Appendix C

Subsidence Specialist Reports

Strata Control Technology

REPORT TO:

GUJARAT NRE COKING COAL LIMITED

Subsidence Assessment for Gujarat NRE Preferred Project Russell Vale No 1 Colliery

NRE14123

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REPORT TO	David Clarkson Group Environment & Approvals Manager Gujarat NRE Coking Coal Limited PO Box 281 FAIRY MEADOW NSW 2519
SUBJECT	Subsidence Assessment for Gujarat NRE Preferred Project Russell Vale No 1 Colliery
REPORT NO	NRE14123
PREPARED BY	Ken Mills
DATE	24 September 2013

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Principal Geotechnical Engineer

SUMMARY

Gujarat NRE Coking Coal Limited (NRE) is proposing to mine eight additional longwall panels in an area referred to as the Wonga East mining area approximately 9km north-north-west of Wollongong in New South Wales. After consideration of submissions from the community and government agencies to its earlier Underground Expansion Project Part 3A (Pt3A) application, NRE has significantly modified the application in a proposal referred to as the Preferred Project Report (PPR). NRE commissioned SCT Operations Pty Ltd (SCT) to estimate the subsidence likely to be associated with mining the proposed longwall panels and to assess the subsidence impacts for the PPR recognising the influence of previous mining in the area. This report presents the results of our assessment.

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. 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. 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 surface 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 (2003).

The approach to predicting subsidence movements 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 essentially predictable albeit with somewhat different characteristics to subsidence over single seam mining operations. The subsidence behaviour in a multi-seam environment is different in respect of the overburden stiffness characteristics and therefore the bridging capacity across individual panels, but is otherwise essentially similar to the subsidence behaviour 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 goaf in both seams. Previous mining in the Bulli and Balgownie Seams is estimated to have caused up to 1.9m of subsidence.

There is considered to be some potential for pillar instability in the Bulli Seam to cause additional surface subsidence when the proposed longwall panels are mined in the Wongawilli Seam, but the area likely to be affected at the northern end of Longwall 1 is not expected to cause significant surface subsidence or significantly greater surface impacts.

Maximum tilts over individual longwall panels in the Wongawilli Seam are expected to range from peaks of 24mm/m over Longwall 10 through to peaks of 51mm/m above Longwall 3. The peak values predicted are expected to be the maximum anywhere in the panel, most likely at goaf 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 peak values.

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

The predicted closure across Cataract Creek ranges up to 400mm adjacent to the ends of Longwalls 6 and 7 and up to 210mm at the end of Longwall 5. These closure estimates are recognised as being upper limit values because they are based on experience in deep gorges at high stress levels. Monitoring so far indicates closure movements that are much less than the predicted maxima consistent with the local site conditions.

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 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)	Compressive Strain for PPR Wongawilli Seam (mm/m) and	Maximum Closure on Cataract Creek (mm) (Southern Tributary in
Longwall 1	1.3	2.1	40	12	24	N/A (650)
Longwall 2	1.1	2.1	40	12	24	N/A (610)
Longwall 3	1.3	2.6	51	15	31	N/A (350)
Longwall 4	1.9	2.1 (**1.6**)	35 (**30**)	10.5 (**7.5**)	21 (**14**)	N/A
Longwall 5	0.9	1.9 (**1.5***)	36 (**16***)	10.8 (**4.5***)	22 (**14***)	210 (**20***)
Longwall 6	1.5	2.1	38	11	23	400
Longwall 7	1.2	1.5	28	8	17	400
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

(*mining still in progress)

Movement outside the goaf edge are expected to be essentially 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 be up to 300-500mm and the goaf edge subsidence profile is expected to be general softer 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.

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, and sandstone cliffs including the Illawarra Escarpment, 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 mining 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 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.

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.

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 and none are considered to be significant based on the assessment criteria presented in PAC (2010). 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.

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 30mm of this maximum having already occurred from mining Longwall 4. These low level vertical movements are expected to be imperceptible for all practical purposes although tensile cracking adjacent to the topographic high ground south of Cataract Creek and closure of up to a maximum of 125mm of closure predicted using the ACARP Method is expected at Cataract Creek. There is considered to be no potential for significant horizontal movements to impact the Picton Road Interchange.

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.

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 also a number of small pre-existing Bulli Seam goaf areas that are located within the 0.7 times depth protection zone around the FSL. It is considered unlikely that the proposed mining will interact with these pre-existing goaf areas and currently there does not appear to be any connection between the reservoir and the mining horizon. Nevertheless, the presence of these goafs reduces the effectiveness of the 0.7 times depth barrier between the FSL and the proposed mining, particularly for mining of Longwalls 7 and 9.

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.

Ongoing management and review by a technical committee of subsidence impacts to Mount Ousley Road using the same approach as for Longwalls 4 and 5 is considered suitable to manage the potential for any future impacts. 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.

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 them to remain structurally stable during mining. There is usually a significant lead time involved in getting cruciforms approved, financed, designed, and constructed.

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 considered to be 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 localised existing extraction in the Bulli Seam.

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'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, and can be ongoing.

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 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.

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 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 processes involved.

There are a number of geological structures located in the general area of the proposed mining, but only two are 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 accepted 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 are incomplete and may be inaccurate but the significance of any surface subsidence that may result is considered to be low, especially in terms of impacts to major surface infrastructure.

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 NRE'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 natural erosion processes of cliffs. .

The subsidence monitoring systems being used at NRE 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 NRE. 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. Further monitoring is also expected to provide greater understanding of the processes involved and guide future design.

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1. INTRODUCTION

Gujarat NRE Coking Coal Limited (NRE) is proposing to mine eight additional longwall panels in an area referred to as the Wonga East mining area approximately 9km north-north-west of Wollongong in New South Wales. After consideration of submissions from the community and government agencies to its earlier Underground Expansion Project Part 3A (Pt3A) application, NRE has significantly modified the application in a proposal referred to as the Preferred Project Report (PPR). NRE commissioned SCT Operations Pty Ltd (SCT) to estimate the subsidence likely to be associated with mining the proposed longwall panels and to assess the subsidence impacts for the PPR recognising the influence of previous mining in the area. This report presents the results of our assessment.

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.

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 Interferometry 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 Southern Coalfields Inquiry. The longwall panels discussed in this report and shown in Figure 1 include Longwall 4 in the Wongawilli Seam which has already been mined and Longwall 5 which has been substantially 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

NRE No. 1 Colliery is located at Russell Vale, to the west of Bellambi, in the Illawarra region of New South Wales (NSW). NRE purchased the Colliery in December 2004, but 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.

The colliery holding includes a number of sub leases between NRE 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 establishment 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.

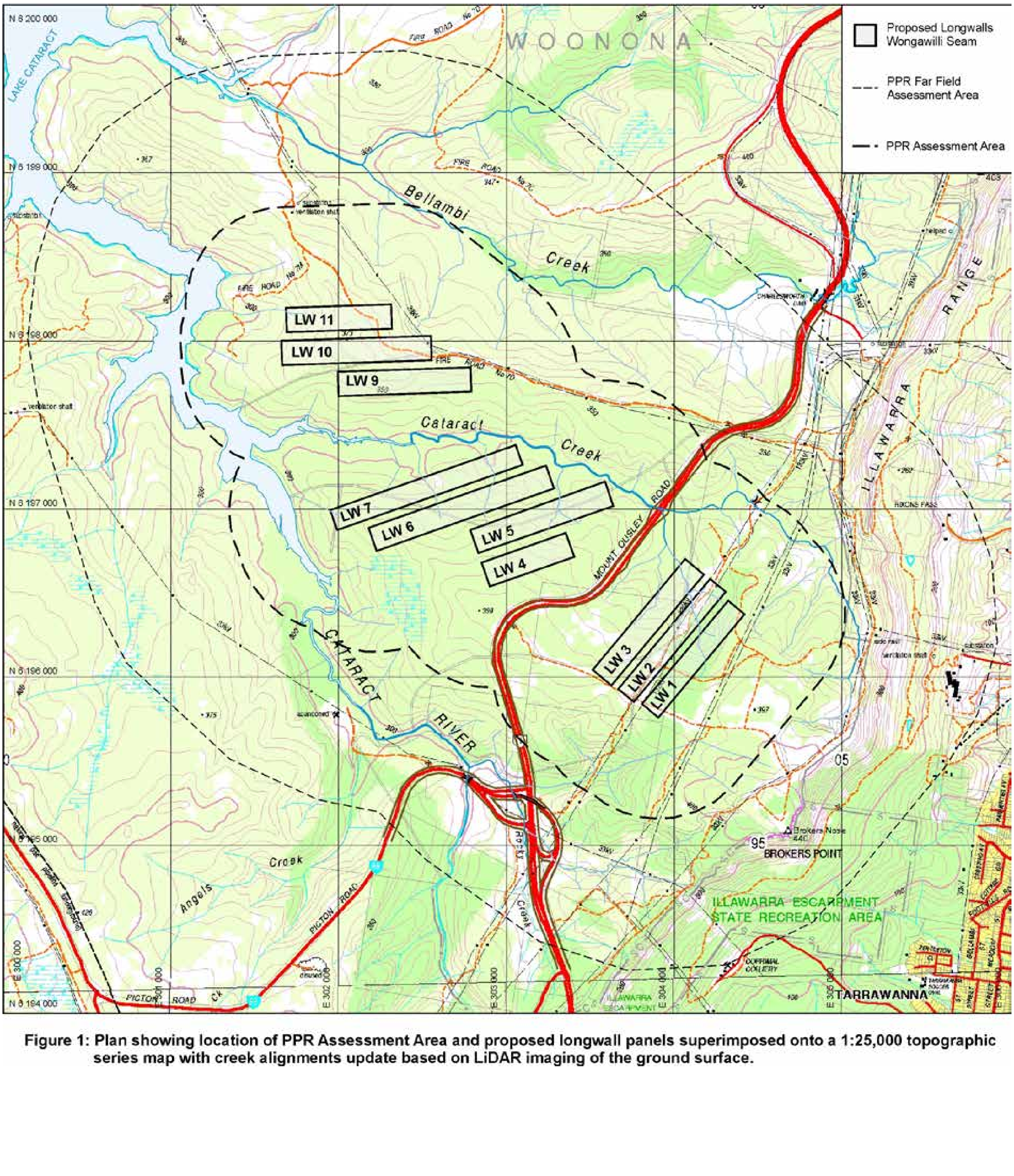


Figure 1: Plan showing location of PPR Assessment Area and proposed longwall panels superimposed onto a 1:25,000 topographic series map with creek alignments update based on LiDAR imaging of the ground surface.

As a result of the submissions received on the application, NRE has 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, 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:
    - 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.
    - Avoiding mining directly under the third and fourth order sections of Cataract Creek.
    - 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.
    - 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.

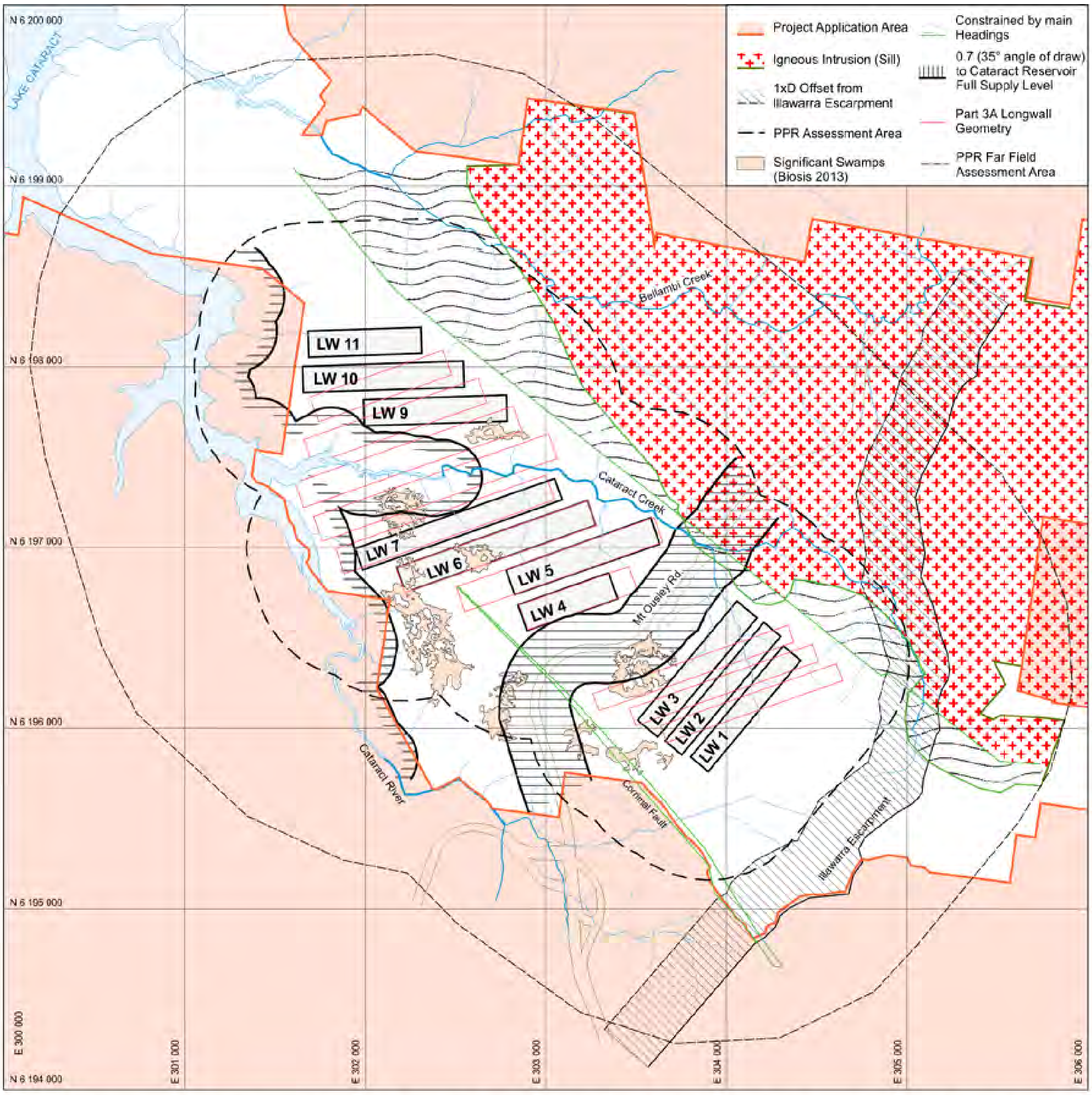


Figure 2: Plan showing the design constraints (lease, geological, mining, and surface protection) as the basis for the PPR mine layout design.

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 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 which has already been mined and Longwall 5 which is currently in the process of being mined are included in the assessment area and this subsidence assessment because:

- Although they have been 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.

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 NRE. 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).

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.

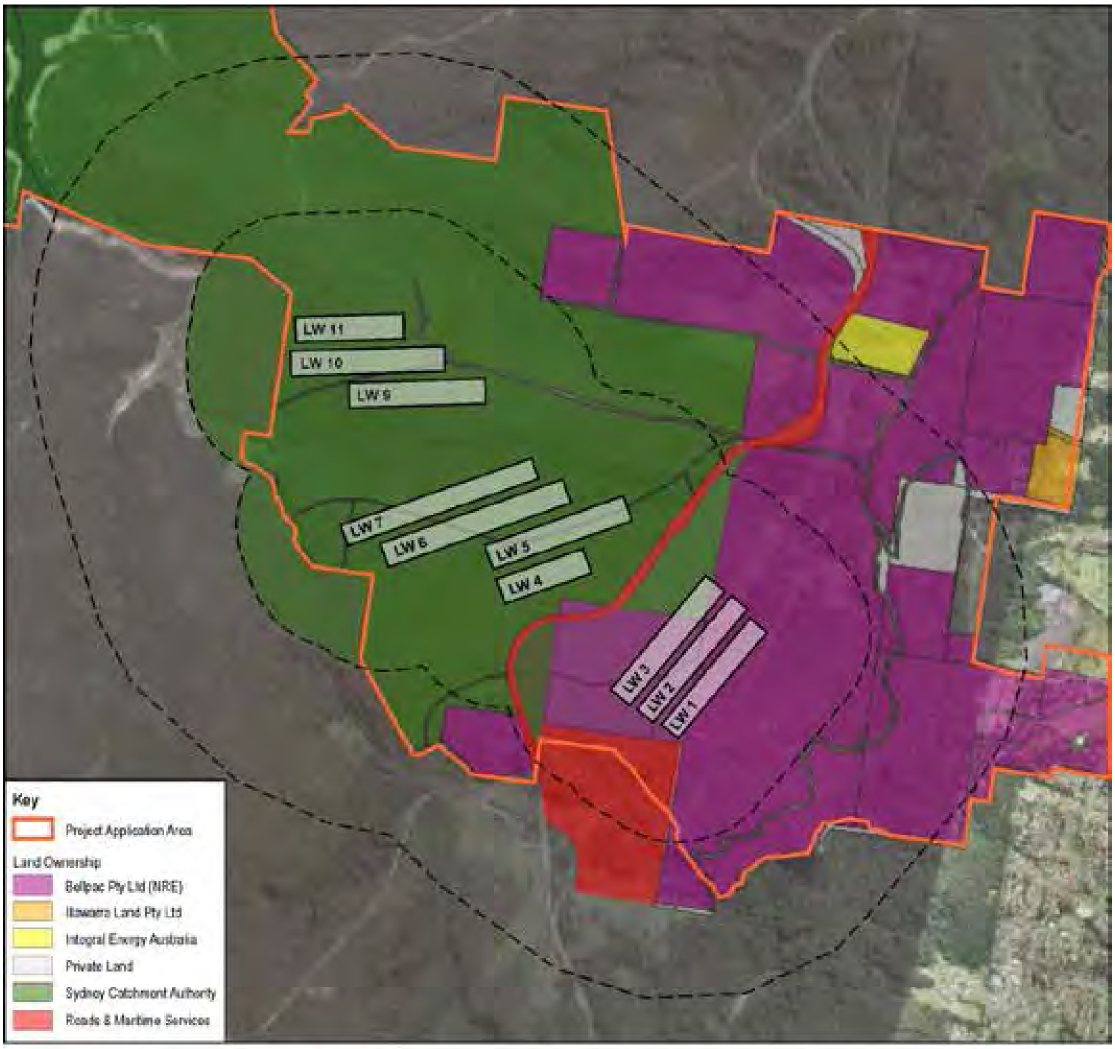


Figure 3: Plan showing land ownership within PPR Application Area. (Diagram modified from Figure 1.5 of EA from Environmental Resources Management Drawing Number 0079383s_EA_GIS013_RO.mxd dated 22/9/10)

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 Notification Area (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 within the Assessment Area but all except for a few isolated sections are less than 5m high and none are considered to be significant using the significance criteria developed by the Planning Assessment Commission (PAC) in 2010 for the Bulli Seam Operations PAC Report (PAC 2010).

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 dips 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

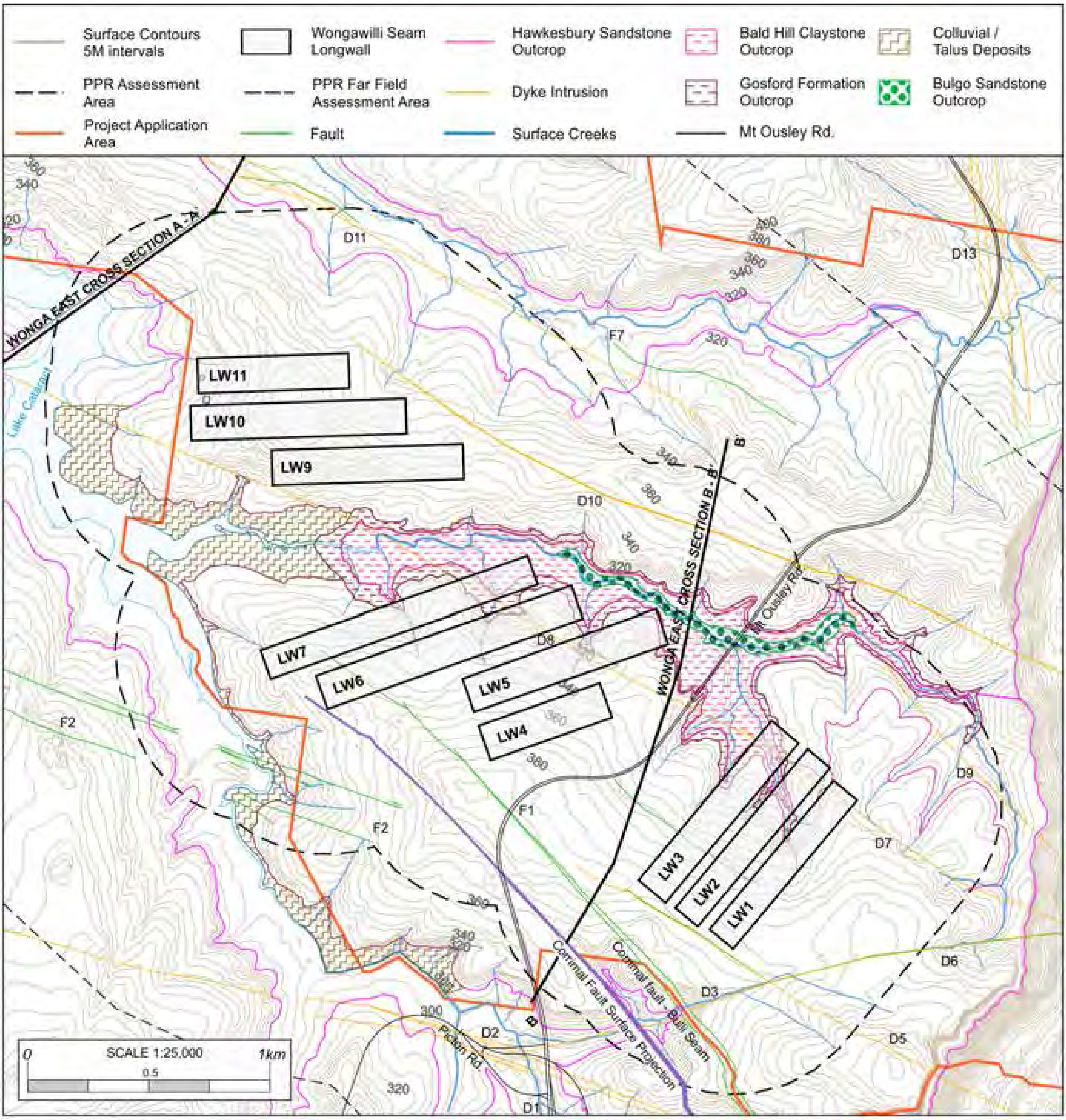


Figure 4: Plan showing geological outcrop at the surface and the location of major geological structures. (reproduced from Figure 11 of Clark 2013)

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. 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 roof strata.

