Strata Control Technology

Ashton Coal Operations Pty Ltd

Subsidence Assessment for the Extraction Plan for Longwalls 205-208 in the Upper Lower Liddell Seam

ASH4927_Rev 2

Mining Research and Consulting Group

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TITLE	Subsidence Assessment for the Extraction Plan for Longwalls 205-208 in the Upper Lower Liddell Seam
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SUMMARY

Ashton Coal Operations Pty Ltd (ACOL) is planning to mine Longwalls 205-208 in the Upper Lower Liddell (ULLD) Seam as part of their ongoing multi-seam operations at the Ashton Underground Mine (AUM). In accordance with development consent DA 309-11-2001i (MOD6) for the Ashton Coal Project (ACP), ACOL is preparing an Extraction Plan (EP) addressing secondary extraction of these longwall panels. ACOL commissioned SCT Operations Pty Ltd (SCT) to undertake a subsidence assessment to forecast the subsidence effects and assess impacts expected from the proposed mining to support their EP application. This report presents the results of our assessment.

Our assessment indicates that subsidence behaviour is expected to be similar to the subsidence behaviour forecast and currently observed for Longwalls 201-203 in the ULLD Seam. Maximum conventional subsidence effects forecast for the primary subsidence parameters are consistent with those predicted for Modification 6 (MOD6) to development consent DA 309-11-2001i. These forecast parameters are updated where necessary.

Notwithstanding the input of other specialists, subsidence impacts and environmental consequences from the proposed extraction of Longwalls 205-208 are expected to be compliant with the subsidence performance measures of ACP approval conditions, with the required management plans and associated risk control measures in place.

Impacts to the natural section of Bowmans Creek and diversion channels are expected to be consistent with those forecast in the MOD6 environmental assessment. Impacts to the drainage of the landform are expected to be manageable using a combination of mitigation and remediation strategies to reduce the potential for ponding.

Impacts to the general surface terrain, infrastructure and built features are expected to be similar to those observed above previous areas of multi-seam mining at AUM. ACOL has managed previous impacts to these surface features effectively and these subsidence management practices are expected to continue to be effective above Longwalls 205-208.

Impacts to major public utilities, including Lemington Road, mining related and mine owned built features and infrastructure are expected to be manageable, albeit with significant effort and comprehensive management plans, in some cases, required to minimise risks to serviceability and public safety.

Potential impacts from subsidence movements are not expected to constitute a principal hazard as defined by the *Work Health and Safety (Mines and Petroleum Sites) Regulation 2014* under provisions of existing and the required management plans that manage risks to health and safety from subsidence.

Ongoing and additional subsidence monitoring is recommended as a critical component to manage risks. Further detailed analysis and interpretation of subsidence monitoring data to revise existing, or inform future, multi-seam subsidence forecasts and assessments, is also recommended.

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1. INTRODUCTION

Ashton Coal Operations Pty Ltd (ACOL) is planning to mine Longwalls 205-208 in the Upper Lower Liddell (ULLD) Seam as part of their ongoing multi-seam operations at the Ashton Underground Mine (AUM) near Camberwell in the Hunter Valley of New South Wales (NSW). In accordance with Modification 6 (MOD6) to development consent DA 309-11-2001i for the Ashton Coal Project (ACP), ACOL is preparing an Extraction Plan (EP) addressing secondary extraction of these longwall panels. ACOL commissioned SCT Operations Pty Ltd (SCT) to undertake a subsidence assessment to forecast the subsidence effects and assess impacts expected from the proposed mining to support the EP application. This report presents the results of our assessment.

The report is structured to provide:

- Conclusions and recommendations including:
    - a summary of subsidence forecasts for the proposed mining
    - a review of subsidence performance measures as outlined in the ACP Approval conditions
    - a review of performance indicators
    - recommendations for ongoing subsidence monitoring and management.
- A brief overview of the site as context for the planned ULLD mining including a general description of significant surface features identified within the EP Assessment Area (EP Area) and a description of the mining geometry.
- Estimates of the incremental and cumulative subsidence effects expected as a result of the planned mining in the ULLD Seam within the EP Area including comparisons with previous subsidence predictions for longwall mining, an assessment of reliability of forecasts and a discussion of unconventional subsidence effects.
- A description of subsidence impacts to surface features and surface infrastructure located across the EP Area expected as a result of the forecast subsidence movements.

A review of items requiring assessment as detailed in the Subsidence Management Plan (SMP) guidelines is presented in Appendix 1.

An overview of previous multi-seam subsidence experience at AUM and a summary of understanding gained since the original Project Approval was granted is presented in Appendix 2.

Figure 1 shows an overall site plan for AUM with the planned Longwalls 205-208 and existing longwalls panels, superimposed onto a recent (August 2018) aerial image of the area. The EP Area and surface features of relevance to this assessment are also shown. The EP Area is based on an angle of draw of 26.5° or 0.5 depth to the ULLD Seam from the outermost goaf edge of all panels in all seams. The various surface features assessed for subsidence impacts and environmental consequences as required for an EP are also shown.

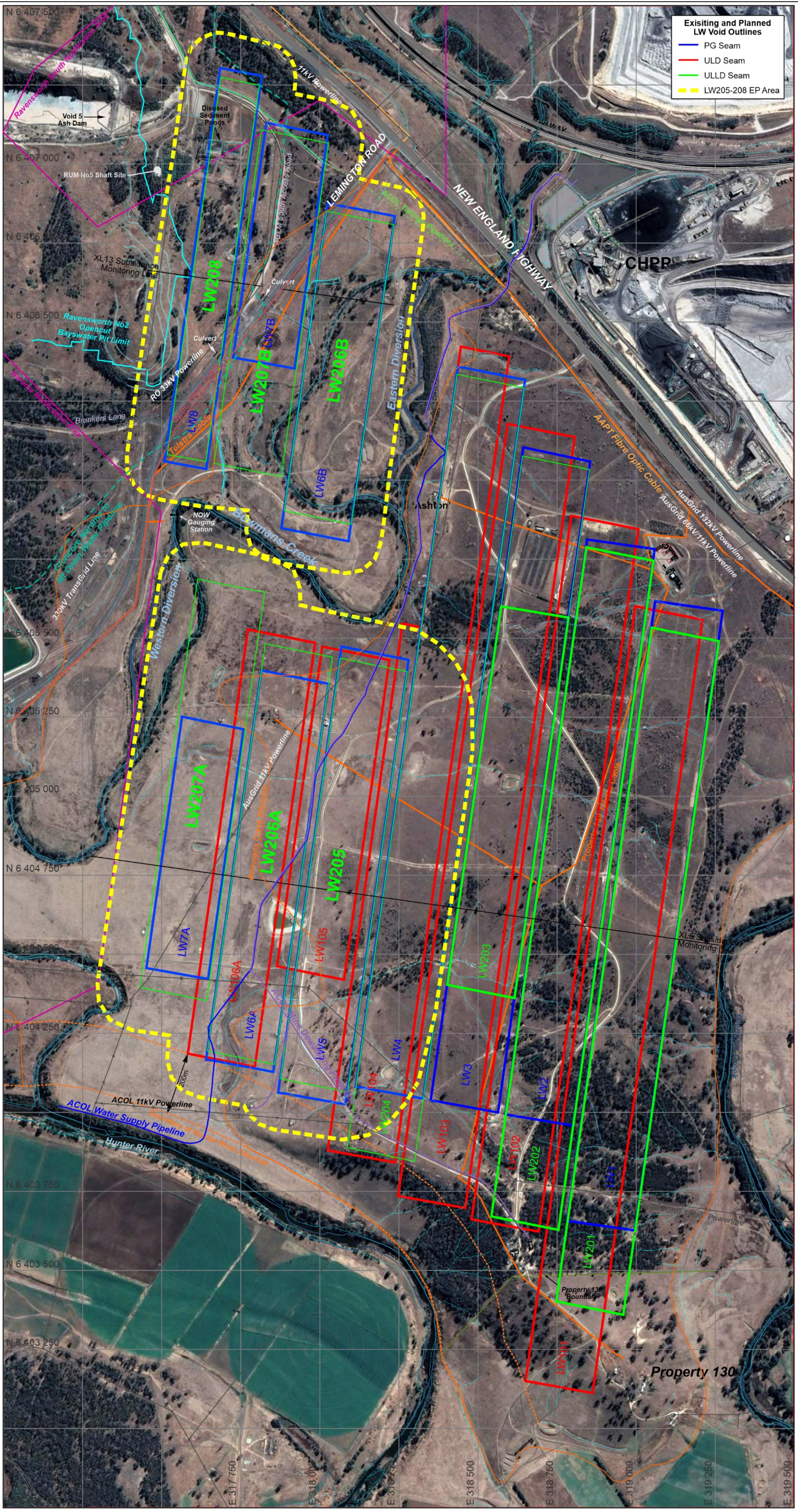


Figure 1: Overall Site Plan for AUM.

The subsidence effects and impacts to surface features are also assessed in the context of requirements under the *Work Health and Safety (Mines and Petroleum Sites) Regulation 2014* to manage risks to health and safety associated with subsidence.

SCT understands that other specialist assessments of subsidence impacts and associated environmental consequences for Surface and Groundwater, Biodiversity, and Aboriginal Heritage are to be included as supporting information within the EP. The findings of those assessments are not included in this report.

2. CONCLUSIONS AND RECOMMENDATIONS

The incremental subsidence effects forecast for Longwalls 205-208 are similar to those forecast for, and being observed over, Longwalls 201-203. The maximum cumulative subsidence effects forecast for Longwalls 205-208 are expected to be consistent with those predicted for MOD6 to DA 309-11-2001i. Forecasts of maximum strain and tilt values around stacked and undercut goaf edges have been increased as a result of monitoring experience at AUM.

In general, the incremental subsidence impacts from the forecast subsidence effects are expected to similar in nature and magnitude to those forecast for the mining of Longwalls 105-107 in the ULD Seam. Similar management strategies to those used for Longwalls 105-107 and Longwalls 201-204 are expected to be effective to mitigate and remediate subsidence impacts and environmental consequences from the planned mining of Longwalls 205-208.

Impacts to the natural section of Bowmans Creek and diversions channels are expected to be imperceptible and less than or consistent with those forecast in the MOD6 environmental assessment.

Impacts to landform drainage are expected to be manageable using a series of drainage channels to reduce the potential for ponding, although some of these would need to be substantial. Ponding would need to be managed during the period of mining as the surface topography changes in response to the mining and panel sequence. Farm dams may increase in volume and it is envisaged that these dams and other natural depressions on the broader flood plain where water ponded prior to mining would be retained with greater storage capacity.

Impacts to the minor infrastructure and built features are expected to be similar to impacts observed above the previous multi-seam mining areas. Previous impacts to these features have been effectively managed by ACOL. Subsidence management practices are expected to be effective for the surface features affected by Longwalls 205-208.

Impacts to major public utilities, mining related or mine owned built features and infrastructure are expected to be manageable, albeit with significant effort. A comprehensive subsidence management plan is required for mining below Lemington Road and associated infrastructure. This plan is expected to control hazards, minimise risk to serviceability and maintain public safety.

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

2.1 Subsidence Forecast

Table 1 summarises the primary subsidence parameters for conventional subsidence expected across each longwall in the EP Area as a basis for developing performance indicators. These are provided for both incremental and cumulative subsidence movements in general background areas away from overlying pillar or panel edges and for areas near stacked goaf edges.

Table 1: Maximum Incremental and Cumulative Subsidence Parameters Forecast for ULLD Seam Longwall Panels

ULLD Seam Longwall Panels Minimum Depth (m) – (Depth Range in brackets)	Longwalls 205-208 Forecast						
	ULLD Subs (m)	ULLD Strain (mm/m)			ULLD Tilt (mm/m)		
		General	Stacked Edges	Undercut Edges	General	Stacked Edges	Undercut Edges
Incremental Subsidence Parameters							
LW205 185 (185-225)	2.8	30	53	N/A	53	106	N/A
LW206A 205 (205-240)	2.8	27	48	N/A	48	96	N/A
LW206B 175 (175-210)	2.5	29	50	N/A	56	100	N/A
LW207A 220 (220-260)	2.6	24	41	47	45	83	95
LW207B 190 (190-225)	2.5	26	46	53	52	92	105
LW208 210 (210-240)	2.2	21	37	N/A	33	73	N/A
Cumulative Subsidence Parameters							
LW205 185 (185-225)	5.8	47	110	N/A	94	219	N/A
LW206A 205 (205-240)	5.8	42	99	N/A	85	198	N/A
LW206B 175 (175-210)	3.9	33	78	N/A	67	156	N/A
LW207A 220 (220-260)	4.4	30	70	80	60	140	160
LW207B 190 (190-225)	4.2	33	77	88	66	155	177
LW208 210 (210-240)	3.1	22	52	N/A	44	103	N/A

The maximum values of cumulative vertical subsidence forecast for the Longwalls 205-208 EP are consistent with forecasts in previous assessments for approval modifications or for extraction plans. The values of tilt and strain forecast for Longwalls 205-208 are consistent with those forecast for two and three seams of mining in DA 309-11-2001i (MOD6) for the Bowmans Creek Diversion (BCD) Environmental Assessment (EA).

2.2 Subsidence Performance Measures

Table 2 summarises the subsidence performance measures and the status of compliance expected during the secondary extraction of Longwalls 205-208, notwithstanding the input of other specialists.

Table 2: Subsidence performance measures and compliance status expected during the planned mining of Longwalls 205-208

Subsidence Performance Measure		*Status of compliance expected during planned mining*
Water		
Bowmans Creek	No greater subsidence impact or environmental consequences than predicted in the EA and the previous EIAs	Compliance expected because no greater subsidence effects compared to EA and previous Environmental Impact Assessments (EIAs) (other specialists to assess)
Bowmans Creek – Eastern and Western Diversions	Hydraulically and geomorphologically stable	Compliance expected because no significant subsidence effects forecast (other specialists to assess)
Bowmans Creek alluvium aquifer	No greater subsidence impact or environmental consequences than predicted in the EA and the previous EIAs	Compliance expected because no greater subsidence effects compared to EA and the previous EIAs (other specialists to assess)
Biodiversity		
Threatened species, populations, habitat or ecological communities	Negligible impact	Compliance expected because no greater subsidence effects compared to EA and the previous EIAs (other specialists to assess
Aboriginal Heritage Features		
Waterhole Site	Negligible impact	Compliance expected (planned mining remote so no impact expected)
Other Aboriginal heritage sites	No greater subsidence impact or than approved under a permit issued under section 90 of the national Parks and Wildlife Act 1974	Compliance expected because no greater subsidence effects compared to EA and the previous EIAs (other specialists to assess)
Built Features		
New England Highway, including the bridge over Bowmans Creek	Always safe and serviceable. Damage that does affect safety or serviceability must be fully repairable, and must be fully repaired	Compliance expected (planned mining remote so no impact expected)
Lemington Road and Brunkers Lane	In accordance with recommendations of the report prepared under condition 36	Compliance expected (impacts managed via provisions of Lemington Road Subsidence Management Plan [LRSMP])
Other built features, including other public infrastructure	Always safe. Serviceability should be maintained wherever practicable. Loss of serviceability must be fully compensated. Damage must be fully repaired or replaced, or else fully compensated	Compliance expected (impacts managed via provisions of Public Safety Management Plan [PSMP], Private Property Management Plan (PPMP) and Built Features Management Plan [BFMPs])
Public Safety		
Public Safety	No additional risk due to mining (in U/G mining area)	Compliance expected (impacts managed via PSMP, PPMP, BFMP and LRSMP)

The subsidence impacts associated with the planned extraction of Longwalls 205-208 are expected to be compliant with the subsidence performance measures outlined in the approval conditions assuming the required management plans and associated risk control measures are in place.

2.3 Performance Indicators

Condition 29 of Schedule 3 (Environmental Performance Measures) of the ACP Approval DA 309-11-2001-I (MOD6) requires detailed performance indicators are defined in the various management plans under the approval for each of the subsidence performance measures in Table 10 of MOD6. Condition 32 (d) requires detailed performance indicators be included in the EP for each of the subsidence performance measures in Table 10 (Table 2 above).

To prevent triggering reporting processes for events that are of no practical consequence, we recommend setting performance indicators for conventional subsidence effects at 20% above the best estimate of subsidence parameters to account for natural variability. The forecast for incremental subsidence parameters should generally not be used for performance indicators due the subjective nature of determining the measured incremental subsidence values in some locations.

Unconventional subsidence movements may exceed performance indicators, in some locations but these phenomena are easily identifiable. The effects of unconventional subsidence movements tend to be localised within narrow zones. We recommend that any exceedances associated with unconventional subsidence do not trigger formal exceedance reporting processes because unconventional subsidence movements are not an indication that subsidence behaviour is out of range or non-compliant with forecasts. Subsidence movements that exceed the performance indicators and are not associated with unconventional subsidence behaviour should trigger formal reporting processes.

The Aboriginal heritage grinding grooves site referred to as the "waterhole site" is approximately 200 metres (m) outside the EP Area, so that there is no credible potential for impacts from the proposed mining. Notwithstanding the input of other specialists, the absence of perceptible impacts following the completion of mining in Longwalls 205-208 is considered likely to be an appropriate performance indicator for this site.

The New England Highway pavement and bridge over Bowmans Creek are outside the EP Area. The bridge is more than 250m from the boundary of the EP Area. No impacts are expected at the bridge. Any impacts to the highway are expected to be imperceptible for all practical purposes and not expected to compromise safety or serviceability. Notwithstanding the input of other specialists, the absence of perceptible impacts following the completion of mining in Longwalls 205-208 is considered likely to be an appropriate performance indicator for this infrastructure.

Impacts to the Lemington Road / Brunkers Lane and associated infrastructure are expected to be manageable under the provision of a LRSMP in accordance with the recommendations of the specialist report and as required by Condition 36 of Schedule 3 of the ACP Approval DA 309-11-2001-i. Compliance with this management plan is likely to be an appropriate performance indicator for this infrastructure.

