A length of cliff formation associated with archaeological site 52-2-3941 appears to have been subjected to fracturing and resultant rock falls which are likely to have been caused by subsidence associated with mining activity in the Bulli Seam. The nature of the fracturing and the age of the rock weathering appear consistent with the rock fall having occurred many decades ago.

A small rock fall of only a few cubic metres of material was also observed above Longwall 10 in the Balgownie Seam. The rock fall is located at the head of a small gully where the horizontal compression movements have been concentrated as the strata has subsided.

A rock fall located over the proposed Longwall 11 in the Wongawilli Seam was observed during a recent surface inspection. This rock fall involving several tens of cubic metres appears to have occurred from natural causes over the last few years. The site is remote from recent mining activity and there is evidence of tree root invasion at the back of the fall.

There are numerous examples of much older natural rock falls along the slopes below most of the cliff formations. These isolated boulders are consistent with the natural processes of erosion. Similar boulders are observed in areas where there has been no mining.

3.3.3 Iron Staining

Water rich in iron is observed to be flowing into several watercourses from the base of the sandstone cliff formations at several locations on the slopes above the southern side of Cataract Creek. These watercourses are dry upstream of the sandstone outcrop and show signs of iron staining downstream of the point where water flows from the strata into the creek.

This phenomenon is consistent with horizontal shear movement at the base of the Hawkesbury Sandstone outcrop caused by mining subsidence. The sandstone strata that is fractured, both naturally and as a result of mining subsidence, appears to be acting as a sub-surface reservoir that delivers water into watercourses downstream of the outcrop of the shear horizon even when there is no overland flow from upstream.

More intense iron staining observed during site inspections appears likely to be a result of recent mining in the Wongawilli Seam.

3.3.4 Cataract Creek

Subsidence monitoring above Longwall 11 in the Balgownie Seam indicates that Cataract Creek was subsided by more than 0.4m over a 400m length of the creek with maximum subsidence of 1.3m over about 40m. The same length of creek is also estimated to have been subsided 0.2-0.4m during mining in the Bulli Seam.

Inspection of the bed of Cataract Creek indicates that there is almost no physical disturbance to the rock strata in the bed of the creek that is attributable to mining activity despite the indicated closure of 310mm. This level of closure would typically be apparent as surface cracking in Hawkesbury Sandstone strata.

Geological mapping presented in Figure 4 indicates that this section of the creek is located in outcrop of the Bald Hill Claystone and Newport/Garie Formations immediately below it. The presence of the Bald Hill Claystone is considered likely to have contributed to the lack of physical disturbance evident in the bed of Cataract Creek.

The presence of iron staining in the water of Cataract Creek is consistent with previous mining activity in the area causing disturbance to the overlying Hawkesbury Sandstone. Recent mining of Longwall 4 in the Wongawilli Seam appears to have increased the level of iron rich precipitate in the tributary leading down from the area above Longwall 4.

3.3.4 Power Transmission Towers

The power transmission towers T56 (on the 330kV line) and E57 (on the 132kV line) are located 100m and 200m respectively from the area of cracking at the start of Longwall 3 in the Wongawilli Seam and directly over Longwall 3 in the Balgownie Seam where there has been 1-1.2m of subsidence. The tower locations are noted on subsidence plans as T56 and T52 so it appears that they had been constructed prior to mining Longwall 3 in 1975. These towers do not appear to have been significantly impacted by previous mining and there does not appear to have been any mitigation or remediation.

3.3.5 Mount Ousley Road

The construction of the Mount Ousley Road on its current alignment appears to have taken place after mining directly below the alignment in the Bulli Seam and Balgownie Seams was complete. Bulli Seam mining was complete in the 1950's and by 1979 mining in the Balgownie Seam had progressed to Longwall 9 well to the west of the alignment.

There does not appear to have been any significant impact of historical mining on the operation of the highway despite up to approximately 1.0m of subsidence from Longwall 7 measured from 1976 to 1978 directly below the road alignment. The Cataract deviation was opened in 1980. Although recent mining in the Wongawilli Seam has caused minor cracking on the hard surface of the Mount Ousley Road that coincides with the goaf edges of previous mining activity in the Bulli and Balgownie Seams suggesting the possibility of remobilising pre-existing subsidence cracks.

4. SUBSIDENCE PREDICTION METHODOLOGY

In this section, the subsidence monitoring from Longwalls 4 and 5 in the Wongawilli Seam is reviewed as a basis for predicting future subsidence behaviour. The subsidence prediction methodology is described and the accuracy and sensitivity of the method are examined.

4.1 Review of Mining in the Wongawilli Seam

Two longwall panels have so far been mined in the Wongawilli Seam, both creating voids at the mining horizon that are 150m wide. Longwall 4 was extracted between 21 April and 21 September 2012. Longwall 5 was extracted between 15 January 2013 and early January 2014 although the panel was substantially complete by 18 December 2013.

The subsidence monitoring associated with the mining of these two panels provides insight into the incremental subsidence behaviour when multiple seams have already been mined, the magnitude of subsidence movements, and the nature of surface impacts. In this section, the results of recent subsidence monitoring in Longwalls 4 and 5 are reviewed.

It is convenient to discuss the surface subsidence as comprising two components. These two components are described in detail in Mills (1998).

The first component, called sag subsidence, is the subsidence that results from the overburden strata draping down into the void created by each longwall panel. Sag subsidence increases with increasing panel width up to a maximum at a distance referred to as critical width. Sag subsidence also increases as the overburden depth reduces, as the thickness of the coal seam mined increases, and with the presence of previous mining activity in the overlying seams. Sag subsidence is a measure of the capacity of the overburden strata to bridge across each longwall panel and in wide panels the vertical support able to be provided by the extracted goaf.

The second component, called strata compression subsidence, is the subsidence that results from compression of the chain pillar between panels and the rock strata above and below the chain pillar. The total strata compression is seen on the surface as subsidence. The increased load on rock strata above and below the chain pillar contributes almost all of the compression subsidence with compression of coal in the chain pillar contributing only a relatively small proportion of the total.

Strata compression subsidence increases with depth from less than 100mm when the overburden depth is less than 100m to 600-800mm at an overburden depth of 400m. Strata compression subsidence is function of the compression of the strata between panels and is largely independent of the sag subsidence and the capacity of the strata to bridge across each panel.

4.1.1 Vertical Subsidence

Figure 18 shows a summary of the results of subsidence monitoring over Longwall 4 and 5 on the two centreline subsidence lines and three cross-lines, including one short line, M Line, located across the chain pillar to measure strata compression above the chain pillar.

At the completion of Longwall 4, the maximum subsidence in the centre of the panel was 1.3m and this represents the sag subsidence for a single panel 150m wide and about 340m deep. When Longwall 5 had finished, centreline subsidence ranged from 1.1-1.8m and the centreline subsidence on Longwall 4 had increased to 1.6-1.8m consistent with strata compression at the intermediate chain pillar. Subsidence monitoring on M Line indicated that the total elastic chain pillar compression was approximately 0.7m based on superposition of the subsidence measured on M Line during Longwall 5 and goaf edge monitoring observed during mining of Longwall 4.

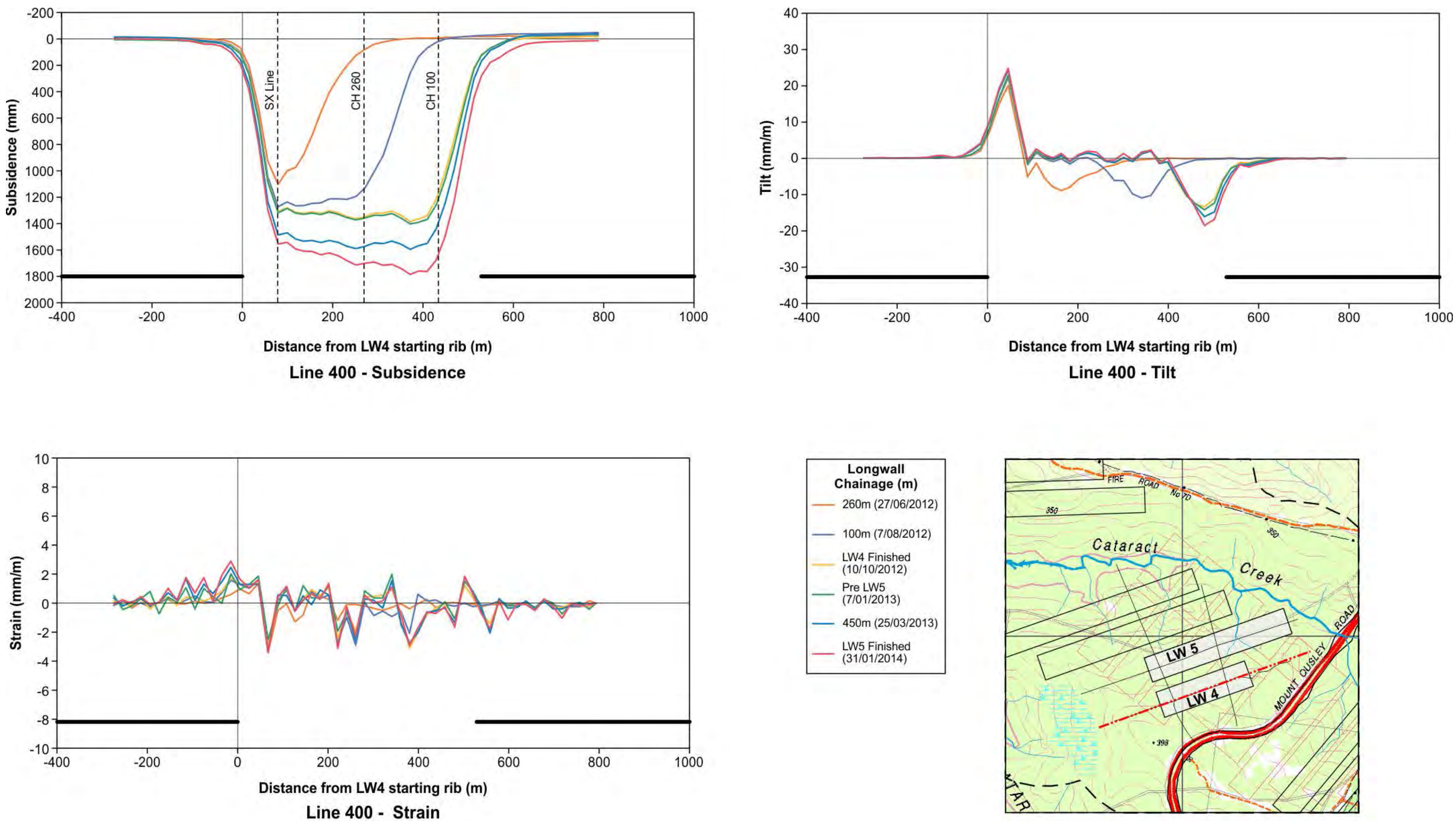


Figure 18a: Summary of Subsidence Monitoring Results from Longwalls 4 in the Wongawilli Seam.

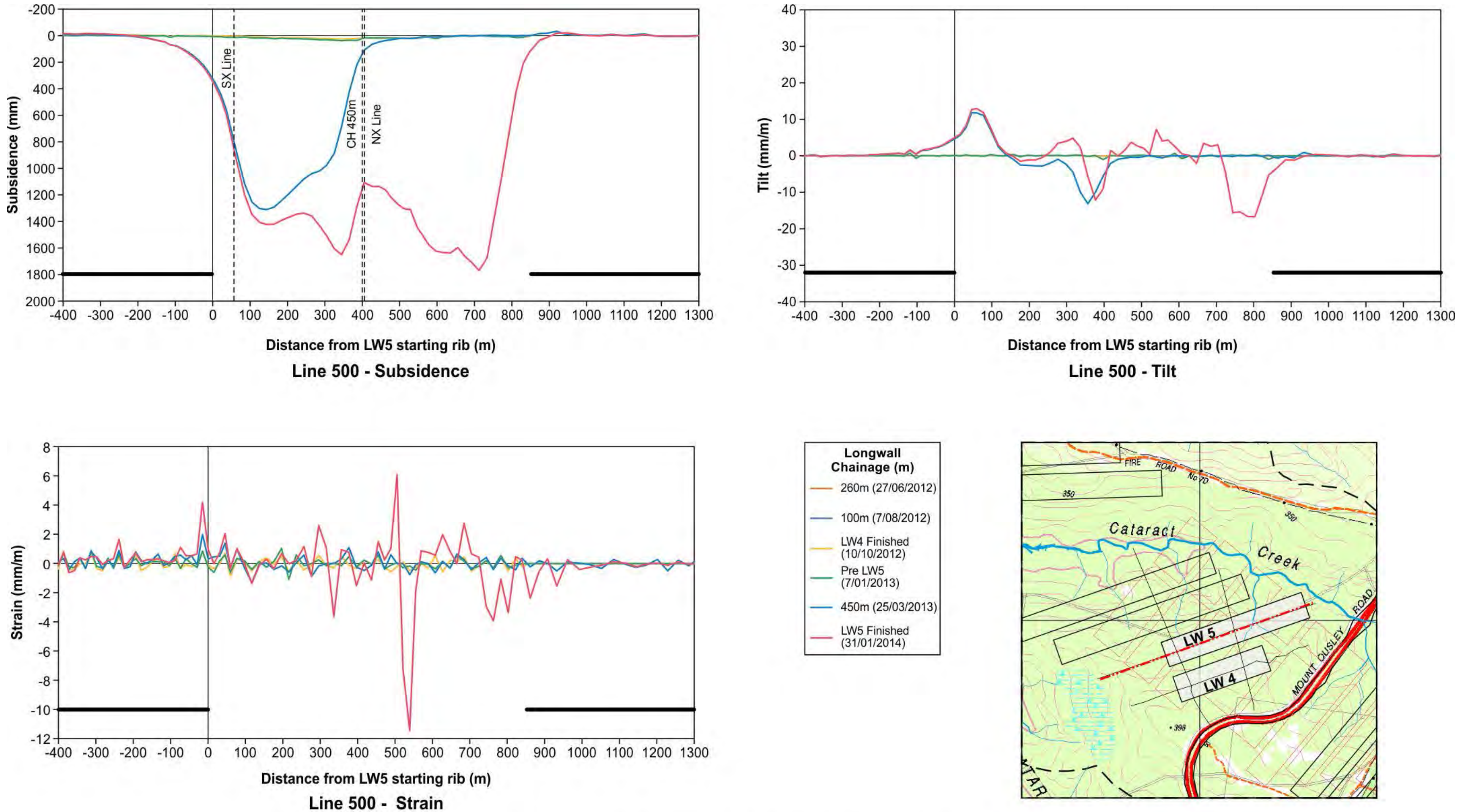


Figure 18b: Summary of Subsidence Monitoring Results from Longwall 5 in the Wongawilli Seam.

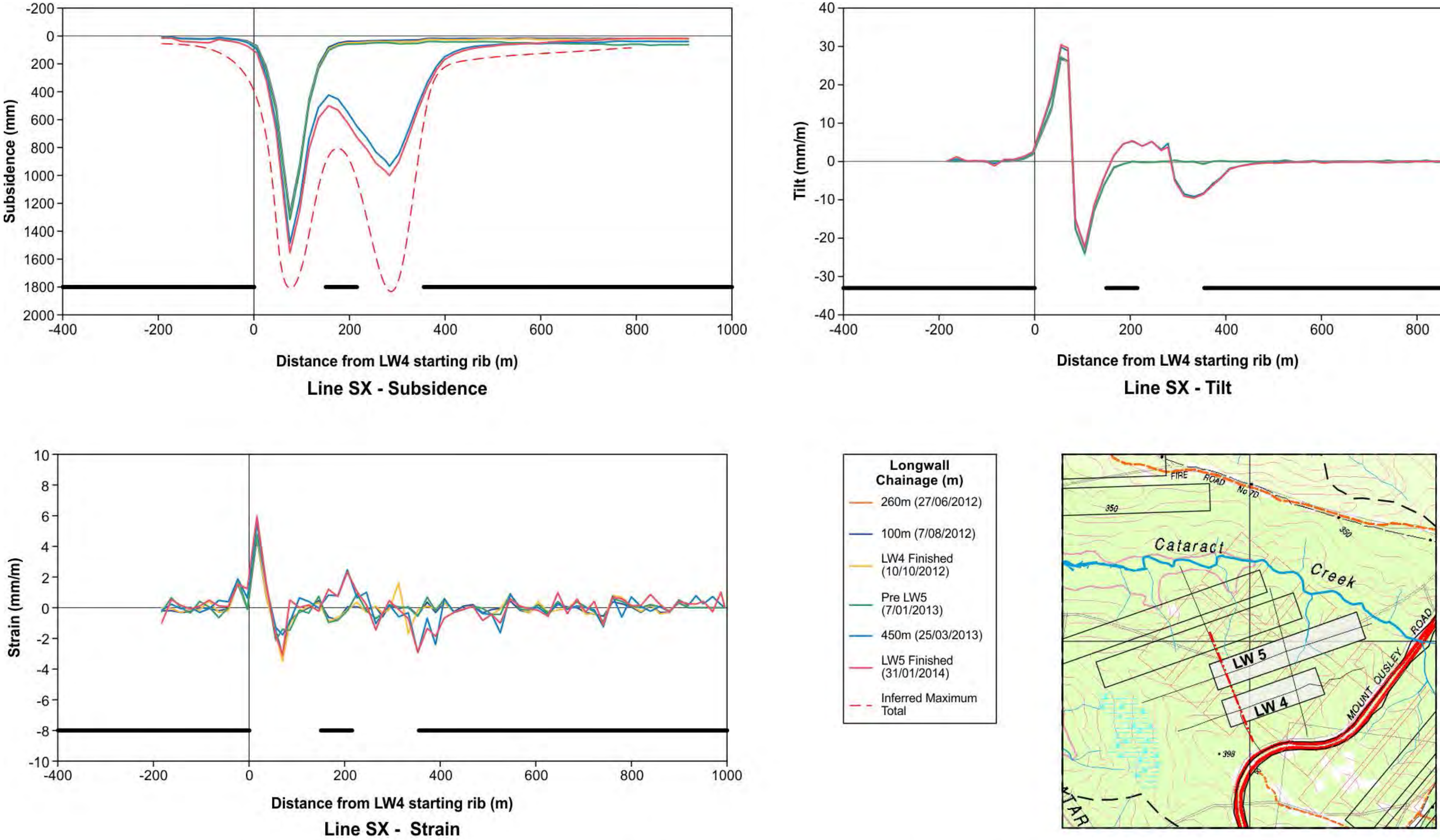


Figure 18c: Summary of Subsidence Monitoring on SX Cross Line – Longwalls 4 and 5 in Wongawilli Seam.

