REPORT: SUBSIDENCE PREDICTIONS AND IMPACT ASSESSMENTS

GLENCORE:

Tahmoor Colliery – Longwalls 31 to 37

Subsidence Predictions and Impact Assessments for Natural and Built Features in Support of the SMP Application

VOLUME 1

DOCUMENT REGISTER

Revision	Description	Author	Checker	Date
01	Draft Issue	DK / PA / JB	-	18th Dec 14
A	Final Issue	DK / PA / JB	PD / BM	22nd Dec 14

Report produced to:- Support the SMP Application for Longwalls 31 to 37.

Background reports available at *www.minesubsidence.com:-*

Introduction to Longwall Mining and Subsidence (Revision A)

General Discussion of Mine Subsidence Ground Movements (Revision A)

Mine Subsidence Damage to Building Structures (Revision A)

EXECUTIVE SUMMARY

Tahmoor Colliery proposes to extend its underground coal mining operations, which is located in the Southern Coalfield of New South Wales, by extracting coal from the Bulli Seam, to the north of the existing workings, using longwall mining techniques. Tahmoor Colliery has previously mined Longwalls 1 to 27 to the south of the proposed longwalls, and is currently mining Longwall 28.

Mine Subsidence Engineering Consultants Pty Ltd was commissioned by Tahmoor Colliery to study the mining proposals and prepare a subsidence report to support the Subsidence Management Plan (SMP) application for the proposed Longwalls 31 to 37, which are a continuation of a series of longwalls that extend into the Tahmoor North Lease area, which began with Longwall 22.

The mining of Longwalls 22 to 28 occurred predominately beneath the urban and suburban areas of the Tahmoor township. Longwalls 29 to 37 will occur predominately beneath the rural areas, with the depths of cover typically ranging between 435 metres and 555 metres. The proposed longwalls are located between the townships of Tahmoor, Thirlmere and Picton.

The subsidence predictions for the proposed longwalls have been obtained using the Incremental Profile Method (IPM), which has been calibrated using the extensive ground monitoring data from Tahmoor Colliery. The maximum predicted ground movements resulting from the proposed longwalls are: 1,225 mm vertical subsidence; 6.0 mm/m tilt (i.e. 0.6 %, or 1 in 165); 0.09 km^{-1} hogging curvature (i.e. minimum radius of curvature of 11 kilometres); and 0.13 km^{-1} sagging curvature (i.e. minimum radius of curvature of 8 kilometres). The predicted subsidence parameters for the proposed longwalls are similar to those predicted for the existing and approved Longwalls 22 to 30.

The predicted strains have been based on a statistical analysis of the measured strains at Tahmoor Colliery. The maximum predicted strains above the proposed longwalls, away from the streams (i.e. excluding valley related compressive strains) are: 0.9 mm/m tensile and 1.8 mm/m compressive based on the 95 % confidence level; and 1.5 mm/m tensile and 3.5 mm/m compressive based on the 99 % confidence level. The compressive strains in the bases of the larger streams are expected to be similar to those observed in similar types of streams at Tahmoor Colliery and elsewhere in the Southern Coalfield, which were between 10 mm/m and 20 mm/m.

Areas of increased subsidence (i.e. the observed vertical incremental subsidence was up to two times that predicted) occurred above Longwall 24A and above the south-eastern ends of Longwalls 25 to 27. The higher levels of subsidence have decreased with the successive longwalls in the series, with the observed subsidence above the south-eastern end of Longwall 28 being similar to that predicted. Increased subsidence is not anticipated above the proposed longwalls. In any case, the impact assessments provided in this report for the natural and built features have considered the potential impacts if the observed movements exceed those predicted by factors of up to two times.

The proposed longwalls will be extracted in two series, separated by a barrier of unmined coal. Based on the observations of mining around other barriers of unmined coal, elsewhere in the Southern Coalfield, it is expected that additional vertical subsidence could develop above the barrier pillar, up to 150 mm greater than that predicted using the IPM. Whilst the observed vertical subsidence could exceed the predictions in this location, previous experience has found that this is not accompanied by any significant tilts, curvatures or strains, i.e. less than 0.5 mm/m which is in the order of survey tolerance.

The SMP Area under consideration in this report is the area that will be affected by the mining of the proposed Longwalls 31 to 37. The SMP Area, as a minimum, has been defined as the surface area enclosed by the: 35 degree angle of draw from the limit of proposed mining, as defined in Section 6.2 in the SMP Guideline; and the predicted 20 mm subsidence contour, which has been calibrated using the extensive ground monitoring data from Tahmoor Colliery. The natural and built features located outside this area which are predicted to experience far-field movements and, could be sensitive to these movements, have also been included in the impact assessments provided in this report.

The assessments provided in this report should be read in conjunction with the assessments provided in the other specialist consultant reports on the project. The main findings from this report are as follows:-

- The main streams (i.e. 3rd order or greater) located within the SMP Area are: Redbank Creek and Tributary 2 to Redbank Creek which are located above the proposed Longwalls 31 and 32; Stonequarry and Cedar Creeks which are partially located above the proposed Longwall 33; Matthews Creek which is located above the proposed Longwalls 35 to 37; and Tributary 1 to Matthews Creek which is located above the proposed Longwall 37.

  There are no predicted reversals of grade along these streams as a result of the proposed mining. The natural grade of Stonequarry Creek reduces to an almost flat grade in one location, upstream of the tailgate of Longwall 33, and there could be locally increased potential for ponding in this location. There could also be localised areas along other streams with small increases in the potential for ponding where the natural gradients are low.

It is expected that fracturing will develop along the sections of the streams located directly above the proposed longwalls. In some locations along the streams, the surface water flows will be diverted into the dilated strata beneath the beds, which could result in the partial or complete loss of surface water flows and the drainage of pools. It is unlikely that there would be any net loss of water from the catchment, as the depth of buckling and dilation resulting from longwall mining is generally less than 10 metres to 15 metres, with the diverted flows expected to re-emerge further downstream.

Tahmoor Colliery has developed a subsidence management plan for managing the potential impacts to streams during the mining of Longwalls 22 to 30. It is recommended that Tahmoor Colliery continue to develop management plans to manage potential impacts on the streams during the mining of the proposed longwalls

- There are 11 cliffs which have been identified within the SMP Area. Two of these cliffs are located along Matthews Creek directly above the proposed Longwall 35, with the remaining nine cliffs located along Cedar Creek outside of the proposed longwalls. There are also rock outcrops located across the SMP Area, primarily along the alignments of the streams.

  The two cliffs located above the proposed longwalls could experience impacts including fracturing and rock falls. The experience of mining beneath cliffs along the Nepean, Cataract and Bargo Rivers indicates that the impacts are likely to represent between 2 % and 5 % of the total lengths of cliff located directly above the longwalls. It is unlikely that the cliffs located outside the proposed longwalls would experience adverse impacts.

  It is recommended, that management strategies are developed to minimise the potential risks resulting from rock falls.

- Natural steep slopes have been identified within the SMP Area along the: banks of Redbank Creek, Cedar Creek and Matthews Creek; and along the sides of ridges, such as the Redbank Range. A total of 84 structures within the SMP Area are located on or near steep slopes, including: four public amenities; 12 public utilities; nine business or commercial establishments; 11 houses; four pools; 41 farm buildings and sheds; and three farm dams. A number of private driveways also traverse along or near the steep slopes.

  Tension cracks could develop at the tops and along the sides of the steep slopes and compression ridges could develop at the bases of these slopes. Localised natural slope slippage has been observed along the Redbank Range and it is possible, therefore, that further localised slope slippages could develop along the ridges that may be attributable to either natural causes, mine subsidence, or both.

  Experience indicates that the probability of large scale slope slippage due to the proposed mining is extremely low due to the significant depth of cover beneath the ridges. No large scale mining-induced slope failures have been observed in the Southern Coalfield at depths of cover exceeding 400 metres. While the risk is extremely low, some risk remains and attention must therefore be paid to any structures or roads that may be located in the vicinity of steep slopes.

  Tahmoor Colliery has developed a subsidence management plan for managing the potential impacts on steep slopes during the mining of Longwalls 22 to 28. It is recommended that this management plan be extended to include the steep slopes and the infrastructure on these slopes within the SMP Area. Specific management strategies should be developed for Thirlmere Way which runs along the top of a ridge above and between the proposed longwalls.

- There is approximately 5.0 kilometres of track along the Main Southern Railway which is located within the SMP Area, of which, approximately 630 metres will be directly mined beneath by the proposed longwalls.

  Tahmoor Colliery has successfully mined beneath approximately 1.5 kilometres of the Main Southern Railway during the extraction of Longwalls 25 to 28 and Appin Colliery has successfully mined beneath approximately 2.2 kilometres of the Main Southern Railway using similar management measures. In addition to the railway track, both collieries have successfully managed potential impacts on associated rail infrastructure including railway culverts, bridges, a tunnel, cuttings, embankments and communications and signalling systems.

  While mining-induced impacts have been previously observed, the railway has been maintained such that it has remained safe and serviceable during mining, without impacting on the normal train operations. Management measures include the operation of a Track Expansion System, which is a combination of expansion switches and zero toe load clips, which effectively decouple the rails from mining-induced ground strains.

Tahmoor Colliery and the Australian Rail Track Corporation (ARTC) have developed a detailed risk management plan, via a Rail Management Group, for managing potential mine subsidence impacts on the Main Southern Railway due to the extraction of Longwalls 25 to 28. It is recommended that Tahmoor Colliery and ARTC continue to develop plans to manage potential impacts during the mining of the proposed longwalls. This includes the following key features of the railway track and rail infrastructure within the SMP Area and a small number of bridges that are located outside the SMP Area:

  - Track geometry;
  - Rail stress;
  - Railway bridges located directly above previously approved Longwall 28, which are the Deviation Overbridge at 92.410 km and the Bridge Street Overbridge at 91.000 km (which is planned to be replaced);
  - Railway bridges will not be directly mined beneath by the proposed longwalls but are located either just inside the SMP Area or could be sensitive to differential far field horizontal movements. These are the Thirlmere Way Rail Bridge at 89.326 km, the Connellan Crescent Overbridge at 89.080 km, the Argyle Street Rail Bridge at 86.13 km and the Picton Viaduct over Stonequarry Creek at 85.42 km;
  - The Picton Railway Tunnel and the historic Mushroom Tunnel;
  - Culverts;
  - Embankments;
  - Cuttings; and
  - Communications and signalling infrastructure

- There is approximately 2.8 kilometres of track along the Picton to Mittagong Loop Line within the SMP Area, of which, approximately 1.8 kilometres will be directly mined beneath by the proposed longwalls.

  There are significant differences between the Loop Line and the Main Southern Railway. The main difference is that very few runs operate along the Loop Line, the majority of which occur on weekends. This provides ample time to monitor, inspect and maintain the track on weekdays to ensure that it is safe and serviceable during times of operation. The trains also operate at substantially reduced speeds compared to those running on the Main Southern Railway, which means that the track is able to accommodate greater differential subsidence movements. Finally, the Loop Line railway track is jointed track, rather than continuously welded rail. This means that the impact on mining-induced ground strains on the rails is significantly different. Potential impacts on the joints can be managed by monitoring, inspection prior to the operation of trains.

  Tahmoor Colliery and the New South Wales Rail Transport Museum at Thirlmere have previously managed potential mine subsidence impacts on the Picton to Mittagong Loop Line due to the extraction of Longwall 21, when a corner of the panel extracted directly beneath the Loop Line. A subsidence management plan was also developed in consultation and agreement with the New South Wales Rail Transport Museum to manage the low likelihood risks associated with the mining of Longwalls 24 to 26 at a remote distance away from the Loop Line.

  It is recommended that Tahmoor Colliery and the New South Wales Rail Transport Museum at Thirlmere develop a new plan to manage potential impacts during the mining of the proposed Longwalls 33 to 37. This includes the following key features of the railway track and rail infrastructure within the SMP Area:

  - Track geometry;
  - Rail stress;
  - Culverts;
  - Embankments; and
  - Cuttings

- The local roads within the SMP Area include: Remembrance Drive; Bridge Street; and Thirlmere Way. There are approximately 14.6 kilometres of roads located within the SMP Area, of which, 4.7 kilometres will be directly mined beneath by the proposed longwalls.

  The impacts on roads have been successfully managed during the extraction of Longwalls 22 to 27, which mined beneath approximately 24.5 kilometres of asphaltic pavement and a total of 46 impact sites were observed. The impacts included: cracking and heaving of the road pavements; and impacts to kerb, guttering and drainage pits.

  It is expected that only local and minor impacts would occur to the local roads as a result of the proposed longwalls, similar to those previously observed at the colliery, which could be repaired using normal road maintenance techniques.

Tahmoor Colliery and Wollondilly Shire Council have developed and acted in accordance with an agreed risk management plan to manage potential impacts to local roads during the mining of Longwalls 22 to 30. It is recommended that this management plan is reviewed and updated to incorporate the proposed longwalls.

- There is one road bridge located within the SMP Area where Remembrance Drive crosses Redbank Creek, which is located 350 metres outside the proposed mining. There are additional road bridges adjacent to the SMP Area, including: Remembrance Drive Bridge over Myrtle Creek; and Victoria Bridge over Stonequarry Creek. It is unlikely that these road bridges would experience adverse impacts due to their distances from the proposed longwalls.

  Tahmoor Colliery and Wollondilly Shire Council have previously developed and acted in accordance with agreed risk management plans to manage potential impacts to other road bridges during the mining of Longwalls 22 to 30. It is recommended that this management plan is reviewed and updated to incorporate the roads bridges within and immediately adjacent to the SMP Area.

- The Picton and Mushroom Tunnels are located 380 metres and 470 metres, respectively, from the proposed longwalls. It is unlikely that these tunnels would experience adverse impacts due to their distances from the proposed mining.

  Tahmoor Colliery has successfully managed the potential impacts on the Redbank Railway Tunnel during the extraction of Longwall 26, which mined within a distance of 500 metres from the tunnel. The strategies included: monitoring using automated total stations, tape extensometers and laser distancemeters; visual and traditional ground monitoring; and inclinometers.

  It is recommended that Tahmoor Colliery and ARTC manage potential impacts on the Picton Railway and Mushroom Tunnels.

- There are approximately 8 kilometres of potable water pipelines located within the SMP Area. The pipe sizes typically range between 100 mm and 200 mm and comprise a mixture of: Cast Iron Cement Lined; Ductile Iron Cement Lined ; PVC; and PE.

  Tahmoor Colliery has successfully mined Longwalls 22 to 27 directly beneath approximately 4.8 kilometres of DICL pipe and 19.0 kilometres of CICL pipe, with minimal impact to the distribution network reported. Similar pipelines have also been directly mined beneath elsewhere in the Southern Coalfield, with minimal impacts.

  Tahmoor Colliery and Sydney Water have developed and acted in accordance with an agreed risk management plan to manage potential impacts to potable water infrastructure during the mining of Longwalls 22 to 30. It is recommended that this management plan is reviewed and updated to incorporate the proposed longwalls.

- There are approximately 8.3 kilometres of sewer pipes located within the SMP Area, of which, 1.6 kilometres are located directly above the proposed longwalls. The Thirlmere Carrier Main follows the alignment of Bridge Street, above the proposed Longwalls 31 and 32, and the Tahmoor Carrier Main is located east of the proposed longwalls. The remaining sewer pipes within the SMP Area are gravity or rising mains. The pipelines were designed for mine subsidence and approved by the Mine Subsidence Board.

  Tahmoor Colliery has successfully mined Longwalls 22 to 27 directly beneath approximately 27.3 kilometres of sewer pipes, with no blockages or reversals of grade observed. Physical damage was observed to pipelines in five locations, during the extraction of Longwalls 25 and 26, but in each case the pipes remained serviceable but were required to be repaired.

  It is unlikely that there will be reversals in grade for the gravity mains located directly above the proposed longwalls, as they have been constructed with existing grades well above the maximum predicted tilt resulting from mining.

  Tahmoor Colliery and Sydney Water have developed and acted in accordance with an agreed risk management plan to manage potential impacts to sewer infrastructure during the mining of Longwalls 22 to 30. It is recommended that this management plan is reviewed and updated to incorporate the proposed longwalls.

- The Picton Water Recycling Plant is located on Remembrance Drive, north-east of the proposed longwalls. The plant includes a number of: structures; skimmers; tanks; and treated water storage dams; which are connected by a network of pipes. The design of the plant was approved by the Mine Subsidence Board.

  The plant and dams are not expected to be impacted by the conventional ground movements, due to their distances from the proposed longwalls, and since they were designed for mine subsidence movements. However, the site is located on top of a ridge and near to the location of the Nepean Fault and, therefore, it is recommended that management strategies are developed including: an engineering assessment of the infrastructure; visual and ground monitoring during active subsidence; and development of a response plan if adverse impacts were observed.

- The wastewater treatment plant at Stonequarry Estate is located above the proposed Longwall 33. The site includes: tanks; other structures; and a dam, which were designed and approved by the Mine Subsidence Board.

  It is unlikely that this site would experience adverse impacts, as it was designed to accommodate mine subsidence. It is recommended, that management strategies are developed in the case of non-conventional ground movements, including: engineering assessment of the infrastructure; visual and ground monitoring during active subsidence; and development of a response plan if adverse impacts were observed.

- There are approximately 6.6 kilometres of gas pipelines located within the SMP Area, which comprise: a 160 mm diameter polyethylene main along Remembrance Drive; and a reticulation network of 32 mm to 75 mm diameter nylon mains.

  Tahmoor Colliery has successfully mined Longwalls 22 to 27 directly beneath approximately 16.2 kilometres of gas pipes and no impacts have been reported. It is unlikely, therefore, that the gas pipelines within the SMP Area would experience adverse impacts.

  Tahmoor Colliery and Jemena have developed and acted in accordance with an agreed risk management plan to manage potential impacts to gas infrastructure during the mining of Longwalls 22 to 28. It is recommended that this management plan is reviewed and updated to incorporate the proposed longwalls.

- There are approximately 43.8 kilometres of powerlines located within the SMP Area, which comprise: 66 kV; 11 kV; and low voltage powerlines. The Endeavour Energy Picton Field Service Centre is also located above the proposed Longwall 31.

  Tahmoor Colliery has successfully mined Longwalls 22 to 27 directly beneath approximately 36.2 kilometres of powerlines and no significant impacts have been reported. Some minor impacts have been reported to consumer cables connected to houses. It is unlikely, therefore, that the powerlines within the SMP Area would experience significant impacts. Some minor impacts could occur to the Field Service Centre building, including cracking to concrete floors, wet areas and other finishes, but is expected to remain safe and serviceable.

  Tahmoor Colliery and Energy Australia have developed and acted in accordance with an agreed risk management plan to manage potential impacts to electrical infrastructure during the mining of Longwalls 22 to 30. It is recommended that this management plan is reviewed and updated to incorporate the proposed longwalls.

- Optical fibre cables follow the alignments of Remembrance Drive, Bridge Street, Stilton Lane, Bollard Place, Henry Street, Wonga Road, Thirlmere Way, Barkers Lodge Road and Stonequarry Creek Road, within the SMP Area. There are approximately 13.2 kilometres of optical fibre cables that are located within the SMP Area, of which, 4.5 kilometres will be directly mined beneath by the proposed longwalls.

  The direct buried optical fibre cable along Thirlmere Way and Remembrance Drive did not experience any impacts during the mining of Longwalls 22 to 27. The potential impacts on optical fibre cables have also been successfully managed elsewhere in the Southern Coalfield, including at Appin (Area 7) and West Cliff (Area 5), with the implementation of monitoring and management strategies.

  There are also approximately 24.7 kilometres of copper cables that are located within the SMP Area, of which, 6.3 kilometres will be directly mined beneath by the proposed longwalls. Tahmoor Colliery has successfully mined Longwalls 22 to 27 directly beneath approximately 42 kilometres of copper telecommunications cables, with only minor impacts to some aerial cables and no reported impacts to the direct buried cables.

  It is unlikely that there would be adverse impacts to the telecommunications cables resulting from the proposed longwalls. Tahmoor Colliery and Telstra have developed and acted in accordance with an agreed risk management plan to manage potential impacts to telecommunications infrastructure during the mining of Longwalls 22 to 28. It is recommended that this management plan is reviewed and updated to incorporate the proposed longwalls.

- The public amenities identified within the SMP Area include the: Queen Victoria Memorial Gardens (outside of proposed mining); two Places of Worship (one outside the proposed mining); Picton High School (outside of proposed mining); one Pre-School and Day Care Centre (outside the proposed mining); the Wollondilly Community Leisure Centre (outside of proposed mining); the Bridge Street Sports Centre; the Wollondilly Emergency Control Centre; and the Picton Fire Station (outside proposed mining).

The public amenities located outside the proposed mining are not expected to experience adverse impacts. The sites located directly above the proposed longwalls could experience impacts, but are expected to remain safe, serviceable and repairable. It is recommended that property subsidence management plans are developed for each of the public amenities located directly above the proposed longwalls, including: inspection by a structural engineer prior to active subsidence and, if required, implementation of any preventive measures; visual and ground monitoring; and strategies to manage impacts during active subsidence.

- There are 656 farm buildings and sheds located within the SMP Area, including garages; sheds; carports; tanks; greenhouses; hothouses; playhouses; and shade structures. It is expected, that these structures will remain safe, serviceable and repairable, due to the flexible types of construction and small sizes.

  Tahmoor Colliery has successfully mined Longwalls 22 to 27 directly beneath approximately 1,501 rural structures and impacts have been minor and readily repairable. Tahmoor Colliery has developed and acted in accordance with a risk management plan to manage potential impacts to farm buildings during the mining of these longwalls. It is recommended that this management plan is reviewed and updated to incorporate the proposed longwalls.

- There are 88 farm dams which are located within the SMP Area. The mining induced tilts are predicted to result in changes in freeboard up to 200 mm, which is unlikely to result in any significant reductions in the capacities of the farm dams. Mining could result in cracking or deformations in the dam bases or walls. Experience of mining directly beneath farm dams at the colliery and elsewhere in the Southern Coalfield indicates that the likelihood of adverse impacts on the dams is very low.

  There are building structures and infrastructure located immediately downstream of two large farm dams, being Dams Refs. GG37a and GG38d. It is recommended that detailed management strategies are developed for these dams including: geotechnical assessment of the dam walls; visual and ground monitoring during active subsidence; and management strategies if significant non-conventional ground movements were detected, such as lowering the stored water levels in the dams and providing a temporary water source until remediation has been completed.

- There are a total of 161 structures identified within the SMP Area that are used for industrial, commercial, or business purposes, of which, 77 structures will be directly mined beneath by the proposed longwalls. These include factories, workshops, business and commercial establishments.

  Most of the industrial, commercial and business structures are located around the industrial area along Bridge Street, Redbank Place, Bollard Place and Henry Street. There is another industrial area at Wonga Road.

  The establishments could experience adverse impacts as a result of the extraction of the proposed longwalls. The majority of the impacts are likely to be minor serviceability impacts, such as door swings and issues with roof gutter and wet area drainage, all of which can be remediated using normal building maintenance techniques. More substantial serviceability impacts could develop at some establishments, as a result of non-conventional ground movements, which could require the relevelling of wet areas or, in some cases, the relevelling of parts of the building structures, or repair of cracks to hardstand areas, masonry wall elements or movement at joints of concrete tilt panels.

  A small number of establishments may, however, experience substantial adverse differential subsidence movements, which have the potential to affect the safety and serviceability of the structures. It is difficult to predict which structures may experience these movements as they are influenced by the response of local geology beneath the structures to mining. The potential impacts can, however, be managed with the implementation of an effective and robust management plan, as have been successfully developed and implemented to manage potential impacts to complex factories and businesses during the mining of Longwalls 22 to 27, including a turkey processing plant, a large shopping centre and a number of shopfront structures along Remembrance Drive.

  Each business is unique in terms of the structures on the property and the activities that are conducted on each property. This includes the use of specialised equipment (e.g. concrete hoppers, processing equipment in a workshops and steel fabrication plant).

  Due to the unique nature of each business, it is recommended that individual subsidence management plans be developed in consultation with the owners of each business within the SMP Area to ensure that they remain safe and serviceable during and after the mining of the proposed longwalls.

- There are 31 Aboriginal archaeological sites which are located within the SMP Area: nine open camp sites; 14 rock shelters; two grinding sites (one at a rock shelter site); one modified tree; five PAD; and one burial site.

  The open camp sites are unlikely to experience adverse impacts resulting from the proposed mining. It is recommended that Tahmoor Colliery seek the required approvals from the appropriate authorities prior to any remediation of surface cracking in the vicinity of these sites.

  There are seven rock shelters located directly above the proposed longwalls. It is possible that these sites could experience impacts from the proposed mining, including: fracturing; rock falls; or increased water seepage through the joints. Experience of mining beneath rock shelters in the Southern Coalfield indicates that there is around 10 % likelihood of adverse impacts for each of the sites located directly above the proposed longwalls.

  There is one grinding groove site located directly above the proposed longwalls. It is possible that fracturing could occur in the vicinity of this site as a result of the proposed mining. It is considered very unlikely that the second grinding groove site located outside the proposed longwalls would experience adverse impacts.

  The modified tree is located directly above the proposed longwalls. It is unlikely that this site would experience adverse impacts, due to the high depths of cover and relatively flat terrain. The burial site is located outside the proposed longwalls and, therefore, is unlikely to experience adverse impacts.

- The European heritage sites identified within the SMP Area are: Koorana Homestead (above Longwall 32); Pump House and Weir at Matthews Creek (outside of proposed mining); Sandstone culvert at Matthews Creek (above Longwall 36); Fairly Residence, Picton (outside of proposed mining); Millers House, Picton (outside of proposed mining); the Queen Victoria Memorial Hospital (now called the Queen Victoria Memorial Gardens, outside of proposed mining); the Rural Landscape along Thirlmere Way (partly above proposed longwalls); Cottage on Thirlmere Way, Picton (outside of proposed mining); Thirlmere Way Rail Underbridge (outside SMP Area); Picton Conservation Area (outside of proposed mining); and South Picton Railway Bridge (outside of SMP Area).

  The heritage sites located outside the proposed longwalls are not expected to experience adverse impacts. Minor impacts could occur to some of the sites located above the proposed longwalls, but these are expected to be limited to the external claddings and finishes. It is recommended that management strategies and remediation methods are developed, in consultation with the heritage consultant, for each of the sites located directly above the proposed longwalls.

- There are 222 houses located within the SMP Area, of which, 53 houses (i.e. 24 % of the total) are located directly above the proposed longwalls. The majority of these houses are: single storey structures with lengths less than 30 metres (71 % of the total); brick or brick veneer wall construction (74 % of the total); and have strip footings (53 % of the total). There are 75 houses located outside the declared Mine Subsidence Districts and a further 33 houses that were constructed within the districts, but, prior to their declarations.

  It is expected that the mining induced tilt could result in minor serviceability impacts such as: door swings and issues with roof gutter and wet area drainage, all of which can be remediated using normal building maintenance techniques. More substantial serviceability impacts could develop at some houses, as a result of non-conventional ground movements, which could require the relevelling of wet areas or, in some cases, the relevelling of parts of the building structures.

  The impacts assessments for the houses due to the mining induced curvature and strain were made using the method outlines in ACARP Research Project C12015. It has been assessed that: 90 % or approximately 200 houses would experience Nil or Category R0 impacts; 7 % or approximately 16 houses would experience Category R1 or R2 impacts; and that 3 % or approximately 6 houses would experience Category R3 or greater impacts.

  It is expected that all houses would remain safe, serviceable and repairable at all times. It is possible that, for two or three houses located directly above the proposed longwalls, the costs of repairs could exceed the construction cost of the houses and, in these cases, the houses may need to be rebuilt.

  Tahmoor Colliery has extensive experience of mining beneath urban areas. It has developed and acted in accordance with a risk management plan to manage potential impacts to residential structures during the mining of Longwalls 22 to 28. It is recommended that this management plan is reviewed and updated to incorporate the proposed longwalls.

- There are 44 privately owned swimming pools located within the SMP Area, of which, 11 pools are located directly above the proposed longwalls. Based on the experience of mining beneath pools at the colliery, it is expected that two or three pools (i.e. 21 % of the total) would adverse impacts which could require them to be rebuilt. Tahmoor Colliery has developed management strategies for pools, including inspections to monitor the integrity of pool fences during active subsidence.

The overall findings of the study are that the levels of impact and damage to all identified natural and built features are manageable and can be controlled by the preparation and implementation of Subsidence Management Plans, many of which have already been developed and successfully implemented during the mining of Longwalls 22 to 27.

It is recommended that Tahmoor Colliery continues to develop management plans to manage the potential impacts for surface features. Management measures generally include monitoring of ground movements and the condition of surface features. Some mitigation measures are included to mitigate the risk of serious consequence should impacts occur to some critical surface features.

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MSEC647-34	Predicted Total Subsidence Contours due to Longwalls 22 to 34	A
MSEC647-35	Predicted Total Subsidence Contours due to Longwalls 22 to 35	A
MSEC647-36	Predicted Total Subsidence Contours due to Longwalls 22 to 36	A
MSEC647-37	Predicted Total Subsidence Contours due to Longwalls 22 to 37	A
MSEC647-38	Predicted Cumulative Subsidence Contours due to Longwalls 31 to 37	A
MSEC647- Maps 01 to 48	Building Structures and Farm Dams Maps 01 to 48 (Volume 2)	A

1.1. Background

Tahmoor Colliery (the Colliery) proposes to extend its underground coal mining operations, which is located in the Southern Coalfield of New South Wales, by extracting coal from the Bulli Seam using longwall mining techniques. Tahmoor Colliery is seeking approval to extract the proposed Longwalls 31 to 37, which are located immediately north-east of Longwalls 22 to 28. The overall layout of the longwalls at Tahmoor Colliery is shown in Drawing No. MSEC647-01, which together with all other drawings is included in Appendix F.

The mining of Longwalls 22 to 28 occurred predominately beneath the urban and suburban areas of the Tahmoor township. Longwalls 29 to 37 will occur predominately beneath the rural areas, with the depths of cover typically ranging between 435 metres and 555 metres. The proposed longwalls are located between the townships of Tahmoor, Thirlmere and Picton.

Mine Subsidence Engineering Consultants (MSEC) has been commissioned by Tahmoor Colliery to study the current mining proposals, to identify all the natural features and items of surface infrastructure and to prepare subsidence predictions and impact assessments for the proposed Longwalls 31 to 37.

This report provides information that will support the Subsidence Management Plan (SMP) Application to the NSW Department of Trade, Investment, Regional Infrastructure and Services (DTIRIS) in accordance with the requirements of the Written Report, as described in Chapter 6 of the *Guideline for Applications for Subsidence Management Plan Approvals* (DPI, 2003), as summarised in Table 1.1.

Table 1.1 Information Provided in Support of the SMP Application

Information	Section of the Guideline for "Applications for Subsidence Management Approvals"
The SMP Area or Application Area	Section 6.2
Site Conditions of the SMP Area	Section 6.4
Characterisation of Surface and Sub-surface Features within the SMP Area	Section 6.6
Subsidence Prediction	Section 6.7
Subsidence Impacts	Section 6.10.1
Impact Assessment based on Increased Subsidence Predictions	Section 6.10.3

In some cases, the report will refer to other sources for information on specific natural features and items of surface infrastructure. The report will also provide information to assist the risk assessment section for the SMP Application, as described in Section 6.10.2 of the SMP Guideline (DPI, 2003).

The proposed Longwalls 31 to 37 are located between the Bargo River, to the south-east, and the townships of Tahmoor, Thirlmere and Picton. A portion of each of Longwalls 31 and 32 are located beneath the light industrial area of southern Picton.

A number of natural features and items of surface infrastructure have been identified within the vicinity of the proposed longwalls, including creeks, steep slopes, the Main Southern Railway and the Picton Mittagong Loop Line and associated infrastructure, public roads and associated infrastructure, drainage culverts, potable water infrastructure, sewer infrastructure, gas infrastructure, electrical infrastructure, telecommunications infrastructure, building structures, farm dams, groundwater bores and survey control marks.

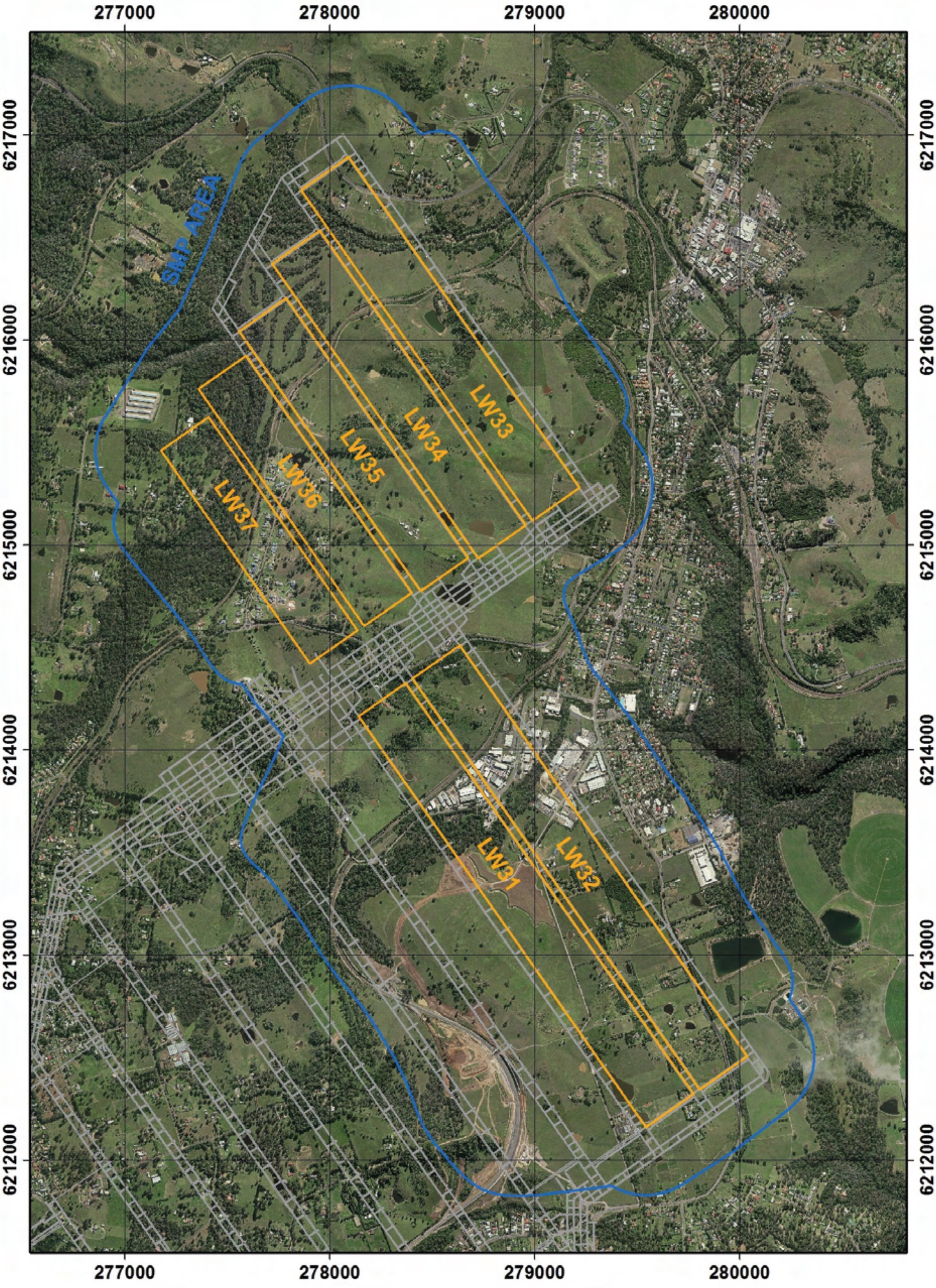


Fig. 1.1 Aerial Photograph Showing Proposed Longwalls and SMP Area

1.2. Mining Geometry

The proposed layout of Longwalls 31 to 37 within the Bulli Seam is shown in Drawing No. MSEC647-01. A summary of the dimensions of these proposed longwalls is provided in Table 1.2.

Table 1.2 Geometry of the Proposed Longwalls 31 to 37

Longwall	Overall Void Length Including Installation Heading (m)	Overall Void Width Including First Workings (m)	Overall Tailgate Chain Pillar Width (m)
Longwall 31	2,450	283	39
Longwall 32	2,450	283	39
Longwall 33	1,970	283	39
Longwall 34	1,755	283	39
Longwall 35	1,545	283	39
Longwall 36	1,410	283	39
Longwall 37	1,270	283	39

The surface level contours, seam floor contours and depth of cover contours are shown in Drawing Nos. MSEC647-05, MSEC647-06 and MSEC647-07, respectively.

The seam floor within the proposed mining area generally dips from the south-west to the north-east, with an average dip varying between 3 % and 5 %. Tahmoor Colliery has advised that the proposed longwalls will extract a minimum height of 2.1 metres within the Bulli Seam.

The depth of cover directly above the proposed longwalls varies between a minimum of 435 metres, along the alignment of Redbank Creek above the proposed Longwall 31, and a maximum of 555 metres, above the proposed Longwall 33.

1.3. Proposed Mining Schedule

It is planned that each longwall will extract coal working north-west from the south-eastern ends. Tahmoor Colliery is currently mining Longwall 28. The current schedule of mining for Longwalls 31 to 37 is shown in Table 1.3.

Table 1.3 Schedule of Mining

Longwall	Start Date	Completion Date
Longwall 31	April 2017	March 2018
Longwall 32	April 2018	February 2019
Longwall 33	March 2019	December 2019
Longwall 34	January 2020	September 2020
Longwall 35	October 2020	June 2021
Longwall 36	July 2021	February 2022
Longwall 37	March 2022	September 2022

1.4. Mining Lease Boundaries

The mining lease boundaries are shown in Drawing No. MSEC647-02.

The proposed longwalls will extract coal within two mining leases, ML 1376 and ML 1539. The Tahmoor North Mining Lease for the rural areas is numbered ML 1376. The Tahmoor North Mining Lease for the urban areas and the railways is numbered ML 1539. The original mining lease for Tahmoor Colliery is numbered CCL 716.

1.5. Planning Approval Boundaries

The planning approval boundaries are shown in Drawing No. MSEC647-02.

Development consent (DA 57/93) was granted in 1994 for land within ML 1376. Development consent (DA 67/98) was granted in February 1999 for mining beneath certain urban areas and railway land not included within ML 1376 and this area is covered by ML 1539.

1.6. Mine Subsidence Districts

The boundaries of the Mine Subsidence Districts are shown in Drawing No. MSEC647-03. It can be seen from this drawing that the SMP Area includes parts of the Bargo and Picton Mine Subsidence Districts.

The Bargo Mine Subsidence District was proclaimed in November 1975. A small section immediately west of Picton was added to the District in 1994, predominately comprising the Picton light industrial area. The Picton Mine Subsidence District was proclaimed in July 1997.

There are also some areas of rural and urban land north of Redbank Creek within the SMP Area that are not part of any Mine Subsidence District.

1.7. Urban and Rural Areas

The extent of urban and rural areas, as defined for the purposes of this SMP, is shown in Drawing No. MSEC647-04. Urban areas include the urban areas within ML 1539 as defined in the development application (DA 67/98), and the urban areas within CCL 716, which have been defined by MSEC for the purposes of the SMP.

1.8. Geological Details

Tahmoor Colliery lies in the southern part of the Permo-Triassic Sydney Basin, within which the main coal bearing sequence is the Illawarra Coal Measures, of Late Permian age. The Illawarra Coal Measures contain four workable seams, the uppermost of which is the Bulli Seam, and it is within this seam that Longwalls 31 to 37 are proposed to be extracted.

All of the sediments that form the overburden to the Bulli Seam belong to the Hawkesbury Tectonic Stage, which comprises three stratigraphic divisions. The lowest division is the Narrabeen Group, which is subdivided into a series of interbedded sandstone and claystone units. It ranges in age from Lower to Middle Triassic and varies in thickness up to 310 metres. Overlying the Narrabeen Group is the Hawkesbury Sandstone Group, which is a series of bedded sandstone units which dates from the Middle Triassic and has a thickness of up to 185 metres. Above the Hawkesbury is the Wianamatta Group, which consists of shales and siltstones and is poorly represented in this region, having a thickness of only a few tens of metres. A typical stratigraphic section for the Southern Coalfield area is shown in Fig. 1.2.

The major sandstone units are interbedded with other rocks and, though shales and claystones are quite extensive in places, the sandstone predominates. The major sandstone units are the Scarborough (Narrabeen Group), the Bulgo (Narrabeen Group) and the Hawkesbury Sandstones (Hawkesbury Sandstone Group) and these units vary in thickness from a few metres to as much as 200 metres. The rocks exposed in the river gorges and creek alignments belong to the Hawkesbury Sandstone Group.

The other rocks generally exist in discrete but thinner beds of less than 15 metres thickness, or are interbedded as thin bands within the sandstone. The major claystone unit is the Bald Hill Claystone, which lies above the Bulgo Sandstone at the base of the Hawkesbury Sandstone. This claystone varies in thickness and is, in some places, more than 25 metres thick. Due to the nature of the clay, which swells when it is wetted, it tends to act as an aquitard.

The geological structures identified at seam level are shown in Drawing No. MSEC647-08. The investigations, to date, have not identified any major geological structures within the extents of the proposed Longwalls 31 to 37. It is noted, that further geological structures could be identified as part of the ongoing investigations including horizontal in-seam drilling and seismic exploration.

The Nepean Fault is located to the east of the proposed longwalls, at distances of 200 metres from Longwall 32 and 350 metres from Longwall 33, at its closest points. The Bargo Fault zone, shown in DPI Geological Series Sheet 9029, is also indicated within the extents of the approved Longwalls 28 and 29, however, this zone has not been identified through the in-seam drilling or in the development headings, and is unlikely to exist.

The Nepean Fault zone is the major structural feature in the Tahmoor complex and it marks the eastern boundary to the existing mining operations at the colliery. The fault zone runs in an approximate north-south direction and is up to 200 metres wide, with the western side of the fault being more disturbed than the eastern side. Lohe et al (1992) advised that the Nepean Fault was a high angle westerly dipping reverse fault, whereas SEA (2002) advised that the Nepean Fault was a series of reverse and normal faults.