Similarly, an appropriate performance measure for other built features would be compliance with the various BFMPs for these items that are designed to maintain safety, serviceability or repair and compensate for loss of serviceability and damage.

The performance indicator for public safety would be the absence of any public safety incidents. Any such incidents would be considered to represent an exceedance of the subsidence performance measure that specifies no additional risk to public safety due to mining.

2.4 Recommendations

The following recommends are made in this report.

2.4.1 Subsidence Monitoring and Interpretation

Full details of the recommended subsidence monitoring are presented in Section 6. In summary, the recommended subsidence monitoring for Longwalls 205-208 includes:

- Three-dimensional monitoring of:
    - cross line XL5, over all the southern longwall panels
    - cross line XL13, over the northern longwalls
    - longitudinal lines located on the ULLD panel centreline (and parallel offset lines where applicable) at the start and end of each panel
    - cross lines XL12 and XL14 during the mining of Longwall 206B and 208 respectively.

- Monitoring of the three-dimensional movements of power poles on:
    - the southern 132 kilovolt (kV) power line located within the EP Area
    - the north–south 11kV power line above Longwalls 205-207A if these poles are not relocated
    - the 33kV powerline adjacent to Lemington Road
    - the 330kV powerline adjacent to Lemington Road.

- Installation and monitoring of survey lines:
    - along Lemington Road between CH100m to CH1350m (where chainage is measured from intersection with the New England Highway)
    - across Lemington Road at CH305m.

- Installation and surveying of monitoring points on:
  - the Lemington Road culverts
  - top of Ravensworth Underground Mine (RUM) No5 Shaft
  - Ravensworth Void 5 Ash Dam.

- A LIDAR survey at the completion of mining all panels in the ULLD Seam.

Routine visual monitoring recommended for the EP Area includes regular inspections of:

- New England Highway, access roads, powerlines, pipelines, buried cable routes, farm infrastructure and general landform in the areas of active subsidence

- Lemington Road and AGL Macquarie (AGLM) and Glencore infrastructure during mining of Longwalls 206B, 207B and 208

- Bayswater Pit interface edge during the mining of Longwalls 207B and 208.

Regular, detailed analysis and interpretation of the monitoring data from the ULLD Seam mining is recommended to revise existing forecasts and inform future subsidence forecasts and assessments. End of panel reports are recommended for each longwall (i.e. Longwall 205, 206B, 207B and 208) with a focus on determining the mechanics of the observed subsidence behaviour.

2.4.2 Subsidence Management

Existing management plans in place at AUM are expected to be suitable to manage most of the potential risks and impacts from further subsidence.

Further recommendations for subsidence monitoring, the application of performance indicators, for risk control measures to mitigate or remediate potential subsidence impacts are made throughout this report. Most of these recommendations are for management strategies or potential inclusions in management plans.

Specific management strategies are required for the New England Highway and associated 11kV powerline, Lemington Road and associated culverts, 330kV, 132kV, 33kV and 11kV power lines, buried fibre optic cables, AGLM's access roads and farm infrastructure, Glencore's Mt Owen water pipeline and ACOL's tailings disposal, water supply and mine dewatering pipelines, access roads and farm infrastructure. These management strategies are detailed in Section 5 of this report.

Options to mitigate the subsidence impacts that cause ponding, including those from the potential inundation of natural ponding areas are considered in the landform drainage section of this report with specific recommendations for further work detailed.

3. SITE DESCRIPTION

This section presents a description of the proposed mining geometry, the surface features within the EP Area, overburden depth, mining section thickness and other parameters of relevance to this assessment.

The EP Area and surface features of relevance to this assessment are shown in Figures 1 and 2. Figure 2 focuses on the area of Longwalls 205-208 and is included for clarity.

The surface topography above the mining area at AUM is dominated by a steeply rising ridge line adjacent to Glennies Creek in the east from which the ground slopes toward Bowmans Creek in the west and to the Hunter River in the south.

The longwall mining area is bounded by surface features, both natural and built. These features include the New England Highway and infrastructure corridor in the north, Glennies Creek to the east, the Hunter River to the south and a combination of Bowmans Creek and its diversion channels and adjacent mining operations to the west. Other infrastructure that crosses the mining area includes Lemington Road and adjacent infrastructure, minor access roads, powerlines, fibre optic cables, water and wastewater pipelines and gas drainage infrastructure.

3.1 Assessment Area

The EP Area for Longwalls 205-208 is determined as the area encompassing all the areas likely to be impacted by vertical subsidence movements. The EP Area is defined by a distance equal to 0.5 times the overburden depth to the ULLD Seam (equal to a 26.5° angle of draw) from the outermost goaf edges of the planned Longwalls 205-208 panel voids or the goaf edges of overlying seams, whichever is the greater. The eastern boundary of the EP Area, adjacent to Longwall 205, extends as far as the eastern goaf edge of Longwall 204 to include the subsidence effects from interactions from mining below Longwall 104 chain pillar.

Based on subsidence monitoring experience at AUM this method of defining the EP Area for Longwalls 205-208 is considered a conservative option for identifying surface features that may be impacted by secondary extraction and assessing potential impacts to these features. Any subsidence related movements beyond this distance are expected to be small enough to be insignificant for all practical purposes. Subsidence sensitive features located outside the area that have potential to be affected by mining subsidence impacts are also included in this assessment.

3.2 Approvals Context

AUM operates under modified development consent DA 309-11-2001i for the ACP. In addition to its open cut operations, the ACP includes the underground longwall mining of four seams. In descending order these seams are the Pikes Gully (PG), Upper Liddell (ULD), ULLD and Lower Barrett (LB) Seams. The exact location of longwall panels is not fixed under the development consent but may vary within the approved footprint to meet mining engineering requirements or to minimise environmental impacts.

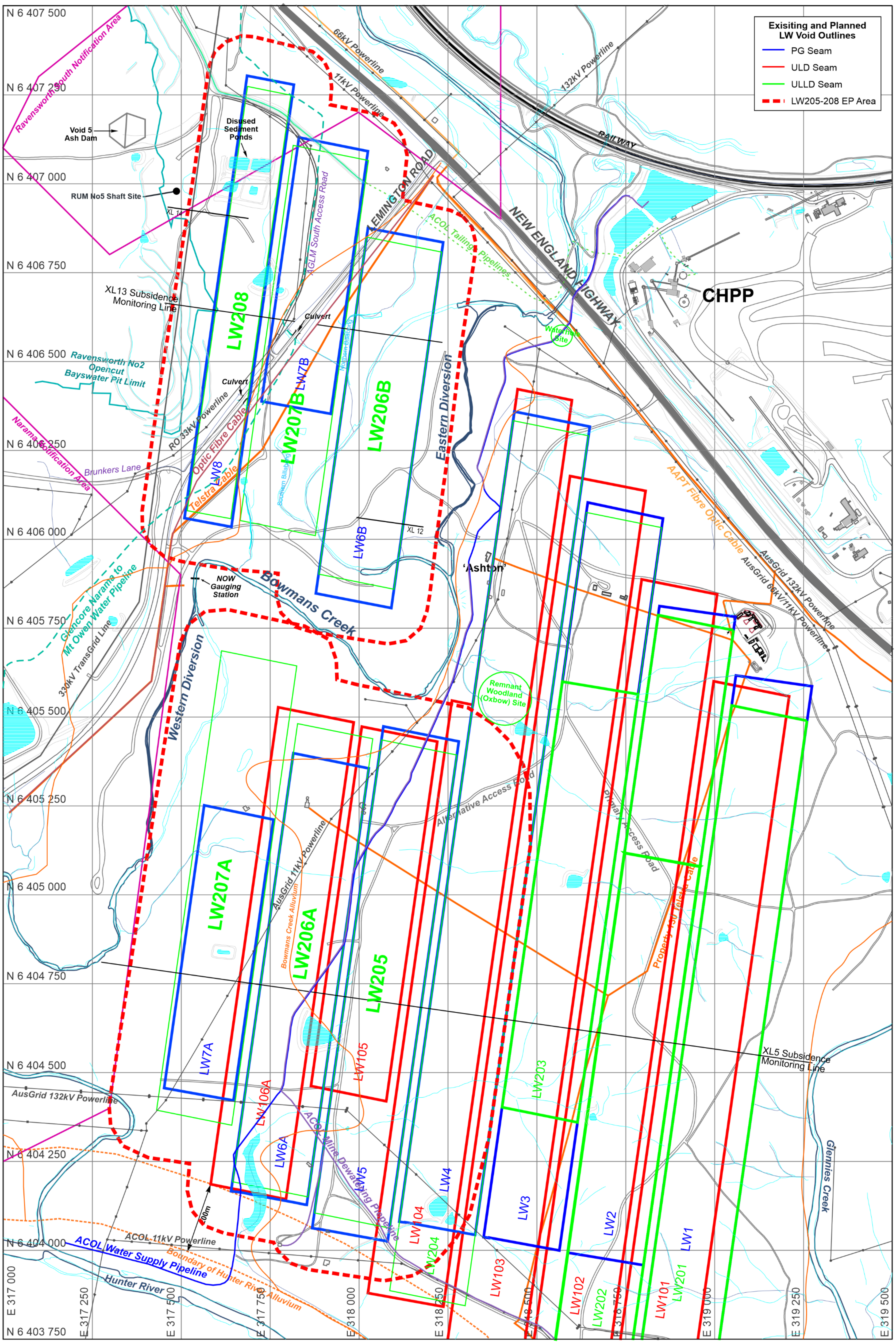


Figure 2: Site Plan for Longwalls 205-208.

The original mine plan included up to seven longwall panels in each seam, subject to satisfying various conditions of consent, most of which related to ongoing assessment and management of impacts to Bowmans Creek and associated alluvial aquifers. The longwall panels in each of the four seams were originally considered in a regular, parallel, stacked (superimposed) geometry.

The number of longwall panels and the layout design has changed several times via modifications to the ACP Approval. These changes include adopting an offset (staggered) geometry, truncating some longwalls and dividing others into two sections and modifying the mining sequence. Most of the changes were made to reduce subsidence effects and impacts to surface features including Bowmans Creek (and diversion channels) and Lemington Road.

AUM currently has EP approvals for Longwalls 105-107 in the ULD Seam and Longwalls 201-204 in the ULLD Seam. These EP approvals cover areas above and adjacent to the proposed mining in Longwalls 205-208, the subject of this assessment.

In accordance with the requirements of Condition 32, Schedule 3 of DA 309-11-2001-i, ACOL is required to prepare and gain approval of an extraction plan prior to undertaking second workings (longwall extraction). To support the preparation of the EP for Longwalls 205-208, this subsidence assessment provides:

- revised forecasts of the conventional and non-conventional subsidence effects

- revised forecasts of subsidence impacts of the proposed second workings, incorporating any relevant information obtained since granting of the Project Approval including incremental and cumulative subsidence effects and impacts from multi-seam mining

- a comparison of forecast subsidence impacts against the subsidence performance measures described in Schedule 3, Condition 29 of DA 309-11-2001-i.

The EP requirements include specific management plans for features within the EP Area including Built Features, Public Safety, Rehabilitation, Water, Biodiversity, Land and Heritage. These plans detail the management of potential subsidence impacts and/or environmental consequences caused by the proposed second workings.

3.3 Land Ownership and Land Use

Most of the surface above the EP Area is within mining leases ML1533 and ML1623 held by ACOL. The area is predominantly farmland owned by ACOL. This land is used for cattle grazing and activities associated with mining, including gas drainage and water management. A triangle of land in the north western corner of the EP Area, mainly to the west of Lemington Road, is owned by AGLM. A small portion is owned by Glencore Ravensworth Operations (RO). The AGLM land is part of the now completed Glencore Ravensworth No 2 open cut mine, the remnant voids of which are being used for ash and tailings disposal.

The Ravensworth Void 5 Ash Dam is outside the EP Area however, the Ravensworth South Notification Area extends over the northwest corner of the EP Area. The Narama Notification Area around the Narama Dam is located adjacent to the EP Area. Both these dams are declared dams under the jurisdiction of the Dams Safety NSW.

A private dairy farm property known as Property 130 is located more than 600m to the southeast of the EP Area.

3.4 Surface Features and Surface Infrastructure

Surface features identified within the EP Area for Longwalls 205-208 are described in this section. Surface and sub-surface features relating to groundwater, biodiversity, and Aboriginal heritage items are not included.

Figure 2 shows the locations of the various surface features identified. These features are identified based on:

- site visits for previous subsidence assessments and end of panel reports over essentially the same area
- review of historical satellite imagery for the site
- site inspections by SCT conducted on 14 November 2018 and 15 January 2020 to inspect subsidence impacts from Longwalls 201 and 202 and the surface above the planned layout of Longwalls 205-208.

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

3.4.1 Natural Features

Major natural features in the EP Area for Longwalls 205-208 include sections of Bowmans Creek (Foys Brook) and associated natural ponds (billabongs), a diversion channel, excised sections of the original channel, the adjacent Bowman Creek Alluvium and the general floodplain landform.

Bowmans Creek flows along a channel incised into the floodplain that merges with the broad Hunter River floodplain in the south of the EP Area. Narrow bands of natural vegetation remain on either side of the creek (and diversion channels) within the Bowmans Creek Riparian Corridor and Woodland.

ACOL diverted Bowmans Creek in two places to allow more efficient recovery of the coal resource. Only two small sections of the western diversion channel are located within the EP Area. The eastern diversion channel is on the boundary of the EP Area. The Hunter River and edge of the Hunter Alluvium are located more than 200m to the south of the nearest goaf edge of the planned panels.

There are several minor ephemeral drainage lines within the EP Area. These flow mainly into Bowmans Creek. A series of minor farm dams, mostly constructed before underground mining commenced, are located on these drainage lines. Numerous depressions both natural and subsidence related exist as part of the current landform of the floodplain. Two natural ponds (billabongs) are located adjacent to the section of Bowmans Creek excised by the eastern diversion channel in the north. A large natural pond (billabong) depression in the south of the EP Area was dammed prior to mining. Overflow from this pond reports to the Hunter River.

Aboriginal heritage sites in the vicinity of Longwalls 205-208 include the Waterhole Site (with grinding grooves) located on Bowman Creek adjacent to the New England Highway and the Remnant Woodland Site located adjacent to Bowmans Creek above Longwall 4 and 104. Both these sites are located outside the EP Area and impacts are to be assessed by other specialists.
Impacts to Biodiversity features including threatened and protected species or endangered ecological communities are also to be assessed by other specialists.

3.4.2 Non-Mining Built Features and Infrastructure

Public utilities in the vicinity of the EP Area for Longwalls 205-208 include the New England Highway, Lemington Road and infrastructure located adjacent to these roads and mainly within the road corridors.

Major infrastructure in the New England Highway corridor includes overhead 132kV, 66kV and 11kV power transmission lines and a buried fibre optic cable linking Sydney and Brisbane. Only small sections of the 11kV powerline are within the EP Area.

Major infrastructure adjacent to Lemington Road includes an overhead 330kV power transmission line, and two local drainage culverts below Lemington Road. The 330kV powerline is positioned just inside and parallel to the western boundary of the EP Area.

Two overhead power transmission lines traverse the southern section of the EP Area. A 132kV powerline crosses from east to west and a local area 11kV power line crosses from south to north.

The NSW Office of Water (NOW) stream gauging station on Bowmans Creek is located just outside the EP Area. This station is serviced by a buried telecommunication (Telstra) cable on the eastern side of Lemington Road.

There are also several survey control stations within the EP Area or area to be impacted by the planned mining.

3.4.3 Mining Related or Mine Owned Built Features and Infrastructure

Mining related infrastructure within the EP Area for Longwalls 205-208 includes infrastructure owned by Glencore, AGLM and ACOL. This infrastructure is located on or traverses land owned by AGLM and ACOL.

Infrastructure on AGLM land includes a 33kV power transmission line located adjacent to and on the western side of Lemington Road. This powerline supplies RO. Other built features and infrastructure on AGLM land include Ashton coal handling and preparation plant (CHPP) tailings disposal pipelines (buried and above ground), access roads, disused sedimentation ponds, and other farm infrastructure including dams, fences and gates.

The pit shell of the filled and capped Ravensworth No 2 open cut (Bayswater Pit) is located within the western boundary of the EP Area with a very small section extending over the western panel edge of Longwall 208.

A fibre optic cable that services RO is understood to run parallel with and to the east of Lemington Road on Glencore and AGLM land. The buried water supply pipeline that runs north from Narama Dam to the Glencore Mt Owen Complex mines crosses land owned by RO and land owned by AGLM.

First workings in the Pikes Gully Seam at RUM extend close to the northwest corner of the EP Area. These main headings development roadways are currently idle because RUM is in ‘care and maintenance’. RUM’s No 5 ventilation shaft was constructed in an area of solid coal and is not currently connected to the underground workings. This shaft is outside the EP Area.

Infrastructure and built features owned by ACOL on ACOL land within the EP Area include buried CHPP tailings disposal pipelines, a buried water supply pipeline from the Hunter River to CHPP, gas management (drainage) installations, mine dewatering pump installations and associated overhead power supply lines and buried discharge pipelines.

Other infrastructure located within the EP Area includes a disused residential farmhouse with associated buildings, buried telecommunication (Telstra) cables, access roads/tracks, agricultural land and minor farm infrastructure such as water reticulation systems, dams, fences, gates and cattle grids.

The alternative access road to Property 130 crosses the south eastern part of the EP Area, directly above Longwall 205 for the majority of the length of this panel.

3.5 Proposed Mining

This section presents an overview of the mining at AUM to date, the planned mining layout for Longwalls 205-208 and seam geometry details relevant to this assessment.

3.5.1 History of Mining

In descending order, the four coal seams approved to be mined are the PG, ULD, ULLD and LB Seams. The naming convention for overlying panels is: Longwall 1 in the PG Seam, Longwall 101 in the ULD Seam and Longwall 201 in the ULLD Seam.

A series of eight longwall panels were mined in the PG Seam. Longwall mining in this seam is now complete. To date, six of the planned seven longwall panels in the second seam (ULD Seam) have been extracted or partly extracted. The northern part of the sixth longwall (Longwall 106B) and two parts of the seventh longwall (Longwalls 107A and 107B) have not been mined. The third longwall (Longwall 203) panel in the third seam (ULLD Seam) is being mined at the time of writing this report.