The Wongawilli Seam is located approximately 20m below the Balgownie Seam and ranges in thickness from 7.7m to 11.9m, but only the lower 2.6-2.8m is economic to mine and this section is planned to be targeted by proposed mining. 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 80mAHD at the north eastern corner of Longwall 1 and an elevation of approximately -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.

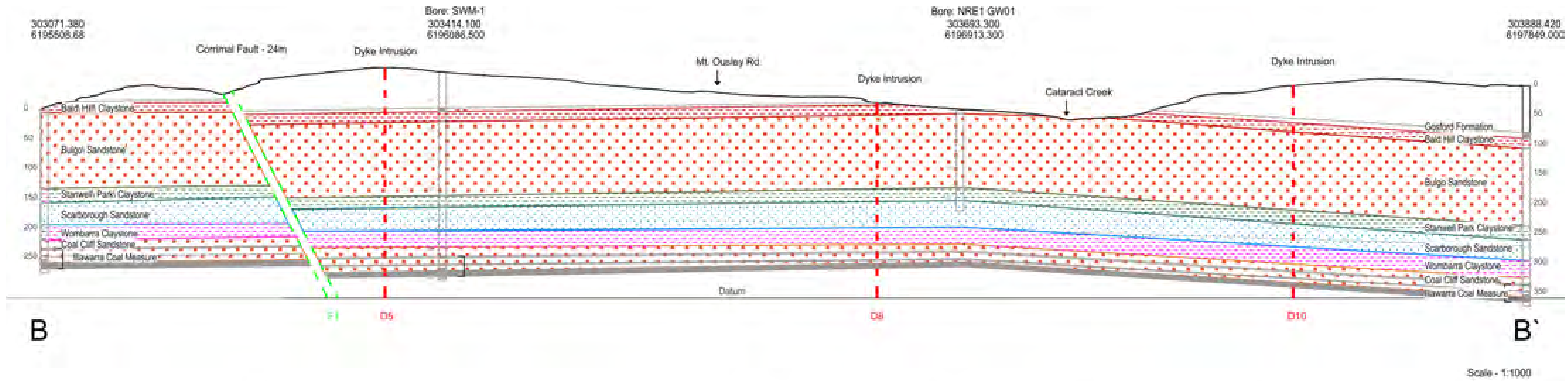


Figure 5: South-North geological section through PPR Application Area in the vicinity of Mount Ousley Road. (reproduced from Figure 12 of Clark 2013) ***Note: vertical scale is the same as the horizontal scale.***

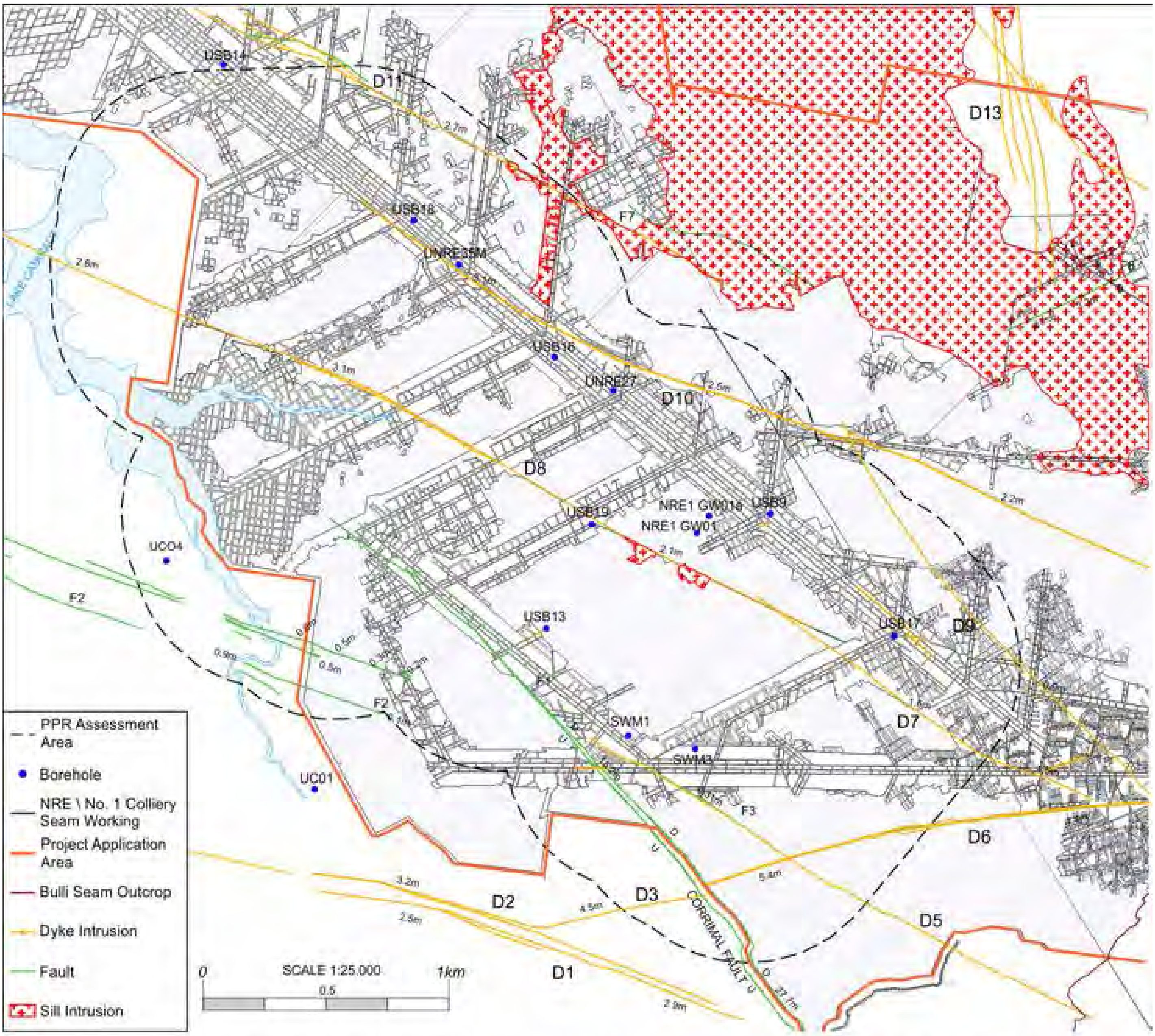


Figure 6: Plan showing geological structures and the extent of mining in the Bulli Seam level. (reproduced from Figure 14 of Clark 2013)

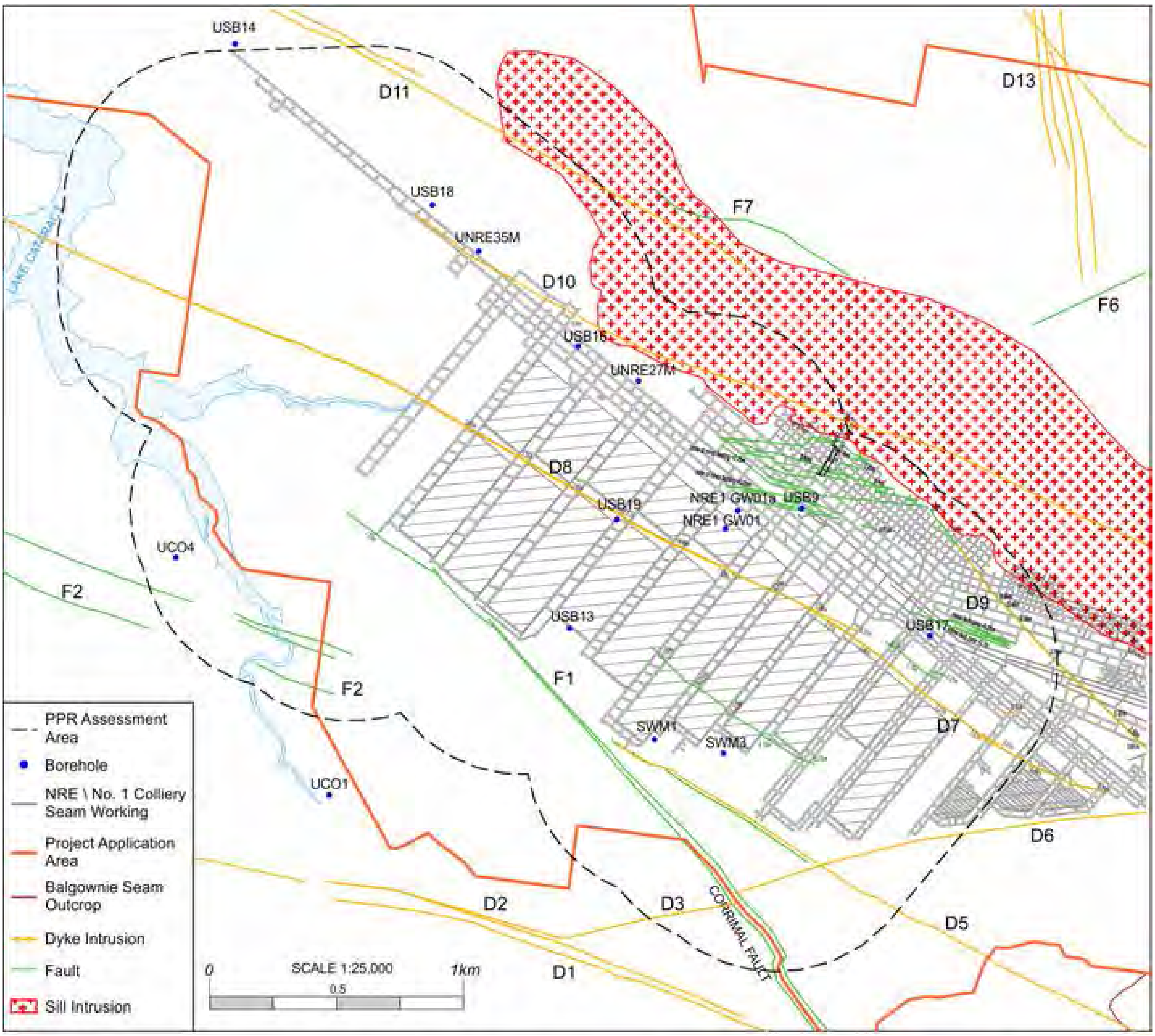


Figure 7: Plan showing geological structures and the extent of mining in the Balgownie Seam level. (reproduced from Figure 15 of Clark 2013)

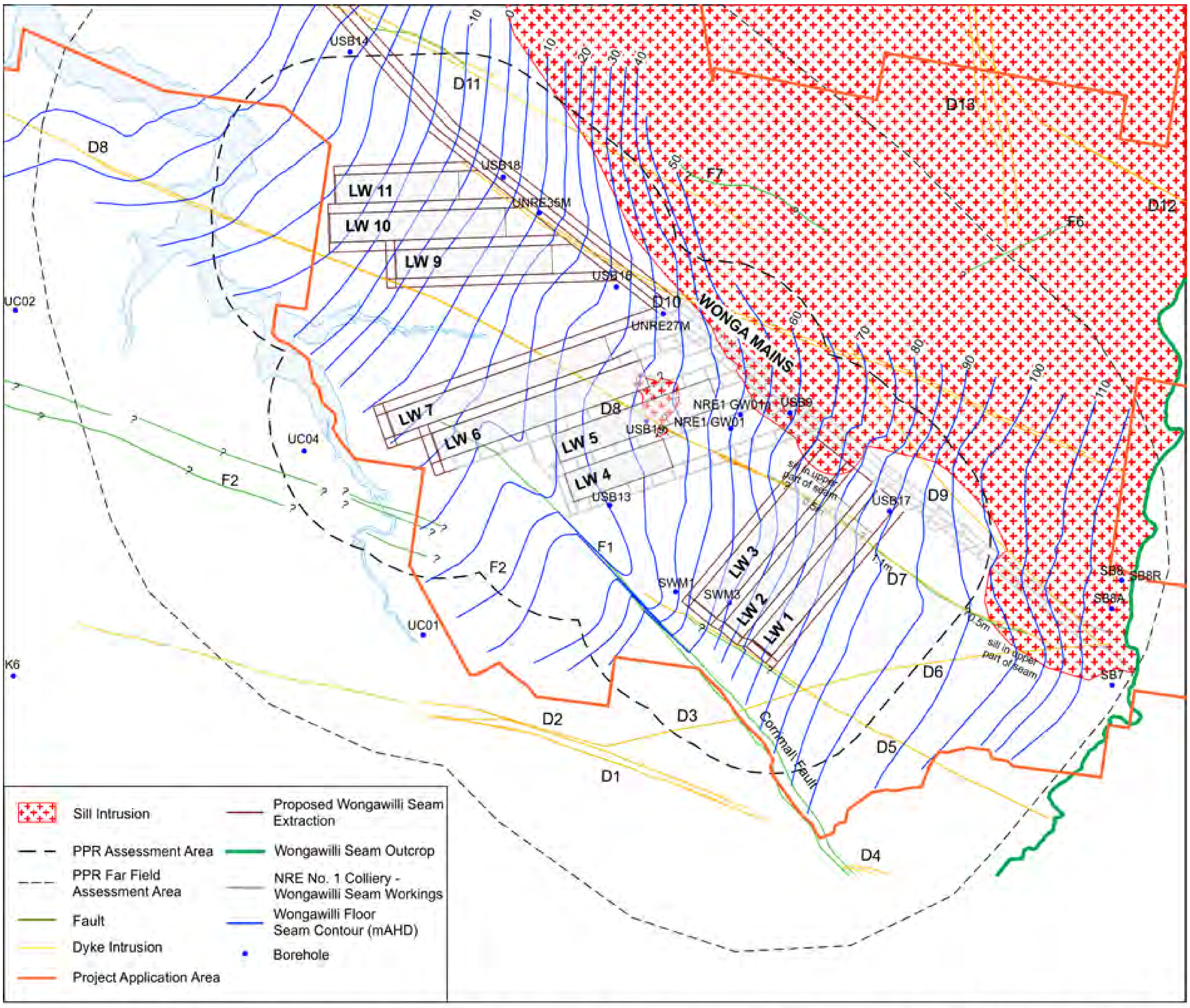


Figure 8: Plan showing geological structures in the Wongawilli Seam (reproduced from Figure 17 of Clark 2013) and floor contours of the Wongawilli Seam based on floor contours in the Bulli Seam.

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 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 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 where it is to be intersected by the gateroads for Longwall 6.

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.

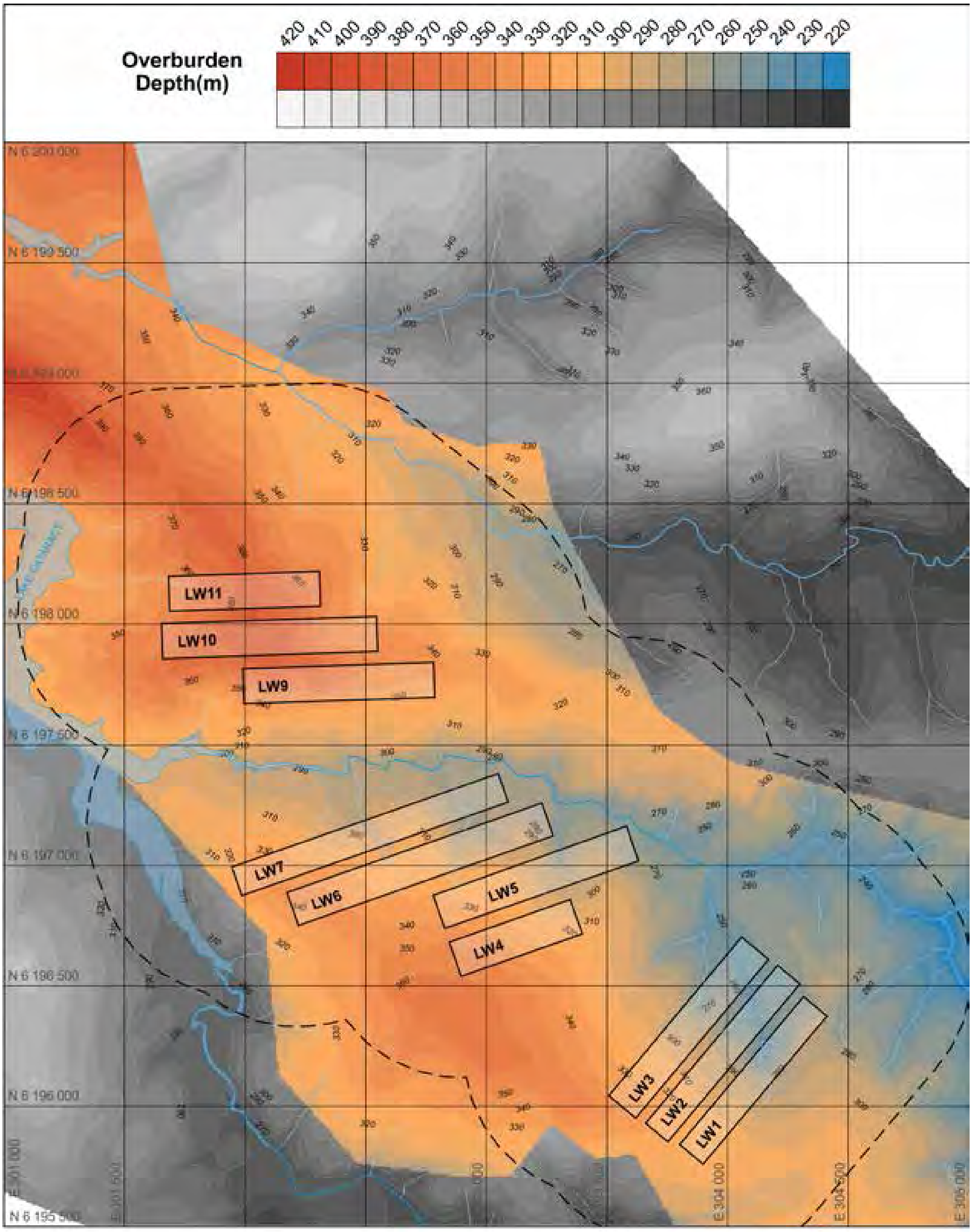


Figure 10: Depth of Overburden to the Wongawilli Seam.

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 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 essentially 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 essentially similar in nature to the impacts that have already occurred.

