01 July 2019

SCT Operations Pty Ltd
ABN 23 078 328 953
www.sct.gs

HEAD OFFICE
Cnr Kembla & Beach Streets Wollongong NSW 2500 Australia
PO Box 824 Wollongong NSW 2520 Australia
Telephone +61 2 4222 2777 Fax: +61 2 4226 4884
Email: sctnsw@sct.gs

BRISBANE OFFICE
Telephone/Fax: 0428 318 009 (international +61 428 318 009)
Email: p.cartwright@sct.gs

BENDIGO OFFICE
Telephone: +61 3 5443 5941
Email: s.macgregor@sct.gs

Ron Bush
Environment and Community Manager
SIMEC Mining
2975 Remembrance Driveway
TAHMOOR NSW 2576

TAH5018

Dear Ron

DISCUSSION OF SUBSIDENCE IMPACTS MINING AWAY FROM CREEK CHANNELS

The Tahmoor Coal Mine (Tahmoor Mine) is an underground coal mine located approximately 80 kilometres (km) south-west of Sydney between the towns of Tahmoor and Bargo, New South Wales (NSW).

The Tahmoor Mine has been operated by Tahmoor Coal Pty Ltd (Tahmoor Coal) since Tahmoor Mine commenced in 1979 using bord and pillar mining methods, and via longwall mining methods since 1987. Tahmoor Coal, trading as Tahmoor Coking Coal Operations (TCCO), is a subsidiary within the SIMEC Mining Division (SIMEC) of the GFG Alliance (GFG).

TCCO is preparing an Extraction Plan (EP) for the Longwalls W1 and W2 that are planned to mine south away from Cedar Creek and Stonequarry Creek and approximately parallel to Cedar Creek and Matthews Creek as shown in Figures 1 and 2. TCCO commissioned SCT Operations Pty Ltd (SCT) to review the EP subsidence assessment report prepared by Mine Subsidence Engineering Consultants (MSEC 2019) and provide a desktop review discussing, from a geotechnical perspective, the potential subsidence impacts from the proposed longwalls given the setbacks to adjacent creeks and associated features. This report presents our review of the MSEC report and a summary of current understanding of the geotechnical processes associated with subsidence that have potential to impact the creeks and cliff features adjacent to Longwalls W1 and W2.

Our review of MSEC (2019) indicates that MSEC have provided a comprehensive assessment of the impacts that can be expected. The setbacks from the adjacent creeks are such that there is likely to be some mining impacts perceptible in the adjacent creeks and cliff formations for the proposed geometry, but the perceptible impacts are expected to be generally of a low level.

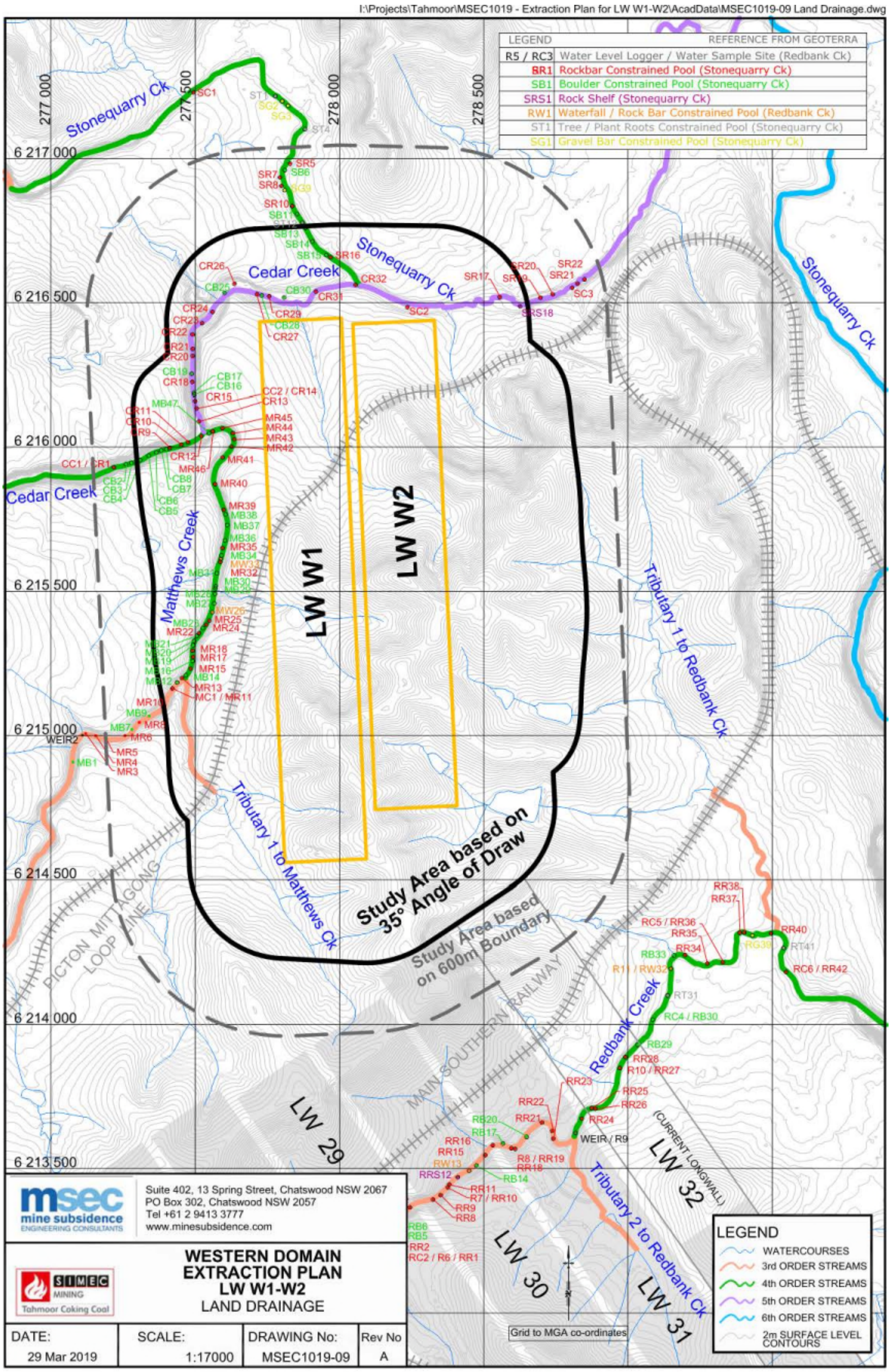


Figure 1: Site plan showing location of western domain longwall panels (reproduced from MSEC 2019).

Figure 2: Site plan based on 1:25,000 topographic series maps (reproduced from MSEC 2019).

From a geotechnical perspective, the processes that cause impacts to creeks are relatively well understood. Impacts to creeks outside the mining footprint are caused primarily by differential horizontal subsidence movements across the creek. The magnitude of these movements is a function of three recognised processes: systematic subsidence movements, valley closure movements caused by dilation of subsiding strata and horizontal stress relief. The horizontal movement experienced by the creek is the sum of these three components. These processes and their relative magnitudes are discussed in detail in this report.