In the offset geometry, the panels in the first seam (PG) and third seam (ULLD) are superimposed. The second seam (ULD) and planned fourth seam (LB) are also largely superimposed but these panels are offset 60m to the west relative to the PG and ULLD Seam panels.

Most of the longwalls form voids that are nominally 216m wide separated by inter-panel chain pillars that are typically 25m wide (measured coal rib to coal rib). Exceptions are Longwalls 7A, 7B and 8 in the PG Seam which vary to accommodate the lease boundary. These panels are 198m, 198m and 134m wide respectively. They are separated by slightly wider chain pillars. Longwall 107A in the ULD Seam was planned to be 161m wide. All panels are aligned in a general north-south direction. The longwall face retreats from south to north and the panel sequence is typically from the east to the west.

The overburden depth to the PG Seam increases from approximately 40m in the northeast corner of Longwall 1 to approximately 180m in the southwest corner of Longwall 7A and along the edge of Longwall 8. The interburden thicknesses are typically in the range 35-40m for the PG to ULD seams, 20-35m for the ULD to ULLD seams and 35-45m for the ULLD to LB seams.

The mining height for each seam has been approximately 2.5 ± 0.3m. Mining heights are a function of either the seam thickness or the practical operating height range of the mining equipment.

The strata dips moderately to the west at approximately 1 in 10. The gradient of the seam is typically greater than the gradient of the surface topography.

3.5.2 Planned Mining Geometry for Longwalls 205-208

For this subsidence assessment, the current mining in the ULLD Seam is assumed to continue so Longwalls 204, 205, 206A, 206B, 207A, 207B and 208 are mined in that order. Longwalls 106B, 107A and 107B in the ULD Seam are not planned to be mined so there will be a combination of double seam mining (Longwalls 206B, 207A, 207B and 208) and triple seam mining (Longwalls 205 and 206A).

The planned layout for Longwalls 205-208 is a continuation of the layout for Longwalls 201-204. The ULLD Seam goaf edges are generally below the PG Seam panel edges and offset 60m to the east of the ULD Seam layout. With previous mining in the PG Seam and over a smaller area in the ULD Seam, there are locations where mining in the ULLD Seam will create a range of different goaf edge types.

Longwalls 205 and 206A form normal triple seam goaf edges such as those that have been developed over most of Longwalls 201-204. The start and finish lines of both panels are inside the footprint of overlying goaf areas in the PG and ULD Seams so undercut goaf edges are not formed but there are goaf edges close together in three seams. Permanent strains and tilts higher than background but less than fully triple seam stacked edge are expected at the start and finish of both panels where goaf edge cracks formed during mining in the PG and ULD Seam are likely to be remobilised.

Longwalls 206B and 208 mine below PG Seam longwall panels forming a double seam mining geometry with double stacked goaf edges on both sides of each panel. Strains and tilts on the sides of the panel are expected to be elevated above those observed in offset geometries and consistent with a fully stacked edge. Both panels start and finish inside the footprint of the overlying goaf in the PG Seam so neither panel forms fully stacked goaf edges or undercut goaf edges at the start or finish. Permanent strains and tilts higher than background but less than fully stacked are expected at the start and finish of both panels when goaf edge cracks formed during mining in the PG Seam above are remobilised.

Longwall 207A mines below a PG Seam longwall goaf forming a double stacked mining geometry with a slightly undercut stacked edge on the western side of the panel and a three seam offset goaf edge on the eastern side of the panel. Longwall 207A starts and finishes outside the PG Seam longwall goaf so that a dynamic stacked edge will form at both ends of the panel. The stacked edge at the finishing end of Longwall 7A in the PG Seam is expected to produce tilts and strains consistent with an undercut goaf edge. The dynamic stacked edge at the start of the panel is expected to subside an area of intact ground more evenly leading to strains and tilts more typical of normal background, double seam mining conditions.

Longwall 207B mines a similar geometry to Longwalls 206B and 208 leading to double stacked edges on both sides of the panel in a two seam mining geometry. Longwall 207B starts outside the footprint of Longwall 7B in the PG Seam leading to a dynamic stacked edge when the start line of Longwall 7B is mined under. Mining a stacked edge from solid to goaf is expected to generate strains and tilts that are more typical of normal background, double seam mining conditions. Longwall 207B finishes within the footprint of Longwall 7B so a stacked edge is not expected to develop. Permanent strains and tilts higher than background are expected when cracks formed during mining in the PG Seam above are remobilised, but these strains and tilts are not expected to be as high as they would be for stacked goaf edge.

This layout maintains a minimum offset of 200m to the Hunter River Alluvium and a 40m offset to the high bank of Bowmans Creek in accordance with the ACP Approval – Statement of Commitments.

Table 3 summarises the nominal dimensions planned for Longwalls 205-208 in the ULLD Seam.

Overburden depth ranges from a minimum 175m above the northeast corner of Longwall 206B to a maximum 260m over the southwest corner of Longwall 207A. The depth is approximately 215m at the southeast corner of Longwall 205 and approximately 220m at the northwest corner of Longwall 208.

The seam thickness of the ULLD varies from 1.6m to 3.0m over the area of Longwalls 205-208 but is mostly within the range 2.0-2.8m. The mining height is assumed to be in the range 2.2m to 2.8m

Table 3: Proposed Longwall 205-208 Panel Dimensions

Panel	Gateroad Width (m)	MG Chain Pillar Width - Rib to Rib (m)	LW Void Width (m)	LW Void Length (m)
LW205	5.4	24.6	216	1343
LW206A	5.4	24.6	216	1300
LW206B	5.4	24.6	216	957
LW207A	5.4	26.6	216	1304
LW207B	5.4	26.6	216	1065
LW208	5.4	24.6	124	1204

ULD to ULLD Seam interburden thickness ranges over the planned layout area of Longwalls 205-208 from approximately 20m to 40m but is more typically in the range 25-35m.

4. FORECAST SUBSIDENCE BEHAVIOUR

The EP process provides an opportunity to update subsidence forecasts and assessment of impacts based on additional information and understanding gained since project approval. This section presents:

- updated forecasts of conventional and unconventional subsidence effects
- reliability and accuracy of subsidence forecasts
- comparisons with previous subsidence forecasts.

A detailed review of previous subsidence monitoring at AUM, the mechanics of ground movement implied and the forecasting approach used for the primary subsidence effects parameters is presented in Appendix 2.

4.1 Forecast Subsidence Movements

Table 1 summarises the primary subsidence parameters for conventional subsidence expected across each longwall in the EP Area. These subsidence parameters are provided for both incremental and cumulative subsidence movements in the centre of panels away from panel goaf edges (general background), at stacked goaf edges where the panels are directly superimposed and at undercut goaf edges where mining in the lower seam extends 0.3 times the interburden depth under the overlying goaf edge.

4.1.1 Vertical Subsidence

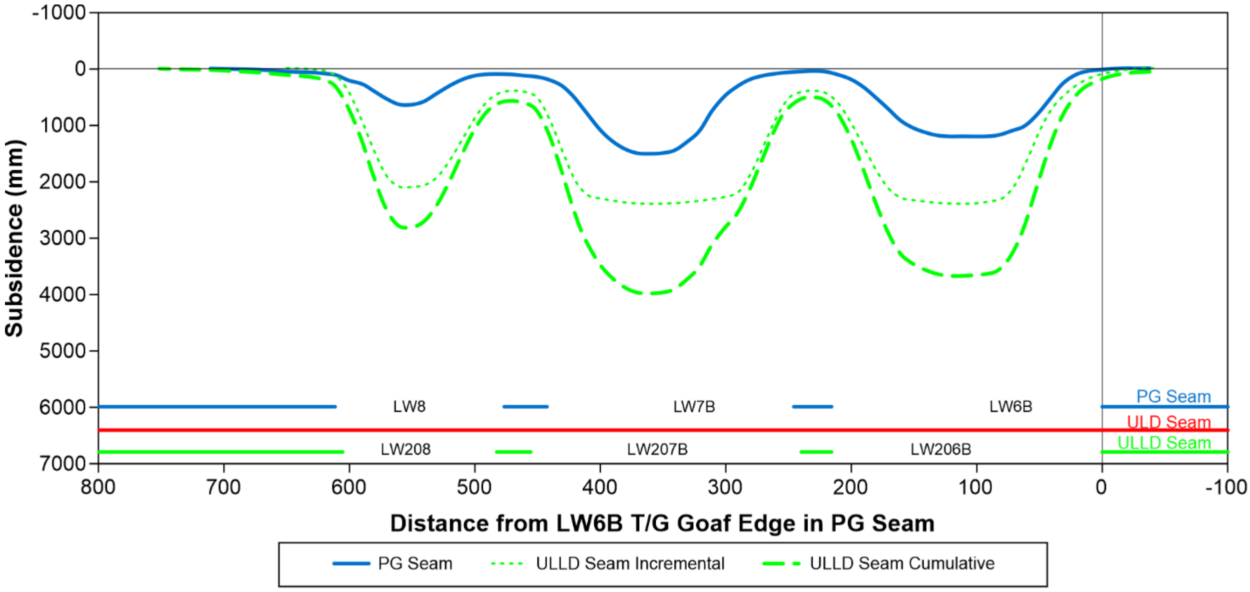
Subsidence from mining Longwalls 205-208 in the ULLD Seam is expected to cause additional incremental vertical subsidence of up to 2.8m. The cumulative vertical subsidence in the central part of longwalls, where there is overlap between panels in three seams, is expected to be generally less than 5.8m. Maximum subsidence is expected to occur within the mining footprint and diminish with distance from the outermost edge of mining. The angle of draw from the outermost goaf edge in a multi-seam mining environment is expected to be similar to the angle of draw in a single seam operation.

Figure 3 shows estimated incremental and cumulative subsidence profiles for Longwalls 205-207A along the XL5 subsidence monitoring line that crosses the southern panels. The estimated incremental and cumulative subsidence profiles along the XL13 Line alignment across Longwalls 206B-208 are also shown. These profiles show the actual subsidence measured for the existing PG and ULD Seam longwalls and include the forecast profiles for the yet to be mined ULLD Seam panels.

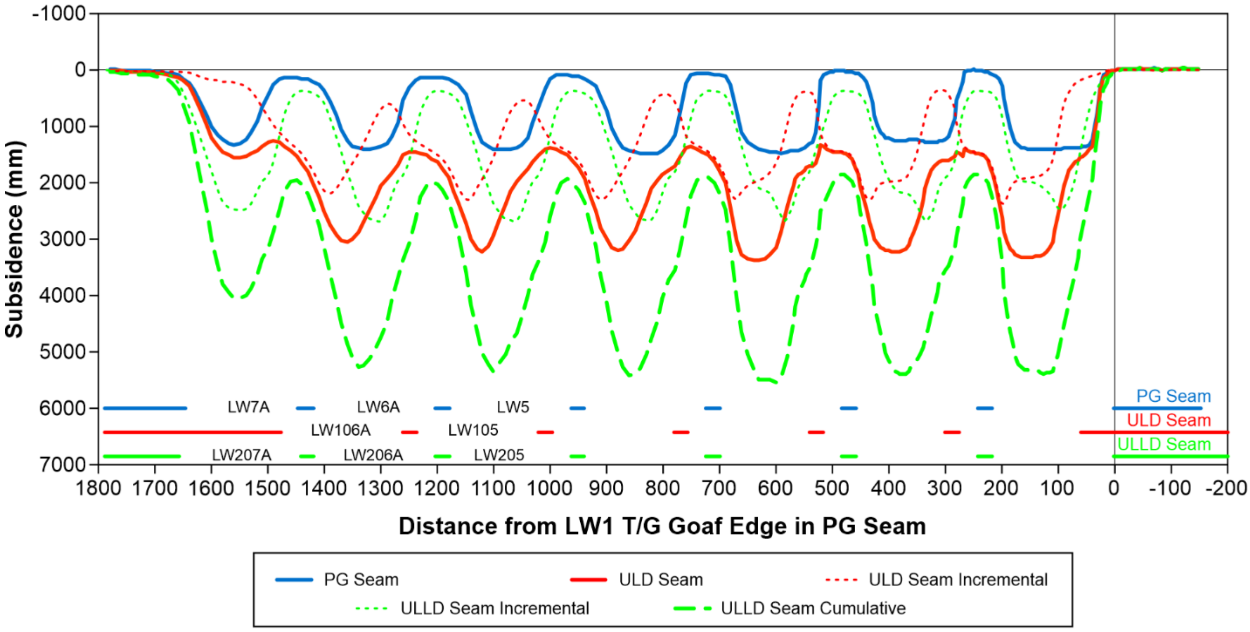
Figure 4 shows the incremental subsidence contours estimated for Longwalls 205-208. Experience indicates maximum vertical subsidence from mining in a single seam is naturally variable by about 15% for any given panel geometry and overburden depth. Multi-seam subsidence is expected to be more variable, so the subsidence contours shown should be regarded as indicative of the general level of subsidence that can be expected rather than as providing a high level of precision of the subsidence value at a point.

Any variations in cutting heights are expected to proportionally influence the maximum subsidence and other subsidence parameters. However, given the magnitude of previous subsidence, the consequences of any variations from forecast are less for the multi-seam mining at AUM than they would be for single seam mining.

Figure 5 shows a summary of the incremental and cumulative subsidence effects measured along XL5 cross-panel monitoring line at the end of mining in the PG Seam and after Longwall 106A in the ULD Seam was completed. The preliminary results for Longwalls 201-203 to date, are also shown.



a) XL13 Subsidence Lines - ULLD Seam LW206B-208 Forecast.



b) XL5 Subsidence Lines - ULLD Seam LW205-207A Forecast.

Figure 3: Estimated incremental and cumulative subsidence profiles for Longwalls 205-208.

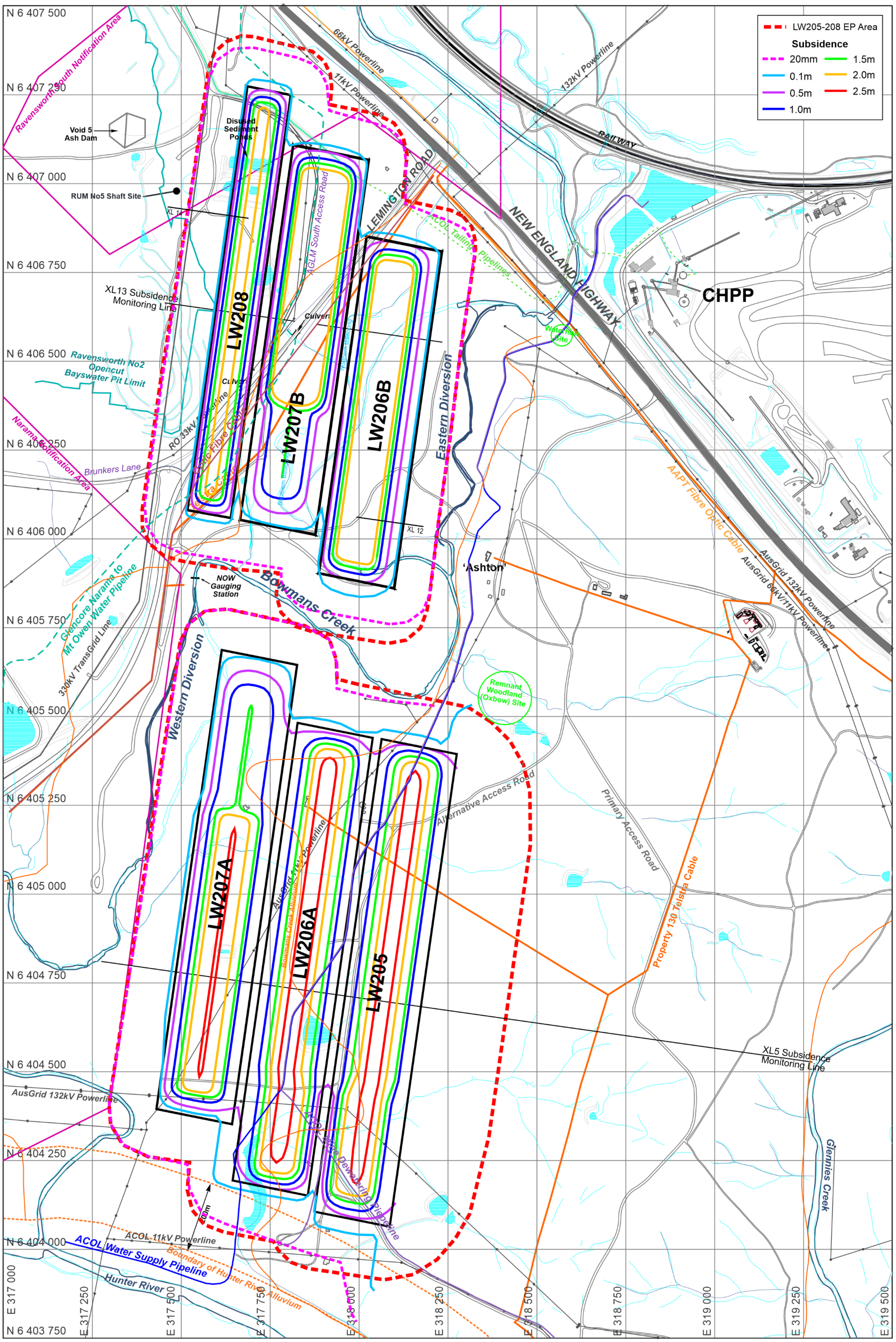


Figure 4: Estimated incremental subsidence contours for Longwalls 205-208.