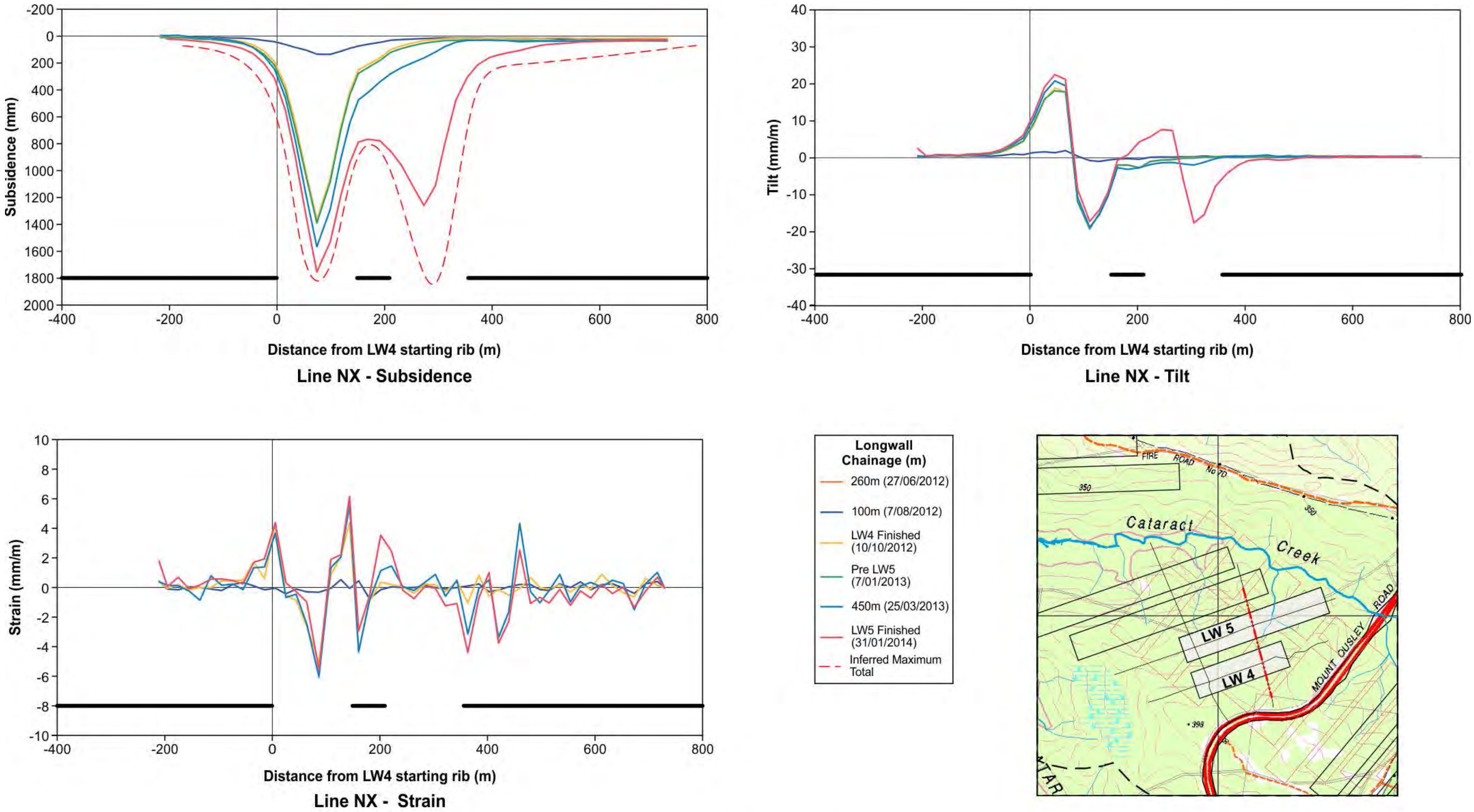
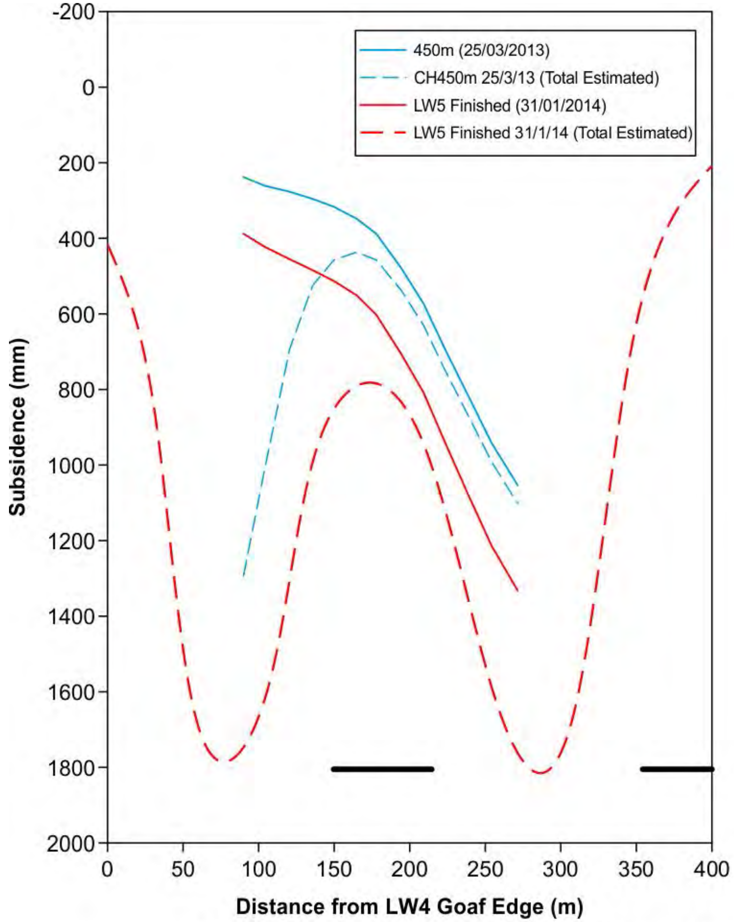


Figure 18d: Summary of Subsidence Monitoring on NX Cross Line – Longwalls 4 and 5 in Wongawilli Seam.



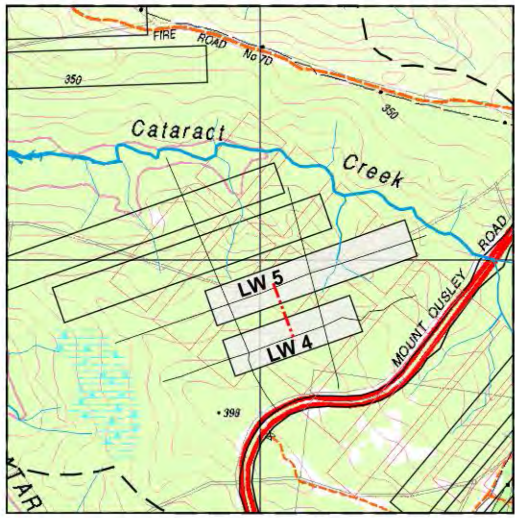


Figure 18e: Summary of Subsidence Monitoring on M Cross Line – Longwalls 4 and 5 in Wongawilli Seam.

The increase in Longwall 4 centreline subsidence from 1.3m at the completion of Longwall 4 to 1.7m when Longwall 5 had been substantially mined is consistent with strata compression above the chain pillar between the panels of about 0.8m causing the surface above one side of the panel to be lowered 0.8m and the surface above the centre of Longwall 4 to be lowered a further 0.4m. There has been no significant increase in sag subsidence over Longwall 4 as a result of mining Longwall 5. The additional subsidence is due to strata compression above the chain pillar between Longwalls 4 and 5.

The sag subsidence above Longwall 5 is of a similar magnitude to the sag subsidence above Longwall 4 although this does not show on the two cross-lines, SX and NX, because SX is too close to the end of the panel for full subsidence to develop and NX is located near the dyke pillar in the Balgownie Seam where subsidence is reduced. The presence of the full 1.8m of subsidence above Longwall 5 is apparent on the longitudinal 500 Line.

Figure 19 shows the sag subsidence plotted as a function of the panel width for Longwalls 4 and 5 and the sag subsidence that is commonly observed in undisturbed strata for a broad range of panel width to overburden depth ratios. Longwall 4 is mined in an area where there is both Bulli Seam goaf and Balgownie Seam goaf above most of the panel. Longwall 5 is mined in an area where there are Bulli Seam main heading pillars that have been partly mined and Balgownie Seam longwall goaf that has been completely extracted. The difference in disturbance to the overburden strata is clearly evident in the sag subsidence results plotted in Figure 19.

Above Longwall 5 where the Balgownie Seam has been fully extracted, the sag subsidence is significantly more than the sag subsidence that would be expected in previously undisturbed strata. Above Longwall 4, the Bulli Seam has also been mined, the sag subsidence is greater again consistent with the additional mining in the overlying Bulli Seam and the greater disturbance to the overburden strata that mining in both overlying seams has caused.

In narrow panels that depend on the overburden bridging to reduce the magnitude of surface subsidence as was the intention in the original Pt3A application, this reduction in the bridging capacity of the overburden strata has a profound effect on the maximum subsidence observed at the surface.

Another way to visualise the reduction in bridging capacity of overburden strata is through the goaf edge subsidence profiles. Figure 20 shows the range of goaf edge subsidence profiles observed in undisturbed strata compared to when one seam and two seams have been mined. These profiles show that as the number of seams mined increases and the disturbance to the overburden strata increases, the shear stiffness and rigidity of the overburden strata decreases.

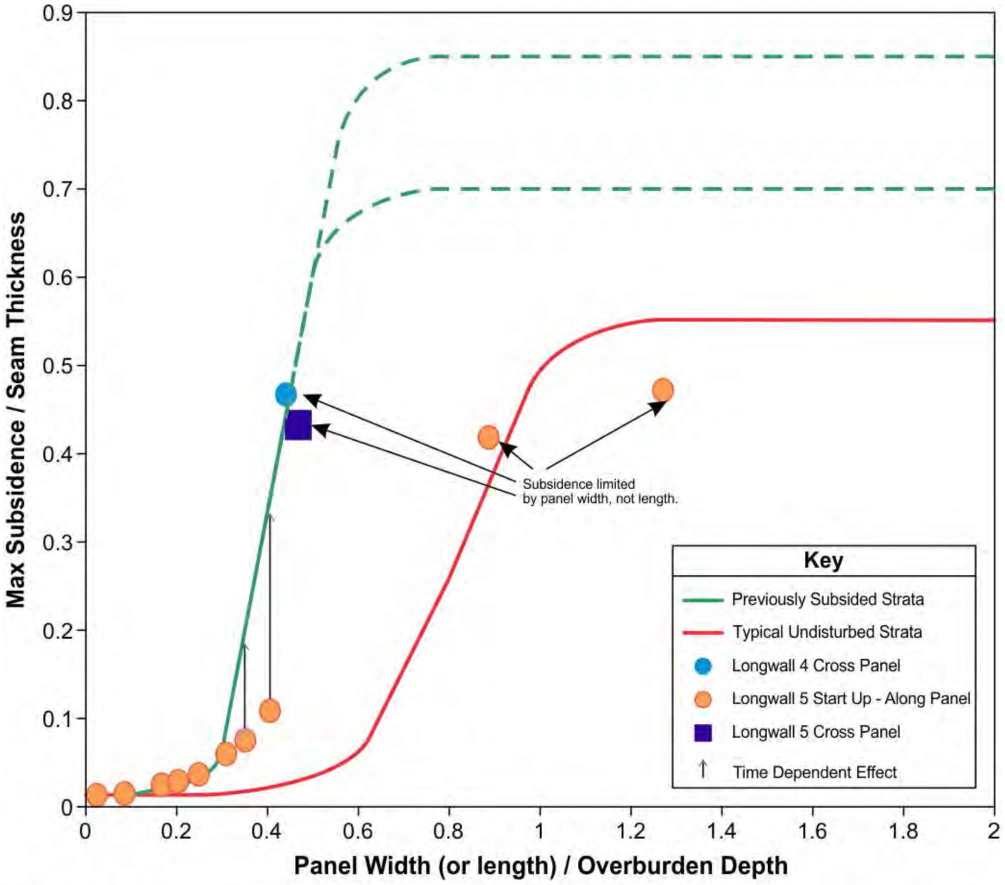


Figure 19: Summary of Sag Subsidence Measured at Start of Longwalls 4 and 5 in the Wongawilli Seam.

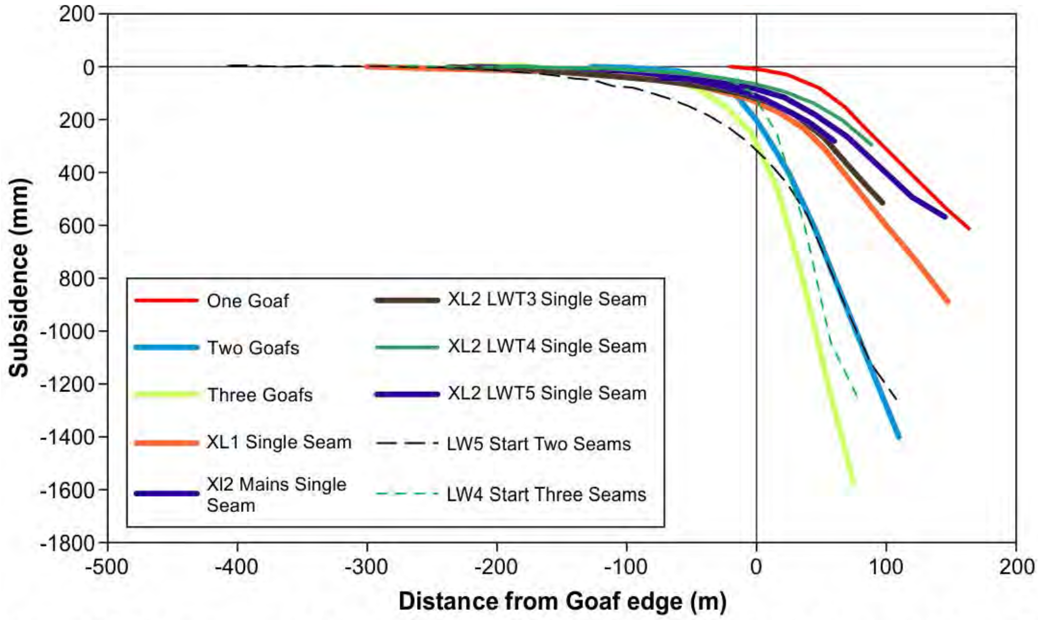


Figure 20: Summary of Goaf Edge Profiles for Mining in One, Two, and Three Seams.

The profiles in Figure 20 show that the sag subsidence behaviour above multiple goafs is consistent with subsidence behaviour observed over panels in single seam mining operations except that the shear stiffness or rigidity of the overburden strata is greatly diminished as a result of the previous mining activity. The reduced shear stiffness leads to reduced bridging capacity of the overburden strata and significantly increased maximum subsidence for the same overburden depth and longwall panel geometry.

In previously undisturbed overburden strata, the maximum subsidence above a 150m wide longwall panel at 300-360m would be of the order of 0.1-0.3m and barely perceptible for all practical purposes. The measured maximum sag subsidence has been 1.3m because softening of the overburden strata by previous mining has significantly increased the sag subsidence.

This phenomenon was also apparent in the Balgownie Seam longwall panels located below Bulli goaf compared to when the longwall panels were mined below solid pillars as summarised in Table 2 above.

Strata compression subsidence of 0.6-0.8m observed above the 60m wide chain pillar between Longwalls 4 and 5 is consistent with the level of strata compression subsidence that would be expected for the panel geometries at an overburden depth of 340m.

A significant characteristic of the subsidence observed over Longwalls 4 and 5 is that the additional sag subsidence caused by mining panels in the deeper seams is substantially limited to within the footprint of the panel, much the same as for single seam mining operations. This characteristic is clearly apparent despite the presence of an irregular overlying mining geometry. In some areas above Longwalls 4 and 5, there are overlying goafs in both seams, in others just one seam and not the other, and in other areas there are standing pillars. And yet, in all three circumstances, the surface subsidence is substantially limited to within the area that has been mined.

The form of the cross-panel subsidence profiles indicates that maximum subsidence in the centre of each panel is not being controlled by recompression of the strata directly above the longwall goaf but rather by the disturbance to the overburden strata from previous mining affecting the ability of the overburden strata to bridge.

There are subtle variations outside the goaf edge associated with previous mining in the overlying seams. More gradual subsidence profiles and greater goaf edge subsidence are evident where there are goaf areas in both the Bulli and Balgownie Seams as can be seen in Figure 21. Where there are goaf areas directly above the goaf edge in only one of the overlying seams, the subsidence profile is sharper and shows less subsidence outside the goaf. When there are no overlying goaf areas, the subsidence profile is sharpest and the subsidence profile beyond the goaf edge is the same as for single seam mining geometries.