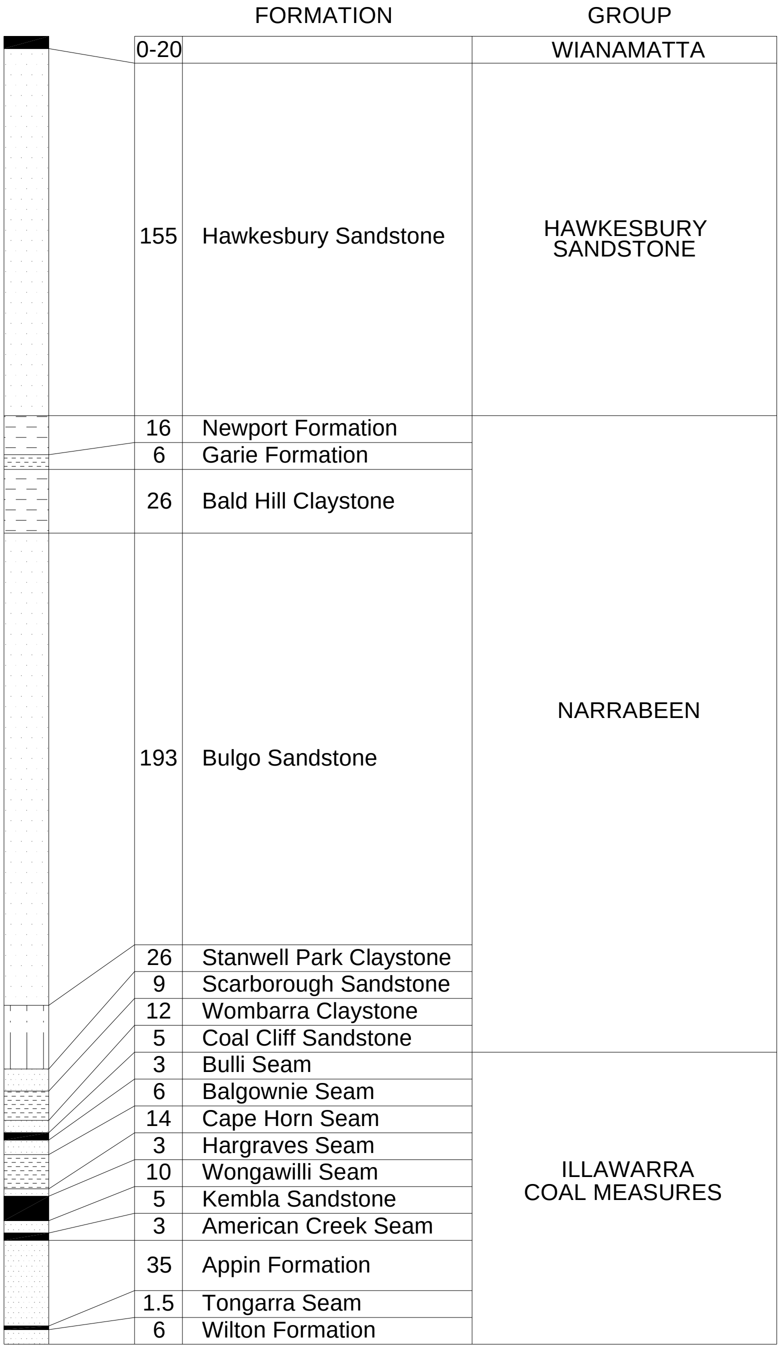


Fig. 1.2 Typical Stratigraphic Section – Southern Coalfield

While no geological structures have been identified directly above the proposed longwalls, the experience of increased subsidence above Longwall 24A and the commencing ends of Longwalls 25, 26 and 27 suggests that the overburden geology is different in these areas. As discussed in Section 4.3, the proximity of the Bargo River or the Nepean Fault appear to be contributing factors to the increased subsidence in these locations. The potential impacts based on increased subsidence for the natural and built features are considered in Chapters 5 and 6.

The surface lithology is illustrated in Fig. 1.3, which shows the proposed longwalls overlaid on Geological Series Sheet 9029, which is published by the DTIRIS, formally the Department of Primary Industries (DPI).

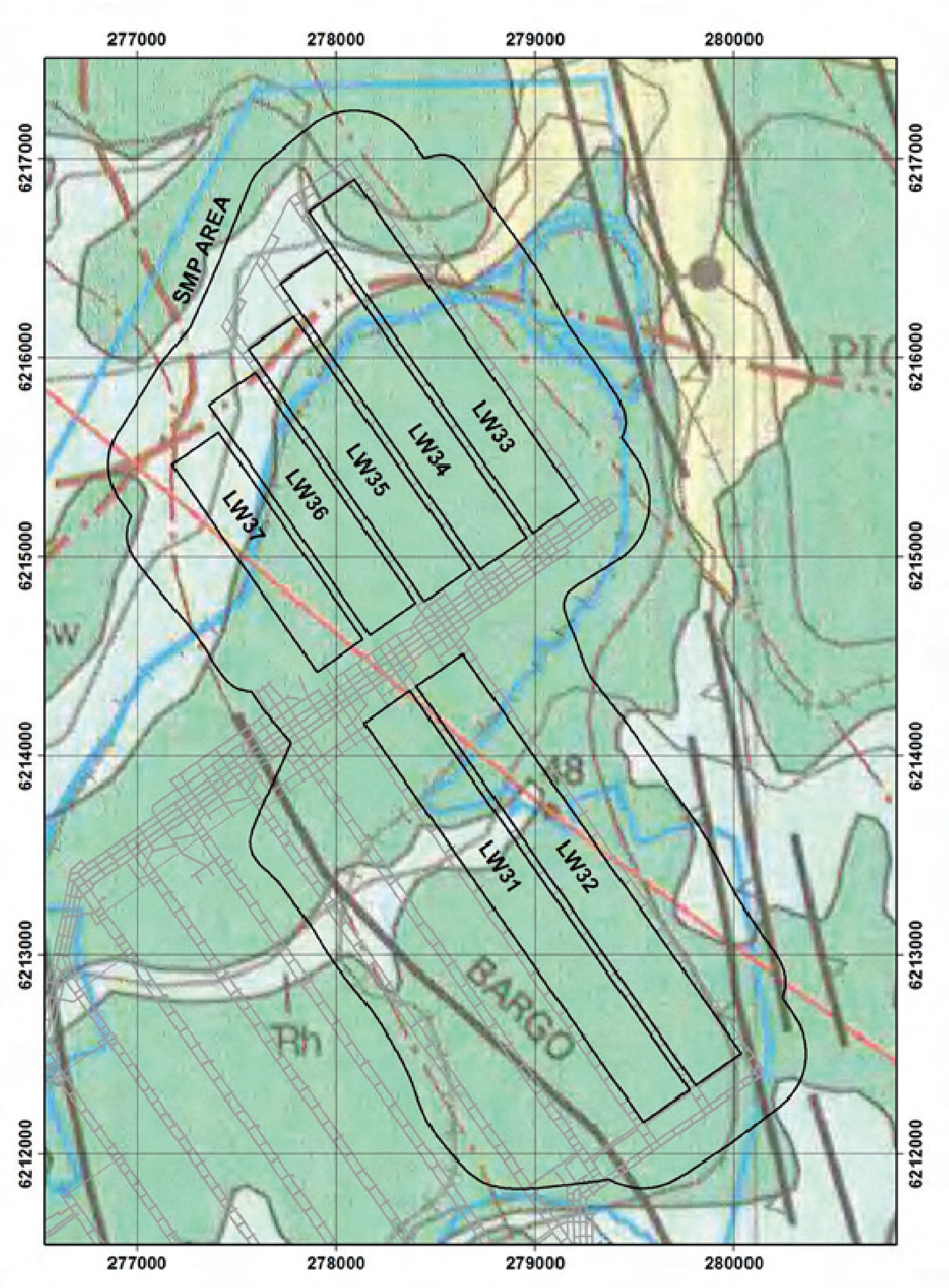


Fig. 1.3 Surface Lithology within the SMP Area (DPI Geological Series Sheet 9029)

The surface lithology above the proposed longwalls generally comprises the Wianamatta Group (Rw), with the Hawkesbury Sandstone Group (Rh) is exposed in Myrtle, Redbank and Matthews Creeks.

2.1. Definition of the SMP Area

The *SMP Area* is defined as the surface area that is likely to be affected by the proposed mining of Longwalls 31 to 37 in the Bulli Seam at Tahmoor Colliery. The extent of the SMP Area has been calculated by combining the areas bounded by the following limits:

- The 35 degree angle of draw line from the extents of the proposed longwalls;
- The predicted limit of vertical subsidence, taken as the predicted 20 mm subsidence contour, which has been determined using the calibrated Incremental Profile Method; and
- Features sensitive to far-field movements.

The depth of cover contours are shown in Drawing No. MSEC647-07. It can be seen from this drawing, that the depths of cover directly above the proposed longwalls vary between a minimum of 435 metres and a maximum of 555 metres. The 35 degree angle of draw line, therefore, has been determined by drawing a line that is a horizontal distance varying between 305 metres and 390 metres around the limits of the proposed longwalls.

The predicted limit of vertical subsidence, taken as the predicted total 20 mm subsidence contour, has been determined using the Incremental Profile Method, which has been calibrated using the extensive ground monitoring data from the colliery, as described in Chapter 3. The distance of the predicted 20 mm subsidence contour outside the proposed longwalls has been calibrated using the observed limits of vertical subsidence (i.e. 20 mm observed subsidence) for the previously extracted longwalls at the colliery.

The angles of draw to the observed limits of vertical subsidence for Longwalls 3 to 19 and Longwalls 22 to 24A were reviewed as part of the SMP Application for Longwalls 27 to 30. The observed limits of vertical subsidence for these previously extracted longwalls was summarised in Section 2.1 of Report No. MSEC355 and were typically between: 31 and 39 degrees adjacent to the longwall maingates (i.e. above solid coal); 41 to 60 degrees adjacent to the longwall tailgates (i.e. above the previously extracted longwalls); and between 11 and 39 degrees adjacent to the longwall ends.

Further reviews for the more recently extracted longwalls 25 to 27 at the colliery found that the angles of draw were also typically within these ranges. In some cases, however, low level subsidence extended for larger distances outside the extracted longwalls, but these were not associated with any measurable tilts, curvatures or strains.

The predicted limits of vertical subsidence for the proposed longwalls were obtained using the calibrated Incremental Profile method and are between: 42 to 44 degrees adjacent to the maingates of Longwalls 32 and 37 (i.e. above solid coal); 60 and 62 degrees adjacent to the tailgate of Longwall 30 (i.e. above the approved longwalls); and 35 degrees adjacent to the longwall ends. The predicted angles of draw for the proposed longwalls, therefore, are similar to the ranges observed for the previously extracted longwalls at the colliery.

A line has therefore been drawn defining the *SMP Area*, based upon the greater of the angle of draw based on the observed limit of subsidence and the predicted 20 mm subsidence contour, which is shown in Drawing No. MSEC647-01.

There are areas that lie outside the *SMP Area* that are predicted to experience either far-field movements, or valley related upsidence and closure movements. The features which may be sensitive to such movements have been identified in this report and have been included as part of the assessments. The features that have been included in the assessments, that are located beyond the extent of the *SMP Area*, are listed below:-

- The streams and the associated built features (i.e. bridges and culverts) within the predicted limits of 20 mm upsidence and 20 mm closure resulting from the extraction of the proposed longwalls;
- Tunnels and other bridges within 600 metres of the proposed longwalls;
- Groundwater bores within 600 metres for the proposed longwalls; and
- Survey Control Marks within the predicted limit of far-field horizontal movements.

2.2. General Description of Surface Features and Infrastructure within the SMP Area

The major natural and built features within the SMP Area can be seen in the 1:25,000 Topographic Map of the area, published by the Central Mapping Authority (CMA), numbered PICTON 9029-4-S. The proposed longwalls and the SMP Area have been overlaid on an extract of this CMA map, as shown in Fig. 2.1.

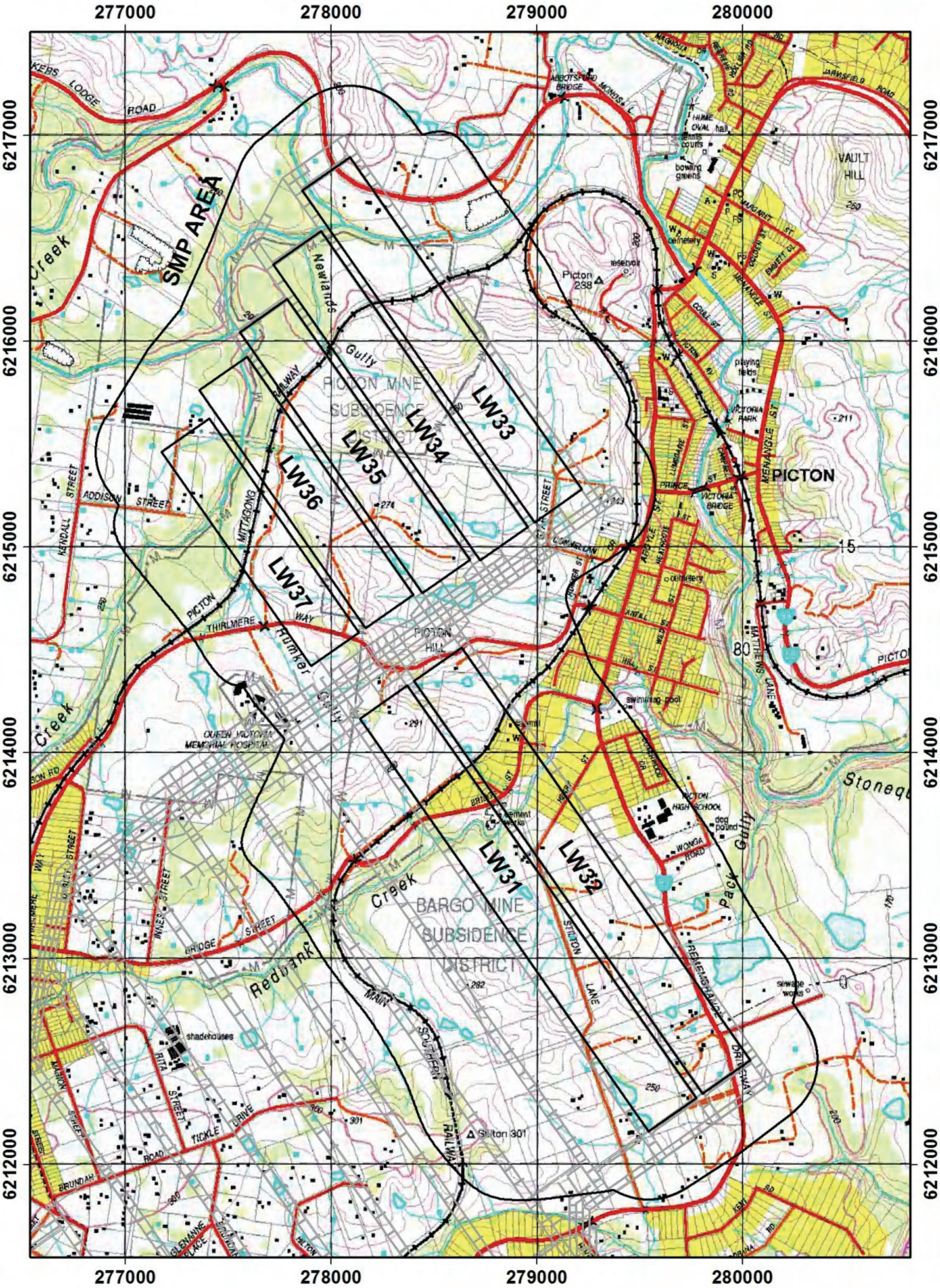


Fig. 2.1 Longwalls 31 to 37 and the SMP Area Overlaid on Part CMA Map PICTON 9029-4-S

A summary of the natural and built features within the SMP Area is provided in Table 2.1, which follows the list included in Appendix B of the SMP Guideline (DPI, 2003). The locations of these features are shown in Drawings Nos. MSEC647-09 to MSEC647-30. The descriptions, predictions and impact assessments for the natural and built features are provided in Chapters 5 and 6. The section number references are provided in Table 2.1.

Table 2.1 Natural and Built Features within the SMP Area

Item	Within SMP Area	Section Number
NATURAL FEATURES		
Catchment Areas or Declared Special Areas	×	
Streams	✓	5.4
Aquifers or Known Groundwater Resources	✓	5.5
Springs or Groundwater Seeps	×	
Sea, Lake or Shorelines	×	
Natural Dams	×	
Cliffs or Rock Outcrops	✓	5.6
Steep Slopes	✓	5.7
Escarpments	×	
Land Prone to Flooding or Inundation	✓	5.8
Swamps or Wetlands	×	
Water Related Ecosystems	✓	5.9
Threatened or Protected Species	✓	5.10
Lands Defined as Critical Habitat	×	
National Parks or Wilderness Areas	×	
State Forests	×	
State Recreation or Conservation Areas	×	
Natural Vegetation	✓	5.11
Areas of Significant Geological Interest	×	
Any Other Natural Features Considered Significant	×	
PUBLIC UTILITIES		
Railways	✓	6.2 & 6.3
Roads (All Types)	✓	6.4
Bridges	✓	6.2, 6.3 & 6.6
Tunnels	✓	6.7
Culverts	✓	6.5
Water, Gas or Sewerage Infrastructure	✓	6.8 to 6.11
Liquid Fuel Pipelines	×	
Electricity Transmission Lines or Associated Plants	✓	6.12
Telecommunication Lines or Associated Plants	✓	6.13
Water Tanks, Water or Sewage Treatment Works	✓	6.10
Dams, Reservoirs or Associated Works	×	
Air Strips	×	
Any Other Public Utilities	×	
PUBLIC AMENITIES		
Hospitals	×	
Places of Worship	✓	6.14.2
Schools	✓	6.14.3 & 6.14.4
Shopping Centres	×	
Community Centres	✓	6.14.5 & 6.14.6
Office Buildings	✓	6.14.7
Swimming Pools	✓	6.14.8
Bowling Greens	×	
Ovals or Cricket Grounds	×	
Race Courses	×	
Golf Courses	×	
Tennis Courts	×	
Any Other Public Amenities	✓	6.14.9 & 6.14.10

Item	Within SMP Area	Section Number
FARM LAND AND FACILITIES		
Agricultural Utilisation or Agricultural Suitability of Farm Land	✓	6.15.1
Farm Buildings or Sheds	✓	6.15.2
Tanks	✓	6.15.3
Gas or Fuel Storages	✓	6.15.3
Poultry Sheds	✓	6.15.5
Glass Houses	×	
Hydroponic Systems	✓	6.15.4
Irrigation Systems	✓	6.15.4
Fences	✓	6.15.7
Farm Dams	✓	6.16
Wells or Bores	✓	6.17
Any Other Farm Features	×	
INDUSTRIAL, COMMERCIAL AND BUSINESS ESTABLISHMENTS		
Factories	✓	6.18
Workshops	✓	6.18
Business or Commercial Establishments or Improvements	✓	6.18
Gas or Fuel Storages or Associated Plants	×	
Waste Storages or Associated Plants	×	
Buildings, Equipment or Operations that are Sensitive to Surface Movements	✓	6.18
Surface Mining (Open Cut) Voids or Rehabilitated Areas	×	
Mine Related Infrastructure Including Exploration Bores and Gas Wells	✓	6.19
Any Other Industrial, Commercial or Business Features	×	
AREAS OF ARCHAEOLOGICAL OR HERITAGE SIGNIFICANCE	✓	6.20 & 6.21
AREAS OF HISTORICAL SIGNIFICANCE	×	
ITEMS OF ARCHITECTURAL SIGNIFICANCE	×	
PERMANENT SURVEY CONTROL MARKS	✓	6.22
RESIDENTIAL ESTABLISHMENTS		
Principal Residences (i.e. Houses)	✓	6.23
Flats or Units	×	
Caravan Parks	×	
Retirement or Aged Care Villages	✓	6.14.1
Associated Structures such as Workshops, Garages, On-Site Waste Water Systems, Water or Gas Tanks, Swimming Pools or Tennis Courts	✓	6.15.2, 6.15.3, 6.23.8 & 6.23.9
Any Other Residential Features	✓	6.23.10 to 6.23.14
ANY OTHER ITEM OF SIGNIFICANCE	×	
ANY KNOWN FUTURE DEVELOPMENTS	✓	6.24

2.3. Areas of Environmental Sensitivity

This section provides a brief summary of features identified as *Areas of Environmental Sensitivity* within the SMP Area, as defined in Section 6.6.3 of the SMP Guideline (DPI, 2003). Further details on each of these features are provided in subsequent sections of this report.

Table 2.2 Summary of Areas of Environmental Sensitivity within the SMP Area

No.	Description	Within SMP Area	Details	Section No. Ref.
1	Land reserved as a State Conservation Area under the *National Parks and Wildlife Act 1974*	None		
2	Land declared as an Aboriginal Place under the *National Parks and Wildlife Act 1974*	None		
3	Land identified as *Wilderness* by the Director, National Parks and Wildlife under the *Wilderness Act 1987*	None		
4	Land subject to a 'conservation agreement' under the *National Parks and Wildlife Act 1974*	None		
5	Land acquired by the Minister for the Environment under Part 11 of the *National Parks and Wildlife Act 1974*	None		
6	Land within State forests mapped as Forestry Management Zone 1, 2 or 3	None		
7	Wetlands mapped under SEPP 14 – Coastal Wetlands	None		
8	Wetlands listed under the Ramsar Wetlands Convention	None		
9	Lands mapped under SEPP 26 – Coastal Rainforests	None		
10	Areas listed on the Register of the National Estate	✓	Queen Victoria Memorial Hospital (indicative place)	6.14.1
11	Areas listed under the *Heritage Act 1977* for which a plan of management has been prepared	None		
12	Land declared as critical habitat under the *Threatened Species Conservation Act 1995*	None		
13	Land within a restricted area prescribed by a controlling water authority	None		
14	Land reserved or dedicated under the *Crown Lands Act 1989* for the preservation of flora, fauna, geological formations or other environmental protection purpose	None		
15	Significant surface watercourses and groundwater resources identified through consultation with relevant government agencies	None		
16	Lake foreshores and flood prone areas	✓	Redbank and Matthews Creeks	5.4
17	Cliffs, escarpments and other significant natural features	✓	Cliffs along Cedar and Matthews Creeks	5.6
18	Areas containing significant ecological values	None		
19	Major surface infrastructure	✓	Main Southern Railway	6.2
20	Surface features of community significance (including cultural, heritage or archaeological significance)	✓	Archaeological and Heritage Sites	6.20 & 6.21
21	Any other land identified by the Department to the titleholder	None		

This chapter provides a brief overview of longwall mining, the development of mine subsidence and the methods that have been used to predict the mine subsidence movements resulting from the extraction of the proposed longwalls. Further details on longwall mining, the development of subsidence the methods used to predict mine subsidence movements are provided in the background reports entitled *Introduction to Longwall Mining and Subsidence* and *General Discussion on Mine Subsidence Ground Movements* which can be obtained from *www.minesubsidence.com*.

3.1. Overview of Longwall Mining

The coal at the project is proposed to be extracted using longwall mining techniques. A cross-section along the length of a typical longwall at the coal face is shown in Fig. 3.1.

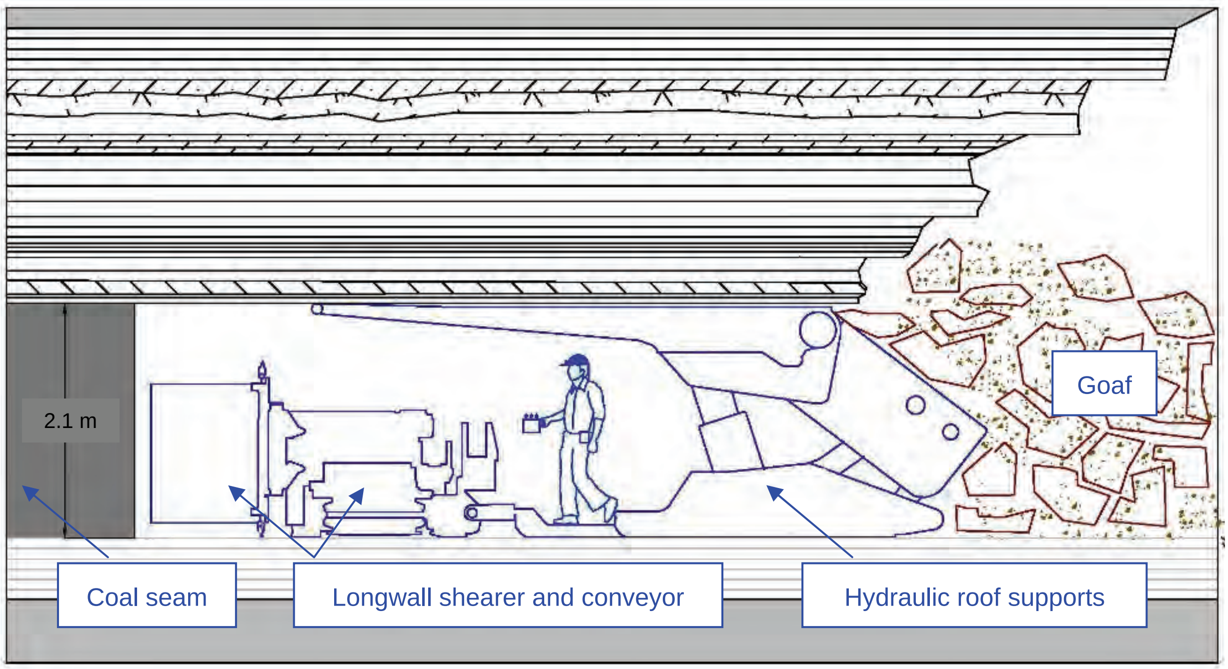


Fig. 3.1 Cross-section along the Length of a Typical Longwall at the Coal Face

The coal is removed by a shearer, which cuts the coal from the coal face on each pass as it traverses the width of the longwall. The roof at the coal face is supported by a series of hydraulic roof supports, which temporarily hold up the roof strata, and provides a working space at the coal face. The coal is then transported by a face conveyor belt which is located behind the shearer. As the coal is removed from each section of the coal face, the hydraulic supports are stepped forward, and the coal face progresses (retreats) along the length of the longwall.

The strata directly behind the hydraulic supports, immediately above the coal seam collapses into the void that is left as the coal face retreats. The collapsed zone comprises of loose blocks and can contain large voids. Immediately above the collapsed zone, the strata remains relatively intact and bends into the void, resulting in new vertical fractures, opening up of existing vertical fractures and bed separation. The amount of strata sagging, fracturing and bed separation reduces towards the surface.

At the surface, the ground subsides vertically as well as moves horizontally towards the centre of the mined goaf area. The maximum subsidence at the surface varies, depending on a number of factors including longwall geometry, depth of cover, extracted seam thickness and geology. The maximum achievable subsidence in the Southern Coalfield for single-seam mining conditions is 65 % of the extracted seam thickness.

3.2. Overview of Conventional Subsidence Parameters

The normal ground movements resulting from the extraction of longwalls or panels are referred to as conventional or systematic subsidence movements. These movements are described by the following parameters:-

- **Subsidence** usually refers to vertical displacement of a point, but subsidence of the ground actually includes both vertical and horizontal displacements. These horizontal displacements in some cases, where the subsidence is small such as beyond the longwall goaf edges, can be greater than the vertical subsidence. Subsidence is usually expressed in units of *millimetres (mm)*.

- **Tilt** is the change in the slope of the ground as a result of differential subsidence, and is calculated as the change in subsidence between two points divided by the distance between those points. Tilt is, therefore, the first derivative of the subsidence profile. Tilt is usually expressed in units of *millimetres per metre (mm/m)*. A tilt of 1 mm/m is equivalent to a change in grade of 0.1 %, or 1 in 1000.

- **Curvature** is the second derivative of subsidence, or the rate of change of tilt, and is calculated as the change in tilt between two adjacent sections of the tilt profile divided by the average length of those sections. Curvature is usually expressed as the inverse of the **Radius of Curvature** with the units of *1/kilometres (km^{-1})*, but the values of curvature can be inverted, if required, to obtain the radius of curvature, which is usually expressed in *kilometres (km)*.

- **Strain** is the relative differential horizontal movements of the ground. **Normal strain** is calculated as the change in horizontal distance between two points on the ground, divided by the original horizontal distance between them. Strain is typically expressed in units of *millimetres per metre (mm/m)*. **Tensile Strains** occur where the distance between two points increases and **Compressive Strains** occur when the distance between two points decreases. So that ground strains can be compared between different locations, they are typically measured over bay lengths that are equal to the depth of cover between the surface and seam divided by 20.

  Whilst mining induced normal strains are measured along monitoring lines, ground shearing can also occur both vertically and horizontally across the directions of monitoring lines. Most of the published mine subsidence literature discusses the differential ground movements that are measured along subsidence monitoring lines, however, differential ground movements can also be measured across monitoring lines using 3D survey monitoring techniques.

- **Horizontal shear deformation** across monitoring lines can be described by various parameters including horizontal tilt, horizontal curvature, mid-ordinate deviation, angular distortion and shear index. It is not possible, however, to determine the horizontal shear strain across a monitoring line using two-dimensional or three-dimensional monitoring techniques.

  High deformations along monitoring lines (i.e. normal strains) are generally measured where high deformations have occurred across the monitoring line (i.e. shear deformations), and vice versa.

A cross-section through a typical single extraction panel, for a horizontal seam in level terrain, showing typical profiles of conventional subsidence, tilt, curvature and strain is provided in Fig. 3.2.

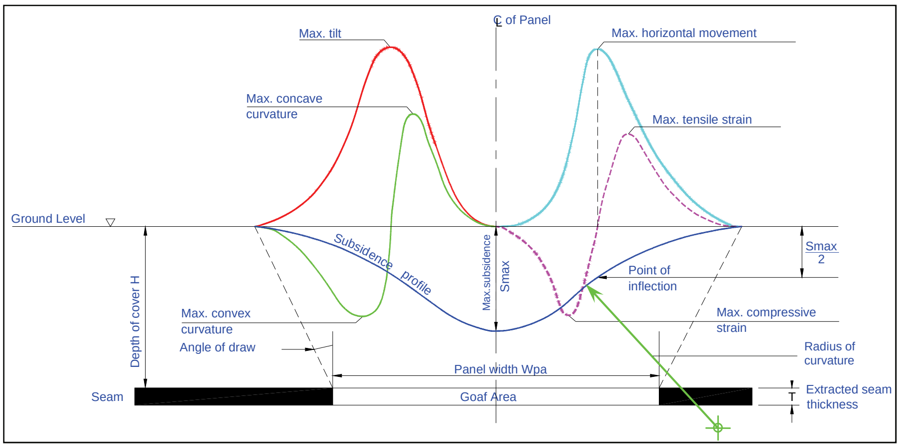


Fig. 3.2 Typical Profiles of Conventional Subsidence Parameters for a Single Extraction Panel

The **incremental** subsidence, tilts, curvatures and strains are the additional parameters which result from the extraction of each longwall. The **total** subsidence, tilts, curvatures and strains are the accumulated parameters which result from the extraction of a series of longwalls. The **travelling** tilts, curvatures and strains are the transient movements as the longwall extraction face mines directly beneath a given point.

3.3. Far-field Movements

The measured horizontal movements at survey marks which are located beyond the mined area and over solid unmined coal areas are often much greater than the observed vertical movements at those marks. These movements are often referred to as *far-field movements*.

Far-field horizontal movements tend to be bodily movements towards the extracted goaf area and are accompanied by very low levels of strain. These movements generally do not result in impacts on natural features or surface infrastructure, except where they are experienced by large structures which are very sensitive to differential horizontal movements.

In some cases, higher levels of far-field horizontal movements have been observed where steep slopes or surface incisions exist nearby, as these features influence both the magnitude and the direction of ground movement patterns. Similarly, increased horizontal movements are often observed around sudden changes in geology or where blocks of coal are left between longwalls or near other previously extracted series of longwalls. In these cases, the levels of observed subsidence can be slightly higher than normally predicted, but these increased movements are generally accompanied by very low levels of tilt and strain.

The method used to predicted far-field horizontal movements is discussed in Section 4.6.

3.4. Overview of Non-Conventional Subsidence Movements

Conventional subsidence profiles are typically smooth in shape and can be explained by the expected caving mechanisms associated with overlying strata spanning the extracted void. Normal conventional subsidence movements due to longwall extraction are easy to identify where longwalls are regular in shape, the extracted coal seams are relatively uniform in thickness, the geological conditions are consistent and surface topography is relatively flat.

As a general rule, the smoothness of the profile is governed by the depth of cover and lithology of the overburden, particularly the near surface strata layers. Where there is a high depth of cover, the observed subsidence profiles along monitoring survey lines are generally smooth. Where the depth of cover is less than 100 metres, the observed subsidence profiles along monitoring lines are generally irregular. Very irregular subsidence movements are observed with much higher tilts and strains at very shallow depths of cover where the collapsed zone above the extracted longwalls extends up to or near to the surface.

Non-conventional ground movements can develop above extracted longwalls, more often at shallower depths of cover or multi-seam conditions, but can also occur at higher depths of cover and single-seam conditions. The irregular movements appear as a localised bump in an otherwise smooth subsidence profile, accompanied by locally elevated tilts, curvatures and strains. The cause of these irregular subsidence movements can be associated with:-

- sudden or abrupt changes in geological conditions;
- steep topography; and
- valley related mechanisms.

Non-conventional movements due to the above mechanisms are discussed in the following sections.

3.4.1. Non-conventional Subsidence Movements due to Changes in Geological Conditions

It is believed that most non-conventional ground movements are a result of the reaction of near surface strata to increased horizontal compressive stresses due to mining operations. Some of the geological conditions that are believed to influence these irregular subsidence movements are the blocky nature of near surface sedimentary strata layers and the possible presence of unknown faults, dykes or other geological structures, cross bedded strata, thin and brittle near surface strata layers and pre-existing natural joints. The presence of these geological features near the surface can result in a bump in an otherwise smooth subsidence profile and these bumps are usually accompanied by locally increased tilts and strains.

Even though it may be possible to attribute a reason behind most observed non-conventional ground movements, there remain some observed irregular ground movements that still cannot be explained with the available geological information. The term "*anomaly*" is therefore reserved for those non-conventional ground movement cases that were not expected to occur and cannot be explained by any of the above possible causes.

It is not possible to predict the locations and magnitudes of non-conventional anomalous movements. In some cases, approximate predictions for the non-conventional ground movements can be made where the underlying geological or topographic conditions are known in advance. It is expected that these methods will improve as further knowledge is gained through ongoing research and investigation.

In this report, non-conventional ground movements have been considered in the statistical analyses of strain, provided in Section 4.5, which have been based on measurements for both conventional and non-conventional anomalous movements. The management strategies developed for the natural and built features should be designed to accommodate movements greater than the predicted conventional movements, so that the potential impacts resulting from non-conventional movements can be adequately managed.

The impact assessments for the natural and built features, which are provided in Chapters 5 and 6, include historical impacts resulting from previous mining which have occurred as the result of both conventional and non-conventional subsidence movements.

3.4.2. Non-conventional Subsidence Movements due to Steep Topography

Non-conventional movements can also occur where longwalls are extracted beneath steep slopes, with increased horizontal movements developing in the downslope direction. In these cases, elevated tensile strains develop near the tops and along the sides of the steep slopes and elevated compressive strains develop near the bases of the steep slopes. The potential impacts resulting from down slope movements include tension cracks at the tops and on the sides of the steep slopes and compression ridges at the bottoms of the steep slopes.

Further discussions on the potential impacts resulting from increased horizontal movements on steep slopes are provided in Section 5.7.

3.4.3. Valley Related Movements

The streams within the SMP Area may be subjected to mining induced valley related movements, which are commonly observed in the Southern Coalfield. Valley bulging movements are a natural phenomenon, resulting from the formation and ongoing development of the valley, as illustrated in Fig. 3.3. The potential for these natural movements are influenced by the geomorphology of the valley.

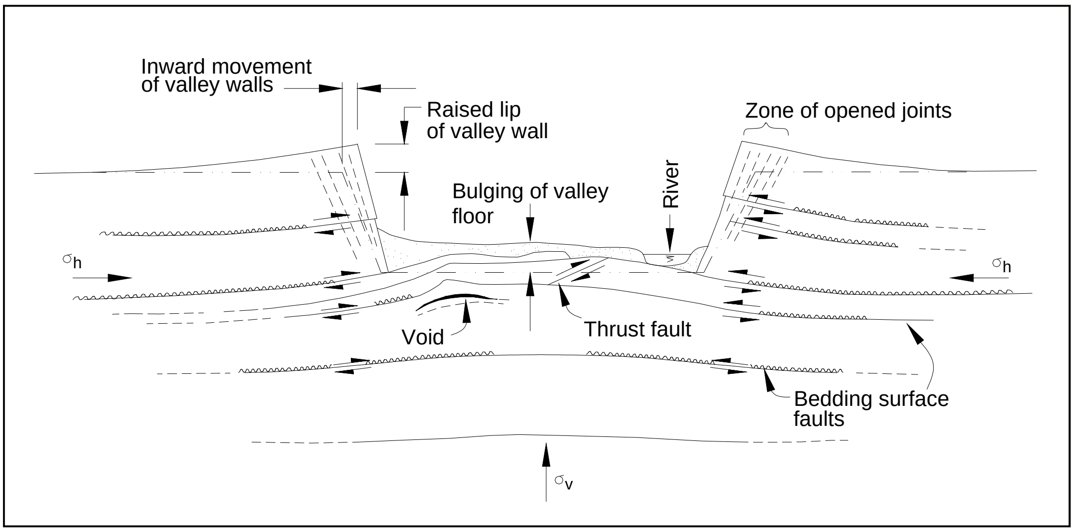


Fig. 3.3 Valley Formation in Flat-Lying Sedimentary Rocks (after Patton and Hendren 1972)

Valley related movements can also be caused by or accelerated by mine subsidence as the result of a number of factors, including the redistribution of horizontal in-situ stresses and down slope movements. Mining induced valley related movements are normally described by the following parameters:-

- **Upsidence** is the reduced subsidence within a valley which results from the dilation or buckling of near surface strata at or near the base of the valley. The term uplift is used for the cases where the ground level is raised above the pre-mining level, i.e. when the upsidence is greater than the subsidence. The magnitude of upsidence, which is typically expressed in the units of *millimetres (mm)*, is the difference between the observed subsidence profile within the valley and the conventional subsidence profile which would have otherwise been expected in flat terrain.

- **Closure** is the reduction in the horizontal distance between the valley sides. The magnitude of closure, which is typically expressed in the units of *millimetres (mm)*, is the greatest reduction in distance between any two points on the opposing valley sides.

- **Compressive Strains** occur within the bases of valleys as a result of valley closure and upsidence movements. **Tensile Strains** also occur in the sides and near the tops of the valleys as a result of valley closure movements. The magnitudes of these strains, which are typically expressed in the units of *millimetres per metre (mm/m)*, are calculated as the changes in horizontal distance over a standard bay length, divided by the original bay length.

The predicted valley related movements resulting from the extraction of the proposed longwalls were made using the empirical method outlined in Australian Coal Association Research Program (ACARP) Research Project No. C9067 (Waddington and Kay, 2002). Further details can be obtained from the background report entitled *General Discussion on Mine Subsidence Ground Movements* which can be obtained at *www.minesubsidence.com*.

3.5. The Incremental Profile Method

The Incremental Profile Method (IPM) was initially developed by Waddington Kay and Associates, now known as MSEC, as part of a study in 1994 to assess the potential impacts of subsidence on surface infrastructure. The method has been continually refined using the extensive monitoring data which has been gathered from the Southern, Newcastle, Hunter and Western Coalfields of New South Wales and from the Bowen Basin in Queensland.

The empirical database comprises monitoring data from numerous collieries including: Angus Place, Appin, Awaba, Baal Bone, Bellambi, Beltana, Blakefield South, Bulga, Bulli, Burwood, Carborough Downs, Chain Valley, Clarence, Coalcliff, Cook, Cooranbong, Cordeaux, Corrimal, Cumnock, Dartbrook, Delta, Dendrobium, Donaldson, Eastern Main, Ellalong, Elouera, Fernbrook, Glennies Creek, Grasstree, Gretley, Invincible, John Darling, Kemira, Kestrel, Lambton, Liddell, Mandalong, Metropolitan, Moranbah North, Mt. Kembla, Munmorah, Nardell, Newpac, Newstan, Newvale, Newvale 2, NRE Wongawilli, Oaky Creek, Ravensworth, South Bulga, South Bulli, Springvale, Stockton Borehole, Teralba, Tahmoor, Tower, Wambo, Wallarah, Western Main, Ulan, United, West Cliff, West Wallsend, and Wyee.

A detailed review of the monitoring data showed that, whilst the final subsidence profiles measured over a series of panels are irregular, the observed incremental subsidence profiles due to the extraction of individual panels are consistent in both magnitude and shape and vary according to local geology, depth of cover, panel width, seam thickness, the extent of adjacent previous mining, the widths and stabilities of the pillars and a time-related subsidence component.

MSEC has developed standard subsidence prediction curves for the Southern, Newcastle and Hunter Coalfields of New South Wales using the empirical database. The prediction curves can then be further refined, for the local geology and local conditions, based on the available monitoring data from the area. Discussions on the calibration of the IPM at Tahmoor Colliery are provided in Section 3.6.

The prediction of subsidence is a three stage process where, first, the magnitude of each increment is calculated, then, the shape of each incremental profile is determined and, finally, the total subsidence profile is derived by adding the incremental profiles from each panel in the series. In this way, subsidence predictions can be made anywhere above or outside the extracted panels, based on the local surface and seam information.

For panels in the Southern Coalfield, the maximum predicted incremental subsidence is initially determined, using the IPM subsidence prediction curves for a single isolated panel, based on the void width (W) and the depth of cover (H). The incremental subsidence is then increased, using the IPM subsidence prediction curves for multiple panels, based on the panel series, panel width-to-depth ratio (W/H) and pillar width-to-depth ratio (W_{pi}/H). In this way, the influence of the panel width (W), depth of cover (H), as well as panel width-to-depth ratio (W/H) and pillar width-to-depth ratio (W_{pi}/H) are each taken into account.

The shapes of the incremental subsidence profiles are then determined using the large empirical database of observed incremental subsidence profiles. The profile shapes are derived from the normalised subsidence profiles for monitoring lines where the mining geometry and overburden geology are similar to that for the proposed panels. The profile shapes can be further refined, based on local monitoring data, which is discussed further in Section 3.6.

Finally, the total subsidence profiles resulting from the series of panels are derived by adding the predicted incremental profiles from each of the longwalls. Comparisons of the predicted total subsidence profiles, obtained using the IPM, with observed profiles indicates that the method provides reasonable, if not, slightly conservative predictions where the mining geometry and overburden geology are within the range of the empirical database. The method can also be further tailored to local conditions where observed monitoring data is available close to the mining area.

3.6. Calibration of the Incremental Profile Method (Outside the Increased Subsidence Area)

The extraction of longwalls at Tahmoor Colliery has generally resulted in observed mine subsidence movements that are typical of those observed above other collieries in the Southern Coalfield of NSW at comparable depths of cover. However, during the mining of Longwall 24A at Tahmoor Colliery substantially increased subsidence was observed over the predicted subsidence levels and then similar increased subsidence movements were also observed above the southern ends of Longwalls 25 to 27. This was a very unusual event for the Southern Coalfield and is discussed further in Section 4.3.

This section of the report describes the calibration and testing of the IPM above the majority of the previously extracted longwalls at Tahmoor Colliery and does not include observations in the areas of increased subsidence, which is addressed separately in Section 4.3.