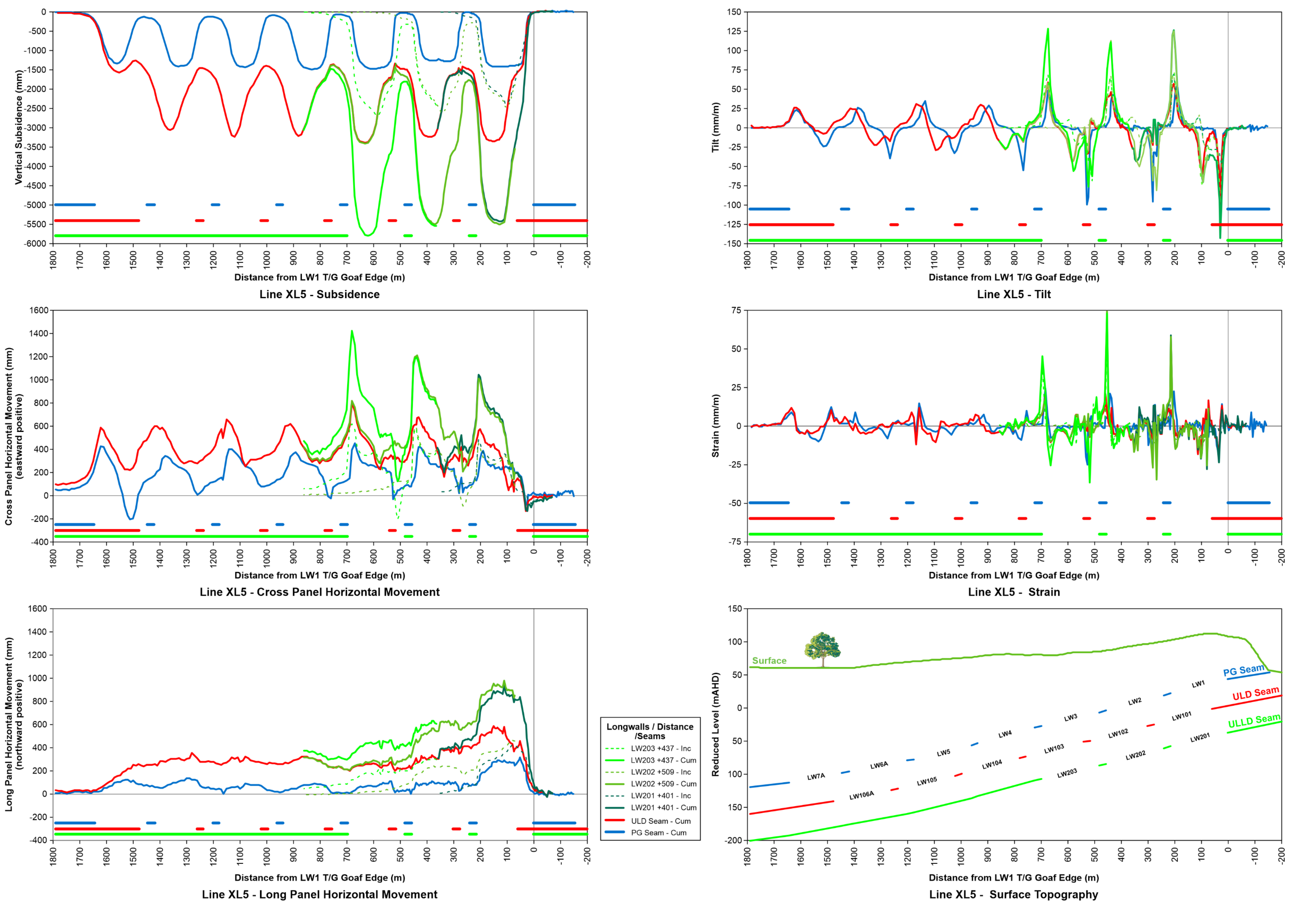


Figure 5: Subsidence summary of the main parameters of subsidence from the monitoring on XL5 Line.

4.1.2 Strain and Tilt

Table 1 presents the estimates of maximum strain and maximum tilt for the mining of Longwalls 205-208. These values are calculated using the Holla approach with K factors derived from the AUM multi-seam monitoring experience. The K factor for cumulative tilt in general background areas has been increased slightly from that used in the Longwalls 201-204 forecast to reflect the monitoring results from Longwalls 201-203.

General background levels of maximum strain and tilt are expected over most of the longwall goaf areas where mining in two and three seam takes place. Permanent strains and tilts are expected to occur at panel edges.

Surface cracking is expected to be similar in character to that observed previously above Longwalls 201-203. Cracks of up to 300 millimetres (mm) wide are expected in areas where there is interaction and reworking of previous fractures from either the PG Seam, ULD Seam or both.

Goaf edges stacked in two or more seams are expected to produce locally elevated strains and tilts when mining in a lower seam causes fractures formed at goaf edges in the overlying seam or seams to be remobilised. Large cracks, locally steep grades and perceptible changes in elevation are expected at stacked edges and these effects are expected to increase with each additional seam mined. Similar effects may be evident when two seams are stacked and the intermediate seam is offset. Large cracks, high strains and high tilts may be temporary just behind the moving longwall face and permanent at the start and finish lines and along the sides of panels.

Very high strains and tilts are expected when the panel being mined undercuts the overlying goaf edge by a distance approximately 0.3 times the interburden between the seams. Within the area of Longwalls 205-208, the only place a full undercut occurs is when Longwall 207A mines under the finish line of Longwall 7A. High dynamic strains and tilts and large cracks are expected approximately 40-50m south of the finish line of Longwall 7A in the PG Seam when Longwall 207A approaches and mines under this area. Strains and tilts are expected to reach their maximum when Longwall 207A is approximately 20m past the finish line of Longwall 7A.

A slight undercut of 5m occurs along the western edge of Longwall 208, but the 60m separation of the seams means that the strains and tilts are likely to be more consistent with a double stacked edge rather than an undercut.

The effects from stacked edges are expected to be most prominent where permanent, triple stacked edges are formed. There are no triple stacked edges formed, but the finish line of Longwall 205 and the start line of Longwall 206A form edges that are within 25-40m of each other. Effects approaching the high strains and tilts of a triple stacked goaf edge are expected at these locations.

Double stacked goaf edges are formed with the PG Seam goaf along the edges of Longwalls 206B, 207A, 207B and 208. Near double stacked goaf edges are formed at the start and finish of all panels except the finish of Longwall 207A and the start of Longwall 207B. Permanent and elevated strains and tilts and large cracks are expected in all these areas.

4.1.3 Horizontal Movements

Analysis of the subsidence monitoring data from AUM indicates that the magnitude, direction, and form of horizontal movements from multi-seam mining are consistent with horizontal movements observed during mining of the single seam (PG) longwalls. The magnitude of total movement increases incrementally with mining additional seams. Total movement has increased during mining both the ULD and ULLD Seams. The influences on horizontal movements of the offset geometry and latent subsidence recovered from the overlying seams are apparent in the profile as a regular pattern of increments.

The maximum cross panel horizontal movement above Longwalls 201-203 is currently around 1400mm. This horizontal movement is dominated by the cumulative cross panel movements of 1100-1200mm to the east (i.e. uphill) at the western edge of the overlap between longwalls voids in each seam. Cross panel horizontal movements are typically 200-300mm at the eastern edge of each panel. Similar horizontal movements are forecast for Longwalls 205-208.

Horizontal subsidence movements measured above each longwall at AUM are typically 20-30% of the magnitude of total vertical subsidence. There is a strong influence of strata dilation in the development of horizontal movements causing a general shift in an uphill direction. There are also strong similarities in the characteristics and distribution of horizontal subsidence movements across longwall panels in each seam indicating a consistent mechanism driving the horizontal movements.

Incremental long panel horizontal movements at AUM are characterised by movement toward the approaching longwall face, followed by movement in the reverse direction after the longwall face has passed.

4.1.4 Unconventional Subsidence Effects

Unconventional subsidence effects considered in this section include:

- far-field horizontal movements outside the mining area
- horizontal movements associated with strata dilation in uneven topography
- shear movements on low strength bedding planes leading to the formation of ripples on the surface
- stepping in the ground surface associated with geological structure.

The effects of unconventional subsidence movements tend to be localised along narrow zones, so impacts and environmental consequences need to be considered in the context of sensitive surface features that may be close to these zones once they are identified.

At AUM, all four mechanisms were observed to occur during mining in the PG and ULD Seams but none of them caused significant impacts to surface infrastructure.

Far-field horizontal subsidence movements associated with mining in the PG and ULD Seams were small beyond the panel edges reducing to less than 100mm at 100m from the goaf edge. These far-field horizontal movements change so gradually that they are imperceptible for all practical purposes. Similar low magnitudes of incremental horizontal movement beyond the panel edges are expected during mining in the ULLD Seam.

There has been a consistent pattern of horizontal movement in an upslope direction over each of the mined panels. This pattern is associated with the same mechanism that causes valley closure. The magnitude of this uniform upslope component of horizontal movement is in the range 200-300mm above Longwalls 201, 202 and 203. Similar strata dilation effects are expected above Longwalls 205-208.

A surface ripple of approximately 100mm in height is evident near the northern end of Longwalls 4 and 104. Differential horizontal movements of about 500mm were measured across this ripple during mining in the PG Seam. A further 300mm of movement occurred during mining in the ULD Seam. In both cases some regrading of the access road was undertaken to smooth the effects of this ripple. Some further differential movement is expected during mining in the ULLD Seam, but the incremental magnitude is expected to continue to decrease with each additional seam mined.

Bedding plane shearing has not been observed in areas above Longwalls 205-208, but the potential for similar features and similar ground behaviour in response to mining still exists and may become apparent during mining ULLD Seam.

A step change was observed at the location of a geological dyke structure above Longwall 2. This step change occurred in an area of bushland remote from any surface infrastructure and was managed following mining by surface regrading. No similar geological features have been identified above Longwalls 205-208, but the potential for similar ground behaviour cannot be eliminated.

4.2 Reliability and Accuracy of Subsidence Forecasts

The prediction methodology used for Longwalls 205-208 was used for Longwalls 201-204. This methodology has been validated by subsequent mining of Longwalls 201-203. The methodology is considered suitable to inform environmental assessment processes and future subsidence impacts at AUM.

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

In a single seam mining environment, the subsidence behaviour is consistent with and largely controlled by the mining geometry in the seam that is mined. In a multi-seam mining environment, the presence of previous mining in overlying seam(s) means that the subsidence behaviour is no longer simply a geometrical function of the seam being mined, but rather a complex interaction of the geometries in two or more seams. Impact assessments need to recognise the effects of earlier mining.

Previous mining has the effect of modifying the behaviour of overburden strata. The magnitude of maximum incremental vertical subsidence as a percentage of the lower seam mining height is typically greater in multi-seam environments, and typically much greater when latent subsidence near chain pillars in the overlying seams is recovered. The magnitude of strains and tilts are also typically greater because of the softer overburden strata.

There are several other less obvious effects as well. One of these effects is that the behaviour of the overburden strata varies significantly in response to the direction of mining below the goaf edge when solid goaf edges are mined under. Mining from below solid ground to below goaf leads to a significantly different subsidence response compared to mining from below goaf to below solid.

The practice of assessing the impacts of 100%, 200% and 300% maximum subsidence referred to in the Subsidence Management Plan Guidelines is not considered credible at AUM given that maximum subsidence is already assessed as 85% of combined seam thickness.

4.3 Comparisons with Previous Subsidence Forecasts

Condition 32, Schedule 3 of DA 309-11-2001-i Notice of Modification requires ACOL to provide revised predictions of the conventional and non-conventional subsidence effects, subsidence impacts and environmental consequences of the proposed second workings, incorporating any relevant information obtained since this consent, that specially addresses the incremental and cumulative subsidence effects and impacts pf multi-seam mining. This report provides revised subsidence forecasts of subsidence effects and impacts. This section provides a summary of changes to predictions made through modifications to the ACP Approval or through SMP/EP approvals.

Table 4 summaries the maximum predicted values after mining in three seams from previous assessments and the forecast for Longwalls 205-208 in the ULLD Seam. It is recognised that the original subsidence predictions in the EIS for ACP were made in 2001 by G.E. Holt and Associates (GHA 2001) prior to multi-seam subsidence studies by Li et al (2007 and 2010). Incremental and cumulative vertical subsidence was predicted but no cumulative predictions of tilt and strains were presented in GHA (2001).

Table 4: Comparison of previously predicted Subsidence Parameters

Assessment	Maximum Subsidence (m)	Maximum Tilt (mm/m)	Maximum Strain (mm/m)
ACP EIS (GHA 2001)	4.2[1]	123[2]	25[3]
BCD MOD6 EA PG, ULD & ULLD (SCT 2009)	5.8	240	110
LW1-8 ULD EP PG & ULD only (SCT 2012)	4.5	132	53
LW105-107 EP PG & ULD only (SCT 2015)	4.0	213	107
Forecasts in this assessment			
LW205-208 EP (LW206B, 207A, 207B, 208) PG & ULLD	4.4	177	88
LW205-208 EP (LW205, 206A) PG, ULD & ULLD	5.8	219	110

[1]Maximum cumulative subsidence predicted (for LW5 in ULLD Seam)
[2]Maximum incremental tilt predicted (for LW1 in PG Seam)
[3]Maximum incremental strain predicted (for LW1 in PG Seam)

Changes to forecast maximum subsidence effects reflect the improved understanding of multi-seam subsidence behaviour at AUM since the ACP was approved, changes to the mining plan layout and variations in seam thickness or proposed mining heights. The improved understanding is based on monitoring of multi-seam subsidence at AUM. Latent subsidence from overlying seams, differences in subsidence behaviour near stacked goaf edges and remote from panel edges and the influence of mining direction on subsidence behaviour are all processes that have been quantified as a result of monitoring experience.

The forecasts presented in this report for Longwalls 205-208 are consistent with, or less than, the predictions in the BCD MOD6 EA.

5. SUBSIDENCE IMPACT ASSESSMENT

This section presents an assessment of the potential subsidence effects and impacts from mining Longwalls 205-208 for various surface features located within or adjacent to the EP Area. Impacts to Surface and Groundwater, Biodiversity, and Aboriginal Heritage are assessed separately by other specialists.

In areas where the ULD Seam longwall panels have not been mined, the impacts from the forecast subsidence effects are expected to similar in nature to those forecast in SCT (2015) for mining of Longwalls 105-107 in the ULD Seam. In areas where the ULD Seam longwall panels have been mined, another increment of subsidence is expected, but the nature of subsidence impacts is expected to be similar. Similar management strategies to mitigate and remediate subsidence impacts and environmental consequences from the planned mining of Longwalls 205-208 are expected to be effective.

5.1 Natural Features

Major natural features in the EP Area for Longwalls 205-208 include Bowmans Creek and two diversion channels, Bowmans Creek Alluvium and the floodplain landform, natural ponds (billabongs) and watercourses and areas of general surface terrain.

5.1.1 Bowmans Creek and Diversions

The main channel of Bowmans Creek (Foys Brook) crosses the EP Area between the northern and southern longwall panels. The creek has been diverted in two diversion channels located on either side of the longwall area. Bowmans Creek is protected from subsidence impacts by solid coal barriers in the PG Seam with similar barriers planned in the ULD and ULLD Seam. No perceptible impacts are expected along the main channel of Bowmans Creek.

Approximately 3.5km of Bowmans Creek including the two diversions is located within the EP Area. The depth to the ULLD Seam ranges along Bowmans Creek from approximately 135m to 235m. The distance from the nearest goaf edge to the main channel is approximately 60m at the closest point and more generally more than 80m. The main channel is within an angle of draw of 26.5° of mining. Vertical and horizontal subsidence movements at the main channel are expected to be less than 50mm and 100mm respectively and imperceptible for all practical purposes.

Horizontal movements would be expected to be generally in a direction away from the creek, so valley closure effects are not expected to cause perceptible impacts in the bed of Bowmans Creek, especially given the alluvial nature of most of the creek bed.

Parts of the natural sections of Bowmans Creek excised by the formation of the diversion channels are above Longwalls 206B, 207A and 207B. These parts would be lowered by the anticipated vertical subsidence forming features similar to other natural ponds on the flood plain. These sections would not be free draining, but ponded water is expected to flow downward through the overburden strata into the mine.

Monitoring experience from adjacent to the eastern diversion channel for the stacked goaf edge of Longwalls 4 and 104 measured low levels of goaf edge subsidence with limited horizontal movements above the solid coal barrier to the west. The maximum depth to Longwall 104 goaf edge is 135m. At its closest point this diversion channel is approximately 80m to the west of Longwalls 4 and 104, above a 265m wide solid coal barrier between Longwalls 4 and 6B. No significant impacts to the diversion channel were evident during or as a result of this mining. The same width protection barrier is planned for mining in the ULLD Seam.

5.1.2 Bowmans Creek Alluvium

The boundary of the Bowmans Creek Alluvium covers sections of each the planned longwalls as shown in Figure 2. The saturated section of the alluvium interpreted from borehole piezometer monitoring covers a smaller area of the planned Longwalls 205-208 mining footprint.

Maximum incremental subsidence of 2.8m and maximum cumulative subsidence of up to 5.8m are expected below areas of Bowmans Creek Alluvium. Some depressurisation of the alluvium is expected, but past experience over Longwall 6B indicates that this depressurisation may be temporary. Potential longer-term impacts to the Bowmans Creek Alluvium from the planned mining of Longwalls 205-208 are assessed by groundwater specialists.

5.1.3 Landform

Most of the surface topography within the EP Area is located within the floodplains and gently sloping terrain associated with Bowmans Creek and the Hunter River. Mining of Longwalls 205-208 is expected to cause further subsidence of up to 2.8m on the slopes and general flood plain adjacent to Bowmans Creek. Maximum cumulative subsidence is expected to reach 5.8m.

There are some areas of steeper ground in the west associated with waste rock dumps from rehabilitated open cut mining areas on AGLM land, but there are no areas that would be regarded as steep slopes. No instability of the steeper ground on AGLM land is anticipated.

Within the subsidence troughs, zones of surface cracks, steps or steeper ground are likely near the panel edges. These types of impacts are likely to be most prevalent where permanent stacked goaf edges are formed. Compression overrides, also known as ripples, may form localised humps within and to the sides of the subsidence troughs.