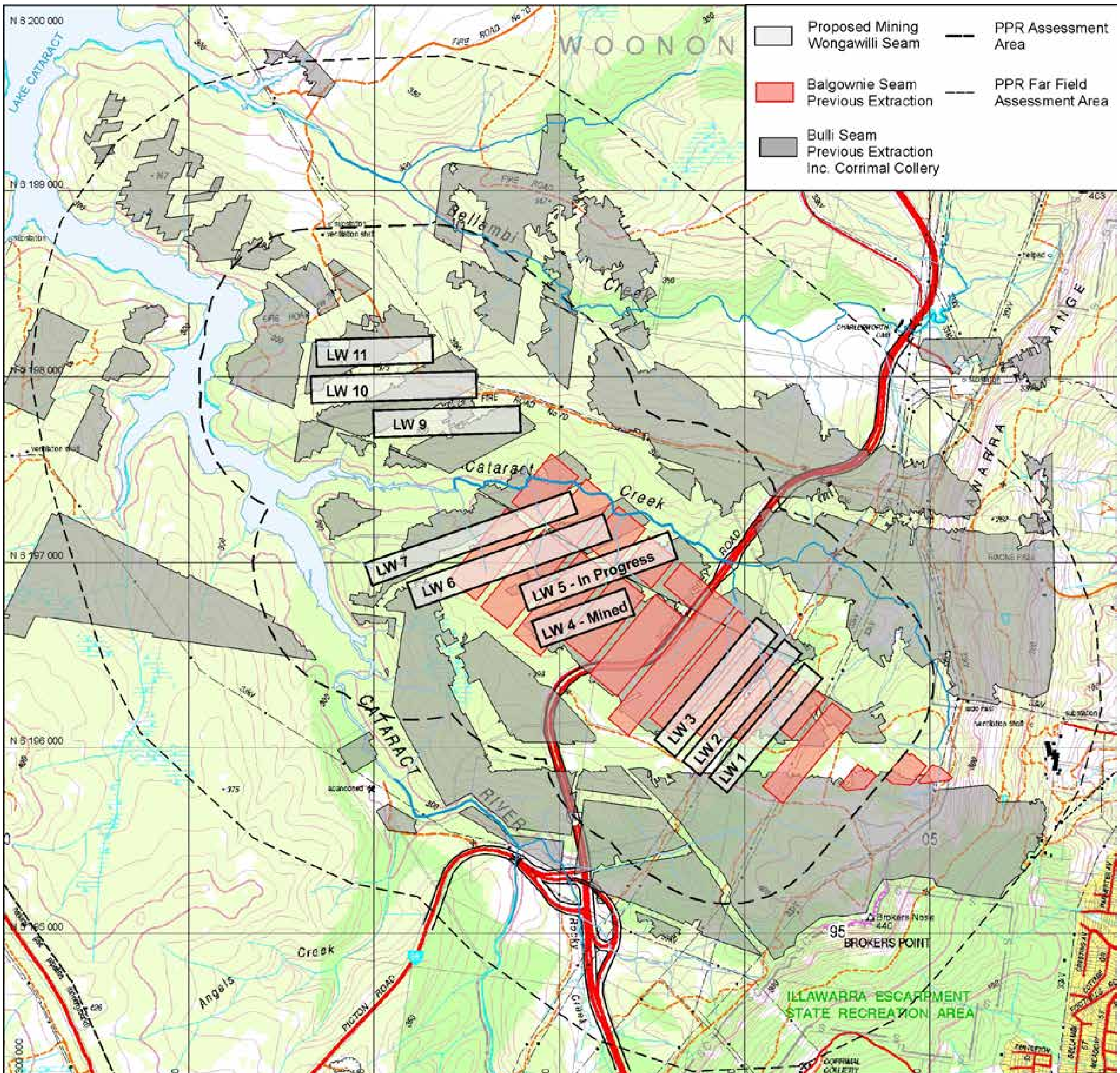


Figure 11: Plan showing extent of previous extraction in Bulli Seam (black) and Balgownie Seam (red) in the PPR Application Area.

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 detailed subsidence records 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 in the areas where subsidence is likely to have occurred as a result of the 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.

A 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.

The detail of the Bulli Seam extraction is lost in some places where large areas have simply been shaded (cross-hatched) in to represent the end of mining there. 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

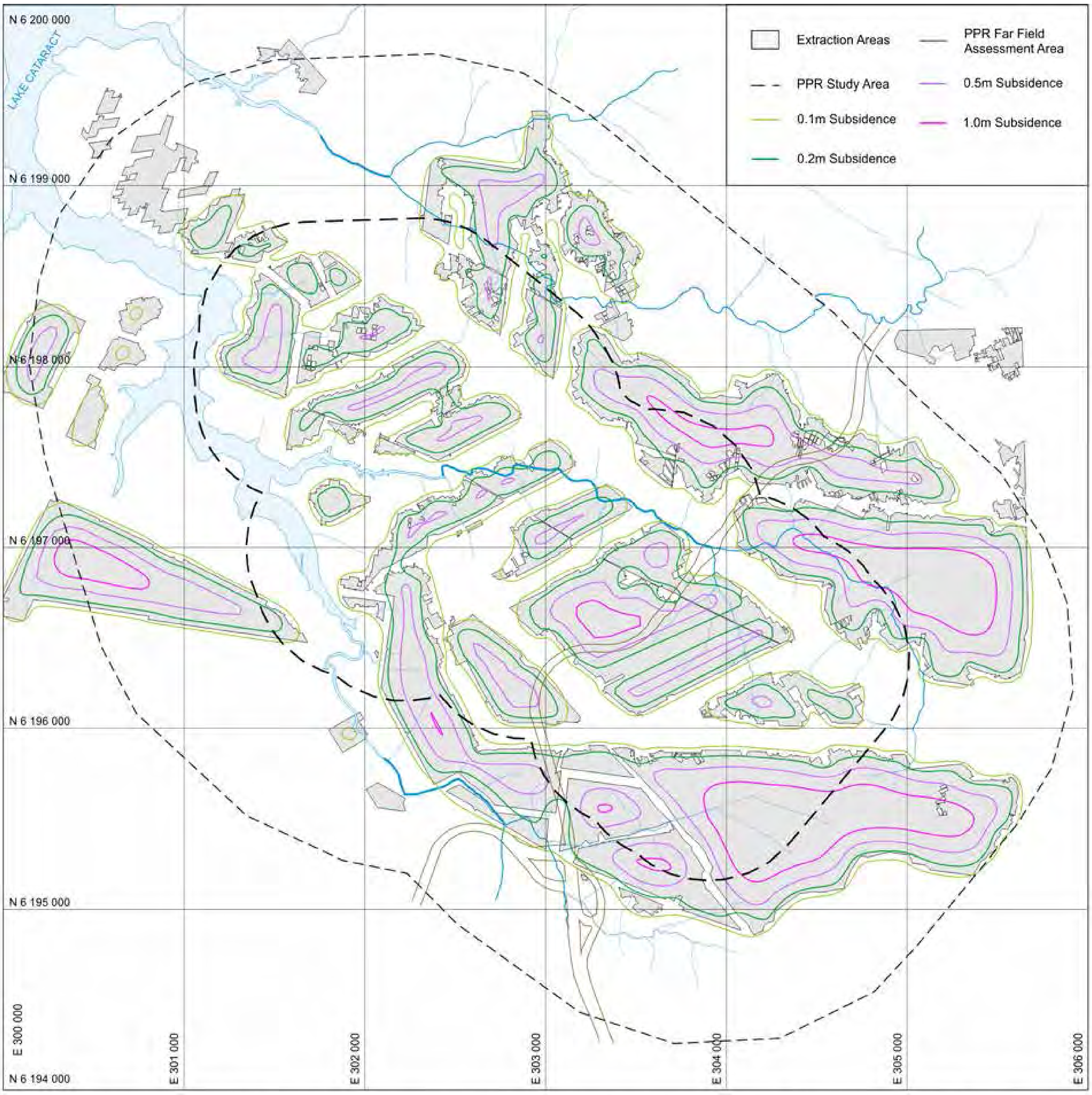


Figure 12: Plan showing estimated subsidence movements likely to have been associated with pillar extraction operations in the Bulli Seam.

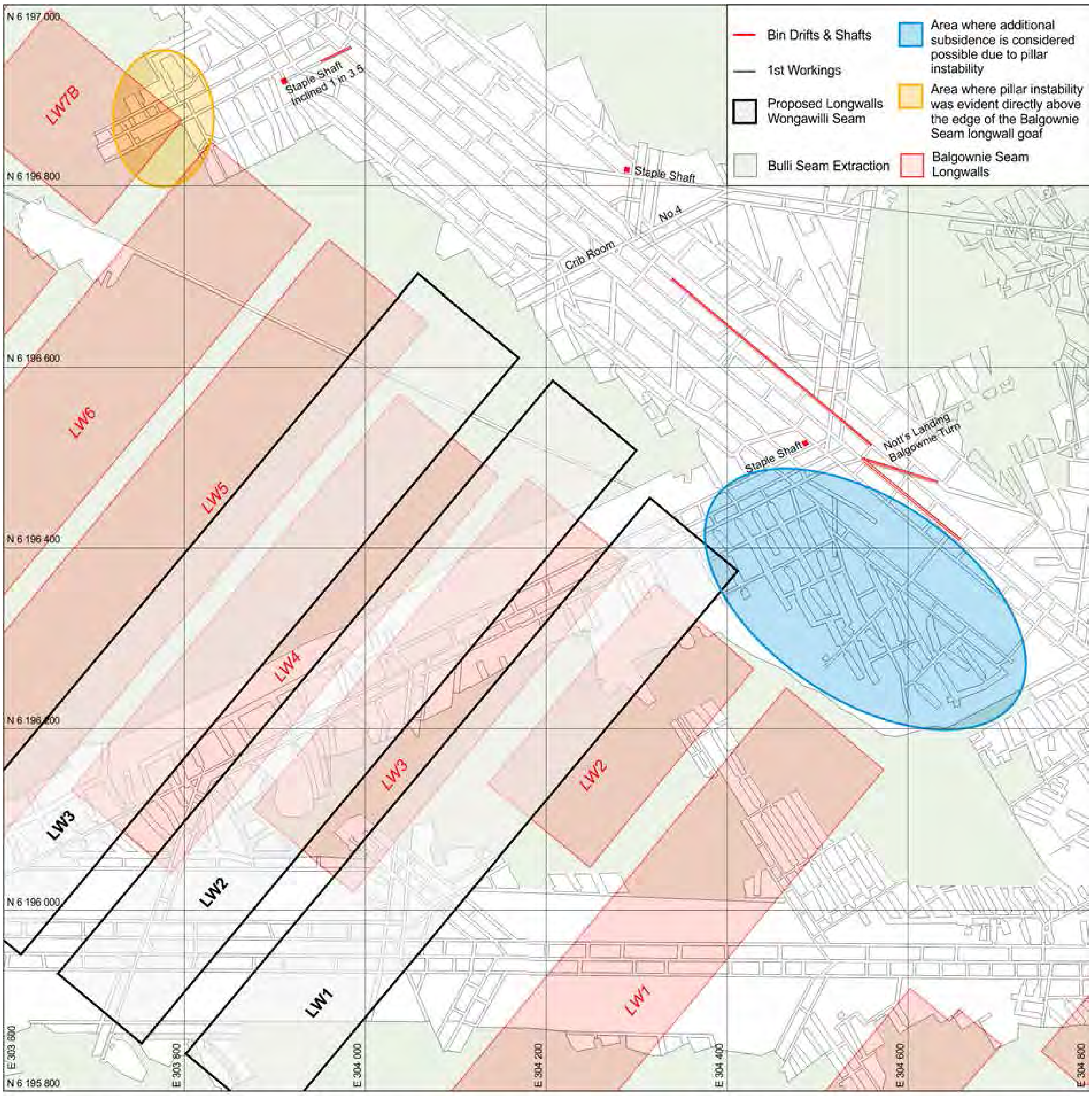


Figure 13: Plan showing areas of pillar instability in overlaying Bulli seam caused or possibly caused by mining in seams below.

the Balgownie Seam longwall panels are considered to have almost certainly 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 has been 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 – 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.

However, the term “pillar run” may also be used to describe the phenomenon of elastic stress redistribution and the relatively smaller ground movements that can be associated with this redistribution. 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 not usually 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 stable 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 Mount Ousley Road 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.

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 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 (0.2m relative to the chain pillar subsidence) in areas where the panels are narrower compared to (0.5m above the wide panels).
- The sag subsidence is much less in areas where there are Bulli Seam main heading pillars.
- The subsidence is greatest (1.42m) over Longwall 10 in an area on the fringe of Bulli Seam goaf where full subsidence was prevented during mining of the Bulli Seam by the presence of solid abutment coal or marginally stable pillars were destabilised.
- Surface subsidence is occurred essentially within the geometry of the 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 and the subsidence beyond the goaf edge is not significantly different to goaf edge subsidence that would be expected in a single seam operation.

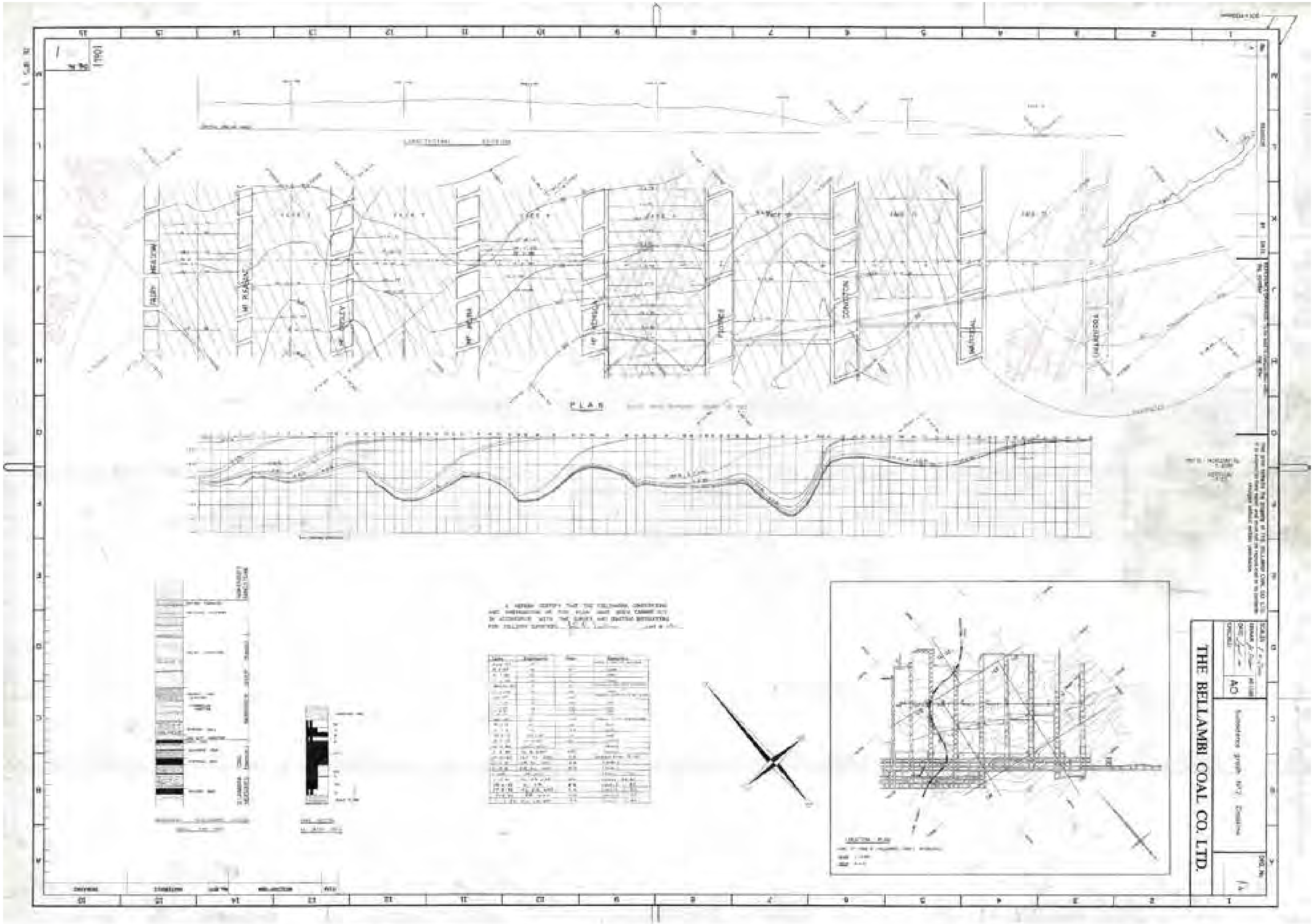


Figure 14: Example of subsidence monitoring of Balgownie Seam longwall panels

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 differentiated as shown in Table 2 based on where there are pillars and goaf in the two seams.

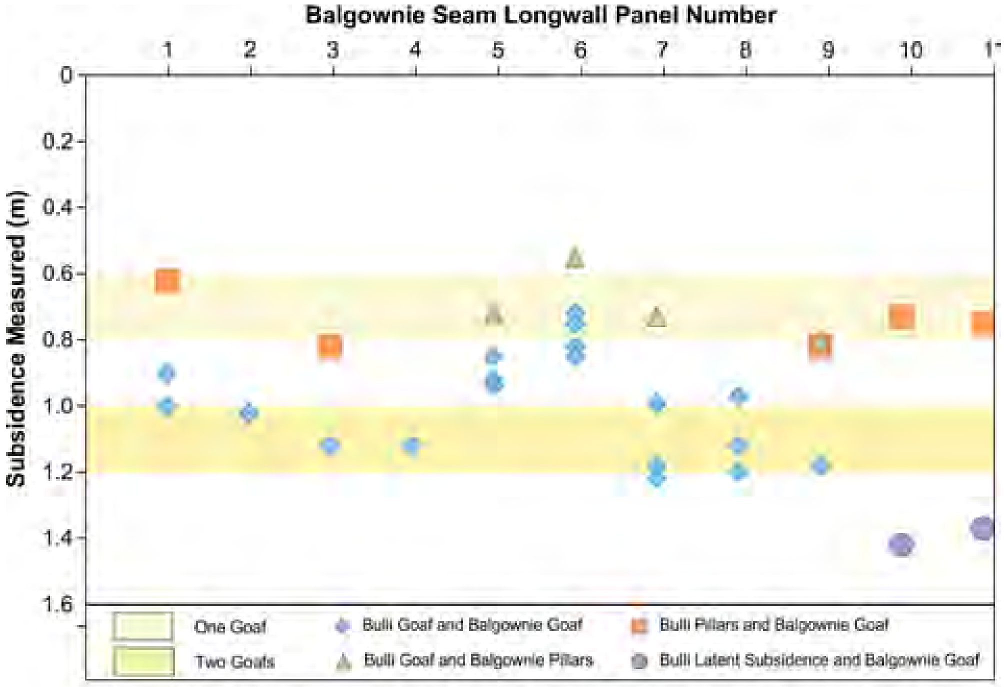


Figure 15: Maximum subsidence observed for each longwall panel in the Balgownie Seam.

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. If there are pillars in one seam and extraction in the other seam, there is between 0.6m and 0.8m of subsidence. 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 in the high subsidence zone over 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 above Longwall 10), the incremental subsidence reaches 1.4m and is of the order of 100% of the mining height of the second seam mined.

It is also possible that the 1.4m of subsidence observed is a result of pillar destabilisation of standing pillars in the Bulli Seam caused by mining in the Balgownie Seam. Up to 0.4m of subsidence would be expected from mining below pillars in the Bulli Seam plus additional subsidence in the Bulli Seam of about 50% of the 2.2m mining height given an extraction ratio of about 50%. The total subsidence would therefore be about 1.5m.

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 at this location of 260m, 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} = 1500-2500 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 peak tensile strains tend to be apparent at the start of panels in ground sloping in the same direction as mining, and along topographic high points such as ridges.

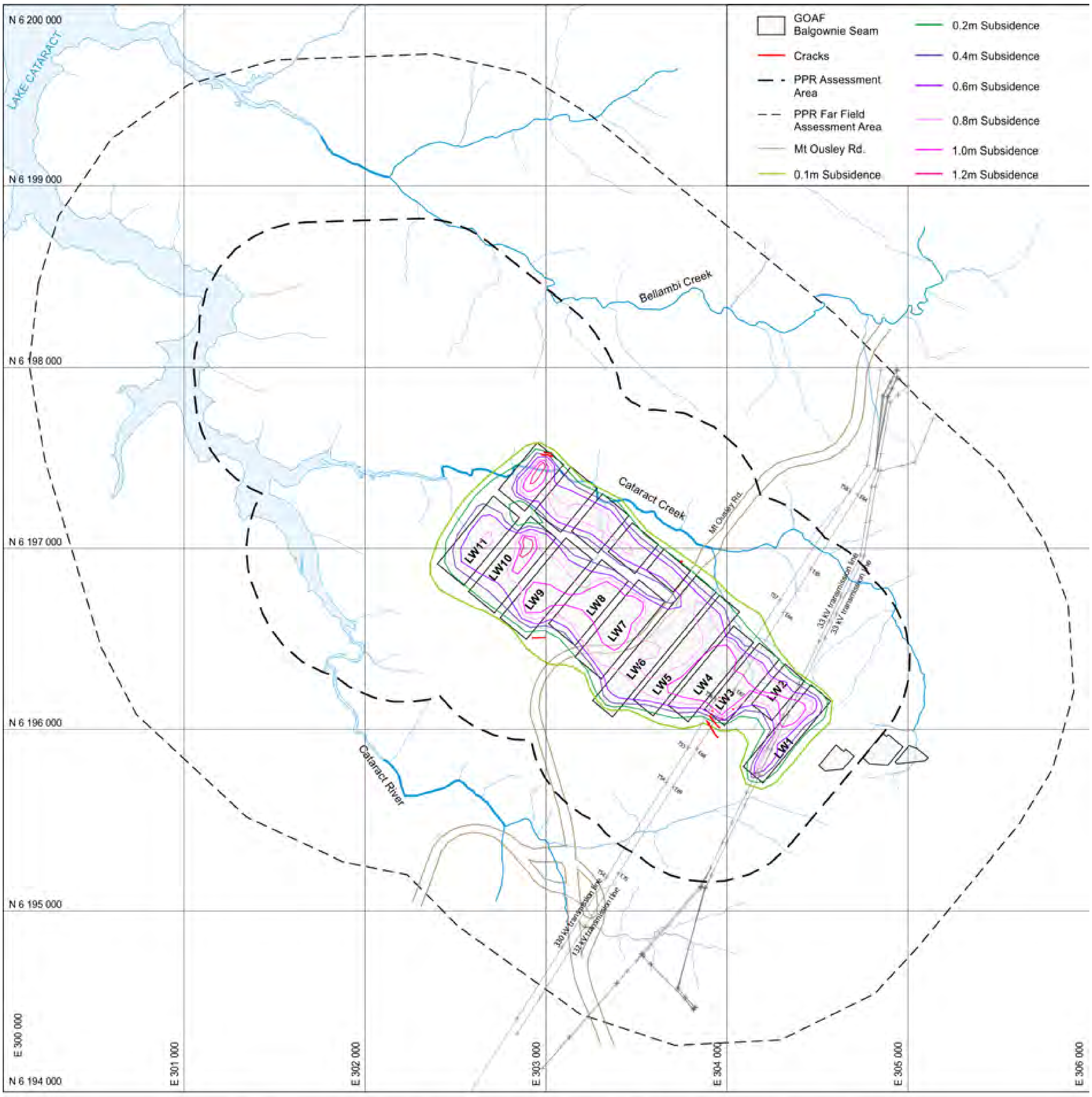


Figure 16: Contours of subsidence measured above the Balgownie Seam longwall panels.