The IPM was previously refined or calibrated using the extensive monitoring data that had been collected during the extraction of Longwalls 22 to 25 at Tahmoor Colliery, to predict the subsidence parameters for Longwalls 27 to 30 at the colliery, and the details of this calibration were provided in Section 3.6 of Report No. MSEC355 (Revision B, July 2009).

The IPM prediction curves from Report No. MSEC355 are the latest calibration of the model and these were tested against the latest available subsidence data from Tahmoor Colliery. The locations of the monitoring lines adopted in the calibration are shown in Fig. 3.4. The reliability of the IPM prediction curves are illustrated by comparing the observed movements with those predicted for the following monitoring lines:

- Fig. 3.5 – Brundah Road Line for Longwalls 23B to 27;
- Fig. 3.6 – Castlereagh Street Line for Longwalls 22 to 27;
- Fig. 3.7 – Remembrance Drive Line for Longwalls 23A to 28;
- Fig. 3.8 – Thirlmere Way Line for Longwalls 23A to 27; and
- Fig. 3.9 – York Street Line for Longwalls 24A to 28.

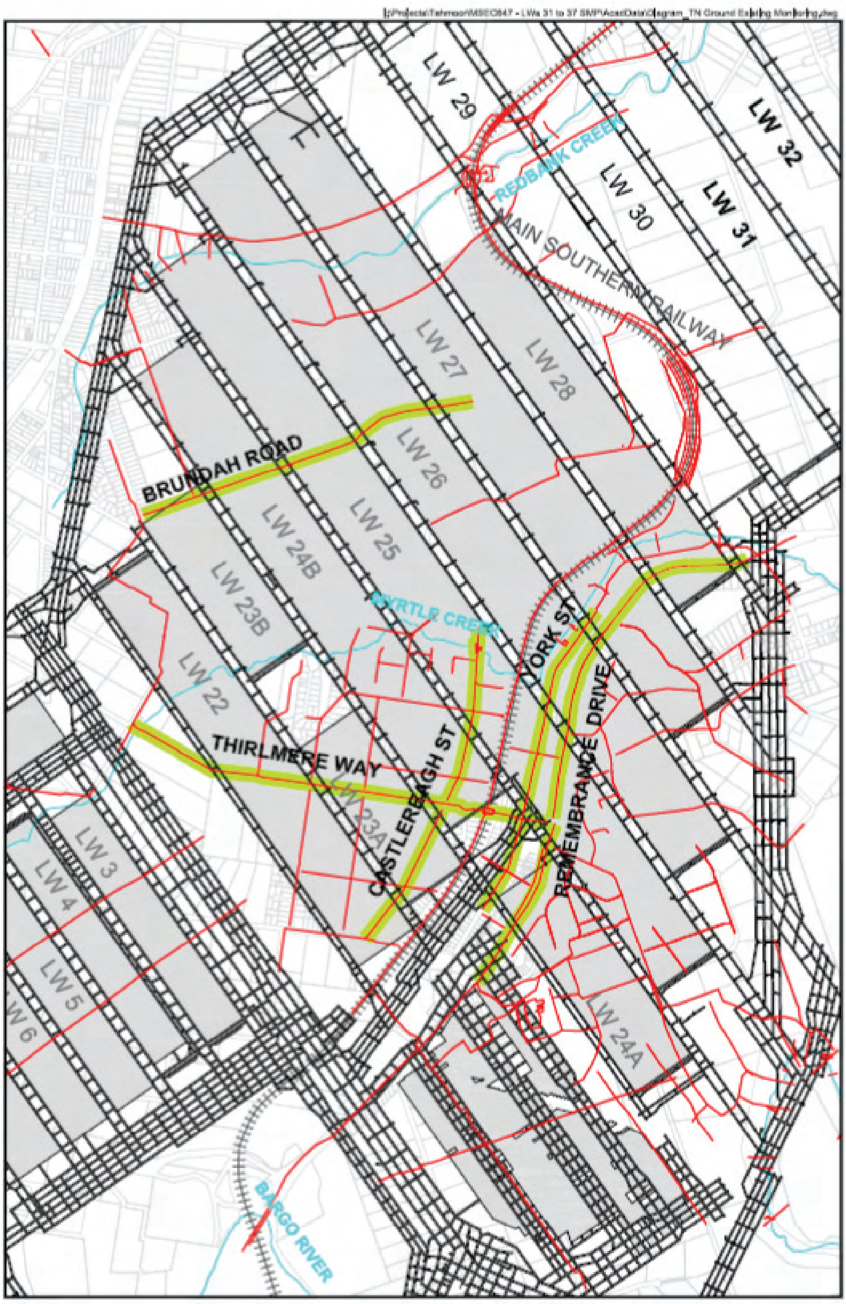


Fig. 3.4 **Monitoring Lines used in the Calibration of the IPM Model**

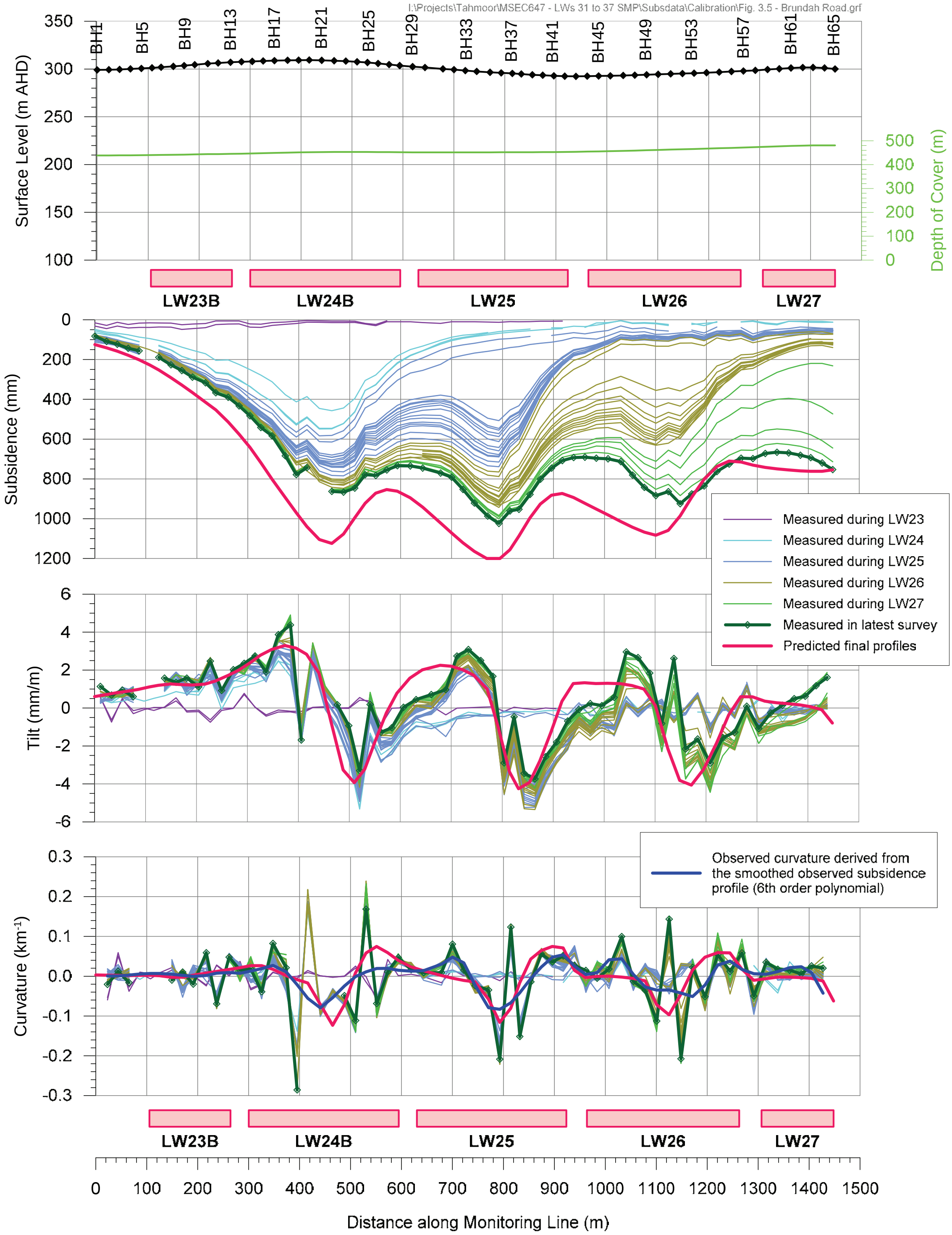


Fig. 3.5 Brundah Road Line for Longwalls 23B to 27

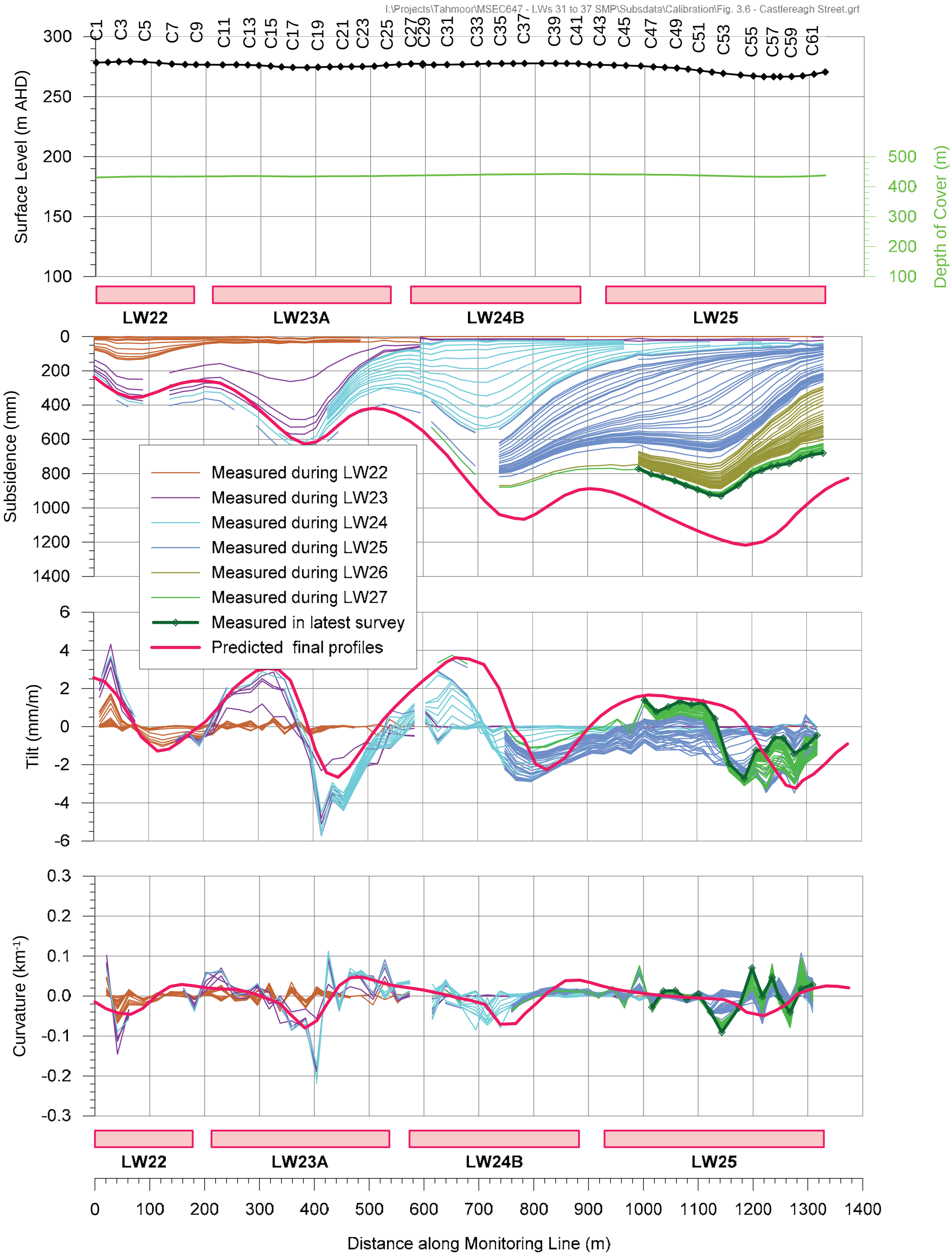


Fig. 3.6 Castlereagh Street Line for Longwalls 22 to 27

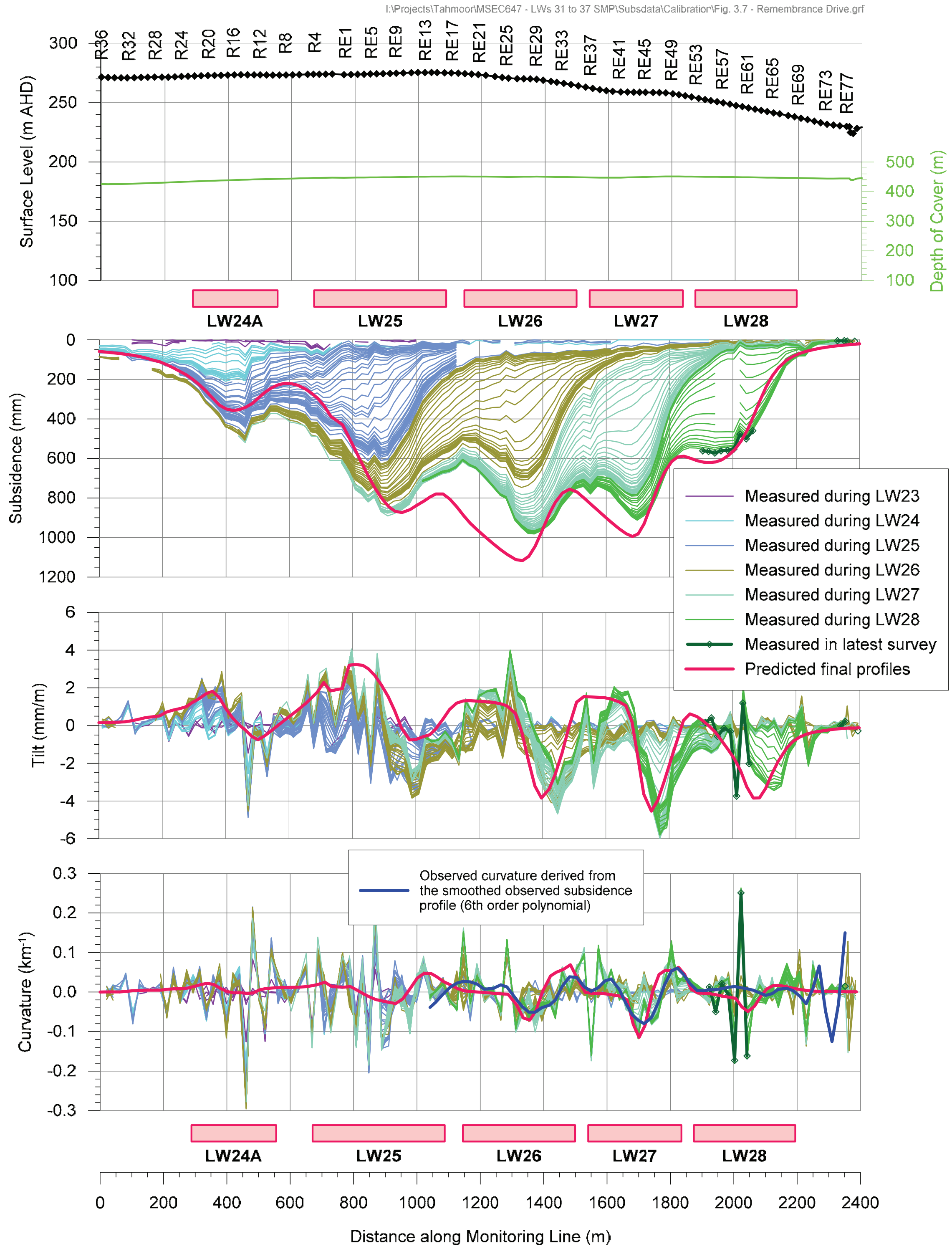


Fig. 3.7 Remembrance Drive Line for Longwalls 23A to 28

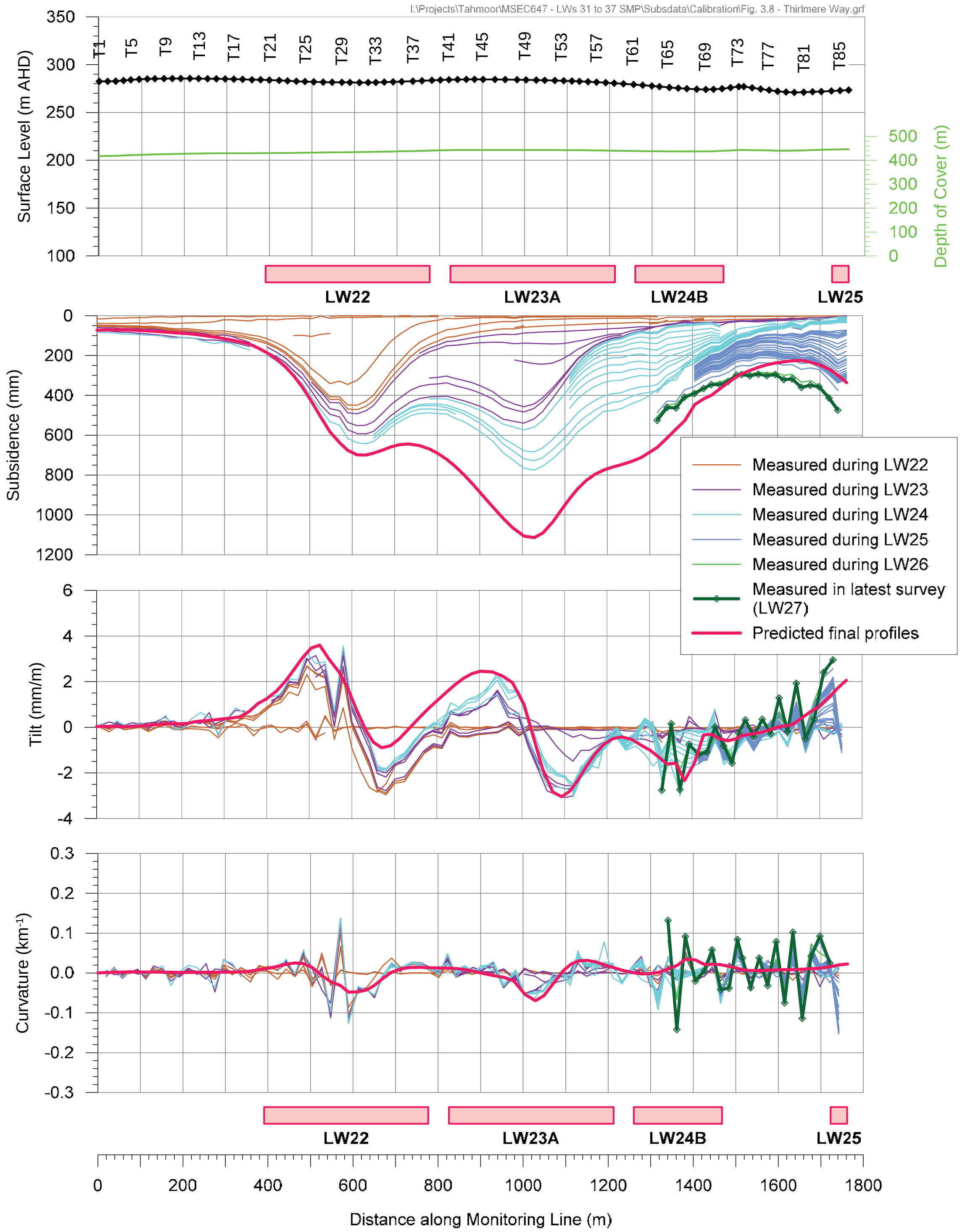


Fig. 3.8 Thirlmere Way Line for Longwalls 22 to 27

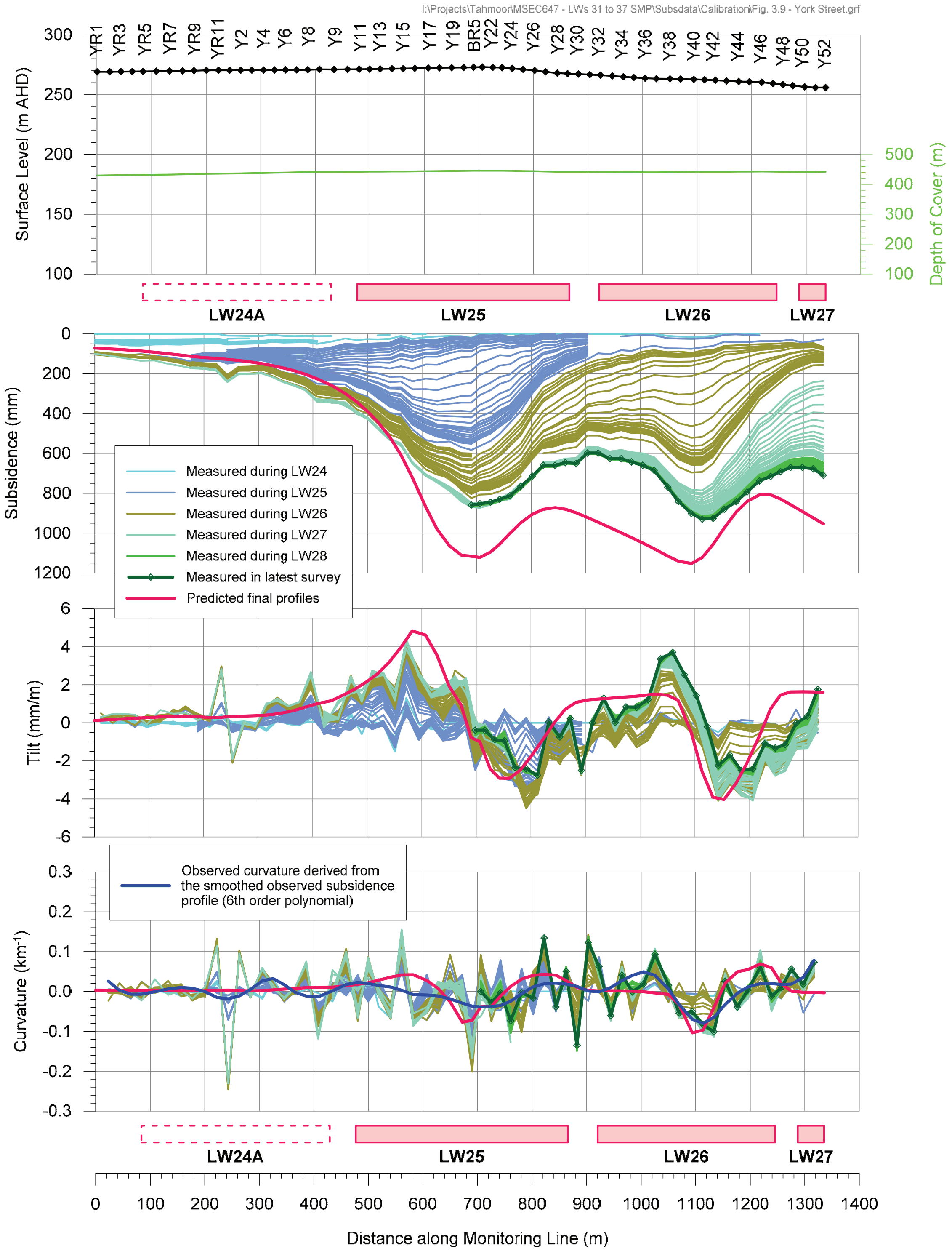


Fig. 3.9 York Street Line for Longwalls 24A to 28

The following observations can be seen from Fig. 3.5 to Fig. 3.9:

- The maximum observed subsidence directly above the extracted longwalls were typically less than the maxima predicted. In some cases, the observed subsidence locally exceeds the prediction above the earlier extracted longwalls, but the magnitudes in these locations were less than the maxima anywhere along the monitoring lines.
- The observed subsidence was slightly greater than those predicted along the following monitoring lines which were located adjacent to the zones of increased subsidence:-
  - o Castlereagh Street above Longwalls 22 and 23A;
  - o Remembrance Drive above Longwalls 24A and the south-eastern end of Longwall 25;
  - o Thirlmere Way above the south-eastern ends of Longwall 24B and Longwall 25; and
  - o York Street above Longwall 24A and the south-eastern end of Longwall 25.

- The profiles of observed subsidence reasonably matched those predicted for each of the monitoring lines. Whilst there was reasonable correlation it is highlighted that, in some locations away from the points of maxima and, in particular, beyond the longwall goaf edges, the observed subsidence locally exceeded that predicted. In the locations beyond the longwall goaf edges, however, the magnitude of subsidence was low and there were very low associated tilts, curvatures and strains.
- The maximum observed tilts and curvatures were, in most cases, similar to the maxima predicted. The observed tilts and curvatures exceeded those predicted at the tributary crossings, at the locations of the upsidence movements, as the predicted profiles did not include non-conventional valley related movements. There was also some scatter in the observed tilt and curvature profiles.
- The observed tilt profiles for these monitoring lines also reasonably matched the predicted profiles using the calibrated prediction curves. Further discussions on the observed curvatures are provided below.

It is more difficult to make meaningful comparisons between the profiles of raw observed curvature and predicted conventional curvature. The reason for this is that survey tolerance can be a large proportion of the measured curvatures and hence this can result in very irregular profiles. The survey tolerance for relative vertical movements is typically around ±3 mm, which equates to a survey tolerance for curvature of approximately 0.05 km^{-1} over a 20 metre bay length. This is important when compared to typical magnitudes of curvatures measured in the Southern Coalfield, which are in the order of 0.05 km^{-1} to 0.15 km^{-1}.

To make meaningful comparisons, the observed curvatures have been derived from smoothed observed subsidence profiles, which removes the small deviations resulting from, amongst other things, survey tolerance. The subsidence profile can be smoothed using either the Savitzky-Golay or Loess algorithm, which removes the localised deviations, but does not reduce the overall maxima. This is illustrated in Fig. 3.10 along a typical monitoring line from the Southern Coalfield, which shows the raw observed subsidence profile, the smoothed subsidence profile, the raw observed curvature profile and the curvature profile derived from the smoothed subsidence.

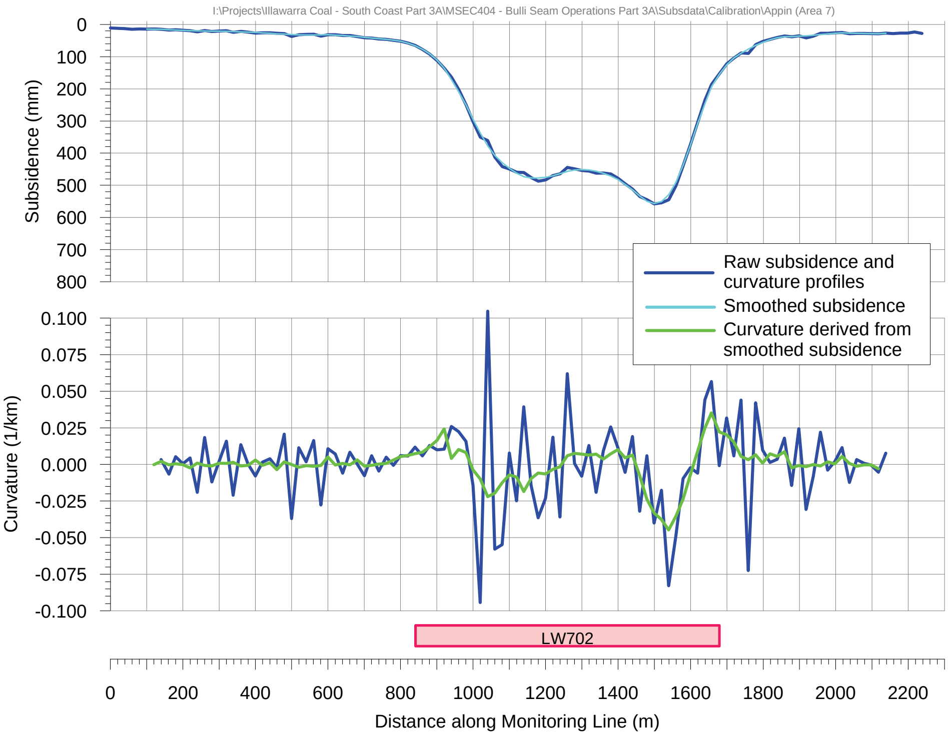


Fig. 3.10 Comparisons of Raw Observed Curvature with Curvature Derived from Smoothed Subsidence for a Typical Monitoring Line from the Southern Coalfield

It can be seen from the above figure, that the smoothed subsidence profile reasonably matches the raw subsidence profile, but the small deviations have been removed. It can also be seen, that the raw observed curvatures are very irregular, due to the small deviations in the raw observed subsidence profile. The curvature derived from the smoothed subsidence profile, however, more clearly shows the locations of overall hogging curvature and overall sagging curvature, rather than the localised curvatures at each mark.

Comparisons between the profiles of observed curvature derived from smoothed subsidence profiles, with the predicted conventional curvature, have been provided along: Brundah Road (refer Fig. 3.5); Remembrance Drive (refer Fig. 3.7); and York Street (refer Fig. 3.9).

The comparisons show that when the observed curvature has been derived from smoothed subsidence profiles, a reasonable correlation between predicted and observed profiles can be found. A reasonable correlation has also been found at surrounding collieries in the Southern Coalfield where the depths of cover are similar to those at Tahmoor Colliery. Where increased subsidence has been observed at Tahmoor Colliery, however, higher than predicted curvatures have been observed, and this is discussed further in Section 4.3.

A comparison between the observed and predicted total subsidence at the individual survey marks at Tahmoor North, at the completion of each of the Longwalls 22 to 27 and in the latest surveys for Longwall 28, is provided in Fig. 3.11. These results have only been provided for the monitoring lines that are located outside the zone of increased subsidence, which is discussed separately in Section 4.3, i.e. these plots do not including survey marks located above Longwall 24A and above the south-eastern ends of Longwalls 25 to 27. However this analysis does include the monitored data from those parts of Remembrance Drive and Castlereagh Street that are close to or near the zone of increased subsidence, i.e. within a transition zone.

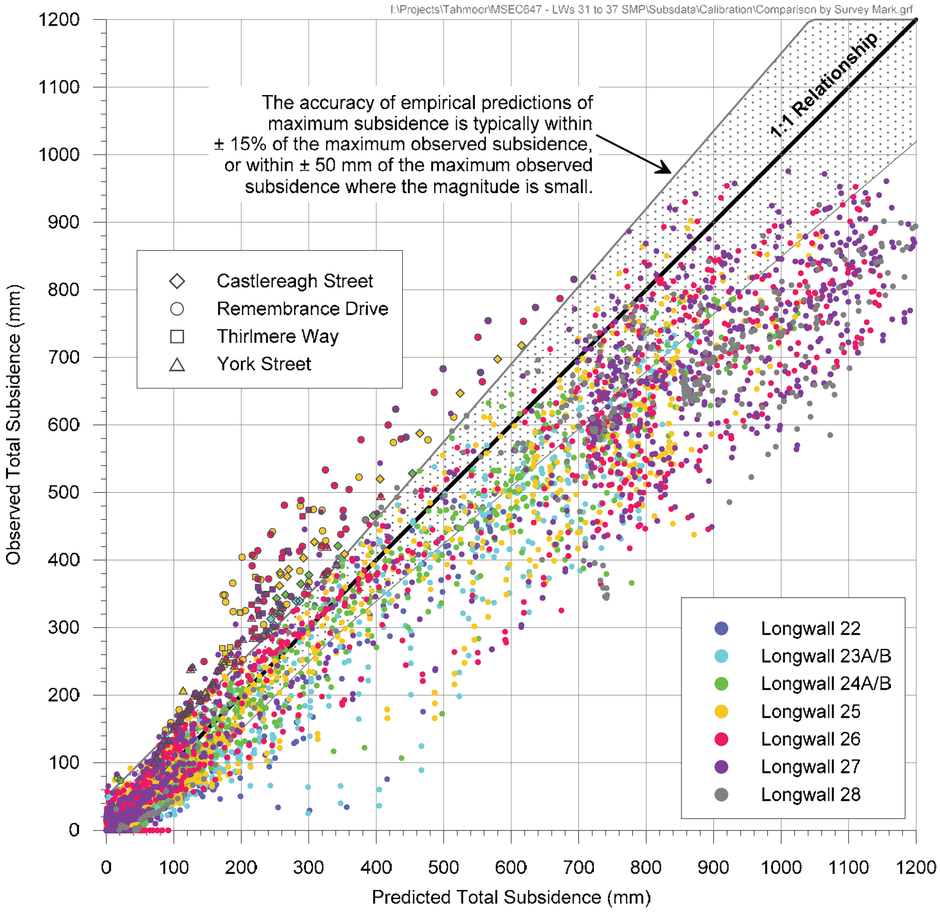


Fig. 3.11 Comparison between Observed and Predicted Total Subsidence at Individual Survey Marks for the Tahmoor North Longwalls 22 to 28

It can be seen from the above figure, that the observed total subsidence at the individual survey marks located outside the zones of increased subsidence at Tahmoor North were generally less than the predicted total subsidence plus 15 %, or less than the predicted total subsidence plus 50 mm, which is generally considered acceptable for subsidence prediction methods. There were several exceedances, however, and these generally occurred along the monitoring lines in those parts of Remembrance Drive and Castlereagh Street that are located close to or near the zone of increased subsidence and from those with lower levels of subsidence.

A further comparison is provided in Fig. 3.12 which compares the maximum observed and the maximum predicted total subsidence anywhere along monitoring lines in the northern parts of the Tahmoor Colliery (i.e. outside the zones of increase subsidence) due to the extraction of Tahmoor Longwalls 22 to 28.

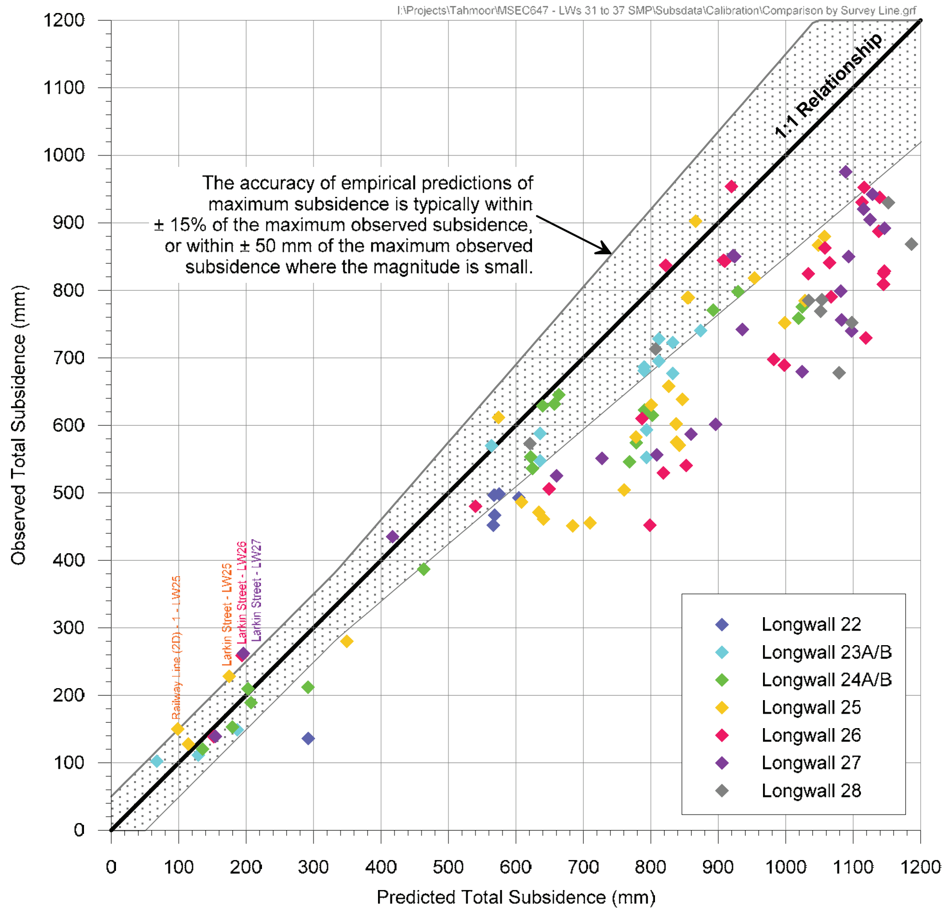


Fig. 3.12 Comparison between Observed and Predicted Maximum Total Subsidence along Whole Monitoring Lines for the Tahmoor North Longwalls 22 to 28

It can be seen from the above figure, that the maximum observed total subsidence anywhere along the whole monitoring lines were generally less than the maxima predicted plus 15 %, or less than the maxima predicted plus 50 mm, except where the magnitudes were small. There were some exceedances at the Railway Line (2D) and Larkin Street, however, these lines are also located close to or near the zone of increased subsidence and are generally occurred along the monitoring lines with lower levels of subsidence.

A further statistical review of these maximum subsidence values along monitoring lines has been undertaken. The distribution of the ratio of the maximum observed to maximum predicted total subsidence for the monitoring lines above Longwalls 22 to 28 is illustrated in Fig. 3.13 (left), which is based on the monitoring lines located outside the zones of increased subsidence and having maximum values greater than 200 mm. A gamma distribution has been fitted to the results and this is also shown in this figure (left). The resulting probabilities of exceedance have been determined, based on this gamma distribution, which is shown on the right of Fig. 3.13.

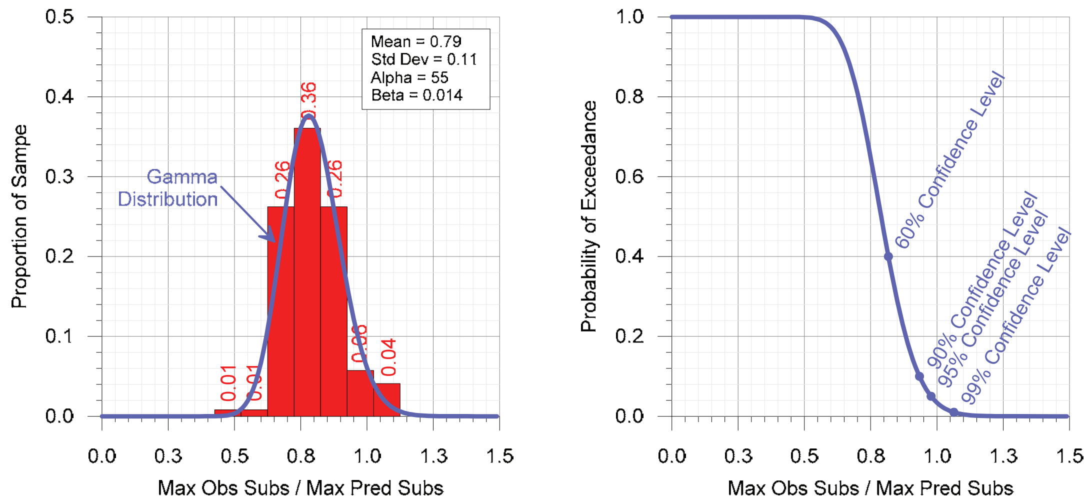


Fig. 3.13 Distribution of the Ratio of the Maximum Observed to Maximum Predicted Total Subsidence for Monitoring Lines at Tahmoor Colliery

It can be seen on the left side of Fig. 3.13 that the maximum observed total subsidence along the monitoring lines outside the zones of increased subsidence were, on average, 79 % of the maximum predicted total subsidence. The maximum observed total subsidence along these monitoring lines was, at most, 10 % greater than the maximum predicted total subsidence.

It can be seen on the right side of Fig. 3.13 that, based on the monitoring data outside the zones of increased subsidence , there is approximately a 97 % confidence level that the maximum observed total subsidence would be less than the maximum predicted total subsidence. That is, there is an approximate 3 % probability that the maximum observed total subsidence would exceed the maximum predicted subsidence anywhere along the monitoring lines.

The subsidence predictions for the proposed Longwalls 31 to 37 were determined using the calibrated IPM. It is expected, based on the statistical review of the accuracy of this method, that the predicted conventional subsidence for these proposed longwalls should generally provide reasonable, if not, slightly conservative results.

However, because of the increased subsidence that has been observed in parts of Tahmoor Colliery, consideration has been made for the observed movements exceeding those predicted as the result of anomalous or non-conventional movements, or for increased subsidence which is discussed in Section 4.3.

3.7. Review of the Observed and Predicted Valley Related Upsidence and Closure Movements at Tahmoor Colliery

The predicted upsidence and closure movements for the longwalls at Tahmoor Colliery have been obtained using the empirical method outlined in Australian Coal Association Research Program (ACARP) Research Project No. C9067 (Waddington and Kay, 2002). The comparisons between the observed and predicted valley related movements for the previously extracted longwalls at the colliery have been provided in the following sections.

3.7.1. Myrtle Creek and the Skew Culvert

Detailed ground monitoring was undertaken where Myrtle Creek and a tributary to this creek (referred to as the Skew Culvert) crosses beneath the Main Southern Railway above Longwalls 26 and 27. A map showing the monitoring lines in these locations is shown in Fig. 3.14.

Fig. 3.14 Monitoring Lines across Myrtle Creek and the Skew Culvert

The development of valley closure at each of the monitoring lines across the Myrtle Creek, during the extraction of Longwalls 24B to 27, are illustrated in Fig. 3.15.

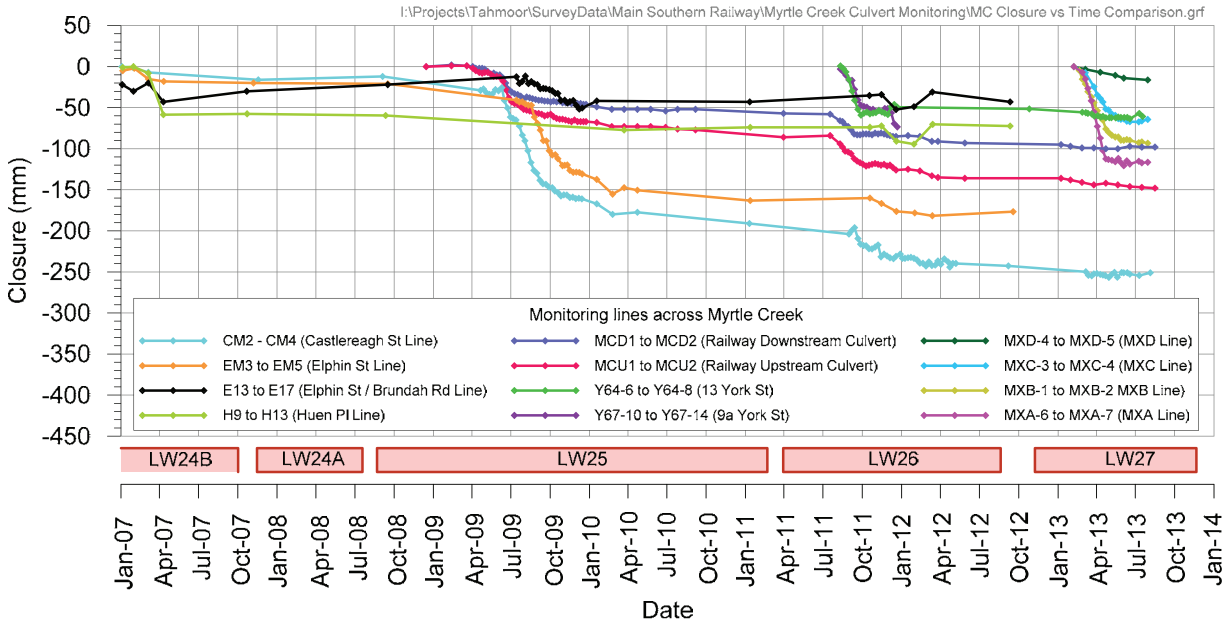


Fig. 3.15 Development of Closure across Myrtle Creek during Longwalls 24B to 27

The development of valley closure at each of the monitoring lines across the creek at the Skew Culvert, during the extraction of Longwalls 26 and 27, are shown in Fig. 3.16.