The change in the landform due to subsidence is expected to restrict natural drainage causing ponding in some areas. The duration of ponding is expected to depend on a range of factors mainly associated with the hydraulic conductivity of the immediate overburden strata. The changes in elevation may lead to ponding that is up to several metres deep depending on the gradients in the original landform and any landform drainage works that may have been undertaken since the completion of mining in the PG and ULD Seams. Ponding has the potential to impact the integrity of surface and sub-surface infrastructure.

ACOL committed to creating a free draining landform at the completion of mining at AUM (i.e. after the LB Seam has been mined), the excised channels of Bowmans Creek excepted. Any increases in the storage volume of farm dams are expected to be retained. Billabongs and other natural depressions on the broader flood plain are likely to require draining in order to maintain the pre-mining character of the landform.

Figure 6 shows the outline of areas where there is potential for ponding without drainage works after the mining of Longwalls 205-208 in the ULLD Seam is completed. The surface contours reflect the estimated landform after the mining of these longwalls. The accuracy of the vertical subsidence estimation methodology at any given location is expected to be of the order of ±0.5m. These estimates are consistent with a review of the potential for ponding at the completion of mining in the LB Seam presented in SCT (2018) with allowance for differences in mining sequence and panels completed.

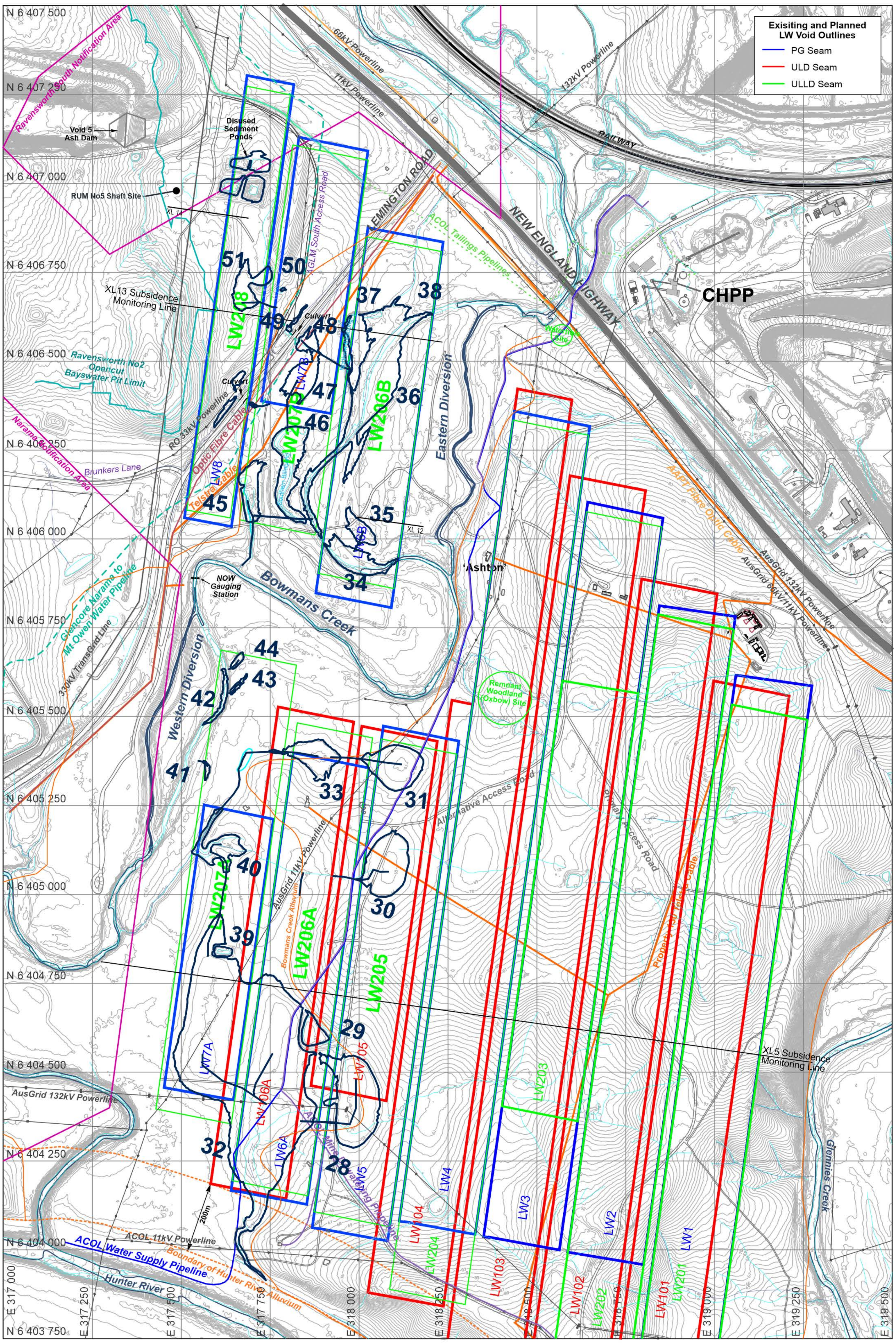


Figure 6: Estimated areas of ponding after Longwalls 205-208.

All areas of potential ponding shown in Figure 6 have been numbered for ease of identification consistent with the system used in SCT (2018). The numbering is chronological in the general mining direction and sequence of the overall AUM footprint. As mining progresses, small depressions merge to form larger basins so some of the smaller pond numbers disappear. The monitoring data now available from Longwalls 201-203 confirms the estimates of incremental and cumulative subsidence used in SCT (2018).

Figure 6 shows the potential for ponding above the northern and southern parts of Longwalls 205 and 206A and over most of Longwall 207A. Runoff is expected to pond in the two natural billabongs and a section of the main channel of Bowmans Creek excised by the eastern diversion channel. Areas either side of the northern culvert on Lemington Road that drain to the northern billabong via a man-made drainage channel constructed as part of the Lemington Road diversion works are also likely to pond.

Vertical subsidence and tilting of the surface is a dynamic process that occurs incrementally as each panel, each domain and each seam is mined. The ponding develops incrementally along each panel as mining progresses and the configuration of the ponds changes as adjacent panels are mined and then again when the next seam is mined.

Infrastructure that may be inundated by potential ponding includes powerlines, pipelines and roads including the alternative access to Property 130 and the south access road on AGLM land.

Strategies to make the surface free draining or limit the area and depth of inundation to natural ponding areas planned for the ULD Seam longwalls, some of which are no longer planned to be mined, are expected to be effective for the planned mining of Longwalls 205-208. The timing of these remediation works needs to consider the practicalities of short-term impacts to infrastructure and further subsidence from adjacent panels and future mining in lower seams. It is likely that further work will be required at the same locations as subsequent panels or seams are mined.

The strategies required to make each of these areas free draining or limit the additional standing water depth at natural ponds, are likely to include a continuation of the current practices of reshaping the surface after subsidence and construction of drainage channels to create a chain-of-ponds flow pathways generally along natural drainage lines to Bowmans Creek. The chain-of-ponds and isolated ponds can be connected by cuts in the high points above each of the chain pillars. In some locations the cuts would need to be up to about 3m deep and may need to extend for distances of the order of 200m.

This strategy is expected to be affective for ponds located over Longwall 205 (Ponds 28, 30 and 31) and the northern parts of Longwalls 206A (Pond 33) and 207A (Ponds 43 and 44). Similar drainage channels are likely to be required along the centre of Longwall 206A (Pond 32) and over the inter-panel chain pillars to keep water at a low level over the southern parts of Longwall 206A.

The standing water level in the section of Bowmans Creek excised by the western diversion channel above Longwall 207A (Pond 42) is expected to increase but this pond would not need to be drained.

It is likely a series of drainage channels in a chain-of-ponds would be required above the centreline of Longwall 207A (including Pond 40) to drain the surface to the southern end of this panel. From here, the large pond likely to form over the southern part of Longwalls 206A and 207A (Pond 32) requires a cut to the Hunter River that is approximately 4m deep and several hundred metres long if it follows an existing drainage line or be deeper if a more direct route to the river is selected.

For the estimated ponding in the vicinity of the northern longwall panels a combination of strategies is likely to be required to make the area free draining and minimise any increase in water depth in natural ponds.

Increasing the depth of the existing man-made channel and constructing new drainage channels are likely to reduce the estimated depth of ponding on both sides of the northern Lemington Road culvert. These works would reduce the potential for inundation of the AGLM south access road and the area around the base of one of the poles on the 33kV powerline at this location. These drainage works involve the existing man-made channel between Ponds 48 and 37 and new channels from Ponds 48 to 47 and 46. These channels would potentially drain all areas to the northern and southern billabongs (Ponds 37 and 46) and the excised section of Bowmans Creek (Ponds 34, 35, 36 and 38).

Some earthworks to cut a new drainage channel from Pond 45 would also minimise impacts from an increased water level in the billabongs and excised section of Bowmans Creek. When inspected on 14 November 2018, Pond 45 was dammed up against the embankment of an access track and appears to be drained by two 150mm diameter polypipes through the road foundation. It is not clear how effective this current configuration is. A culvert or larger diameter pipe through the access track foundation, coupled with new drainage channels to the south in a natural drainage line and to the west, through stockpiled material from the eastern diversion construction, would reduce the potential for ponding at this location and in adjacent billabongs and creek areas.

These new channels would connect the main channel of Bowmans Creek, south, to the southern end of the southern billabong (Pond 46) and the adjacent excised section of Bowmans Creek (Pond 34). This arrangement would bypass the meandering section of the main channel from the eastern diversion channel junction to south of Longwall 207B and provide a flow line that may reduce the depth of standing water in the billabongs and excised section of the creek by up to about 2m. Surface earthworks to reshape the landform after subsidence are expected to help to minimise the potential for ingress of water into the overburden strata and potentially from there into the underground mine workings. Further detailed evaluation of the feasibility of this option is recommended.

5.2 Non-Mining Built Features and Infrastructure

This section presents an assessment of potential subsidence effects and impacts relating to public utilities. The locations of most of these features are shown in Figure 2.

5.2.1 New England Highway

The New England Highway is outside the area significantly affected by mining subsidence. No perceptible impacts to the New England Highway are expected from the planned mining of Longwalls 205-208. The EP Area includes a small section of the New England Highway Road Reserve, west of Lemington Road, but not the road itself. Any subsidence effects in the vicinity of the road reserve are expected to be of a very low magnitude and imperceptible for all practical purposes.

The section of the road reserve within the EP Area is near the northern end of Longwall 208 where overburden depth is approximately 200m. Subsidence monitoring points for the road reserve are located approximately 70m from the north-eastern corner of Longwall 208. Subsidence monitoring measurements from the northern ends of Longwalls 6B, 7B and 8, indicates angle of draws, to 20mm vertical subsidence limit, of less than 10^0 in this area. Similar low angles of draw from the outermost panel edge are expected for the planned mining.

Regular visual inspections of the highway are recommended to confirm there are no perceptible impacts during the period of mining the last 100m of each longwall panel.

5.2.2 11kV Powerline

The EP Area includes small sections of the 11kV powerline adjacent to the New England Highway. These sections are beyond the northern ends of Longwalls 206B, 207B and 208. No significant impacts are expected to this 11kV powerline from the planned mining of Longwalls 205-208.

As shown in Figure 2, a total of three single pole structures are located within to the EP Area. The poles are located above solid coal, typically around 100m from the planned panel edges. Vertical subsidence of less than 30mm with corresponding low levels of ground tilt and strain are expected at the closest pole to Longwall 208. These low-level subsidence effects are not expected to result in significant impacts to the poles or conductors. Nevertheless, regular visual inspections during the periods of mining the last 100m of each panel are recommended.

Other major public utilities infrastructure located in the New England Highway corridor includes overhead 132kV, 66kV and 11kV power transmission lines and the buried Sydney-Brisbane Fibre Optic Cable. This infrastructure is outside the EP Area and is not expected to be impacted by planned mining.

5.2.3 Lemington Road

Longwalls 206B, 207B and 208 are planned to mine below some 850m of the realigned and upgraded Lemington Road. The subsidence impacts are expected to be manageable but are likely to require significant effort.

The impacts are expected to be of a similar nature, magnitude and frequency, to those forecast for ULD Seam mining originally planned in the area and for which approval was given. The ULLD Seam mining is the first mining below the reconstructed Lemington Road that will significantly impact the road formation.

Lemington Road is a two lane, sealed road administered by Singleton Shire Council. Figure 7 shows the road looking south from a position above Longwall 207B. The road was diverted and reconstructed during and following mining of Longwalls 7B and 8 in the PG Seam as part of the Ravensworth North Opencut Mine Project. Longwall 6B in the PG Seam subsequently mined below a small section of the new road causing low level subsidence above the corner of the panel and minor cracking along the edge of the road.

Figure 7: Lemington Road looking south.

The section of Lemington Road planned to be mined under by the ULLD Seam longwalls extends approximately 850m from just north of the Brunkers Lane intersection in the south to approximately 300m south of the intersection with the New England Highway.

Figure 8 shows the estimated road surface profiles along the centre of Lemington Road from current, after subsidence from ULLD Seam longwalls.

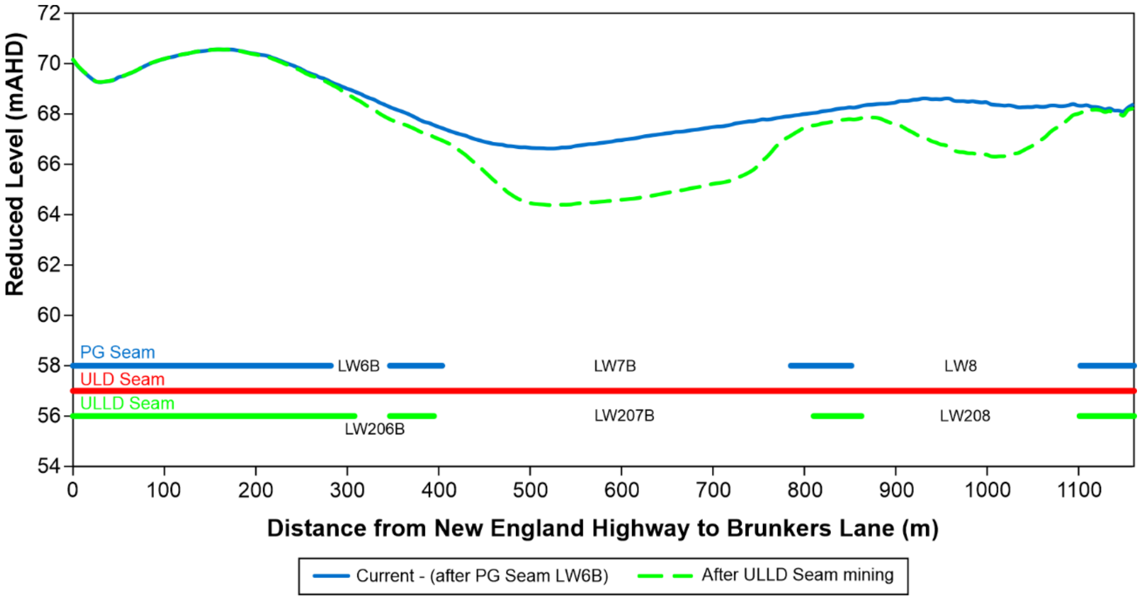


Figure 8: Lemington Road - estimated profiles after subsidence.

The subsidence movements are expected to occur gradually as mining progresses and to move along the road affecting a section up to 100-150m long at any given time. Impacts are expected to occur incrementally in response to mining geometry rather than suddenly. However, with normal longwall retreat rates of 70-100m per week, the impacts at any one location may develop to their maximum over a few days and be substantially complete within one to two weeks.

5.2.3.1 Longwall 206B

Longwall 206B is expected to impact only a short section of Lemington Road with impacts likely to be limited to an area smaller than that impacted during mining of Longwall 6B. The cracks that occurred on the eastern side of the road during mining of Longwall 6B are likely to be reopened as Longwall 206B finishes. These cracks are expected to permanent and require minor remediation. Specific traffic management is unlikely to be required, but regular inspections and maintenance when needed are recommended.

5.2.3.2 Longwall 207B

Longwall 207B is expected to impact a section of Lemington Road that is up to approximately 500m long. Approximately 150-200m of the road is expected to be affected at any given time. Impacts include changes in grade from tilting of the road surface and the appearance of cracks in the pavement. The tilting and cracks are expected to start above the longwall face and reach their maximum at about 50-70m behind the face. The grade is expected to flatten again and cracks to substantially close again by 150m behind the face with some ongoing changes out to 200m. The changes in grade and cracks are expected to be permanent where the road passes over the panel edges and transitory in the section above the centre of the panel. A cross grade is also expected to develop because of the angle that the longwall panels cross Lemington Road but the change in cross grade will be small by comparison with the grade changes along the road.

Maximum incremental subsidence of 2.5m is expected above the centre of the panel. Lemington Road was constructed after Longwalls 7B and 8 in the PG Seam were finished so cumulative subsidence is not significant. In the central part of the panel, maximum strains of 26 millimetres per metre (mm/m) and maximum tilts of 52mm/m are expected to develop.

The eastern and western edges of Longwall 207B are stacked or slightly undercut respectively with the PG Seam. Maximum strains of up to 53mm/m and maximum tilts up to 105mm/m are expected. Existing goaf edge fractures formed during mining in the PG Seam are expected to reopen along the western edge of the panel causing one or more cracks up to 300mm wide sub-parallel to the goaf edge. Sharp changes of grade are expected where these cracks develop.

5.2.3.3 Longwall 208

Longwall 208 is expected to impact a section of Lemington Road that is approximately 500m long and includes a 150m section located above Longwall 207B. The impacts are expected to be generally less than those observed over Longwall 207B because of the narrower panel width. Behaviour similar to that observed over Longwall 207B is expected to develop when Longwall 208 first mines under Lemington Road. As the longwall retreats, the subsidence behaviour is expected to move to a more general lowering of the surface when the longwall face approaches the chain pillar between Longwalls 207B and 208. This later stage lowering is likely to be characterised by closing of permanent cracks from Longwall 207B and a general softening of the grades above the chain pillar.