Table 3: Comparison of Measured and Calculated Upsidence

Balgownie Longwall Panel	Distance from End of Panel (m) (negative over goaf)	Upsidence Indicated (mm) (not necessarily peak)	Overburden Depth (m)	Maximum Subsidence (m)	Calculated Upsidence (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 as measured between pegs spaced 18m apart and the 4mm/m strain measured between the next two pegs spaced 15m apart imply a total closure across the creek of about 310mm. The ACARP method for estimating valley closure by Waddington and Kay (2003) indicates valley closure for this geometry and level of subsidence as being of the order of 200-300mm depending on assumptions about the somewhat irregular geometry associated with the short longwall panels.

Valley closure at other locations is also evident as upsidence in the subsidence profiles that extend across Cataract Creek. The upsidence measured is summarised in Table 3.

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 100-300mm 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 that upsidence from the Balgownie Seam longwall panels would have been in the range 70-130mm for each longwall panel. 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 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.

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 reported on subsidence plans during 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 appears to be associated with subsidence cracking. The

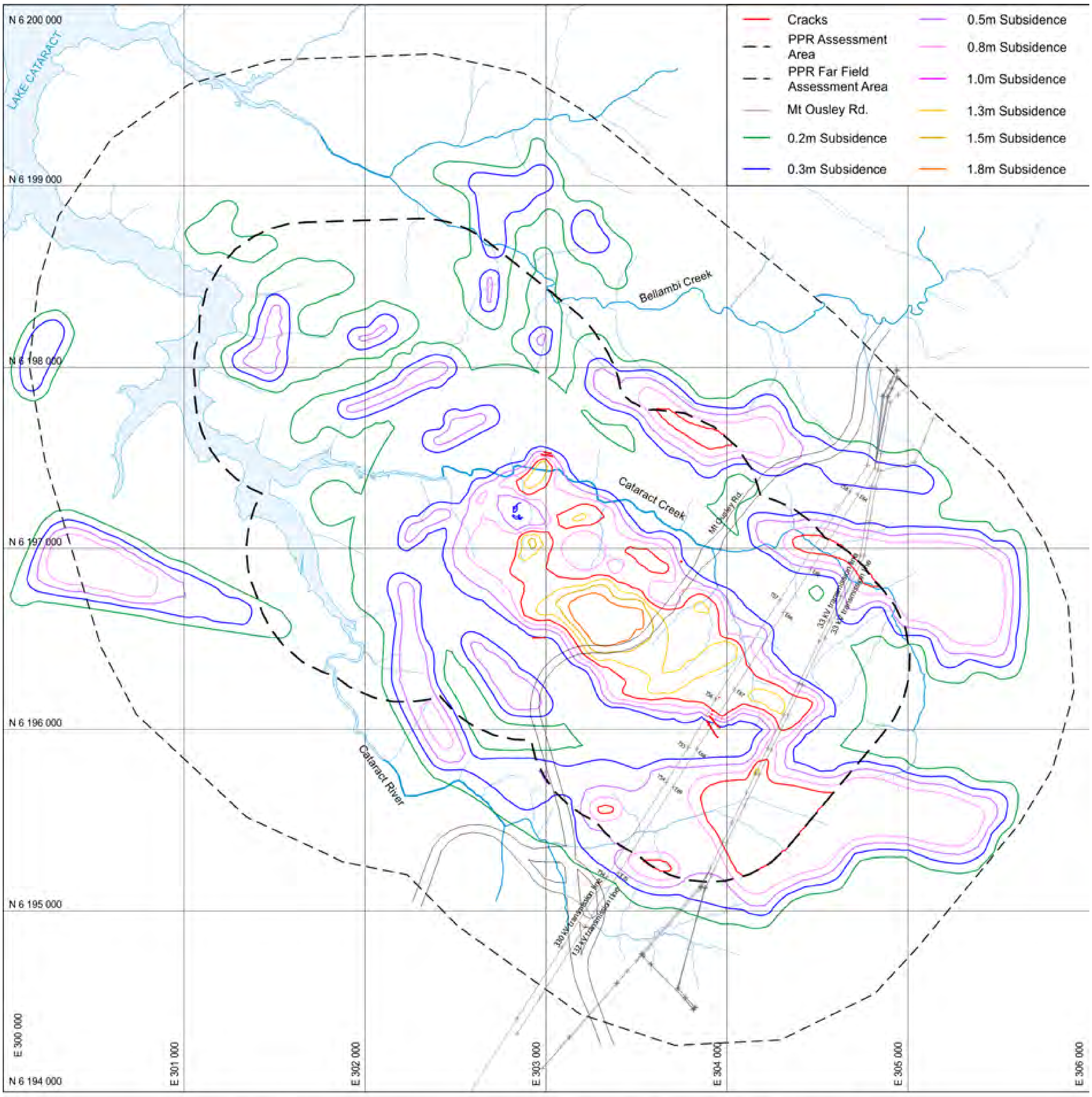


Figure 17: Contours of cumulative subsidence for the Bulli Seam and the Balgownie Seam.

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 Longwalls 4 and 5. The implication of these measurements is that the crack occurred during previous mining but was disguised below the soil and had been substantially infilled by soil material over the period since it formed.

3.3.2 Rock Falls

An inspection of cliff formations across the PPR Assessment Area conducted during the subsidence assessment program indicates 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 length of cliff formation located above Longwall 9 that includes 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 Cataract Creek

Subsidence monitoring above Longwall 11 in the Balgownie Seam indicates that Cataract Creek was subsided by greater 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 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.

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. The Cataract deviation was opened in 1980. Bulli Seam mining was complete in the 1950's and mining in the Balgownie Seam in 1979 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 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 Seam 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. Longwall 4 is a 150m wide panel that was extracted between 21 April and 21 September 2012 and Longwall 5 is a 150m wide panel that commenced on 15 January 2013 and was still continuing at the time of writing this report. 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 essentially 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 elastic strata compression subsidence, is the subsidence that results from elastic compression of the chain pillar between panels and the rock strata above and below the chain pillar. The total elastic strata compression is seen on the surface as subsidence. The compression of coal in the chain pillar contributes a relatively small proportion of the total elastic compression. The rock strata above and below contributes almost all of the elastic compression subsidence. Elastic 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. Elastic strata compression subsidence is function of the compression of the strata between panels and is essentially 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, one short line, M Line, located across the chain pillar to measure elastic chain pillar compression.

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 mined approximately 525m (on 14 June 2013) centreline subsidence ranged from 1.3-1.5m and the centreline subsidence on Longwall 4 had increased to 1.6m consistent with elastic strata compression at the intermediate chain pillar. Subsidence monitoring on M Line indicated that the total elastic chain pillar compression was approximately 0.6m based on superposition of the subsidence measured on M Line during Longwall 5 and goaf edge monitoring observed during mining of Longwall 4.

The increase in Longwall 4 centreline subsidence from 1.3m at the completion of Longwall 4 to 1.6m when Longwall 5 had been substantially mined is consistent with elastic pillar compression of 0.6m lowering the surface above one side of the panel causing 0.3m of additional subsidence in the centre of the panel. In other words, there was no increase in sag subsidence over Longwall 4. The additional subsidence is due entirely to 0.6m of elastic strata compression between Longwalls 4 and 5. The sag subsidence above Longwall 5 was 1.0-1.2m (the measured 1.3-1.5 minus half the elastic strata compression above and below the chain pillar between Longwalls 4 and 5.

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. .

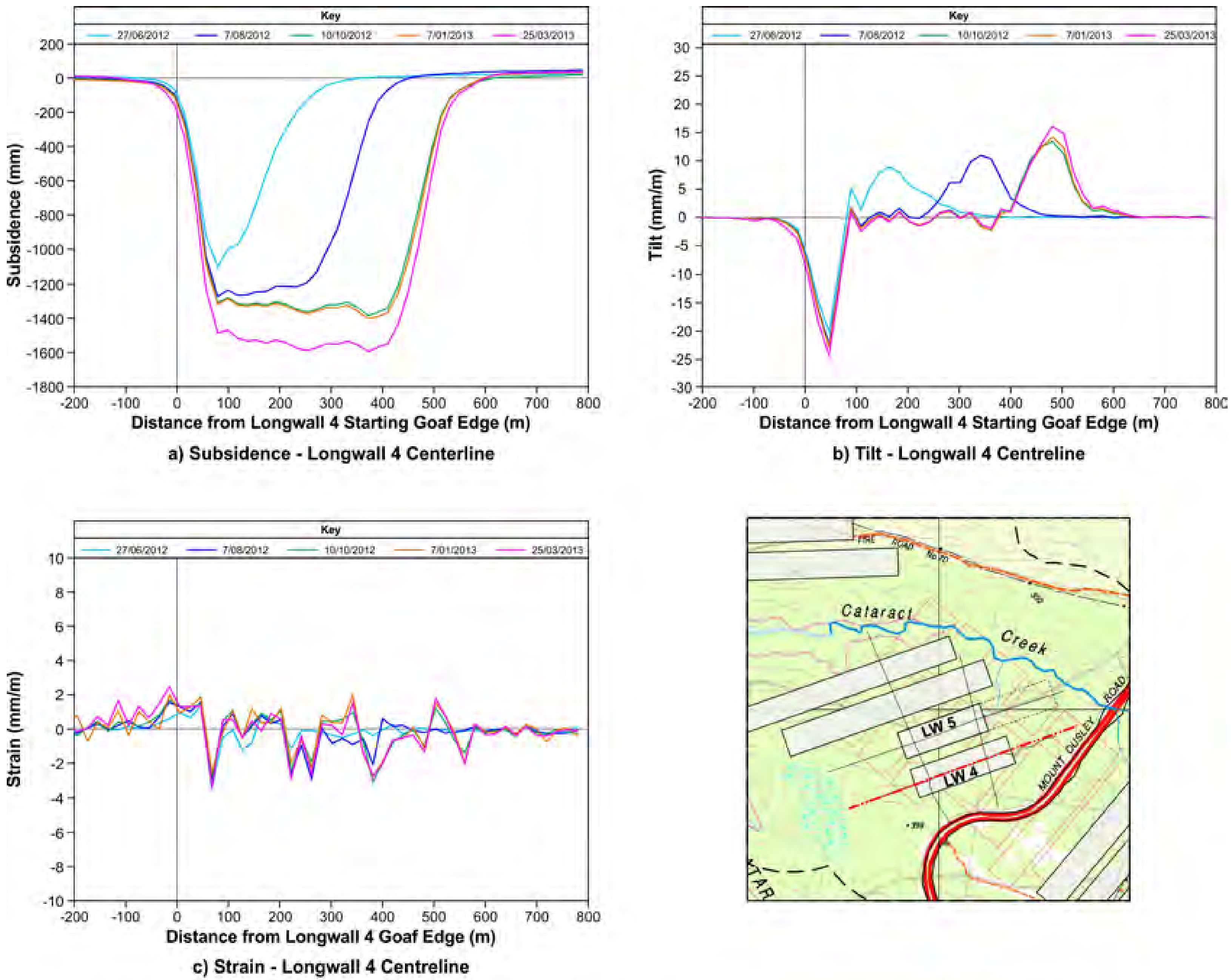
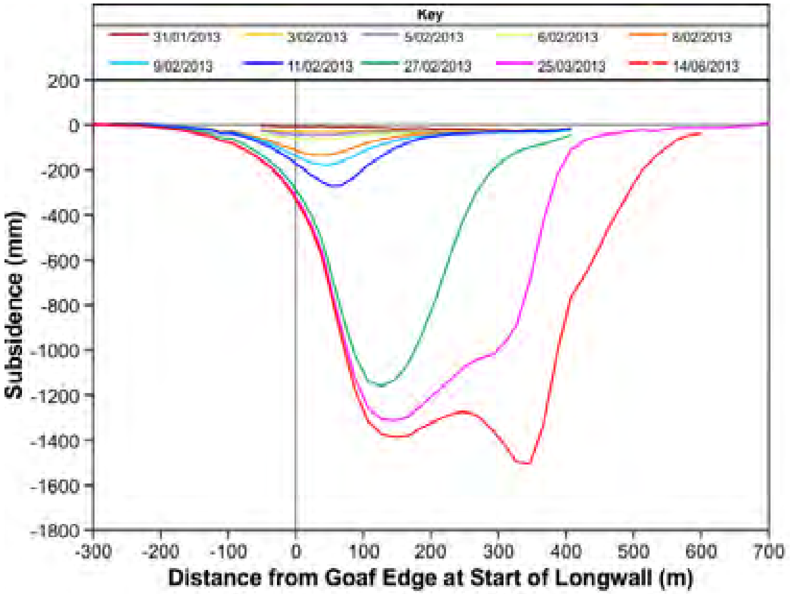
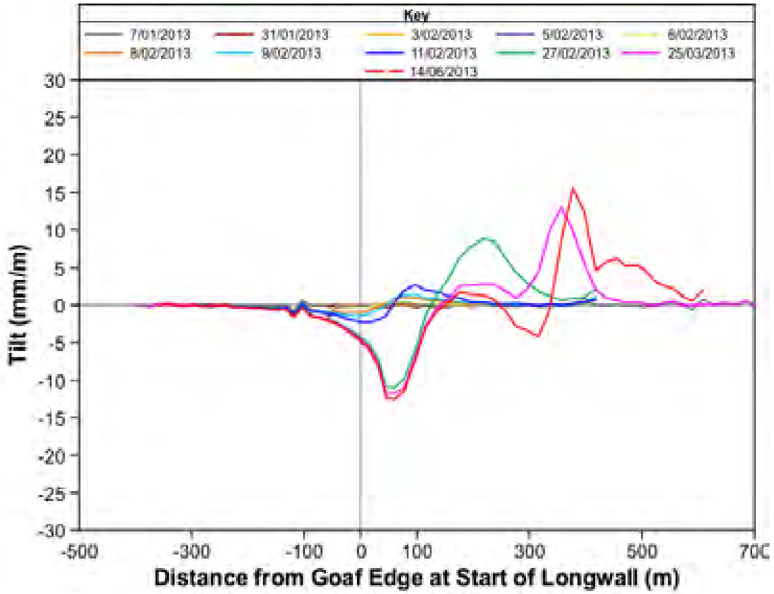


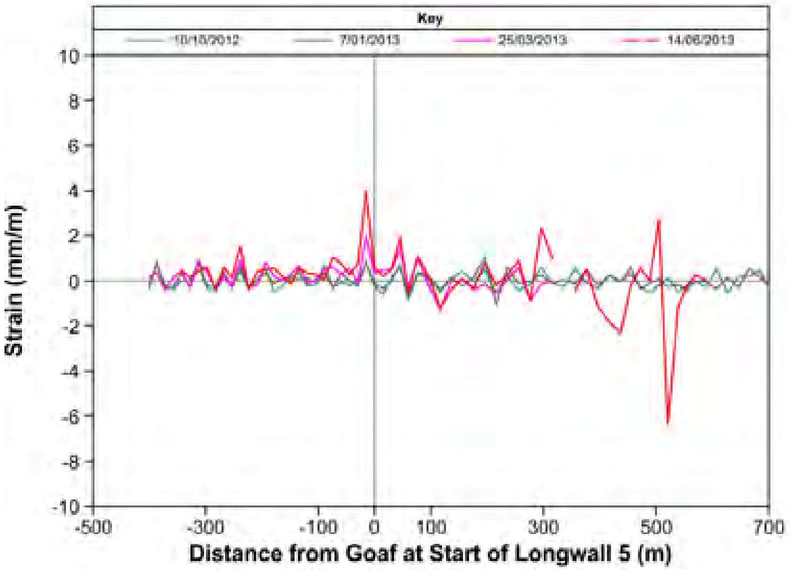
Figure 18a: Summary of Subsidence Monitoring Results from Longwalls 4 in the Wongawilli Seam.



a) Subsidence - Longwall 5 Centerline

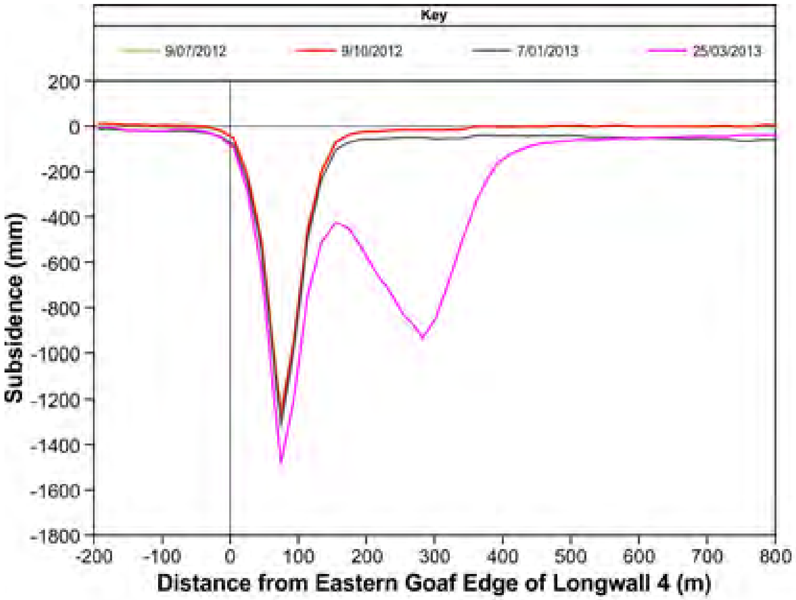


b) Tilt - Longwall 5 Centreline

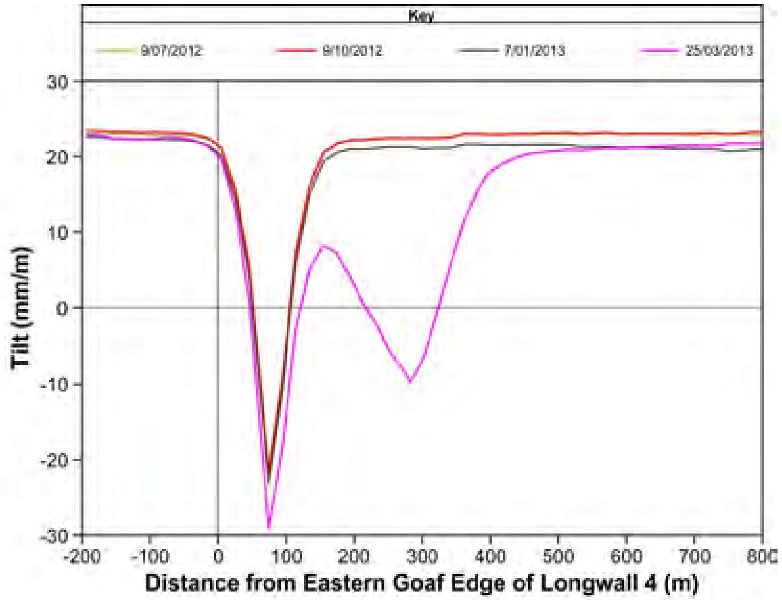


c) Strain - Longwall 5 Centreline

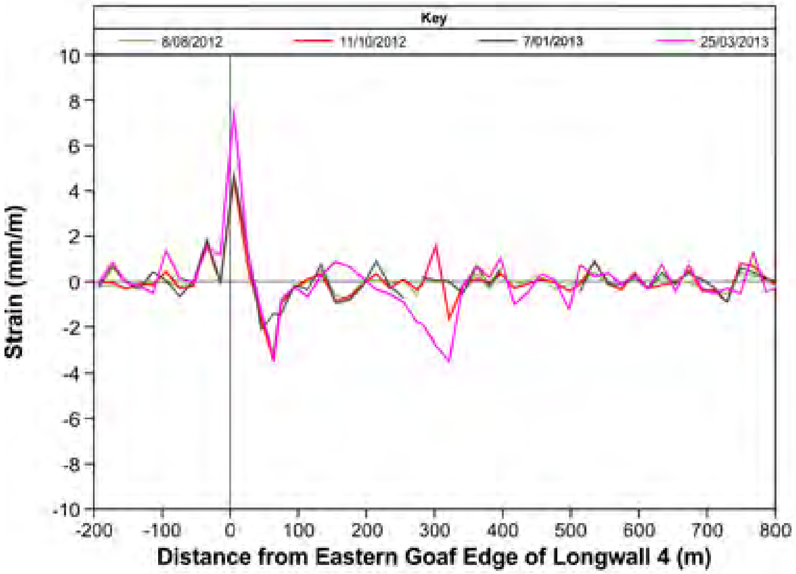
Figure 18b: Summary of Subsidence Monitoring Results from Longwall 5 in the Wongawilli Seam.