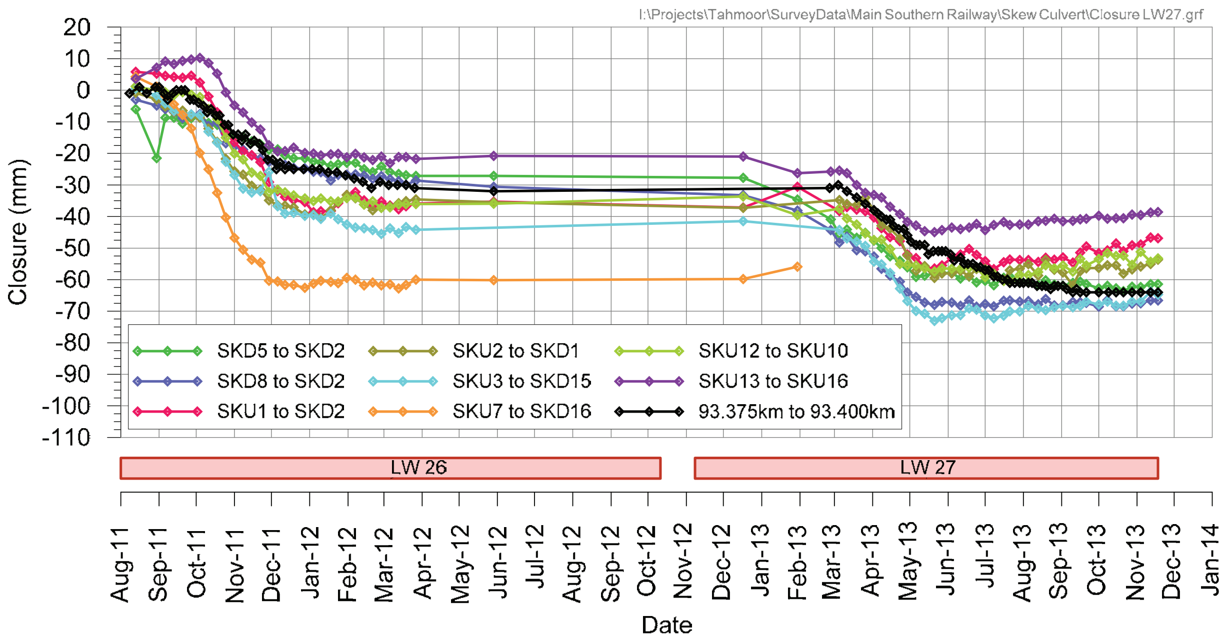


Fig. 3.16 Development of Closure across the Skew Culvert during Longwalls 26 and 27

A summary of the predicted and observed incremental closure across Myrtle Creek and the Skew Culvert is provided in Table 3.1. The predictions are consistent with those provided in Report No. MSEC355, which supported the SMP Application for Tahmoor Longwalls 27 to 30.

Table 3.1 Predicted and Observed Incremental Closure at Monitoring Lines across Myrtle Creek and the Skew Culvert

Location	Category	Predicted and Observed Valley Closure due to Mining of Each Longwall (mm)			
		Due to LW24	Due to LW25	Due to LW26	Due to LW27
Castlereagh Street (Pegs CM2 to CM4)	Predicted	30	55	45	25
	Observed	12	179	52	8
Elphin-Myrtle (Pegs EM3 to EM5)	Predicted	60	70	40	-
	Observed	21	142	22	-
Elphin St / Brundah Rd (Pegs E13 to E17)	Predicted	75	75	30	-
	Observed	0	21	6	-
Huen Place (Pegs H9 to H13)	Predicted	60	35	15	-
	Observed	58	15	20	-
Main Southern Railway Upstream (MCU1 to MCU4) Downstream (MCD1 to MCD4)	Predicted	15	30	30	15
	Observed	-	57 (d/s) to 86 (u/s)	36 (d/s) to 50 (u/s)	5 (d/s) to 12 (u/s)
Skew Culvert (8 cross-sections)	Predicted	< 5	10	25	25
	Observed	-	-	21 to 60 (average 36)	8 to 36 (average 21)
13 York Street (Pegs Y64-6 to Y64-8)	Predicted	-	-	65	50
	Observed	-	-	51	9
9a York Street (Pegs Y67-10 to Y67-14)	Predicted	-	-	85	85
	Observed	-	-	73	No access
MXA Line (Pegs MXA-6 to MXA-7)	Predicted	-	-	-	150
	Observed	-	-	-	116
MXB Line (Pegs MXB-1 to MXB-2)	Predicted	-	-	-	170
	Observed	-	-	-	93
MXC Line (Pegs MXC-3 to MXC-4)	Predicted	-	-	-	150
	Observed	-	-	-	64
MXD Line (Pegs MXD-4 to MXD-5)	Predicted	-	-	-	50
	Observed	-	-	-	16

It can be seen from the above table, that the observed valley closure has substantially exceeded predictions at the Castlereagh Street crossing, at the crossing of the Elphin-Myrtle monitoring line and, to a lesser extent, the crossing of the Main Southern Railway during the mining of Longwall 25. It is considered that the reason for the differences in observations may be linked to the change in orientation of Myrtle Creek as the three above-mentioned monitoring lines are located along the same stretch of Myrtle Creek. It is noted, however, that substantially less closure has developed at Castlereagh Street than predicted during the mining of Longwall 27.

Observed valley closure across the creek at the Skew Culvert has also slightly exceeded predictions, where the differences between predicted and observed closure are relatively small for most cross sections.

Observed valley closure across Myrtle Creek where it flows directly above Longwall 27 (MXA to MXC lines) has been less than predicted, but greater in magnitude than valley observed across monitoring lines upstream of Longwall 27. This was expected because the valley is deeper compared to sections further upstream.

3.7.2. Redbank Creek

Detailed ground monitoring was undertaken along Redbank Creek during the extraction of Longwalls 26 and 27. The ability to survey valley closure across the creek was constrained as access was not provided by the landowners adjacent to the creek. There was no access on the northern bank and limited access on the southern bank of the Redbank Creek.

In light of the access constraints, ground surveys were undertaken in relative 3D from Bridge Street to a monitoring line that is located in cleared pasture land along the top of the valley, as shown in Fig. 3.17. This has provided measurements of total valley closure. Some survey pegs have been installed along a fenceline on the southern side to a point where surveyors can sight a survey peg on Bridge Street. Despite the best efforts of the survey team, the accuracy of the survey is challenged by the lack of cross lines across Redbank Creek. Baseline monitoring indicates that the valley closure measurements were accurate to approximately 20 mm to 30 mm.

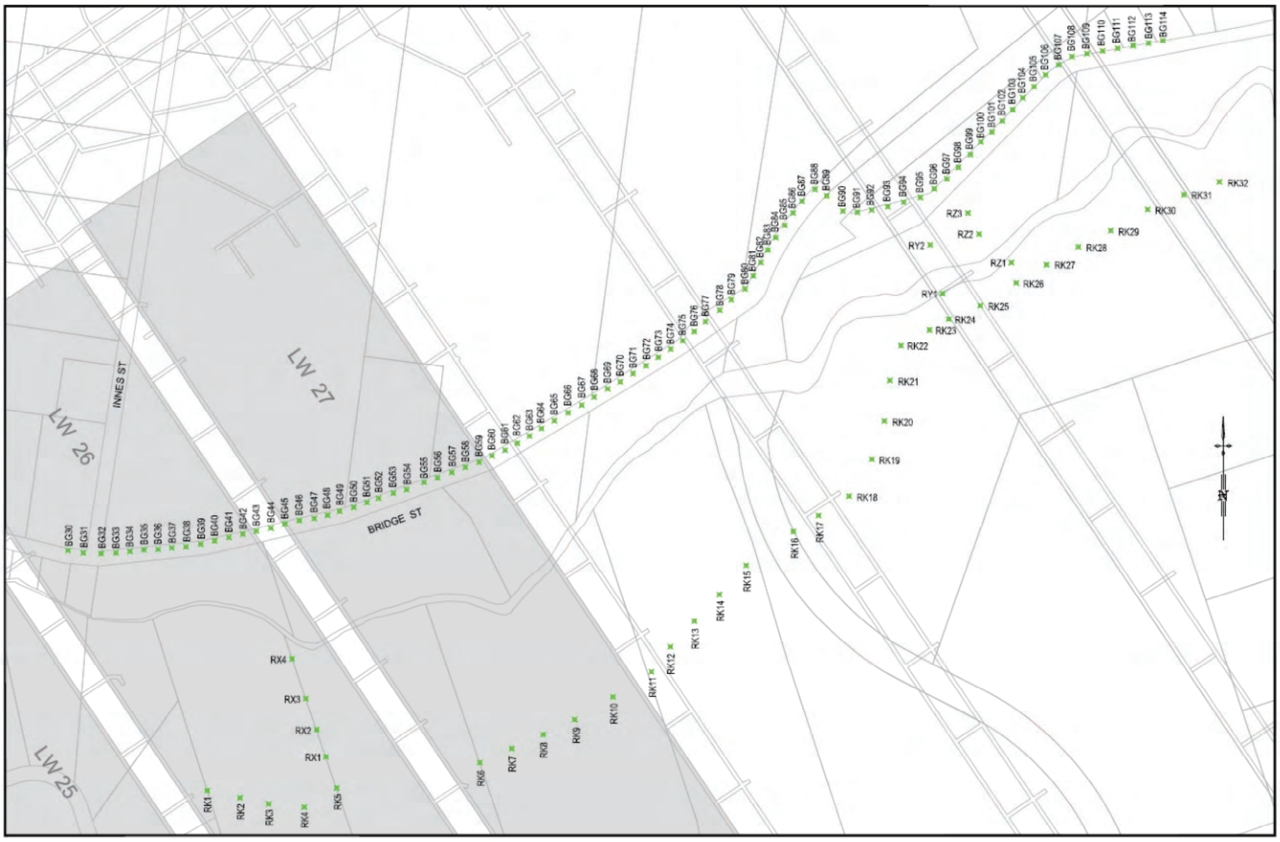


Fig. 3.17 Location of Survey Marks across Redbank Creek

The observed incremental relative horizontal movements during the mining of Longwalls 26 and 27 are shown in Fig. 3.18 and Fig. 3.19.

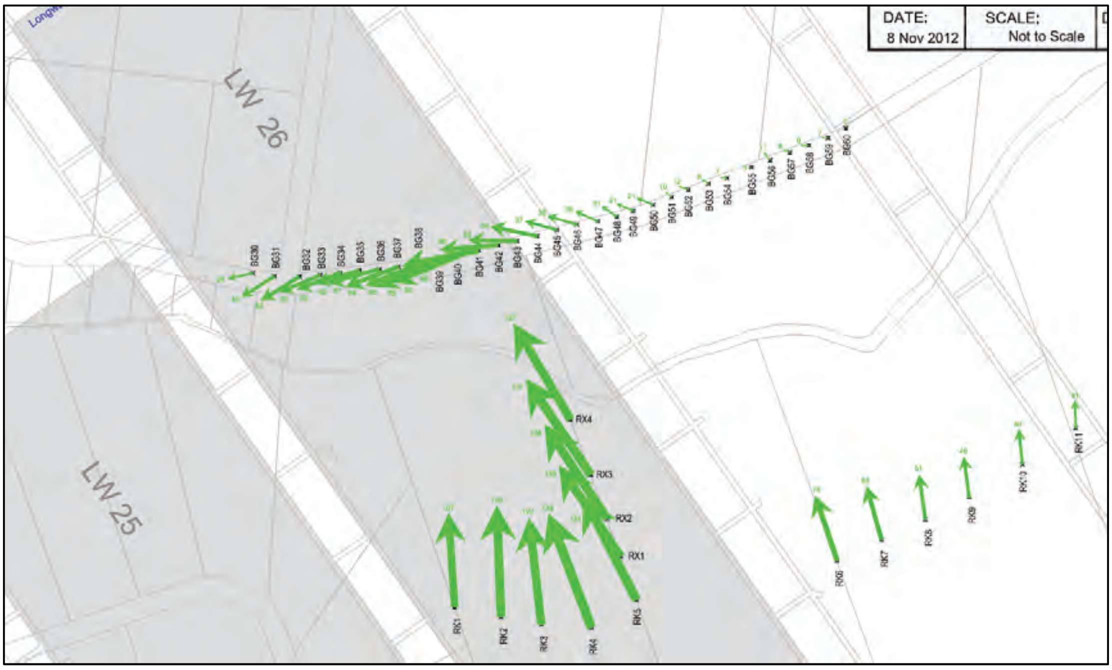


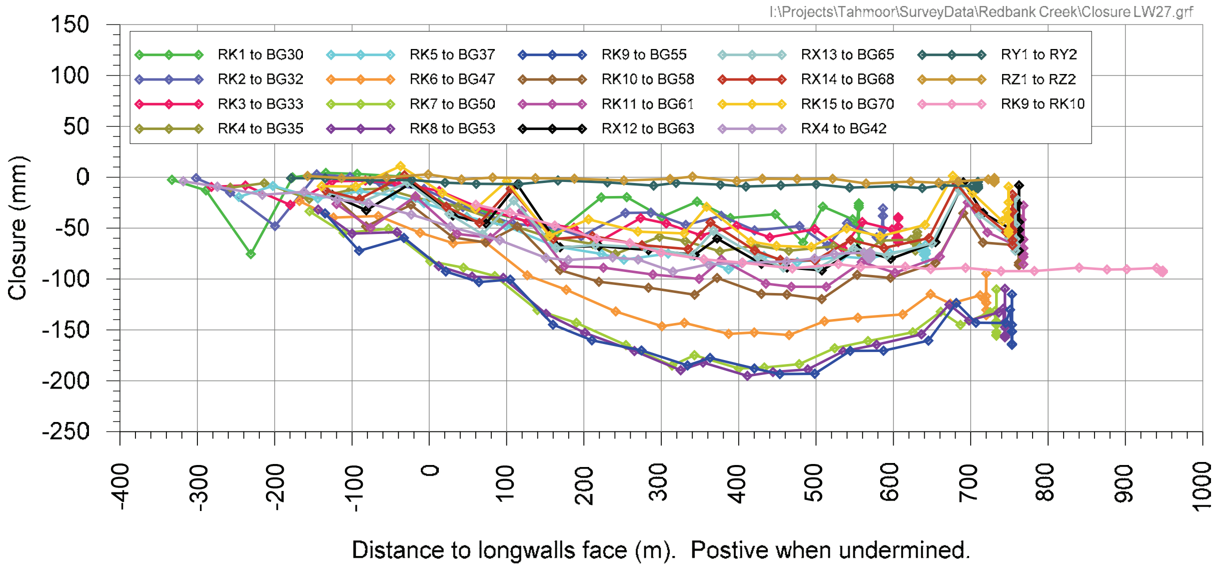
Fig. 3.18 Observed Relative Horizontal Movements across Redbank Creek during Longwall 26

Fig. 3.19 Observed Relative Horizontal Movements across Redbank Creek during Longwall 27

The development of incremental valley closure across Redbank Creek during the mining of Longwall 27 against both time and the distance between the survey pegs and the longwall face are shown in Fig. 3.20.

The closures are based on the calculated changes in horizontal distance between pegs located across the valley in an orientation that is approximately parallel to the longwall. This orientation was chosen as Redbank Creek flows approximately at right angles across the longwall.

Different results can be derived if the calculations were based on different pairs of pegs, though it is considered that if different pairs were chosen, such calculations would include an additional component of conventional or systematic ground shortening that occurs across the panel in both plateau areas and valleys. This is particularly the case if the pegs are located across the width of the longwall from each other. When comparing the results against predictions of valley closure, it was considered simpler to choose pegs that are approximately aligned with longwall direction so as not to make allowances for the additional effects of conventional lateral ground closure movements.



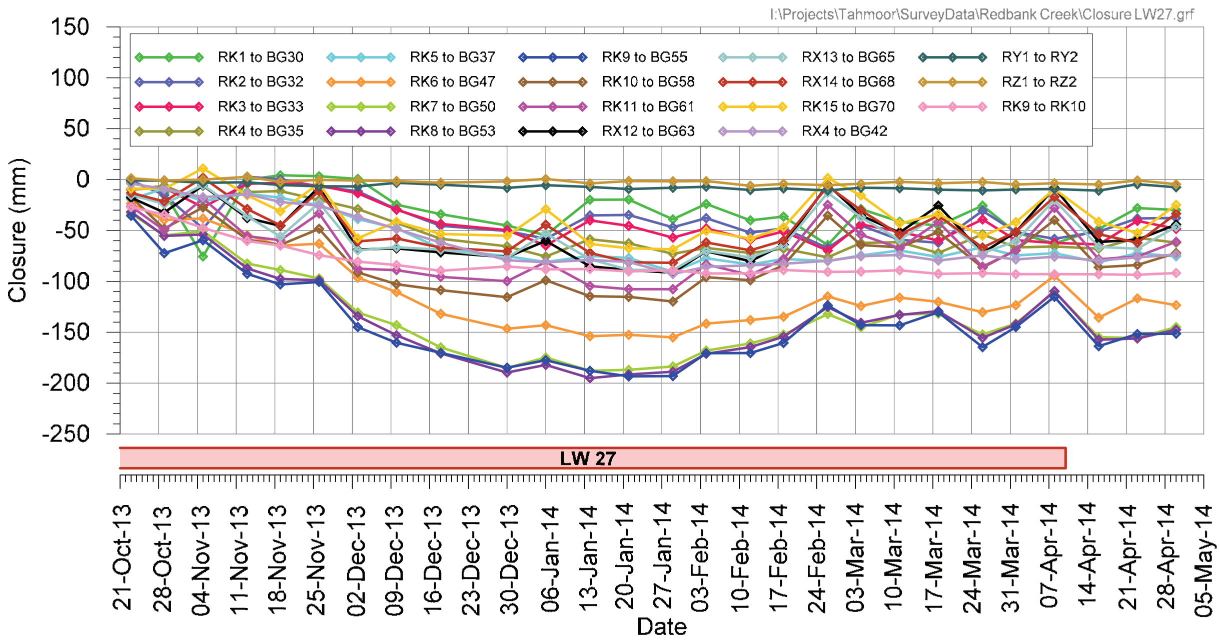


Fig. 3.20 Observed Development of Closure across Redbank Creek

It can be seen from the above figure, that valley closure was greater for a temporary period of time, when the transient effects of the subsidence travelling wave passing through the valley. As the longwall face moved away from Redbank Creek by more than 400 metres, the additional compressive strains from the travelling wave reduced. It can also be seen that very little change in valley closure since early March 2014.

A comparison between observed and predicted valley closure along Redbank Creek is shown in Fig. 3.21. It can be seen that there has been a reasonable correlation between predicted and observed closure at the completion of Longwall 27.

Maximum predicted valley closure due to extraction of Longwall 27 was 155 mm. As shown in the bottom graph of Fig. 3.21, observed maximum incremental valley closure at the completion of Longwall 27 was 151 mm. It can also be seen from the top graph of Fig. 3.21 that observed total closure from the mining of Longwalls 26 and 27 is less than predicted.

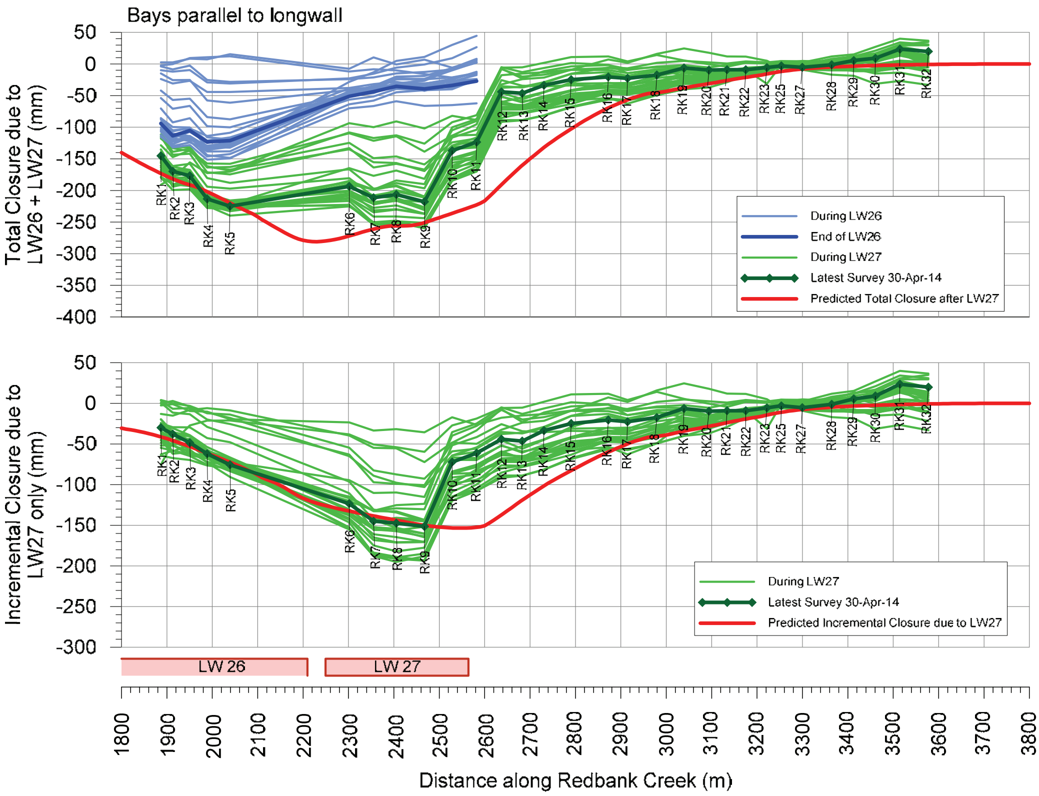


Fig. 3.21 Comparison between Observed and Predicted Valley Closure along Redbank Creek

The results show that while the prediction of valley closure is not an exact science, there is a reasonable correlation between observed and predicted subsidence when measured across the width of the valley from Bridge Street to the RK Line over Longwalls 26 and 27.

Specific ground surveys were also undertaken across Redbank Creek Culvert in the culvert, on the embankment, in the valley sides and across the track.

A total of 18 ground surveys, 5 extensometer surveys and 5 detailed visual inspections were undertaken for the Redbank Creek Culvert and Embankment on a weekly to monthly basis in accordance with the agreed management plans with ARTC, as amended in agreement with DTIRIS, during the mining of Longwall 27.

Observed incremental subsidence and horizontal movement of survey marks are shown in Fig. 3.22. The culvert has subsided between approximately 20 mm and 32 mm during the mining of Longwall 27.

Small gradual changes in valley closure were also observed during the mining of Longwall 27. The weekly changes have been plotted over time and relative to the distance between the survey marks and active longwall face, as shown in Fig. 3.23 and Fig. 3.24.

This ground survey has shown 5 mm of closure across the upstream end of the Redbank Creek Culvert wingwalls. The changes were cross checked with tape extensometer measurements by GHD Geotechnics and only sub millimetre changes have been observed. Measured changes in horizontal distances are within survey tolerances across the remainder of the survey points on the wingwalls, headwalls and culvert barrel, and along the length of the culvert.

It can be seen that valley closure has focussed between Pegs RBCU2 and RBCU4 on the upstream end to the northern side of the culvert structure approximately in line with the low height cliffline. There is no clear location of focussed closure on the downstream end of the culvert. Ground shortening is also observed across the small tributary to Redbank Creek between Pegs RBCCU2 and RBCCU4.

Tape extensometer readings were undertaken by GHD Geotechnics during the mining of Longwall 27. Minor changes are observed, including across the upstream wingwall. Displacements are currently not inferred to be in response to subsidence nor subsidence related and more likely due to seasonal changes as observed at the Skew Culvert and Myrtle Creek Culvert.

In addition to the above ground survey and tape extensometer data, small increases in rail stress were also measured in the rails above RBCC during the mining of Longwall 27.

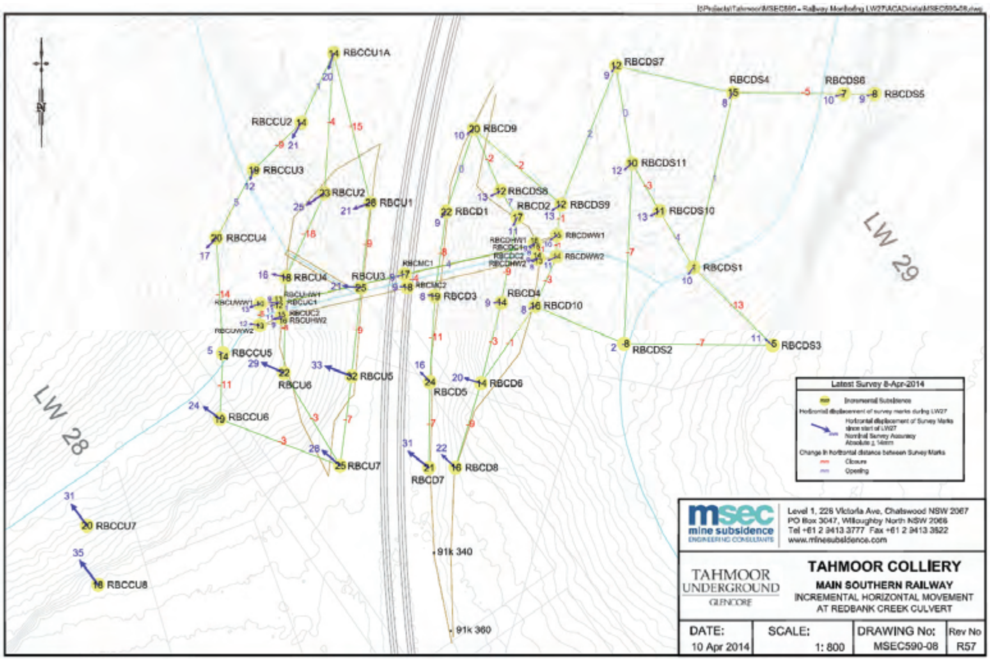


Fig. 3.22 Observed Incremental Horizontal Movement at Redbank Creek Culvert and Embankment during the Mining of Longwall 27

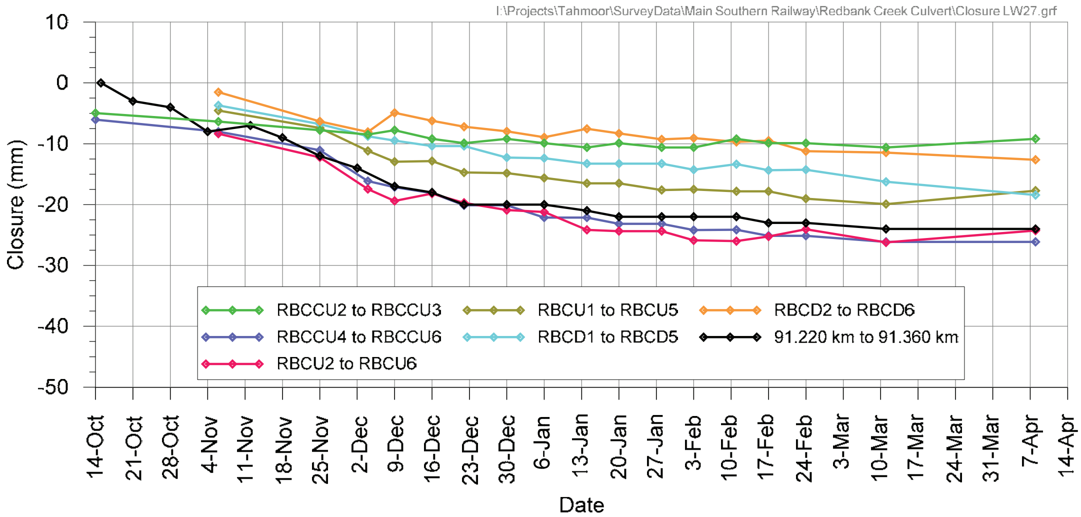


Fig. 3.23 Observed Valley Closure over time across Redbank Creek Culvert at Main Southern Railway during the mining of Longwall 27 only

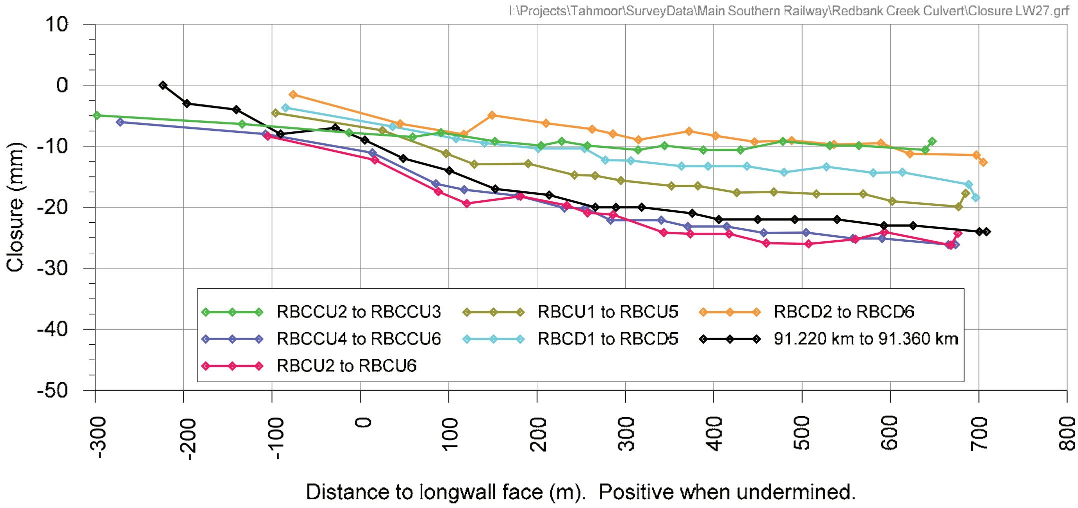


Fig. 3.24 Observed Valley Closure relative to distance to longwall face across Redbank Creek Culvert at Main Southern Railway during the mining of Longwall 27 only

Vertical inclinometer monitoring was also undertaken by GHD Geotechnics during the mining of Longwall 27. Baseline readings were established in April and May 2012 with 3 subsequent reading sets at two monthly intervals in 2012 to contribute to the understanding of the environmental response. Monthly readings were initiated in October 2013 in accordance with the SMP. Following a degree of environmental response in 2012, the recent readings indicate the on-set of shearing within the rockmass, as indicated by a marked increase in horizontal displacement recorded over the most recent month and development of steps in the downhole profiles. Differential horizontal displacements of the order of 10 mm between 17 metres and 30 metres depth are inferred in a direction perpendicular to the goaf of Longwall 27.

3.7.3. Reliability of the Predicted Valley Related Movements

The review of the observed movements at Myrtle and Redbank Creeks indicate that the ACARP Method provides reasonable predictions for valley closure at Tahmoor Colliery. It is noted, however, the observed closures substantially exceeded those predicted in three locations along Myrtle Creek, due to the extraction of Longwall 25, but these all occurred along the same section of creek. Elsewhere, the observed closures were typically similar to or less than those predicted.

The development of the predictive methods for upsidence and closure are the result of recent and ongoing research and the methods do not, at this stage, have the same confidence level as conventional subsidence prediction techniques. As further case histories are studied, the method will be improved, but it can be used in the meantime, so long as suitable factors of safety are applied. This is particularly important where the predicted levels of movement are small, and the potential errors, expressed as percentages, can be higher.

Whilst the major factors that determine the levels of movement have been identified, there are some factors that are difficult to isolate. One factor that is thought to influence the upsidence and closure movements is the level of in-situ horizontal stress that exists within the strata. In-situ stresses are difficult to obtain and not regularly measured and the limited availability of data makes it impossible to be definitive about the influence of the in-situ stress on the upsidence and closure values. The methods are, however, based predominantly upon the measured data from Tower Colliery in the Southern Coalfield, where the in-situ stresses are high. The methods should, therefore, tend to over-predict the movements in areas of lower stress.

Variations in local geology can affect the way in which the near surface rocks are displaced as subsidence occurs. In the compression zone, the surface strata can buckle upwards or can fail by shearing and sliding over their neighbours. If localised cross bedding exists, this shearing can occur at relatively low values of stress. This can result in fluctuations in the local strains, which can range from tensile to compressive. In the tensile zone, existing joints can be opened up and new fractures can be formed at random, leading to localised concentrations of tensile strain.

Another factor that is thought to influence the movements is the characteristics of near surface geology, particularly in stream beds. Upsidence in particular is considered to be sensitive to the way in which the bedrock responds, since thin strata layers may respond differently to thicker ones. The location of the point of maximum upsidence is also considered to be strongly influenced by the characteristics of near surface geology.

Another factor that is thought to influence upsidence and closure movements is the presence of geomorphological features. Recent monitoring along a deeper and more incised valley has shown variable measurements around bends. There tended to be less movement at the apex of the bend than in the straight sections.

Notwithstanding the abovementioned limitations, the ACARP method is the most thoroughly used and tested prediction method for upsidence and closure movements in the Southern Coalfield. It is expected in most cases to provide reasonable, if not, slightly conservative predictions of the valley related movements for the proposed longwalls.

4.1. Introduction

The following sections provide the maximum predicted conventional subsidence parameters resulting from the extraction of proposed Longwalls 31 to 37 at Tahmoor Colliery. The predicted subsidence parameters and the impact assessments for the natural and built features located within the SMP Area are provided in Chapter 5.

The maximum predicted subsidence parameters and the predicted subsidence contours provided in this report show the conventional movements and do not include the valley related upsidence and closure movements, nor the effects of faults and other geological structures. Such effects have been addressed separately in the impact assessments for each feature provided in Chapter 5.

4.2. Maximum Predicted Conventional Subsidence, Tilt and Curvature

The locations of the proposed Longwalls 31 to 37 are shown in Drawing No. MSEC647-01 in Appendix D. The predicted total conventional subsidence contours, after the extraction of each of the proposed longwalls, are shown in Drawing Nos. MSEC647-31 to MSEC647-37. The predicted additional conventional subsidence contours, due to the extraction of Longwalls 31 to 37 only, are shown in Drawing No. MSEC647-38.

A summary of the maximum predicted incremental conventional subsidence parameters, due to the extraction of each of the proposed longwalls, is provided in Table 4.1. A summary of the maximum predicted total conventional subsidence parameters, after the extraction of each of the proposed longwalls, is provided in Table 4.2. A summary of the maximum predicted travelling parameters, during the extraction of each of the proposed longwalls, is provided in Table 4.3.

Table 4.1 Maximum Predicted Incremental Conventional Subsidence, Tilt and Curvature due to the Extraction of Each of the Proposed Longwalls

Longwall	Maximum Predicted Incremental Conventional Subsidence (mm)	Maximum Predicted Incremental Conventional Tilt (mm/m)	Maximum Predicted Incremental Conventional Hogging Curvature (km^{-1})	Maximum Predicted Incremental Conventional Sagging Curvature (km^{-1})
Due to LW31	725	5.5	0.06	0.12
Due to LW32	700	5.5	0.06	0.12
Due to LW33	475	3.0	0.03	0.06
Due to LW34	675	5.0	0.06	0.11
Due to LW35	675	5.0	0.06	0.11
Due to LW36	675	5.5	0.06	0.11
Due to LW37	700	5.5	0.06	0.12

The predicted total conventional subsidence contours, after the extraction of each of the proposed Longwalls 31 to 37, are shown in Drawing Nos. MSEC647-31 to MSEC647-37. A summary of the maximum predicted values of total conventional subsidence, tilt and curvature is provided in Table 4.2.

Table 4.2 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature after the Extraction of Each of the Proposed Longwalls

Longwall	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
After LW31	1,225	6.0	0.09	0.13
After LW32	1,225	6.0	0.09	0.13
After LW33	1,225	6.0	0.09	0.13
After LW34	1,225	6.0	0.09	0.13
After LW35	1,225	6.0	0.09	0.13
After LW36	1,225	6.0	0.09	0.13
After LW37	1,225	6.0	0.09	0.13

The values provided in the above table are the maximum predicted total conventional subsidence parameters which occur within the SMP Area, including the predicted movements resulting from the extraction of Longwalls 22 to 30.

The locations where the maximum predicted total subsidence parameters anywhere above Longwalls 22 to 37 occur are outside the SMP Area for Longwalls 31 to 37. For example, the predicted maximum total vertical subsidence is 1,250 mm and this is located above previously extracted Longwall 27.

Table 4.3 Maximum Predicted Travelling Tilt and Curvature during the Extraction of Each of the Proposed Longwalls

Longwall	Maximum Predicted Travelling Conventional Tilt (mm/m)	Maximum Predicted Travelling Conventional Hogging Curvature (km^{-1})	Maximum Predicted Travelling Conventional Sagging Curvature (km^{-1})
During LW31	3.0	0.03	0.02
During LW32	3.0	0.03	0.02
During LW33	2.0	0.02	0.01
During LW34	2.5	0.03	0.02
During LW35	2.5	0.03	0.02
During LW36	2.5	0.03	0.02
During LW37	2.5	0.03	0.02

The maximum predicted total conventional subsidence within the SMP Area of 1,225 mm occurs above Longwall 29, after the extraction of the proposed Longwalls 30 and 31. The maximum predicted final conventional tilt of 6.0 mm/m (i.e. 0.6 %, or 1 in 165) occurs adjacent to the maingate of Longwall 37. The maximum predicted travelling tilt of 3.0 mm/m (i.e. 0.3 %, or 1 in 335) occurs during the extraction of Longwalls 31 and 32.

The maximum predicted total conventional curvatures transverse to the longwalls are 0.09 km^{-1} hogging and 0.13 km^{-1} sagging, which equate to minimum radii of curvature of 11 kilometres and 8 kilometres, respectively. The maximum predicted travelling curvatures along the alignments of the longwalls are 0.03 km^{-1} hogging and 0.02 km^{-1} sagging, which equate to minimum radii of curvature of 33 kilometres and 50 kilometres, respectively.

The variations in the predicted conventional subsidence parameters across the SMP Area are also illustrated along Prediction Lines 1 and 2, the locations of which are shown in Drawing Nos. MSEC647-31 to MSEC647-37. The predicted profiles of conventional subsidence, tilt and curvature along the Prediction Lines 1 and 2 are shown in Figs. E.01 and E.02, respectively, in Appendix E.

4.3. Areas where Increased Subsidence, compared to Predictions, has been Observed

The extraction of longwalls at Tahmoor Colliery has generally resulted in mine subsidence movements that were typical of those observed above other collieries in the Southern Coalfield of NSW at comparable depths of cover.

However, observed subsidence was greater than the predicted values over Longwalls 24A and the southern parts of Longwalls 25 to 27.

During the mining of Longwall 24A at Tahmoor Colliery, substantially increased subsidence was observed and further increases in observed subsidence compared to the predicted subsidence was observed in Longwall 25.

These increased levels of subsidence were a very unusual event for the Southern Coalfield and immediate investigations were undertaken to identify why it occurred. The conclusions of these studies were published in 2011 in a paper by W. Gale and I. Sheppard, which advised that the increased levels of subsidence were likely to be associated with the proximity of these areas to the Nepean Fault and the Bargo River Gorge and a recognition of the impact of a weathered zone of joints and bedding planes above the water table, which reduced the spanning capacity of the strata below this highly weathered section. This later recognition was determined after extensive computer modelling of factors that may have caused the increased subsidence.

Further subsidence monitoring has occurred over Longwalls 26, 27 and 28 within and around this zone of increased subsidence since 2011. A summary of the monitoring results over Longwalls 24A to 27 is shown in Table 4.4. It can be noted that the zone of increased subsidence extends over the Longwalls 24A to 27, though the extent of the increase in subsidence has reduced in magnitude as each longwall was extracted as shown in the table below.

Table 4.4 Maximum Observed and Maximum Predicted Incremental Subsidence and the Maximum Observed and Maximum Predicted Total Subsidence within the Zones of Increased Subsidence (Longwall 24A to Longwall 27)

Longwall	Assumed Average Seam Thickness Extracted in Zone (m)	Maximum Observed Incremental Subsidence and Proportion of Seam Thickness (mm)	Maximum Predicted Incremental Subsidence and Proportion of Seam Thickness (mm)	Relative Increase in Incremental Subsidence	Maximum Observed Total Subsidence and Proportion of Seam Thickness (mm)	Maximum Predicted Total Subsidence and Proportion of Seam Thickness (mm)	Relative Increase in Total Subsidence
LW24A	2.20	1169 (53%)	500 (23%)	2.34	1262 (57%)	800 (36%)	1.58
LW25	2.20	1216 (55%)	610 (28%)	1.99	1361 (62%)	900 (41%)	1.51
LW26	2.25	893 (40%)	730 (32%)	1.22	1070 (48%)	900 (40%)	1.19
LW27	2.15	823 (38%)	710 (33%)	1.16	896 (42%)	800 (37%)	1.12
LW28	2.10	755 (36%)	710 (34%)	1.06	827 (39%)	785 (37%)	1.05

Further details of the observed zones of increased subsidence over Longwalls 24A to 27 are shown in five longitudinal cross sections along Longwall 24A, Longwall 25, Longwall 26, Longwall 27 and Longwall 28 as Fig. 4.1 to Fig. 4.5 and a discussion on these details is presented below.