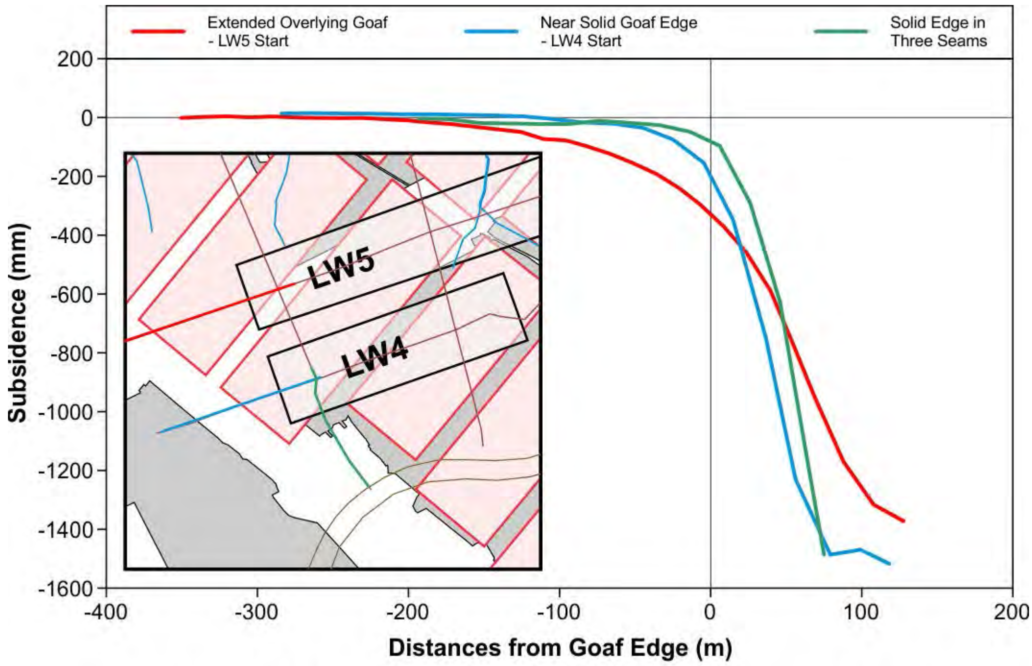


Figure 21: Goaf edge variations above Longwalls 4 and 5.

In areas where there are small standing pillars in the Bulli Seam above the goaf edge, there exists the possibility that mining in the Wongawilli Seam below will cause these pillars to be destabilised. If the pillars were destabilised, the resulting subsidence from the pillar destabilisation could then extend outside the Wongawilli Seam goaf edge to the edge of the overlying pillar panel in the Bulli Seam.

There has been no evidence of this type of behaviour so far from longwall mining in the Wongawilli Seam or in the Balgownie Seam but there is considered to be some opportunity for additional subsidence during mining of Longwall 1. A panel of Welsh bords was visited during the site inspection on 21 June 2012 in an area of the Bulli Seam immediately above and to the northeast of the end of Longwall 1 as shown in Figure 13.

If this area of pillars were to be destabilised, there would be potential for the surface subsidence to extend some 100m to the northeast of the panel and up to 300m east of the eastern corner of Longwall 1, but this subsidence would only occur if Longwall 1 was mined full length and the pillars in the Bulli Seam were destabilised. Maximum additional subsidence of a few hundred millimetres would be expected as a result of this instability. Special consideration is required in this area to manage this potential.

4.1.2 Extent of Vertical Subsidence Outside the Panel

Survey measurements conducted along the edge of the northbound lane of Mount Ousley Road have measured the influence of multi-seam mining based on the distance from the goaf edge providing evidence that vertical subsidence diminishes to low levels a short distance beyond the goaf edge.

Figure 22 shows a summary of the vertical subsidence measured along Mount Ousley Road during mining of Longwall 4 and the timing of the subsidence that developed at key points. The projections of adjacent goaf areas in the Bulli, Balgownie, and Wongawilli Seams are also shown. The subsidence observed is of low level reaching a maximum of approximately 40mm at the projected centre of Longwall 4 some 180m from the goaf edge at an overburden depth of 350m.

These measurements indicate the angle of draw to 20mm of subsidence is greater than 26.5° consistent with experience elsewhere in the Southern Coalfield at this overburden depth. At the projection of the north-eastern corner of Longwall 4 where both the Bulli Seam and the Balgownie Seam have been mined, subsidence at 230m from the goaf corner is 20mm at 320m deep indicates the angle of draw to 20mm off the corner of the panel is equal to 35°. At the south-eastern corner of Longwall 4, where the Balgownie Seam has not been mined but there are areas of mining in the Bulli Seam, the 14mm of subsidence at 225m at 360m overburden depth indicates an angle of draw off the corner of the panel of less than 32°. There does not appear to be any evidence of significant vertical subsidence outside the panel being mined associated with any type of pillar instability.

Other cross line measurements indicate the vertical subsidence is 50mm at between 20m and 100m from the goaf edge.

On the basis of these measurements, the angle of draw to 20mm of subsidence is considered likely to be slightly greater than 35° in areas where both overlying seams have been mined and slightly less than 35° where only one overlying seam has been mined. The angle of draw is therefore not significantly different to the angle of draw that would be expected for mining in a single seam at similar overburden depths. If pillar instability were to occur near the edge of a Wongawilli Seam longwall panel, it is possible that that low level subsidence may extend outside the panel edge and potentially increase the angle of draw slightly. However, the impact of any such increase is expected to be small.

4.1.3 Far-Field Horizontal Movements

There are several sources of far-field horizontal subsidence measurements available from mining Longwalls 4 and 5. The Mount Ousley Road P Line and Picton Road Interchange provide measurements of horizontal movements based on three dimensional GPS controlled surveying and the closure measurements across Cataract Creek provide an indication of the horizontal movement in the middle distance. Observations of cracks on Mount Ousley Road provide an indication of the horizontal distance that changes potentially associated with mining have been observed.

The GPS controlled surveying does not show any convincing evidence of far-field horizontal movements. The survey tolerance of the systems being used is ±20mm. The monitoring at Picton Road Interchange is approximately 1300m from the southern end of Longwall 4 and there is no evidence that there has been any differential or even total movement at the interchange associated with mining Longwalls 4 and 5.

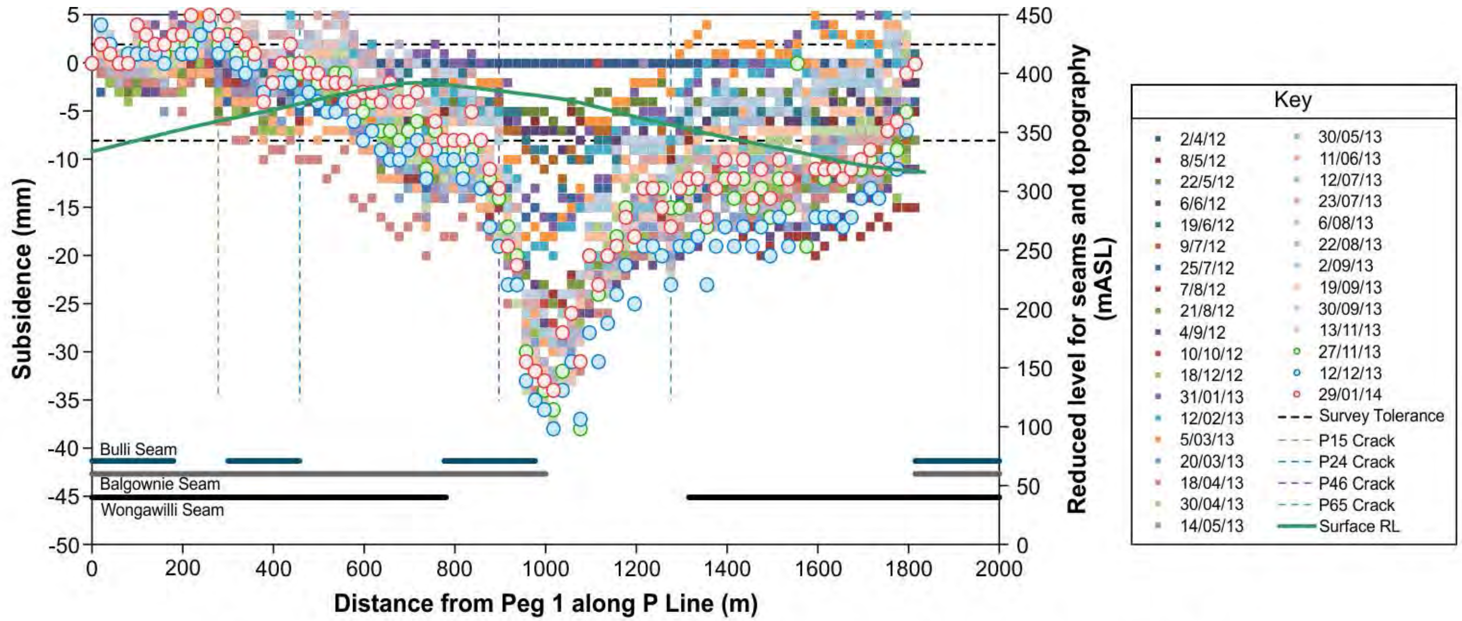
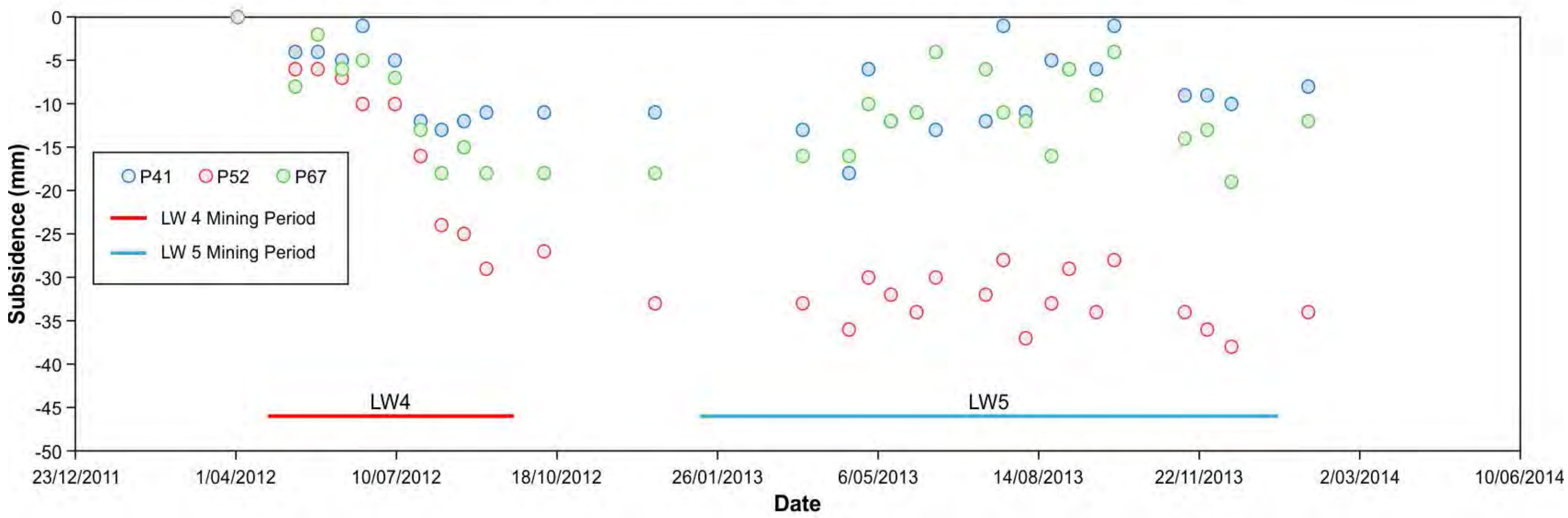


Figure 22a: Subsidence measured on P Line alongside Mount Ousley Road.



a) Development of P Line Subsidence over Time.

Figure 22b: Development of subsidence on P Line over time and as a function of longwall retreat.

Figure 23 shows the closure measurements on Cataract Creek observed during mining of Longwall 5. Closure measurements across Cataract Creek first became evident at three of the four measurement points when Longwall 5 was approximately 450m from the finishing end of the panel (i.e. at longwall chainage CH400m). The longwall face at this position was approximately 320m from CC4, 420m from CC2, 530m from CC1, and 700m from CC3.

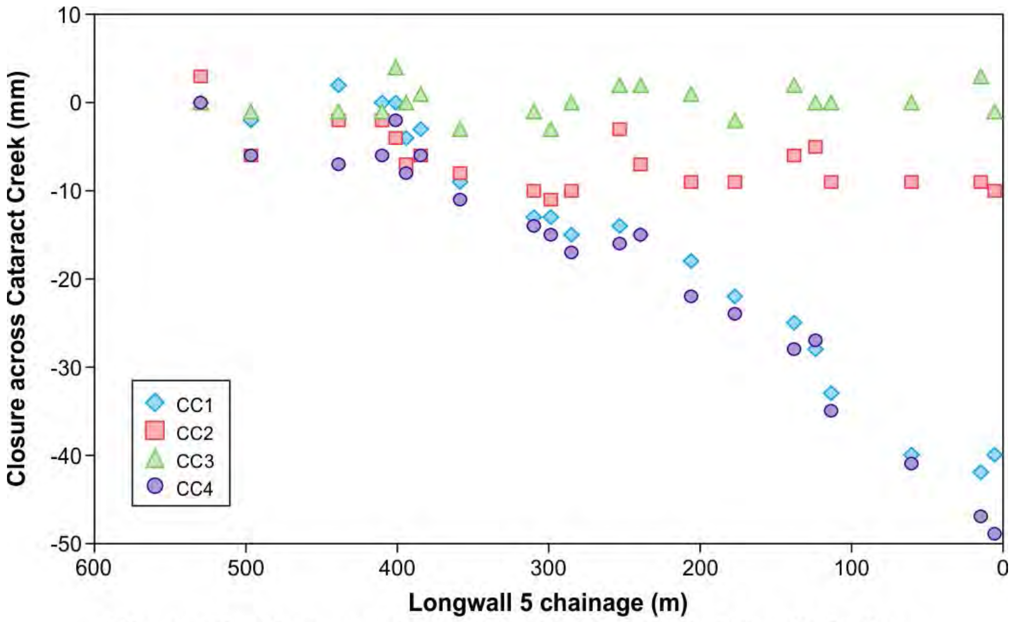


Figure 23: Closures observed across Cataract Creek during mining of Longwall 5.

At Cataract Creek where the measurement points are located, the overburden depth to the Wongawilli Seam is approximately 280m, so the horizontal closure movements have been observed out to a distance from the goaf edge equal to between 1.1 and 2.9 times depth.

The closure measured on the Cataract Creek closure lines has steadily increased as Longwall 5 has continued to retreat. These measurements indicate that far-field downslope movements have been evident to a distance of up to about 450m from the approaching longwall panel but increase linearly with longwall retreat so that the longwall retreat required to generate a set amount of closure can be estimated with confidence.

Relatively fresh cracks that have appeared on Mount Ousley Road at P24 and P25 are approximately 500m from the southern end of Longwall 4 at an overburden depth of about 360m, so there is some evidence of small horizontal movements to a distance of about 1.4 times overburden depth.

Small far-field movements are evident from the longwall mining conducted so far in the PPR Assessment Area but these movements are of low magnitude and decrease with distance from mining.

4.2 Subsidence Prediction Methodology

The subsidence prediction methodology used in this assessment is based on consideration of the mechanics of the subsidence processes involved, particularly the differences between the two components of subsidence, sag subsidence and strata compression subsidence and using measured subsidence profiles to characterise the subsidence behaviour and provide a basis for prediction of subsidence associated with future mining.

This approach is considered to be appropriate in the relatively complex mining environment that exists within the PPR Assessment Area especially now that there is actual subsidence data available from Longwalls 4 and 5.

The presence of mining in two other overlying seams makes the use of methods such as the Incremental Profile Method which relies on repeatable elastic superposition of goaf edge profiles and the Influence Function Method which assumes elastic strata behaviour less reliable because of the variable characteristics of the overburden strata.

The method used to estimate subsidence in all three seams is primarily based on existing monitoring data. Contours of subsidence for the Bulli Seam mining operations have been estimated using subsidence profiles measured in the 1990's over the longwall panels at South Bulli Colliery (now owned by NRE). These profiles have been adjusted for overburden depth and contours of subsidence have been drawn in AutoCAD relative to the edges of goaf areas indicated on mine record tracings.

The subsidence observed on the surface above the Balgownie Seam longwall panels also provides an indication of the status of the Bulli Seam mining. The Bulli Seam subsidence contours have been modified slightly to reflect this indicated status. The subsidence contours thus produced have then been converted into gridded model of subsidence values on a 10m by 10m grid using Golden Software's Surfer program.

Hard copies of measured subsidence from each of the Balgownie Seam longwall panels are available in the mine archives. These drawings have been scanned, scaled, and converted into a format that allows the final subsidence across all the panels to be contoured. The contours have then been converted to a 10m x 10m grid of subsidence using the same approach described above for the Bulli Seam subsidence.

Subsidence predictions for mining in the Wongawilli Seam are based on measured subsidence profiles from Longwalls 4 and 5. These profiles have been adjusted for panel width and overburden depth and allowances have been made for possible chain pillar interactions with the overlying Balgownie Seam longwall goafs above Longwalls 1-3. The contour plots generated have again been drawn in AutoCAD and then gridded in Surfer onto a 10m by 10m grid.

The combined subsidence from each seam or from combinations of seams has then been determined by adding together the components from each seam.

Contours of the surface topography have been generated from LiDAR data on the same 10m by 10m grid to allow the subsidence to be added and subtracted from the surface topography. Contours of the three coal seams have been developed from survey information of floor seam contours available in the Bulli Seam within the mine lease boundary.

The Balgownie and Wongawilli Seam floor contours have been estimated from the Bulli Seam floor contours assuming a separation of 10m and 30m to the Bulli Seam respectively. Overburden depth to the Wongawilli Seam has been determined as the difference in the Surfer model between the surface topography and the estimated Wongawilli Seam floor contours.