a) Subsidence - SX Cross Line

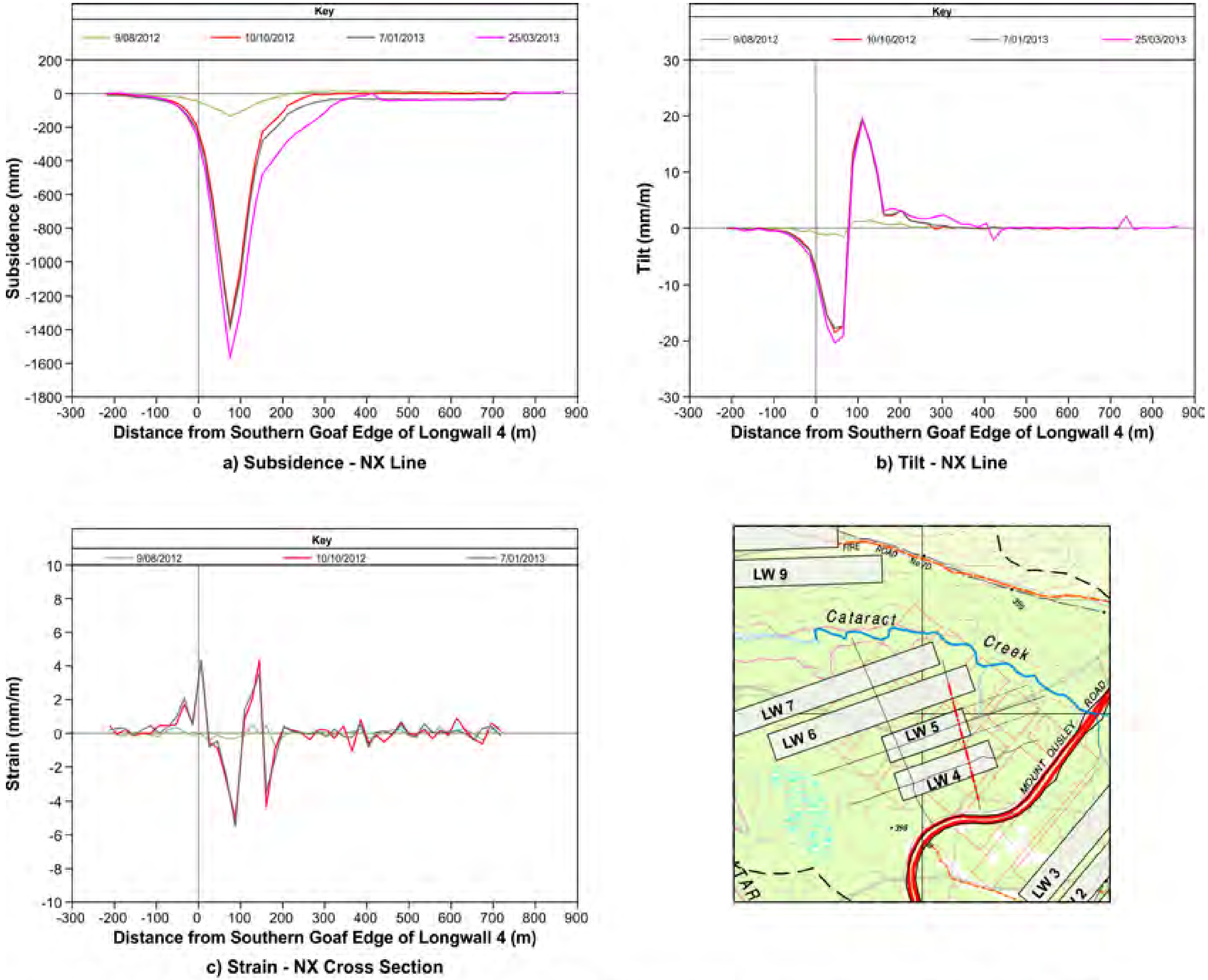


b) Tilt - SX Cross Line



c) Strain - SX Cross Section

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

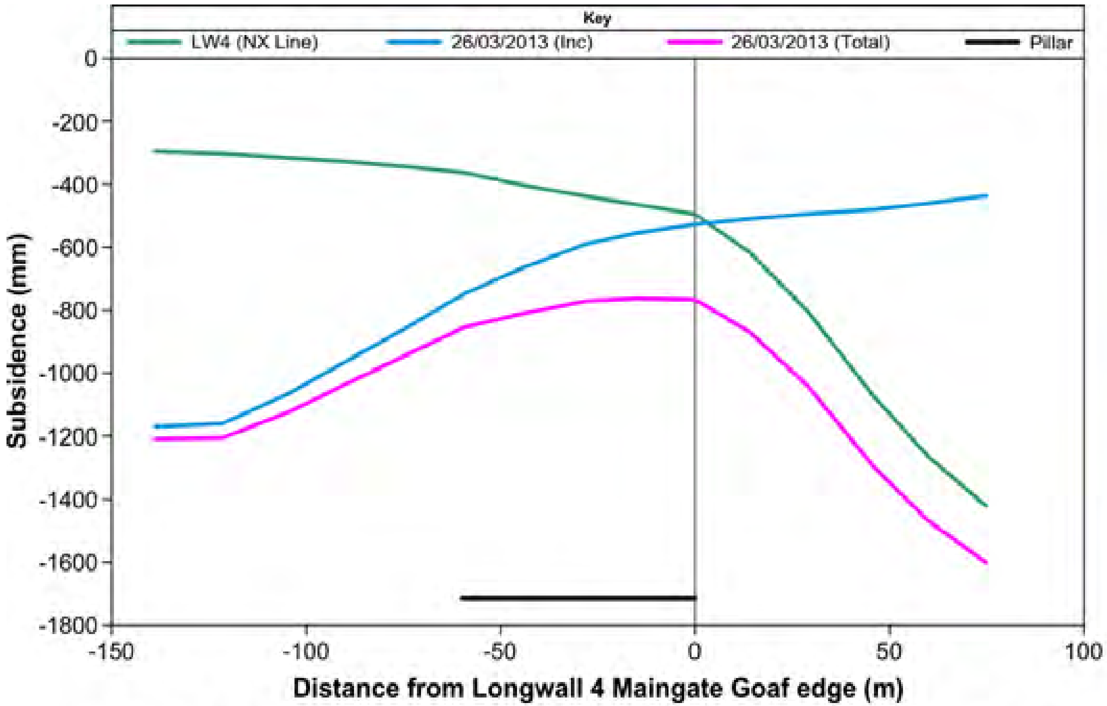


a) Subsidence - NX Line

b) Tilt - NX Line

c) Strain - NX Cross Section

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



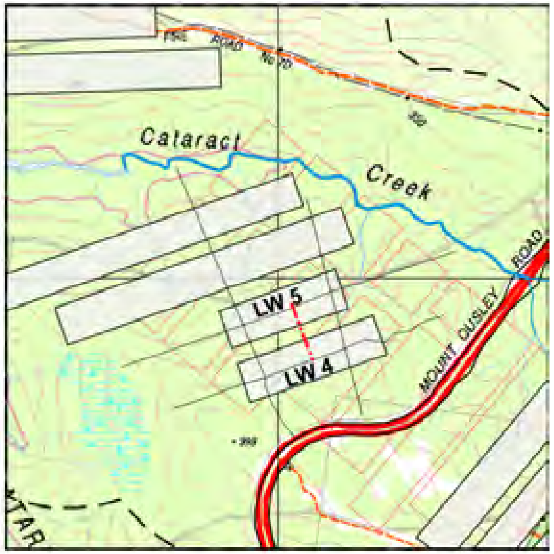


Figure 18e: Summary of Subsidence Monitoring on M Cross Line – Longwalls 4 and 5 in Wongawilli Seam.

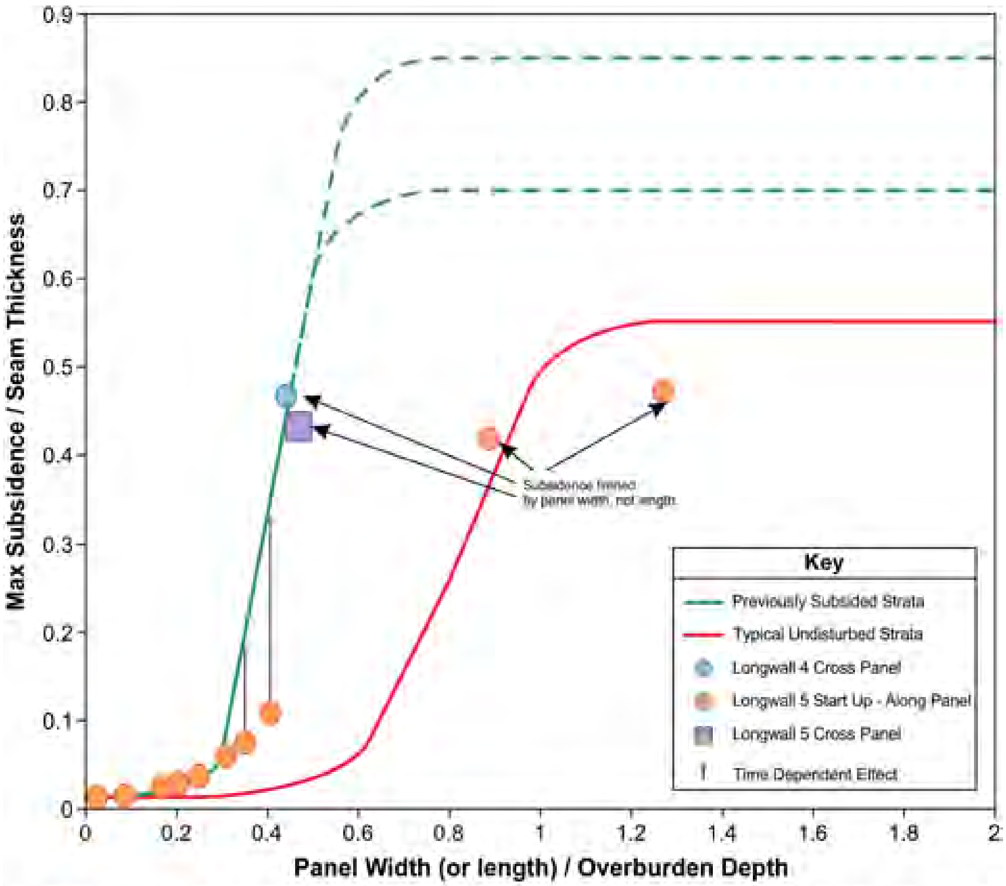


Figure 19: Summary of Sag Subsidence Measured at Start of Longwalls 4 and 5 in the Wongawilli Seam.

The profiles in Figure 20 show that the sag subsidence behaviour above multiple goafs is essentially 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 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.

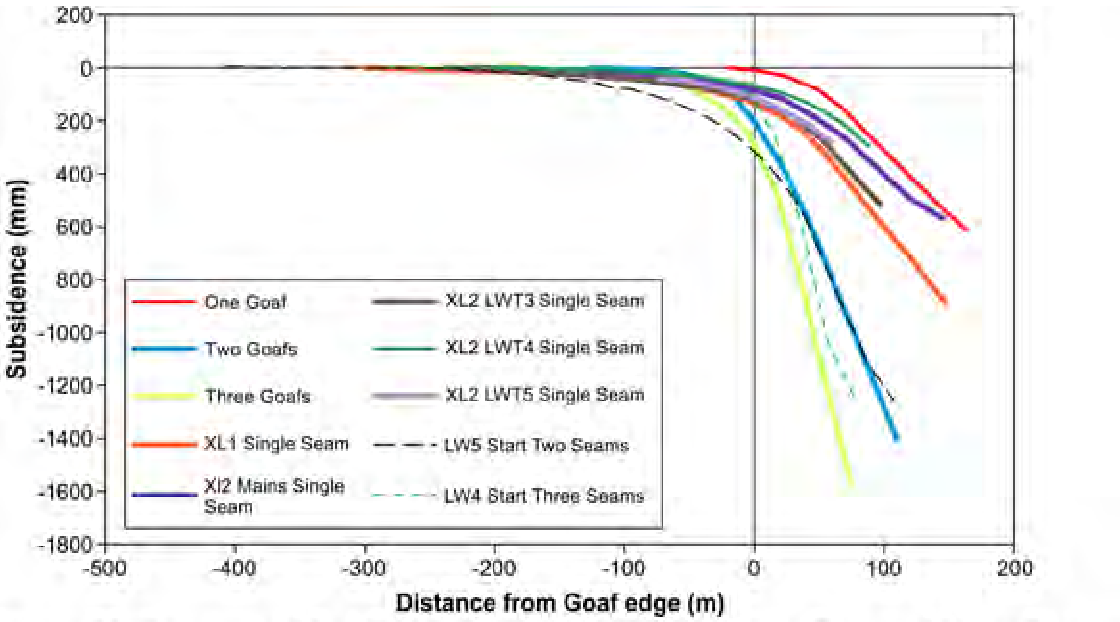


Figure 20: Summary of Goaf Edge Profiles for Mining in One, Two, and Three Seams.

Elastic pillar compression subsidence of 0.6m 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 somewhat variable overlying goafs. 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 also 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 compared to single seam mining operations. Softer 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 essentially the same as for single seam mining geometries.

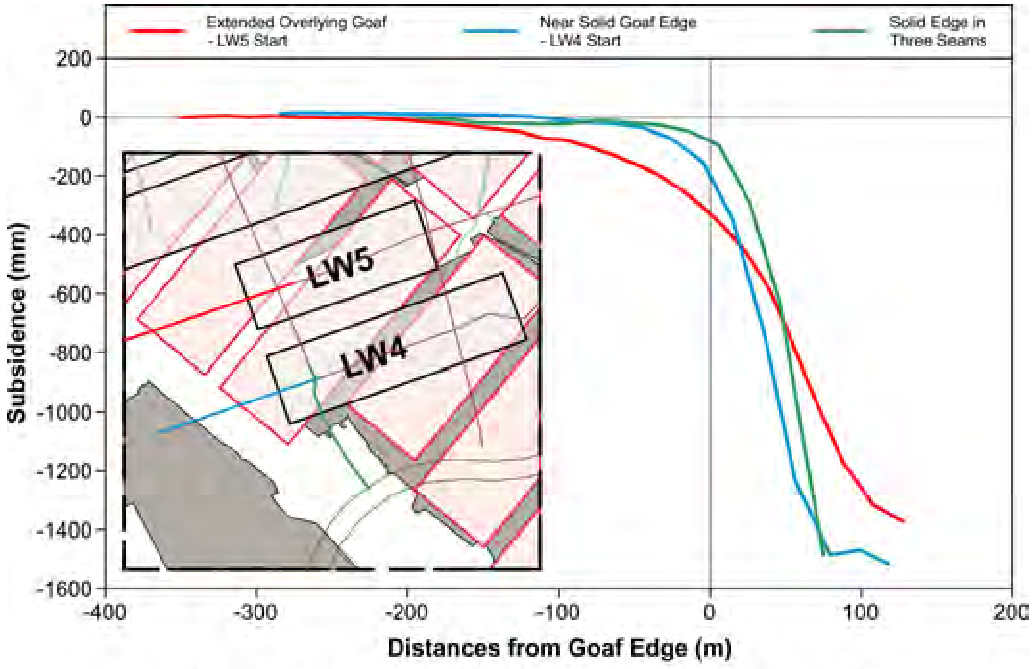


Figure 21: Goaf edge variations above Longwalls 4 and 5.

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. 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. The projections of adjacent

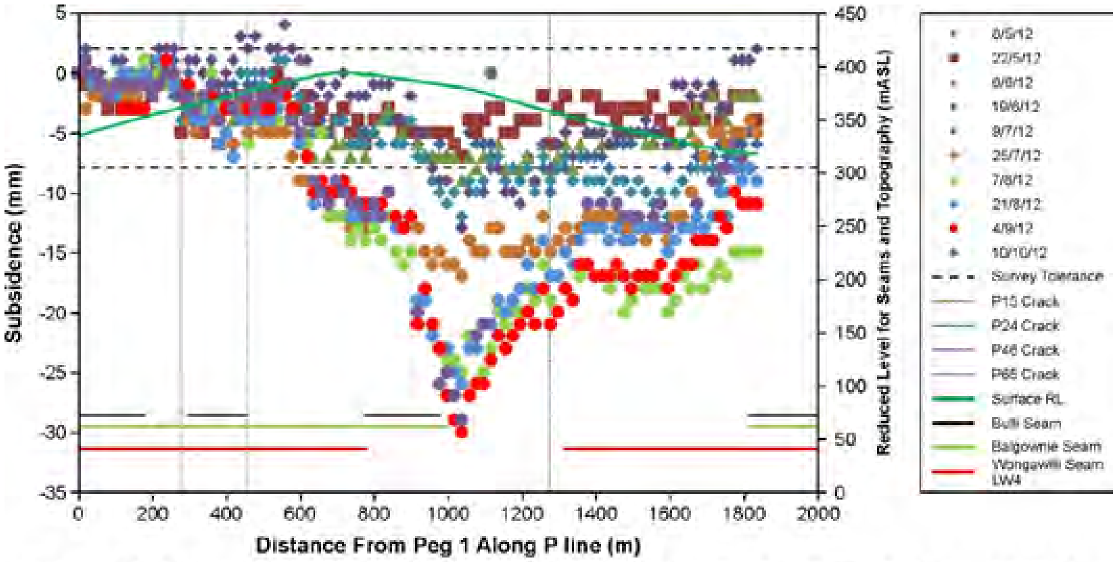


Figure 22: Subsidence measured on P Line along Mount Ousley Road during mining of Longwall 4 in the Wongawilli Seam and Relationship to Mining Geometries in the Bulli Seam, Balgownie Seam, and Wongawilli Seam.

goaf areas in the Bulli, Balgownie, and Wongawilli Seams are also shown. The subsidence observed is of low level reaching a maximum of 31mm 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°.

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. There does not appear to be any evidence of significant vertical subsidence outside the panel being mined associated with any type of pillar run.

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 23 shows the closure measurements on Cataract Creek up until the end of August 2013. Closure measurements across Cataract Creek first became evident at three of the four measurement points when Longwall 5 was 450m from the finishing end of the panel (i.e. at longwall chainage CH450m). The longwall face at this position was approximately 320m from CC4, 420m from CC2, 530m from CC1, and 700m from CC3.

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 closure lines has steadily increased to about 20mm at CH205m (250m from CC1) as Longwall 5 has continued to retreat. These measurements indicate that far-field downslope movements have been evident to a distance of between 530m and 700m from the approaching longwall panel but are of low magnitude (less than 20mm) at a distance beyond 250m (0.9 times overburden depth).

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.