The nature of impacts to creeks is also relatively well understood. Differential horizontal movements typically lead to horizontal compression across the valley floor that when large enough can overload and fracture the sandstone bedrock that forms the base of the creek and rock bars along the creek that retain water in pools in the creek. These fractures provide a pathway for flow to occur below the base of the creek. At times of low flow, the fracture network may be large enough that there is no surface flow and pools dry out. Oxidation of freshly fractured sandstone can lead to reduced dissolved oxygen, introduction of heavy metals that can oxidise to cause iron staining and smothering where the water emerges downstream. Other, typically less significant impacts include tilting of the creek bed leading to changes in flow patterns, changes in level causing changes in level of bank relative to the pool and a reduction in groundwater level over and near the longwall footprint that changes the balance between gaining and losing creek systems.

1. Summary of impacts expected

Impacts in the flooded section of Stonequarry Creek are expected to be low and generally imperceptible because the longwall panels are mining away from the creek so that the different components of horizontal movements tend to cancel each other out and the water level is controlled by a rock bar that is remote from mining activity.

Impacts in the east-west section of Cedar Creek are expected to also be minor because the longwall panels are mining away from the creek so that the different components of horizontal movement tend to cancel each other out.

Impacts to the north-south section of Cedar Creek and Matthews Creek are expected to be perceptible in places. Valley closure movements are expected to be large enough to cause some perceptible impacts to sandstone in the creek bed with potential for reduced water level and iron staining along some sections of both creeks, especially those sections closer to the longwall panels, where the creek is deeply incised and flow levels are naturally ephemeral.

The east-west sections of Cedar Creek and Matthews Creek are unlikely to be perceptibly impacted. The high ground on either side of these sections of creek are not directly mined under so no significant valley closure movements are expected.

2. MECHANICS OF HORIZONTAL MOVEMENTS IN SLOPING TERRAIN

Mills (2014) presents a review of the mechanics of horizontal movements associated with coal mine subsidence. The discussion presented in this report is based substantially on that paper.

The ground movements associated with underground longwall mining are recognised to include horizontal subsidence movements. Over the last two decades, three dimensional subsidence monitoring has become routine in Australia and provided a wealth of measurements of horizontal movements caused by mining subsidence. These measurements and other sub-surface observations allow the processes that cause mining induced horizontal movements to be inferred and subsequently verified. In this report, the mechanics of the processes that cause horizontal movements, particularly those in sloping topography are described and discussed on the basis of field observations.

There are several processes recognised to generate horizontal subsidence movements. In flat terrain, systematic horizontal movements cause the surface to move initially toward the newly created goaf and subsequently in the direction of mining. Tectonic energy stored as horizontal stress is released by mining and when the horizontal stresses are high, the magnitude of this horizontal stress relief movement is large enough to be perceptible for some kilometres from the panel. In sloping terrain, there is an additional component of horizontal movement that occurs in a downslope direction. This downslope horizontal movement, also referred to as valley closure movement, has a magnitude that is typically much greater than systematic or stress relief movements.

2.1 Components of horizontal movement

Three main components of horizontal movement are readily identifiable from the results of three dimensional subsidence monitoring above longwall panels in NSW:

- Systematic horizontal movements associated with sag subsidence above individual panels or trough subsidence above multiple panels involving a change of direction soon after the longwall face has passed and typically with a magnitude of less than about 200-300mm.

- Horizontal movements associated with release of horizontal tectonic stresses within the overburden strata, typically with a magnitude of less than 200mm at the goaf edge but extending up to several kilometres from the active panel.

- Horizontal movements that occur in a downslope direction in sloping terrain or up dip when the coal seam dips relative to the ground surface also referred to as valley closure movements. These movements have a magnitude that ranges up to about the magnitude of maximum vertical subsidence in steep terrain but is usually less than about 0.3-0.5 times the magnitude of maximum vertical subsidence in most situations.

Horizontal movements observed in the vicinity of longwall panels are a combination of all three components in varying proportions depending on location relative to the longwall panel.

2.1.1 Systematic Horizontal Subsidence Movements

Systematic horizontal subsidence movements are most readily observed in flat terrain when the other two processes that cause horizontal movements are not present or of low magnitude (Mills 1998).

Figure 3 illustrates the horizontal movements typically observed above a single retreating longwall panel in flat terrain. Initial movements are in a direction toward the active mining area from all sides. Typically, the magnitude of this initial movement is of the order of 10% of the eventual vertical subsidence, so 100-150mm of initial movement is typical for subsidence of 1-1.5m and this maximum occurs over the longwall footprint.

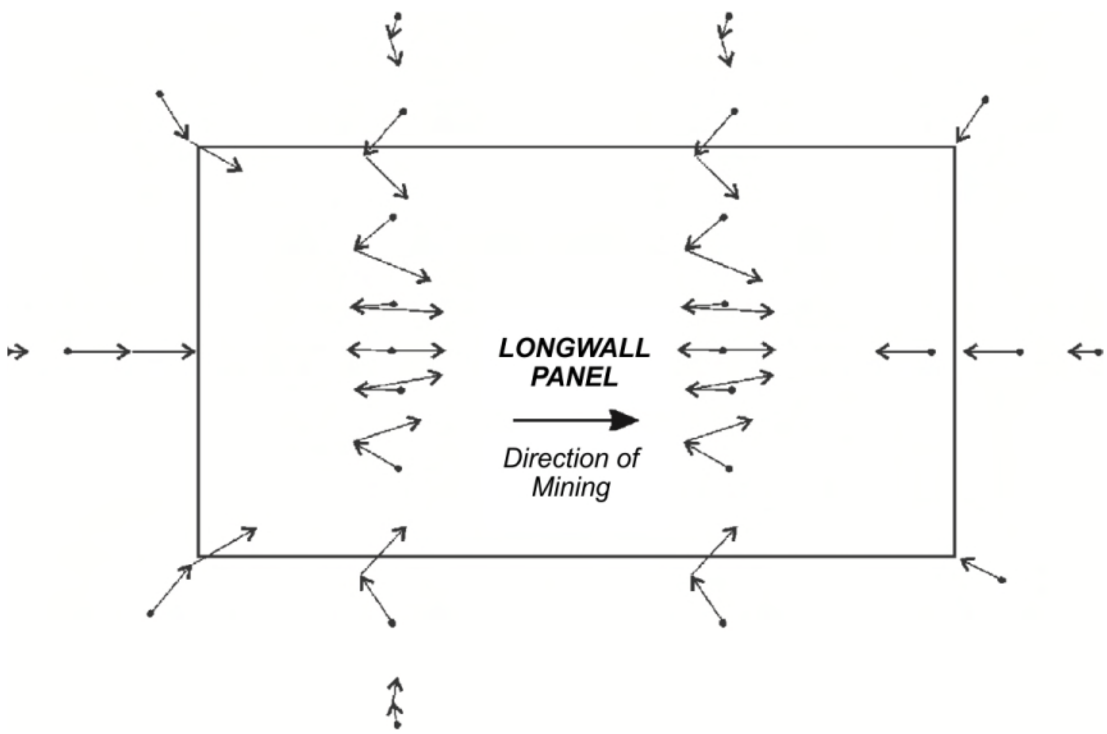


Figure 3: Sketch illustrating the direction of systematic horizontal movements observed in flat terrain.