Estimates of strains and tilts presented in this assessment are based on measured values and the experience more broadly of monitoring in the Southern Coalfield reported by Holla and Barclay (2000). This broader experience is considered to provide a strong basis for predicting maximum surface strains and tilts. Based on the subsidence measurements that have been made over Longwalls 4 and 5 and previously above the Balgownie Seam longwall panels, the method described by Holla and Barclay (2000) appears to provide a reasonable and conservative basis to predict the incremental maximum strains and tilts even for multi-seam mining environments.

The strains and tilts are highly variable and are generally of a much lower magnitude than the maximum values. For prediction purposes, the maximum values have been determined to be conservative. The exact position of the maximum values is difficult to determine accurately, although it is recognised that maximum tensile strains are most likely to occur at topographic high points and at the start of panels, particularly in those areas where mining is proceeding in a downslope direction. Maximum compressive strains are most likely to occur in topographic low points or near the finishing end of the panel particularly when mining in a downslope direction.

The measurements of incremental tilts and strains made so far indicate that the background values of tilts are more generally of the order of 50-80% of the maximum values indicated by the approach presented by Holla and Barclay (2000). Similarly, background values of strains are more generally of the order of 20-30% of the maximum values indicated.

Closures across Cataract Creek have been estimated using the ACARP method developed by Waddington, Kay and Associates (2002). This method is recognised to be an upper limit prediction method based on a limited database. Nevertheless, the method provides a consistent approach to estimating closure that can be used to compare with measured values and provide a basis for extrapolation to give realistic closure estimates.

4.3 Accuracy and Sensitivity Assessment

The subsidence monitoring data available from eleven longwall panels in the Balgownie Seam mined 10m below the Bulli Seam and more recent subsidence data from Longwall 4 mining under two levels of previous mining and from Longwall 5 mining under Balgownie Seam goaf and Bulli Seam main heading pillars is considered to provide a strong basis to predict future subsidence.

The accuracy of the subsidence predictions is limited by the uncertainties that exist in a natural environment combined with additional uncertainties about the detail of mining geometries in the Bulli Seam and some aspects of subsidence behaviour in a multi-seam mining environment.

Available subsidence monitoring data from mining in the PPR Assessment Area indicates that the subsidence associated with multi-seam subsidence in this area is similar to the subsidence behaviour in a single seam mining environment except that the bridging capacity of the overburden strata is significantly reduced. The key observations are:

- Reduced bridging capacity affects the magnitude of the maximum sag subsidence over the centre of each longwall panel.

- Subsidence occurs predominantly within the footprint of the panel being mined except where there is potential for pillar instability as discussed separately below.

- Panel width can still be used to control the magnitude of maximum subsidence.

- Strata compression subsidence above the chain pillars between longwall panels is of a similar magnitude to that which occurs in single seam mining operations.

- Subsidence at the goaf edge is softened by previous mining activity in overlying seams, but the effect is small and of second order significance.

- The angle of draw to 20mm of subsidence is of the order of 35° and consistent with experience in single seam mining operations.

The uncertainties that remain from predicting subsidence behaviour in a multi-seam environment are offset somewhat by the benefits of having previous subsidence monitoring experience and the opportunity to review the longer term recovery of surface impacts associated with earlier mining activity. The ability to inspect all three levels of mining underground also improves confidence in the understanding of the mechanics involved at this site.

There exists some potential in areas where there are small standing pillars in the Bulli Seam above the goaf edge for these pillars to be destabilised by mining in the Wongawilli Seam below. This destabilisation is evident in the Bulli Seam beyond the end of Longwall 7 in the Balgownie Seam. If overlying pillars are destabilised at the goaf edge, the resulting subsidence from the pillar destabilisation could then extend outside the Wongawilli Seam goaf edge to the edge of the overlying pillar panel in the Bulli Seam. The magnitude of additional subsidence resulting from pillar instability is expected to be small. The only place where this type of behaviour appears likely is in an area beyond the northeast corner of Longwall 1 (see Figure 13).

The monitoring data indicates that maximum sag subsidence is able to be controlled by the width of individual panels. It is nevertheless helpful to have an indication of the maximum credible subsidence that might result. Li et al (2010) provide a summary of the experience of multi-seam mining subsidence that indicates maximum subsidence of up to 83% of the cumulative mining height for all seams compared to 65% for single seam mining. The maximum subsidence indicated by this approach provides an upper limit to the maximum subsidence.

The combined mining height for all three seams ranges 5.4-6.9m depending on how much the thickness of the Bulli Seam is discounted to allow for the realistic recovery rates of pillar extraction and bord and pillar mining. The maximum subsidence using 85% of this thickness would be 4.6-5.8m.

Maximum subsidence of up to 1.4m has so far been observed above the Balgownie Seam with an additional 0.5m estimated for the Bulli Seam to give a maximum of 1.9m of subsidence from previous mining. Using the Li et al approach would indicate maximum subsidence from mining in the Wongawilli Seam would be likely to be in the range 2.7m (allowing for the 1.9m that may have already occurred) to 5.8m (in areas of small standing pillars in the Bulli Seam that may be destabilised by further mining and are coincident with the goaf edge of Balgownie Seam longwall panels).

Above Longwalls 4 and 5, the maximum subsidence measured in the centre of the longwall panels ranges 1.3-1.8m and is therefore much less than the maximum subsidence that would be expected if these panels were wider. Although the bridging capacity of previously mined strata is less than the bridging capacity of previously undisturbed strata, the narrower panel widths of Longwalls 4 and 5 and the remaining longwalls proposed within the PPR are clearly still limiting maximum subsidence to well below the level that would be observed if the panels were wider and full subsidence could develop in the centre of each panel.

Strain and tilt values observed to date are within the range of predicted values using the approach presented by Holla and Barclay (2000). While it is possible that higher values of strain and tilt may be observed in isolated locations, the approach used for prediction is considered unlikely to significantly underestimate maximum strain and tilt values.

Small errors or tolerances in the data used in the assessment are not considered likely to significantly influence the accuracy of the subsidence predictions. The LiDAR surface data is expected to be accurate to a few tens of centimetres across the entire PPR Assessment Area. The Bulli Seam floor contours have been surveyed and are therefore likely to be accurate to about a metre.

The PPR Assessment Area extends beyond the mine lease boundary so the floor contours beyond the lease boundary have been extrapolated and are therefore of lower confidence, but are nevertheless considered suitable for the purposes of this assessment. There is considered to be potential for a 5-10m difference in seam separation across the PPR Assessment Area that will slightly affect the calculation of overburden depth, but not significantly.

5. PREDICTED SUBSIDENCE

In this section, the predicted subsidence parameters above the proposed Wongawilli Seam longwall panels are presented and discussed.

5.1 Vertical Subsidence

Figures 24a and 24b shows the contours of subsidence predicted above the proposed longwall panels in the PPR Assessment Area at the same scale as other diagrams (Figure 24a) and at a magnified scale (Figure 24b). The area is also shown where special consideration of the potential for pillar instability in the Bulli Seam is recommended. Table 4 presents a summary of the predicted subsidence movements for mining in the Wongawilli Seam, as well as estimated and measured subsidence in the Bulli Seam and Balgownie Seam in the area of each Wongawilli Seam longwall panel. Actual measurements from the Balgownie Seam longwalls and Longwalls 4 and 5 in the Wongawilli Seam are shown in brackets as a basis for comparison with the predictions.

Maximum subsidence over individual longwall panels in the Wongawilli Seam is predicted to range from 1.5m over the slightly narrower Longwall 7 through to 2.6m over Longwall 3 where the overburden depth is shallowest and there is overlying goaf in both seams.

5.2 Tilts and Strains

Maximum tilts over individual longwall panels in the Wongawilli Seam are expected to range up to maxima of 24mm/m over Longwall 10 through to maxima of 51mm/m above Longwall 3. Although these maxima may occur anywhere in the panel, they are most likely to occur at panel edges in overlying seams and in areas of topographic change in gradient. More generally across the panel, systematic tilts are likely to be in the range 50-90% of the maximum values.

Maximum strains over individual longwall panels in the Wongawilli Seam are expected to range up maxima of 14mm/m over Longwall 10 to maxima of 31mm/m over Longwall 3. Although these maxima may occur anywhere within the panel, maximum tensile strains are most likely to occur at

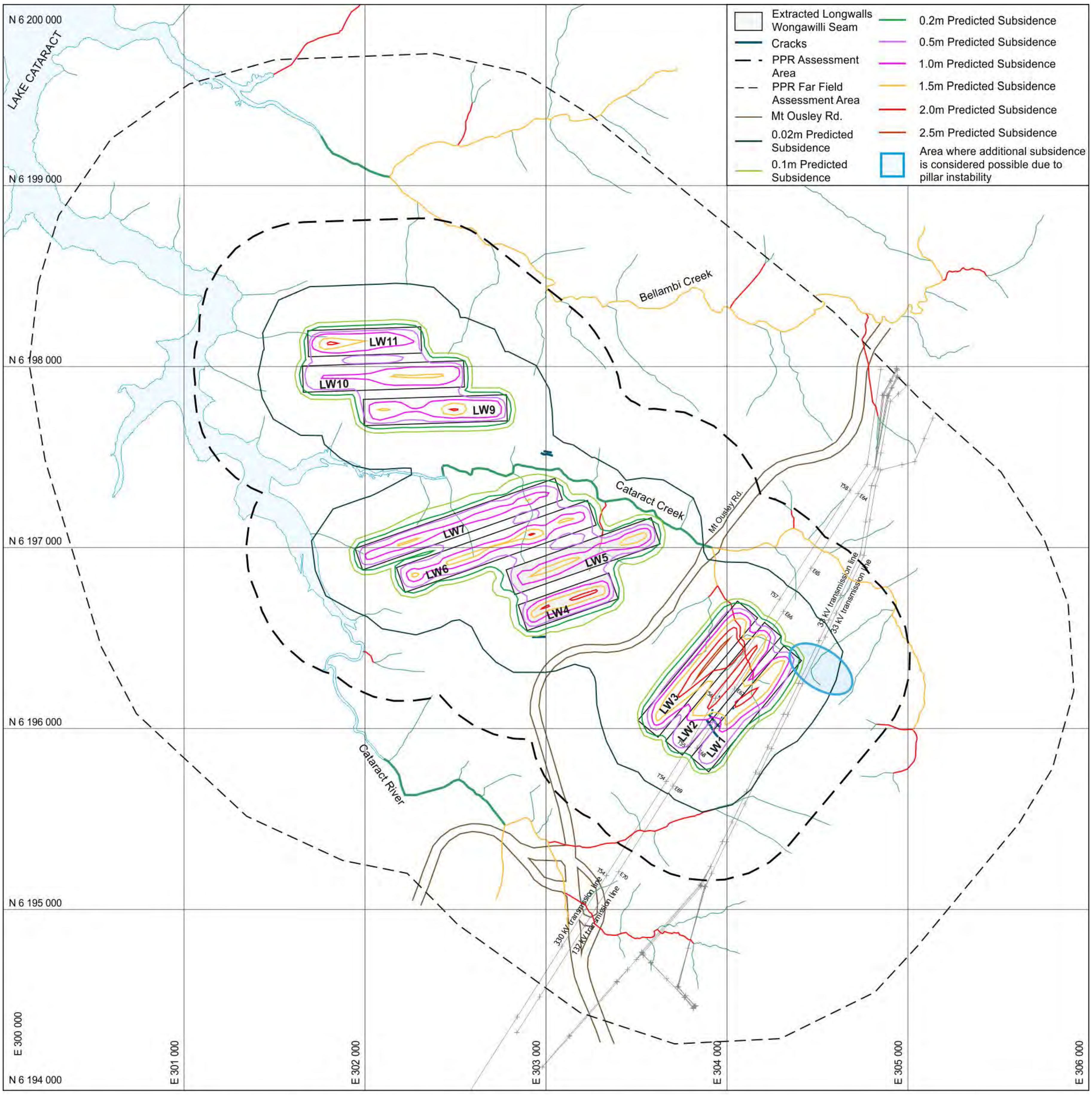


Figure 24a: Contours of predicted subsidence from the Wongawilli Seam (at same scale as previous diagrams).

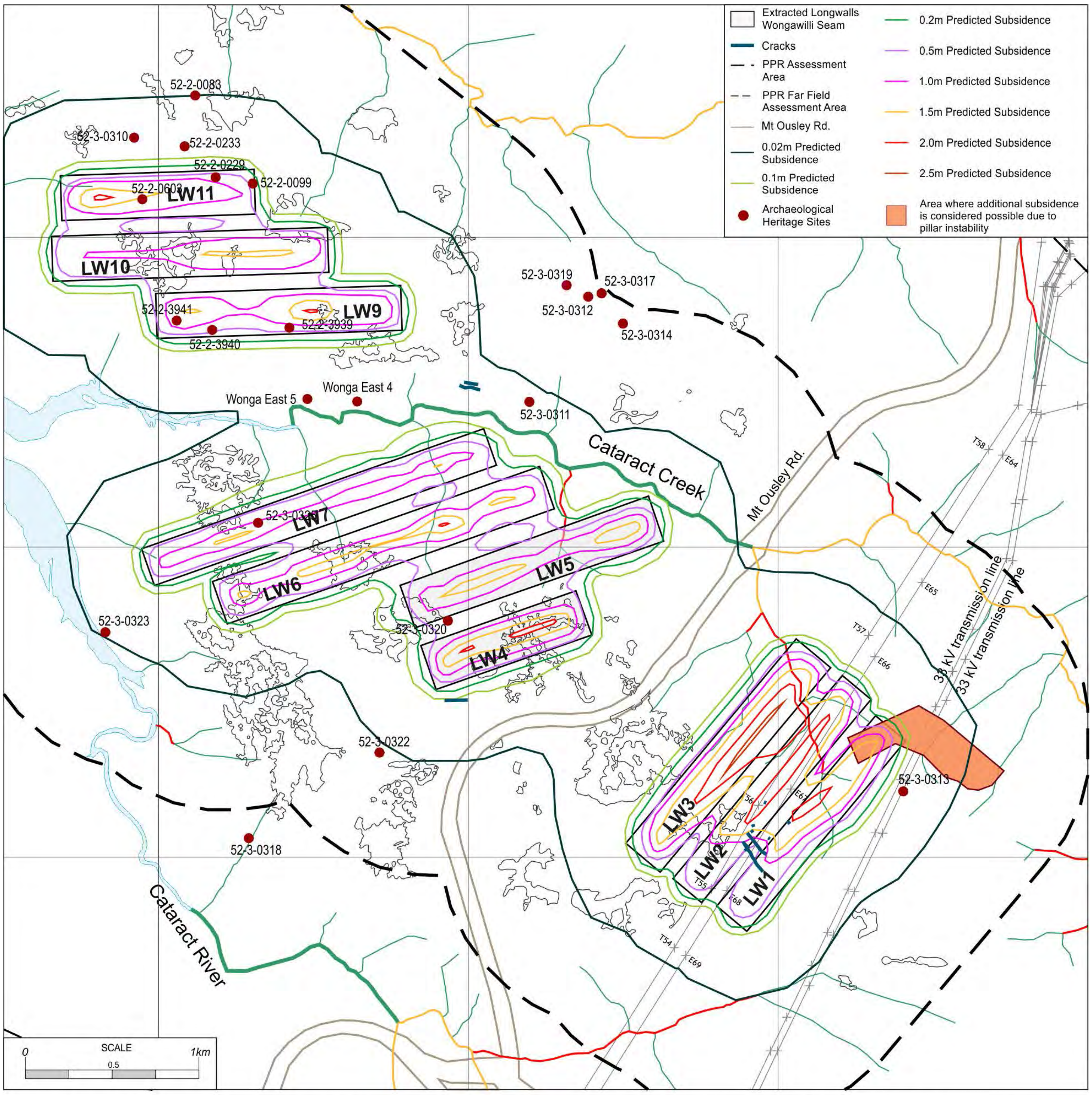


Figure 24b: Enlarged view showing contours of predicted subsidence from the Wongawilli Seam relative to surface features.

Table 4: Subsidence Predictions for PPR Assessment Area

General Observations Above Individual Panels	Overburden Depth to WWSM (m)	BUSM and BASM Subsidence (m)	WWSM Subsidence Predicted (m) and Measured (in bold)	BASM Tilt (mm/m)	Predicted WWSM Tilt (mm/m) and Measured (in bold)	BASM Max Tensile Strain (mm/m) and Typical (in brackets)	Predicted WWSM Tensile Strain (mm/m) and Measured (in bold)	BASM Max Compressive Strain (mm/m) and Typical (in brackets)	Predicted WWSM Compressive Strain (mm/m) and Measured (in bold)	Closure on Cataract Creek Observed Directly and Inferred from Upsidence (mm)	Closure on Cataract Creek (mm) (Southern Tributary in Brackets)
Longwall 1	260	1.3	2.1	19	40	N/A	12	N/A	24	N/A	N/A (700)
Longwall 2	260	1.1	2.1	19	40	N/A	12	N/A	24	N/A	N/A (300)
Longwall 3	255	1.3	2.6	13	51	N/A	15	N/A	31	N/A	N/A (150)
Longwall 4 (completed)	300	1.9	2.1 (**1.8**)	11	35 (**30**)	N/A	10.5 (**7.5**)	N/A	21 (**14**)	100	N/A
Longwall 5 (completed)	265	0.9	1.9 (**1.8**)	11	36 (**16**)	N/A	10.8 (**6**)	N/A	22 (**12**)	130	300 (**49**)
Longwall 6	280	1.5	2.1	18	38	7.5 (3)	11	14 (4)	23	310	290
Longwall 7	270	1.2	1.5	18	28	7.5 (3)	8	14 (4)	17	310	290
Longwall 9	330	0.5	2.1	N/A	32	N/A	10	N/A	19	N/A	50
Longwall 10	340	0.6	1.6	N/A	24	N/A	7	N/A	14	N/A	30
Longwall 11	350	0.6	2.1	N/A	30	N/A	9	N/A	18	N/A	10
SELECTED NATURAL FEATURES											
Threatened frog habitat CRUS2 Trib	300		0	5 estd	0	3	0	4	0		
Threatened frog habitat CRUS1 Trib1	320	0.5	0	5 estd	0	3	0	4	0		
Threatened frog habitat CRUS1 Trib2	320	0.5	0.02	11 estd	0	3	0	4	0		
CCUS4 Trib	270	0.9	1.5	18	28	7.5 (3)	8	14 (4)	17		
Cliffs over LW9	330	1.2	2.1	N/A	32	N/A	10	N/A	19		
Cataract Creek	260	0.5	0.1	15 estd	1	N/A	0	N/A	N/A		

topographic high points and maximum compression strains are most likely to occur at topographic low points. More generally across the panel, systematic strains are likely to be 20-30% of the maximum values.