These various observations indicate that while there are small far-field movements evident from the longwall mining conducted so far in the PPR Assessment Area, these movements are of low magnitude and decrease with distance from mining

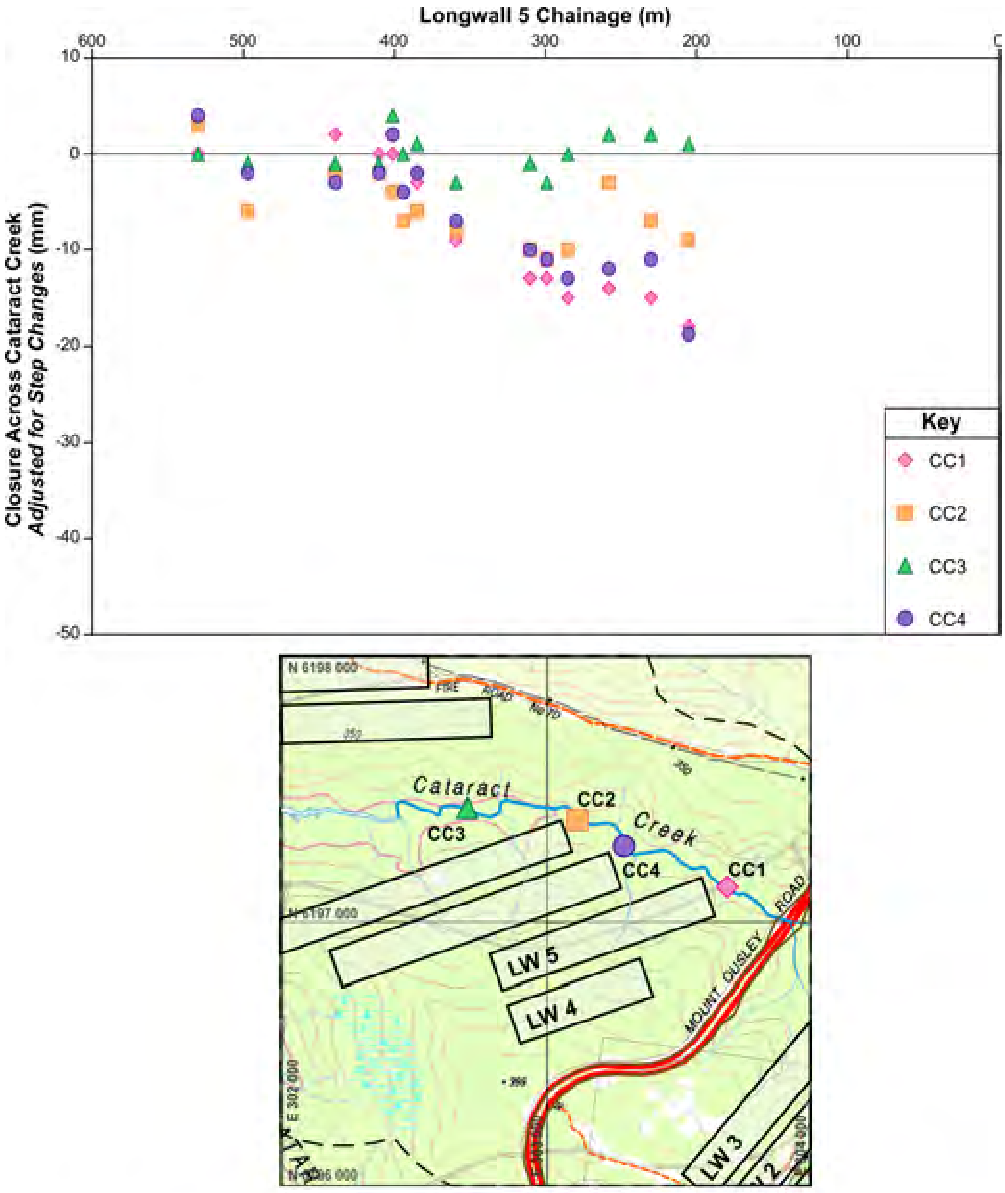


Figure 23: Closures observed across Cataract Creek to 29/8/2013 during mining of Longwall 5.

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 elastic 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 essentially elastic strata behaviour somewhat unreliable because of the complex and variable characteristics of the overburden strata when mining has occurred in multiple seams.

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 in AutoCAD. 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 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 more modest magnitude than the peak values. For prediction purposes, the peak values have been determined to be conservative and recognise that the exact position of the maximum values is difficult to determine accurately. Although the exact position of peak strains is difficult to determine, it is recognised that peak tensile strains are most likely to occur at topographic high points and the start of panels, particularly in areas where mining is proceeding in a downslope direction. Peak 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 peak values and background values of strains are more generally of the order of 20-30% of the peak values indicated by the approach presented by Holla and Barclay (2000).

Closures across Cataract Creek have been estimated using the ACARP method developed by Waddington, Kay and Associates (2003). This method is recognised to be an upper limit prediction method and an alternative approach has also been used based on the increment from only the nearest panel.

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 Longwalls 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 essentially similar to the subsidence behaviour in a single seam mining environment except that the bridging capacity of the overburden strata is significantly reduced.

This reduction in bridging capacity affects the magnitude of the maximum sag subsidence over the centre of each longwall panel. Importantly though, subsidence occurs predominantly within the footprint of the panel being mined – notwithstanding the possibility of pillar instability which is discussed separately below – and the panel width can still be used to control the magnitude of maximum subsidence. Also, elastic strata compression subsidence above the chain pillars between longwall panels appears to be of a similar magnitude to that which occurs in single seam mining operations.

Subsidence at the goaf edge is also somewhat 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 appears to be 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 underground mining 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 similar to the destabilisation that is evident in the Bulli Seam beyond the end of Longwall 7 in the Balgownie Seam. 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. The only place where this type of behaviour appears credible is in an area beyond the northeast corner of Longwall 1 (see Figure 13). Special consideration is required in this area to manage this potential.

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 1.3-1.6m and is therefore much less than the maximum subsidence that would be expected if these panels were wider. The subsidence observed above Longwalls 4 and 5 is significantly reduced from this maximum by the bridging characteristics of the overburden strata albeit the bridging capacity is reduced compared to undisturbed strata.

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 is considered unlikely to significantly underestimate 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 and at a magnified scale. 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 from peaks of 24mm/m over Longwall 10 through to peaks of 51mm/m above Longwall 3. The peak values predicted are expected to be the maximum anywhere in the panel, most likely at goaf 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 peak values.

Maximum strains over individual longwall panels in the Wongawilli Seam are expected to range from peaks of 14mm/m over Longwall 10 to peaks of 31mm/m over Longwall 3. The peak values predicted are expected to be the maximum anywhere in the panel. More generally across the panel, systematic strains are likely to be 20-30% of the peak 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 ACARP Method. The predicted closure ranges up to 400mm adjacent to the ends of Longwalls 6 and 7 and up to 210mm at the end of Longwall 5. These closure estimates are recognised as being upper limit values because they are based on experience in the 70m deep gorges around Tower Colliery where the in situ stresses are much higher.

The measurements made so far during mining of Longwall 5 indicate measured closure values are much lower those predicted using the ACARP method. The closure monitoring at Cataract Creek off the end of Longwall 5 indicates closures of 20mm compared to 80mm that are predicted using the ACARP Method for the equivalent longwall face position. On this basis, although maximum closures of 400mm are predicted across Cataract Creek from mining Longwalls 6 and 7, the actual closure is expected to be significantly less than predicted by the ACARP Method. Closures of 600mm are predicted using the ACARP Method for the southern tributary of Cataract Creek above Longwalls 1-3. This section of the creek is a second order creek and some impacts are expected. The northern tributary is the main channel of Cataract Creek. This section, some of which is third order stream is remote from the proposed mining and no significant closure is 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 located substantially on the northern side of the ridge and any downslope horizontal movements are expected to occur mainly on the northern slope 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 essentially 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 be up to 300-500mm and the goaf edge subsidence profile is expected to be general softer 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.

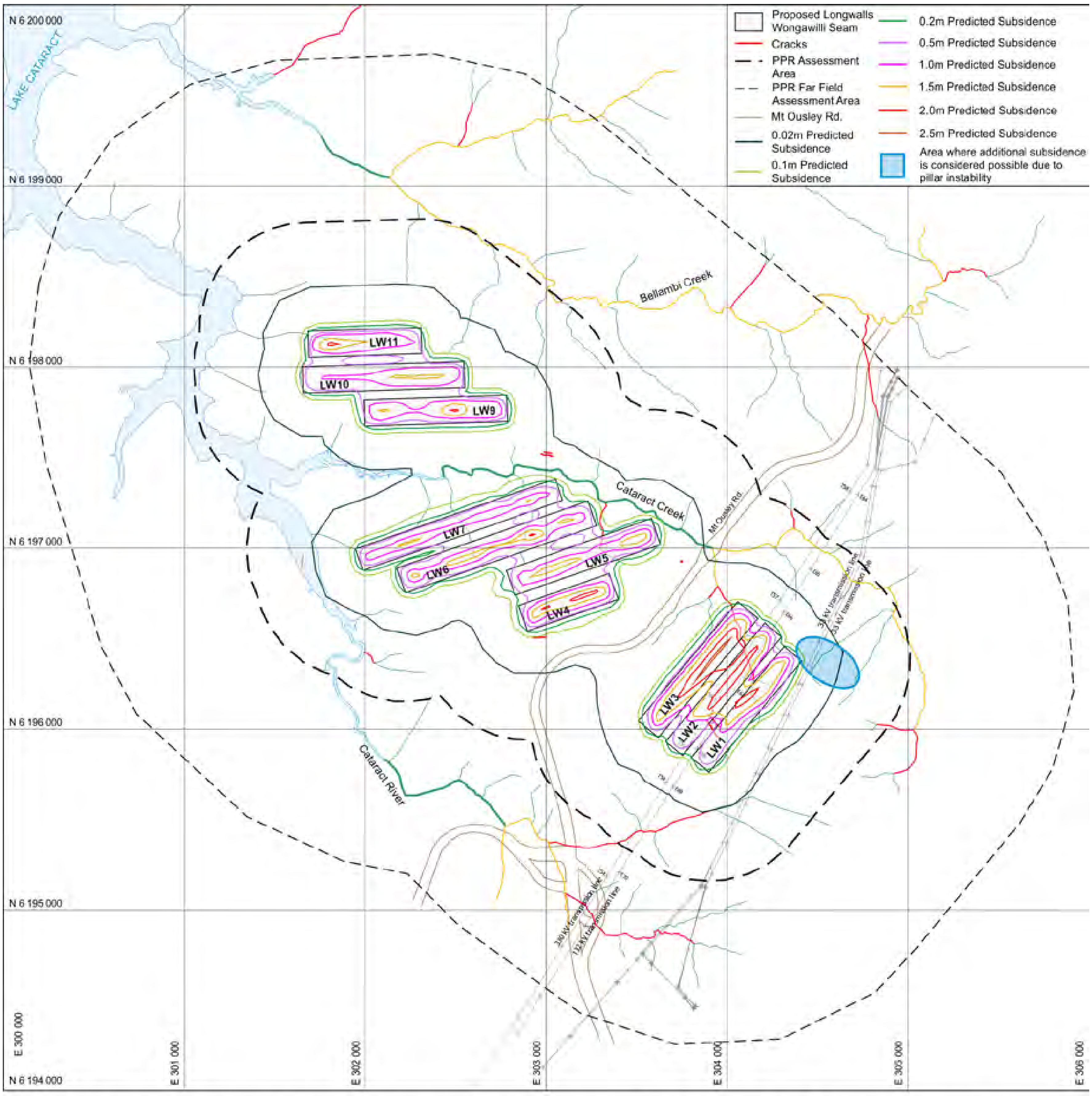


Figure 24a: Contours of predicted subsidence from the Wongawilli Seam (at same scale as previous diagrams).

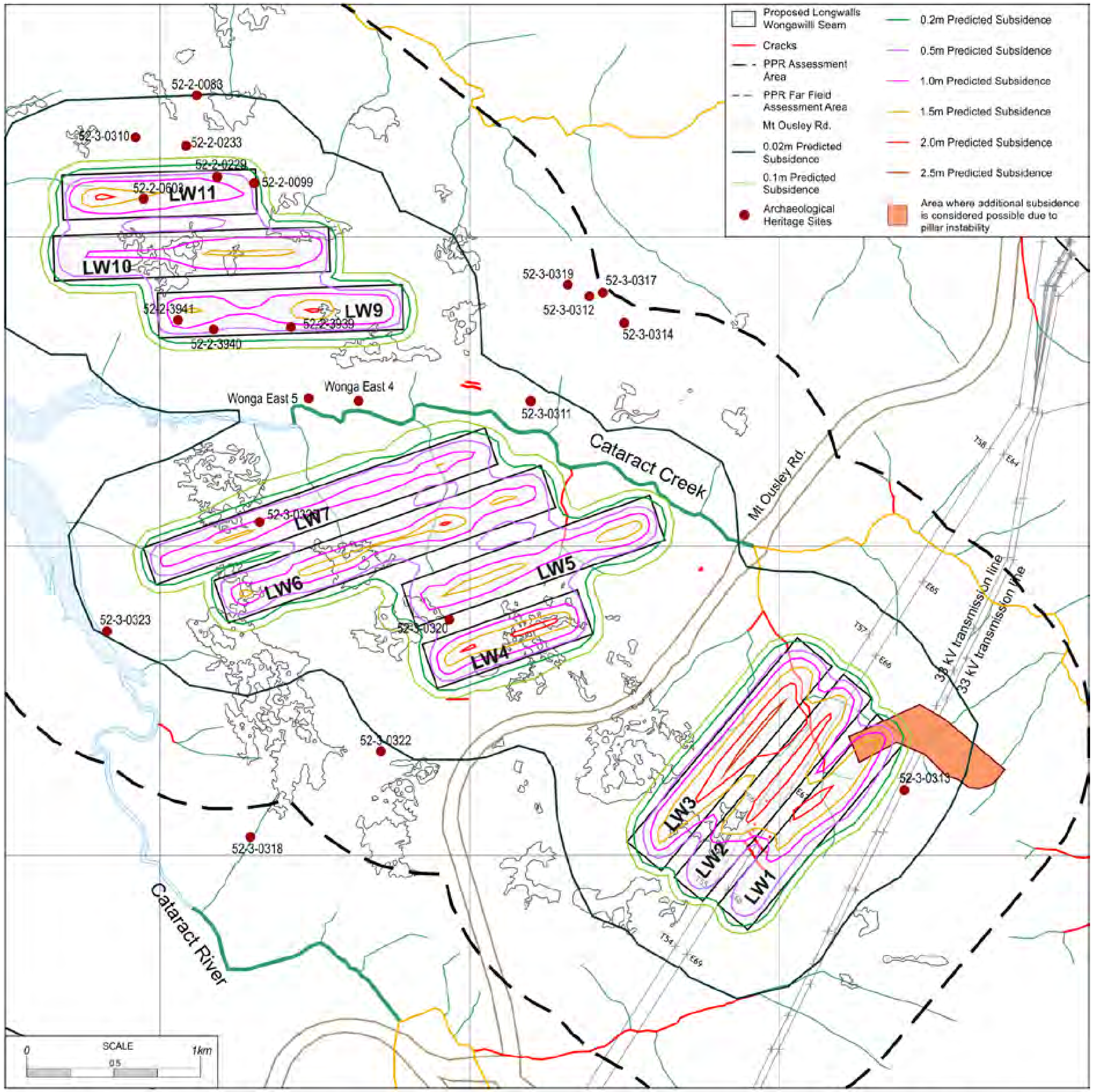


Figure 24b: Enlarged view showing contours of predicted subsidence from the Wongawilli Seam relative to surface features.

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 (650)
Longwall 2	260	1.1	2.1	19	40	N/A	12	N/A	24	N/A	N/A (610)
Longwall 3	255	1.3	2.6	13	51	N/A	15	N/A	31	N/A	N/A (350)
Longwall 4	300	1.9	2.1 (**1.6**)	11	35 (**30**)	N/A	10.5 (**7.5**)	N/A	21 (**14**)	100	N/A
Longwall 5 (*mining still in progress)	265	0.9	1.9 (**1.5***)	11	36 (**16***)	N/A	10.8 (**4.5***)	N/A	22 (**14***)	130	210 (**20***)
Longwall 6	280	1.5	2.1	18	38	7.5 (3)	11	14 (4)	23	310	400
Longwall 7	270	1.2	1.5	18	28	7.5 (3)	8	14 (4)	17	310	400
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		

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 (as depicted in NSW Department of Planning 2008).

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 order and higher 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 subside1.4m.

A management approach based on monitoring closure and stopping the longwall panels if these reach unacceptably high values is considered an appropriate method of managing the closures across Cataract Creek.

Experience in Hawkesbury Sandstone river channels indicates that there has been not been total loss of surface flow in major river channels such as Cataract Creek where valley closure is less than 200mm. By adopting a

TARP system based on maintaining closure to less than 200mm, it is anticipated that the potential for loss of surface flow can be managed.

Figure 25 shows the profile of the southern branch of Cataract Creek located over Longwalls 1-3 and its continuation downstream to Cataract Reservoir. This 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. 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.

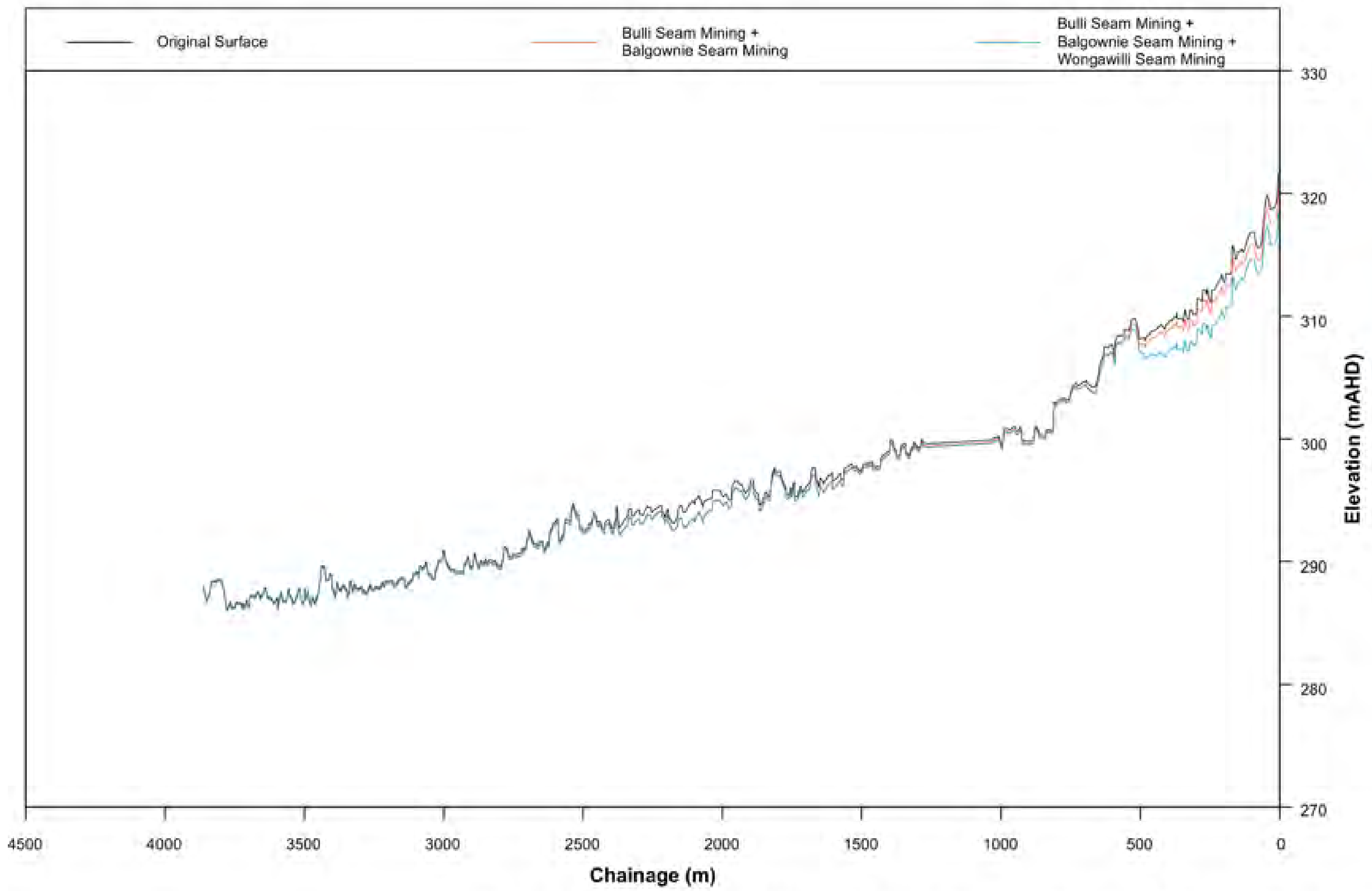
Although there is potential for water to pool in this area, valley closure effects are expected to increase the potential for sub-surface flow so pooling may only be short lived during periods of heavy rain. Valley closures are expected to cause perceptible cracking and surface flow diversion in the 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 from this area as a result.

Further downstream above Longwalls 2 and 3 and downstream of the crossing below Mount Ousley Road where the creek will not be directly mined under, the bed of the stream is located mainly in Bald Hill Claystone and only low levels of perceptible impact are expected in this strata 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.

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.