When the vertical subsidence has reached about half of its maximum, typically some 0.3 times depth after the longwall face has passed, there is a change in direction so that subsequent horizontal movements occur in a direction toward the retreating longwall face.

Above the central part of the longwall panel, this change causes a complete reversal in direction. The magnitude of the subsequent movement is typically larger than the initial movement so that there is a permanent offset in the direction of mining. In other places around the panel edges, the change in direction is more subdued. At the start of the panel, both the initial movement and the subsequent movement are in the same direction so the two are additive. Systematic horizontal movements are therefore typically greatest at the start of the panel. At the finishing end of the panel, only the initial movement occurs. The subsequent movement does not develop because the longwall does not continue past the finishing line. As a result, systematic horizontal movements over the finishing rib of the panel tend to have lower magnitude than elsewhere around the panel edge.

Barbato (2017) and Barbato et al (2017) describe a method for predicting horizontal movement and strain at the surface due to longwall mining.

2.1.2 Horizontal Stress Relief Movements

Horizontal tectonic stresses within the overburden strata store considerable energy as evidenced by the damage caused when these stresses are released suddenly during earthquake events. In coal mining areas, the release of energy occurs when the rock strata overlying the longwall panel fails in horizontal compression allowing elastic stress relief to occur within the surrounding strata. This stress relief can extend for several kilometres from the goaf edge of active mining at overburden depths of 400-500m.

Reid (1998, 2001) reports on first order surveys in the Southern Coalfield of NSW showing perceptible horizontal movements occur at distances of up to about 1.5km from active mining. The direction of movements observed is predominantly in a north-east south-west orientation consistent with the regional horizontal stress direction.

Hebblewhite et al (2000) report on horizontal ground movements around the Cataract and Nepean Gorges at Tower Colliery. These movements are not aligned with the direction of the major horizontal stress but instead with the direction toward the free surface of the Nepean Gorge. The magnitude of horizontal closure across the gorge approached 300mm when the gorge was directly mined under.

Usually stress relief horizontal movements occur incrementally with longwall retreat, but there is evidence from far-field monitoring observations at Ulan Coal Mine and elsewhere that initial movements may occur as several discrete events rather than incrementally (Mills et al 2011). The characteristics of the movements observed at Ulan are consistent with elastic stress relief of in situ horizontal stresses causing the ground to move laterally up to 200mm.

Pells (2011) presents the results of far-field horizontal subsidence monitoring from Appin West Colliery in NSW. A simple elastic model is shown to be capable of explaining the far-field movements. These movements have a magnitude at the goaf edge of about 200mm and are detectable using a well-controlled survey network for several kilometres outside the mining area.

The mechanics of the process of horizontal stress relief movements are consistent with the failure of rock strata directly above individual longwall panels. The interpretation of the sag subsidence above individual longwall panels combined with extensometer and other monitoring data indicates that a zone of rock failure extends upward to a height above the mining horizon equal to about 1.4-1.7 times the longwall panel width (Mills 2012, Mills and O'Grady 1998). This failure process allows tectonic energy stored as horizontal stresses within the rock mass beyond the panel edges to be released and thereby allows the ground to move toward the failed rock strata above each longwall panel or in very steep topography toward the gorge.

The tectonic energy stored as horizontal stress tends to be reduced at shallower depths and far-field horizontal movements tend to reduce also. Far-field horizontal movements tend to zero at mining depths of less than about 150m.

2.1.3 Horizontal Movement in a Downslope Direction

The effects of topography are widely recognised to modify subsidence behaviour although the mechanics of the processes have only become apparent relatively recently. Kapp (1973, 1980) reported high compressive strains at topographic low points in NSW consistent with valley closure. Holla and Barclay (2000) note similar experience in the USA reported by Gentry and Abel (1978) and Ewy and Hood (1984). Holla and Barclay observe that given the varying geological settings, the occurrence of large ground strains and reduced vertical subsidence in topographic low points appears to be due to forces generated by topography rather than being a unique characteristic of the geological setting.

Holla (1997) describes the results of horizontal movements in steep terrain in NSW based on levelling and peg to peg strain measurements. Holla recognised the effect of horizontal movements but with only having strain measurements in one direction, found it difficult to interpret the mechanics involved.

Kay (1991) presents the results of a program of three dimensional surveying at Baal Bone Colliery that measured horizontal movements in steep terrain. These measurements and other conducted subsequently at the colliery (Mills 2001) show that horizontal movements in steep terrain include a component of movement additional to the systematic horizontal movements in in a direction toward the valley (i.e. in a downslope direction).

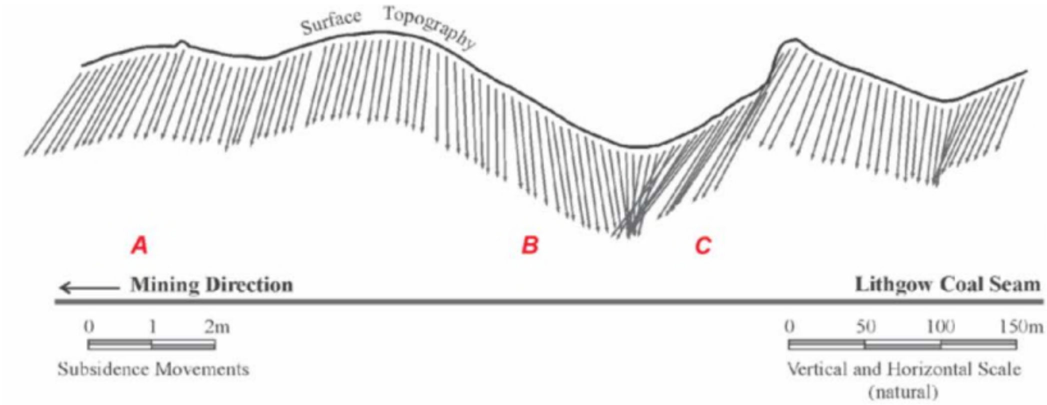
Seedsman and Watson (2001) illustrated this effect by removing systematic horizontal movements calculated for flat terrain from the measured subsidence vectors in an area where a topographic ridge had been mined under. The resulting vectors showed that the residual movement not associated with systematic subsidence occurred as movements in a downslope direction off both sides of the ridge sympathetic with the topography.