5.3 Valley Closure

The upper limit of valley closure across Cataract Creek downstream of the Mount Ousley Road has been estimated using the 2002 ACARP Method. The predicted closures across Cataract Creek have been revised slightly from the earlier report. Total closures are predicted to range up to 300mm adjacent to the end of Longwall 5 and up to 290mm adjacent to the end of Longwalls 6 and 7. Closure across the second order southern branch of Cataract Creek upstream of the Mount Ousley Road crossing is predicted to reach 700mm. These closure estimates are recognised as being upper limit values because they are based on experience in deep gorges at high stress levels. Monitoring to date indicates closure movements of up to 49mm. These movements are less than 40% of the 135mm predicted for Longwall 5 only.

Closures of 700mm are predicted for the southern tributary of Cataract Creek above Longwalls 1-3. This section of the creek is a second order creek and perceptible impacts from the proposed mining are expected along this section. The northern tributary is the main channel of Cataract Creek. Some of this northern tributary is a third order stream but it is remote from the proposed mining and no significant closure movements are expected.

Cataract River is located to the south of the longwall panels. There is considered to be no potential for significant valley closure movements along the section of Cataract River adjacent to the start of Longwalls 6 and 7. These longwall panels are mainly located on the northern side of the ridge and any downslope horizontal movements are expected to occur mainly on the northern slope causing movement toward Cataract Creek.

There is considered to be potential for valley closure across numerous first, and second order creeks where longwall panels are located directly below the slopes that lead down to these creeks and the creeks are within about 300m of the longwall panel goaf edge.

5.4 Subsidence Movements Beyond the Goaf Edge

Movement outside the goaf edge are expected to be similar to the movements observed so far during mining of Longwalls 4 and 5. Vertical movements of greater than 20mm are expected to be limited to within a distance of 0.7 time overburden depth from the nearest goaf edge equivalent to an angle of draw of 35°. In areas where there has been previous mining in both the overlying seams, vertical subsidence at the goaf edge is expected to reach up to 300-500mm and the goaf edge subsidence profile is expected to be generally more gradual than elsewhere. In areas where there is either solid coal or substantial coal pillars directly above the goaf edge, goaf edge subsidence is expected to be of the order of 100-200mm.

The area of potential pillar instability adjacent to the end of Longwall 1 may cause additional vertical subsidence of up to about 0.7m over a limited area to a distance of about 300m from the goaf corner in an area where the overburden depth is about 270m.

Horizontal movements are also expected to be of low magnitude but may still be perceptible at up to 1.5-3 times overburden depth from the nearest goaf edge. These movements may be concentrated above previous goaf edges such as has been observed to date along the Mount Ousley Road. Horizontal downslope movements associated with valley closure have been observed at the site to extend ahead of mining in a downslope direction to distances ranging from 1 times overburden depth to 2.9 times overburden depth when mining below the slope.

6. SUBSIDENCE IMPACTS

In this section, the subsidence impacts on the range of surface features identified within the PPR Assessment Area and the far field assessment area are assessed.

6.1 Natural Features

The natural features considered in this section include Cataract Creek and its tributaries, Cataract River and its tributaries, swamps across the area identified and mapped by Biosis (2013), cliff formations associated with the Hawkesbury Sandstone outcrop, and the Illawarra Escarpment.

The stored waters of Cataract Reservoir are discussed in the surface infrastructure section.

6.1.1 Rivers and Creeks

Figure 24 shows the creeks across the PPR Assessment Area coloured to show their stream order. The creeks and their order are consistent with the approach used in the Southern Coalfields Inquiry (NSW Department of Planning Southern 2008). The location of the creeks has been adjusted to surface contours derived from LiDAR surveys.

6.1.1.1 Cataract Creek

Cataract Creek flows west across the PPR Assessment Area and is the major creek system within the assessment area. The creek starts as first order creeks west of the Illawarra Escarpment and becomes a fourth order creek from where it flows under Mount Ousley Road to where it joins Cataract Reservoir. There is no mining proposed directly under the third and fourth order sections of Cataract Creek. Second order sections of the southern branch of Cataract Creek are mined under by Longwalls 2 and 3 and a short section of another branch has been mined under by Longwall 5. First order tributaries are mined under by all but three of the panels.

Almost all the second and higher order sections of Cataract Creek that are either directly mined under or are close to longwall panels are flowing within the outcrop of the Bald Hill Claystone. Previous experience of mining under the Bald Hill Claystone outcrop in Cataract Creek indicates that there have not been any significant long term effects on the bed of the creek or the character of the creek despite Longwall 11 in the Balgownie Seam causing the creek bed to subside up to 1.4m.

A management approach based on monitoring closure and stopping the longwall panels if the closure reaches unacceptably high values is considered an appropriate method of managing the closures across Cataract Creek. Barbato et al (2014) report experience in Hawkesbury Sandstone river channels indicating that flow diversion and perceptible cracking in major river channels such as Cataract Creek has not been observed where valley closure is predicted to be less than 100mm with the proportion of pools impacted increasing linearly with closure to be 100% by 700mm of predicted closure. By adopting a TARP based system and adaptive management strategy for limiting closure, it is anticipated that the potential for flow diversion and perceptible impacts on Cataract Creek can be maintained at low levels. SCT understand that acceptable trigger levels will be set in management plans developed in consultation with regulatory authorities.

Figure 25 shows the stream bed profile of the southern branch of Cataract Creek located over Longwalls 1-3 and Cataract Creek downstream to Cataract Reservoir past the ends of Longwalls 4-7. This stream bed profile has been generated from the Surfer model derived from LiDAR imaging of the surface. The subsided profiles at the completion of mining in the Bulli Seam, Balgownie Seam, and Wongawilli Seam are shown. Variation in level associated with the gridding process used to generate the profile has been smoothed.

The vertical subsidence predicted mainly influences the creek profile in the second order section above Longwalls 1-3. In this area there is potential for up to 2.6m of subsidence below the creek alignment. Although there is potential for water to pool in this area, valley closure effects are expected to increase the potential for sub-surface flow so pooling may only be short lived during periods of heavy rain. Valley closures are expected to cause perceptible cracking and surface flow diversion in the upper reaches of the southern branch of Cataract Creek, particularly where it flows across Hawkesbury Sandstone outcrop above Longwall 1. Some loss of surface water and iron staining is expected in this area as a result.

Figure 25 also shows the closures predicted using the 2002 ACARP Method. These closure predictions are sensitive to the approach used to estimate valley depth.

Above Longwalls 2 and 3 and downstream of the crossing below Mount Ousley Road where the creek is not be directly mined under, the bed of the stream is located mainly in Bald Hill Claystone. Only low levels of perceptible impact are expected in this section based on previous experience. Iron staining and flow diversion into the surface strata are not expected to be so apparent in Bald Hill Claystone because of its finer grained nature and high levels of natural fracturing.

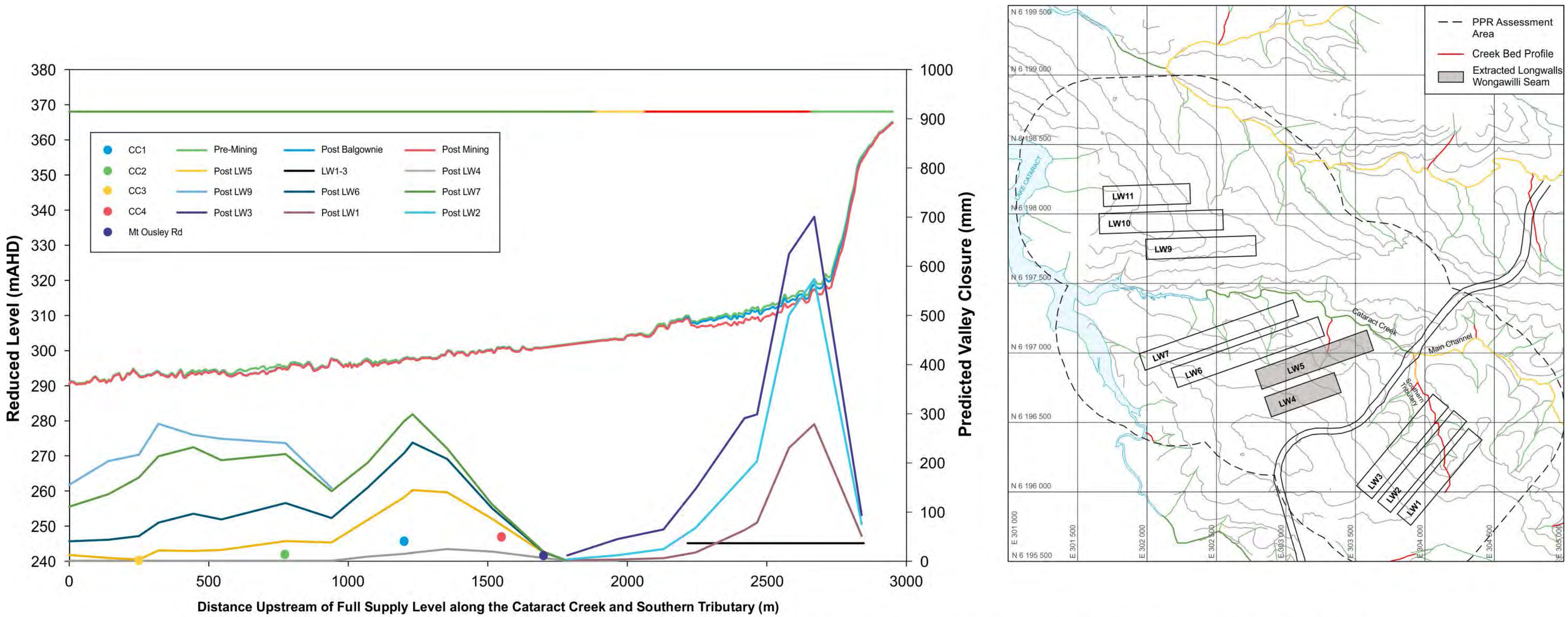


Figure 25: Thalweg profile (pre and post mining) and closure estimates for Cataract Creek from Southern Tributary Headwaters to the Full Supply Level of Cataract Reservoir.

A management strategy based on closure monitoring and cessation of mining if there is a likelihood of significant perceptible impacts becoming apparent is considered to be an effective method of managing the potential for subsidence impacts on Cataract Creek.

6.1.1.2 Cataract River

Cataract River is located on the southern side of the ridge that runs below the start of Longwalls 4-7. Only the southern ends of Longwalls 6 and 7 mine directly below the slopes that lead down to Cataract River and mining is in an upslope direction at the start of these panels. As a result, only very low levels of valley closure are expected across Cataract River from mining these two panels. The maximum valley closure indicated by the ACARP method is approximately 30mm and 40mm from Longwalls 6 and 7 respectively. The nature of the bed of Cataract River in this area is such that these low levels of closure will have no perceptible impact on Cataract River or the surface flows.

6.1.1.3 Cataract River Tributary

A second order tributary of Cataract River flows west-south-west and joins the river at Picton Road Interchange. This tributary flows off the Hawkesbury Sandstone outcrop at a point that is approximately 260m south of the start of Longwall 1. No significant valley closure or perceptible impacts are expected along this section of creek because Longwalls 1-3 do not mine under any significant part of the slope that leads down to this creek. Instead they start under the ridge and mine to the north so that downslope movements are expected to occur mainly on the northern slopes toward Cataract Creek.

6.1.2 Upland Swamps

Biosis (2013) has mapped and described 33 separate upland swamps within the PPR Assessment Area. Figure 26 shows the location of these swamps. Different swamps are differentiated on the basis of the creeks into which they flow and the nature of the swamp vegetation.

Many of these swamps have been previously mined under in both the Bulli Seam and Balgownie Seam. The proposed mining is not expected to cause significantly different impacts to those already experienced. The subsidence parameters estimated and measured for previous mining and predicted for proposed mining in the Wongawilli Seam are presented in Appendix 1.

Individual swamps cover large areas and may be somewhat discontinuous in nature. The prediction of relevant subsidence parameters is challenging because of the large area of some swamps and the relatively large change in subsidence parameters such as strain and tilt over short distances.

The approach taken has been to present the maximum subsidence parameters that are considered credible based on the experience presented in Holla and Barclay (2000) and recognise that these may only occur in one

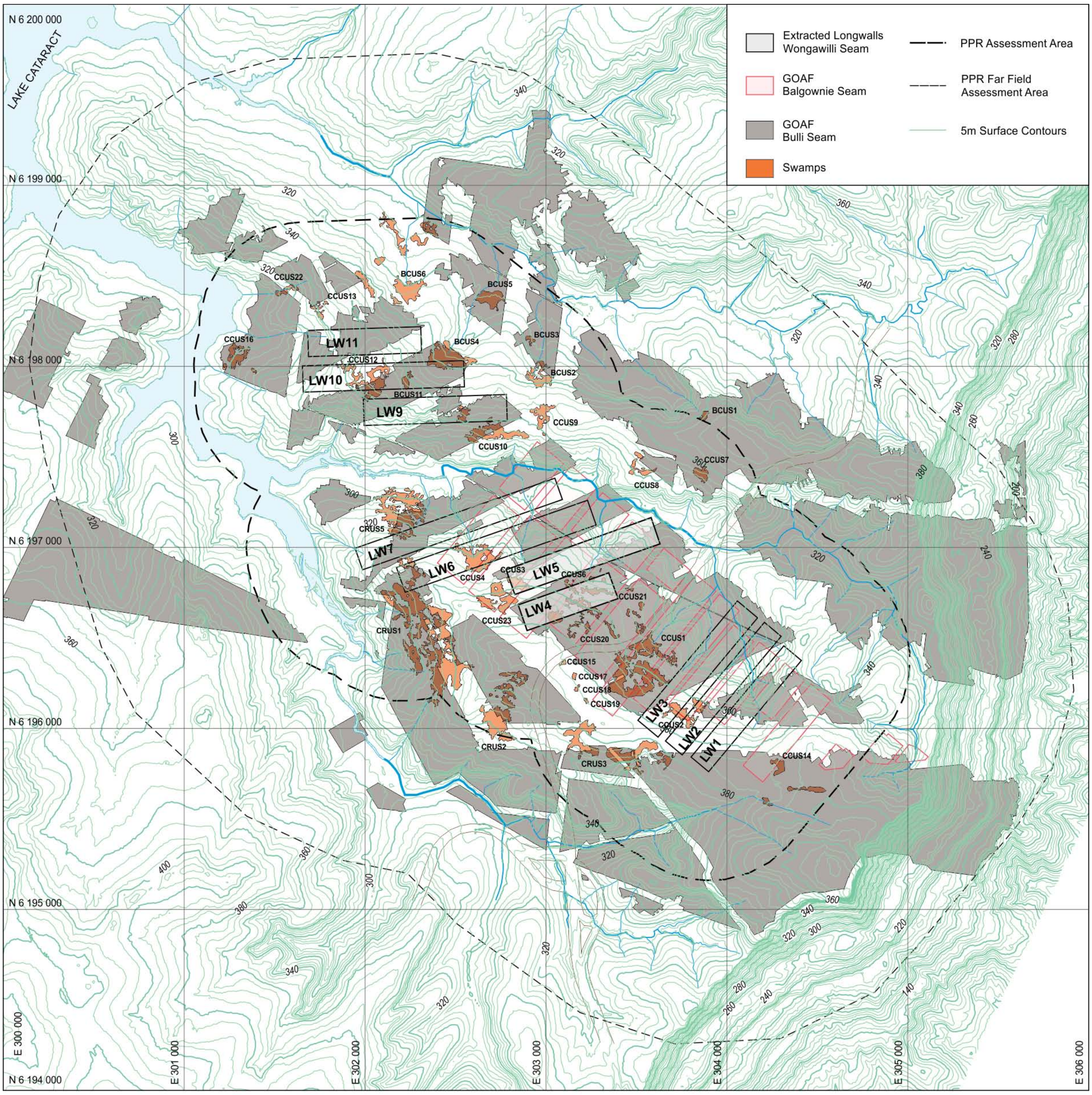


Figure 26: Location of Peat Swamps relative to historic mining and proposed longwall panels.

isolated area of a swamp, if at all. The subsidence parameters more likely to occur are in the order of 50-80% of the peak values for tilt and in the order of 20-30% of the peak values for horizontal strain.

Maximum subsidence within the bounds of the swamp may not necessarily be a good indicator of the maximum subsidence parameters of strain and tilt given that maximum strain and tilt typically occur on the fringes of a subsided area. The maximum strain and tilt values have been estimated based on the level of subsidence within the general proximity of a swamp that would contribute to maximum strains and tilts within the swamp boundary.

When strains are greater than about 1-2mm/m in tension and 2-3mm/m in compression, perceptible fracturing of the sandstone strata below swamps are expected.

It is unclear how sensitive swamps are to mining subsidence. There is a clear association between mining and short term loss of piezometric pressure after rain within the surface layers of some swamps. However, the swamps located within the PPR Assessment Area appear to be thriving despite having been previously subsided to levels that are of the same order as the subsidence expected above future longwall panels. This observation suggests that the drop in piezometric pressure observed when some swamps are mined under may not have had a significant impact on their long term condition.