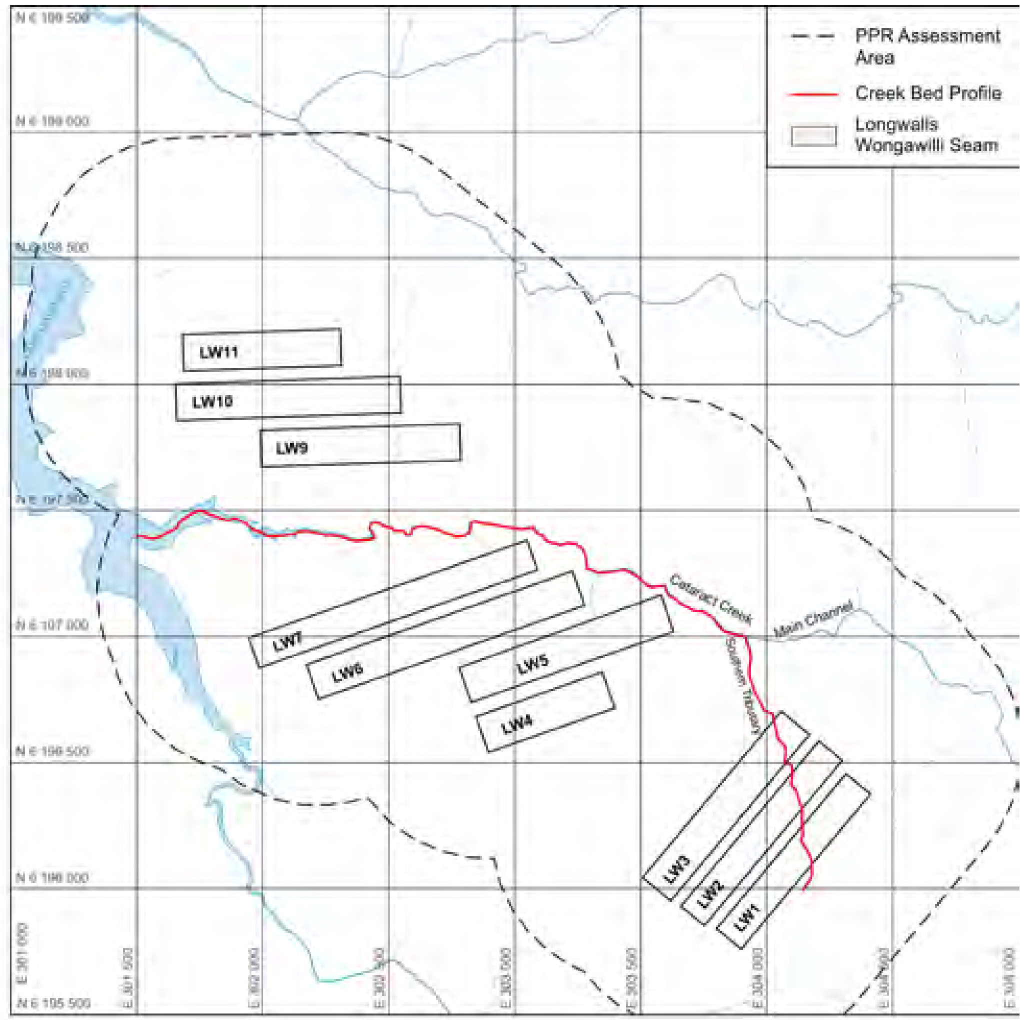


Figure 25: Profile of Bed of Cataract Creek from the Southern Tributary Headwaters to Junction with Cataract Reservoir.

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 tributaries 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 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.

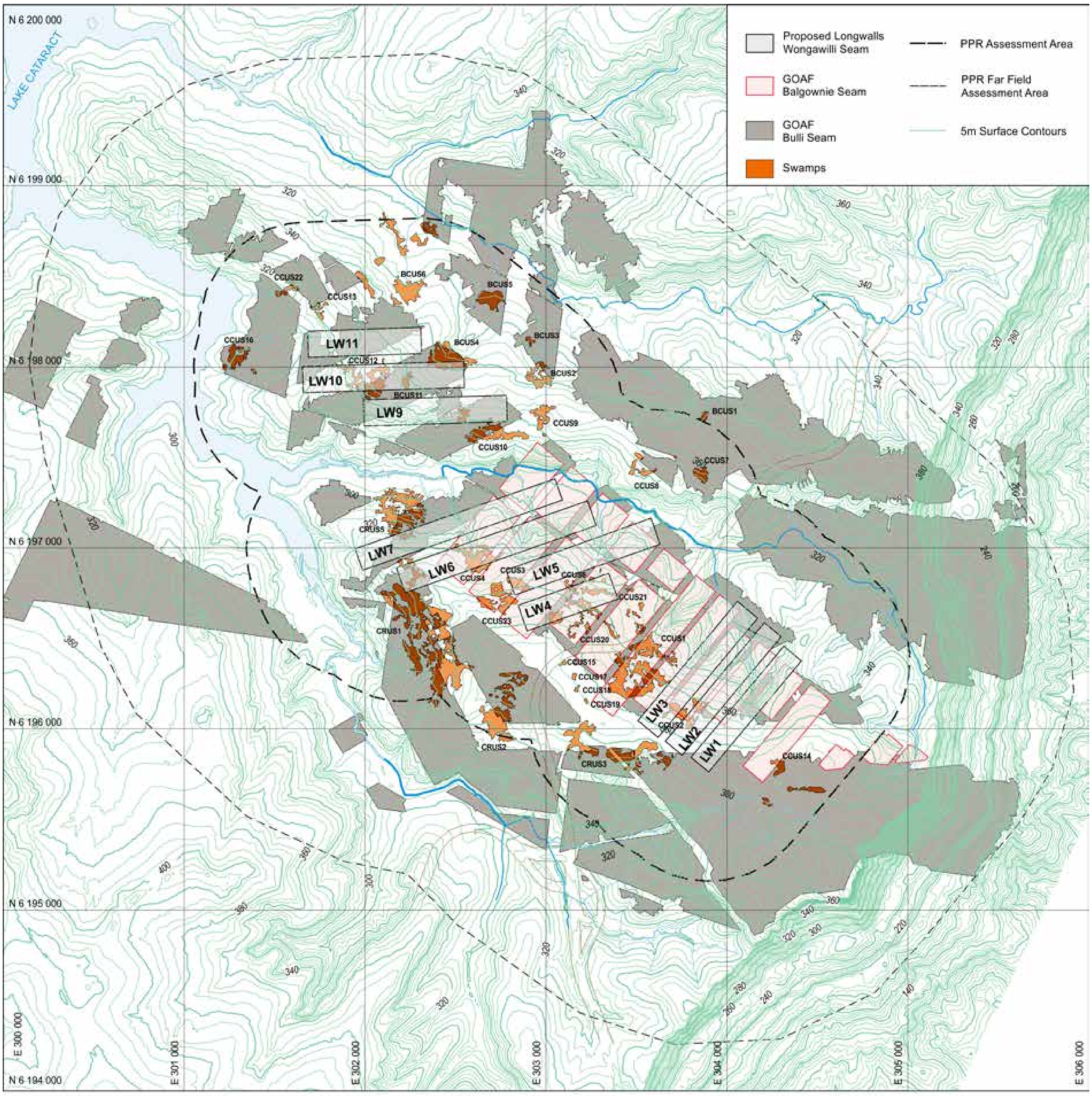


Figure 26: Location of Peat Swamps relative to historic mining and proposed longwall panels.

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 a significant impact on their long term condition.

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 changes that are expected from proposed mining are nominally sufficient to cause significant 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 Cataract Creek and several short sections of slightly 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 lower 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.

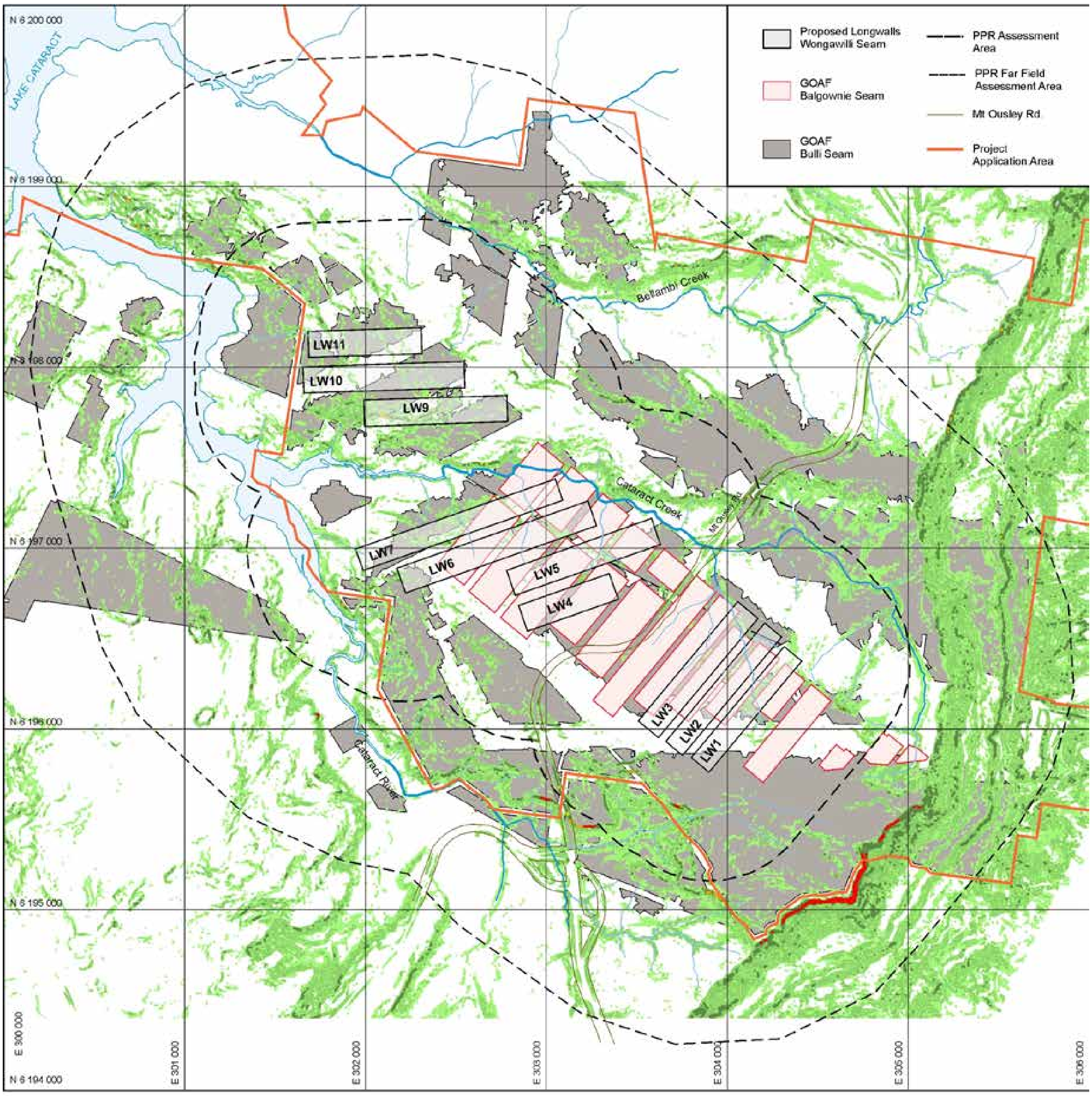


Figure 27: Location of steep slopes and cliff formations.

The approach outlined in the NSW PAC (2010) is used as the basis for assessing significance. The categories of significance adopted are:

- Special significance – cliff formations that are longer than 200m, higher than 40m, and higher than 5m that constitute waterfalls.

- Minor environmental consequences – cliff formations where isolated rock falls of less than $30m^3$ are anticipated but where rock falls do not impact on Aboriginal heritage, endangered ecological communities, public safety and the like and rock falls and occur on less than 5% of the total length of cliff formations.

- Negligible environmental consequences – occasional displacement of boulders, hairline cracks, isolated dislodgement of overhanging rock slabs impacting less than 0.5% of the total length of a cliff formation.

- Nil environmental consequences – no mining impacts, although it is recognised that natural processes that cause ongoing erosion such as diurnal and seasonal thermal variations, high intensity rainfall, and the like continue to operate at a low level irrespective of mining activities.

Only the cliff formations associated with Brokers Nose are significant using the criteria outlined in the PAC (2010) based on their physical characteristics alone. Brokers Nose is 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.

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.




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

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 29 relative to proposed mining and summarised in Table 5.

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 will be mined under or adjacent to. 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.

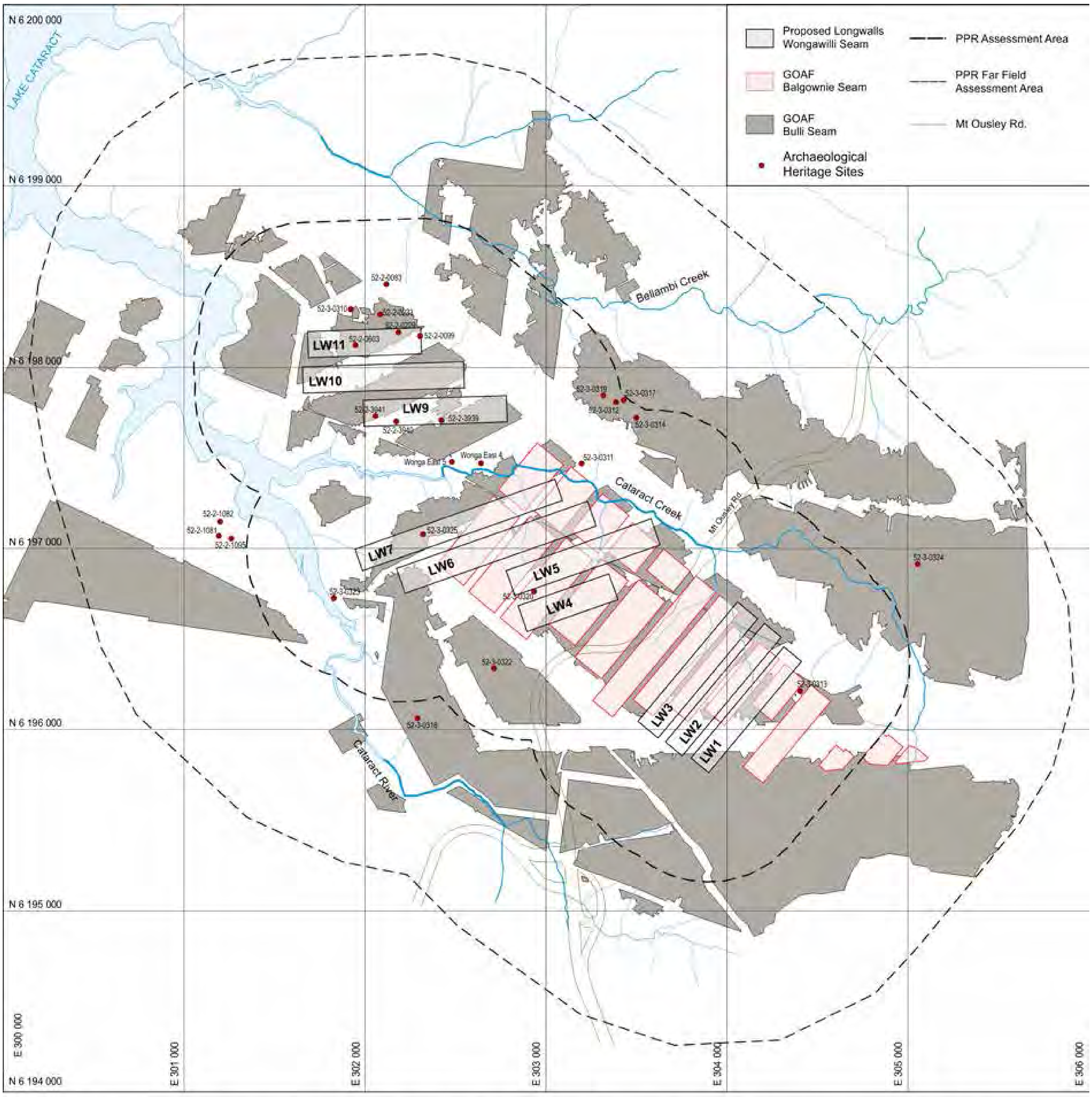


Figure 29: Location of Archaeological Heritage Sites relative to historic mining and proposed longwall panels.

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 30. 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 30: 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 31.

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

Figure 31: Photograph of Archaeological Site 52-2-3940.

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.

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 32 shows a photograph of the site including the fractured rock strata where the boulder has detached from the general cliff formation.

Figure 32: Photograph of Archaeological Site 52-2-3941.

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 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 33. 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.

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.

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Figure 33: Photograph of Archaeological Site 52-2-0603.

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

The 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 30mm of this maximum having already occurred from mining Longwall 4. These low level vertical movements are expected to be imperceptible for all practical purposes.
The 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	30	30
5	50	80
2	5	85
3	40	125

The upper limit of 125mm of compression in the bottom of the valley estimated at the completion of proposed mining is expected to be accompanied by a similar level of cumulative tensile cracking toward the top of the slope. Cracking is likely to continue to develop at the same location once a crack has formed. Some of the tensile cracking that began during Longwall 4 appears to be continuing during mining of Longwall 5.

The current program of monitoring and visual inspection is considered appropriate while mining is ongoing in Longwalls 2 to 5. A reduced survey frequency is considered likely to be appropriate during mining of the other longwall panels. Some localised resealing of the cracked sections of Mount Ousley Road is likely to be required at the completion of mining or whenever the tensile cracking becomes too wide to be considered serviceable. The cracking is expected to develop incrementally with mining and so a program of repairs can be scheduled based on forecast longwall retreat.

Tension cracking is likely to be concentrated on the road pavement near the top of the ridge between Cataract Creek and Cataract River. In this area, 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 pot holes to develop on the road surface.

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 mine predominantly below the slope that leads down to Cataract Creek rather than the south facing slope that leads to Cataract River and its tributaries. 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 likely to be appropriate.

The road cutting on the northern side of Cataract Creek has been formed in Hawkesbury Sandstone strata to form high embankments. 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 34 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

Figure 34: Power transmission lines above Longwalls 1 and 2.

one is supported on double pole structures that appear to have been replaced in the last few years.

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 construction of the lines.

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 that they had been constructed prior to mining Longwall 3 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 managed through rotation from vertical of the suspended insulators as can be seen in Figure 34. In contrast, E57 is located on a straight section of line and the insulators hang vertically.

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 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 35.

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

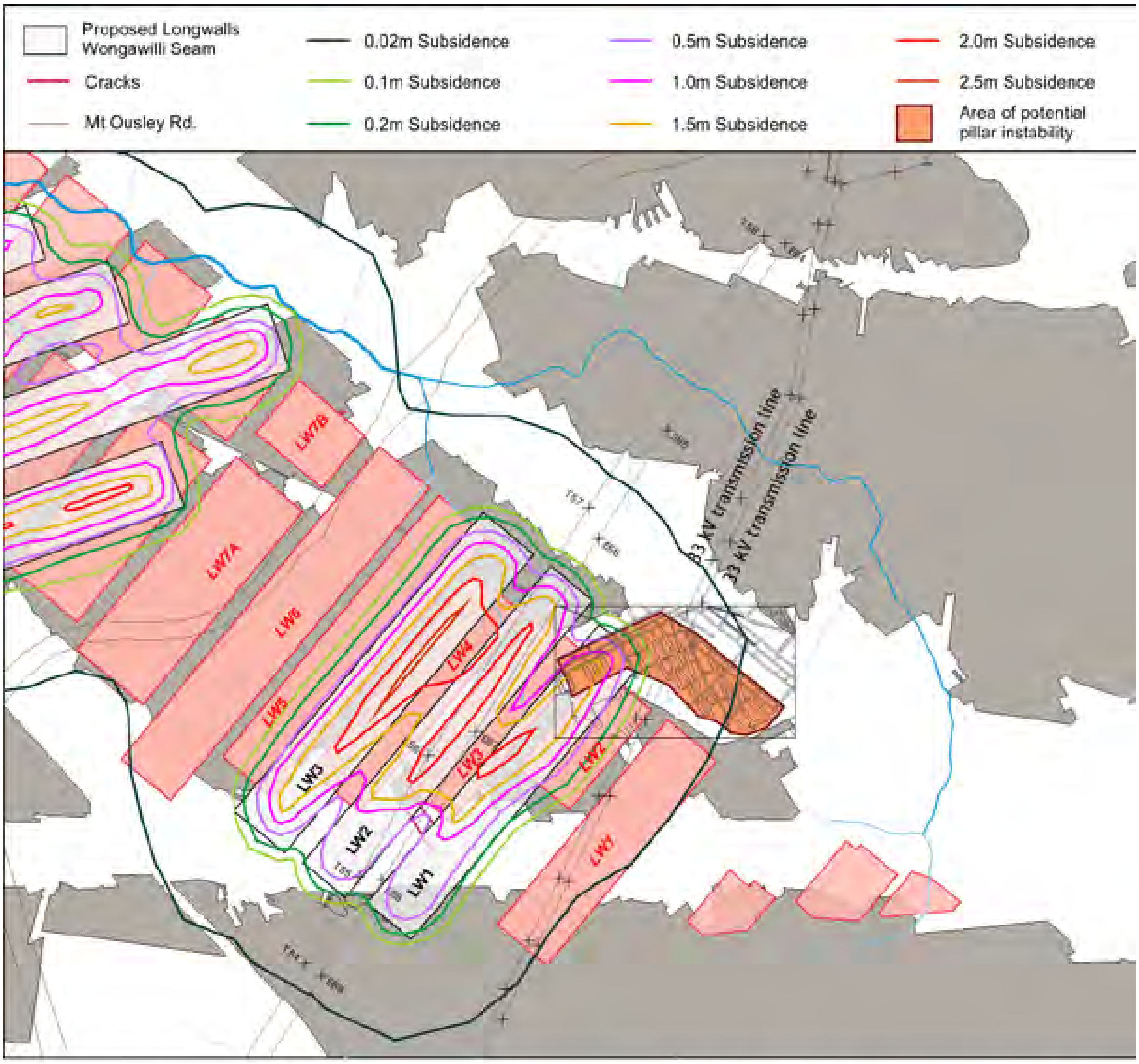

Figure 35: Location of power transmission structures relative to proposed longwalls, Balgownie Seam longwalls, and area of potential pillar instability in the Wongawilli Seam.