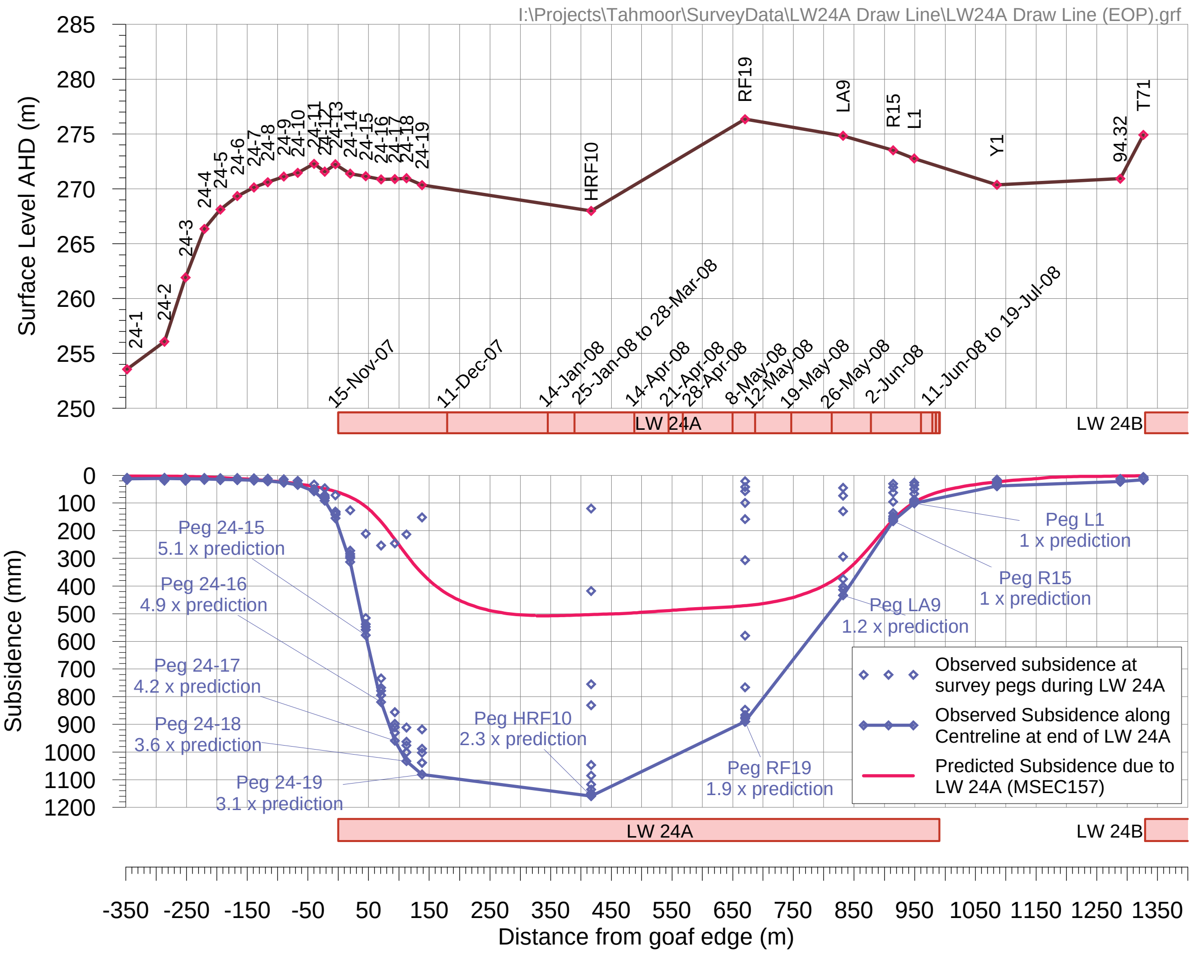


Fig. 4.1 Observed Incremental Subsidence along Centreline of Longwall 24A

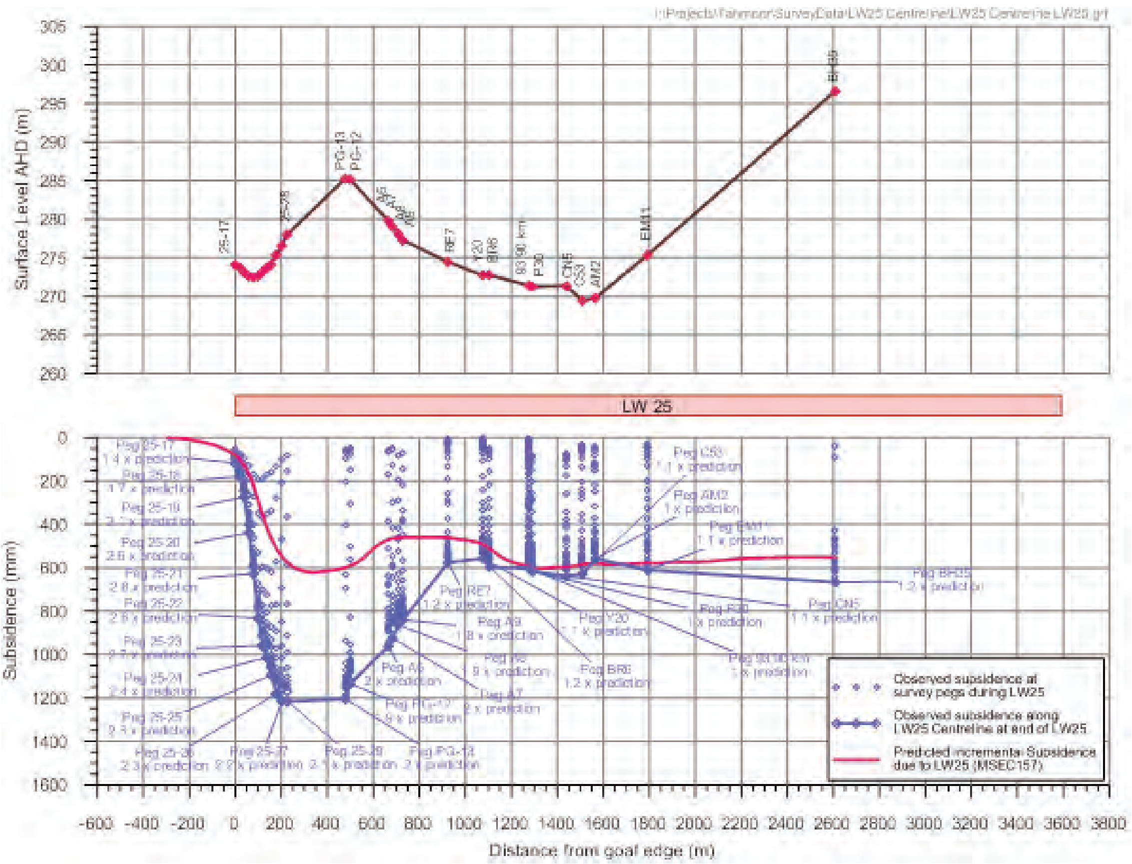


Fig. 4.2 Observed Incremental Subsidence along Centreline of Longwall 25

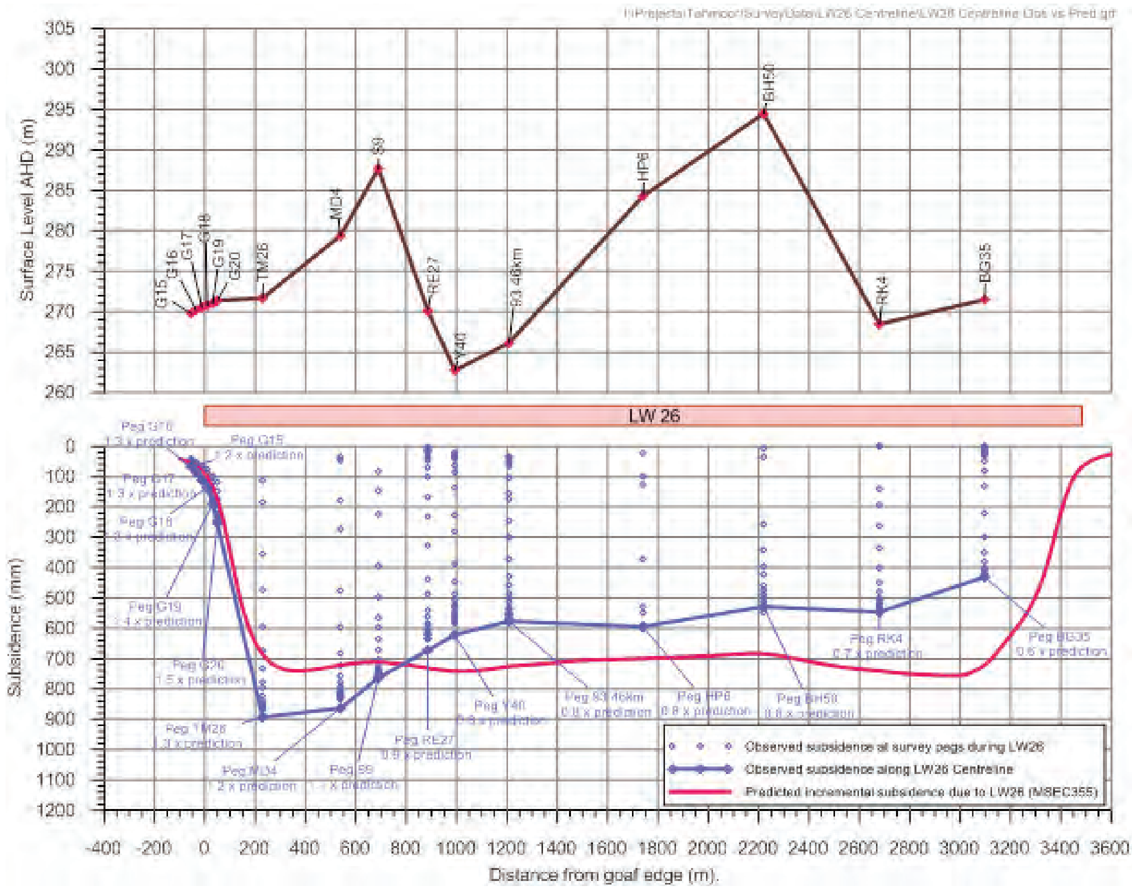


Fig. 4.3 Observed Incremental Subsidence along Centreline of Longwall 26

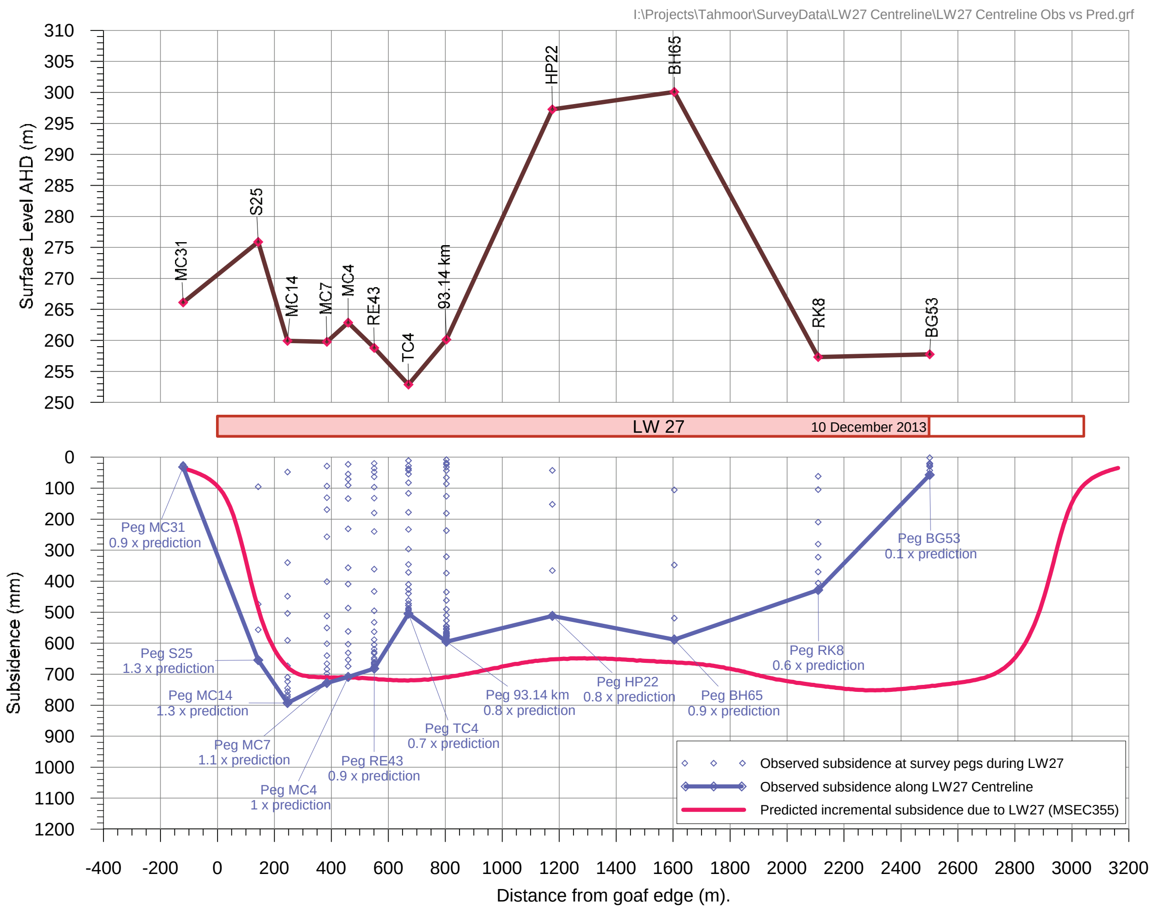


Fig. 4.4 Observed Incremental Subsidence along Centreline of Longwall 27

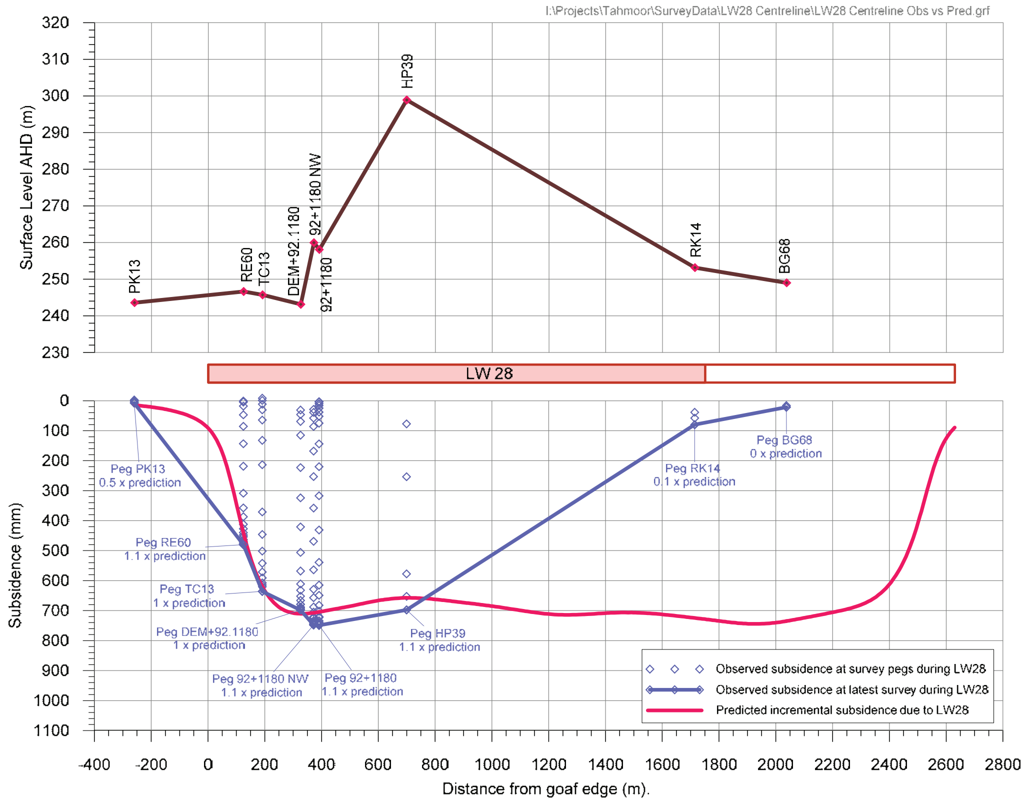


Fig. 4.5 Observed Incremental Subsidence along Centreline of Longwall 28 as at 17-Dec-14

Observed Increased Subsidence during the mining of Longwall 24A

- Fig. 4.1 shows the surface levels, the locations of various survey pegs along the centre of Longwall 24A and the observed incremental subsidence profiles at these survey pegs. It can be seen that the area of greatest increase in observed subsidence was in an area above the southern half of Longwall 24A that is closer to the Bargo River Gorge, closer to the Nepean Fault Zone and within 100 metres of a smaller fault zone that, like several other parallel faults, runs off the Nepean Fault in an en echelon style and within 140 metres of previous total extraction workings in the 204 panel. The extent of the increased subsidence then gradually reduced in magnitude towards the northern half of the longwall, which was directly beneath the urban area of Tahmoor.
- It can be seen from Fig. 4.1 that the observed subsidence was similar to the predicted levels near Peg R15 on Remembrance Drive. Survey pegs RF19 and LA9 were located within a transition zone where subsidence gradually reduced from areas of maximum increased subsidence to areas of normal subsidence.

Observed Increased Subsidence during the mining of Longwall 25

- Fig. 4.2 shows the observed incremental subsidence at survey pegs located along the centreline of Longwall 25. It can be seen that the area of greatest increase in observed subsidence was in an area above the southern half of Longwall 25 that is closer to the Bargo River Gorge and closer to the Nepean Fault Zone.
- The observed incremental subsidence is similar to but only slightly more than was predicted at Peg RE7 and is similar to the prediction at Peg Y20 and at all pegs located further along the panel. Survey pegs A6, A7, A8 and A9 are located within a transition zone where subsidence has gradually reduced from areas of maximum increased subsidence to areas of normal subsidence.

Observed Increased Subsidence during the mining of Longwall 26

- Fig. 4.3 shows the observed incremental subsidence at survey pegs located along the centreline of Longwall 26. Increased incremental subsidence was observed during the first stages of mining Longwall 26, but at a reduced magnitude compared to the incremental subsidence observed above Longwalls 24A and 25.
- Observed subsidence reduced along the panel until Peg Y40 on York Street, where it was less than prediction. Survey pegs S9 and RE27 are located within a transition zone where subsidence has gradually reduced from areas of maximum increased subsidence between Pegs TM26 and MD4 to areas of normal subsidence at Peg Y40 and beyond.

Observed Increased Subsidence during the mining of Longwall 27

- Fig. 4.4 shows the observed incremental subsidence at survey pegs located along the centreline of Longwall 27. Increased incremental subsidence was observed during the first stages of mining Longwall 26, but at a reduced magnitude compared to the incremental subsidence observed above Longwalls 24A, 25 and 26.
- As shown in Fig. 4.4 the observed subsidence reduced along the panel until Peg 93.140 km on the Main Southern Railway. Survey pegs MC4, MC7, RE43 and TC4 are located within a transition zone where subsidence has gradually reduced from areas of maximum increased subsidence between Pegs MC14 and 93.140 km to areas of normal subsidence along the Railway and beyond.

Observed Subsidence during the mining of Longwall 28

- Fig. 4.6 shows the observed incremental subsidence at survey pegs located along the centreline of Longwall 28. It can be seen that observed subsidence has returned to normal levels, and within 6% of subsidence predictions.
- As shown in Fig. 4.6, there is a reasonable correlation between the observed and predicted subsidence profile along the centreline of Longwall 28.

4.3.1. Analysis and Commentary on the Zone of Increased Subsidence

The cause for the increased subsidence was investigated during the extraction of Longwall 25 by Strata Control Technology (SCT) on behalf of Tahmoor Colliery as discussed in the previously referenced paper by Gale and Sheppard (2011).

These investigations concluded that the areas of increased subsidence was consistent with localised weathering of joint and bedding planes above a depressed water table adjacent to an incised gorge. This conclusion was further confirmed in further recent report by Gale W. of SCT (2013a), who confirms that:

> "*Longwall panels 24A and 25 both show increased maximum subsidence to approximately 1.0-1.2m, where predicted subsidence was in the order of 0.5 - 0.8m. In the study by Gale and Sheppard, (2011), it became apparent that the increased subsidence is likely to be due to reduction in joint friction and stiffness due to the weathering process in the strata above the water table where the water table is considerably lower due to the Bargo Gorge. The intact rock properties were not changed, only the properties of the joints were altered*."

There have been many locations where monitoring near faults has revealed little increase of observed subsidence and there are many locations where monitoring near deep gorges and valleys has revealed little increases in observed subsidence. In summary, it appears that the location of the zones of increased subsidence is linked to both the;

- close proximity and the alignment of the Nepean Fault, which is within 1,000 metres of these zones; and
- close proximity to the Bargo River Gorge, which is approximately 100 metres deep, within 700 metres of these zones. The presence of the Bargo River Gorge has permitted groundwater flows to weather the joint and bedding plane properties of the surrounding strata.

In light of the above conclusions and observations, three areas or zones have been identified from the observed subsidence monitoring above the extracted Longwalls 24A to 27 at Tahmoor:

- Maximum increased subsidence zone – where the observed vertical subsidence is substantially greater than the predicted subsidence;
- Transition zone – where the subsidence behaviour appears to be transitioned between areas of maximum increased subsidence and normal subsidence; and
- Normal subsidence zone – where the observed vertical subsidence is within the normal range and correlates well with predictions.

The locations of the three zones are plotted on a plan, using the surveyed pegs that were identified along the centrelines above Longwalls 24A to 28 as a guide, as shown in Fig. 4.6, it can be seen that the transition zone is roughly consistent in width above Longwall 24A, Longwall 25 and Longwall 26 and possibly slightly narrower above Longwall 27. The orientation of the transition zone is also roughly parallel to the Nepean Fault and the magnitude of the increased subsidence above Longwalls 26 and 27 is reduced compared to Longwalls 24A and 25. There was no increased subsidence identified above Longwall 28.

It can be seen in Fig. 4.6, that the alignment of the Nepean Fault is further away from the Bargo River gorge and further away from Longwalls 26 and 28, where the magnitudes of the increased subsidence reduced, indicating that the cause of the movements is clearly linked to the proximity of the Bargo River. This observation confirms the findings of Gale and Sheppard (2011) that the increased subsidence is linked to localised weathering of joint and bedding planes above a depressed water table adjacent to the incised gorge of the Bargo River and the presence of the major fault.

It should be noted that the potential impacts of increased subsidence on the structures and infrastructure within the overlying urban areas of Tahmoor Township were successfully managed by Tahmoor Colliery through the implementation of effective subsidence management plans.

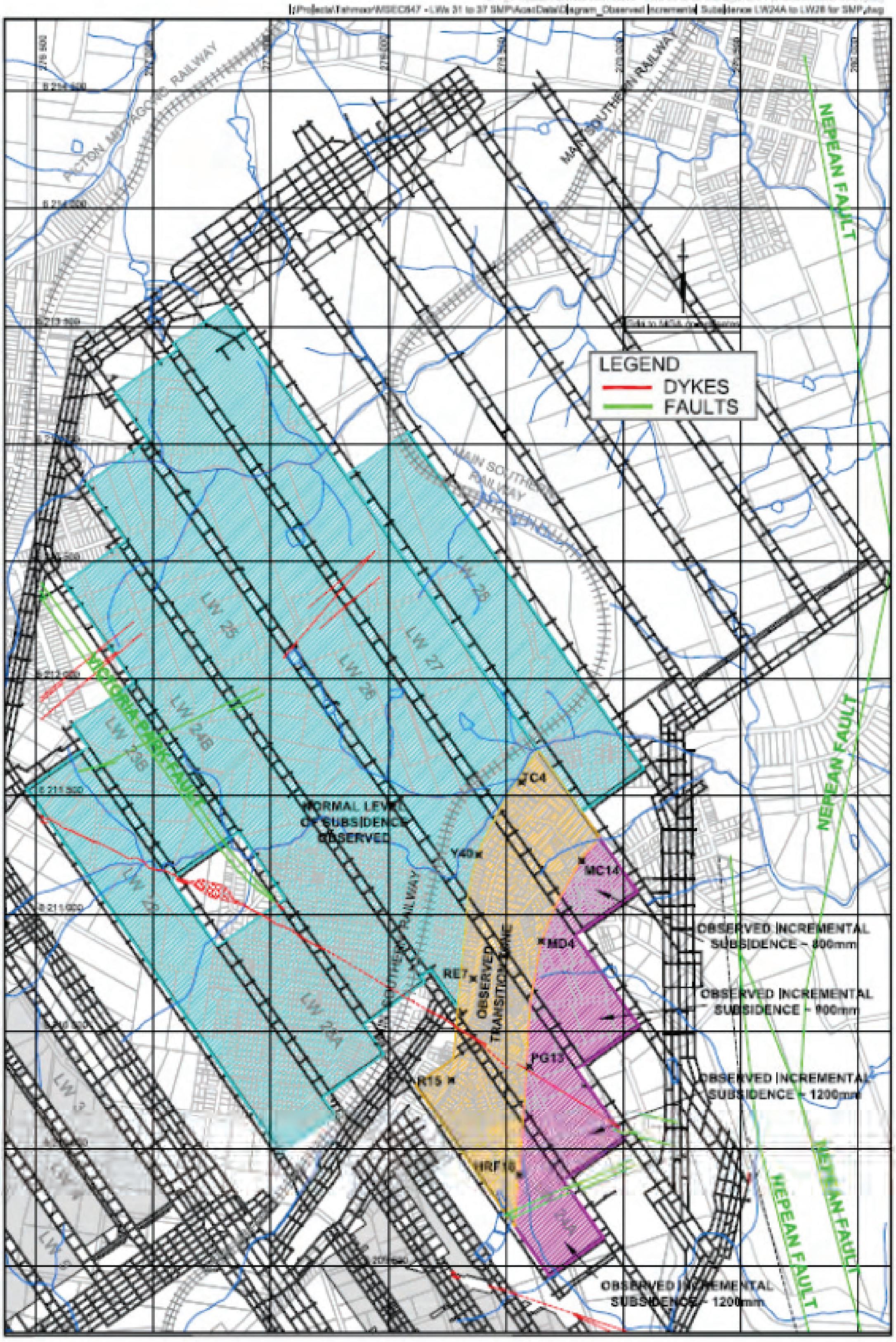


Fig. 4.6 Figure Showing the Zones of Increased Subsidence over Longwalls 22 to 28

4.4. Potential additional settlement above coal barriers between proposed and previous mine workings

The proposed longwalls will be extracted in two series, separated by a barrier of unmined coal, except for development headings.

Additional vertical settlement has been observed within the following areas at Tahmoor that were located above solid intact coal between previously extracted areas, such as;

- Between Longwall 3 and Longwall 22 at Tahmoor Mine,
- Between Longwall 23A and 23B at Tahmoor Mine,
- Between Longwall 24A and the 200 Panels at Tahmoor Mine,
- Between Longwalls 22 to 24B and Longwall 24A and the 200 Panels and Longwall 25 (i.e. mining on three sides of a corridor of intact coal) at Tahmoor Mine,
- Between Longwalls 8-12, Longwall 18 and Longwall 408 at Appin Colliery, and
- Between Longwalls 14-18, 301-302 and 401 at Appin Colliery.

The amount of additional vertical settlement in these areas has been generally been between 50 and 150 mm of subsidence above what was predicted using the IPM and generally low levels of tilt and strain were measured within these areas. Increased subsidence has not always been observed in these situations. For example, it was not observed between Longwalls 3-9 and Longwall 20 at Tahmoor Mine.

While observed subsidence may exceed predictions above the coal barrier between proposed Longwall series 22 to 32 and Longwall series 33 to 37, subsidence monitoring has shown that it is usually accompanied by relatively low systematic tilts, curvature and strains (less than 0.5 mm/m and usually within survey tolerance).

4.5. Predicted Strains

The prediction of strain is more difficult than the predictions of subsidence, tilt and curvature. The reason for this is that strain is affected by many factors, including curvature and horizontal movement, as well as local variations in the near surface geology, the locations of pre-existing natural joints at bedrock, and the depth of bedrock. Survey tolerance can also represent a substantial portion of the measured strain, in cases where the strains are of a low order of magnitude. The profiles of observed strain, therefore, can be irregular even when the profiles of observed subsidence, tilt and curvature are relatively smooth.

In previous MSEC subsidence reports, predictions of conventional strain were provided based on the best estimate of the average relationship between curvature and strain. Similar relationships have been proposed by other authors. The reliability of the strain predictions was highlighted in these reports, where it was stated that measured strains can vary considerably from the predicted conventional values.

Adopting a linear relationship between curvature and strain provides a reasonable prediction for the conventional tensile and compressive strains. The locations that are predicted to experience hogging or convex curvature are expected to be net tensile strain zones and locations that are predicted to experience sagging or concave curvature are expected to be net compressive strain zones. In the Southern Coalfield, it has been found that a factor of 15 provides a reasonable relationship between the maximum predicted curvatures and the maximum predicted conventional strains.

The maximum predicted conventional strains resulting from the extraction of Longwalls 31 to 37, based on applying a factor of 15 to the maximum predicted curvatures, are 1 mm/m tensile and 2 mm/m compressive.

At a point, however, there can be considerable variation from the linear relationship, resulting from non-conventional movements or from the normal scatters which are observed in strain profiles. When expressed as a percentage, observed strains can be many times greater than the predicted conventional strain for low magnitudes of curvature. In this report, therefore, we have provided a statistical approach to account for the variability, instead of just providing a single predicted conventional strain.

The range of potential strains above the proposed longwalls has been determined using monitoring data from the previously extracted longwalls at Tahmoor Colliery. The range of strains measured during the extraction of these longwalls should, therefore, provide a reasonable indication of the range of potential strains for the proposed longwalls.

The data used in the analysis of observed strains included those resulting from both conventional and non-conventional anomalous movements, but did not include those resulting from valley related movements, which are discussed in Section 5.4 and in the impact assessments for the natural and built features provided in Chapters 5 and 6. The strains resulting from damaged or disturbed survey marks have also been excluded.

4.5.1. Analysis of Strains Measured in Survey Bays

For features that are in discrete locations, such as building structures, farm dams and archaeological sites, it is appropriate to assess the frequency of the observed maximum strains for individual survey bays.

The survey database has been analysed to extract the maximum tensile and compressive strains that have been measured at any time during the extraction of the previous longwalls at Tahmoor Colliery, for survey bays that were located directly above goaf or the chain pillars that are located between the extracted longwalls, which has been referred to as "*above goaf*".

The histogram of the maximum observed total tensile and compressive strains measured in survey bays above goaf is provided in Fig. 4.7. A number of probability distribution functions were fitted to the empirical data. It was found that a *Generalised Pareto Distribution (GPD)* provided a good fit to the raw strain data, which have also been shown in this figure.

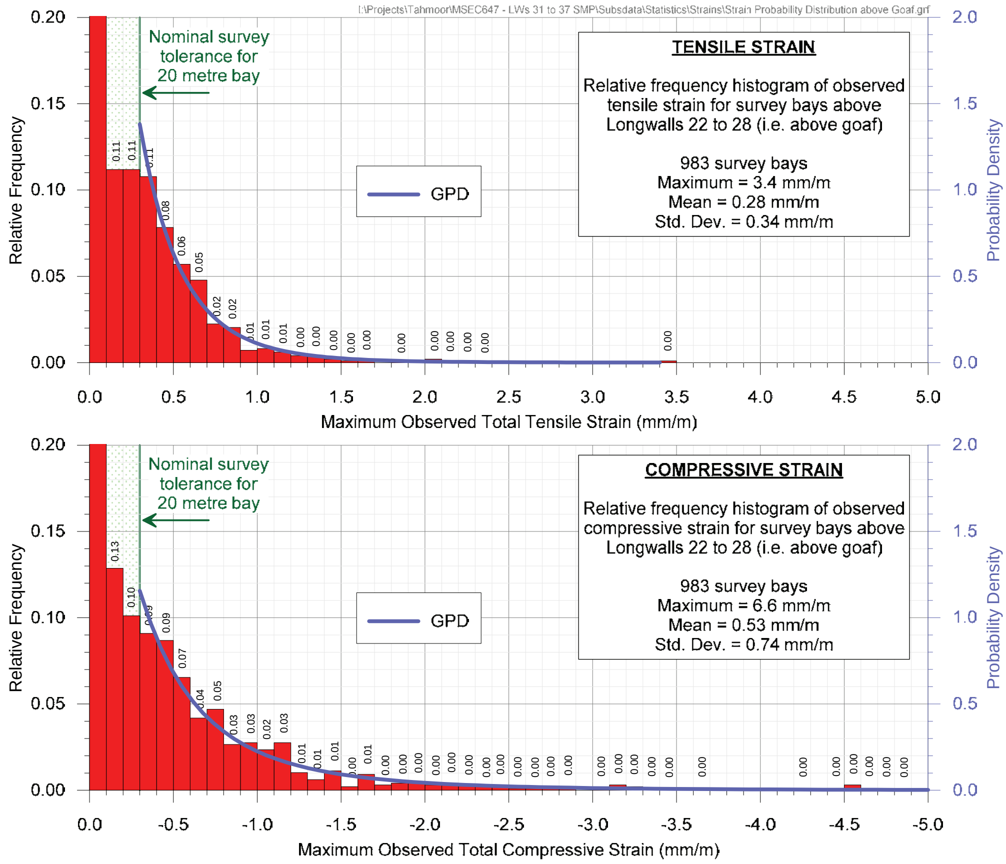


Fig. 4.7 Distributions of the Measured Maximum Tensile and Compressive Strains during the Extraction of Previous Longwalls at Tahmoor Colliery for Bays Located Above Goaf

Confidence levels have been determined from the empirical strain data using the fitted GPDs. In the cases where survey bays were measured multiple times during a longwall extraction, the maximum tensile strain and the maximum compressive strain were used in the analysis (i.e. single tensile strain and single compressive strain measurement per survey bay).

A summary of the probabilities of exceedance for tensile and compressive strains for survey bays located above goaf, based on the fitted GPDs, is provided in Table 4.5. The analysis does not include the strains resulting from valley related movements, which are discussed separately in Section 5.4 and in the impact assessments for the natural and built features provided in Chapters 5 and 6.

Table 4.5 Probabilities of Exceedance for Strain for Survey Bays Located above Goaf

Strain (mm/m)		Probability of Exceedance
Compression	-8.0	1 in 1,100
	-6.0	1 in 450
	-4.0	1 in 140
	-2.0	1 in 25
	-1.0	1 in 7
	-0.5	1 in 3
	-0.3	1 in 2
Tension	+0.3	1 in 3
	+0.5	1 in 5
	+1.0	1 in 25
	+2.0	1 in 330
	+3.0	1 in 2,500

The 95 % confidence levels for the maximum total strains that the individual survey bays above goaf experienced at any time during mining were 0.9 mm/m tensile and 1.8 mm/m compressive. The 99 % confidence levels for the maximum total strains that the individual survey bays above goaf experienced at any time during mining were 1.5 mm/m tensile and 3.5 mm/m compressive.

The probabilities for survey bays located above goaf are based on the strains measured anywhere above the previously extracted longwalls at Tahmoor Colliery. As described previously, tensile strains are more likely to develop in the locations of hogging curvature and compressive strains are more likely to develop in the locations of sagging curvature.

This is illustrated in Fig. 4.8, which shows the distribution of incremental strains measured above previously extracted longwalls in the Southern Coalfield. The distances have been normalised, so that the locations of the measured strains are shown relative to the longwall maingate and tailgate sides. The approximate confidence levels for the incremental tensile and compressive strains are also shown in this figure, to help illustrate the variation in the data.

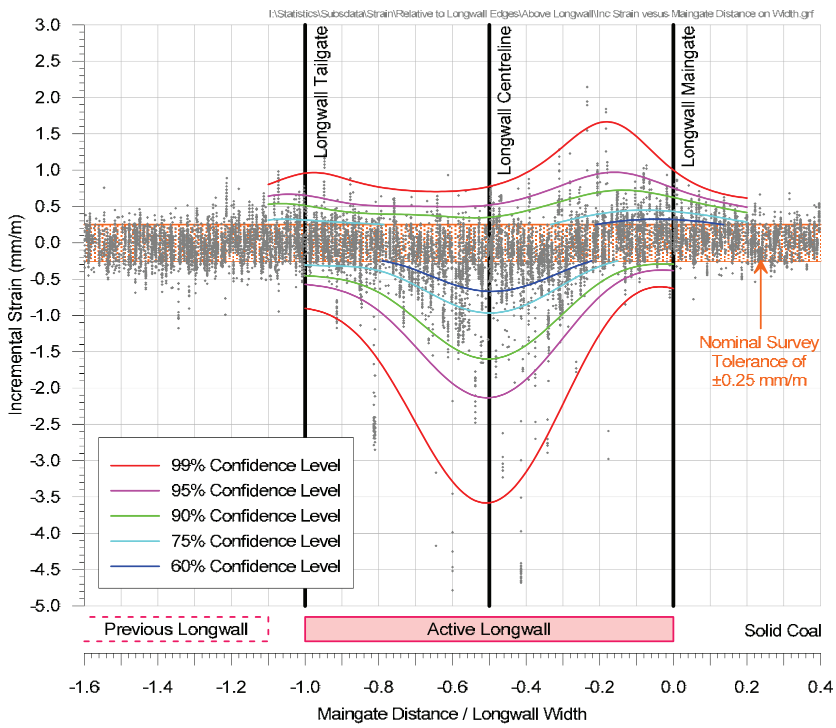


Fig. 4.8 Observed Incremental Strains versus Normalised Distance from the Longwall Maingate for Previously Extracted Longwalls in the Southern Coalfield

The survey database has also been analysed to extract the maximum tensile and compressive strains that have been measured at any time during the extraction of the previous longwalls in the Southern Coalfield, for survey bays that were located outside and within 200 metres of the nearest longwall goaf edge, which has been referred to as "*above solid coal*".

The histogram of the maximum observed tensile and compressive strains measured in survey bays above solid coal is provided in Fig. 4.9. The probability distribution functions, based on the fitted GPDs, have also been shown in this figure.

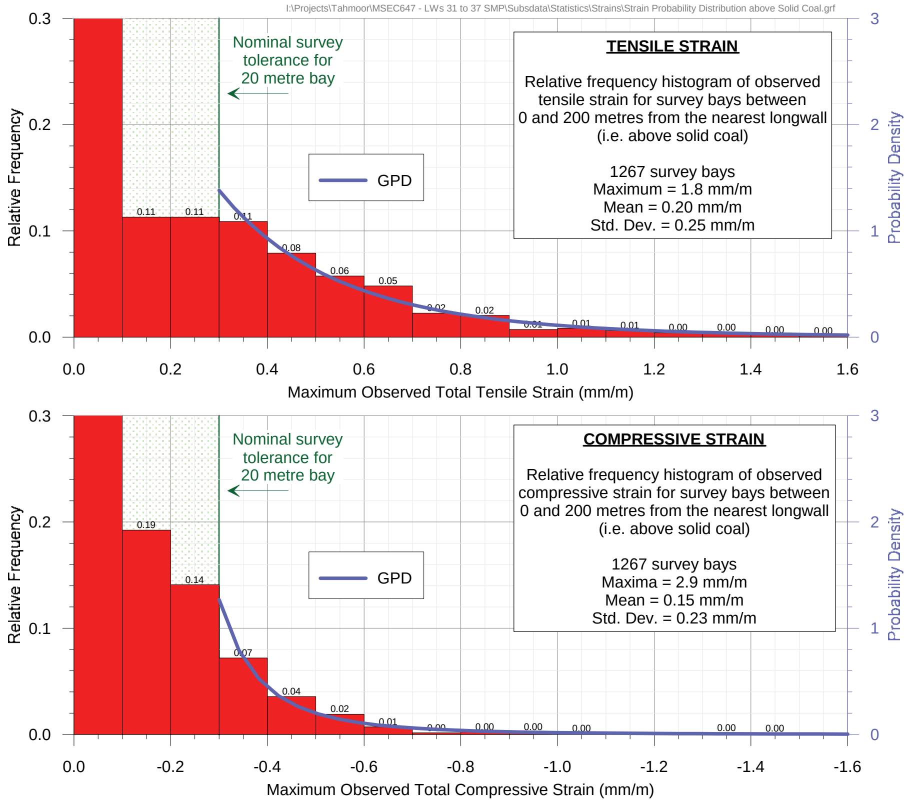


Fig. 4.9 Distributions of the Measured Maximum Tensile and Compressive Strains during the Extraction of Previous Longwalls at Tahmoor Colliery for Bays Located Above Solid Coal

Confidence levels have been determined from the empirical strain data using the fitted GPDs. In the cases where survey bays were measured multiple times during a longwall extraction, the maximum tensile strain and the maximum compressive strain were used in the analysis (i.e. single tensile strain and single compressive strain measurement per survey bay).

A summary of the probabilities of exceedance for tensile and compressive strains for survey bays located above solid coal, based the fitted GPDs, is provided in Table 4.6. The analysis does not include the strains resulting from valley related movements, which are discussed separately in Section 5.4 and in the impact assessments for the natural and built features provided in Chapters 5 and 6.

Table 4.6 Probabilities of Exceedance for Strain for Survey Bays Located above Solid Coal

Strain (mm/m)		Probability of Exceedance
Compression	-3.0	1 in 2,200
	-2.0	1 in 800
	-1.5	1 in 400
	-1.0	1 in 150
	-0.5	1 in 25
	-0.3	1 in 7
Tension	+0.3	1 in 4
	+0.5	1 in 10
	+1.0	1 in 80
	+1.5	1 in 400
	+2.0	1 in 1,600

The 95 % confidence levels for the maximum total strains that the individual survey bays above solid coal experienced at any time during mining were 0.6 mm/m tensile and 0.5 mm/m compressive. The 99 % confidence levels for the maximum total strains that the individual survey bays above solid coal experienced at any time during mining were 1.1 mm/m tensile and 0.9 mm/m compressive.

4.5.2. Analysis of Strains Measured Along Whole Monitoring Lines

For linear features such as roads, cables and pipelines, it is more appropriate to assess the frequency of the maximum observed strains along whole monitoring lines, rather than for individual survey bays. That is, an analysis of the maximum strains measured anywhere along the monitoring lines, regardless of where the strain actually occurs.

The histogram of maximum observed total tensile and compressive strains measured anywhere along the monitoring lines, at any time during or after the extraction of the previous longwalls at Tahmoor Colliery, is provided in Fig. 4.10.