Waddington and Kay (2004) present a handbook reviewing the experience of mining under cliffs and river channels. The effect of valley closure is recognised and an empirical method for predicting an upper bound magnitude is presented. This method remains the primary method for estimating valley closure in NSW and is widely used.

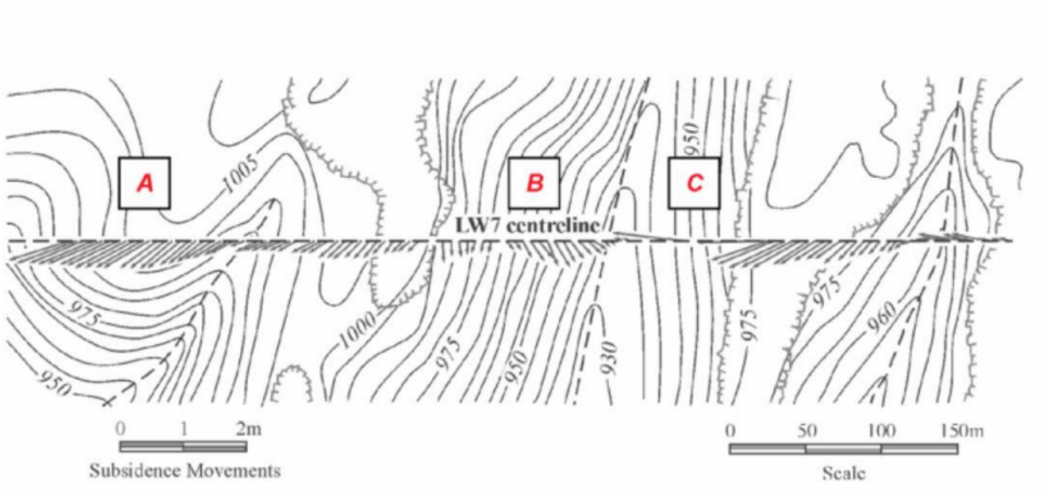
Waddington and Kay also postulate on the mechanics of the processes that cause valley closure but focus on horizontal stress concentrations in the base of the valley as the primary cause of the phenomenon. While this mechanism may contribute to observed valley closure in the Southern Coalfield where the Waddington and Kay study is primarily focused, the phenomenon of horizontal movement in a downslope direction is also observed in areas where the in situ horizontal stresses have been measured and the magnitude is small and insufficient to give rise to the magnitude of movements observed (Mills 2001). The characteristics of a horizontal stress driven mechanism for valley closure are also not consistent with the behaviour observed at multiple sites or with the low horizontal stresses measured in valley floors (ACARP 2009).

Figure 4 shows the horizontal movements measured in section at natural scale and in plan above Longwall 7 at Baal Bone Colliery. The subsidence line was surveyed in three dimensions before and after mining. The displacement vectors shown are exaggerated in magnitude but are drawn at natural scale so that both the vertical and horizontal components are at the same scale. The overburden depth ranges from 100m in the valley to 175m on the ridge tops. The longwall panels create a mined area that is 211m wide. The seam section mined is approximately 2.5m thick.

These measurements show that there is a general tendency for horizontal movement in the direction of mining as in flat terrain. Superimposed on this general tendency is a downslope component that responds to surface topography. In the area where the direction of mining and the slope coincide (C), the horizontal movements occur directly downslope. In areas where there is a cross-slope (A), there is a component of horizontal movement in the direction of this cross-slope. In areas where the slope is opposite to the direction of mining (B), there is still downslope movement, but the absolute magnitude is lower because of the offsetting effects of the systematic movement in the opposite direction and other effects discussed in the next section.



a) Vertical section showing longitudinal displacement vectors.



b) Plan showing longitudinal horizontal displacement vectors superimposed on topography.

Figure 4: Three dimensional subsidence movements observed above Longwall 7 at Baal Bone Colliery (Mills 2001).

2.2 Mechanics of horizontal subsidence movements in a downslope direction

Observations from multiple sites of horizontal subsidence movements at the surface and shear movements within the overburden strata are consistent with the following explanation of the mechanics that cause downslope horizontal movements.

Longwall mining has the effect of removing the vertical stress supporting the overburden strata. The resulting downward movement under the action of gravity releases potential energy that is available to do work. The downward movements associated with mining induced subsidence movements in a vertical direction cause the overburden rock strata to dilate or grow in volume as it fails. This failure causes fractures to form.

This process is recognised as a property of granular geomaterials such as sand and rock and is known in the soil and rock mechanics literature as dilatancy. The term dilatancy refers strictly speaking to the volume increase that is observed in the elastic range prior to rock failure but is used in this context to also include the volume increase associated with macro scale rotations of adjacent blocks of rock strata and normal displacements on irregular fracture surfaces.

Dilatancy means that the rock strata occupies more volume after it has failed and fractured than it did in its pre-failure state. The volume of actual rock material remains the same, but the volume of the rock mass increases by the volume of the fractures.

Lateral horizontal movement associated with strata dilation is largely suppressed in flat terrain where systematic horizontal movements and horizontal stress relief movements tend to dominate. In effect, the horizontal dilation is largely constrained by the intact, undisturbed material on either side of the panel. This intact strata tends to move inward toward the extracted panel and leaves no room for volume increase in a lateral direction. Instead, the fracture volume created by rock failure can only result in strata dilatancy in a vertical direction. Vertical dilation tends to reduce vertical subsidence.

In sloping terrain, however, there is an imbalance in the constraint on the downslope side that is set up by the terrain. As the overburden strata subsides over the goaf below a hillside, the free surface of the valley cannot offer any resistance to the dilating strata within the slope. There is also no horizontal stress to oppose the tendency for dilation. The direction of movement is governed by the law of conservation of energy. Horizontal dilation occurs in all directions, but the path of least resistance is directly toward the valley in the direction of maximum gradient, i.e. in a downslope direction. As a result, horizontal movement occurs in this downslope direction.

As shown in Figure 4, the magnitude of horizontal movement in a downslope direction can be as high as 1.5m in steep terrain but is usually in the range 0.3-0.7m for more moderate terrain.

Dilatancy is recognised to be sensitive to confining pressure with greater dilatancy observed when the confinement is less. This phenomenon contributes to the different horizontal movement observed in Figure 4 on opposite side of the valley.

In the stretching phase of the systematic subsidence cycle that occurs ahead of and immediately behind the longwall face, confinement is reduced and so the potential for dilatancy is greater than during the compression phase of the systematic cycle that occurs subsequently over the subsiding panel. As mining approaches the valley from under the hill, the slope is being stretched at the same time as the hillside is subsiding and dilating laterally so horizontal movements are large, and in the case shown in Figure 4 approach the magnitude of the vertical subsidence because of the steepness of the terrain.

As mining proceeds from the valley toward the hill, there is no dilatant lateral push to cause downslope movement until mining is well under the hill. By the time this push starts, the slope is in the compressive phase of the systematic subsidence cycle and dilatancy is suppressed by the increased confinement associated with this compression. As a result of the combination of these two processes horizontal movements are much less.