Maximum incremental subsidence of 2.2m is expected above the centre of the panel. In the central part of the panel, maximum strains of 21mm/m and maximum tilts of 33mm/m are expected.

The western and eastern edges of Longwall 208 are stacked in two seams. Maximum strains of 37mm/m and maximum tilts of 73mm/m are expected to develop at these stacked goaf edges. Existing subsidence fractures caused by mining in the PG Seam are expected to reopen along the stacked edge causing cracks up to 200-300mm wide. Sharp changes of grade are expected where these cracks develop.

5.2.3.4 Management

The comprehensive subsidence management plan required by the Lemington Road Subsidence Deed for mining the ULD Seam longwalls is expected to be suitable to use for the ULLD Seam longwalls and would be expected to maintain serviceability of the road whilst safeguarding road users and the general public.

The Lemington Road Subsidence deed of agreement between RO, ACOL and Singleton Shire Council sets out the roles and responsibilities for subsidence monitoring, management, and the distribution of costs likely to be incurred during mitigation and remediation activities.

Subsidence management conditions of the deed require ACOL to develop a monitoring and maintenance plan for each seam with detailed risk control measures. These includes monitoring and maintenance works to keep the surface of the new road in a serviceable and safe condition during and immediately after subsidence events caused by extraction of each seam until subsidence effects on the new road have stabilised.

The deed of agreement was finalised in 2013 following the mining of Longwall 6B below a small section of the road and the completion of an independent review report on the alignment of Lemington Road (GHD 2013). GHD (2013) reports that RO and ACOL have indicated a preference for the current alignment to be retained as the final alignment and as such the current alignment be reinstated (repaired) after each episode of subsidence. Development consent conditions require a review of subsidence impacts, monitoring and management measures following extraction of each seam including any continuing need to realign Lemington Road. GHD (2013) is consistent with these develop consent conditions.

The mining plan depicted in GHD (2013) does not coincide with the actual mining layout currently approved and planned for ULLD Seam, especially now that no mining in the ULD Seam is planned below Lemington Road. The impacts from mining the PG and ULLD Seams only are expected to be similar to those for mining the PG and ULD Seams only. Both are considered manageable using the same risk control measures.

The experience of the planned ULLD Seam mining is expected to provide a benchmark for the management of subsidence impacts to Lemington Road associated with future mining of the LB Seam.

5.2.4 Lemington Road Culverts

Figure 9 shows one of the concrete culverts constructed as part of the diversion of Lemington Road. This structure is located just north of the AGLM south access road above the centre of Longwall 207B and provides the main drainage pathway to Bowmans Creek in this area. A similar structure is located between the southern access road and Brunkers Lane above Longwall 208 and the Longwall 207B chain pillar.

Longwall 207B is expected to cause vertical subsidence in the range 2.0-2.5m at the northern culvert. Incremental strains and tilts are likely to be at general background levels with transient levels up to 25mm/m and 45mm/m respectively. Subsidence effects at the southern culvert are expected to be less but permanent due to this culvert being located close to a chain pillar.

Ground movements have the potential to damage the concrete structures potentially leading to failure of the road base and impacts to the road surface. Mitigation and remediation works are expected to be effective in maintaining the integrity and functions of the culverts. A program of monitoring the response and integrity of these structures is recommended with remediation measures taken as necessary.

Figure 9: Lemington Road northern Culvert.

5.2.5 330kV Powerline

Figure 10 shows the 330kV power transmission line owned by TransGrid. The powerline is located west of Lemington Road and traverses along the western boundary of the EP Area adjacent to Longwall 208. Five steel truss pylons that support the conductors are within the EP Area. No impacts are expected to this powerline from the planned mining of longwalls in the ULLD Seam.

The powerline was relocated into the corridor along the lease boundary between AUM and RUM as part of the Ravensworth North Opencut expansion to minimise impacts from future mining. Three of the five towers located adjacent to Longwall 208 are positioned over solid coal beyond the RUM workings in the PG Seam. The other two are located on the fill and capping material approximately 40m from the edge of the Ravensworth No 2 Bayswater Pit. The tower foundations are designed and built to accommodate the combined subsidence movements associated with the mining of all four seams proposed to be mined at both AUM and RUM.

The towers are approximately 90-100m from the edge of Longwall 8 in the PG Seam and Longwall 208 in the ULLD. Absolute vertical and horizontal movements at the towers are expected to be less than 50mm and 100mm respectively and imperceptible for all practical purposes. The tower foundations are expected to be able to accommodate any small differential movements that may occur.

Figure 10: 330kV TransGrid Powerline along western boundary of EP Area.

No impacts to towers or the continued operation of the 330kV powerline are expected from the proposed mining in the EP Area. Nevertheless, a program of regular monitoring during the period of mining near each of the towers is recommended. Monitoring of the full three-dimensional subsidence movements in the general vicinity of towers at the end of each longwall panel is also recommended to confirm that the subsidence movements are as expected.

5.2.6 Telstra Cable

A buried copper wire telephone cable owned by Telstra is located on the eastern side of Lemington Road on the alignment shown in Figure 2. This cable is understood to service subdivided blocks associated with RO and the NOW Stream Gauging Station located on Bowmans Creek. Subsidence impacts are expected to affect the serviceability of the cable without mitigation and remediation works being conducted.

The cable passes through areas of stacked goaf edges at the northern end of Longwall 206B where maximum cumulative strains of 78mm/m are forecast. These strains significantly exceed the expected nominal 20mm/m capacity of buried copper cables. The cable also passes over stacked goaf edges above Longwalls 207B and 208 where strains of 77mm/m and 52mm/m are forecast.

If the cable is required to remain serviceable throughout the period of mining in the ULLD Seam, options include:

- using mobile phone technology
- rerouting the line alongside the 330kV power transmission line where ground movements are within the tolerance of buried cable telecommunication systems.

5.2.7 132kV Powerline Traversing Southern Longwalls

Figure 11 shows a photograph of a 132kV power transmission line that crosses the southern ends of most of the southern longwalls at AUM. This line is owned by AusGrid. Impacts to this powerline are expected to be minor and manageable under existing BFMP management plans.

Figure 11: Southern 132kV AusGrid Powerline.

The original timber two pole structures have been progressively upgraded by ACOL to concrete poles structures during the mining of the PG and ULD Seam longwalls. The installation of these replacement poles and other engineering features to accommodate subsidence have made this powerline more tolerant of the subsidence movements. Only one original two pole timber frame remains above the planned mining footprint. This frame above Longwall 207A is shown to the right in Figure 11. SCT understands that the last timber frame will be replaced before Longwall 207A is mined.

The program of upgrading the support structures on this line has allowed the subsidence movements to be successfully managed as three seams have been mined below the line. Completion of the planned upgrades is expected to allow the subsidence movements associated with Longwalls 205-208 to also be managed successfully.

There is potential for some poles in areas where surface ponding is expected to become periodically submerged. Surface drainage works are expected to be effective in managing the potential for ponding.

5.2.8 11kV Powerline Traversing Southern Longwalls

Figure 12 shows a photograph of an 11kV power transmission lines that traverses the EP Area generally in a north-south direction above Longwalls 205, 206A and 207A. This line is owned by AusGrid. Subsidence impacts are expected to have the potential to affect the serviceability of this infrastructure without mitigation and/or remediation works.

Figure 12: 11kV AusGrid Powerline above Longwall 5.

SCT understands that, prior to subsidence effects from Longwalls 205-208,most poles on this section of the line are to be relocated, in consultation with AusGrid, into an area where subsidence movements will be small enough not to require any further mitigation or remediation works. One pole near the finish of Longwall 205 will need monitoring and management of subsidence effects and impacts in consultation with the asset owner.

5.2.9 Survey Control Stations

Permanent survey control marks within about a 2-3km radius around longwall mining should be considered vulnerable to far-field subsidence movements.

There are no survey marks directly above Longwalls 205-208 but a small number of permanent marks or state survey marks within an area likely to be affected by low-level horizontal movements.

A BFMP that includes:

- notifying the asset owner to temporarily 'decommission' a mark that is located within the extent of far-field effects around current mining by removing its coordinates from the database during the period of active subsidence
- re-establishing the horizontal and vertical position once subsidence is complete
- returning the mark to service with revised coordinate and height valves

is considered a practical way to manage the subsidence impacts on survey control stations from mining and one that is regularly used.

5.3 Mining Related or Mine Owned Built Features and Infrastructure

This section presents an assessment of the potential subsidence effects and impacts to infrastructure or built features owned by Glencore (Ravensworth and Mt Owen), AGLM or ACOL.

5.3.1 Ravensworth 33kV Powerline

Figure 13 shows a photograph of one of the 10 single pole structures on the 33kV power transmission line located within or immediately adjacent to the EP Area. This powerline is owned by RO. The line traverses the surface immediately to the west of Lemington Road before changing direction to follow the AGLM south access road to the north west. The line was constructed prior to mining Longwall 8 in the PG Seam. Subsidence impacts are expected to have the potential to affect the serviceability of this infrastructure without mitigation and remediation works.

Seven poles located above or between Longwalls 207B and 208 and most are expected to experience the full range of temporary and permanent subsidence effects forecast. Poles located near the panel edges are expected to experience the maximum subsidence effects. Three poles positioned above solid coal outside the outermost panel edges are not expected to be significantly affected by the likely ground movements although increased conductor tension at these poles may affect pole alignment. When inspected, several of the poles along the straight sections of the line had roller sheaves fitted to support the conductors and allow conductor tension to be equilibrated. Tension poles at changes in direction did not have sheaves fitted. These poles were stabilised with guy wires.

Figure 13: 33kV Powerline adjacent to AGLM south access road.

Maximum cumulative subsidence of up to 4.2m in the centre of Longwall 207B and tilt of up to 155mm/m is forecast at poles near the stacked goaf edges of Longwall 207B.

The single pole construction of this line makes it possible to consider managing the subsidence impacts while the line is operational, but management of the tension in the stay and conductor tensions and clearances on this line is likely to be required to keep the line operational during the period of active subsidence. A specific assessment and management strategy for each pole on this line is recommended.

Other options that may be more cost effective given the expectation of further mining in this area would include:

- relocation of the line further to the west into lower subsidence corridor adjacent to the 330kV line

- temporary decommissioning of the line with removal of the conductors during periods of active subsidence and possible replacement of poles that are excessively tilted.

If the poles are not relocated, regular survey monitoring of the poles is recommended during the period of active subsidence.

There is potential for one of the poles on this line located near the northern Lemington Road culvert to become periodically submerged. Surface drainage works are expected to be effective in managing the potential for ponding.

5.3.2 Ravensworth Fibre Optic Cable

SCT understands that Glencore owns a fibre optic cable that services RO. The cable is understood to run generally alongside and to the east of Lemington Road and was installed after the ACP approval was granted. Mining Longwalls 206B, 207B and 208 is expected to compromise the serviceability of this fibre optic cable.

The cable passes through areas of stacked goaf edges at the northern end of Longwall 206B where maximum cumulative strains of 78mm/m are forecast. These strains are expected to exceed the tolerance of a buried fibre optic cable. The cable also passes over stacked goaf edges above Longwalls 207B and 208 where strains of 77mm/m and 52mm/m are forecast.

If this fibre optic cable is required to remain serviceable throughout the period of mining in the ULLD Seam, options include:

- exposing the fibre optic cable so that high strain zones can be accommodated without causing the cable to be damaged
- relocating the cable to the low subsidence corridor alongside the 330kV powerline
- decommissioning the cable and using a different technology.

The potential for ponding in the expected subsidence troughs should be considered in deciding on an appropriate strategy.

5.3.3 AGLM South Access Road

Figure 14 shows a photograph of the AGLM south access road looking north from where it intersects Lemington Road. At this location the access road is above Longwall 207B. The road continues north west over Longwall 208. Subsidence impacts to the unsealed section of this road are expected to be similar to those experienced on unsealed roads above the current mining areas at AUM. Regular regrading of the road during the period of active subsidence is expected to be an effective approach to maintaining access.

Maximum incremental subsidence of 2.5m and 2.2m and maximum cumulative subsidence of 4.2m and 3.1m are expected over the centre of Longwalls 207B and 208 respectively. Maximum incremental strain of 26mm/m is expected along the centreline of Longwall 207B with permanent strains over the western edges of Longwalls 207B and 208 of up to 46mm/m and 37mm/m respectively. Maximum incremental tilts of 52mm/m are expected over the centreline of Longwall 207B with permanent tilts over the western edges of Longwalls 207B and 208 of 92mm/m and 73mm/m respectively.

These strains and tilts are expected to cause surface cracking up to 200-300mm wide and compression humps greater than 100mm high as well as localised steep gradients along and across the road. Most of the surface cracks are expected to occur at the same locations as the cracks that formed when Longwalls 7B and 8 were mined.

Figure 14: AGLM south access road.

The nature of the road and the limited traffic flow means that impacts to the access road are likely to be manageable. Measures to control traffic volume, the use of warning signs, speed restrictions, regular inspections, and timely remediation of any impacts during the period of active subsidence are considered appropriate measures to manage potential impacts.

There may also be a need to raise the level of approximately 100m of the road near the northern Lemington Road culvert by approximately 0.5m to reduce the impacts of ponding that is expected to occur in this area if drainage works to reduce these impacts are not undertaken.

Impacts to the sealed section of the AGLM access road adjacent to Lemington Road are expected to be similar to the impacts to Lemington Road. The impacts can be managed using temporary filling and regular regrading during the period of active mining. Resealing is likely to be required once the road formation has been regraded and cracks have been filled.

5.3.4 Disused Sediment Ponds

Figure 15 shows one of the clusters of four disused sedimentation ponds located over and on the edge of Longwall 208. SCT understands that AGLM do not intend to use these ponds again other than as farm dams/wildlife habitat. Impacts are expected to include cracking of the dam walls and tilting with potential loss of water from the ponds. The impacts are likely to be repairable to a state in keeping with their current and planned usage with some relatively significant earthworks.

Figure 15: AGLM disused sediment ponds.

Loss of water from these ponds is not expected to pose an operational risk to mining underground and is not considered to be an inrush hazard.

The sedimentation ponds are positioned where incremental subsidence of up to 2.2m is expected with maximum cumulative subsidence of up to 3.1m. Maximum incremental strains of 37mm/m and maximum tilts of 73mm/m are expected over the stacked edge of Longwall 208. Large permanent cracks and significant changes in grade are expected, particularly along the eastern side of the ponds.

5.3.5 Dams, Roads, Fences and Gates

Other minor infrastructure on AGLM land includes access tracks/roads, two farm dams, fences and gates. Impacts to access tracks/roads are expected to include cracking, steps or humps and tilting resulting in change of grades. Measures similar to those recommended for the AGLM south access road and currently used more generally above AUM are expected to be effective in minimising risk from subsidence impacts, maintaining serviceability and repairing roads to an acceptable standard.

Impacts to a farm dam located over the chain pillar between Longwalls 207B and 208 are expected to be minor but may involve loss of storage capacity. Any loss of water during the mining of Longwalls 207B and 208 is not expected to pose an operational risk to mining underground and is not an inrush hazard. The minor impacts expected are likely to be easily repairable with a small amount of remediation work.

Impacts to fences are expected to be greater in areas of high strain. Impacts could include broken or loosened wires to the extent that fences become ineffective. Any impacts to fences or gates are expected to be minor and repairable. Temporary electric fencing is recommended for stock control.

A program of control measures, monitoring and appropriate remediation as required is considered an effective way to manage the expected impacts to minor infrastructure from the mining of Longwalls 205-208.

5.3.6 Ravensworth No2 Bayswater Pit and RUM No5 Shaft

Figure 2 shows a section of the filled and largely rehabilitated Bayswater open cut pit is within the western boundary of the EP Area. No significant impacts are expected to this rehabilitated surface mining area. Some surface cracking may be evident in the area located directly above the edge of Longwall 208.

A very small section of this pit is planned to be mined under by Longwall 208 to form a stacked edge with Longwall 8 in the PG Seam. The depth from the current surface level to the as-mined floor of the Bayswater Seam at this point is approximately 10m. No significant impacts occurred during mining Longwall 8. Impacts are not expected to be significantly different to those of the natural landform in an area where there is a double stacked goaf edge.

Most of the Bayswater Pit within the EP Area is located over solid coal and more than 40m from the edge of the nearest longwall panel. The current surface landform slopes towards the east. Vertical subsidence along this edge of pit is expected to be generally less than 100mm with low levels of tilt and strain.

The RUM No. 5 Ventilation Shaft is approximately 120 m west of the goaf edge of Longwall 8 in the PG Seam. The shaft was constructed after Longwall 8 was mined. The shaft is outside the EP Area and not connected to the underground workings but, is assessed because of its proximity to the EP Area.

The planned mining of Longwalls 205-208 may cause horizontal shear movements within the overburden strata that extend as far as the RUM shaft. However, the magnitude of these movements is likely to be so small as to be of no practical significance for the operational integrity of the shaft if it is the be used in the future. Including this shaft site in the subsidence monitoring program for Longwalls 205-208 is recommended.

5.3.7 Ravensworth Void 5 Ash Dam

Figure 2 shows the location of AGL's Void 5 Ash Dam approximately 260m from the edge of Longwall 208 and outside the EP Area. The dam is a prescribed dam as defined by the Dams Safety Act. No significant impacts to this structure are expected but planned extraction is expected to require approval from the Dams Safety NSW and the Chief Inspector of Coal Mines.

The Void 5 Ash Dam was constructed during 2013 and 2014 on fill material at the end of a remnant void in the Ravensworth No 2 Bayswater Pit. The void is being used to store ash from nearby power stations. The dam wall is constructed from rock fill material that is likely to be tolerant to the small far-field subsidence movements expected from mining Longwalls 206B, 207B and 208.

Longwall 208 is planning to mine within the Ravensworth South Notification Area for the Void 5 Dam and within the 1.2D and 1.7D zones from the dam wall. This mining is more than one times the depth (45^0 angle of draw) from the toe of the dam. Vertical and horizontal subsidence movements from the mining of Longwalls 205-208 are expected to be imperceptible at the dam wall and have no potential to cause any impact to the dam structure.