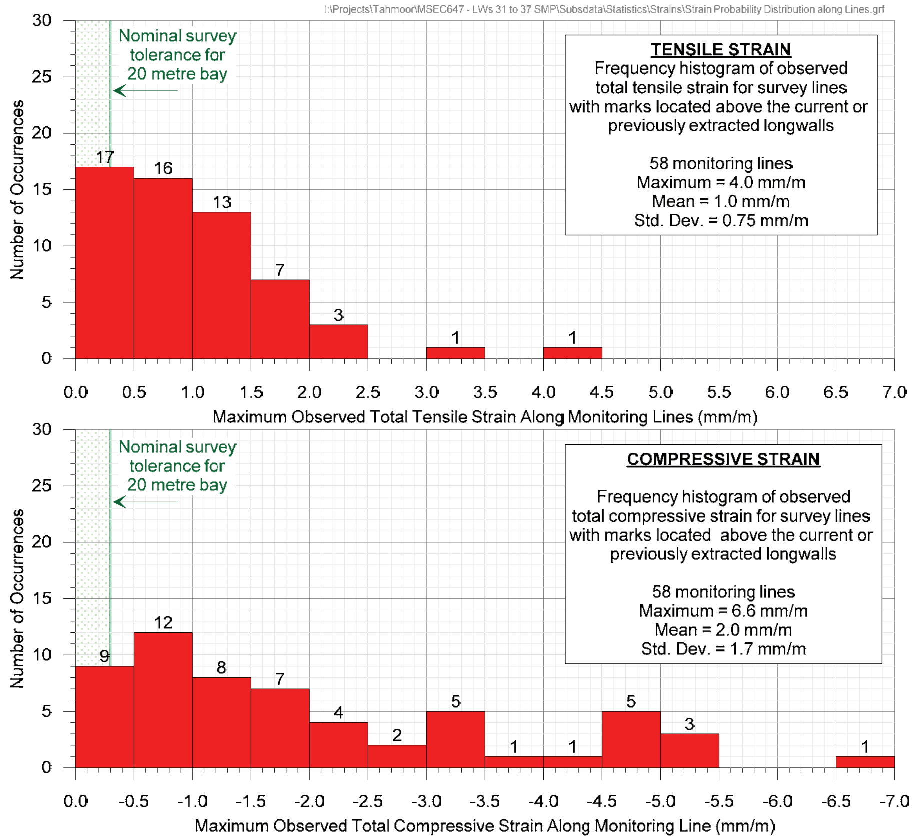


Fig. 4.10 Distributions of Measured Maximum Tensile and Compressive Strains along the Monitoring Lines during the Extraction of Previous Longwalls at Tahmoor Colliery

It can be seen from the above figure, that 33 of the 58 monitoring lines (i.e. 57 %) had recorded maximum total tensile strains of 1.0 mm/m, or less, and that 53 monitoring lines (i.e. 91 %) had recorded maximum total tensile strains of 2.0 mm/m, or less. It can also be seen, that 36 of the 58 monitoring lines (i.e. 62 %) had recorded maximum compressive strains of 2.0 mm/m, or less, and that 48 of the monitoring lines (i.e. 83 %) had recorded maximum compressive strains of 4.0 mm/m, or less.

4.5.3. Analysis of Shear Strains

As described in Section 3.2, ground strain comprises two components, being normal strain and shear strain, which can be interrelated using Mohr's Circle. The magnitudes of the normal strain and shear strain components are, therefore, dependent on the orientation in which they are measured. The maximum normal strains (i.e. principal strains) are those in the direction where the corresponding shear strain is zero.

Normal strains along monitoring lines can be measured using 2D and 3D techniques, by taking the change in horizontal distance between two points on the ground and dividing by the original horizontal distance between them. This provides the magnitude of normal strain along the orientation of the monitoring line and, therefore, this strain may not necessarily be the maximum (i.e. principal) strain.

Shear deformations are more difficult to measure, as they are the relative horizontal movements perpendicular to the direction of measurement. However, 3D monitoring techniques provide data on the direction and the absolute displacement of survey marks and, therefore, the shear deformations perpendicular to the monitoring line can be determined. But, in accordance with rigorous definitions and the principles of continuum mechanics, (e.g. Jaeger, 1969), it is not possible to determine horizontal shear strains in any direction relative to the monitoring line using 3D monitoring data from a straight line of survey marks.

As described in Section 3.2, shear deformations perpendicular to monitoring lines can be described using various parameters, including horizontal tilt, horizontal curvature, horizontal mid-ordinate deviation, angular distortion and shear index. In this report, horizontal mid-ordinate deviation has been used as the measure for shear deformation, which is defined as the differential horizontal movement of each survey mark, perpendicular to a line drawn between two adjacent survey marks.

The frequency distribution of the maximum total horizontal mid-ordinate deviations measured at survey marks above goaf, for previously extracted longwalls in the Southern Coalfield, is provided in Fig. 4.11. As the typical survey bay length was 20 metres, the calculated mid-ordinate deviations were over a chord length of 40 metres. The probability distribution function, based on the fitted GPD, has also been shown in this figure.

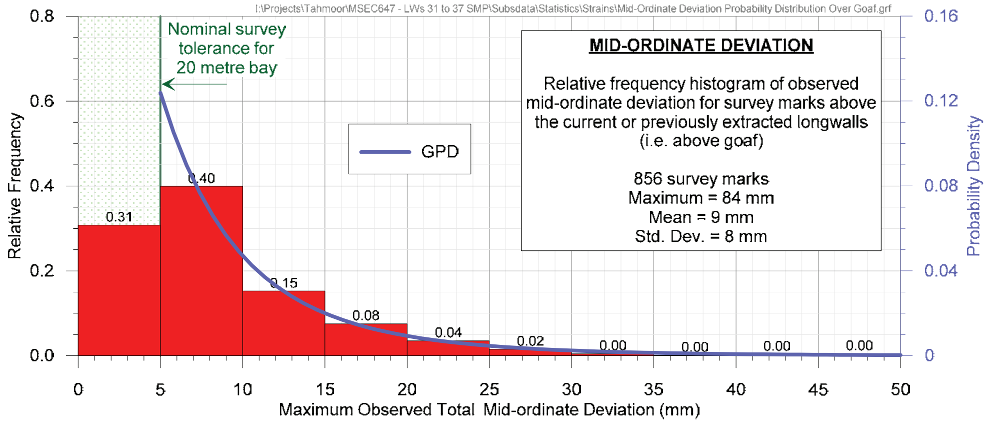


Fig. 4.11 Distribution of Measured Maximum Mid-ordinate Deviation during the Extraction of Previous Longwalls in the Southern Coalfield for Marks Located Above Goaf

A summary of the probabilities of exceedance for total horizontal mid-ordinate deviation for survey bays located above goaf, based the fitted GPD, is provided in Table 4.7. The analysis does not include the strains resulting from valley related movements, which are discussed separately in Section 5.4 and in the impact assessments for the natural and built features provided in Chapters 5 and 6.

Table 4.7 Probabilities of Exceedance for Mid-Ordinate Deviation for Survey Marks above Goaf for Monitoring Lines in the Southern Coalfield

Horizontal Mid-ordinate Deviation (mm)		Probability of Exceedance
Mid-ordinate Deviation over 40 metre Chord Length	10	1 in 3
	20	1 in 15
	30	1 in 40
	40	1 in 110
	50	1 in 250
	60	1 in 550
	70	1 in 1,000
	80	1 in 1,900

The 95 % and 99 % confidence levels for the maximum total horizontal mid-ordinate deviation that the individual survey marks located above goaf experienced at any time during mining were 23 mm and 39 mm, respectively.

4.6. Predicted Far-Field Horizontal Movements

In addition to the conventional subsidence movements that have been predicted above and adjacent to the proposed longwalls, and the predicted valley related movements along the streams, it is also likely that far-field horizontal movements will be experienced during the extraction of the proposed longwalls.

The observed incremental far-field horizontal movements resulting from the extraction of each longwall, in any location above goaf (i.e. above the currently mined or previously mined longwalls) or above solid coal (i.e. unmined areas of coal) are provided in Fig. 4.12. The observed incremental far-field horizontal movements above solid coal only, i.e. outside the extents of extracted longwalls, are provided Fig. 4.13. The confidence levels, based on fitted *Generalised Pareto Distributions* (GPDs), have also been shown in these figures to illustrate the spread of the data. It can be seen from Fig. 4.12 and Fig. 4.13 that the magnitude of the observed far-field horizontal movements over solid unmined areas of coal are lower and more consistent than the observed far-field horizontal movements over previously extracted longwalls.

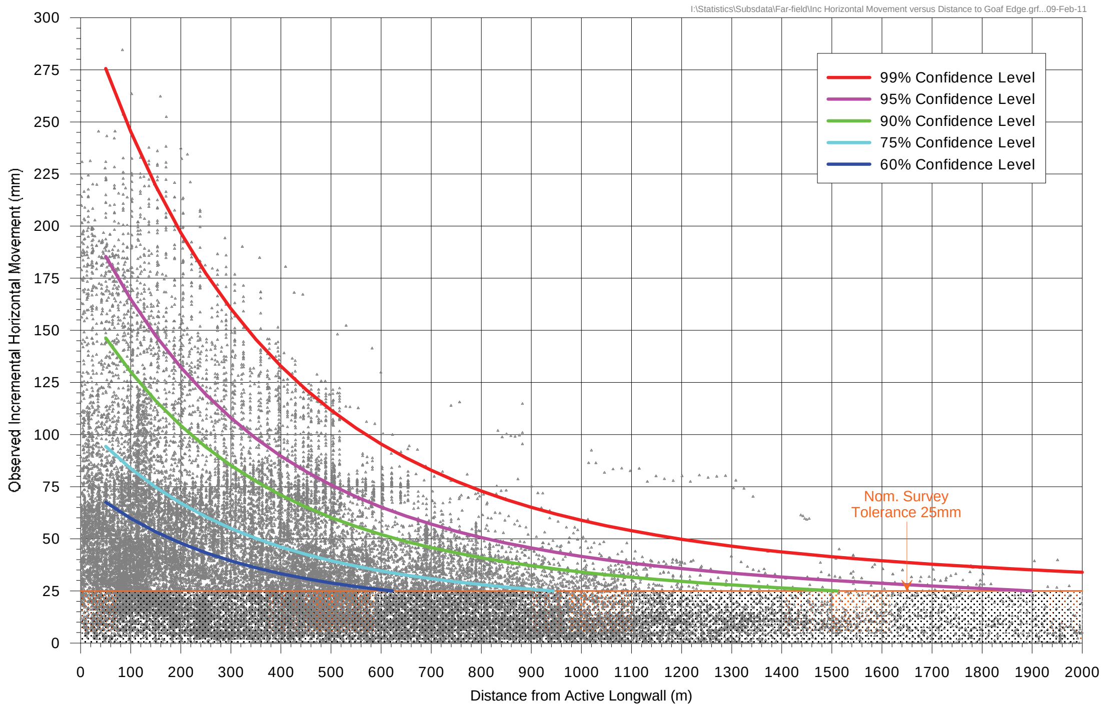


Fig. 4.12 Observed Incremental Far-Field Horizontal Movements above Goaf or Solid Coal

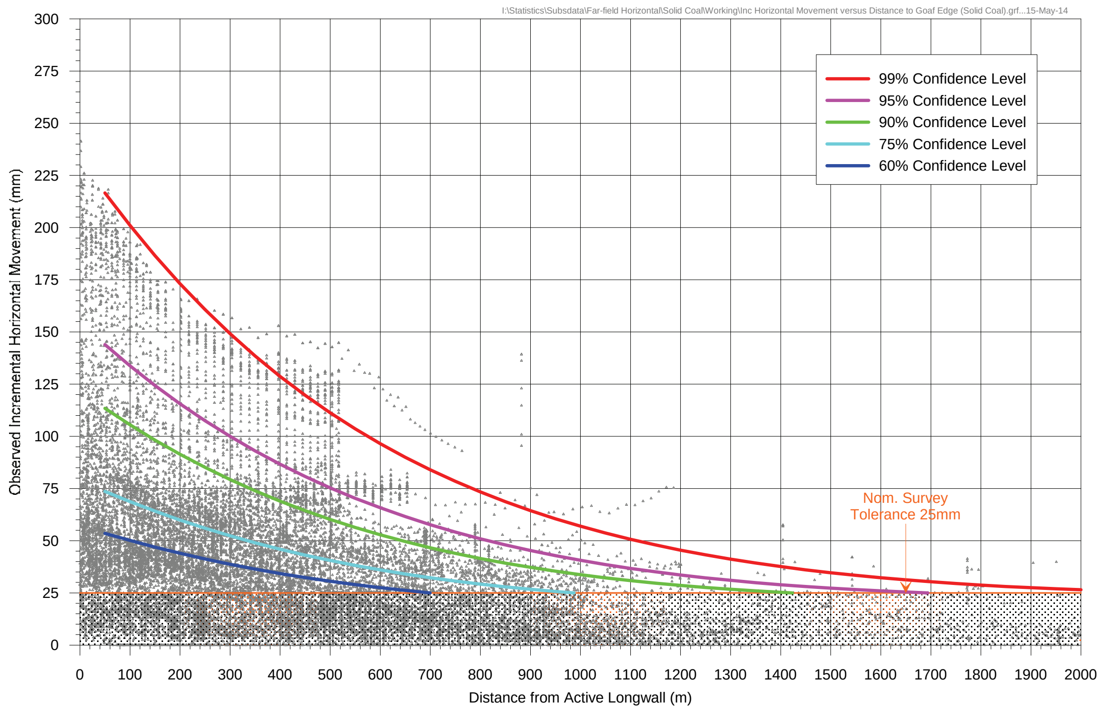


Fig. 4.13 Observed Incremental Far-Field Horizontal Movements above Solid Coal Only

As successive longwalls within a series of longwalls are mined, the magnitudes of the incremental far-field horizontal movements decrease. This is possibly due to the fact that once the in situ stresses within the strata have been redistributed around the collapsed zones above the first few extracted longwalls, the potential for further movement is reduced. The total far-field horizontal movement may be less, therefore, than the sum of the incremental far-field horizontal movements for the individual longwalls.

The predicted far-field horizontal movements resulting from the extraction of the proposed longwalls are very small and could only be detected by precise surveys. Such movements tend to be bodily movements towards the extracted goaf area, and are accompanied by very low levels of strain, which are generally less than the order of survey tolerance (i.e. less than 0.3 mm/m). The potential impacts of far-field horizontal movements on the natural and built features within the vicinity of the proposed longwalls are not expected to be measurable, with possibly the exception of the larger infrastructure such as the road and railway bridges, which is discussed further below.

The potential for impacts on the larger infrastructure outside the SMP Area do not result from absolute far-field horizontal movements, but rather from differential horizontal movements over the lengths of the structures. For example, differential horizontal movements along the alignments of the bridges could potentially affect the widths of the expansion joints or the capacities of the support bearings. Differential horizontal movements across the alignments of concrete bridges could potentially induce eccentricities into the structure or affect the capacities of the support bearings.

The potential for differential horizontal movements at the infrastructure outside the SMP Area has been assessed by statistically analysing the available 3D monitoring data from the Southern Coalfield. The observed incremental differential longitudinal movements for survey marks spaced at 20 metres ±10 metres, relative to the distance from the active longwall, is shown in Fig. 4.14. The 95 % confidence levels have also been shown in this figure, which were determined from the empirical data using the fitted *Generalised Pareto Distributions* (GPDs).

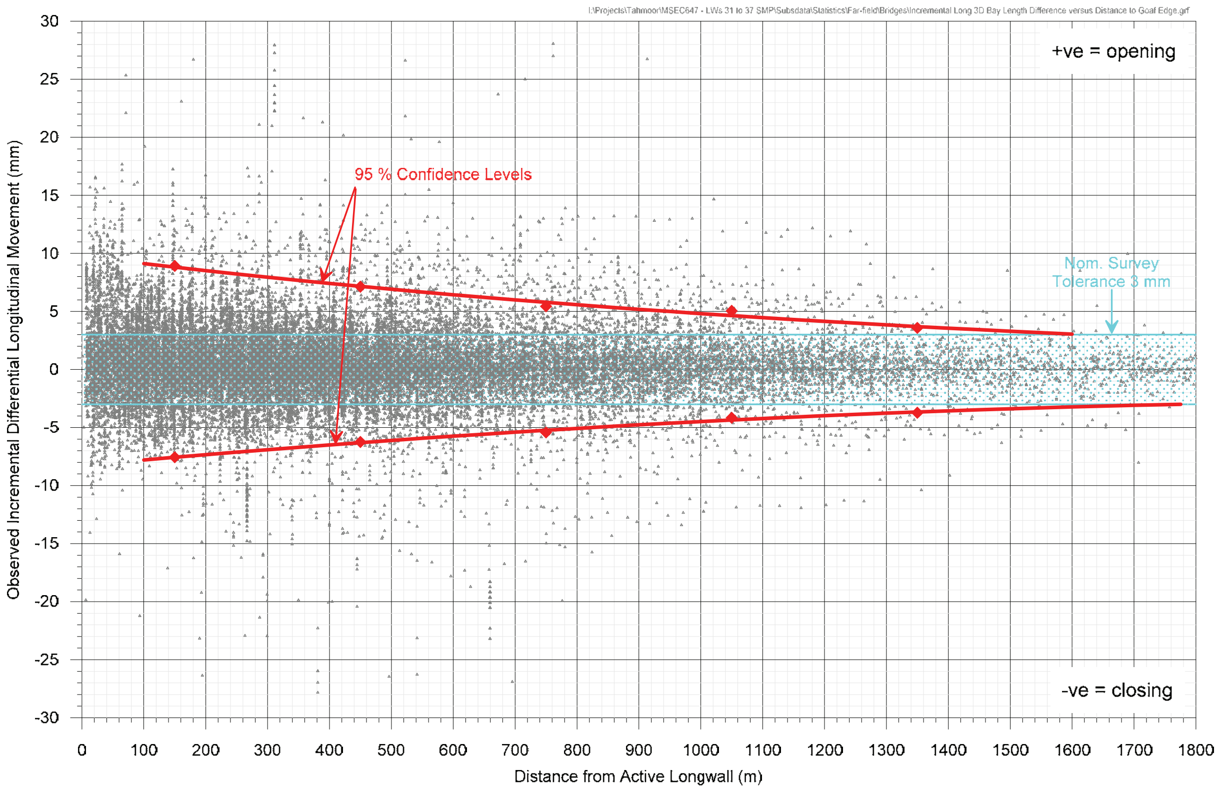


Fig. 4.14 Observed Incremental Differential Horizontal Movements versus Distance from Active Longwall for Marks Spaced at 20 metres ±10 metres

Mid-ordinate deviation is a measure of differential lateral movement, which is the change in perpendicular horizontal distance from a point to a chord formed by joining points on either side. A schematic sketch showing the mid-ordinate deviation of a peg compared to its adjacent survey pegs between two survey epochs is provided in Fig. 4.15.

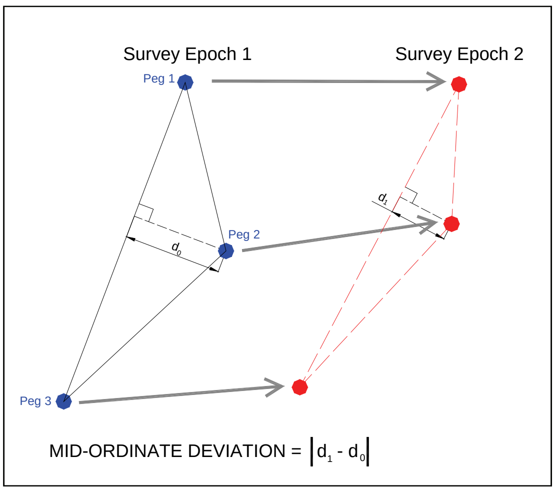


Fig. 4.15 Schematic Representation of Mid-Ordinate Deviation

The distribution of the observed incremental horizontal mid-ordinate deviation for survey marks spaced at 20 metres ±10 metres, relative to the distance from the active longwall, is shown in Fig. 4.16.

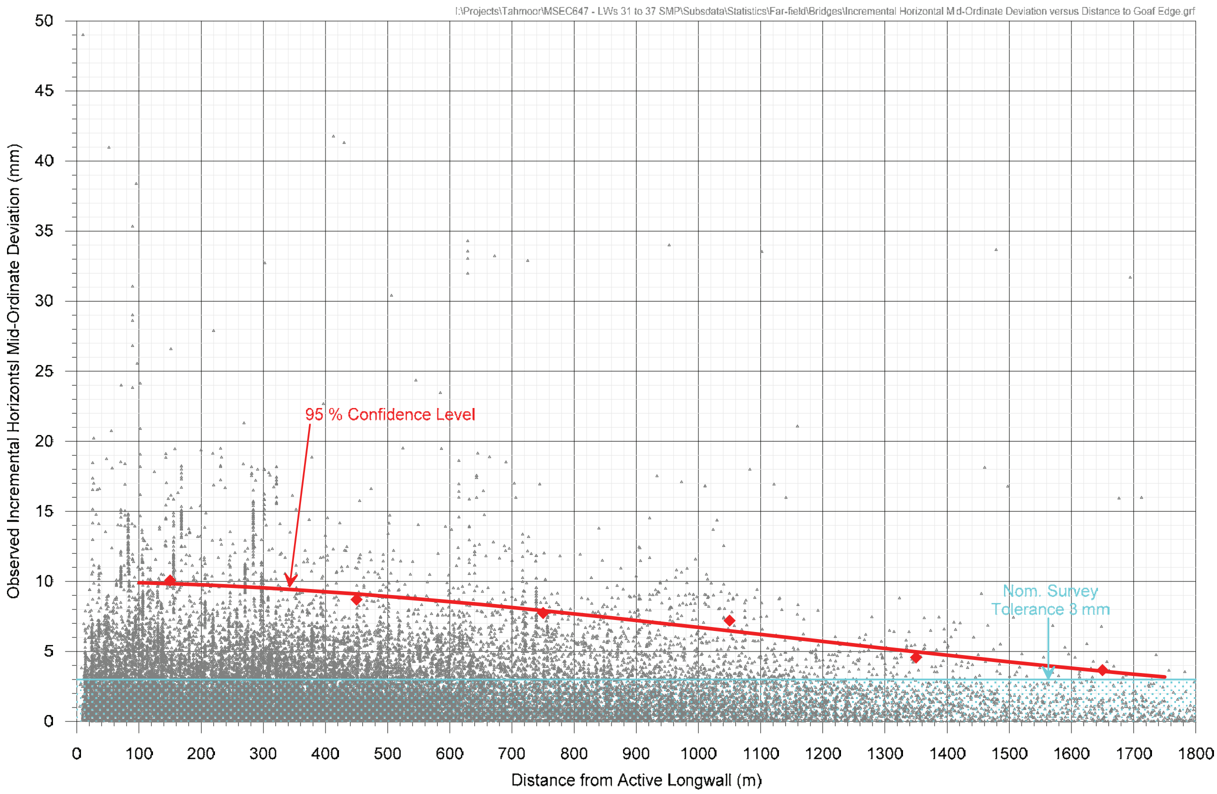


Fig. 4.16 Observed Incremental Horizontal Mid-Ordinate Deviation versus Distance from Active Longwall for Marks Spaced at 20 metres ±10 metres

The predicted far-field differential horizontal movements have been determined from the empirical data using the fitted GPDs based on the 95 % confidence levels. In the cases where survey marks or survey bays were measured multiple times during a longwall extraction, the maximum opening, maximum closing and maximum horizontal mid-ordinate deviation were used in the analysis (i.e. single measurement per survey mark or survey bay).

A summary of the maximum incremental differential longitudinal movements and horizontal mid-ordinate deviation, based on the 95 % confidence levels for the fitted GPDs, is provided in Table 4.8. It is noted, that a large proportion of these measured movements comprise survey tolerance, which is around ±3 mm

Table 4.8 Maximum Observed Far-field Differential Horizontal Movements based on Monitoring Data from the Southern Coalfield

Distance from the Active Longwall (m)	Observed Differential Movement based on a 95 % Confidence Level		
	Maximum Incremental Longitudinal Opening over a 20 metre Bay Length (mm)	Maximum Incremental Longitudinal Closing over a 20 metre Bay Length (mm)	Maximum Incremental Horizontal Mid-Ordinate Deviation over a 40 metre Bay Length (mm)
200	9	7	10
600	6	6	9
1,200	4	4	6
1,800	3	3	3

The impact assessments for the larger infrastructure located outside the SMP Area, due to these far-field horizontal movements, are provided in Chapter 6.

4.7. Non-Conventional Ground Movements

There is a potential for non-conventional ground movements to occur within and around the SMP Area, due to near surface geological conditions, steep topography and valley related movements, which were discussed in Section 3.4. These non-conventional movements are often accompanied by elevated tilts, curvatures and strains, which are likely to exceed the conventional predictions.

Specific predictions of upsidence, closure and compressive strain due to the valley related movements are provided for the streams in Section 5.4. The impact assessments for the streams are based on both the conventional and valley related movements. The potential for non-conventional movements associated with steep topography is discussed in the impact assessments for the steep slopes provided in Section 5.7.

In most cases, it is not possible to predict the exact locations or magnitudes of the non-conventional anomalous movements due to near surface geological conditions. For this reason, the strain predictions provided in this report are based on a statistical analysis of measured strains in the Southern Coalfield, including both conventional and non-conventional anomalous strains, which is discussed in Section 4.5. In addition to this, the impact assessments for the natural and built features, which are provided in Chapters 5 and 6, include historical impacts resulting from previous longwall mining which have occurred as the result of both conventional and non-conventional subsidence movements.

Mining beneath urban and semi-rural areas at Tahmoor and Thirlmere by Longwalls 22 to 27 provides valuable “whole of panel” information. A plot of locations of potential non-conventional movement is shown in Fig. 4.17. The locations were selected based on ground monitoring results or observed impacts that appear to have been caused by non-conventional movement. A total of approximately 46 locations (not including valleys) have been identified over the five extracted longwalls. The surface area directly above the longwalls is approximately 5.2 km^2. This equates to a frequency of 9 sites per square kilometre or one site for every 11.3 hectares. The non-conventional movements were mainly characterised by elevated compressive ground strains that varied up to a maximum of approximately 5 mm/m.

The largest known case of non-conventional movement in the Southern Coalfield occurred above Appin Colliery Longwall 408 (Swarbrick *et al*, 2007). In this case, a low angle thrust fault was re-activated in response to mine subsidence movements, resulting in differential vertical and horizontal movements across the fault. Observations at the site showed that the non-conventional movements developed gradually and over a period of time. Regular ground monitoring across the fault indicated that the rate of differential movement was less than 0.5 mm/day at the time non-conventional movements could first be detected. Subsequently as mining progressed, the rate of differential movement increased to a maximum of 28 mm/week.

4.8. Mining Induced Ground Deformations

Longwall mining can result in surface cracking, heaving, buckling, humping and stepping at the surface. The extent and severity of these mining induced ground deformations are dependent on a number of factors, including the mine geometry, depth of cover, overburden geology, locations of natural jointing in the bedrock and the presence of near surface geological structures.

Faults and joints in bedrock develop during the formation of the strata and from subsequent distressing associated with movement of the strata. Longwall mining can result in additional fracturing in the bedrock, which tends to occur in the tensile zones, but fractures can also occur due to buckling of the surface beds in the compressive zones. The incidence of visible cracking at the surface is dependent on the pre-existing jointing patterns in the bedrock as well as the thickness and inherent plasticity of the soils that overlie the bedrock.

Cracking in the surface soils as the result of conventional subsidence movements, i.e. away from valleys and steep slopes, is not commonly observed at the higher depths of cover, i.e. greater than 400 metres, such as the case within the SMP Area. Surface cracking that has been observed as the result of conventional subsidence movements has generally been relatively isolated and of a minor nature.

Cracking is found more often in the bases of valleys due to the compressive strains associated with upsidence and closure movements, which is discussed in Section 5.4. Cracking can also occur at the tops or on the sides of steep slopes as the result of increased horizontal movements in the downslope direction, which is discussed in Section 5.7.

The locations of identified surface cracks and pavement impacts during the mining of Longwalls 22 to 25, as of May 2009, are shown in Fig. 4.18. In all cases, the cracks and humps in the pavement had not extended into the adjacent ground surface. It is expected that similar experiences will be observed during the mining of the proposed longwalls.

Fig. 4.17 Locations of Observed Non-Conventional Ground Movement above Longwalls 22 to 27

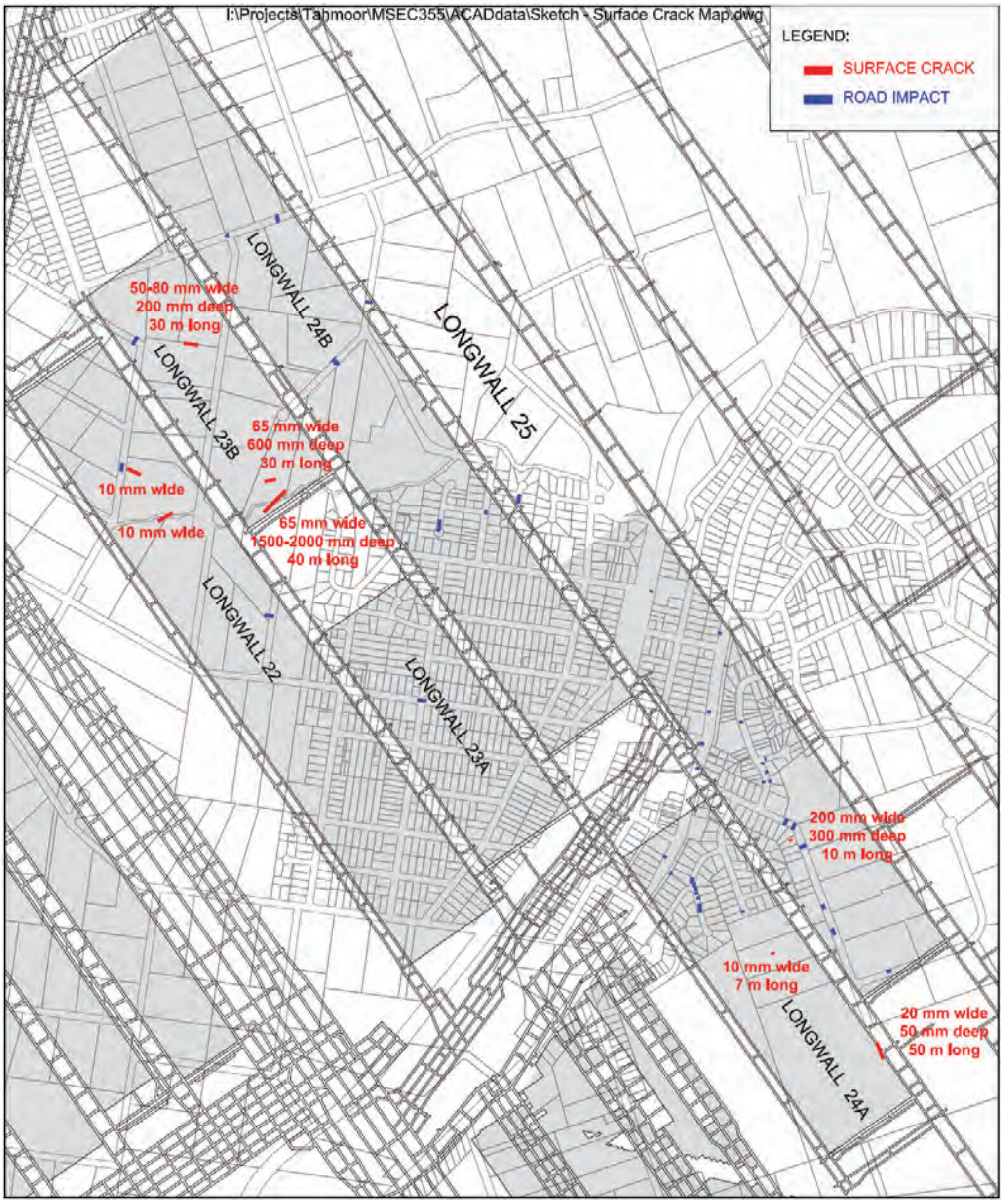


Fig. 4.18 Observed Surface Cracks and Pavement Impacts during mining of Longwalls 22 to 25

5.1. Introduction

The following sections provide the predicted subsidence parameters for the natural features located within the SMP Area. The predictions have been made using the Incremental Profile Method, which has been calibrated to local conditions using the extensive monitoring data at the Colliery, and is described in Sections 3.5 and 3.6.

Impact assessments have been made for each of these features based on the predicted subsidence parameters and based on the experience gained from the mining of previous longwalls at Tahmoor Colliery. All significant natural features located outside the SMP Area, which may be subjected to valley related or far-field horizontal movements and may be sensitive to these movements, have also been included as part of these assessments.

5.2. Catchment Areas and Declared Special Areas

There are no catchment areas or declared special areas within the SMP Area. The nearest catchment area is the Warragamba Special Area, and its closest point to the proposed longwalls is at Thirlmere Lakes National Park, which is located approximately 3.7 kilometres south-west of the proposed longwalls.

5.3. Rivers

There are no rivers within the SMP Area. The closest river is the Nepean River, which is located more than 1 kilometre from the proposed longwalls.

5.4. Streams

5.4.1. Descriptions of the Streams

The locations of the streams within the SMP Area are shown in Drawing No. MSEC647-09. There are two main ephemeral creeks that flow through the SMP Area and these are Redbank Creek and the Matthews, Cedar and Stonequarry Creek system. Water flows into the creeks are considerably restricted due to the retention of surface water by the many farm dams in the catchment.

The NSW Government's Strategic Review into the Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield (DoP, 2008) recommended that risk management zones (RMZs) be applied to all streams of 3rd order or above, in the Strahler stream classification. The stream orders, as mapped in the Strategic Review, are shown in Drawing No. MSEC647-09. A summary of the streams of 3rd order or above within the SMP Area is provided below in Table 5.1.

The report by *GeoTerra* (2014) provides a description of the streams with accompanying photographs.

Table 5.1 Major Streams within the SMP Area

Location	Strahler Stream Order within SMP Area	Description of Stream Location Relative to Proposed Longwalls
Redbank Creek	3rd to 4th Order	Located directly above previously extracted LWs 25 to 27, and future SMP approved LWs 28 to 30. Total length of approximately 2.3 kilometres within SMP Area, of which approximately 800 metres will be directly mined beneath by LWs 31 and 32.
Tributary 2 to Redbank Creek	1st to 3rd Order	Whole stream will be directly mined beneath by LW31. Total length of stream is approximately 1 kilometre.
Stonequarry Creek	4th to 5th Order	Total length of approximately 1.6 kilometres within SMP Area, of which approximately 600 metres will be directly mined beneath by LW33.
Cedar Creek	4th to 5th Order	Total length of approximately 1.5 kilometres within SMP Area, of which approximately 90 metres will be directly mined beneath by LW33.
Matthews Creek	3rd to 4th Order	Total length of approximately 1.6 kilometres within SMP Area, of which approximately 1,050 metres will be directly mined beneath by LW35 to LW37.
Tributary 1 to Matthews Creek	1st to 3rd Order	Total length of stream is approximately 1.5 kilometres and the whole length is within SMP Area. Approximately 130 metres of the 3rd order stream will be directly mined beneath by LW37.

The pools along the streams have flow controlling features along their alignments that include rockbars, boulders, tree roots and gravel. The locations of pools along these streams were determined by Geoterra and are shown in Drawing No. MSEC647-09.

Redbank Creek flows above the proposed Longwalls 31 to 32 in the southern portion of the SMP Area. The creek flows towards the north-east, where it joins Stonequarry Creek approximately 830 metres east of proposed Longwall 32, which then drains to the Nepean River. The creek falls approximately 30 metres over a total length of approximately 2,300 metres within the SMP Area, with an inferred average gradient of 13 mm/m (i.e. 1.3 %).

Redbank Creek flows over predominantly Hawkesbury Sandstone bedrock within the SMP Area. There are a number of channel constraints, including rockbars, boulders and rock shelves, which form standing pools along the alignment of the creek. Natural iron seepage flows into the creek, resulting in red colouration of the banks and pools. Example photographs of Redbank Creek are shown in Fig. 5.1 and Fig. 5.2.

Photograph courtesy GeoTerra (2014)

Fig. 5.1 Pool RR1 on Redbank Creek above Longwall 29 prior to Mining

Photograph courtesy GeoTerra (2014)

Fig. 5.2 Pool RR24 on Redbank Creek above chain pillar between Longwalls 31 and 32

Redbank Creek flows alongside Bridge Street for the majority of its length, draining a catchment comprising a mixture of rural, urban and industrial properties. The creek passes beneath the Main Southern Railway above Longwall 29, beneath a number of industrial properties above the proposed Longwalls 30 to 32, and beneath Remembrance Drive approximately 360 metres to the side of Longwall 32. A small concrete weir is located directly above proposed Longwall 31.

Tributary 2 to Redbank Creek is located directly above the proposed Longwall 31. The NSW Government's Strategic Review into the Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield (DoP, 2008) displayed the lower portion of this tributary as 3rd order due to the confluence of a network of small 1st order streams. As shown in Fig. 5.3, Tributary 2 flows through predominantly cleared grazing land, the lower 3rd order portion has been infilled by earthworks.

Photograph courtesy Pidgeon Civil Engineering (2012)

Fig. 5.3 Tributary 2 to Redbank Creek

Stonequarry Creek flows directly above the proposed Longwall 33 in the northern portion of the SMP Area. The catchment comprises mainly rural properties. The creek flows towards the south-east in the SMP area and joins with Matthews Creek, Cedar Creek and Redbank Creek before it drains to the Nepean River. The section of creek within the SMP Area falls approximately 13 metres over a total length of approximately 1,600 metres, with an inferred average gradient of 8 mm/m (i.e. 0.8 %).

Stonequarry Creek flows over predominantly Hawkesbury Sandstone bedrock within the SMP Area, though it can be seen that sediments are present on the banks of some pools. There are a number of channel constraints, including rockbars, boulders and rock shelves, which form standing pools along the alignment of the creek. Example photographs are shown in Fig. 5.4 and Fig. 5.5.

Photograph courtesy GeoTerra (2014)

Fig. 5.4 Pool SR7 on Stonequarry Creek north of Longwall 33

Photograph courtesy GeoTerra (2014)

Fig. 5.5 Pool SC2 on Stonequarry Creek above Longwall 33

Cedar Creek flows within 50 metres of the proposed Longwalls 34 and 35 in the northern portion of the SMP Area and directly above the proposed Longwall 33, where it joins Stonequarry Creek. The catchment comprises mainly rural properties. The creek flows towards the north-east in the SMP area. The section of creek within the SMP Area falls approximately 30 metres over a total length of approximately 1,500 metres, with an inferred average gradient of 20 mm/m (i.e. 2 %).

Cedar Creek flows over predominantly Hawkesbury Sandstone bedrock in the SMP Area, though it can be seen that sediments are present on the banks of some pools. There are a number of channel constraints, including rockbars, boulders and rock shelves, which form standing pools along the alignment of the creek. Example photographs are shown in Fig. 5.6 to Fig. 5.8.

Photograph courtesy GeoTerra (2014)

Fig. 5.6 Pool SR12 on Cedar Creek near confluence with Matthews Creek near Longwall 35

Photograph courtesy GeoTerra (2014)

Fig. 5.7 Pool CB25 on Cedar Creek approximately 200 metres from Longwall 34

Photograph courtesy GeoTerra (2014)

Fig. 5.8 Pool CR32 on Cedar Creek at confluence with Stonequarry Creek above Longwall 33

Matthews Creek flows above the proposed Longwalls 35 to 37 in the northern portion of the SMP Area. The catchment comprises mainly rural properties. The creek flows towards the north, where it joins Cedar Creek near the northern end of Longwall 35. The creek falls approximately 40 metres over a total length of approximately 1,600 metres within the SMP Area, with an inferred average gradient of 25 mm/m (i.e. 2.5 %).

Matthews Creek flows over predominantly Hawkesbury Sandstone bedrock within the SMP Area though it can be seen that sediments are present on the banks of some pools. There are a number of channel constraints, including rockbars, boulders and rock shelves, which form standing pools along the alignment of the creek. Example photographs are shown in Fig. 5.9 to Fig. 5.11.

A concrete weir is located approximately 320 metres to the side of proposed Longwall 37.

Photograph courtesy GeoTerra (2014)

Fig. 5.9 Pool MB23 on Matthews Creek above Longwall 37

Photograph courtesy GeoTerra (2014)

Fig. 5.10 Pool MR39 on Matthews Creek above Longwall 36

Photograph courtesy GeoTerra (2014)

Fig. 5.11 Rockbar MR45 on Matthews Creek above the Northern End of Longwall 35

Tributary 1 to Matthews Creek flows above the proposed Longwall 37 in the northern portion of the SMP Area. The creek flows towards the north, where it joins Matthews Creek above Longwall 37. A portion of the 1st order stream flows directly above Longwall 30 and a portion of the 3rd order stream flows directly above the proposed Longwall 37. The creek falls approximately 60 metres over a total length of approximately 1,500 metres within the SMP Area, with an inferred average gradient of 40 mm/m (i.e. 4 %).

The upper reaches of the tributary flow through cleared grazing land. It then crosses beneath Thirlmere Way and some houses on Stonequarry Road via a concrete pipe. The creek resurfaces after crossing beneath Stonequarry Road and flows beneath the Picton to Mittagong Loop Line, after which it drains to Matthews Creek.

The section of Matthews Creek classed as a 3rd order stream under the Strahler system begins upstream of the Picton to Mittagong Loop Line, a photograph of which is shown in Fig. 5.12. It can be seen that this section of creek flows over predominantly Hawkesbury Sandstone bedrock. The section of creek within the SMP Area is steeply incised with isolated vertical scarps above the proposed longwalls. There are a number of channel constraints, including rockbars, boulders and rock shelves, which form standing pools along the alignment of the creek.

Fig. 5.12 Tributary 1 to Matthews Creek upstream of Picton to Mittagong Loop Line approximately 60 metres to the side of Longwall 37

5.4.2. Predictions for the Streams

The streams, which are located directly above the proposed longwalls, could experience the full range of predicted subsidence movements. A summary of the maximum predicted conventional subsidence movements within the SMP Area is provided in Chapter 4.

The predicted profiles of subsidence, upsidence and closure along Redbank Creek, Tributary 2 to Redbank Creek, Stonequarry Creek, Cedar Creek, Matthews Creek and Tributary 1 to Matthews Creek are shown in Figs. E.03 to E.08, in Appendix E.

A summary of the maximum predicted values of total subsidence, upsidence and closure along these creeks, after the extraction of each of the proposed longwalls, is provided in Table 5.2. The predicted subsidence movements are the maximum values which occur along the stream, including the predicted movements resulting from the extraction of Longwalls 22 to 30. The predicted upsidence and closure movements are the maximum values which occur within the predicted limits of 20 mm additional upsidence and 20 mm additional closure, due to the extraction of Longwalls 31 to 37, but also include the predicted movements resulting from the extraction of Longwalls 22 to 30.

Table 5.2 Maximum Predicted Total Subsidence, Upsidence and Closure for the Creeks Resulting from the Extraction of Longwalls 22 to 37

Creek	Longwall	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Upsidence (mm)	Maximum Predicted Total Closure (mm)
Redbank Creek (maximum within SMP Area is almost the same as the maximum anywhere along Creek)	After LW30	1,250	500	500
	After LW31	1,250	525	575
	After LWs 32 to 37	1,250	575	625
Tributary 2 to Redbank Creek	After LW30	150	175	425
	After LW31	750	500	800
	After LWs 32 to 37	1050	650	1000
Stonequarry Creek	After LW32	< 20	< 20	< 20
	After LW33	475	150	90
	After LW34	650	250	125
	After LW35	675	300	150
	After LW36	675	300	175
	After LW37	675	300	175
Cedar Creek	After LW32	< 20	< 20	< 20
	After LW33	275	80	70
	After LW34	375	200	100
	After LW35	375	200	150
	After LW36	375	200	225
	After LW37	375	200	250
Matthews Creek	After LW33	< 20	< 20	< 20
	After LW34	40	40	60
	After LW35	100	125	150
	After LW36	650	275	250
	After LW37	800	425	325
Tributary 1 to Matthews Creek	After LW30	175	175	125
	After LW31	275	300	175
	After LWs 32 to 36	300	350	200
	After LW37	325	350	225

The profiles of the equivalent valley heights that were used to determine the predicted valley related upsidence and closure movements along the creeks are shown in Figs. E.03 to E.08. An equivalent valley height factor of 0.85 was adopted for these creeks, which was determined based on a review of observed and predicted valley related movements above the previously extracted longwalls at the colliery.