In summary, horizontal downslope movements are much larger when mining from high ground toward a valley compared to mining from a valley toward high ground. Longwall panels mining away from a valley are observed to cause much less impact than longwall panels mining toward a valley. Longwall panels mining parallel to a valley tend to be somewhere between.

2.3 Basal shear horizon

Figure 5 shows how the propensity for horizontal movement in a downslope direction that can cause horizontal movements above the level of the valley floor is constrained below the valley floor by the presence of rock strata on the opposite side of the valley. The difference in horizontal movement above and below the valley floor needs to be accommodated within the rock strata. Visual observations, borehole observations, and inclinometer monitoring indicate that the difference in horizontal movements is accommodated as horizontal shearing along a bedding plane or similar horizon at the level of the valley floor or more typically just below the valley floor as illustrated in Figure 5.

Although valley closure movements are common, it is less common to be able to directly observe the presence of shear horizons because they usually occur just below the floor of the valley where they cannot easily be seen. Lizard Creek Waterfall in the Southern Coalfield of NSW is located in an area adjacent to longwall mining. The waterfall spills from an incised valley half way up a vertical cliff into an amphitheatre of near vertical cliffs. The presence of the vertical cliffs provides a window into the sub-surface where a horizontal shear horizon can be observed directly. A mining induced shear horizon is evident along the face of this cliff at the level of the base of the incised channel. Iron stained water flows from this shear horizon consistent with it being freshly formed by mining, being hydraulically conductive, and laterally extensive.

A borehole calliper logging program in approximately 100 shallow boreholes was conducted in the base of the Waratah Rivulet in the Southern Coalfield of NSW to characterise the nature of mining induced fractures. These measurements are reported by Mills (2007) and in an Australian Coal Association Research Program report (ACARP 2009). They indicate that a horizontal shear horizon located at approximately 4-6m below the surface of the river channel has accommodated valley closure of up to about 600mm. The shear horizon was observed in boreholes to extend at least 60m from the river channel as a fracture zone with elevated hydraulic conductivity. Surface subsidence monitoring indicated that the shear horizon most likely extended below the entire hillside to the centre of the ridge, but no confirmation of this inference was possible until recently.

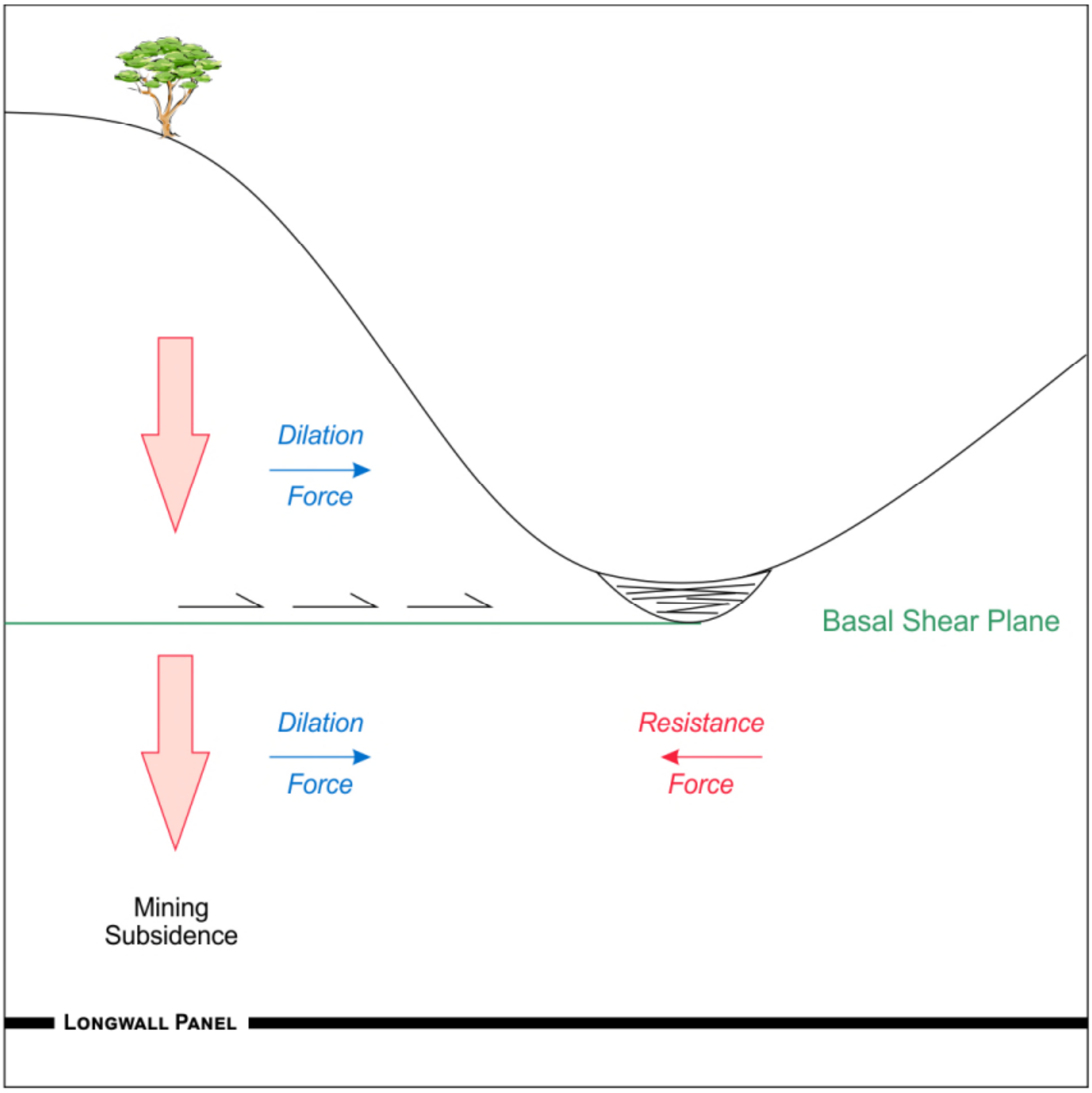


Figure 5: Sketch illustrating the mechanics of the process that causes horizontal movement in a downslope direction (also known as valley closure).

Monitoring at Sandy Creek Waterfall (Walsh et al 2014) provides definitive confirmation of the presence of horizontal shear horizons and mining induced subsidence movement localised onto these planes. The bed of Sandy Creek drops about 30m in elevation at a waterfall. When horizontal closure movements were first detected on inclinometers distributed across the site up to 350m from the creek, they were localised onto two horizons that corresponded in elevation with approximately 6m below the base of Sandy Creek upstream of the waterfall and about 10-15m below Sandy Creek downstream of the waterfall. The presence of large boulders in the bed of the creek downstream of the waterfall makes it difficult to determine the effective elevation of the creek bed, but it is likely that the deeper shear horizon also corresponded with an elevation at or just below the solid base of the creek downstream of the waterfall.