Longwall 8 was mined in 2012. Any far-field subsidence movements that occurred at the dam site at that time were complete before the dam wall was constructed. Monitoring for additional stress relief horizontal movements associated with mining Longwalls 207B and 208 is recommended.

5.3.8 Narama – Mt Owen Water Supply Pipeline

A 315mm diameter polyethylene pipeline supplies water from the Glencore Narama Dam to Mt Owen Complex mines to the north. The location of this pipeline is shown in Figure 2. Within the EP Area, the pipeline crosses Lemington Road once and the southern AGLM access road twice. The pipeline crosses the stacked goaf edges above Longwall 207B and 208. Potential impacts include damage to the pipeline, loss of water supply and a possible environmental issue associated with unlicensed discharge.

The pipeline crosses the double stacked goaf edges on the western side of Longwall 208 and the northern end of Longwall 208 and traverses the area above Longwall 207B. Cumulative maximum strain is expected to reach 77mm/m at the stacked edges and 33mm/m more generally. If all the strain is localised at single, pre-existing fractures, as is expected, there is potential for the pipeline to be damaged.

Strategies to manage the potential impacts at these locations would include:

- uncovering the pipeline through the areas where it crosses stacked goaf edges, areas of active mining and at major changes of direction
- managing operations so that the potential for a leak can be identified quickly and flow can be stopped before there is any risk of environmental harm.

Regular inspections during the period of active subsidence are recommended.

5.3.9 ACOL Tailings Disposal Pipelines

Figure 2 shows the route of several polylines delivering tailings from the Ashton CHPP to the ACP Tailings Dam and the decant return back to Ashton CHPP. These pipelines are laid in open trenches where they cross double stacked goaf edges along the northern end of Longwalls 208 and the corner of Longwall 207B and they are buried on ACOL land near the end of Longwall 206B. Figure 16 shows the pipelines in the open trench above the north eastern corner of Longwall 207B. No significant impacts are expected to these pipelines because they are located on the surface and free to move independently of subsidence movements.

Figure 16: ACOL tailings disposal pipelines in open trench.

Regular inspections during the period of active subsidence are recommended to ensure that operations are maintained, and any potential environmental risk is minimised.

5.3.10 ACOL Water Supply Pipeline

The water supply for the ACP CHPP is pumped via a buried 200mm diameter polyline from an intake at the Hunter River. Figure 2 shows the pipeline route from the intake in the southwest corner of the EP Area, above Longwalls 206A and 205 and north across Longwall 4. There is potential for subsidence movements localised at pre-existing fractures and at compression overrides to cause damage to the pipeline within possible loss of water supply and minor environmental impacts. Potential impacts can be managed if they are found to be a recurring problem by exposing the pipeline.

Figure 17 shows a photograph of this pipeline where it is exposed near the pump.

Figure 17: ACOL water supply pipeline.

This pipeline currently crosses the start of Longwall 106A and the finish line of Longwall 105 where stacked goaf edges are formed with the overlying PG Seam longwall panels. The mining of Longwalls 205 and 206A is expected to increase strains at these locations to an estimated 110mm/m.

Strain levels of this magnitude have potential to exceed the nominal strain limits of this pipe, particularly in zones of high tensile strain at the stacked goaf edges and high compressive strain where overrides develop.

Strategies to manage the potential impacts include:

- uncovering the pipeline through areas of stacked goaf edges and at major changes of direction
- regular inspections in areas of active subsidence

- installing a monitoring system, if one doesn't already exist, that can detect a drop in water pressure as a means to identify potential damage.

These strategies are expected to be effective to maintain operations and minimise any possible environmental risk.

5.3.11 ACOL Mine Dewatering Equipment and Pipeline

ACOL pump water from underground back to the ACP CHPP via a buried, 355mm diameter polyline that crosses the EP Area. Figure 2 shows the route of this pipeline from the back-road ventilation shaft area via the alternative right of way access road and then north beside the Hunter River water supply pipeline. Branch lines from other underground sump areas join the main pipeline. Potential impacts include rupture of the pipeline with environmental consequences.

Longwalls 205 and 206A would mine below the pipeline creating a double stacked goaf edge at the start and sides of Longwalls 205 and 206A, and an almost triple stacked goaf edge at the finish line of Longwall 205. This pipeline was mined under previously including a double stacked goaf edge at the start of Longwall 202.

Maximum strains of 110mm/m are expected at the double stacked goaf edges and almost triple stacked goaf edge above the finish of Longwall 205. There is potential for these ground strains to exceed the nominal strain limits of this pipe, particularly in zones of high tensile strain at the stacked goaf edges and high compressive strains at compression overrides.

Strategies to manage the potential for subsidence impacts include:

- uncovering the pipeline through the areas of stacked goaf edges and at major changes of direction in the pipeline
- regular inspection and visual monitoring during the period of active subsidence to confirm that there is sufficient slack in the lines to accommodate the ground movements occurring.
- a system for monitoring pressure or flow that can detect a leak and shut down the pumping system
- isolating the line during the period of active subsidence and only returning it to service after it has been pressure tested.

5.3.12 ACOL Gas Management Equipment and Pipelines

ACOL have a network of gas drainage collection pipelines in place across the EP Area as part of the gas management system for AUM. These pipelines have been designed to accommodate subsidence movements. Surface to seam boreholes with collar equipment installations are also included in this network. SCT understands that further gas drainage boreholes are planned on AGLM land for areas above Longwalls 205-208. Impacts to this infrastructure are expected to be similar to those already experienced and successfully managed at AUM above Longwalls 201-203.

5.3.13 ACOL 11kV Powerline

A 11kV power transmission line that supplies the back-road ventilation fan/upcast shaft, BOC Nitrogen Plant, and several mine dewatering pumps crosses the southern part of the EP Area but outside the panel edges. Figure 2 shows the location of this powerline. No significant impacts are expected.

Poles are located where vertical and horizontal subsidence movements from mining Longwalls 205-208 are expected to be less than 100mm with corresponding low levels of tilt and strain.

5.3.14 ACOL Farm Infrastructure

Farm infrastructure on ACOL land within the EP Area includes:

- a disused residential farm house with associated buildings or features including buried telecommunication (Telstra) cables located above Longwall 206A

- access roads/tracks, and other minor farm infrastructure such as water reticulation systems, dams, fences, gates and cattle grids.

- agricultural land.

Impacts to these built features are expected to be similar in nature and magnitude to those experienced from previous mining in the PG, ULD and ULLD Seams to date.

Many of the features are expected to experience the full range of subsidence effects forecast for mining of Longwalls 205-208.

Further impacts to the farmhouse, outbuildings and other built features at this site are expected. Most of this site has been mined under previously by Longwall 6A and Longwall 106A. Further impacts to brick walls, masonry structures such as fireplaces and large concrete slabs are expected to become evident.

These structures are not expected to remain safe or serviceable during the period of active mining directly beneath them. They should not be occupied during the period of active subsidence and until the structures have been adequately repaired.

Impacts to access tracks/roads are expected to include cracking, steps, compression humps, changes in grades and flooding. These impacts have all been observed previously at AUM and have been effectively managed via controls measures such as restricted access, warning signs, speed restrictions and supervised access. These actions coupled with regular inspections and remediation works have been able to maintain serviceability of the access tracks/ roads and to minimise risk. Continuation of these actions is expected to be effective above Longwalls 205-208.

Experience of mining below farm dams at AUM and elsewhere indicates that some cracking may cause minor water loss in a small proportion of dams. These losses have not posed an operational risk to mining underground at AUM in the past and do not pose an inrush risk. Dams are typically restored to their original condition with a small amount of remediation work.

Impacts to fences are expected to include broken or loosened wires to the extent that fences become ineffective for stock control. These impacts are likely to occur most in areas of high strain and areas of active mining. Any impacts to fences, gates, cattle grids or stockyards are expected to be minor and repairable.

Impacts to the utilisation and suitability of the existing agricultural land are expected to be consistent with those from previous underground mining. Any impacts are expected to be able to be remediated using the strategies adopted over previous mining areas at AUM.

A program of control measures, regular monitoring and appropriate remediation as required is considered an effective way to manage the expected impacts to farm infrastructure from the mining of Longwalls 205-208.

5.4 Property 130

No mining related subsidence impacts to Property 130 are expected from the planned mining of Longwalls 205-208.

The primary access road and Telstra telecommunication cable that service this private property are outside the EP Area.

Daily access is expected to be maintained throughout the period of mining. Longwall 205 is located below the alternative right of way access road. Some crack filling, regrading and drainage works may be necessary as a result of mining Longwall 205.

5.5 Public Safety

The existing ACOL PSMP is designed to safeguard members of the public from the hazards of mining induced subsidence impacts. The subsidence performance measures and conditions of the ACP approval (DA 309-11-2001i) require that there is no additional risk due to mining and to ensure public safety in the underground mining area. An updated version of the PSMP for areas on ACOL and AGLM land is expected to be effective in managing the risk to public safety from the planned mining of Longwalls 205-208.

The comprehensive subsidence management required by the Lemington Road Subsidence deed of agreement is expected to be effective in managing the likely impacts to this major public utility.

The hazards for public safety include surface cracking, changes in road surface condition, potential flooding and other effects that might affect traffic safety on public and private roads including Lemington Road, the AGLM south access road and the alternative right of way to Property 130.

Controls, monitoring and remedial action, identified as core items in the PSMP include:

- regular monitoring in areas of active subsidence
- erection of warning signs
- entry restrictions and supervision (sentries)
- backfilling of surface cracks and remediation of any areas with adverse changes to road surface or potential ponding restricting passage
- provision of timely notification of mining progress to the landholder, community and any other stakeholders.

6. SUBSIDENCE MONITORING

ACOL routinely conducts subsidence monitoring to meet regulatory commitments and develop understanding of subsidence behaviour at AUM.

Subsidence monitoring is recommended to enhance the existing AUM subsidence monitoring database, to manage operational, personal and public safety risks and to address the specific requirements of DA 309-11-2001i conditions including the subsidence monitoring program.

Continuation of subsidence monitoring for Longwalls 205-208 using current site practices and high standards is recommended. A review of the current subsidence monitoring program consistent with the improved understanding of multi-seam subsidence is recommended. This revised program should include:

- three-dimensional monitoring of cross line XL5, over all the southern longwall panels
- three-dimensional monitoring of longitudinal lines located on the ULLD panel centreline (and parallel offset line where applicable) at the start and end of each panel
- three-dimensional monitoring of the cross line, XL13, over the northern longwalls, recognising that this line extends over the fill material in the Ravensworth No2 Bayswater Pit
- three-dimensional resurvey of the existing monitoring cross lines XL12 and XL14 during the mining of Longwall 206B and 208 respectively
- monitoring of the three-dimensional movement of power poles on the southern 132kV power line within the EP Area.
- monitoring of the three-dimensional movement of power poles on the 33kV powerline adjacent to Lemington Road

- monitoring of the three-dimensional movement of power poles on the 330kV powerline adjacent to Lemington Road.

Additional subsidence monitoring including:

- a survey line along Lemington Road between CH100m to CH1350m (where chainage is measured from intersection with the New England Highway)
- a 100m long survey line perpendicular to and centred about Lemington Road at CH305m
- monitoring of the Lemington Road culverts
- monitoring of the RUM No5 Shaft location (including XL14 Line)
- monitoring of Ravensworth Void 5 Ash Dam.

Routine visual monitoring recommended for the EP Area include:

- regular inspections of the access roads, powerlines, pipelines, cables, farm infrastructure and general landform in the areas of active subsidence.
- regular inspections of the Bayswater Pit interface edge during the mining of Longwalls 207B and 208.

Where new subsidence monitoring lines are required to be established, survey marks should be spaced at intervals of 1/20th of depth or 20m whichever is less.

Monitoring should include survey control for each survey that uses Global Navigation Satellite System (GNSS) control points located well outside the far-field effects zone on all sides of the mining area. This control should be established to provide an absolute accuracy of better than about 30mm. Intermediate pegs should be surveyed with a nominal relative accuracy of better than ±10mm.

Monitoring frequencies should be dictated by the various built features or infrastructure management plans or other technical requirements. Surveys should be timed to capture maximum subsidence movements where practical.

The commissioning of LIDAR surveys of the surface at the completion of mining in each seam is recommended.

7. REFERENCES

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SCT 2016b "Subsidence Assessment for the Extraction Plan for Longwalls 201-204 in the Upper Lower Liddell Seam" SCT Report ASH4552 REV3 - 21 October 2016.

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

	Within EP Area	Relevant Section
Natural Features		
1) Catchment areas and declared Special Areas;	N	
2) Rivers and creeks;	Y	*3.4, 5.1.1*
3) Aquifers, known groundwater resources;	Y	*1, 3.4, 5.1.2*
4) Springs;	N	
5) Sea/lake;	N	
6) Shorelines;	N	
7) Natural dams;	Y	*3.4, 5.1.3*
8) Cliffs / pagodas;	N	
9) Steep slopes;	N	
10) Escarpments;	N	
11) Land prone to flooding or inundation;	Y	*3.4, 5.1.3*
12) Swamps, wetlands, water related ecosystems;	N	
13) Threatened and protected species;	Y	*1, 3.4*
14) National parks;	N	
15) State conservation areas;	N	
16) State forests particularly areas zoned FMZ1,2 &3	N	
17) Natural vegetation;	Y	*3.4*
18) Areas of significant geological interest, and	N	
19) Any other feature – Endangered Ecological Communities.	Y	*1, 3.4*
Public Utilities		
1) Railways;	N	
2) Roads (all types);	Y	*3.4, 5.2.1, 5.2.3*
3) Bridges;	N	
4) Tunnels;	N	
5) Culverts;	Y	*3.4, 5.2.4*
6) Water/gas/sewerage pipelines;	N	
7) Liquid fuel pipelines;	N	
8) Electricity transmission lines (overhead/underground) and associated plants;	Y	*3.4, 5.2.2, 5.2.5, 5.2.7, 5.2.8*
9) Telecommunication lines (overhead/underground) and associated plants;	Y	*3.4, 5.2.6*
10) Water tanks, water and sewage treatment works;	N	
11) Dams, reservoirs and associated works;	N	
12) Air strips,	N	
13) Any other infrastructure items.	N	
Public Amenities		
1) Hospitals	N	
2) Places of worship	N	
3) Schools	N	
4) Shopping centres	N	
5) Community centres	N	
6) Office buildings	N	
7) Swimming pools	N	
Public Amenities		
8) Bowling greens	N	
9) Ovals and cricket grounds	N	
10) Race courses	N	
11) Golf courses	N	
12) Tennis courts	N	
13) Any other amenities considered significant	N	

	Within EP Area	Relevant Section
Farm Land and Facilities		
1) Agricultural utilisation or agricultural suitability of farm land;	**Y**	*3.4, 5.3.14*
2) Farm buildings / sheds;	**Y**	*3.4, 5.3.14*
3) Gas and / or fuel storages;	**N**	
4) Poultry sheds;	**N**	
5) Glass houses;	**N**	
6) Hydroponic systems;	**N**	
7) Irrigation systems;	**N**	
8) Fences;	**Y**	*3.4, 5.3.14*
9) Farm dams;	**Y**	*3.4, 5.3.14*
10) Wells, bores, and	**N**	
11) Any other feature – Access tracks.	**Y**	*3.4, 5.3.14*
Industrial, Commercial and Business Establishments		
1) Factories;	**N**	
2) Workshops;	**N**	
3) Business or commercial establishments;	**N**	
4) Gas and / or fuel storages and associated plants;	**N**	
5) Waste storages and associated plants;	**N**	
6) Buildings, equipment and operations that are sensitive to surface movements;	**N**	
7) Surface mining (open cut) voids and rehabilitated areas;	**Y**	*3.4, 5.3.6, 5.3.7*
8) Mine infrastructure including tailings dams and emplacement areas, and	**Y**	*3.4, 5.3.4, 5.3.5, 5.3.6, 5.3.7*
9) Any other feature considered significant		
Railways;	**N**	
Bridges;	**N**	
Roads;	**Y**	*3.4, 5.3.3*
Water/gas/pipelines;	**Y**	*3.4, 5.3.8, 5.3.9, 5.3.10, 5.3.11, 5.3.12*
Powerlines	**Y**	*3.4, 5.3.1, 5.3.13*
Communication Cables (underground);	**Y**	*3.4, 5.3.2, 5.3.14*
Other infrastructure	**Y**	*3.4, 5.3.3, 5.3.4, 5.3.5, 5.3.6*
Areas of Archaeological and/or Heritage Significance	**Y**	*3.4*
Items of Architectural Significance	**N**	
Permanent Survey Control Marks	**Y**	*5.2.9*
Residential Establishments		
1) Houses;	**N**	
2) Flats / Units;	**N**	
3) Caravan parks;	**N**	
4) Retirement/aged care villages;	**N**	
5) Associated structures such as workshops, garages, on-site waste water systems, water or gas tanks, swimming pools and tennis courts, and	**N**	
6) Any other feature considered significant.	**N**	

APPENDIX 2 - MONITORING DATABASE AND FORECASTING APPROACH

ACOL has conducted a comprehensive subsidence monitoring program involving high confidence three-dimensional (3D) survey measurements since the start of longwall mining at the AUM site in 2007. This data and the field observations of subsidence impacts provide a strong basis to forecast subsidence behaviour and assess impacts for Longwalls 205-208. This appendix provides a review of the experience of subsidence monitoring at AUM and the approach used to forecast subsidence effects at AUM.

A2.1 Subsidence Behaviour

Subsidence monitoring in the PG Seam at AUM was consistent with single seam supercritical width subsidence behaviour. Single seam subsidence behaviour above longwall panels is relatively well understood and well documented. The magnitude of subsidence can be estimated with reasonable confidence for a wide range of overburden depths and panel widths. Strains and tilts can be estimated based on well-established empirical relationships.

AUM provides an opportunity, almost unique in NSW, to monitor multi-seam subsidence where the panels in different seams are of the same width and aligned to provide a regular and consistent geometry at gradually increasing overburden depths.