The range of non-valley related movement strains above the proposed longwalls is expected to be similar to the range of strains measured during the previously extracted longwalls in the Southern Coalfield, which is described in Section 4.5. It is also likely that the streams would experience elevated compressive strains as a result of valley closure movements.

The compressive strains resulting from valley related movements are more difficult to predict than conventional strains. It has been observed in the past, however, that compressive strains due to valley related movements between 10 mm/m and 20 mm/m (over a standard 20 metre bay length) have occurred above previously extracted longwalls at similar depths of cover, where the magnitudes of closure were similar to those predicted for the streams in the SMP Area.

There are also small tributaries located across the SMP Area which are expected to experience upsidence and closure movements, as well as localised and elevated compressive strains due to these valley related movements. The surface infrastructure which cross these tributaries are also expected to experience these valley related movements, which includes the direct buried telecommunications cables, pipelines and drainage culverts.

A summary of the maximum predicted upsidence and closure movements at the tributary crossings, resulting from the extraction of the proposed longwalls, is provided in Table 5.3. The maximum predicted compressive strains have also been provided in this table, which are based on a statistical analysis of strains measured across drainage lines within the Southern Coalfield which have effective valley heights less than 20 metres and survey bay lengths between 15 metres and 25 metres.

Table 5.3 Maximum Predicted Total Upsidence, Closure and Compressive Strain for the Tributary Crossings within the SMP Area

Location	Maximum Predicted Total Upsidence (mm)	Maximum Predicted Total Closure (mm)	Maximum Predicted Compressive Strain (mm/m)		
			60 % Confidence Level	90 % Confidence Level	95 % Confidence Level
Crossings Located Directly above the Proposed Longwalls	300	350	2.0	5.5	7.5
Crossing Located Outside but within 200 metres of the Extents of the Proposed Longwalls	100	100	< 0.5	1.5	2.5
Crossing Located more than 200 metres from the Extents of the Proposed Longwalls	< 50	< 50	< 0.5	0.8	1.5

5.4.3. Predicted Changes in Stream Gradients

The natural surface levels and grades and the predicted post mining surface levels and grades along Redbank Creek and Matthews, Cedar and Stonequarry Creeks are illustrated in Fig. 5.13 and Fig. 5.14.

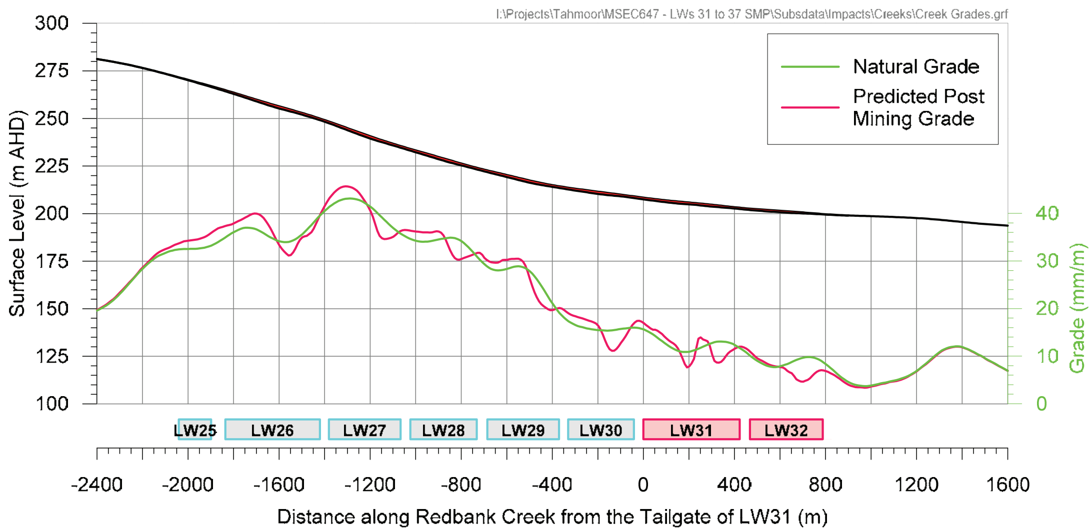


Fig. 5.13 Natural and Predicted Post-Mining Levels and Grades along Redbank Creek

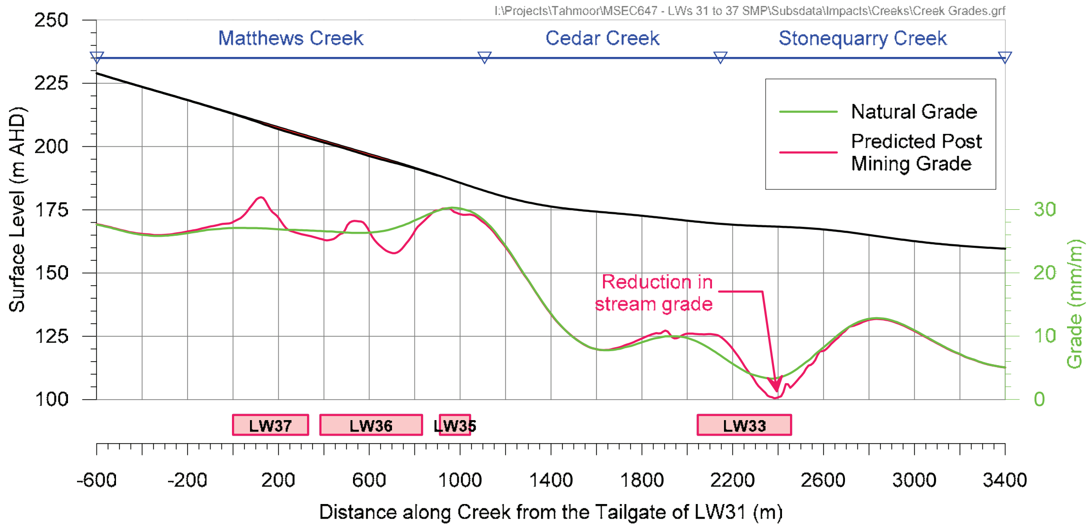


Fig. 5.14 Natural and Predicted Post-Mining Levels and Grades along Stonequarry, Cedar and Matthews Creeks

A summary of the maximum predicted total conventional tilt and curvature along the alignments of the creeks, after the extraction of each of the proposed longwalls, is provided in Table 5.4. The maximum predicted increases in grades occur downstream of the longwall goaf edges, whilst the maximum predicted decreases in grade occur upstream of the longwall goaf edges.

Table 5.4 Maximum Predicted Total Conventional Tilt and Curvature along the Alignments of the Creeks Resulting from the Extraction of Longwalls 22 to 37

Creek	Longwall	Maximum Predicted Total Conventional Tilt (mm/m)		Maximum Predicted Total Conventional Curvature (km^{-1})	
		Increase in Grade	Decrease in Grade	Hogging	Sagging
Redbank Creek (maximum within SMP Area is almost the same as the maximum anywhere along Creek)	After LW30	3.5	6.0	0.09	0.15
	After LW31	3.5	5.5	0.09	0.15
	After LWs 32 to 37	3.0	5.0	0.09	0.15
Tributary 2 to Redbank Creek	After LW30	< 0.5	1.0	< 0.01	< 0.01
	After LW31	1.0	4.5	0.06	0.06
	After LWs 32 to 37	1.0	3.5	0.11	0.11
Stonequarry Creek	After LW32	< 0.5	< 0.5	< 0.01	< 0.01
	After LW33	2.0	2.5	0.03	0.06
	After LW34	3.0	3.0	0.03	0.06
	After LW35	3.0	3.0	0.03	0.06
	After LW36	3.0	3.0	0.03	0.06
	After LW37	3.0	3.0	0.03	0.06
Cedar Creek	After LW32	< 0.5	< 0.5	< 0.01	< 0.01
	After LW33	2.0	< 0.5	0.02	< 0.01
	After LW34	3.0	< 0.5	0.03	< 0.01
	After LW35	3.0	< 0.5	0.03	< 0.01
	After LW36	3.0	< 0.5	0.03	< 0.01
	After LW37	3.0	< 0.5	0.03	< 0.01

Creek	Longwall	Maximum Predicted Total Conventional Tilt (mm/m)		Maximum Predicted Total Conventional Curvature (km^{-1})	
		Increase in Grade	Decrease in Grade	Hogging	Sagging
Matthews Creek	After LW33	< 0.5	< 0.5	< 0.01	< 0.01
	After LW34	< 0.5	< 0.5	< 0.01	< 0.01
	After LW35	< 0.5	1.0	0.01	< 0.01
	After LW36	3.5	4.0	0.06	0.10
	After LW37	5.0	4.0	0.07	0.12
Tributary 1 to Matthews Creek	After LW30	< 0.5	1.0	0.03	0.01
	After LW31	< 0.5	2.0	0.04	0.01
	After LWs 32 to 36	< 0.5	2.0	0.04	0.01
	After LW37	2.0	2.0	0.06	0.01

The maximum predicted conventional curvatures for the streams located directly above the approved and the proposed longwalls are 0.11 km^{-1} hogging and 0.15 km^{-1} sagging, which equate to minimum radii of curvature of 9 kilometres and 7 kilometres, respectively. These maxima occur outside the SMP Area (i.e. above the existing longwalls) and, therefore, are greater than the maxima within the SMP Area which are summarised in Table 4.2.

5.4.4. Impact Assessments for the Streams

The impact assessments for the streams within the SMP Area are provided in the following sections. The assessments provided in this report should be read in conjunction with reports by *GeoTerra* (2014) and *Niche* (2014a and 2014b), which assess the consequences of the impacts on surface water flows and ecology.

Potential for Increased Levels of Ponding, Scouring or Desiccation due to Mining Induced Tilt

Mining can potentially result in increased levels of ponding in locations where the mining induced tilts oppose and are greater than the natural stream gradients that exist before mining. Mining can also potentially result in an increased likelihood of scouring of the stream beds in the locations where the mining induced tilts considerably increase the natural stream gradients that exist before mining.

It can be seen from Fig. 5.13 that Redbank Creek is unlikely to experience a reversal of grade, as the natural grades are sufficiently large in comparison with the mining induced tilts. A reduction in grade is predicted to occur upstream of the maingate of Longwall 32 and this may result in localised ponding in this location.

It can be seen from Fig. 5.14 that the natural grade of Stonequarry Creek is predicted to reduce to an almost flat grade in one location upstream of the tailgate of Longwall 33. Hence there is increased potential for ponding in this location. Elsewhere, there are no predicted reversals of grade due to the proposed mining.

It is possible that there could be localised areas along the streams which could experience small increases in the levels of ponding, where the predicted maximum tilts occur in the locations where the natural gradients are low. As the predicted changes in grade are less than 1 %, however, any localised changes in ponding are expected to be minor and not result in adverse impacts on these streams.

It can also be seen from the above figures that the stream gradients increase where they flow into the predicted subsidence trough near the edges of the proposed longwalls. The streams flow predominantly over Hawkesbury Sandstone, which has a high resilience to scouring. The predicted maximum increases in grade are less than 1 %, which are relatively small compared to the natural gradients and, therefore, the potential for increased scouring is not expected to be substantial.

Further discussions on the potential changes in ponding and flooding along the streams and the impacts, consequences and implications of the changes are provided in the report by *GeoTerra* (2014).

Potential for Fracturing and Surface Water Flow Diversion in the Streams

Where the longwalls mine directly beneath the streams it is considered likely that fracturing could result in surface water flow diversions. Upsidence and compressive strains due to valley closure are expected to be of sufficient magnitude to cause the underlying strata to dilate, buckle and induce fracturing at the surface at some locations along the stream alignments. This can lead to the diversion of surface water flows from the stream into the dilated strata beneath it.

It has been observed in the past, that the depth of buckling and dilation of the uppermost bedrock, resulting from longwall mining, is generally less than 10 metres to 15 metres (Mills 2003, Mills 2007, and Mills and Huuskes 2004). It is unlikely, therefore, that there would be any net loss of water from the catchment since the redirected flow would not intercept any flow path that would allow the water to be diverted into deeper strata or the mine.

If substantial fracturing were to occur, partial or complete diversion of surface water and drainage of pools could occur at locations and times where the rate of flow diversion is greater than the rate of incoming surface water. The majority of the streams are ephemeral and so water typically flows during and for a period of time after each rain event, but long standing pools are maintained along the streams. In times of heavy rainfall, the majority of the runoff would flow over the beds of the streams and would not be completely diverted into the dilated strata below the stream beds. In times of low flow or prolonged periods of dry weather, however, some or all of the water could be diverted into the strata below the stream beds for those sections of the streams that are located over the mined panels.

While much of the channel beds are exposed bedrock, sediments were also commonly found in the creek beds throughout the SMP Area. Where such loose materials occur, it is possible that fracturing in the bedrock would not be seen at the surface. In the event that fracturing of the bedrock occurs in these locations within the alignments of the streams, the fractures may be filled with sediment during subsequent flow events reducing the flow through the fractures.

Tahmoor Colliery has previously extracted longwalls beneath streams and their ability to naturally fill mining-induced fractures has varied, mainly depending on the availability of sediment.

- Longwalls 1 and 2 were mined in 1987 directly beneath a 500 metre section of Teatree Hollow immediately downstream of the proposed longwalls. Bord and pillar workings with secondary extraction also took place prior to longwall mining directly beneath this stream.

  Substantial fracturing was observed by Tahmoor Colliery at one location in a small tributary to Teatree Hollow directly above the bord and pillar workings with secondary extraction. It is likely that this fracturing was mining-induced.

  No flow diversions were reported at this location, nor in other sections of Teatree Hollow located directly above Longwalls 1 and 2. Water flows in the section of Teatree Hollow, which is located above the previously extracted longwalls and secondary extraction workings, were greatly controlled by Tahmoor Colliery's licensed stormwater discharge point LDP4 and this has likely aided in filling the mining-induced fractures.

- Longwalls 8, 10 to 13 were mined between 1991 and 1994 directly beneath a 2 kilometre section of the Bargo River and directly beneath a 1 kilometre section of Dog Trap Creek.

  These were the first series of longwalls to be mined directly beneath the Bargo River at Tahmoor Colliery. Very little monitoring of the river occurred during this time, although extensive protective works were undertaken at the Rockford Road Bridge that was located over Longwall 12.

  Surface fracturing of exposed bedrock was observed near and upstream of the supporting piers of the Bridge following the extraction of Longwalls 12 and 13. Fractures were also observed in and around flute holes downstream of the bridge over the goaf edge of Longwall 13, which were first observed during the extraction of Longwall 12 (Holla and Barclay, 2000). The fractures were localised and did not consistently run along the length of the river valley. They appeared to be the result of localised shearing and compressive buckling and some fractures were located where there was noticeable cross bedding within the river bed. There were no reports of impact to water flows along this section of river.

  While surface fracturing is still visible in the flute holes that are located on a large, exposed rockbar, surface water diversion is not evident and large pools exist directly above the previously extracted longwalls, as Tahmoor Colliery's licensed discharge has contributed to the base flow to this section of the Bargo River.

Fig. 5.15 Large pool in the Bargo River, located upstream of Rockford Road Bridge, directly above previously extracted Longwall 12, ten years after mining

Very little monitoring of Dog Trap Creek occurred when Longwalls 12 and 13 mined directly beneath it, although extensive monitoring and works were undertaken at the small road bridge over Dog Trap Creek on Arina Road. No surface fractures are visible in the stream at the location, however, and pools are observed to exist. It is noted that this section of Dog Trap Creek contains plenty of sediment that could assist in the filling of fractures.

Fig. 5.16 Ponded water in Dog Trap Creek near Bridge over Arina Road above previously extracted Longwall 13, ten years after mining

- Longwalls 14 to 19 were mined between 1995 and 2002 directly beneath a 1.7 kilometre section of the Bargo River.

  Limited monitoring indicated little impact on the River during the extraction of Longwalls 14 to 17. Fracturing was not observed on the surface, although many sections were concealed by alluvial and talus deposits.

The first adverse impacts on the river were reported in January 2002, after the extraction of Longwall 18, when residents alerted Tahmoor Colliery to reduced pool levels downstream of the mining area. Due to low rainfalls, there was very little water in the Picton Weir at that time and surface flows from the weir were reduced to a mere trickle during this time. Inspections of the river indicated minor fracturing of rock shelves in the river bed and drainage of some shallow pools. The river was drained directly above Longwall 18 and the length of drainage extended for some distance beyond Longwall 14. Detailed subsidence monitoring of survey pegs within the Bargo River over the centre of Longwall 18 indicated that total upsidence was 250 mm, the total valley closure was approximately 400 mm and the maximum measured valley closure strain was 18 mm/m.

Shortly after this time a large rainfall event occurred, which filled the Weir and restored surface water flows along the river. However, by July 2002 the Picton Weir was empty and surface flows had ceased again, with the furthest drained pool from the longwalls being located 125 metres upstream of Longwall 19. This coincided with the completion of this longwall.

A further period of heavy rainfall occurred in February 2003 which filled the upstream Picton Weir which then overtopped. It was then observed that the surface water flows above the longwalls were progressively restored. It is believed that the high sediment load in the river, retained by the Picton Weir except when it is overtopped, had filled the fractures in the bedrock reducing the redirection of surface water flows.

The extraction of Longwalls 14 to 19 also mined directly beneath small tributaries to the Bargo River. Fracturing and surface flow diversions were observed in two unnamed tributaries, which are located above previously extracted Longwalls 15 and 19. The stream channel bed in this case was exposed bedrock.

- Longwalls 22 to 27 have mined, since 2004, beneath a 2.6 kilometre section of Myrtle Creek.

  The impacts observed along this creek were localised bed cracking in exposed sandstone areas, surface flow diversions in four locations over Longwalls 22, 23B and 25 as well as cracking in soil within the upper banks and flanks over Longwall 23B. Three areas of isolated cracking of exposed sandstone were also observed in the base or sides of generally dry pools above Longwall 25.

  The extraction of Longwalls 26 and 27 has resulted in further mining-induced fractures on exposed bedrock. At times of low flow, pools have been observed to drain. The sub-surface flow diversion was observed to re-emerge downstream of Longwall 27.

- Longwalls 25 to 27 have mined, since 2008, beneath a 0.97 kilometre section of Redbank Creek.

  The impacts observed along the creek were pool desiccation in two locations along a clay incised section of the creek above Longwall 25, fracturing in exposed sandstone bedrock above Longwall 26 (with no obvious effect on pool holding capacity), and sandstone rock bar cracking with reduced flow over the rockbars in two locations downstream of Longwall 26, (although no observed effect on the holding capacities of the downstream pools). Stream bed cracking and loss of pool holding capacity has been observed in numerous pools and stream reaches in both creeks over Longwalls 25 to 27. The sub-surface flow diversion was observed to re-emerge downstream of Longwall 27.

Based on the previous experience of mining beneath streams at Tahmoor Colliery, it is likely that fracturing and surface flow diversions will occur in the sandstone bedrock along the streams, particularly for streams that are located directly above the proposed longwalls. In some of these locations, the fracturing could impact the holding capacity of the standing pools, particularly those located directly above the proposed longwalls. It is unlikely, however, that there would be any net loss of water from the catchment.

Where there are substantial sediment accumulations upstream of these areas, it is expected that some of the fractures would be naturally filled over time with sediment during subsequent flow events, as was observed in the Bargo River and Dog Trap Creek. Where little sediment is present, the impacts are likely to remain for longer periods of time and remediation may be required after the completion of mining, which could include sealing these fractures and voids with grout.

With respect to streams or sections of streams located away from the proposed longwalls, the likelihood of fracturing and surface flow diversions reduces substantially compared to stream sections located directly above the proposed longwalls. One of the furthest known rockbar impact sites where fracturing resulted in the diversion of surface water was at Pool F in the Waratah Rivulet that was being affected by a previously extracted longwall on one side and by the end of another longwall, i.e. the rockbar was located over solid unmined coal, but it was located in the corner between two longwalls. This site was located 160 metres to the side of one longwall and 230 metres from the approaching face of the active longwall. Surface water diversions have also been observed at three sites from the sides of longwalls at distances between 125 metres and 100 metres at the Bargo River, Waratah Rivulet and Native Dog Creek. Surface water diversion has only been observed at one site at Pool G1 in the Waratah Rivulet beyond the ends of the longwalls and in this case the closest distance was approximately 75 metres.

Monitoring of pools in Myrtle Creek and Redbank Creek by *GeoTerra* (2014) during times of low flow has found reductions in pool water levels for distances up to approximately one panel width away from the extracted longwalls. The furthest observed fracturing and loss of water was in a pool in Redbank Creek that was located approximately 300 metres to the side of Longwall 26 after the extraction of this longwall (GeoTerra, 2014). Fracturing and loss of water was also observed in a pool in Myrtle Creek that was located approximately 250 metres to the side of Longwall 26 after the extraction of this longwall (GeoTerra, 2014). In both cases, the streams are flowing over sandstone bedrock.

Minor and isolated fracturing could also occur outside the extents of the proposed longwalls. The furthest distance of an observed fracture from longwall mining was at the base of Broughtons Pass Weir, which was located approximately 415 metres from Appin Colliery Longwall 401. Another minor fracture was also recorded in the upper Cataract River, approximately 375 metres from Appin Colliery Longwall 301. This fracture occurred in a large rockbar, which was formed in thinly bedded sandstone, which had experienced movements from nearby previously extracted longwalls. These are the furthest most recorded fractures from longwall mining in the NSW Coalfields.

Further discussions on the potential impacts of surface cracking and on changes in surface water flows are provided in the reports by *GeoTerra* (2014) and *Niche* (2014a and 2014b).

Potential for Gas Emissions and Changes to Water Quality

Gas emissions from the sandstone strata have been previously observed above and adjacent to mining areas in the Southern Coalfield, although never at Tahmoor Colliery, and some gas emissions have also been observed in water bores. Analyses of gas compositions indicate that the Bulli seam is not the direct and major source of the gas and that the most likely source is the Hawkesbury Sandstone (APCRC, 1997).

All recorded examples of gas emissions have occurred in collieries located to the east and to the north-east of Tahmoor Colliery. No gas emissions or consequential changes in water quality have been reported over Tahmoor Colliery in the Bargo River, Redbank Creek or Myrtle Creek.

It is unlikely that gas emissions will occur as a result of the mining of the longwalls at Tahmoor Colliery. Gas is often released into rivers and streams as these areas form topographical low points in the landscape. Where these gas releases occur into the water column there is insufficient time for any substantial amount of gas to dissolve into the water. The majority of the gas is released into the atmosphere and is unlikely to have an adverse impact on water quality.

It is possible for substantial gas emissions at the surface to cause localised vegetation die-back. This is a rare event and has only been observed to occur previously on one occasion at Tower Colliery, over small areas in the base of the Cataract Gorge that had been directly mined beneath by Longwalls 10 and 14. These impacts were limited to small areas of vegetation, local to the points of emission, and when the gas emissions declined, the affected areas were successfully restored.

Descriptions of potential water quality impacts, including iron stains, and environmental consequences are presented in the surface water and ecology reports by *GeoTerra* (2014) and *Niche* (2014a and 2014b).

5.4.5. Impact Assessments for the Creeks Based on Increased Predictions

The impact assessments due to predicted mining tilts indicate that reversal of grade is very unlikely given that the predicted tilts are substantially less than natural grades. An exception may apply in a localised section on Stonequarry Creek above the downstream edge of Longwall 32, where a reversal of grade could occur over a short length of stream, resulting in increased ponding.

The impact assessments for fracturing and flow diversion are mainly based on historical experience of impacts on streams in the Southern Coalfield (including at Tahmoor Colliery) rather than directly on the magnitude of predicted subsidence movements. It is, however, reasonable to expect a greater probability of impact for the creeks if the predicted upsidence and closure movements were increased.

5.4.6. Management of Potential Impacts to Streams

Tahmoor Colliery has developed a subsidence management plan for managing the potential impacts to streams during the mining of Longwalls 22 to 30. The management plan includes ground monitoring, water quality and pool level monitoring and visual inspections. The plan also commits to remediation of aquatic ecosystems if impacts occur.

It is recommended that Tahmoor Colliery continue to develop management plans to manage potential impacts on the streams during the mining of the proposed longwalls.

5.5. Aquifers and Known Groundwater Resources and Seeps

The potential for adverse impacts on groundwater and seeps as a result of mine subsidence is provided in a report by *GeoTerra* (2014).

GeoTerra advise that it is possible that groundwater seepage may discharge in the streams in addition to the non-mining induced springs observed in Redbank Creek, Matthews Creek and Cedar Creek. If an adverse change in stream water quality occurs through development of an isolated new, or change to an existing, ferruginous spring occurs, it is anticipated that due to the ephemeral nature of the streams and the generally low flow volumes in the creeks, the effect will be localised around the point of discharge and will not adversely affect the overall water quality discharging out of the SMP Area.

In relation to aquifer / aquitard interconnection, GeoTerra advise that, from past experience in NSW Coalfields, it has been assessed that hydraulic connection of surface water or alluvial groundwater systems is not likely at mining depths of cover greater than 150 metres.

A temporary lowering of the regional piezometric surface over the subsidence area due to horizontal dilation of strata may occur due to the increase in secondary porosity and permeability. This effect will be more notable directly over the area of greatest subsidence and dilation, and will dissipate laterally out to the edge of the subsidence zone.

Based on similar observations within the Longwall 22 to 28 mining area and similar observations in other areas in the Southern Coalfield, GeoTerra advise that groundwater levels may reduce by up to 15 metres, and may stay at that reduced level until maximum subsidence develops at a specific location. The duration of the reduced levels depends on the time required to develop maximum subsidence, the time for subsidence effects to migrate away from a location as mining advances to subsequent panels, and the length of time required to recharge the secondary voids.

On the basis that the pre-mining circumstances of rainfall recharge and bore pumping remain the same, and based on observation of groundwater levels over Longwalls 22 to 28, it is anticipated that groundwater levels generally recover over a few months to a year or so as the secondary void space is recharged by rainfall infiltration.

5.6. Cliffs and Rock Outcrops

5.6.1. Descriptions of Cliffs and Rock Outcrops

For the purposes of this report, a cliff has been defined as a *"Continuous rock face, including overhangs, having a minimum length of 20 metres, a minimum height of 10 metres and a minimum slope of 2 to 1 (>63.4°)"*, as per the definition of cliffs provided in the NSW Department of Planning and Environment Standard and Model Conditions for Underground Mining (DoPE, 2012).

The locations of the cliffs are shown in Drawing Nos. MSEC647-11 and MSEC647-12, which have been identified using the 1 metre surface level contours generated from a Light Detection and Ranging (LiDAR) survey, an orthophotograph of the area, and from site investigations.

A total of 11 cliffs have been identified within the SMP Area, of which two are located directly above Longwall 35. There are cliffs located along Cedar Creek (Refs. C_C01 to C_C09) to the north of the proposed Longwalls 35 to 37; and along Matthews Creek (Refs. C_M01 and C_M02) above the proposed Longwall 35 and to the north and west of the proposed Longwalls 36 and 37.

The details of the cliffs identified within the SMP Area are provided in Table 5.5.

Table 5.5 Details of the Cliffs within the SMP Area

Stream	Cliff Ref.	Maximum Height (m)	Overall Length (m)
Cedar Creek	C_C01	13	57
	C_C02	16	33
	C_C03	11	35
	C_C04	15	73
	C_C05	11	24
	C_C06	12	49
	C_C07	11	24
	C_C08	12	29
	C_C09	12	55
Matthews Creek	C_M01	10	21
	C_M02	10	23

Rock outcrops have been defined in this report as any surface with a slope steeper than 2 to 1 (i.e. > 63.4º), irrespective of its length or height. The locations of the rock outcrops are also shown in Drawing Nos. MSEC647-11 and MSEC647-12.

A number of rock outcrops have been identified within the SMP Area, of which five are located directly above the proposed longwalls. The rock outcrops are located along Matthews Creek and Cedar Creek. There is also one rock outcrop identified within the SMP Area above Longwall 29 at Redbank Creek.

Photographs of some of the cliffs and rock outcrops located within the SMP Area are shown in Fig. 5.17 to Fig. 5.19 (Source: GeoTerra, 20414).

Fig. 5.17 Cliffs along Matthews Creek (Source: GeoTerra, 2014)

Fig. 5.18 Overhang along Matthews Creek (Source: GeoTerra, 2014)

Fig. 5.19 Overhang along Cedar Creek (Source: GeoTerra, 2014)

The identified cliffs and rock outcrops have predominantly developed in the Hawkesbury Sandstone group. The exposed rock faces demonstrate various stages of weathering or erosion, with many overhangs and undercuts. The cliffs are categorised as an area of environmental sensitivity for the purposes of the SMP approval process.

5.6.2. Predictions for the Cliffs and Rock Outcrops

The predicted profiles of incremental and total conventional subsidence along Cedar Creek and Matthews Creek, resulting from the extraction of the proposed longwalls, are shown in Figs. E.06 and E07 in Appendix E. A summary of the maximum predicted values of total conventional subsidence, tilt and curvature at the cliffs, resulting from the proposed mining, is provided in Table 5.6. The predicted tilts and curvatures are the maxima in any direction during or after the extraction of each of the proposed longwalls.

Table 5.6 Maximum Predicted Total Conventional Subsidence Parameters for the Cliffs Resulting from the Extraction of the Proposed Longwalls

Cliff Ref.	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Total Conventional Tilt (mm/m)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
C_C01	20	< 0.5	< 0.01	< 0.01
C_C02	20	< 0.5	< 0.01	< 0.01
C_C03	70	< 0.5	< 0.01	< 0.01
C_C04	50	< 0.5	< 0.01	< 0.01
C_C05	70	< 0.5	< 0.01	< 0.01
C_C06	80	0.5	< 0.01	< 0.01
C_C07	30	< 0.5	< 0.01	< 0.01
C_C08	30	< 0.5	< 0.01	< 0.01
C_C09	20	< 0.5	< 0.01	< 0.01
C_M01	175	2	0.02	< 0.01
C_M02	125	1	0.01	< 0.01

The cliffs along Cedar Creek are located outside the extents of the proposed longwalls. These cliffs are predicted to experience strains less than 0.5 mm/m tensile and compressive. The cliffs along Matthews Creek are partially located above the proposed Longwall 35 and, therefore, the predicted strains for these cliffs have been based on the statistical analysis of strains provided in Section 4.5.

The cliffs along Matthews Creek are at more discrete locations and, therefore, the most relevant distributions of strain are the maximum strains measured in individual survey bays above previous longwall mining, which are summarised in Section 4.5.1. These cliffs could experience both tensile and compressive strains, but due to their location near the longwall commencing end, are expected to be in a net tensile zone after the completion of mining.

The rock outcrops are located across the SMP Area and, therefore, are expected to experience the full range of predicted mine subsidence movements. The maximum predicted subsidence parameters resulting from the extraction of the proposed longwalls are provided in Chapter 4.

5.6.3. Impact Assessments for the Cliffs and Rock Outcrops

Cliffs and rock outcrops located directly above the longwalls

Given that the proposed longwalls will mine directly beneath and adjacent to cliffs C_M01 and C_M02 near the confluence of Cedar and Matthews Creeks, it is possible that rock falls could occur in this location. Studies of mining directly beneath cliffs located along the Nepean, Cataract and Bargo Rivers, suggests that the extent of impact is between 2 % and 5 % of the cliff line located directly above the extracted longwalls.

The extraction of the proposed longwalls is likely to result in some fracturing of the rock outcrops and, where the rock is marginally stable, could then result in instabilities. Previous experience in the Southern Coalfield indicates that the percentage of rock outcrops that are likely to be impacted by mining is very small. The potential for isolated rock falls, however, could result in a public safety risk where there is access beneath or above the rock outcrops located above the proposed longwalls.

Cliffs and rock outcrops not located directly above the longwalls

The remainder of the cliffs and rock outcrops within the SMP Area are located outside the extents of the proposed longwalls. The likelihood of cliff instabilities within the SMP Area can be assessed using case studies where previous longwall mining has occurred close to but not directly beneath cliffs, though it is noted that the cliffs and rock outcrops in the SMP Area are substantially smaller in height than those mentioned in the case studies below.

The case studies show that, although very minor rock falls have been observed over solid coal outside the extracted goaf areas of longwall mining in the Southern Coalfield, there have been no recorded large cliff instabilities outside the extracted goaf areas of longwall mining in the Southern Coalfield. This statement is based on the following observations:-

- *Appin Longwalls 301 and 302 near the Cataract River*

  Appin Longwalls 301 and 302 mined adjacent to a number of cliff lines located along the Cataract River valley. A total of 68 cliffs were identified within a 35 degree angle of draw from the longwalls. The cliffs had continuous lengths ranging between 5 metres and 230 metres, overall heights ranging between 10 metres and 37 metres and had been formed within the Hawkesbury Sandstone.

  Appin Longwalls 301 and 302 have void widths of 260 metres, solid chain pillar widths of 40 metres and were extracted from the Bulli Seam at a depth of cover of 500 metres. These longwalls mined to within 50 metres of the identified locations of the cliffs along the Cataract River valley.

  There were no large cliff instabilities observed as a result of the extraction of Appin Longwalls 301 and 302. There were, however, five minor rock falls or disturbances which occurred during the mining period, of which, three were considered likely to have occurred due to a significant rainfall event and natural instability of the cliff overhang. The length of cliff line disturbed as a result of the extraction of Appin Longwalls 301 and 302 was, therefore, estimated to be less than 0.5 % of the total face area of the cliff lines within the mining domain.

- *Tower Longwalls 18 to 20 and Appin Longwalls 701 to 703 near the Nepean River*

  Tower Longwalls 18 to 20 and Appin Longwalls 701 to 703 mined adjacent to a number of cliff lines located along the Nepean River valley. A total of around 50 cliffs were identified within a 35 degree angle of draw from these longwalls. The cliffs had continuous lengths ranging between 5 metres and 225 metres, overall heights ranging between 10 metres and 40 metres and had been formed within the Hawkesbury Sandstone.

  Tower Longwalls 18 to 20 have void widths of 235 metres, solid chain pillar widths of 40 metres and were extracted from the Bulli Seam at a depth of cover of 500 metres. Appin Longwalls 701 to 703 have void widths of 320 metres, solid chain pillar widths of 40 metres and were extracted from the Bulli Seam at a depth of cover of 500 metres.

  Tower Longwall 20 mined directly beneath some cliffs located at the confluence of Elladale Creek and the Nepean River. Appin Longwalls 701 to 703 mined to within 75 metres of the identified locations of the cliffs along the Nepean River valley.

  There were no cliff instabilities observed as a result of the extraction of Tower Longwalls 18 to 20 and Appin Longwalls 701 to 703.

Based on the previous experience of mining at Appin and Tower Collieries, it is possible that isolated rock falls could occur as a result of the extraction of the proposed longwalls for the cliffs and rock outcrops within the SMP Area that are not directly above the proposed longwalls.

While the risk of large cliff instabilities is extremely low, some risk remains and attention must therefore be paid to any structures or roads that are located in the vicinity of the cliffs. The following sections provide discussions on the risks associated with the cliffs which are located in the vicinity of the proposed longwalls.

The cliffs are located on privately owned land that is thick with vegetation. The likelihood that a person or persons would be present if and when a rock fall occurred is considered to be extremely low. It is recommended, however, that management strategies are developed with the land owners to minimise the potential risks resulting from rock falls.

Tahmoor Colliery has developed a subsidence management plan for managing the potential impacts to natural features during the mining of Longwalls 22 to 30. It is recommended that Tahmoor Colliery include measures to manage the potential consequences of rock falls at the cliffs and rock outcrops during the proposed mining. This would include consultation with the landowner and visual inspections before and after the completion of each longwall.

5.6.4. Impact Assessments for the Cliffs and Rock Outcrops Based on Increased Predictions

If the actual tilts exceeded those predicted by a factor of 2 times, the maximum tilt at the cliffs would be 4.0 mm/m (i.e. 0.4 %), or a change in grade of 1 in 250. The tilts at the cliffs would still be extremely small in comparison with the existing slopes of the rockfaces, which exceed 2 in 1. In addition to this, tilt does not directly induce differential movements along cliffs, which is the main cause of cliff instabilities and, therefore, the potential for impacts would not be expected to significantly increase.

If the actual curvatures exceeded those predicted by a factor of 2 times, the maximum curvature at the cliffs would be around 0.04 km^{-1}, which represents a minimum radius of curvature of 25 kilometres. The curvatures at the cliffs would still be small and, therefore, the likelihood of cliff instabilities would not be expected to increase significantly.

While the predicted ground movements are important parameters when assessing the potential impacts on the cliffs, it is noted that the impact assessments for cliff instabilities have primarily been based on historical observations from previous longwall mining in the Southern Coalfield. The overall levels of impact on the cliffs, resulting from the extraction of the proposed longwalls, are expected to be similar to those observed where longwalls have previously mined close to but not directly beneath the cliffs in the Southern Coalfield, as the majority of the cliffs are located outside the extents of the proposed longwalls.

In any case, the levels of impact on the cliffs within the SMP Area are expected to be much less than those observed where previous longwall mining has occurred directly beneath cliffs in the Southern Coalfield. An example of this is Tower Longwalls 1 to 17, which were mined beneath approximately 5 kilometres of cliffline within the Cataract River and Nepean River valleys. There were a total of 10 cliff instabilities recorded along these valleys which represents approximately 4 % of the total length of the clifflines directly mined beneath.

If the actual subsidence movements exceeded those predicted by a factor of 2 times, the extent of fracturing and, hence, the incidence of impacts would increase for the rock outcrops located directly above the proposed longwalls. Based on the previous experience of mining beneath rock outcrops in the NSW Coalfields, it would still be expected that the incidence of impacts on the rock outcrops in the SMP Area would still be small if the actual movements exceeded those predicted by a factor of 2 times.

5.7. Steep Slopes

5.7.1. Description of Steep Slopes

For the purposes of this report, a steep slope has been defined as "*An area of land having a gradient between 1 in 3 (33% or 18.3º) and 2 in 1 (200% or 63.4º)*", as per the definition of steep slopes provided in the NSW Department of Planning and Environment Standard and Model Conditions for Underground Mining (DoPE, 2012).

The maximum slope of 2 to 1 represents the threshold adopted for defining a cliff or rock outcrop. The minimum slope of 1 to 3 represents a slope that would generally be considered stable for slopes consisting of rocky soils or loose rock fragments. Clearly the stability of natural slopes varies depending on their soil or rock types, and in many cases, natural slopes are stable at much higher gradients than 1 to 3, for example, talus slopes in Hawkesbury Sandstone.

The locations of the steep slopes within the SMP Area are shown in Drawing Nos. MSEC647-11 and MSEC647-12, which have been identified using the 1 metre surface level contours generated from a Light Detection and Ranging (LiDAR) survey, an orthophotograph of the area, and from site investigations.

Natural steep slopes have been identified along the banks of Redbank Creek, Cedar Creek and Matthews Creek, where the near surface lithology is part of the Hawkesbury Sandstone group. Natural steep slopes are also located along the sides of ridges within the SMP Area, such as the Redbank Range, where the near surface lithology is part of the Wianamatta Shale group.

An analysis of the LiDAR survey has also identified steep slopes that have been constructed, such as dam walls, embankments and cutting faces. Potential impacts on these slopes are addressed in Chapter 6 of this report.

A total of 84 structures within the SMP Area are located on or near steep slopes. A summary of these built features is provided in Table 5.7.

Table 5.7 Structures located on or near Steep Slopes

Structure Type	Description	No.
PA	Public Amenity	4
PU	Public Utility	12
C	Business and Commercial Establishments	9
H	House	11
U	Flats or Units	0
A	Retirement Village / Aged Care	0
P	Pools	4
R	Other residential structures	0
F	Farm buildings and sheds	41
D	Farm dams	3
	Total	**84**

The locations of the structures and dams on or near steep slopes are shown in Drawing Nos. MSEC647-11 and MSEC647-12. It can be seen from these drawings that a number of business and commercial establishments, and public amenity and public utility structures are located close to the banks of Redbank Creek. Some houses, pools and farm buildings, particularly on Thirlmere Way, are located on or near steep slopes on the ridges within the SMP Area.

A number of driveways have also been identified from an aerial photograph that traverse along or near steep slopes and their locations are also shown in Drawing Nos. MSEC647-11 and MSEC647-12.

5.7.2. Predictions and Impact Assessments for Steep Slopes

The steep slopes are located across the SMP Area and are expected to experience the full range of subsidence movements, which are summarised in Chapter 4.

There has been extensive experience of mining directly beneath the steep slopes along the banks of Myrtle Creek and Redbank Creek during the previous extraction of Longwalls 22 to 27 at Tahmoor Colliery. No slope instabilities have been observed during mining. Soil cracking up to 65 mm wide was observed on both the upper banks and flanks of Myrtle Creek at one location above Longwall 23B. The cracks extended into the soil to depths of approximately 1.5 to 2.0 metres and over a length of approximately 40 metres.

There is extensive experience of mining beneath steep slopes elsewhere in the Southern Coalfield, including the mining of Longwalls 14 to 19 at Tahmoor Colliery. The majority of the steepest slopes above previous mining within the Southern Coalfield were within the Hawkesbury Sandstone group, along the Cataract, Nepean, Bargo and Georges Rivers, and no slope instabilities have been observed.

There is some experience of mining beneath slopes in the Wianamatta Shale group at Tahmoor Colliery, during the mining of Longwalls 27 and 28 directly beneath the ridge that runs along Tickle Drive. No slope instabilities have been observed during mining.

Potential impacts on steep slopes would generally result from the increased horizontal movements in the downslope direction, causing tension cracks to appear at the tops or along the sides of the slopes and compression ridges to form at the bases of the slopes. These movements are consistent with observations of upsidence and closure of creek valleys where compression is developed at the bottoms of the valleys and tension is developed at the tops of the valleys. If tension cracks were left untreated it is possible that soil erosion could occur.

It is possible, therefore, that some remediation might be required to ensure that mining-induced cracking does not result in the formation of soil erosion channels. In some cases, erosion protection measures may be needed, such as the planting of additional vegetation in order to stabilise the slopes in the longer term.

While any impacts on slopes are likely to consist of surface cracking, there remains a possibility of slope slippage on the ridges. Localised natural slope slippage has been observed in the Redbank Range and it is possible, therefore, that further localised slope slippages could develop along the Redbank Range and other ridges that may be attributable to either natural causes, mine subsidence, or both. Experience indicates that the probability of slope slippages due to mining is extremely low due to the significant depth of cover beneath the ridges. No large scale mining-induced slope failures have been observed in the Southern Coalfield at depths of cover exceeding 400 metres. While the risk is extremely low, some risk remains and attention must therefore be paid to any structures or roads that may be located in the vicinity of steep slopes.

A total of 81 structures and three dams have been identified on or near to steep slopes within the SMP Area. There are also a number of privately owned driveways or tracks that are located on or near these steep slopes.