The effects of nearby longwall mining were closely monitored using a range of instruments including several manual inclinometers and a shaped accelerometer array (SAA). First evidence of closure movements was observed across the array of inclinometers on two main shear horizons when the longwall panels approached the waterfall. The initial movements were of low magnitude and did not have potential to significantly affect the integrity of the waterfall rock structure. Mining continued for several hundred metres more before the movements were considered large enough to be a potential threat to the integrity of the waterfall and the longwall was stopped (Walsh et al 2014).

The SAA inclinometer recorded the inclination at 0.5m intervals over a 50m vertical section at 1 minute intervals allowing the nature of the initial shear movements to be determined. Figure 6 shows that initial movements observed and the changes that were observed subsequently. The initial step change occurred at 9:56pm on 16 November 2012. Movements since then continued incrementally with additional longwall retreat and then more gradually once the longwall finished. Since the completion of mining, there have been several high intensity rainfall events. These events have been accompanied by small step changes in shear, but the shear movements have gradually stabilised since adjacent mining finished.

At the Sandy Creek Waterfall site, the level of monitoring data available was enough to allow an analysis of the body forces acting on a two dimensional slice through the site as shown in Figure 7. The horizontal stresses were measured at several locations including high up on the slope and in the valley floor. Piezometers measured the groundwater level and a 4m rise in water level due to two high intensity rainfall events that occurred after mining was complete. These two events caused shear on the basal shear plane and remobilisation of downslope movement.

By considering the balance of horizontal forces at limiting equilibrium in the two cases of no movement prior to the rainfall events and movement following a 4m rise in pore pressure, the friction angle on the basal shear plane can be estimated with a high degree of confidence. This analysis indicates that the friction angle on the basal shear plane is in the range 9°-14°, depending on assumed pore pressure conditions within the rock mass. This friction analysis is consistent with the range that would be expected for bedding planes in Hawkesbury Sandstone based on laboratory shear tests.

The key observations of interest from the Sandy Creek Waterfall monitoring in terms of characterising the shear horizons are:

- The nature of the shear movements observed is consistent with movement on near horizontal shear surfaces at an elevation just below the base of the valley.
- A step in the elevation of the valley floor leads to the development of two shear horizons, each just below the floor of the valley.

- The timing and magnitude of the shear movements are consistent with the valley closure movements observed.
- The movement observed is consistent with shear on a residual shear surface without the large energy release that would be associated with fracturing fresh rock.
- The remobilisation of shear movement following rainfall events and the gradual reduction in shear over time indicate that the shear surface is in a state of limiting equilibrium where even very small changes in horizontal load are capable of causing additional horizontal movement.
- The basal shear horizon extends outward from the valley as far as required to accommodate the horizontal movements observed on the surface.

3 IMPACT ASSESSMENT

The processes that cause valley closure and have potential to impact creeks above and near longwall panels were discussed in conceptual terms in Section 2. The challenge for assessing potential impacts to creek channels is to translate this conceptual understanding into likely impacts. Several approaches are discussed in this section. The impacts indicated in MSEC (2019) are consistent with the approaches discussed.

MSEC (2019) present an empirical relationship between impacts observed in creek channels in NSW and predicted total closure using the method presented in ACARP (2002) and Barbato et al (2014). This relationship is presented in Figure 8. A significant number of creeks have been mined under and near in NSW, so the database of experience is considered likely to be representative of an upper bound of the impacts expected around Longwalls W1 and W2 at Tahmoor Mine.

For the Longwalls W1 and W2 mining geometries, MSEC estimate maximum closure of 180mm, implying less than about 5% of rock bars are likely to be perceptibly fractured and less than 5% of pools are likely to see a reduction in surface water flow.

Another approach to estimating the level of impact is based on consideration of the rock strength and strain levels expected. Experience of monitoring valley closure impact zones indicates that the width of the impact zone is typically of the order of 30-40m wide. For maximum valley closure of 180mm, the average rock strain across a 30m length of rock is 0.6% or 6000$\mu\varepsilon$ (microstrain). Intact Hawkesbury Sandstone is observed to fail in unconfined compression tests conducted in the laboratory at strain levels in the range 1000-3000$\mu\varepsilon$ depending on a range of factors including the degree of weathering.

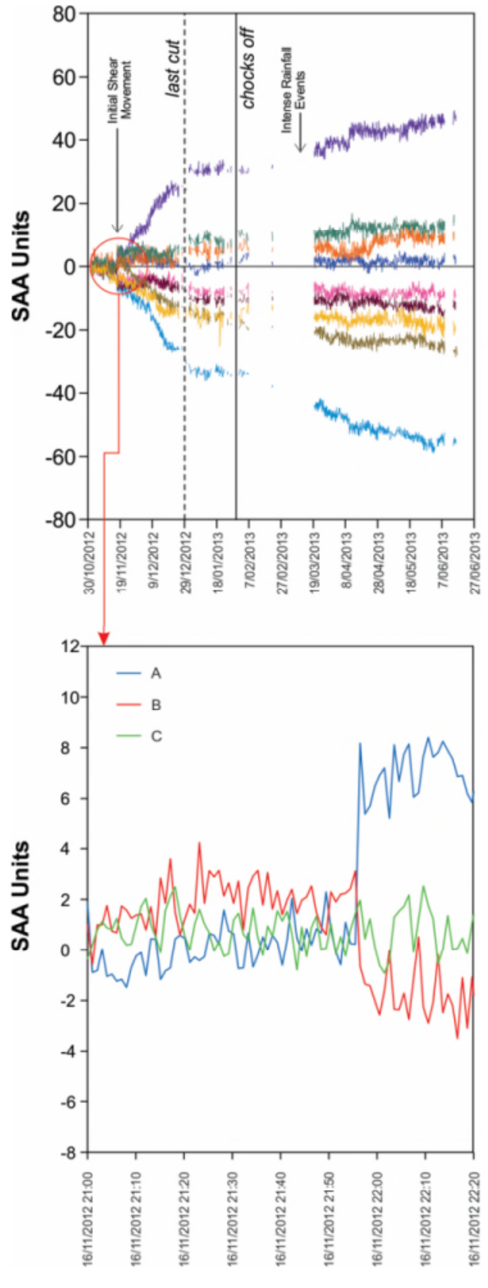


Figure 6: Results of Shaped Accelerometer Array (SAA) Inclinometer shear monitoring illustrating deformation characteristics of the basal shear plane at Sandy Creek Waterfall.