Monitoring data from the six longwalls panels in the second seam (ULD) and three panels in the third seam (ULLD) provides insight into the mechanics that drive the subsidence interactions in the multi-seam environment at AUM. These insights into the mechanics of multi-seam subsidence have allowed the forecasting of subsidence behaviour over future panels.

As an example, the magnitude of incremental and cumulative measurements for the primary subsidence parameters across the first four panels in the ULLD Seam were able to be forecast based on the understanding developed from mining in the ULD Seam. The subsidence effects subsequently measured above the first three panels in the ULLD Seam are consistent with the forecasts for the ULLD Seam in the Longwalls 201-204 EP.

Effects such as the differences in behaviour between strata that is undisturbed by previous mining and strata that has already been subsided, the recovery of latent subsidence adjacent to pillars in the overlying seam, the particular behaviour that occurs in the vicinity of stacked goaf edges and the effect of mining direction on subsidence above stacked goaf edges have all become possible to investigate.

The analysis and interpretation of the monitoring data indicates that multi-seam subsidence behaviour, although more complex than single seam subsidence behaviour, is nevertheless regular and predictable. This behaviour falls into three distinct categories; subsidence remote from pillar and goaf edges, subsidence in the vicinity of stacked goaf edges and subsidence above pillars that are not stacked where latent subsidence may be recovered.

The method to forecast primary subsidence parameters for the Longwalls 205-208 EP is the same as that used to forecast subsidence parameters for the Longwalls 201-204 EP. Incremental vertical subsidence movements over previous goaf areas (disturbed or modified ground) are estimated. These subsidence movements are added to latent subsidence recovered from mining below the overlying chain pillars. When the overlying seam was mined, the chain pillars caused subsidence above them and for some distance to each side to be reduced to less than the full subsidence that would have occurred if the chain pillars were not there. Mining below the chain pillars causes them to be destabilised so that the full subsidence in the overlying seam is recovered. This additional subsidence is called latent subsidence.

The combination of subsidence generated by mining in the ULLD Seam and recovery of latent subsidence in the overlying seams is used to generate an incremental subsidence profile. This incremental profile is then added to the actual measured cumulative vertical subsidence profile (where available) from the overlying ULD and PG Seams or if the ULD Seam is yet to be mined to forecast incremental and cumulative vertical subsidence for the ULD Seam.

The estimated incremental subsidence profile for Longwalls 205-208 is based on 85% of the planned mining height of the ULLD Seam recognising the softer behaviour of the disturbed or modified overburden from previous mining, plus an allowance for the amount of latent subsidence to be recovered from around pillar and abutment edges in the overlying seam (or seams). The allowance for latent subsidence is somewhat interpretative but is consistent with the similar seam mining heights and improved understandings of multi-seam subsidence gained from the monitoring conducted for the six ULD Seam longwalls and three ULLD Seam longwalls.

The forecast of a cumulative subsidence profile for the ULLD Seam mining is then derived by adding the incremental profile to the existing cumulative profile for the previous PG and ULD Seam mining. For areas that were not mined in the ULD Seam, the forecast of incremental subsidence from SCT (2015) has been added to the actual measured PG Seam profile. A small additional factor is applied for any remaining uncertainties around the extent of multi-seam interactions and any other variations in mining heights and overburden depths along the panels.

At stacked edges, where the goaf edge in one seam is located directly above or below the goaf edge in another seam either dynamically or permanently, a different approach is used to determine the subsidence profile. The subsidence profile is determined by recognising the formation of pre-existing goaf edge fractures and the softening effect of previous mining on overburden stiffness characteristics. The effect of pre-existing fractures is to localise further ground movements at the location of these fractures significantly increasing the size of surface cracks. The effect of overburden softening is to increase goaf edge tilts and strains. Each time another seam is mined at a stacked edge, the surface cracks, strains and tilts increase further.

Strains and tilts are estimated based on the Holla (1991) approach for the Western Coalfield of NSW:

$$\varepsilon+_{max} = K_1 \; S_{max} / D$$

$$\varepsilon-_{max} = K_2 \; S_{max} / D$$

$$G_{max} = K_3 \; S_{max} / D$$

where $\varepsilon+_{max}$, $\varepsilon-_{max}$ and G_{max} are respectively, the maximum tensile strain, the maximum compressive strain and the maximum tilt, K_1, K_2 and K_3 are constants of proportionality determined from field measurements, S_{max} is the maximum subsidence and D is the overburden depth at the point of interest.

This approach was used for Longwalls 201-204 and appears to provide reasonable estimates of tilt and strain. The maximum values measured from the mining of Longwalls 201-203 are consistently less than the maxima forecast.

The Holla approach captures the key parameters that affect the magnitude of maximum tilt and maximum stain i.e. proportionality to subsidence and inverse proportionality to depth. The different behaviour associated with stacked geometries is accommodated by varying the constants of proportionality, K_1, K_2 and K_3. The K values used to forecast tilts and strains for Longwalls 205-208 were determined using monitoring data from six ULD Seam longwalls and the first three ULLD longwall panels. It should be recognised that maximum dynamic tilt and strain values measured are sensitive to the timing of the periodic surveys when mining up to and undercutting stacked goaf edges. A conservative approach has been taken to estimating K values.

A2.2 Review of Previous Subsidence Monitoring and Behaviour

Subsidence monitoring of single seam longwall operations began with the commencement of mining in the PG Seam in early 2007 and has continued above all the panels mined since then. Multi-seam subsidence monitoring above the ULD Seam longwalls commenced in 2012. Subsidence monitoring above three seams of mining started in 2017 with the commencement of Longwall 201 in the ULLD Seam.

For the PG Seam longwalls, some 35 monitoring lines were installed and regularly surveyed. These subsidence monitoring lines are aligned both along the panels (longitudinal) and across the panels (transverse). Additional three-dimensional monitoring has also been conducted at other surface features or infrastructure.

For the ULD Seam mining, a series of 12 longitudinal lines have been established in offset alignments to the PG Seam lines at both the southern and northern ends of panels. Measurements have regularly been recorded on these ULD Seam monitoring lines to supplement further surveys on the cross-panel lines previously installed for the PG Seam mining. Additional lines, or extensions to PG Seam lines, are planned for mining ULLD Seam longwalls.

The main cross-panel line (XL5) extends over all southern longwalls in the four seams planned to be mined. In addition to the surveys of sections of the line for individual longwall panels, this line was resurveyed along its full length at the completion of the PG Seam longwalls and again after the sixth longwall in the ULD Seam. Sections of XL5 above Longwalls 201-203 have been surveyed for the ULLD Seam mining to date.

A2.2.1 Single Seam Subsidence Behaviour and Parameters

Subsidence behaviour observed for the PG Seam mining is consistent with the subsidence behaviour expected in panels of supercritical width and within the range as indicated by the Holla (1991) Western Coalfield guidelines as applied to the Hunter Valley.

Measurements for the PG Seam mining at AUM indicate single seam mining of undisturbed ground causes surface vertical subsidence of generally about 50-60% of the seam mining height.

A summary of the monitoring conducted during the mining of Longwalls 1-8 indicates maximum values for the primary subsidence parameters of vertical subsidence in the range 1.5m to 1.6m, maximum tilt of around 100mm/m, and maximum strain of around 50mm/m. The strain value excludes the increased compressive strain measured across the bedding plane shear horizon over Longwall 4 discussed in section A2.2.4.

A2.2.2 Multi-Seam Subsidence Behaviour and Parameters

Figure 5 shows a summary of the incremental and cumulative subsidence effects measured along XL5 cross-panel monitoring line at the end of mining in the PG Seam and after Longwall 106A in the ULD Seam was completed. The preliminary results for Longwalls 201-203 to date, are also shown.

The survey of XL5 Line at the completion of Longwall 106 indicates a maximum cumulative vertical subsidence of 3.4m above Longwall 3 and 103. The maximum incremental subsidence, including a latent subsidence component from adjacent to the PG Seam pillar edges, is 2.4m over Longwall 1 and 101.

Remote for pillar and abutment edges incremental vertical subsidence of greater than 80% of the second seam mining height is apparent. The incremental subsidence is greater than 90% when latent subsidence is taken into account, but the magnitude of this additional subsidence is not a function of the seam mining height in the second seam so representing it as a proportion of this seam height is somewhat misleading.

The results of the ULD Seam monitoring show that subsidence behaviour falls into two categories depending on the relative geometries of the mining in the two seams. In most areas, subsidence behaviour can be categorised as general background subsidence behaviour with tilts and strains of similar magnitude to those observed in the PG Seam, despite the greater vertical subsidence. Where the goaf edges in the two seams are located directly above each other, a different style of behaviour is apparent.

Remote from pillar and goaf edges the maximum values of tilt and strains are typically of a similar or lower magnitude to the tilt and strains measured for the first seam mined despite the greater total vertical subsidence. The maximum values of tilt and strain are typically less than the maximum calculated assuming single seam mining conditions but occasionally increase to the same magnitude as those measured during mining in the PG Seam. This behaviour is thought to be due to a general softening effect of the multi-seam mining and the difference in behaviour between strata that is undisturbed by previous mining and strata that has already been subsided (disturbed or modified).

A different behaviour is observed in areas where overlying goaf edges interact to form a stacked goaf edge. At these stacked goaf edges and particularly when the deeper seam has undercut the upper seam, transient tilts and strains have been recorded as being much higher than elsewhere.

At a stacked goaf edge where the lower seam is mined into solid from below an existing goaf in the upper seam, a double goaf edge is formed. Maximum tilts in these areas are observed to be about double the maximum general background levels. Horizontal strains are observed to peak at about four times the background levels observed more generally along the panel. These maxima are observed when the goaf edge in the upper seam is undercut by a distance equal to about 0.7 times the interburden thickness or where the caving of the goaf at the lower seam longwall face intersects the goaf edge in the upper seam.

The presence of the transition from goaf to solid at a goaf edge created by mining in the overlying seam appears to focus additional subsidence movements associated with mining the deeper seam into the same location. In effect, the presence of the pre-existing fractures from subsidence movements from the upper seam mining acts as a preferred separation point so that further deformations from the lower seam mining are concentrated at these fractures temporarily elevating the tilt and strain levels.

Where the lower seam is mined as a single seam situation and merges under an overlying goaf, a variation of a stacked goaf edge is formed. The nature of the subsidence profile in this circumstance is significantly different with a large block above the start of the overlying panel subsiding en-masse as the existing goaf edge is mined under in the lower seam. The disturbance caused to the ground by mining each of the two longwall panels in two different seams leaves a triangular wedge of largely undisturbed ground above the start of the upper seam longwall. This triangle of rock subsides gradually en-masse as mining in the underlying seam progresses. The subsidence parameters of tilt and strain in this situation are of similar magnitude to single seam mining.

Analysis of the monitoring for Longwalls 101-104 has recorded maximum cumulative tilts near stacked edges of up to 200mm/m with a peak of around 250mm/m measured during the undercutting of one stacked goaf edge, although it is possible the actual maximum may not have been recorded due to the frequency of surveys. The maximum cumulative strain and the same location was approximately 125mm/m.

The direction of mining in the second seam under an existing goaf has a significant influence on the surface effects that develop. Mining from a goaf to under solid leads to a stacked goaf edge that produces very high tilts and strains that are much higher than the general background values. Mining from solid to under a goaf produces an en masse subsidence effect with tilts and strains that are comparable to general background levels.

Incremental vertical subsidence above second seam chain pillars is also observed to be significantly different to that in single seam mining environments. This subsidence is much greater than the elastic strata compression observed above the chain pillars formed by mining in the first seam in the same area. This is likely to be a result of compression of the disturbed ground above the lower seam chain pillar and the reduced stiffness of this ground from the previous episode of mining.

Analysis of the subsidence monitoring data from AUM indicates that the magnitude, direction, and form of horizontal movements from multi-seam mining are consistent with the horizontal movements observed during mining of the single seam (PG Seam) longwalls. The magnitude of total movement has increased, with an increased increment, from the mining of both the ULD and ULLD Seams to date. The influences of the offset geometry and latent subsidence recovered from the overlying seam or seams are seen in the profile as a regular pattern of incremental horizontal movements.

Horizontal subsidence movements measured above each longwall have been typically in the range of 20-30% of the total vertical subsidence. There is a strong similarity in the characteristics and distribution of horizontal subsidence movements between the longwalls in each seam indicating a consistent mechanism driving the horizontal movements. There is also a strong influence of strata dilation in the development of horizontal movements causing a general shift in an uphill direction.

The maximum total horizontal movement above the longwalls has included from around 500mm for the PG seam mining to about 800mm after Longwall 106 in the ULD Seam. The total horizontal movement above Longwalls 201-202 is currently around 1200mm. This total horizontal movement is dominated by the cumulative cross panel movements which is currently around 1100mm to the east (i.e. uphill) at a location near the western edge of the overlap between each of the overlying longwalls voids.

The incremental long panel horizontal movements are characterised by movement toward the approaching longwall face, followed by movement in the reverse direction after the longwall face has passed. This behaviour has been observed during the mining in each seam with varying magnitudes of displacement consistent with the level of subsidence and the timing of surveys.

Other conventional single seam concepts such as angle of draw and subcritical/supercritical behaviour are less meaningful in a multi-seam environment. The angle of draw outside of the outermost goaf edge appears unchanged but angle of draw over disturbed or modified strata is observed to extend further. The modified overburden strata appears to have reduced shear stiffness resulting in a greater sag subsidence component than for what would be expected from a supercritical geometry in a single seam situation.

A2.2.3 Multi-Seam Subsidence Insights from Third Seam of Mining

Preliminary analysis of subsidence monitoring data from Longwall 201, Longwall 202 and the southern section of Longwall 203 indicates that the methodology for forecasting the subsidence behaviour for the third seam of mining is providing a reasonable estimation of subsidence parameters consistent with those forecast in SCT (2016b).

The magnitude of incremental and cumulative measurements for the primary subsidence parameters along XL5 Line, across the first two panels in the ULLD Seam, have been consistent with expectations and generally less than the maxima forecast.

Figure 5 includes a summary of the primary subsidence parameters for the third seam of mining to date.

The incremental vertical subsidence profile across Longwalls 201-203, with prominent latent subsidence areas, is the mirror image of the incremental ULD Seam profile due to the offset panel geometries relative to the overlying seam. Although the maximum latent subsidence areas are located slightly further (10-20m) to the west, potentially as a result of the steeply dipping seams and overburden strata. The incremental profile also indicates a further 'softening' of the overburden from the third episode of mining. Physical ground impacts observed include the reopening of surface cracks along the directly overlying PG Seam panel edges in areas that had been remediated.

The monitoring data from the longitudinal lines at the start of Longwalls 201 and 202 provide further insights and understanding into the effects of mining direction on ground behaviour. This includes the behaviour when mining from solid to under a goaf edge at a location for the second time and the release of latent subsidence from a source and mechanism not previously observed. The cumulative subsidence measured along these lines to date, is less than the maxima forecast.

The interpretation of the incremental subsidence component from within the total cumulative subsidence measurement for some locations is seen as subjective. That is, the incremental value is relative to the reference survey used for the increment calculation and the level of subsidence at that location at that time. The level of subsidence at the location needs to consider the offset geometry, what would be regarded as typical for the location and the extent of mining. On that basis forecast of incremental subsidence measurements should generally not be used for performance indicators.

The total cumulative subsidence also needs to be considered in the context of compliance with incremental subsidence forecasts as the impact assessment of environmental consequences is generally based on the forecast of maximum cumulative subsidence parameters.

Furthermore, incremental and cumulative effects of all subsidence parameters for the multi-seam mining need to consider the starting value from the previous mining for the second seam and each subsequent episode of mining.

Additional, detailed analysis and interpretation of the monitoring data from the ULLD Seam mining, to revise existing or inform future subsidence forecasts and assessments, is recommended.

A2.2.4 Unconventional Subsidence

Minor unconventional subsidence effects have been observed at AUM during mining in the PG and ULD Seams. The observed effects include; far-field horizontal movements outside the mining area, horizontal movements associated with strata dilation in uneven topography, shear movements on low strength bedding planes leading to the formation of ripples on the surface and stepping in the ground surface associated with geological structure. However, none of the occurrences of these unconventional movements caused significant impacts to surface infrastructure, particularly by comparison with the subsidence movements associated with stacked goaf edges in multiple seams.

Far-field horizontal subsidence movements measured outside the panel edges from mining in the PG Seam and ULD Seams are small (around 100 mm at 100m) and change so gradually as to be imperceptible for all practical purposes. The mechanism that is recognised to cause far-field horizontal movements is associated with horizontal stress relief. Mining in the PG Seam is likely to have relieved most of the horizontal stress directly over the mining area so that any changes to horizontal stress associated with mining subsequent seams are likely to be small.

Strata dilation effects are generally observed as valley closure. There has been no direct evidence of valley closure at the AUM however, there has been a consistent pattern of horizontal movement in an upslope direction over each of the mined panels. This pattern is considered to be associated with the same mechanism that causes valley closure. At AUM the general dip of the strata is to the west at a rate greater than the topography. This general dip has the effect of causing the dilating strata to move upslope toward the free surface in a similar way that dilating strata moves toward the free surface of a valley in horizontally bedded strata. The magnitude of this upslope horizontal movement has been up to about 200-300mm near the panel edge of Longwalls 201-203 to date.

There is evidence of low strength bedding plane shear movements causing a surface ripple of approximately 100mm in height near the northern end of Longwalls 4 and 104. Differential horizontal movements of about 500 mm were measured across this ripple during mining in the PG Seam with a further 300 mm during mining of the ULD Seam. In both cases some regrading of the access road was undertaken to smooth the effects of the ripple. Some further differential movement is expected during mining in the ULLD Seam, but the incremental magnitude is expected to continue to decrease with each additional seam mined.

A step change was observed at the location of a geological dyke structure above Longwalls 2 and 102. This step change occurred in an area of bushland remote from any surface infrastructure. The surface impacts are not considered to be significant in the context of the regular ongoing remediation activities untaken by ACOL.