More work is required to determine the relationship between mining subsidence and the long term health of swamps. The extended baseline of subsidence impacts over 60-100 years in the Bulli Seam and 30-40 years in the Balgownie Seam provides a rare opportunity to study these effects at this site. Proposed mining is expected to cause impacts to the rock strata and to surface and near surface water flows in the areas directly mined under, so it would be helpful to study how and if the wide range of swamps present above the site are significantly impacted by further mining.

6.1.3 Sandstone Cliff Formations and Steep Slopes

There are numerous sandstone cliff formations located within the Hawkesbury Sandstone outcrop in the PPR Assessment Area. Figure 27 shows the distribution of these cliff formations relative to the proposed longwall panels based on an interpretation of LiDAR data by Mine Subsidence Engineering Consultants (MSEC).

Many of these features have previously been mined directly beneath. The impacts of previous mining were able to be assessed during site visits to inspect the surface area.

The most significant cliff formations are those associated with Brokers Nose on the Illawarra Escarpment located some 900m east of the southern end of Longwall 1. Within the PPR Assessment Area, there are several short sections of cliffs between 3m and 10m high located on the northern side of

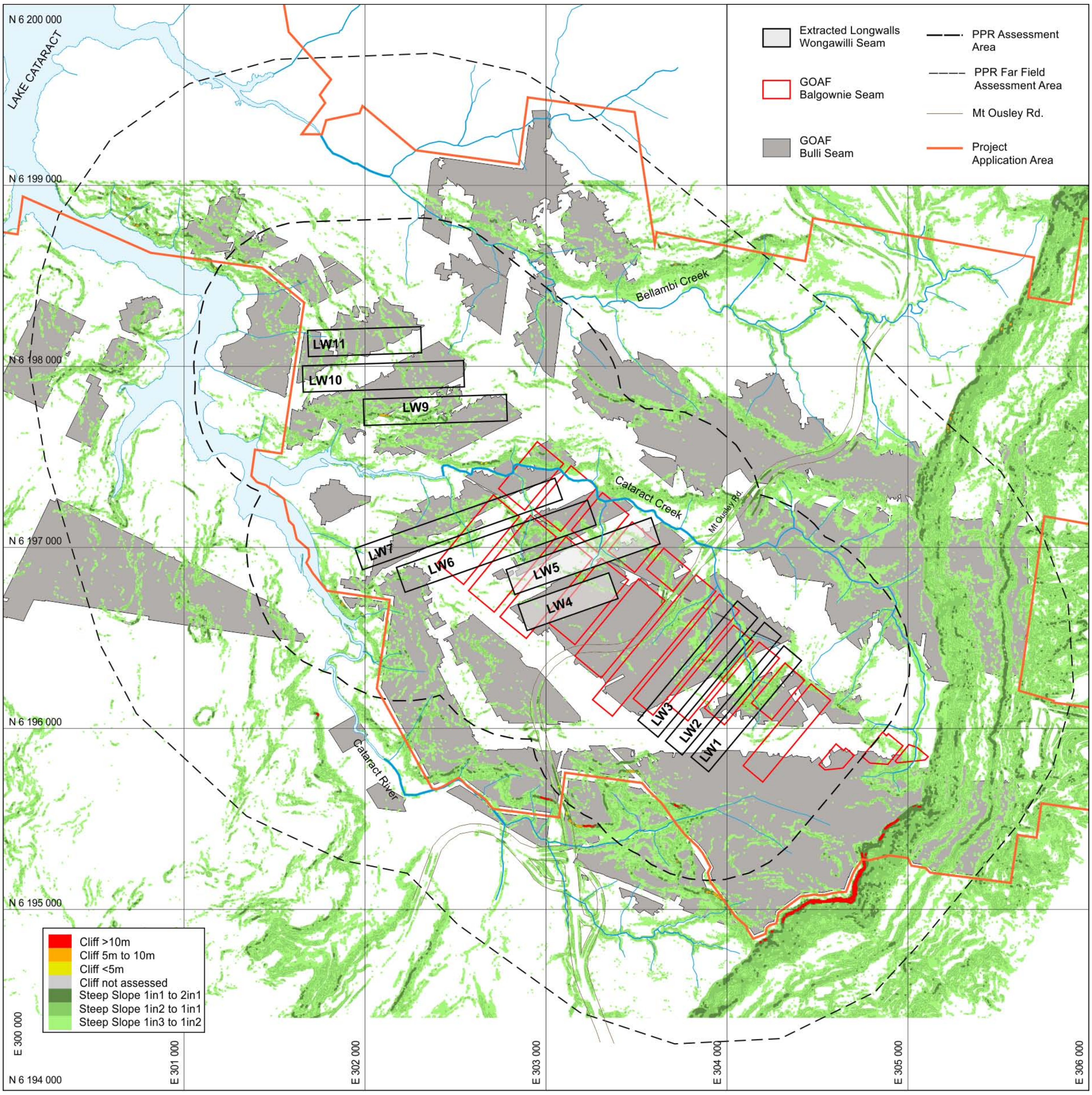


Figure 27: Location of steep slopes and cliff formations.

Cataract Creek and several short sections of cliffs typically less than 3m high but up to about 7m at drainage lines along the Hawkesbury Sandstone outcrop on the southern side of Cataract Creek. There are also some cliff formations of greater than 10m high cliff formations along the southern periphery of the PPR Assessment Area.

Most of the sandstone cliff formations are less than 3m high and occur along the edge of the Hawkesbury Sandstone outcrop as a series of typically discontinuous outcrops and detached boulders. Figure 28 shows a variety of photographs of sandstone cliff formations typical of the PPR Assessment Area. Individual sandstone rock formations are typically less than 20m in length with sections of overhang in some of the formations and numerous isolated or toppled boulders scattered on the slopes immediately below.

On the southern side of Cataract Creek there are several locations where flow down drainage lines has locally increased the height of the cliff formation.

Figure 29 shows one such cliff formation located immediately downstream of CCUS4. This site was not identified during site visits conducted prior to preparation of the initial PPR subsidence assessment. It was inspected during a site visit on 28 May 2014. The sandstone cliff formation at this site is approximately 3m high and 110m long tapering from a rocky outcrop at either end to a maximum height at the watercourse of about 7.1m.

At the location of the watercourse the 3.3m thick sandstone unit has been undercut by the erosion of a softer mudstone layer to create a 4.5m deep overhang and void that is approximately 3.8m high and 30m long. At the time of the site visit on 28 May 2014, water emanating from CCUS4 was flowing over the edge of this formation. There is evidence of impacts from previous mining in the Balgownie Seam that includes collapse of section of overhanging formation to the west that is some 20m long and some subsidence related cracking of the sandstone outcrop to the west of the watercourse.

Several similar features are located further to the east along the same outcrop at other drainage lines. These other features are either located on drainage lines that have no permanent flow or have been impacted by previous mining so that water emerges from the base of the rock formation during periods of low flow rather than flowing over it. Some impact from previous mining is apparent at each of these rock formations. Proposed mining is expected to cause further impacts including rock falls and cracking.

The cliff formations associated with Brokers Nose on the Illawarra Escarpment are remote from proposed mining and there is considered to be no potential for mining subsidence movements to impact the cliff formations along the Illawarra Escarpment.

The critical factor for the stability of sandstone cliff formations is horizontal compression along the line of the cliffs. Once this compression is greater than about 50-100mm per 20m length of cliff formation, rock falls become likely and their frequency increases as the compression increases, as the overhang increases, and as tree root invasion becomes more prevalent.




Figure 28: Sandstone cliff formations typical of the PPR Assessment Area.

Figure 29: Overhanging sandstone formation downstream of CCUS4.

There is considered to be some potential for rock falls on up to 5% of the length of cliff formations directly mined under with potential for perceptible impacts such as tension cracking on up to 30% of the length of cliff formations directly mined under and extending outside the goaf edge to a distance of 0.4 times overburden depth (typically about 140m). A minor rock fall at approximately MGA 302600E, 6197000N on Hawkesbury Sandstone outcrop is considered likely to have been associated with mining activity in the Balgownie Seam and is typical of the impacts that are expected. This rock fall was difficult to detect, and was relatively minor in the context of ongoing natural erosion at the site.

The environmental consequences of impacts on steep slopes are considered to be generally negligible although some cracks may need to be filled in where they are crossed by vehicle access tracks.

6.2 Heritage Features

Nineteen Aboriginal heritage sites have been identified within the PPR Assessment Area. These are described separately in Biosis (2013). The locations of these sites are shown in Figure 30 relative to proposed mining and summarised in Table 5.

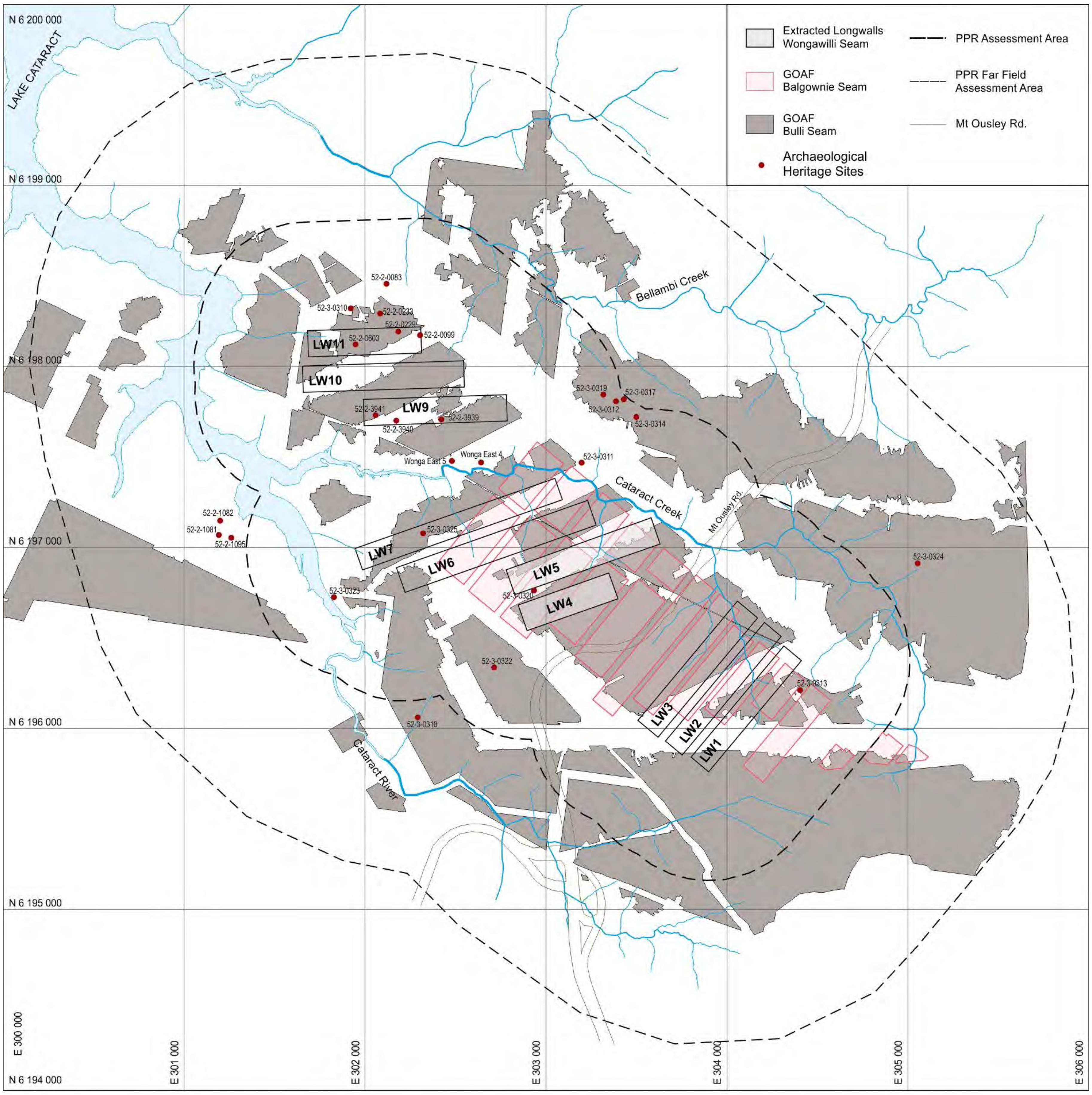


Figure 30: Location of Archaeological Heritage Sites relative to historic mining and proposed longwall panels.

Table 5: Subsidence Parameters Expected at Heritage Sites

Site ID	Subsidence at Site (m)	Adjacent Subsidence Used for Strain and Tilt Calcs (m)	Overburden Depth (m)	Max Tensile Strain (mm/m)	Max Comp Strain (mm/m)	Max Tilt (mm/m)	Compressive Horizontal Movement Along 20m Section of Cliff (mm)
52-2-3939	0.8	2	340	8.8	18	29	350
52-2-3940	0.6	1.5	340	6.6	13	22	250
52-2-3941	1.2	1.5	340	6.6	13	22	250
52-2-0603	1.5	1.5	340	6.6	13	22	250
Wonga East 4	< 0.1	< 0.1	300	< 0.5	< 1	< 2	< 20
Wonga East 5	< 0.1	< 0.1	300	< 0.5	< 1	< 2	< 20
52-3-0320	0.7	2	340	8.8	18	29	350
52-3-0325	1.1	1.5	315	7.1	14	24	250
52-3-0311	< 0.1	< 0.1	285	< 0.5	< 1	< 2	< 20
52-3-0310	< 0.1	< 0.1	385	< 0.5	< 1	< 2	< 20
52-2-0099	0.4	1	355	4.2	8	14	150
52-2-0229	0.7	1	365	4.1	8	14	150

There are two sites on the southern side of Cataract Creek that are above or adjacent to proposed longwall panels. Three more sites are located over Longwall 9, another above Longwall 11, and the rest are located in areas that are unlikely to be significantly affected by mining subsidence.

Estimates and measurements of subsidence movements associated with past mining activity and predictions of subsidence movements for proposed mining activity are presented in Appendix 1. Table 5 presents a summary of the subsidence parameters expected from mining in the Wongawilli Seam.

6.2.1 Site 52-2-3939

Site 52-2-3939 site forms part of a 3-5m high sandstone cliff formation that protrudes from the general line of the cliffs with a 6m overhang as shown in Figure 31. The site is protected somewhat by being relatively short in length and protruding out from the general line of the cliffs in the area. The probability of rock falls at the site is assessed as being 2% which means that there is likely to be rock fall within the general area of the site i.e. somewhere along the 100-200m of cliff line that are located within a short distance of the site. Perceptible tensile cracking is assessed as having a 30% probability of being evident on rock surfaces in the general area including possibly through the site.

Figure 31: Photograph of Archaeological Site 52-2-3939.

6.2.2 52-2-3940

Site 52-2-3940 is part of an extended (100m long) line of 4-6m high cliff formations, some of which have already fallen either naturally or as a result of previous mining in the Bulli Seam more than 50 years ago, and has a 5m overhang as shown in Figure 32.

The site is estimated to have previously experienced approximately 0.1m of subsidence with horizontal compression of about 0.1m. Proposed mining of Longwall 9 in the Wongawilli Seam is expected to cause up to 0.6m of additional subsidence with 1.5m expected nearby, up to 250mm of additional compression at the site, and tensile strains of about 7mm/m.

The site is considered to be vulnerable to further rock falls because it is part of a long line of cliffs, some of which have already collapsed. The probability of rock falls at the site is assessed as being 5% which equates to a 5m rock fall being likely somewhere along the 100m section of cliff line adjacent to the site. Perceptible tensile cracking is assessed as having a 30% probability of being evident on rock surfaces in the general area including possibly through the site.

Figure 32: Photograph of Archaeological Site 52-2-3940.

6.2.3 52-2-3941

Site 52-2-3941 is part of a 3-4m high cliff formation that been previously involved in a rock fall. The overhang that constitutes the site is located below a detached boulder and has an overhang of approximately 4m. Figure 33 shows a photograph of the site including the fractured rock strata where the boulder has detached from the general cliff formation.

There are several characteristics of the rock fall that indicate it is likely to have been associated with mining in the Bulli Seam more than 50 years ago. The site is estimated to have previously experienced approximately 0.2m of subsidence with horizontal compression of about 0.1m. Proposed mining of

Longwall 9 in the Wongawilli Seam is expected to cause up to 1.2m of additional subsidence with 1.5m expected nearby, up to 250mm of additional compression at the site, and tensile strains of about 7mm/m.

The site itself is not considered vulnerable to further rock falls because it is detached from the cliff line and is not large enough to experience significant lateral compression so the probability of a rock fall at the site is considered to be low (<1%). However, the probability of further rock falls in the general

Figure 33: Photograph of Archaeological Site 52-2-3941.

vicinity of the site along the standing cliff line is assessed as being 5%. This probability equates to a 5m length of the adjacent 100m of cliff formation likely to experience a rock fall. Perceptible tensile cracking is assessed as having a 30% probability of being evident on rock surfaces in the general area although a tension crack directly through the site is considered unlikely.

6.2.4 52-2-0603

Site 52-2-0603 is located high up on the ridge line. The cliff formation is estimated to be 50-70m long and the overhang where the rock art is located is approximately 4m deep and 3m high as shown in Figure 34. The rock in the roof of the overhang is only about 1-2m thick but relatively continuous.

The site is estimated to have experienced up to 0.3m of subsidence as a result of previous Bulli Seam mining activity with horizontal movement of about 0.1m although it is possible that the geometry of the Bulli Seam mining was sufficiently narrow in this area to prevent significant subsidence movements at the site. Proposed mining of Longwall 11 is expected to cause up to 1.5m of additional subsidence and up to 250mm of horizontal compression.

Figure 34: Photograph of Archaeological Site 52-2-0603.

The site's location near the top of the ridge is likely to have reduced some of the horizontal compression because there is currently no evidence of a rock fall within the period of previous mining. There is a rock fall evident on a nearby formation, but this fall appears to be too recent (last few years) for it to have been directly associated with previous mining subsidence.