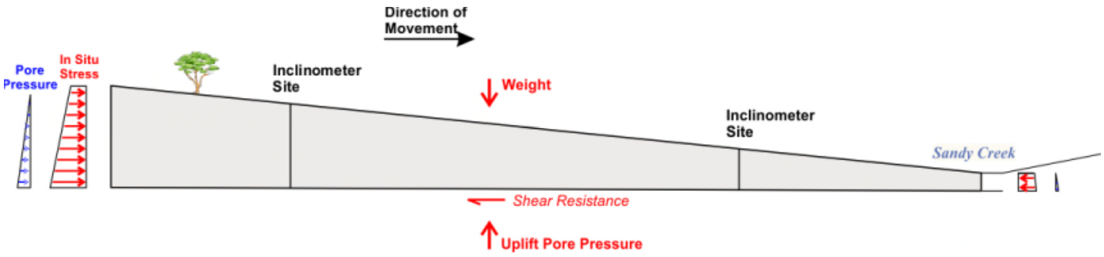


Figure 7: Free body diagram showing loads on the valley slopes above Sandy Creek sliding along a basal shear plane.

Pre-existing stresses in the bedrock of creek channels are not typically known and are likely to vary from location to location. These pre-existing stresses have the effect of reducing the additional strain that intact rock can support before failure occurs. The observation in Figure 8 of no perceptible impacts at 80mm of closure (equivalent to 0.26% or 2600$\mu\varepsilon$) is consistent with the pre-existing stresses being of low magnitude.

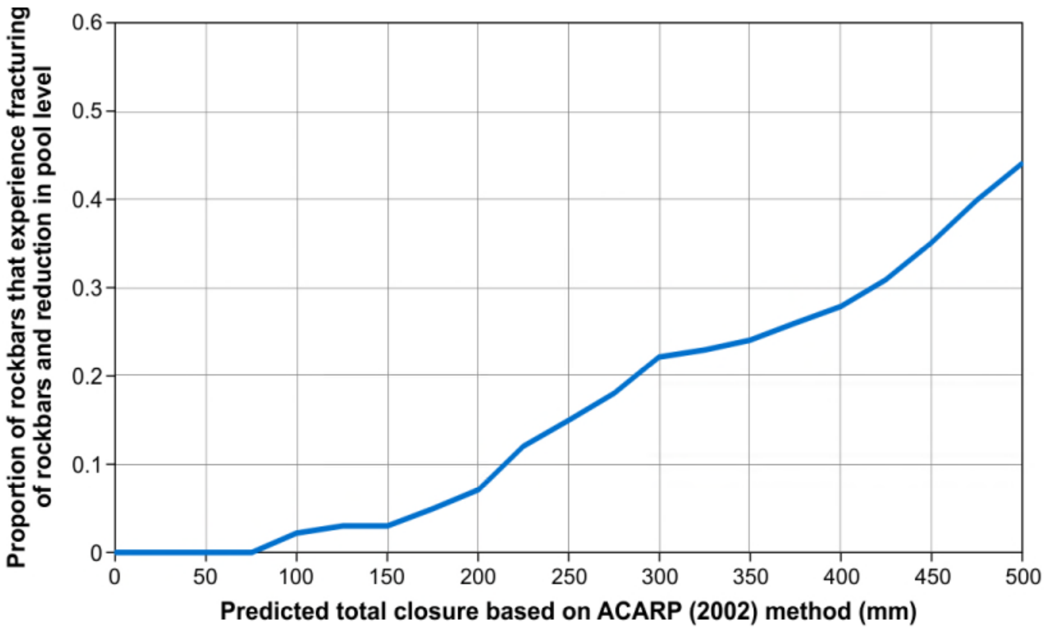


Figure 8: MSEC (2019) Rockbar impact model for Southern Coalfield.

The temperature range experienced naturally by rock materials can be used to estimate the significance and context of other loading effects. The surface temperature experienced on exposed rock bars is observed to range from -5°C up to 50°C seasonally and 10-20°C diurnally. Diurnal variations are observed to become muted at a depth below surface of about 5-6m. Seasonal variations are observed to be muted at about 10m below the surface.

A 55°C change in temperature in sandstone rock is expected to cause thermal expansion strains of up to 0.1% (1000$\mu\varepsilon$) equivalent to 30mm of valley closure. Sandstone experiencing repeated cycles of 0.1% thermal loading is likely to become overstressed over time. This process of repeated thermal stressing is considered one of the primary mechanisms responsible for natural erosion and deepening of creek channels. The presence of natural basal shear planes at depths of 5-6m below the surface of creek channels is consistent with this mechanism.

Valley closure movements causing rock strains of 6000$\mu\varepsilon$ on top of any pre-existing in situ stress are significantly higher than the natural thermal effects and would be expected to start to become perceptible as rock fracturing and lowering of pool levels. On this basis, the experience captured in Figure 8 is considered broadly consistent with loading conditions expected in the base of creek channels.

3.1 Stonequarry Creek

MSEC (2019) estimate maximum valley closure in Stonequarry Creek caused by mining Longwalls W1 and W2 of 60mm. SCT understands that the approach used to estimate this closure does not take account of the mechanics of valley closure discussed in Section 2.2. This estimate is therefore considered an upper limit on the valley closure expected given Longwalls W1 and W2 are mining away from the creek.

Impacts in the flooded section of Stonequarry Creek are expected to be low and generally imperceptible because the low levels of closure expected are in the range that sandstone in the bed of the creek is likely to experience naturally over time from thermal effects. The water level in Stonequarry Creek is controlled by a rock bar that is further downstream remote from mining activity. No impacts are expected at this rock bar so the water level in the pool upstream are not expected to be impacted even in the unlikely event that there is some fracturing of the creek bed.

From an impact management perspective, Longwall W2 can be shortened following the mining of Longwall W1 if the valley closure from Longwall W1 is greater than the maximum 30mm expected. Given that 30mm of valley closure is not likely to cause any closure movements greater than the range experienced naturally from thermal effects, this management strategy is expected to be robust.

3.2 East-west section of Cedar Creek

Impacts in the east-west section of Cedar Creek are expected to also be minor because the longwall panels are mining away from the creek. As discussed, the various components of horizontal movement tend to cancel each other out in this circumstance so impacts are expected to be low. Furthermore, the maximum estimated valley closure is of a similar magnitude to the changes expected naturally from thermal stresses.

3.3 North-south sections of Cedar Creek and Matthews Creek

Impacts to the north-south section of Cedar Creek and Matthews Creek are expected to be perceptible in places. Valley closure movements are expected to be large enough to cause some perceptible impacts to sandstone in the creek bed with potential for reduced water level and iron staining along some sections of both creeks, especially those sections closer to the longwall panels, where the creek is deeply incised and flow levels are naturally ephemeral.

MSEC estimate maximum valley closure after Longwall W1 of 120-130mm in these sections of the creek increasing to 170-180mm after Longwall W2. These estimates are likely to be upper limits on the valley closure but unlike at the start of the panels, the direction of mining is not expected to reduce the magnitude of valley closure estimated.

The empirical experience summarised in Figure 8 indicates that 3% of rock bars and pools are likely to be perceptibly impacted by mining Longwall W1 and a further 2% (total 5%) are likely to be perceptibly impacted by mining Longwall W2.