There is also an area where there is some potential for pillar collapse in the Bulli Seam. This area is shown in Figure 35. Fortunately, the towers and poles are located outside the area likely to be affected by any pillar instability.

Permanent horizontal movement in the direction of mining is expected to occur at all the four towers located directly over the longwall panels. 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, the risk of new cracking causing structural damage is considered to be too high without some form of mitigation. It is considered that all four towers require some mitigation works to remain serviceable during the period of mining Longwalls 1, 2 and 3.

The use of a cruciform foundation is considered likely to be effective to protect the structural integrity of the tower foundations. 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 20m above the ground of about 800mm. This movement is likely to 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 active phase of mining below the structures.

A single point tie down may be required on the western leg of the cruciform for T56 to accommodate the lateral loads associated with the slight change in direction at this tower. The loads involved are expected to be able to be accommodated through appropriate design of the cruciform.

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 the towers are on 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 the local site conditions, but a site specific risk assessment is required to develop a mitigation strategy for this tower.

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 and 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 also a number of small pre-existing Bulli Seam goaf areas that are located within the 0.7 time depth protection zone around the FSL. The largest width of any of these is 200m and it is located within 80m of the FSL at an overburden depth to the Bulli Seam of approximately 260m. It is considered unlikely that the proposed mining will interact with these pre-existing goaf areas and there does not appear to be any connection between the reservoir and the mining horizon. Nevertheless, the presence of these goafs reduces slightly the effectiveness of the 0.7 times depth barrier between the FSL and the proposed mining, particularly during mining of Longwalls 7 and 9.

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.

The only monitoring system that is likely to be effective would be in situ stress change monitoring. This equipment can be deployed in a borehole in the sandstone strata and remotely monitored to confirm that there have been no significant changes. The system is significantly more sensitive than conventional surveying.

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 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 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 conveniently be established. The four that are currently located across Cataract Creek are considered suitable locations. 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 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 sub-grade. There is then potential for water ingress to cause damage to the road base and potential for particle migration into the cracks that eventually has potential to cause a pot hole.

Continued survey monitoring of the Mount Ousley Road, perhaps at reduced frequency, and in due course the power transmission towers and poles is recommended 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 mid panel 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.

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 them to remain structurally stable during mining. 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 reflectors on the structures to capture tilt and high resolution surveying of the relative position of individual legs relative to each other and in three dimensions for the cruciforms would be appropriate.

Strain gauge monitoring of the steel structures and automatic regular logging of the changes transmitted back to a website portal is a practical solution for towers that are on the periphery of the mining area and do not have cruciforms.

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 any subsidence that occurs as a result of pillar destabilisation in this area.

All the 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 particularly that there is no unaccounted for loss of water into inaccessible storage deeper in the mine or into adjacent mines.

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 goafs 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.

SCT understand that NRE has engaged a consultant to prepare a Mine Closure plan for the DSC to manage any uncontrolled inflow of water and prevent its egress from the mine workings. However, it should be recognised that there are limited options to control any significant inflow 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.

A remotely logged borehole strain cell located in the rock strata between Longwall 1 and the Illawarra Escarpment would provide confirmation of the level of any stress concentrations that may occur. These instruments are more sensitive than conventional survey monitoring in this situation.

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, and can be ongoing.

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 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 design and the design process.

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 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 essentially similar to single seam subsidence in its general characteristics. There are some subtle differences but these are second order effects and do not change the general characteristics. Another difference is that there is potential for pillar instability in areas of standing pillars in overlying seams in some areas and this potential needs to be recognised.

For the most part though, the subsidence mechanics in a multi-seam environment are essentially similar to the mechanics in a single seam environment. 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 is softer behaviour evident over previously mined goaf compared to over solid, but the differences are relatively small and tend to soften the 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 is not expected to have an impact on any surface features of significance.

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 two are 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 essentially 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 from about Longwall 6. This type of tapering behaviour is typical of geological faults in the Southern Coalfield. The Corrimal Fault is not expected to have any significant influence on either 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 are incomplete and may be inaccurate.

Nevertheless, 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 a 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 tower 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 credible, the significance of any surface subsidence that may result is considered to be low, especially in terms of impacts to major surface 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, 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 NRE 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 two 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 NRE.

The subsidence monitoring systems being used at NRE 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 NRE including the significant revision to the mine layout represented by the PPR. Closure monitoring across Cataract Creek is being used to control the length of Longwall 5 and is planned to be used for Longwalls 6 and 7 as well.

9. REFERENCES

Biosis 2013 "NRE No. 1 Colliery – Underground Expansion Project: Preferred Project Report – Biodiversity" Report for Gujarat NRE Coking Coal Ltd. Authors: N.Garvey & K.Beyer, Biosis Pty Ltd, Wollongong. Project no. 16646

Clark B. 2013 "Geological Report on the Wonga East Area" Report prepared by Gujarat NRE Technical Services Department, dated August 2013.

DSC 2013 Official Notices of NSW Government 1 March 2013 Cataract Notification Area p534.

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

Li G., P. Steuart, R. Paquet, and R. Ramage 2010 "A case study on mine subsidence due to multi-seam longwall extraction" Proceedings of 2nd Australasian Ground Control in Mining Conference. 23-24 November University of N.S.W. Sydney pp191-200

Mills, K.W. 1998, "Subsidence mechanisms about longwall panels" Proceedings of International Conference on Geomechanics/Ground Control in Mining and Underground Construction (GGM98), 14-17 July 1998, University of Wollongong, Vol 2 pp. 745-756.

OzRoads 2012 "National Route 1 Mount Ousley Section" http://www.ozroads.com.au/NSW/Freeways/MtOusley/mtousley.htm 12 November 2012-11-15

PAC 2010 "Bulli Seam Operations PAC Report July 2010" prepared for the NSW Department of Planning by the NSW Planning Assessment Commission (PAC).

NSW Department of Planning 2008 "Impacts of underground coal mining on natural features in the Southern Coalfield – Strategic Review" July 2008 ISBN 978 0 7346 5901 6

Vecovski, P. 2012 personal communication email from Roads and Maritime Services 15 November 2012

Waddington Kay and Associates 2003 "Management Information Handbook on Undermining of Cliffs, Gorges, and River Systems" ACARP Projects C8005 and C9067.

APPENDIX 1 - SUBSIDENCE MOVEMENTS PREDICTED FOR SWAMPS AND ARCHAEOLOGICAL SITES

Seam Depths

Swamp	RL of Bulli Seam Floor (mAHD)	Surface RL (m AHD)	Overburden Depth to Bulli Seam (m)	Overburden Depth to Balgownie Seam (m)	Overburden Depth to Wongawilli Seam (m)
CCUS1	75	360	285	295	320
CCUS2	85	370	285	295	320
CCUS3	55	355	300	310	335
CCUS4	50	340	290	300	325
CCUS5	38	310	272	282	307
CCUS6	65	350	285	295	320
CCUS7	85	355	270	280	305
CCUS8	75	345	270	280	305
CCUS9	52	345	293	303	328
CCUS10	50	330	280	290	315
CCUS11	5	345	310	320	340
CCUS12	15	370	355	365	390
CCUS13	5	340	335	345	370
CCUS14	115	390	275	285	310
CCUS15	60	385	325	335	360
CCUS16	0	300	300	310	335
CCUS17	60	385	325	335	360
CCUS18	60	385	325	335	360
CCUS19	60	385	325	335	360
CCUS20	70	360	290	300	325
CCUS21	70	350	280	290	315
CCUS22	-2	315	317	327	352
CCUS23	55	365	310	320	345
CRUS1	50	350	300	310	335
CRUS2	65	275	210	220	245
CRUS3	80	375	295	305	330
BCUS1	90	360	270	280	305
BCUS2	50	335	285	295	320
BCUS3	50	315	265	275	300
BCUS4	35	330	295	305	330
BCUS5	37	310	273	283	308
BCUS6	17	325	308	318	343
BCUS11	25	360	335	345	370
52-2-3939					340
52-2-3940					340
52-2-3941					355
52-2-0603					380
Wonga East 4					300
Wonga East 5					300
52-3-0320					340
52-3-0325					315
52-3-0311					285
52-3-0310					385
52-2-0099					355
52-2-0229					365

Subsidence Movements after Bulli Seam was Mined

Swamp	Subsidence Used (m)	Overburden Depth (m)	Max Tensile Strain (mm/m)	Max Comp Strain (mm/m)	Max Tilt (mm/m)
CCUS1	0.7	285	3.7	7.4	12
CCUS2	0.1	285	0.5	1.1	2
CCUS3	1	300	5.0	10.0	17
CCUS4	0.1	290	0.5	1.0	2
CCUS5	0.5	272	2.8	5.5	9
CCUS6	1	285	5.3	10.5	18
CCUS7	1	270	5.6	11.1	19
CCUS8	0.1	270	0.6	1.1	2
CCUS9	0.1	293	0.5	1.0	2
CCUS10	0.5	280	2.7	5.4	9
CCUS11	1	340	4.4	8.8	15
CCUS12	0.5	355	2.1	4.2	7
CCUS13	0.1	335	0.4	0.9	1
CCUS14	1	275	5.5	10.9	18
CCUS15	0.1	325	0.5	0.9	2
CCUS16	0.5	300	2.5	5.0	8
CCUS17	0.1	325	0.5	0.9	2
CCUS18	0.1	325	0.5	0.9	2
CCUS19	0.1	325	0.5	0.9	2
CCUS20	1	290	5.2	10.3	17
CCUS21	1	280	5.4	10.7	18
CCUS22	0.5	317	2.4	4.7	8
CCUS23	0.1	310	0.5	1.0	2
CRUS1	0.5	300	2.5	5.0	8
CRUS2	0.5	210	3.6	7.1	12
CRUS3	0.4	295	2.0	4.1	7
BCUS1	1	270	5.6	11.1	19
BCUS2	0.5	285	2.6	5.3	9
BCUS3	0.5	265	2.8	5.7	9
BCUS4	0.5	295	2.5	5.1	8
BCUS5	0.5	273	2.7	5.5	9
BCUS6	0.1	308	0.5	1.0	2
BCUS11	0.5	335	2.2	4.5	7

Site ID	Subs 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	0.2	0.2	340	0.9	1.8	3	40
52-2-3940	0.1	0.1	340	0.4	0.9	1	20
52-2-3941	0.2	0.2	355	0.8	1.7	3	40
52-2-0603	0.3	0.3	380	1.2	2.4	3.9	50
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	0.1	0.1	310	0.5	1	2	20
52-3-0325	0.3	0.3	285	1.6	3	5	60
52-3-0311	< 0.1	< 0.1	255	< 0.5	< 1	< 2	< 20
52-3-0310	0.1	0.1	355	0.4	1	1	20
52-2-0099	0.1	0.1	325	0.5	1	2	20
52-2-0229	0.2	0.2	335	0.9	2	3	40

Incremental Subsidence Measured During Balgownie Seam Mining

Swamp	Subsidence Used (m)	Overburden Depth (m)	Max Tensile Strain (mm/m)	Max Comp Strain (mm/m)	Max Tilt (mm/m)
CCUS1	0.8	295	4.1	8.1	14
CCUS2	1	295	5.1	10.2	17
CCUS3	1	310	4.8	9.7	16
CCUS4	0.8	300	4.0	8.0	13
CCUS5	0.1	282	0.5	1.1	2
CCUS6	1	295	5.1	10.2	17
CCUS7	0.1	280	0.5	1.1	2
CCUS8	0.1	280	0.5	1.1	2
CCUS9	0.1	303	0.5	1.0	2
CCUS10	0.1	290	0.5	1.0	2
CCUS11	0.1	340	0.4	0.9	1
CCUS12	0.1	365	0.4	0.8	1
CCUS13	0.1	345	0.4	0.9	1
CCUS14	0.1	285	0.5	1.1	2
CCUS15	0.5	335	2.2	4.5	7
CCUS16	0.1	310	0.5	1.0	2
CCUS17	0.3	335	1.3	2.7	4
CCUS18	0.1	335	0.4	0.9	1
CCUS19	0.1	335	0.4	0.9	1
CCUS20	1	300	5.0	10.0	17
CCUS21	1	290	5.2	10.3	17
CCUS22	0.1	327	0.5	0.9	2
CCUS23	1	320	4.7	9.4	16
CRUS1	0.1	310	0.5	1.0	2
CRUS2	0.1	220	0.7	1.4	2
CRUS3	0.1	305	0.5	1.0	2
BCUS1	0.1	280	0.5	1.1	2
BCUS2	0.1	295	0.5	1.0	2
BCUS3	0.1	275	0.5	1.1	2
BCUS4	0.1	305	0.5	1.0	2
BCUS5	0.1	283	0.5	1.1	2
BCUS6	0.1	318	0.5	0.9	2
BCUS11	0.1	345	0.4	0.9	1

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 (m)
52-2-3939	< 0.1	< 0.1	340	< 0.5	< 1	< 2	< 20
52-2-3940	< 0.1	< 0.1	340	< 0.5	< 1	< 2	< 20
52-2-3941	< 0.1	< 0.1	355	< 0.5	< 1	< 2	< 20
52-2-0603	< 0.1	< 0.1	380	< 0.5	< 1	< 2	< 20
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	1.1	1.2	320	5.6	11	19	200
52-3-0325	N/A	N/A	295	N/A	N/A	N/A	N/A
52-3-0311	< 0.1	< 0.1	265	< 0.5	< 1	< 2	< 20
52-3-0310	N/A	0.1	365	N/A	N/A	N/A	N/A
52-2-0099	N/A	0.1	335	N/A	N/A	N/A	N/A
52-2-0229	N/A	0.2	345	N/A	N/A	N/A	N/A

Incremental Subsidence for Proposed Mining of Wongawilli Seam

Swamp	Subsidence Used (m)	Overburden Depth (m)	Max Tensile Strain (mm/m)	Max Comp Strain (mm/m)	Max Tilt (mm/m)
CCUS1	1.5	320	7.0	14.1	23
CCUS2	2	320	9.4	18.8	31
CCUS3	1.5	335	6.7	13.4	22
CCUS4	2	325	9.2	18.5	31
CCUS5	1.5	307	7.3	14.7	24
CCUS6	2	320	9.4	18.8	31
CCUS7	0.1	305	0.5	1.0	2
CCUS8	0.1	305	0.5	1.0	2
CCUS9	0.1	328	0.5	0.9	2
CCUS10	0.8	315	3.8	7.6	13
CCUS11	2	340	8.8	17.6	29
CCUS12	1.5	390	5.8	11.5	19
CCUS13	0.1	370	0.4	0.8	1
CCUS14	0.1	310	0.5	1.0	2
CCUS15	0.1	360	0.4	0.8	1
CCUS16	0.1	335	0.4	0.9	1
CCUS17	0.1	360	0.4	0.8	1
CCUS18	0.1	360	0.4	0.8	1
CCUS19	0.1	360	0.4	0.8	1
CCUS20	0.1	325	0.5	0.9	2
CCUS21	2	315	9.5	19.0	32
CCUS22	0.1	352	0.4	0.9	1
CCUS23	1.5	345	6.5	13.0	22
CRUS1	1.5	335	6.7	13.4	22
CRUS2	0.1	245	0.6	1.2	2
CRUS3	0.1	330	0.5	0.9	2
BCUS1	0.1	305	0.5	1.0	2
BCUS2	0.1	320	0.5	0.9	2
BCUS3	0.1	300	0.5	1.0	2
BCUS4	1.5	330	6.8	13.6	23
BCUS5	0.1	308	0.5	1.0	2
BCUS6	0.1	343	0.4	0.9	1
BCUS11	1.5	370	6.1	12.2	20

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 (m)
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

Cumulative Subsidence at the Completion of Bulli and Balgownie Seam Mining

Swamp	Subsidence Used (m)	Overburden Depth (m)	Max Tensile Strain (mm/m)	Max Comp Strain (mm/m)	Max Tilt (mm/m)
CCUS1	2	285	10.5	21.1	35
CCUS2	1.1	285	5.8	11.6	19
CCUS3	1.1	300	5.5	11.0	18
CCUS4	0.9	290	4.7	9.3	16
CCUS5	0.6	272	3.3	6.6	11
CCUS6	2	285	10.5	21.1	35
CCUS7	1	270	5.6	11.1	19
CCUS8	0.1	270	0.6	1.1	2
CCUS9	0.1	293	0.5	1.0	2
CCUS10	0.6	280	3.2	6.4	11
CCUS11	1	340	4.4	8.8	15
CCUS12	0.5	355	2.1	4.2	7
CCUS13	0.1	335	0.4	0.9	1
CCUS14	1.2	275	6.5	13.1	22
CCUS15	0.2	325	0.9	1.8	3
CCUS16	0.5	300	2.5	5.0	8
CCUS17	0.1	325	0.5	0.9	2
CCUS18	0.1	325	0.5	0.9	2
CCUS19	0.1	325	0.5	0.9	2
CCUS20	2	290	10.3	20.7	34
CCUS21	2	280	10.7	21.4	36
CCUS22	0.5	317	2.4	4.7	8
CCUS23	0.9	310	4.4	8.7	15
CRUS1	0.5	300	2.5	5.0	8
CRUS2	0.6	210	4.3	8.6	14
CRUS3	0.6	295	3.1	6.1	10
BCUS1	1	270	5.6	11.1	19
BCUS2	0.5	285	2.6	5.3	9
BCUS3	0.5	265	2.8	5.7	9
BCUS4	0.6	295	3.1	6.1	10
BCUS5	0.5	273	2.7	5.5	9
BCUS6	0.1	308	0.5	1.0	2
BCUS11	0.5	335	2.2	4.5	7

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 Cliff (m)
52-2-3939	0.2	0.7	340	3.1	6.2	10	120
52-2-3940	0.1	0.7	340	3.1	6.2	10	120
52-2-3941	0.2	0.7	355	3.0	5.9	10	120
52-2-0603	0.3	0.6	380	2.4	4.7	7.9	120
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	1.1	1.2	320	5.6	11	19	200
52-3-0325	0.3	0.3	315	1.4	3	5	60
52-3-0311	< 0.1	< 0.1	285	< 0.5	< 1	< 2	< 20
52-3-0310	0.1	0.1	385	0.4	1	1	20
52-2-0099	0.1	0.1	355	0.4	1	1	20
52-2-0229	0.2	0.2	365	0.8	2	3	40

Total Cumulative Subsidence at Completion of Bulli, Balgownie and Wongawilli Seam Mining

Swamp	Subsidence Used (m)	Overburden Depth (m)	Max Tensile Strain (mm/m)	Max Comp Strain (mm/m)	Max Tilt (mm/m)
CCUS1	2	285	10.5	21.1	35
CCUS2	3	285	15.8	31.6	53
CCUS3	2.5	300	12.5	25.0	42
CCUS4	2.4	290	12.4	24.8	41
CCUS5	1.8	272	9.9	19.9	33
CCUS6	3.8	285	20.0	40.0	67
CCUS7	1	270	5.6	11.1	19
CCUS8	0.1	270	0.6	1.1	2
CCUS9	0.1	293	0.5	1.0	2
CCUS10	1.5	280	8.0	16.1	27
CCUS11	3	340	13.2	26.5	44
CCUS12	1.5	355	6.3	12.7	21
CCUS13	0.1	335	0.4	0.9	1
CCUS14	1.3	275	7.1	14.2	24
CCUS15	0.2	325	0.9	1.8	3
CCUS16	0.5	300	2.5	5.0	8
CCUS17	0.1	325	0.5	0.9	2
CCUS18	0.1	325	0.5	0.9	2
CCUS19	0.1	325	0.5	0.9	2
CCUS20	2	290	10.3	20.7	34
CCUS21	3.8	280	20.4	40.7	68
CCUS22	0.5	317	2.4	4.7	8
CCUS23	2.1	310	10.2	20.3	34
CRUS1	0.8	300	4.0	8.0	13
CRUS2	0.6	210	4.3	8.6	14
CRUS3	0.6	295	3.1	6.1	10
BCUS1	1	270	5.6	11.1	19
BCUS2	0.5	285	2.6	5.3	9
BCUS3	0.5	265	2.8	5.7	9
BCUS4	2	295	10.2	20.3	34
BCUS5	0.5	273	2.7	5.5	9
BCUS6	0.1	308	0.5	1.0	2
BCUS11	2	335	9.0	17.9	30

SiteID	Subs 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 (m)
52-2-3939	1	2.4	340	10.6	21.2	35	450
52-2-3940	0.7	1.6	340	7.1	14.1	24	300
52-2-3941	1.4	1.6	355	6.8	13.5	23	250
52-2-0603	1.8	1.8	380	7.1	14.2	23.7	300
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	1.8	3.2	340	14.1	28	47	450
52-3-0325	1.4	1.8	315	8.6	17	29	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	0.5	1	355	4.2	8	14	150
52-2-0229	0.9	1	365	4.1	8	14	150