The level of horizontal compression expected is assessed as being likely to cause perceptible cracking in the vicinity of the site with the probability of rock fall assessed as being 5-10%. The nature of the site is such that a rock fall anywhere along the 30-40m length of the overhang is likely to be considered as having impacted the site.

6.2.5 Grinding Groove Sites

There are several grinding groove sites located on bare rock areas in upland areas away from creeks. Perceptible cracking is expected in up to 30% of bare rock areas when these areas located directly above longwall panels

Outside the goaf edge, the frequency of cracking is expected to decrease in magnitude with distance from the goaf edge and become imperceptible beyond a distance of about 0.4 times the overburden depth or about 120-150m from the goaf edge.

Within any given site where cracking occurs, individual cracks may be perceptible as tension cracks that cause the rock to move apart, usually on natural joints if these exist but also through intact rock, shear cracks that cause opening and lateral displacement of the two sides, and compression cracks that result in the rock surface popping up in slabs. Shear and tension cracks tend to be more prevalent in upland areas.

The probability of one of the tension or shear cracks directly intersecting a grinding groove depends on the site characteristics, but is generally low because such cracks tend to be widely spaced (5-10m). However, the potential for a bare rock sites to be impacted generally is expected to up to about 30%.

Compression fracturing tends to be more prevalent in topographic low points and the fracturing that occurs tends to affect a larger proportion of the site.

6.2.6 Other Sites

The Wonga East 4, Wonga East 5, 52-3-0310, and 52-3-0311 sites are located beyond the footprint of the longwall panels and are not expected to be perceptibly impacted by mining subsidence because of their location.

Sites 52-2-0099, 52-2-0229, 52-3-0320 and 52-3-0325 are located within the boundaries of the longwall panels and some perceptible impacts are expected in the general area of these sites as a result. Those sites that are associated with detached boulders such as 52-3-0325 are considered unlikely to be significantly impacted.

6.3 Surface Infrastructure

Surface infrastructure located within the PPR Assessment Area includes the Mount Ousley Road, four power transmission lines that run between Mount Ousley and the Illawarra Escarpment with two of these lines having pylons directly over the Longwall 2 and the chain pillar between Longwalls 1 and 2, and the storage of Lake Cataract. Other infrastructure within the extended assessment area includes the Picton Road Interchange and communications tower infrastructure near the top of Brokers Nose.

6.3.1 Mount Ousley Road

Mount Ousley Road is protected from direct mine subsidence by a horizontal distance from the nearest goaf edge of greater than half overburden depth. Low levels of vertical subsidence of less than about 100mm in total are expected in the vicinity of Mount Ousley Road with up to approximately 40mm of this maximum having already occurred from mining Longwall 4 and 5. Longwalls 6-11 are not expected to cause additional subsidence along the road alignment. Longwalls 2 and 3 are expected to cause all additional subsidence that occurs on the road alignment. These low level vertical movements expected are expected to be imperceptible for all practical purposes.

The 2002 ACARP Method for predicting valley closure indicates horizontal movement in a downslope direction caused by mining below the slope on the southern side of Cataract Creek is likely to generate closure at the creek crossing as summarised in Table 6.

Table 6: Predicted Horizontal Closure Across Cataract Creek at Mount Ousley Road

Longwall	Maximum Incremental Closure Predicted (mm)	Maximum Cumulative Closure Predicted (mm)
4	6	6
5	11 **(10)**	17
2	1	18
3	1	19

The upper limit of 19mm of compression in the bottom of the valley estimated at the completion of all proposed mining is expected to be accompanied by a similar level of cumulative tensile cracking toward the top of the slope. Some of the tensile cracking that began during Longwall 4 appears to be continuing during mining of Longwall 5 particularly at Peg 46 on P Line. The ongoing cracking observed near Peg 46 may also include sub-base deterioration associated with repetitive vehicle loading and fines migration into the crack that that formed during Longwall 4.

The Picton Road Interchange is located on the opposite side of Cataract River and the opposite side of a tributary that joins Cataract River at the interchange. Longwalls 1-5 are located predominantly below the north facing slope that leads down to Cataract Creek. As these longwall panels start below the ridge and mine away to the north, horizontal movements in a downslope direction are considered unlikely to extend across Cataract River to interact with the Picton Road Interchange. The bridge on the Picton Road Interchange is further protected by being on the far side of the west flowing tributary to Cataract River.

On this basis, there is considered to be no potential for significant horizontal movements to impact the Picton Road Interchange. A monitoring strategy is considered appropriate to confirm that subsidence movements are of low level and of no significance for the structures around the interchange. Once this monitoring regime has established there is no significant interaction, a reduction in the frequency of monitoring is considered appropriate.

The road cutting on the northern side of Cataract Creek has been formed in Hawkesbury Sandstone strata to create embankments up to about 10m high. These embankments are located beyond 500m from the nearest longwall panel on the opposite side of Cataract Creek. There is considered to be no potential for mining induced cliff falls to occur along this section of exposed rock.

6.3.2 Power Transmission Lines

There are four power transmission lines located in two corridors between Mount Ousley Road and the Illawarra Escarpment. Figure 35 shows photographs of the four different types of support structure used on these lines. The 330kV and 132kV lines are supported on trussed steel pylons. One of the 33kV lines is supported on single pole structures and the other one is supported on double pole structures that appear to have been replaced in the last few years.

All four lines were potentially mined under by late stage pillar extraction in the main heading pillars in the Bulli Seam, although the Bulli Seam mining may have preceded construction of the lines and by Longwalls 1 and 3 in the Balgownie Seam.

The power transmission towers T56 (on the 330kV line) and E57 (on the 132kV line) are suspension towers located in an area where there was 1-1.2m of vertical subsidence measured during mining of the Longwall 3 in the Balgownie Seam. The tower locations are noted on subsidence plans as T56 and T52 so it appears likely that they were in place when Longwall 3 was mined in 1975.

In general, suspension towers are located on straight sections of line and the conductors are suspended from the tower structure on hanging insulators rather than directly to fixed insulators on the structure. However, it is noted that T56 is located at a slight change of direction in the line. The side load associated with this slight change in direction is counteracted by rotation from vertical of the suspended insulators as can be seen in Figure 35. In contrast, E57 is located on a straight section of line and the insulators hang vertically.

Figure 35: Power transmission lines above Longwalls 1 and 2.

The towers T56 and E57 are 100m and 200m respectively down slope from the area of cracking at the topographic high point near the start of proposed Wongawilli Seam Longwall 3. The tension cracking observed is consistent with expected ground movements. These towers do not appear to have been significantly impacted by previous mining possibly because they are located on Hawkesbury Sandstone and, fortuitously, the cracks have not passed between the legs of the towers.

The structural integrity of pylons is sensitive to even small levels of differential displacement between the four legs. It would appear that cracking or differential movement did not occur through the sandstone strata between the tower legs so that the tower foundations moved together as one unit allowing any subsidence and tilting of the pylons to occur without compromising the structural integrity of the towers themselves. Small tilting and horizontal movements of the towers as a whole are normally able to be accommodated by rotation of the suspended insulators that support the conductors. Realigning the insulators during subsequent maintenance allows any misalignment to be rectified.

The predicted subsidence at the tower locations are detailed in Table 7 and illustrated in Figure 36.

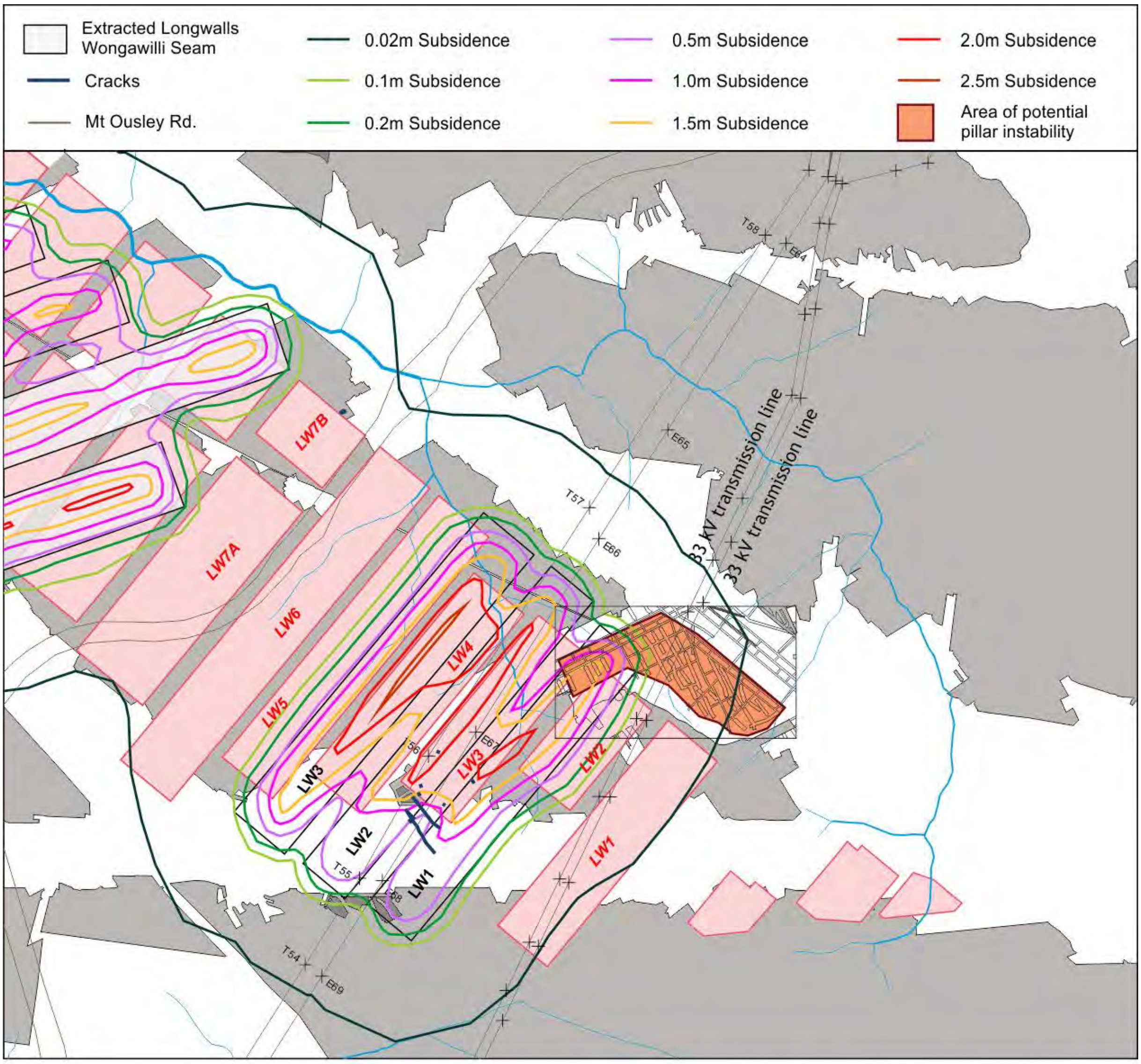


Figure 36: Location of power transmission structures relative to proposed longwalls, Balgownie Seam longwalls, and area of potential pillar instability in the Wongawilli Seam.

There is an area where there is some potential for pillar collapse in the Bulli Seam to cause additional subsidence. This area is shown in Figure 36. Fortunately, the towers and poles are located outside the area likely to be affected by any pillar instability.

Table 7: Subsidence Expected at Power Pylon Locations

Tower	Subs (m)	Maximum Tensile Strain (mm/m)	Maximum Compressive Strain (mm/m)	Maximum Tilt (mm/m)	Differential movement over 10m (mm)	Horizontal Movement (m)
330kV T54	0.03	< 0.2	0	< 0.5	< 2	< 0.1 NE
330kV T55	0.5	4.6	9	15	50	0.3 NE
330kV T56	2.2	11.2	22	37	120	0.7 NE
330kV T57	0.05	< 0.2	0.0	< 0.5	< 2	<0.1 SW
132kV E66	0.07	< 0.2	0.0	< 0.5	< 2	<0.1 SW
132kV E67	1.8	11.8	0.0	39	120	0.3 NE
132kV E68	0.3	4.8	10	16	50	0.7 NE
132kV E69	0.03	< 0.2	0	< 0.5	< 2	<0.1 NE
33kV Lines	< 0.1	< 0.2	0	< 0.5	N/A	<0.1 W

The four towers located directly over the longwall panels are expected to permanently move in the direction of mining. The horizontal movement is expected to range up to 700mm and is likely to be greatest on the two towers located directly over the goaf, T56 and E67.

The proposed mining is expected to cause ground movements that have potential to compromise the structural integrity of towers T55, T56, E67 and E68 if the movements occur differentially between the tower legs.

Although there has been previous cracking nearby and such cracking is likely to continue to localise further ground movements (i.e. movement will occur by further opening existing cracks rather than forming new cracks) the risk of new cracking causing structural damage is considered to be too high to be acceptable without some form of mitigation. It is considered likely that all four towers would require some mitigation works if the hazard of differential movements is to be eliminated during the period of mining Longwalls 1, 2 and 3.

The use of a cruciform foundation is one of several options that can be used to mitigate the potential impacts of mining. Some active realignment is likely to be required, particularly on Tower E67 where permanent tilts of up to 39mm/m are expected. Tilting of 39mm/m equates to a horizontal movement at the top of the tower of about 800mm. This movement may be able to be accommodated by rotation of the hanging insulators, but this needs to be checked in consultation with the power utility companies that own the infrastructure. It may be necessary to suspend the conductor in roller sheaves during the period of active subsidence to equalise conductor tensions.

A single point tie down may be required on the western leg of the cruciform for T56 to provide rotational stability of the structure given the lateral loads associated with the slight change in direction at this tower but the loads involved are expected to be small enough to be able to be accommodated through appropriate design.

The adjacent towers to the south T54 and E69 are considered to be sufficiently remote from mining for there to be no significant potential for ground movements. These towers are protected by an angle of draw of 30°. Both towers are located on ground that is sloping away from the direction of mining in an area where the slope is not directly mined under. Some monitoring of these towers is recommended, but there does not appear to be a compelling case to provide additional protection.

The adjacent towers to the north T57 and E66 are protected by an angle of draw of 26° and 23° respectively, and they are therefore remote enough for systematic ground movements to be low. However, both towers are located on top of a ridgeline where tension cracks tend to be concentrated. While the direction of mining toward the ridge tends to lessen the potential for cracking on the ridge line, there is nevertheless considered to be a low level hazard associated with the potential for cracking between the tower legs with potential to compromise the structural integrity of the tower. It may be possible to cut a slot or confirm that the tower will be protected by detailed consideration of the local site conditions, but a site specific risk assessment is required to develop a mitigation strategy for these towers.

There is a significant change in direction on both the 330kV and 132kV transmission lines at a point approximately 1km north of the northern ends of Longwalls 1, 2 and 3. Some additional monitoring of these structures may be appropriate to monitor and manage any changes in conductor tension that results from the subsidence movements. Far-field movements are not expected to create any significant hazard in terms of the structural integrity of these towers because of the low levels of movement and even lower levels of differential movement expected at 1km from the goaf edge.

The 33kV lines are supported on single and double pole structures. The double pole structure appears to be relatively new. These structures are tolerant to mine subsidence movements. Mining of Longwall 1 in the Balgownie Seam caused subsidence of 0.8-1.2m below four of these pole locations and 0.4-0.6m on four others. It is considered unlikely that this mining caused any significant impact to these lines although they may have needed to be straightened up at the completion of mining.

The 33kV single and double pole structures are relatively tolerant of subsidence movements and because these structures are located more than 60m outside of the footprint of the longwall panels, only low levels of subsidence and no significant impacts are expected. No protection measures are considered necessary for the 33kV single and double pole structures, although some before and after mining survey monitoring program is recommended to confirm the low levels of ground movement that are expected.

6.3.3 Cataract Water Supply Reservoir

No impacts are expected on the Cataract Reservoir from the proposed mining. The FSL including the section that extends up Cataract Creek is protected from the nearest longwall goaf by a nominal horizontal distance of greater than 203m at 290m overburden depth (equivalent to 0.7 times overburden depth or an angle of draw of 35°). Vertical subsidence at the FSL is expected to be less than about 20mm.

Geological structures within the PPR Assessment Area are relatively well defined because of the previous mining that has occurred in the overlying Bulli Seam over a large area and the overlying Balgownie Seam in a more limited area. The only geological structure that extends through to the proposed longwall panels in the PPR Assessment Area and the reservoir is Dyke D8. The horizontal distance along the dyke from the end of Longwall 10 to the FSL is approximately 560m at an overburden depth of 320m at the FSL.

The faults labelled F2 are apparent in the workings in Corrimal Colliery but become degraded in the Bulli Seam workings at South Bulli Colliery. These faults are not proposed to be directly intersected in the Wongawilli Seam but there is a flow pathway between the faults and the Wongawilli Seam mining horizon through the Bulli Seam mine workings that intersect both.

There is considered to be no potential for proposed mining to intersect the stored waters directly. There may be potential for flow along the dyke via the Bulli Seam, but experience in the Southern Coalfield indicates that dykes are very rarely hydraulically conductive except when affected by mining subsidence at shallow depth. There does not appear to have been any significant inflow associated with mining the Bulli Seam on this dyke. Mining in the Wongawilli Seam 560m away from the reservoir is not expected to have any potential to increase hydraulic conductivity between the reservoir and the mine.

There are a number of small pre-existing Bulli Seam mining areas where coal has been extracted that are located within the 0.7 times depth protection zone around the FSL. There does not appear to be any direct connection between the reservoir and the mining horizon through these mining areas. Although their presence appears to reduce the effectiveness of the 0.7 times depth barrier between the FSL and the proposed mining somewhat, particularly for mining of Longwalls 7 and 9, the pathway for seepage from the reservoir to the mine is likely to be predominantly along horizontal shear planes at or just below the level of the valley. The calculated height of depressurisation using the method forwarded by Tammetta (2012) for a Bulli Seam pillar extraction panel is well below the level of any horizontal shear planes capable of interacting with the reservoir.