From a management perspective, shortening Longwall W2 is not expected to have any significant effect on the magnitude of valley closure in these sections of creek. The additional closure across these sections of creek is likely to be an expected consequence of mining Longwall W2.

3.4 East-west sections of Cedar Creek and Matthews Creek

The east-west sections of Cedar Creek and Matthews Creek are unlikely to be perceptibly impacted. The high ground on either side of these sections of creek are not directly mined under. Without subsidence, there is no potential for strata dilation and therefore no significant valley closure movements are expected from mining Longwalls W1 or W2.

If you have any queries or require further clarification of any of the issues raised, please don't hesitate to contact me directly.

Yours sincerely

Ken Mills
Principal Geotechnical Engineer

References

ACARP (2002) "Management information handbook on the undermining of cliffs, gorges and river systems-Version 1" ACARP Research Projects C8005 and C9067, A.A. Waddington and D.R. Kay, September 2002.

ACARP (2009) "Damage criteria and practical solutions for protecting river channels" Australian Coal Association Research Project Report C12016, K. Mills, May 2009.

Barbato J. (2017) "Development of improved methods for the prediction of horizontal movement and strain at the surface due to longwall mining" PhD thesis, UNSW.

Barbato J. Brassington G. and Walsh R. (2014) "Valley closure impact model for rock bar controlled streams in Southern Coalfield" Proceedings of the 9th Triennial Conference of the Mine Subsidence Technological Society, Pokolbin 11-13 May 2014, Vol1 pp221-226.

Barbato J, Hebblewhite B, Mitra R, Mills K and Waddington A (2017) "Development of predictive methods of horizontal movement and strain at the surface due to longwall mining" Proceedings of the 10th Triennial Conference Mine Subsidence Technical Society, Hunter Valley 6-7 November 2017, p 207.

Ewy, R.T. and Hood, M. (1984). "Surface strain over longwall coal mines: its relation to the subsidence trough curvature and to surface topography" In: International Journal of Rock Mechanics, Mining Sciences, and Geomechanics Abstracts, 21(3):155-160.

Gentry, D.W., Abel, J.F. (1978). "Surface response to longwall coal mining in mountainous terrain" In: Bulletin of Association of Engineering Geologists, XV(2):191-220.

Hebblewhite, B., Waddington, A., Wood, J. (2000). "Regional horizontal surface displacements due to mining beneath sever surface topography" In: Proceedings of the 19th International Conference on Ground Control in Mining, August 8-10, 2000, pp149-157.

Holla, L. (1997). "Ground movement due to longwall mining in high relief areas in New South Wales, Australia" In: International Journal of Rock Mechanics, Mining Sciences, and Geomechanics Abstracts, 34(5):775-787.

Holla L., Barclay, E. (2000). Mine subsidence in the Southern Coalfield of NSW, Australia. NSW Department of Mineral Resources.

Kapp, W.A. (1973). "Subsidence at Kemira Colliery" In: Proceedings of the Symposium on Subsidence in Mines, ed. A.J. Hargraves, Australasian Institute of Mining and Metallurgy, Illawarra Branch, Wollongong, pp 7.1-7.9.

Kapp, W.A. (1980). "A study of mine subsidence at two collieries in the Southern Coalfield, New South Wales" In: Proceedings of Australasian Institute of Mining and Metallurgy, No. 276, pp 1-11.

Kay, D. (1991). "Effects of subsidence on steep topography and cliff lines" End of Grant Report Number 1446 of National Energy Research, Development, and Demonstration Program.

Mills, K.W. (1998). "Subsidence mechanisms about longwall panels" In: Proceedings of International Conference on Geomechanics/Ground Control in Mining and Underground Construction (GGM98), Wollongong, 14-17 July 1998, Vol 2, pp745-756.

Mills, K.W. (2001). "Observations of horizontal subsidence movement at Baal Bone Colliery" In: Proceedings of 5th Triennial Conference of the Mine Subsidence Technological Society, Maitland, 26-28 August 2001, pp 99-111.

Mills, K.W. (2007). "Subsidence impacts on river channels and opportunities for control" In: Proceedings of the 7th Triennial Conference of the Mine Subsidence Technological Society, University of Wollongong, 26-27th November 2007, pp 207-217.

Mills, K.W. (2012). "Observations of ground movements within the overburden strata above longwall panels and implications for groundwater impacts" In: Proceedings of the 38th Symposium on the Advances in the Study of the Sydney Basin, Hunter Valley, May 10-11, 2012, pp 1-14.

Mills, K.W. (2014) "Mechanics of horizontal movements associated with coal mine subsidence in sloping terrain deduced from field measurements" Proceedings of 33rd International Conference on Ground Control in Mining, Morgantown WV July 29-31, 2014, pp 304-311.

Mills, K.W., O'Grady P. (1998). "Impact of longwall width on overburden behaviour" In: Proceedings of Coal 98 Conference, Wollongong, 18-20 February 1998, pp 147- 155.

Mills, K.W., Morphew, R.H., Crooks, R.J. (2011). "Experience of monitoring subsidence at Ulan Coal Mine" In: Proceedings of the 8th Triennial Conference of the Mine Subsidence Technological Society, Hunter Valley, 15-17 May 2011, pp 89-100.

MSEC (2019) "Subsidence predictions and impact assessments for natural and built features due to the extraction of proposed Longwalls W1 and W2 in support of the Extraction Plan Application" Draft report to SIMEC Mining. Revision A dated April 2019.

Pells, P.J.N., (2011). "A simple method of estimating far field movements associated with longwall mining" In: Australian Geomechanics, Vol 46 (3) September 2011, pp1-8.

Reid, P. (1998). “Horizontal movements around Cataract Dam, Southern Coalfield” In: Proceedings of the 4th Triennial Conference of the Mine Subsidence Technological Society, University of Newcastle, 11-13th July 1998, pp 157-170.

Reid, P. (2001). “Further analysis of horizontal movements around Cataract Dam, 1980 to 1997” In: Proceedings of 5th Triennial Conference of the Mine Subsidence Technological Society, Maitland, 26-28 August 2001, pp 211-218.

Seedsman, R.W., Watson, G. (2001). “Sensitive infrastructure and horizontal ground movements at Newstan Colliery” In: Proceedings of 5th Triennial Conference of the Mine Subsidence Technological Society, Maitland, 26-28 August 2001, pp 171-180.

Waddington, A.A., Kay, D. (2004). “Management information handbook on undermining cliffs, gorges, and river systems” In: ACARP Research Projects C8005 and C9607, February 2004.

Walsh, R.V., Hebblewhite, B.K., Li, G., Mills, K.W., Nicholson, M.A., Barbato, J., Brannon, P.J. (2014). “Sandy Creek Waterfall – Case study of successful management of the impacts of longwall mining a sensitive natural surface feature” Proceedings of 33rd International Conference on Ground Control in Mining, Morgantown WV July 29-31, 2014 pp71-79.