As a result, there is not considered to be any potential for these existing Bulli Seam mining areas to significantly reduce the effectiveness of the 0.7 time depth barrier.

6.3.4 Telecommunications Infrastructure

There is a telecommunications tower located on Brokers Nose on the Illawarra Escarpment. This telecommunications infrastructure and the cliff formations at Brokers Nose are protected by a horizontal distance of approximately 1km from the nearest point on Longwall 1. No ground movements are expected at this distance from the proposed mining because there is no potential for significant horizontal stress concentration along the escarpment and no potential for change in any of the other stress components.

7. Management Strategies

The subsidence management strategies have been discussed in the previous section, but are consolidated in this section.

7.1 Survey Monitoring

Survey monitoring is expected to provide the primary basis for informing the processes used to manage subsidence impacts. This monitoring is discussed first because it underpins all the other management processes.

Conventional subsidence monitoring using repeat surveys in three dimensions with far-field GPS control is considered to provide the industry best practice subsidence monitoring technique in steep terrain. This type of three dimensional surveying captures the full three dimensional ground movements independent of location to an accuracy that is suitable to characterise the nature of the ground movements. Strains and tilts are not necessarily captured to the same level of accuracy as is possible with levelling and peg to peg chaining but the reduced accuracy is offset by capturing all components of movement rather than just the components in the direction of the subsidence line. It is recommended that the existing survey lines are monitored in three dimensions using this approach.

Two cross lines across each panel and a centreline subsidence line are considered appropriate to monitor subsidence movements in the relatively complex subsidence environment above Longwalls 1-11. The three dimensional movements on the active sections of these lines should be monitored regularly, particularly at the commencement of each longwall panel and during mining below or near significant infrastructure. The broader network should be resurveyed at the midpoint and end of each longwall panel or about every 2-3 months whichever occurs first.

It is recommended that a survey monitoring base line is extended to include three dimensional far field GPS control for a distributed array of monitoring points that are located at easily accessible locations across the mining area as well as around the periphery of the mining area out to about 3km. This monitoring network can then be checked at any time and used to confirm the levels of movement that have occurred on all the monitoring lines and infrastructure in the area. This distributed array is intended to provide an overview of any movements that are occurring. The array can also be used to provide confirmation of the accuracy of the survey control grid.

High resolution point to point measurement of valley closure across Cataract Creek is recommended at as many crossing points as can practically be established from an environmental perspective. The four that are currently located across Cataract Creek are considered suitable locations and the establishment of a similar measurement point at Mount Ousley Road would add another. The establishment of further closure points would be recommended across the southern branch of Cataract Creek prior to mining Longwalls 1-3. It would be useful to extend these somewhat to increase the horizontal coverage so as not to miss any closure movements that occur beyond the ends of the convergence line, although the practical difficulties of surveying in a rainforest environment are recognised.

7.2 Infrastructure Management

The mining impacts on infrastructure that need to be managed include the Mount Ousley Road, the power transmission lines, the Cataract Water Supply Storage, and the telecommunications facility at Brokers Nose.

7.2.1 Mount Ousley Road

Management of the Mount Ousley Road and any subsidence impacts using a technical committee such as was used for Longwalls 4 and 5 is considered appropriate for the ongoing management of subsidence impacts to the road.

The half depth stand-off of mining from Mount Ousley Road is considered to significantly reduce the potential for impacts on the highway and this potential will reduce further as active mining moves away from the road.

Some low level ground movements have been observed and surface cracking has also been observed on the road surface particularly around the crest of the ridge between Cataract Creek and Cataract River where stretching movements are expected. It is recommended that the observed surface cracks are filled from time to time to reduce potential for ingress of surface water into the formation because unlike conventional road cracks that are likely to occur mainly in the surface layers, these subsidence cracks are likely to extend through the full section including into the foundation rock. It is possible that water ingress into the road formation through cracks may cause loss of fines from the sub-base with increased potential for pavement cracking, surface deterioration, deterioration in ride quality generally, and ultimately public safety.

Continued visual monitoring of the Mount Ousley Road, perhaps at reduced frequency is recommended, as well as survey monitoring at the end of each panel as the basis to confirm the actual subsidence movements are consistent with those predicted.

A high level of monitoring of the Mount Ousley Road and Picton Road Interchange have been appropriate during mining of Longwalls 4 and 5 in close proximity to the highway. However, some reduction in the frequency of the survey monitoring is now considered appropriate given the low level and zero change respectively that have so far been observed. A management strategy based on regular visual inspections and end of panel surveying unless otherwise triggered would appear to be sufficient to manage the levels of impacts expected once Longwalls 4 and 5 have been completed.

The frequency of monitoring, particularly of the Mount Ousley Road may need to increase again during mining of Longwalls 2 and 3.

Some refinement to the surveying technique is recommended to better measure opening movements at the top of the ridge and closure across Cataract Creek. Point to point surveying between fixed prisms, a general upgrade to three dimensional surveying, and replication of P Line survey marks to the edge of the southbound lanes is recommended.

7.2.2 Power Transmission Towers

A technical committee comprising representatives from the colliery, the power utility companies, the Mine Subsidence Board, and government regulators is recommended to manage potential impacts on the power transmission towers. This forum provides all interested parties with understanding and control of the management processes.

Several of the power transmission towers are likely to require the construction of cruciform bases to allow the hazard associated with differential subsidence to be eliminated. It is noted that there is usually a significant lead time involved in getting cruciforms approved, financed, designed, and constructed.

Monitoring on the power transmission poles and towers needs to be designed in consultation with the power utility companies. It is envisaged that automatic monitoring systems capable of transmitting data back to a website portal would be a practical solution for capturing tilt and differential movements between individual legs.

Prior to the approach of Longwall 1, a number of short survey lines should be located in the vicinity of the panel of small pillars at the northern end of the panel to confirm the nature and extent of subsidence that may occur as a result of any pillar destabilisation in this area.

All the survey monitoring points for the power transmission towers and the telecommunications infrastructure on Brokers Nose should be linked back into the distributed array of monitoring points and the control already established for Mount Ousley Road.

7.2.3 Cataract Reservoir

The Dams Safety Committee (DSC) is a statutory body with legal powers to manage mining to protect the stored waters in Cataract Reservoir. As is appropriate, the DSC takes a conservative view of the potential threats of mining to the stored waters because of the challenges of effectively remediating any leakage of water from the reservoir to the mine. The DSC also recognises that some minor loss is inevitable and is tolerable. The colliery has been working with the DSC for many years and it is considered that the management process that has been adopted in the past continues to be appropriate.

The management of potential impacts revolves around providing a sufficient standoff from the FSL, confirming that there are no geological structures with potential to provide elevated hydraulic conductivity between the reservoir and the mining horizon and that any such structures will not be adversely affected by mining, and monitoring the mine water balance to confirm the magnitude of any flows that occur.

The 0.7 times depth (nominally 203m) stand-off from the FSL is considered to be the primary control for protecting the stored waters of Cataract Reservoir and this barrier is expected to provide a high level of protection to these stored water. The presence of existing pillar extraction areas within the barrier reduces the protection afforded by the barrier to 80m from the FSL in some areas.

Geological structure in the area is well defined by the presence of previous mining. The D8 dyke is considered to be the only geological structure with potential for increased hydraulic conductivity but there is a separation between the reservoir and the mine along the dyke of approximately 500m horizontally and 360m vertically and exposures underground do not indicate a history of increased inflow despite previous mining adjacent to the dyke directly under Cataract Creek.

A review of the integrity of the mine water balance is recommended to confirm that all sources of water are accounted for on a regular and ongoing basis with suitably calibrated monitoring equipment.

The piezometer monitoring network currently in place provides an indication of the changes in groundwater characteristics around the site. Further monitoring in areas where there are multiple levels of mining stacked above each other and in the area between the reservoir and the mine would increase confidence in and understanding of the impacts of mining on the groundwater system. The design of this monitoring would need to be done in consultation with the DSC.

It is noted that there are limited options to control any significant inflow from the reservoir through sealing up the longwall panels or the mine portals because the Wongawilli Seam, the Balgownie Seam, and the Bulli Seam are all hydraulically connected in this area through the interconnected goafs. The 0.7 times depth offset between the longwall panels and the FSL has been designed as the primary control and is expected to be effective to control an potential for inflow from Cataract Reservoir into the mine.

7.2.4 Telecommunications Infrastructure

No mining subsidence movements are expected at the site of the telecommunications infrastructure located on Brokers Nose. Nevertheless engagement with the owners of the infrastructure and regular monitoring to confirm that there have been no changes is recommended.

7.3 Natural Features

The detail of monitoring of swamps, heritage sites, and creek biota is beyond the scope of this report and has been addressed in other specialist reports.

However, it is recommended that one or more technical committees are formed to design monitoring programs that not only review the changes that may be associated with proposed mining but also take the opportunity to review the longer term impacts from previous mining in the same area. These technical committees should include external expertise from the community where appropriate so that monitoring programs are targeted, appropriate, can be ongoing, and are transparent to all stakeholders.

8. RESPONSE TO SUBMISSIONS

A range of submissions were received in response to the Underground Expansion Project Pt3A. These submissions were received prior to the PPR amendments. The PPR amendments have already addressed many of the issues raised. In this section, a number of these issues are discussed in the context of the PPR design and how they have driven the changes that have been made to the layout.

A second set of submissions were prepared in response to the PPR. The response to this second set of submissions is included in Appendix 1 of this report. Many of the issues addressed in this second set of submissions have been addressed in this update of the PPR subsidence assessment.

8.1 Accuracy of Prediction

The reduced level of accuracy of the prediction methodology in multi-seam environments was raised in a number of submissions.

While this concern is valid, the recent subsidence monitoring above Longwalls 4 and 5 and a review of previous subsidence monitoring above the Balgownie Seam longwall panels and a review of local Bulli Seam subsidence profiles provides a strong basis of local site based experience to allow more accurate predictions to be made.

The subsidence prediction technique used has been updated to reflect the available data. The revised approach is based on using the available data to provide insight in the subsidence mechanics and continuing to develop this understanding recognising the various subsidence processes involved.

The results of this previous monitoring indicate that, although the magnitude of subsidence is greater in a multi-seam environment where there has been previous subsidence of the overburden strata because of the lower shear stiffness of previously disturbed strata, the subsidence behaviour in a multi-seam environment is similar to single seam subsidence in its general characteristics. There are some differences but these are generally subtle, second order effects and do not change the general characteristics of subsidence behaviour. A difference that does need to be recognised is the potential for pillar instability in areas of standing pillars in overlying seams.

The subsidence monitoring above Longwalls 4 and 5 indicates that subsidence occurs primarily over the panel being mined with only low levels of ground movement outside. Vertical subsidence occur as low level movements at the goaf edge and become less than 20mm at about 0.7 times depth from the goaf edge. There are more gradual profiles evident over previously mined goaf compared to over solid, but the differences are relatively small and tend to soften the ground movements at the goaf edge. Sag subsidence can be controlled by limiting the width of the panel but the panel widths required to keep subsidence to any given level are much less than in a single seam mining environment because of the reduced bridging capacity of previously disturbed overburden strata.

The issue of pillar instability and recovery of latent subsidence associated with bridging strata at the goaf edge is recognised as having potential to cause additional subsidence. This potential needs to be considered on a site by site basis, but experience of mining the Balgownie Seam longwalls and Longwalls 4 and 5 in the Wongawilli Seam suggest that the potential is less than was initially envisaged and the impacts are of a relatively low level. Nevertheless, an area of standing pillars near the finish of Longwall 1 is recognised as having potential to become destabilised with potential for additional subsidence. Additional monitoring is recommended in this area, but it is noted that any additional subsidence associated with pillar instability is not expected to have a significant impact on any infrastructure or significant natural features in the area near the finish of Longwall 1.

Although there is somewhat greater uncertainty for subsidence predictions in a multi-seam environment, the available data and further monitoring data is expected to continue to provide a strong base for further understanding. The behaviour observed is repeatable and consistent with the mechanics of the processes involved.

8.2 Geological Structures

There are a number of geological structures located in the general area of the proposed mining, but only one is considered to be significant in the context of the proposed mining. The others are located away from the areas of mining and are not considered to have any significant potential to be affected by mining.

A significant benefit of the previous mining activity is that the dykes and faults through the area are very well defined by previous mining activity. It is not credible that there could be other major structures in the proposed longwall area because any such geological structures would be evident in the overlying seams. This certainty of location of geological features gives this site a significant advantage in terms of potential geological issues.

A dyke referred to as D8 crosses several of the longwall panels and passes close to several others. The dyke is continuous through to the surface and vertical. There is no experience of it being hydraulically conductive or in any way affecting the subsidence behaviour except in so far as the dyke has modified the mine layout which has itself altered the surface subsidence.

The Corrimal Fault is located to the south and east of the proposed longwall area and dips to the north. This structure tapers to the west and is not evident in the mine workings in the Bulli Seam above Longwall 6 proposed to be mined in the Wongawilli Seam. This type of tapering behaviour is typical of geological faults in the Southern Coalfield. The Corrimal Fault dips to the north. The fault is remote from Longwalls 4 and 5 and has tapered to less than 1m throw by the gateroads of the proposed Longwall 6. The Corrimal Fault is therefore not expected to have any significant influence on either height of fracturing, subsidence behaviour, or the hydraulic conductivity of the overburden strata.

Other faults such as the Rixons Pass Fault and Woonona Fault are remote from the area of mining and are not expected to be affected by mining.

8.3 Pillar Instability in the Bulli Seam

The potential for pillar instability in the Bulli Seam has been discussed above. There is certainly some potential in the vicinity of Longwall 1 and the particular area where this potential exists has been identified as needing special consideration. Other areas where there may be a similar potential are more difficult to identify because the mine records for the period of mining may be incomplete or inaccurate.

A large part of the Bulli Seam mine workings have been mined under by the Balgownie Seam longwall panels (1970-1982) and more recently by the Wongawilli Seam longwalls (2012-2013). The subsidence monitoring from both periods of mining indicate that there has been no evidence of any significant subsidence event associated with pillar instability although there are several areas where a low level of additional subsidence has been observed and this is additional subsidence is attributed to recovery of latent subsidence from earlier mining activity.

Even if such instability were to occur, the irregular nature of the panels that have been developed and their limited width mean that the surface subsidence that results is likely to be less than a few hundred millimetres and limited in size to within the area of the panel affected. Such a low level of additional subsidence is within the tolerance of the subsidence predictions that have been made and the impacts associated with any such subsidence would be within the range of predicted impacts.

The Mount Ousley Road is protected by a barrier of approximately 170m and the area adjacent to the Mount Ousley Road has already been mined under by the Balgownie Seam longwall panels so it is not credible that there could be marginally stable pillars in the Bulli Seam still standing in this area.

Some of the towers on the power transmission lines are planned to be subsided up to several metres and the additional subsidence that may result from pillar instability in the Bulli Seam is not considered to have potential to cause any significant additional impacts compared to those that are already planned for.

Although the potential for pillar instability in the Bulli Seam is possible, the significance of any surface subsidence that may result is considered to be low, especially in terms of impacts to major surface infrastructure. Major infrastructure will need to be protected from expected subsidence. The increment of additional subsidence due to pillar stability is not expected to have any significant incremental impact on this infrastructure.

8.4 Valley Closure, Upsidence and Far-Field Movements

The prediction of valley closure, upsidence, and far-field movements is recognised as not being an exact science even for single seam mining. Nevertheless some characteristics are recognised. The influence of horizontal stresses as a source of energy to displace rock strata is dependent on their magnitude. Near to the Illawarra Escarpment and adjacent to previous mining activity as this site is, the in situ horizontal stresses are likely to be significantly diminished both as a result of the free surface of the escarpment and as a result of previous mining activity.

Nevertheless, SCT understands that a far-field subsidence monitoring survey network has been installed and is planned to be further upgraded to allow measurement of any such movements. These movements are unlikely to be significant in the context of any of the infrastructure located in the vicinity of the proposed mining area.

The predictions of valley closure and upsidence are recognised as being upper bound predictions because they are based on experience in deep gorges where the in situ stresses are much higher than they are at this site. A program of predicting, monitoring and response (limiting the length of longwall panels) is considered to be an effective method of managing this uncertainty. The monitoring available from the Balgownie Seam longwall panels and from Longwall 5 indicates that this method is likely to be effective in terms of managing impact on Cataract Creek.

The offsets that have been designed into the revised mine layout and the avoidance of mining directly under the main channel of Cataract Creek provide a buffer against closure related impacts. The commitment by WC to stop the longwalls short if closure movements become excessive provides an additional level of management control.

8.5 Illawarra Escarpment

There is considered to be no potential for the proposed mining to impact on the Illawarra Escarpment and in particular the section of Hawkesbury Sandstone outcrop at Brokers Nose. It should be recognised that there is always potential for cliff falls to occur naturally as part of the natural erosion processes of cliffs. Two such natural events have occurred in the last six years, one on Mount Keira in 2007 and a second at Clifton in 2013.

The only recognised mechanism for the cliff formations on the Illawarra Escarpment at Brokers Nose to be impacted by mining would be for horizontal stress concentrations to occur along the line of the escarpment. However, the cliffs associated with Brokers Nose are 900-1000m from Longwall 1 and are therefore too far away from the proposed longwall panels for there to be any potential for significant horizontal stress concentrations between the longwall panels and the escarpment.

8.6 Subsidence Management Methods

In the submissions there has been some discussion over the accuracy of the surveying and the adaptive management approach proposed by WC.

The subsidence monitoring systems being used at Russell Vale Colliery are undergoing continued upgrading from two dimensional surveying techniques used during the initial stages of mining Longwall 4 through to full three dimensional subsidence monitoring with a far-field GPS survey control network. The monitoring network used for Longwall 5 is considered to be an intermediate step. Additional monitoring and further upgrading of the monitoring is proposed in this report.

Adaptive management strategies are being practiced by WC including the significant revision to the mine layout represented by the PPR. Closure monitoring across Cataract Creek is planned to be used for Longwalls 6 and 7.

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