Tahmoor Colliery has developed a subsidence management plan for managing the potential impacts on steep slopes during the mining of Longwalls 22 to 28. The management plan includes:

- Identification of structures, dams and roads that lie in close proximity to steep slopes;
- Site investigation and landslide risk assessment of structures near slopes by a qualified geotechnical engineer. This has been conducted previously by GHD Geotechnics for all structures near steep slopes that may experience subsidence during the mining of Longwalls 22 to 28;
- Site investigation and structural assessment of structures where recommended by the geotechnical engineer. This may include recommendations to mitigate against potential impacts;
- Monitoring, including ground survey and visual inspections; and
- Remediation if cracking or slippage occurs.

While no impacts have been observed on structures or dams due to mining-induced slope instabilities during the mining of Longwalls 22 to 28, it is recommended that Tahmoor Colliery continue to develop strategies to manage potential impacts on slopes during the mining of the proposed longwalls.

Thirlmere Way runs along the top of a ridge within the SMP Area. As shown in Drawing No. MSEC647-12, steep slopes are located on either side of the road directly above the end of proposed Longwall 32 and between Longwalls 31/32 and Longwalls 36/ 37. A cross-section through the ridgeline, adjacent to the finishing end of the proposed longwall 32, is provided in Fig. 5.20.

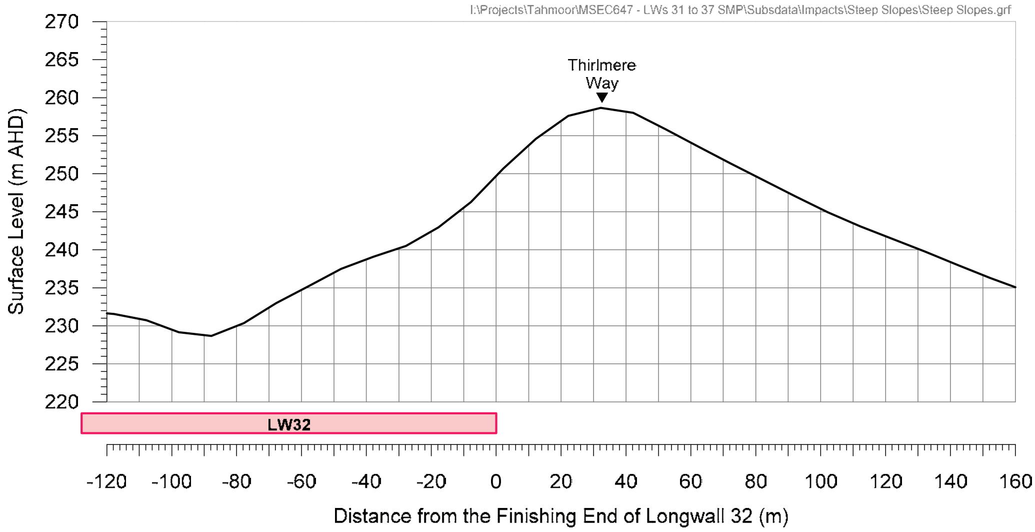


Fig. 5.20 Cross-section through Thirlmere Way and the Ridgeline adjacent to Longwall 32

Thirlmere Way narrows in this section, with no shoulders on either side of the pavement. Small but deeply incised valleys are located adjacent to the road on the southern side. It is possible that surface cracks or slippage may develop near the top of the ridge as a result of the extraction of the proposed longwalls, and that these may intersect with the Thirlmere Way pavement. Whilst repairs can be readily undertaken, traffic would need to be managed carefully during these works.

It is recommended that Tahmoor Colliery, in consultation with Wollondilly Council, undertake additional management measures in relation to the steep slopes along Thirlmere Way prior to the mining of Longwall 31. These may include:

- Site investigation and landslide risk assessment of slopes along Thirlmere Way by a qualified geotechnical engineer;
- Monitoring, including ground survey and visual inspections. The design of the monitoring activities should take into account safe working procedures along the narrow road corridor along Thirlmere Way; and
- Remediation if cracking or slippage occurs, in accordance with safe working procedures along Thirlmere Way.

5.8. Land Prone to Flooding or Inundation

Potential flood prone areas have been identified within the SMP Area along Myrtle and Redbank Creeks and are shown in the report by *WRM* (2014). Flood modelling has been undertaken by WRM based on the existing topography as surveyed by LiDAR and predicted subsidence movements due to the extraction of the proposed longwalls.

The study found that flows are generally contained within the channels of Matthews Creek, Redbank Creek, Cedar Creek and Stonequarry Creek with depths in excess of 4 metres in the main channels within the SMP Area. The subsidence resulting from the mining of the proposed Longwalls 31 to 37 does not result in an increase in flood levels in the Redbank Creek and Matthews Creek catchment areas (WRM, 2014).

5.9. Water-Related Ecosystems

The potential impacts on the water-related ecosystems within the SMP Area are discussed in the report by *Niche* (2014a).

5.10. Threatened, Protected Species, other Fauna and Natural Vegetation

Impact assessments for threatened and protected species, other fauna and natural vegetation within the SMP Area are provided in the report by *Niche* (2014a and 2014b).

5.11. Natural Vegetation

The vegetation in the SMP Area has been cleared for residential, agricultural and commercial land uses. There is natural vegetation along the alignments of the streams and along the ridges. A survey of the natural vegetation within the SMP Area has been undertaken by *Niche* (2014a and 2014b).

6.1. Introduction

The following sections provide the predicted subsidence parameters for the built features located within the SMP Area. The predictions have been made using the Incremental Profile Method, which has been calibrated to local conditions using the extensive monitoring data at the Colliery, and is described in Sections 3.5 and 3.6.

Impact assessments have been made for each of these features based on the predicted subsidence parameters and based on the experience gained from the mining of previous longwalls at Tahmoor Colliery. All significant built features located outside the SMP Area, which may be subjected to valley related or far-field horizontal movements and may be sensitive to these movements, have also been included as part of these assessments.

6.2. The Main Southern Railway

The location of the Main Southern Railway and the associated infrastructure within the SMP Area are shown in Drawing No. MSEC647-13. The predictions and impact assessments for these items of infrastructure are provided in the following sections.

6.2.1. General Description of the Main Southern Railway

There is a total length of 5.0 kilometres of the Main Southern Railway located within the SMP Area, of which, approximately 630 metres will be directly mined beneath by the proposed longwalls.

The Main Southern Railway is the main rail link between Sydney and Melbourne and runs above the proposed Longwalls 31 and 32, as shown in Drawing No. MSEC647-13. It can also be seen from the drawing that north of Longwall 32, the rail corridor runs along the edge of the SMP Area boundary. The section of track within the SMP Area is between track kilometrages 87.200 km and 92+1200 km.

Fig. 6.1 View of Main Southern Railway looking south from 89.785 km

The original main southern line extended from Picton to Mittagong through Thirlmere in 1867. The railway deviation through Tahmoor was constructed around 1919, when the new railway alignment from Picton to Mittagong was opened. The former line through Thirlmere was retained and termed the Picton to Mittagong Loop Line.

During the 1990's, construction commenced on upgrading the Up and Down tracks to strengthen the track infrastructure. This has included replacing timber sleepers with heavy duty concrete sleepers and resurfacing, regrading and realigning the existing 53 and 60 kg/m head hardened rail. The dual track is configured as dedicated Up and Down lines, with all signals being remotely controlled by ARTC Train Control located at Junee. The track between Picton Station and Tahmoor Railway Station is controlled by the new Microlok signalling system, which sends coded digital signals through the rails to locate trains within this section of track.

Approximately 70 trains run along the railway per day, which equates to one train every 30 to 45 minutes each way. The Up and Down tracks service a range of rail traffic including:

- Heavy haul coal and minerals traffic;
- Containerised traffic;
- Grain and agricultural products; and
- Local, Interstate and Intrastate passenger traffic.

The speed limits range between 70 and 80 km/hr for normal services, and between 75 and 85 km/hr for XPT services.

The Main Southern Railway is considered to be major surface infrastructure and an area of environmental sensitivity for the purposes of the SMP approval process.

There are a number of items of rail infrastructure along the Main Southern Railway, including bridges, the Picton Tunnel, culverts, cuttings, embankments and signalling and communications systems. Further details on these items of infrastructure are provided in the sub-sections below.

6.2.2. Predictions for the Main Southern Railway

The predicted profiles of incremental and total conventional subsidence and change in grade along the alignment of the Main Southern Railway, resulting from the extraction of the proposed longwalls, are shown in Fig. E.09, in Appendix E. The predicted profiles of the grade along the alignment of the railway after the extraction of the proposed longwalls, are also shown in this figure.

The predicted profiles of incremental and total conventional horizontal movement across the alignment of the Main Southern Railway, change in track cant and long twist, resulting from the extraction of the proposed longwalls, are provided in Fig. E.10 in Appendix E.

A summary of the maximum predicted values of incremental conventional subsidence, change in grade and curvature along the alignment of the Main Southern Railway, due to the extraction of each of the proposed longwalls, is provided in Table 6.1. A summary of the maximum predicted values of total conventional subsidence, change in grade and curvature along the alignment of the railway, after the extraction of each of the proposed longwalls, is provided in Table 6.2.

Table 6.1 Maximum Predicted Incremental Conventional Subsidence, Change in Grade and Curvature along the Main Southern Railway Resulting from the Extraction of Longwalls 31 to 37

Longwall	Maximum Predicted Incremental Subsidence (mm)	Maximum Predicted Incremental Change in Grade (%)	Maximum Predicted Incremental Hogging Curvature (1/km)	Maximum Predicted Incremental Sagging Curvature (1/km)
Due to LW31	700	0.55	0.06	0.11
Due to LW32	700	0.45	0.04	0.09
Due to LW33	30	< 0.10	< 0.01	< 0.01
Due to LW34	< 20	< 0.10	< 0.01	< 0.01
Due to LW35	< 20	< 0.10	< 0.01	< 0.01
Due to LW36	< 20	< 0.10	< 0.01	< 0.01
Due to LW37	< 20	< 0.10	< 0.01	< 0.01

Table 6.2 Maximum Predicted Total Conventional Subsidence, Change in Grade and Curvature along the Main Southern Railway Resulting from the Extraction of Longwalls 22 to 37

Longwall	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Change in Grade (%)	Maximum Predicted Total Hogging Curvature (1/km)	Maximum Predicted Total Sagging Curvature (1/km)
After LW30	1,100	0.55	0.08	0.12
After LW31	1,200	0.50	0.09	0.12
After LW32	1,200	0.50	0.09	0.11
After LW37	1,200	0.50	0.09	0.11

The values provided in the above table are the maximum predicted total conventional subsidence parameters which occur within the SMP Area, including the predicted movements resulting from the extraction of the approved Longwalls 22 to 30.

The predicted strains for the railway have been based on the statistical analysis of strains provided in Section 4.5. The railway is a linear feature and, therefore, the most relevant distributions of strain are the maximum strains measured anywhere along whole monitoring lines above the previously extracted longwalls, which are discussed in Section 4.5.2.

The railway will also experience transient subsidence movements as each of the longwalls are extracted directly beneath it. The railway is essentially perpendicular to the proposed longwalls and, therefore, the predicted transient tilts, curvatures and strains along the alignment of the railway are less than the predicted final values. This is illustrated in Fig. E.11, which shows the development of subsidence, changes in grade and long bay lengths due to the extraction of each of the proposed longwalls, for every 50 metres of travel, which represents approximately one week of mining. It can be seen from this figure that subsidence will firstly develop at the country (southern) end of the track during the mining of each longwall. The active subsidence zone will then migrate along the track towards the north as the longwalls progress.

The predictions for the infrastructure and services associated with the Main Southern Railway are provided in the impact assessments for each of these features in the following sections.

6.2.3. Impact Assessments for the Main Southern Railway

Since 2008, Tahmoor Colliery and the Australian Rail Track Corporation (ARTC) have developed detailed risk management plans for managing potential mine subsidence impacts on the Main Southern Railway due to the extraction of Longwalls 25 to 28. Illawarra Coal has also developed similar plans to manage the potential impacts on the railway due to the extraction of Longwalls 703 to 706 at Appin Colliery.

The management measures described in these plans have been developed in consultation with ARTC and successfully implemented during the mining of eight longwalls directly beneath the Main Southern Railway at Tahmoor and Appin Collieries.

A Rail Management Group has been coordinated to develop the risk management strategies. This Rail Management Group includes representatives from ARTC, Tahmoor Colliery and specialist consultants in the fields of railway track engineering, geotechnical engineering, structural engineering, track signalling, rail construction and maintenance, mine subsidence, risk assessment and project management.

Works by the Rail Management Group include:-

- Identification of all potential impacts to the railway;
- Undertaking a risk management approach, where all identified risks are assessed and risk control measures are implemented;
- Development of management measures that include mitigation and preventive works, monitoring plans, triggered response plans and communication plans; and
- Supervision and oversight of railway track and infrastructure mitigation, monitoring and maintenance of affected rail track and infrastructure.

It is recommended that Tahmoor Colliery and ARTC continue to develop plans to manage potential impacts during the mining of the proposed longwalls.

The following sub-sections provide details of the potential impacts to the Main Southern Railway and management measures that have been developed by the Rail Management Group to ensure that the railway remains safe and serviceable during mining.

6.2.4. Changes in Track Geometry

Mine subsidence will result in changes to track geometry. Changes to track geometry are described using a number of parameters:-

- Vertical misalignment (top) – vertical deviation of the track from design;
- Horizontal misalignment (line) – horizontal deviation of the track from design;
- Changes in Track Cant – changes in superelevation across the rails of each track from design; and
- Track Twist – changes in superelevation over a defined travel distance, such as 13.2 metres for long twist.

The Australian Rail Track Corporation's National Code of Practice for Track Geometry provides allowable deviations in track geometry. A summary of the maximum allowable and maximum predicted changes in geometry are provided in Table 6.3.

Table 6.3 Allowable and Predicted Maximum Changes in Track Geometry due to Conventional Subsidence Movements

Track Geometry parameter	Description	Value at which speed limit is first applied*	Value at which trains are stopped*	Predicted Maximum due to Conventional Subsidence
Top	Mid-ordinate vertical deviation Design Offset	14 mm over 4m chord 56 mm over 20m chord	16 mm over 4m chord 66 mm over 20m chord	< 5
Line	Mid-ordinate horizontal deviation over a 10 m chord	34 mm	44 mm	< 5
Change in Cant	Deviation from design superelevation across rails spaced 1.435 m apart	20 to 50 mm (depends on whether track is on a straight or curve)	40 to 75 mm (depends on whether track is on a straight or curve)	15
Long Twist	Changes in Cant over a 14 m chord	46 mm	52 mm	< 3

<u>Note</u>: Values have been taken from the trigger levels in the Tahmoor Mine LW28 Railway Management Plan, which were based on the ARTC National Code of Practice.

Predictions of conventional subsidence, tilt and horizontal movement have been made at 5 metre intervals along the railway to calculate each track geometry parameter at any stage of mining. The predicted changes in cant and long twist for the railway are shown in Fig. E.10.

A summary of the maximum predicted values of incremental conventional horizontal movement across the alignment of the Main Southern Railway, change in cant and long twist, due to the extraction of each of the proposed longwalls, is provided in Table 6.4. A summary of the maximum predicted values of total conventional horizontal movement across the alignment of the railway, change in cant and long twist, after the extraction of each of the proposed longwalls, is provided in Table 6.5.

Table 6.4 Maximum Predicted Incremental Horizontal Movement Across the Main Southern Railway, Change in Cant and Long Twist Resulting from the Extraction of Longwalls 31 to 37

Longwall	Maximum Predicted Incremental Horizontal Movement Across the Alignment (mm)	Maximum Predicted Incremental Change in Cant (mm)	Maximum Predicted Incremental Long Twist over 13.2 m Bay lengths (mm)
Due to LW31	10	1	< 1
Due to LW32	40	4	1
Due to LW33	< 5	< 1	< 1
Due to LW34	< 5	< 1	< 1
Due to LW35	< 5	< 1	< 1
Due to LW36	< 5	< 1	< 1
Due to LW37	< 5	< 1	< 1

Table 6.5 Maximum Predicted Total Horizontal Movement Across the Main Southern Railway, Change in Cant and Long Twist Resulting from the Extraction of Longwalls 22 to 37

Longwall	Maximum Predicted Total Horizontal Movement Across the Alignment (mm)	Maximum Predicted Total Change in Cant (mm)	Maximum Predicted Total Long Twist over 13.2 m Bay lengths (mm)
After LW30	60	6	1
After LW31	50	5	1
After LW32	50	5	1
After LW37	50	5	1

When the predicted values are compared to Table 6.3, it can be seen that the maximum allowable deviations specified in the ARTC National Code of Practice are an order of magnitude greater than the predicted conventional subsidence movements. For example, the maximum allowable change in cant is 40 to 75 mm over a length of 1505 mm before the trains are stopped. In mining terminology, this represents a tilt of approximately 27 to 50 mm/m, which is substantially greater than the maximum predicted conventional tilt of 6 mm/m due to mine subsidence.

It is recognised that subsidence predictions in the Southern Coalfield are generally based on the results of surveys of pegs that are spaced nominally 20 metres apart. The bay lengths used to measure the track geometry parameters, described in Table 6.3, are less than these peg spacings, particularly for changes in track cant and twist.

Confidence in the predictions is gained, however, from visual inspections and daily track geometry recordings during the mining, which have confirmed that the impact of normal subsidence movements on track geometry has generally been very low and close to predictions, and these very small changes in track geometry developed very gradually.

It is, however, possible that mine subsidence could result in changes in track geometry that exceed ARTC Standards in the following ways:-

- Track becomes unstable as the result of rail stress, which is discussed in Section 6.2.6; or
- Track loses support as the result of failure or collapse of culverts or embankment slopes, which is discussed in Sections 6.2.9 and 6.2.10; or
- Development of substantial non-conventional ground movements.

Non-conventional movements can occur and have occurred in the Southern Coalfield as a result of, among other things, valley upsidence and closure movements and anomalous movements. The impact assessments for the valley related movements at the stream crossings are provided in Section 6.2.9. Discussion on the likelihood and nature of anomalous movements is provided in Sections 3.4 and 4.7.

An example of substantial non-conventional movement in the Southern Coalfield occurred above Appin Longwall 408. In this case, a low angle thrust fault was re-activated in response to mine subsidence movements, resulting in differential vertical and horizontal movements across the fault. Observations at the site showed that the non-conventional movements developed gradually and over a long period of time. Regular ground monitoring across the fault indicated that the rate of differential movement was less than 0.5 mm/day at the time non-conventional movements could first be detected. Subsequently as mining progressed, the rate of differential movement increased to a maximum of 28 mm/week. In comparison with the National Code of Practice, the maximum allowable deviations in track geometry are much larger than the measured daily rates of change due to mining.

Two localised non-conventional subsidence events have adversely impacted on track geometry. Differential subsidence movements developed gradually at each site, such that visual inspections could detect small changes at an early stage. This allows time to resurface the track in between the passing of trains and return track geometry parameters to within safety limits. Localised changes in track geometry in areas of good track condition are more noticeable to drivers. This can result in rough ride reports from train drivers and imposition of Temporary Speed Restrictions well before trigger levels are reached.

It is therefore considered that while non-conventional movements may potentially result in changes to track geometry that exceed the National Code of Practice, the potential risk to track safety can be managed through early detection via monitoring and early response through the implementation of triggered response plans. A number of management measures are proposed to manage changes in track geometry:-

- Assess pre-mining track condition and adjust track (if necessary) so that pre-mining track geometry is at or close to design prior to the development of subsidence;
- Identify potential sites of non-conventional movement, such as creeks and geological structures;
- Install a monitoring system, which includes, among other things, the monitoring of ground movements, rail stress, rail temperature, switch displacement and track geometry;
- Regularly review and assess the monitoring data;
- Conduct regular visual inspections of the track; and
- Adjust the track in response to monitoring results during mining if required to keep the track well within safety limits.

With an appropriate management plan in place, it is considered that potential impacts on track geometry can be managed during the mining of the proposed longwalls, even if actual subsidence movements are greater than the predictions or substantial non-conventional movements occur.

6.2.5. Changes in Track Grades

The Main Southern Railway climbs steadily in a southbound direction through the SMP Area from Picton to Tahmoor.

Existing track gradients have been estimated from Curve and Gradient Diagrams provided by ARTC. The maximum gradient along the Main Southern Railway within the SMP Area is 1.35% (1 in 74), which is located between 90.4 km and 90.8 km, above the proposed longwalls. Steeper grades exist regionally along the track, such as 1 in 63 (1.59% or 15.9 mm/m) between Moss Vale and Exeter.

The predicted changes in track gradient along the Main Southern Railway and the predicted gradients along the track after the completion of mining are shown in Fig. E.09.

It can be seen that the predicted maximum grade after mining is 1.5% or 1 in 67, which is slightly less than the regional maximum grades.

It should be noted, however, that the locations of steeper grades exist over short lengths (a couple of hundred metres), which is of less concern as freight trains are many hundreds of metres long.

6.2.6. Changes in Rail Stress

Mine subsidence will result in changes to rail stress unless preventive measures are implemented. If no action is taken, it is likely that the rail track will become unstable as a result of mine subsidence. The maximum predicted reduction in stress free temperature is 49 degrees if 100 % of predicted ground strains are transferred into the rails. By comparison a reduction in stress free temperature of approximately 14 degrees is sufficient to warrant immediate preventative action on a track with concrete sleepers.

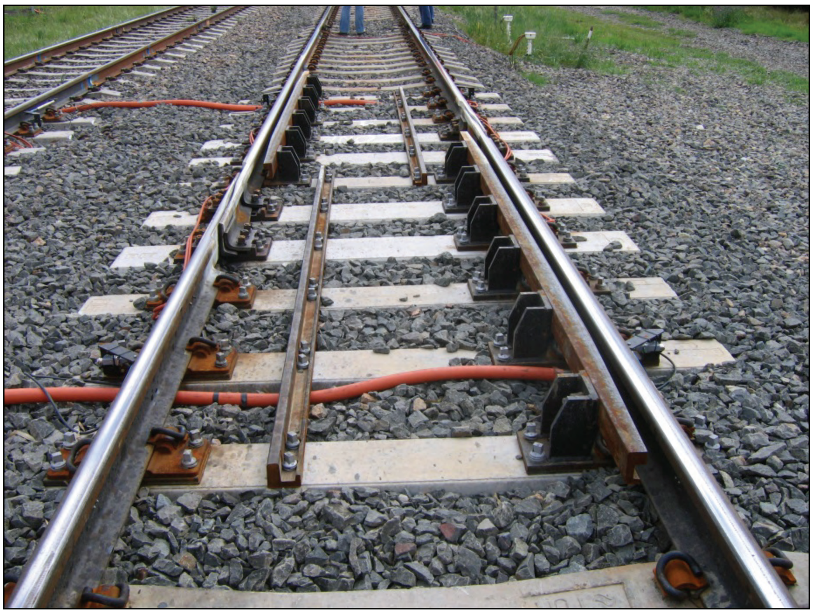
Management of rail stress during active mine subsidence has been the primary focus of the Rail Management Group. Traditionally, rail stress has been managed in Australia and overseas by rail strain or stress monitoring. Once measured changes in rail stress reach defined triggers, the stress is dissipated by unclipping the rails from the sleepers, cutting the rails and adding or removing steel to the rails as required, followed by re-stressing the rails back to their desired stress. This process is effective but it is labour intensive and very difficult to undertake on busy tracks such as the Main Southern Railway, particularly if the frequency of required rail re-stressing is likely to be less than weekly, as would be expected during the mining of the proposed Longwalls 31 and 32.

For this reason, the Rail Management Group has introduced a combination of rail expansion switches and zero toe load clips to dissipate mining and temperature related rail stress during mining. Rail expansion switches consist of a tapered joint in the track, which allow the rails to slide independently. Maximum allowable displacements of expansion switches vary between different types of switches and the latest units that have been employed at Tahmoor are approximately 310 mm. Expansion switches are standard rail equipment and operate in non-subsidence applications in Australia and overseas to accommodate, for example, differential thermal movements between bridges and natural ground.

Zero toe load clips allow the rails to slide longitudinally along the track while maintaining lateral stability. In combination, the rails are able to expand or contract in response to mine subsidence and thermal loads into and out of the expansion switches. It is estimated that the switches will be spaced between 100 and 200 metres apart along the track within the subsidence area.

The rail track expansion system has been well proven at Tahmoor Colliery and at Appin Colliery and has been approved for use by ARTC under New Equipment and System Approval No. 11/9643.

A photograph of a rail expansion switch is shown in Fig. 6.2 and a photograph of a zero toe clip is shown in Fig. 6.3.



Photograph courtesy Pidgeon Civil Engineering

Fig. 6.2 Rail Expansion Switch

Photograph courtesy Pidgeon Civil Engineering

Fig. 6.3 Zero Toe Load Clips

The combination of expansion switches and zero toe load clips has successfully been deployed during the mining of Longwalls 25 to 28 at Tahmoor Colliery.

A substantial advantage of using rail expansion switches and zero toe load clips is that the system is flexible and can be adjusted during mining should the tolerance of the switches reach their design limits. The rails are cut and steel is added or removed to restore capacity in the switches. The process is significantly faster than conventional re-stressing work and can be safely achieved in between the passage of trains.

The following management measures are adopted to manage the risks associated with rail stress:-

- Assess pre-mining track condition and adjust track if required so that pre-mining track geometry and sleeper arrangements are at or close to design prior to the development of subsidence,
- Identify potential sites of non-conventional movement, such as creeks and geological structures,
- Assess the required spacing of expansion switches based on the predicted ground movements,
- Install the expansion switches and zero toe load clips,
- Install a monitoring system, which includes, among other things, the monitoring of ground movements, rail stress, rail temperature, switch displacement and track geometry,
- Regularly review and assess the monitoring data,
- Conduct regular visual inspections of the track, switches and clips, and
- Adjust the track in response to monitoring results during mining if required.

With an appropriate management plan in place, it is considered that potential impacts on rail stress can be managed during the mining of the proposed longwalls, even if actual subsidence movements are greater than the predictions or substantial non-conventional movements occur.

6.2.7. Railway Bridges

The locations of the railway bridges are shown in Drawing No. MSEC647-13. The bridges are classified as either: *overbirdges* where they pass over the railway track; or *underbridges* where the reverse occurs.

There are two railway bridges located within the SMP Area. There are an additional four bridges that are located at the boundary or outside the SMP Area, but have been included in this report, as they may be sensitive to differential far-field horizontal movements. The railway bridges are summarised in Table 6.6.

Table 6.6 Railway Bridges within or close to the SMP Area

Bridge	Kilometrage (km)	Description	Location relative to Proposed Longwalls
Deviation Overbridge	92.410km	New single span reinforced concrete bridge with reinforced soil abutments	Above LW29
Bridge Street Overbridge	91.000km	Single span concrete arch bridge, reinforced with steel rails, with brick spandrel walls. The bridge will be replaced prior to influence of LW29 with a new reinforced concrete bridge with reinforced soil abutments	Above LW29
Thirlmere Way Rail Underbridge	89.326km	Single span brick arch bridge with brick spandrel walls	Outside SMP Area. Approx. 480 m from LWs 33 & 34 and 620 m from LW32
Connellan Crescent Overbridge	89.080km	Single span concrete arch bridge, reinforced with steel rails, with brick spandrel walls.	Approx. 350 m from LW33
Argyle Street Rail Underbridge	86.13 km	Single span brick arch bridge with brick spandrel walls	Outside SMP Area. Approx. 830 m from LW33
Picton Viaduct over Stonequarry Creek	85.42 km	Five span stone arch bridge with stone spandrel walls	Outside SMP Area. Approx. 725 m from LW33

Deviation Overbridge at 92.410 km

An overbridge has been constructed as part of the Deviation works to provide farm access across the Deviation track. The Overbridge has been designed and constructed in accordance with Australian Standards to suit potential future use as a vehicular road bridge. The Overbridge is located at 92.410 km, within the new cutting. A photograph of the Overbridge, looking from the western side, is shown in Fig. 6.4.

Photograph courtesy GHD Geotechnics

Fig. 6.4 Photograph of the Railway Deviation Overbridge at 92.410 km and the Reinforced Soil Wall Viewed from the Western Side

It can be seen from this image that the Overbridge is a single span structure of approximately 30 metres. It bears upon reinforced soil walls. The Overbridge was designed to accommodate substantial subsidence movements. From a subsidence management point of the view, the key features of the bridge are:

- Simply supported single span reinforced concrete deck;
- Bearings and expansion joints that allow the deck to accommodate spreading and/or closure, lateral movement and/or rotation and changes in height between the abutments. The expansion joint gap between the bridge girders and abutment is 860 mm;
- Provision for jacking and realignment / resupport of the deck, if required;
- Abutments with pad footings supported on reinforced soil walls (RSW); and
- Compressible polystyrene behind the RSWs to accommodate potential differential movement of the rock face on bedding planes or joints in response to mine subsidence movements, particularly closure.

The overbridge is located directly above Longwall 29 and approximately 400 metres from the side of Longwall 31. A summary of the maximum predicted values of total conventional subsidence, tilt and curvature at the Overbridge, after the extraction of each of the proposed longwalls, is provided in Table 6.7.

Table 6.7 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature at the Deviation Overbridge Resulting from the Extraction of Longwalls 22 to 37

Longwall	Maximum Predicted Subsidence (mm)	Maximum Predicted Tilt (mm/m)	Maximum Predicted Hogging Curvature (1/km)	Maximum Predicted Sagging Curvature (1/km)
After LW30	825	2.4	0.07	< 0.01
After LW31	950	2.0	0.07	< 0.01
After LW32	980	1.8	0.07	< 0.01
After LW37	980	1.8	0.07	< 0.01

It can be seen from Table 6.7 that the majority of the predicted subsidence movements will occur prior to the mining of the proposed Longwalls 31 and 32.

The following management measures are adopted to manage the risks associated with the Deviation Overbridge:-

- 3D surveys of survey marks on the bridge and surrounding ground,
- Detailed visual inspections are undertaken during mining. The inspections include measurements of displacements at the bridge bearings,
- In the unlikely event of substantial differential subsidence movements, jack the deck and reseat bearings to keep the bridge deck planar.

With an appropriate management plan in place, it is considered that potential impacts on the Deviation Overbridge can be managed during the mining of the proposed longwalls, even if actual subsidence movements are greater than the predictions or substantial non-conventional movements occur.

Bridge Street Overbridge at 91.000 km

Bridge Street Railway Overbridge (Chainage 91.000 km) lies within the SMP Area. The bridge will be directly mined beneath by the approved Longwall 29 and is located approximately 400 metres south-west of Longwall 31, at its closest point to the proposed longwalls. Bridge Street is one of three roads that connect Thirlmere and Picton. The two-lane bridge is constructed with masonry abutments and the deck is supported by a reinforced concrete arch, as shown in Fig. 6.5.

No impacts occurred during the mining of Longwall 27 as expected. Given the existing condition of the bridge, a new overbridge is proposed to be constructed adjacent to the old bridge prior to the influence of Longwall 29, after which the existing bridge is proposed to be demolished.

Fig. 6.5 Bridge Street Railway Overbridge at 91.000 km

The new replacement Overbridge will be located adjacent to the existing bridge on the southern side. It will be designed and constructed to accommodate substantial subsidence movements. The design will be similar in nature to the new Deviation Overbridge at 92.410 km

A summary of the maximum predicted values of total conventional subsidence, tilt and curvature at the Overbridge, after the extraction of each of the proposed longwalls, is provided in Table 6.8.

Table 6.8 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature at the Replacement Bridge Street Overbridge Resulting from the Extraction of Longwalls 22 to 37

Longwall	Maximum Predicted Subsidence (mm)	Maximum Predicted Tilt (mm/m)	Maximum Predicted Hogging Curvature (1/km)	Maximum Predicted Sagging Curvature (1/km)
After LWs 29 & 30	925	4.9	0.07	< 0.01
After LW31	1,025	4.4	0.07	< 0.01
After LW32	1,050	4.3	0.07	< 0.01
After LW37	1,050	4.3	0.07	< 0.01

It can be seen from Table 6.8 that the majority of the predicted subsidence movements will occur prior to the mining of the proposed Longwalls 31 and 32.

It is recommended that the management measures developed at the Deviation Overbridge be adopted for the new replacement Bridge Street Overbridge. These include :-

- 3D surveys of survey marks on the bridge and surrounding ground,
- Detailed visual inspections are undertaken during mining. The inspections include measurements of displacements at the bridge bearings,
- In the unlikely event of substantial differential subsidence movements, jack the deck and reseat bearings to keep the bridge deck planar.

With an appropriate design to accommodate substantial subsidence movements and an appropriate management plan in place, it is considered that potential impacts on the new Bridge Street Overbridge can be managed during the mining of the proposed longwalls, even if actual subsidence movements are greater than the predictions or substantial non-conventional movements occur.

Bridges located at the edge of or just outside the SMP Area

There are four railway bridges that are located at the edge of or just outside the SMP Area. These bridges could experience differential far-field movements and could be sensitive to these movements and, therefore, have been included in the impact assessments. Descriptions of these bridges are provided below:

- The Thirlmere Way Rail Underbridge (89.326 km) is located 480 metres south-east of the proposed Longwalls 33 and 34. The bridge is a single span brick arch structure with brick spandrel walls, as shown in Fig. 6.6;
- The Connellan Crescent Railway Overbridge (89.080 km) is located 350 metres south-east of the proposed Longwall 33. The bridge is constructed with masonry abutments and the deck is supported by a reinforced concrete arch, as shown in Fig. 6.7;
- The Argyle Street Rail Underbridge (86.13 km) is located 830 metres north-east of the proposed Longwall 33. The bridge is a single span masonry brick arch structure with brick spandrel walls, as shown in Fig. 6.8. It is an item of heritage significance; and
- The Picton Viaduct (85.42 km) is located 725 metres north-east of the proposed Longwall 33. The viaduct is a five-span stone arch structure across Stonequarry Creek, as shown in Fig. 6.9. It is an item of heritage significance.

Fig. 6.6 Thirlmere Way Rail Underbridge at 89.326 km

Fig. 6.7 Connellan Crescent Railway Overbridge at 89.080 km

Fig. 6.8 Argyle Street Rail Underbridge at 86.13 km

Fig. 6.9 Picton Viaduct at 85.42 km over Stonequarry Creek

The four railway bridges are located at distances between 350 metres and 830 metres from the proposed longwalls. At these distances, the bridges are predicted to experience less than 20 mm vertical subsidence. Whilst the Thirlmere Way Rail Underbridge and the Connellan Crescent Overbridge could experience very low levels of vertical subsidence, they are not expected to experience any measurable tilts, curvatures or strains, even if the predictions were exceeded by a factor of 2 times.

These bridges could experience far-field horizontal movements resulting from the proposed mining. It can be seen from Fig. 4.13, that incremental far-field horizontal movements around 150 mm and 75 mm have been measured at distances of 350 metres and 800 metres, respectively, from previously extracted longwalls in the NSW Coalfields.

The potential for impacts on these bridges do not result from absolute far-field horizontal movements, but rather from differential horizontal movements over the lengths of the structures. The potential for differential horizontal movements at these bridges has been assessed by statistically analysing the available 3D monitoring data from the Southern Coalfield.

The observed incremental differential longitudinal movements and mid-ordinate deviation for survey marks spaced at 20 metres ±10 metres, relative to the distance from the active longwall, are shown in Fig. 4.14 and Fig. 4.16. The 95 % confidence levels have also been shown in this figure, which were determined from the empirical data using the fitted *Generalised Pareto Distributions* (GPDs). A summary of the maximum predicted incremental differential horizontal movements for these bridges, based on the 95 % confidence interval, is provided in Table 6.9.

Table 6.9 Maximum Predicted Incremental Differential Horizontal Movement for the Bridges Located Outside and Adjacent to the SMP Area

Bridge	Minimum Distance from Proposed Longwalls (m)	Maximum Predicted Opening (mm)	Maximum Predicted Closure (mm)	Maximum Predicted Mid-Ordinate Deviation (mm)
Picton Viaduct over Stonequarry (85.42 km)	725	6	5	8
Argyle Street Rail Underbridge (86.13 km)	830	6	5	8
Connellan Crescent Overbridge (89.080 km)	350	8	7	10
Thirlmere Way Rail Underbridge (89.326 km)	480	7	6	9

The predicted differential horizontal movements at the railway bridges are small and comprise a large proportion of survey tolerance, which is in the order of ±3 mm. It is unlikely, therefore, that these bridges would experience adverse impacts resulting from the mining induced far-field movements.

There is, however, a small chance that differential horizontal movements could develop at the bridges due to the extraction of the proposed longwalls. If impacts were to occur, they are most likely to be observed in the form of minor cracking of a bridge.

In the case of the Thirlmere Way Rail Underbridge and the Connellan Crescent Overbridge, the potential exists due to the offset distance of the proposed longwalls to the bridges.

The Argyle Street Rail Underbridge is located very close to or on top of part of the Nepean Fault. While the proposed longwalls are set back approximately 830 metres from the Bridge, there is a remote chance that differential movements could occur.

Stonequarry Creek runs along the alignment of the Nepean Fault where it crosses beneath the Picton Viaduct. While the proposed longwalls are set back approximately 725 metres from the Viaduct, there is a remote chance that differential movements could occur at the structure. A prediction of valley closure and upsidence was also undertaken on account of the presence of Stonequarry Creek. It was found that the maximum predicted total valley related movements for the viaduct are 5 mm upsidence and 5 mm closure, which is within survey tolerance.

Whilst the likelihood of impacts on the bridges is extremely low, it is recommended that Tahmoor Colliery in consultation with ARTC consider measures to manage potential impacts on the four bridges during the mining of the proposed longwalls. It is recommended that the management measures include :-

- Assess pre-mining condition of the bridges;
- Install a monitoring system, which includes, among other things, the monitoring of bridge movements and movements of the ground around each bridge;
- Regularly review and assess the monitoring data; and
- Conduct regular visual inspections of the bridges.

It is also recommended that Tahmoor Colliery undertake a far field horizontal movement monitoring program to investigate further the potential for differential horizontal movements across the Nepean Fault. The monitoring program should be undertaken during the mining of Longwalls 31 and 32.

6.2.8. Picton Rail Tunnel and Mushroom Tunnel

The Picton Tunnel and Mushroom Tunnel are located at minimum distances of 380 metres and 470 metres, respectively, north-east of Longwall 33. Subsidence predictions and impacts assessments are provided in Section 6.7.

6.2.9. Railway Culverts

There are 10 railway culverts located within the SMP Area and their locations are shown in Drawing No. MSEC647-13. A summary is provided in Table 6.10. For completeness, the table also includes five culverts that are located just outside the SMP Area.

Table 6.10 Railway Culverts within SMP Area

Kilometrage (km)	Width (mm)	Height (mm)	Description	Location relative to Proposed Longwalls
87.331km	1200 dia		Brick arch culvert with concrete extension on UP side. Culvert could not be inspected due to thick vegetation on both sides. Estimated size based on nearby culvert on the Picton-Mittagong Loop Line that is just downstream of this culvert.	Approx. 400 m from LW33
87.918km	600 dia		Brick arch culvert with drop down inlet pit and buried outlet pit, which connects to new reinforced concrete pipe that runs alongside the track from the Picton Tunnel portal on the Down side. Not in a natural drainage line.	Just outside SMP Area, approx. 480 m from LW33
88.091km	900 dia		Brick arch culvert	Just outside SMP Area, approx. 490 m from LW33
88.133km	2900	3900	Brick Subway with Concrete Ballast Top Bridge	Just outside SMP Area, approx. 490 m from LW33
88.232km	600 dia		Brick arch culvert	Just outside SMP Area, approx. 450 m from LW33
88.496km	900 dia		Brick arch culvert with concrete extension on UP side	Approx. 320 m from LW33
88.698km	600 dia		Brick arch culvert with inlet at base of cutting	Approx. 270 m from LW33
89.216km	2500 dia		Brick arch culvert	Outside SMP Area Approx. 460 m from LW33
89.785km	1200 dia		Brick arch culvert	Approx. 160 m from side of LW32
90.252km	800	800	Brick arch culvert with concrete extension on UP side	Above LW32

Kilometrage (km)	Width (mm)	Height (mm)	Description	Location relative to Proposed Longwalls
90.676km	1000	1000	Brick arch culvert with concrete extension on UP side	Above LW30
91.265km	3200	3200	Redbank Creek Culvert Reinforced Brick arch culvert	Above LW28 & LW29
91.935km	1050 dia		Reinforced concrete pipe	Above LW29
92.060km	1500 dia		Reinforced concrete pipe	Above LW29
92+1200km	1800 dia		Reinforced concrete pipe	Above LW28

The Redbank Creek railway culvert (91.265 km) is located over the pillar between Longwall W28 and Longwall 29, and partly above Longwall 29. Two watercourses converge within the culvert. The main culvert carries water from Redbank Creek. A secondary culvert carries water from a nearby tributary to the creek and joins the main culvert approximately 15 metres from the main inlet. The culvert is constructed with masonry arches, as shown in Fig. 6.10. The main culvert has an internal diameter of approximately 3.2 metres and is approximately 60 metres long. The secondary culvert is approximately 1.5 metres wide and 1.3 metres high. The culvert appears to be in good condition, although minor cracking was observed in the brickwork. A substantial 20 metre high, 60 metre wide (at the base) short stocky embankment is located above the Redbank Creek railway culvert.

Fig. 6.10 Redbank Creek Railway Culvert at 91.265 km

There are a number of smaller culverts within the SMP area. The majority of these culverts are brick arch culverts. Some of the original masonry culverts have been extended with round concrete pipes to transport water beneath the vehicular access track. The three southern-most culverts are new reinforced concrete pipe culverts, which were installed by Tahmoor Colliery along the Redbank Tunnel Deviation track.

There is only one culvert, at 90.252 km, that is directly above the proposed Longwalls 31 and 32. A photograph of the 800 mm diameter brick arch culvert is provided in Fig. 6.11. A photograph of the 1200 mm diameter culvert at 89.785 km is shown in Fig. 6.12.

Fig. 6.11 Culvert at 90.252 km above proposed Longwall 32

Fig. 6.12 Culvert at 89.785 km adjacent to proposed Longwall 32

The locations of the culverts associated with the Main Southern Railway are shown in Drawing Nos. MSEC647-13 and MSEC647-15. A summary of the maximum predicted conventional subsidence and valley related movements for the railway culverts is provided in Table 6.11.

Table 6.11 Predicted Conventional Subsidence and Valley Related Movements for the Main Southern Railway Drainage Culverts within the SMP Area

Location	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Tilt (mm/m)	Maximum Predicted Total Hogging Curvature (1/km)	Maximum Predicted Total Sagging Curvature (1/km)	Maximum Predicted Total Upsidence (mm)	Maximum Predicted Total Closure (mm)
87.331 km	25	< 0.5	< 0.01	< 0.01	50	125
87.918 km	20	< 0.5	< 0.01	< 0.01	No valley	No valley
88.091 km	20	< 0.5	< 0.01	< 0.01	< 5	< 5
88.133 km	20	< 0.5	< 0.01	< 0.01	No valley	No valley
88.232 km	20	< 0.5	< 0.01	< 0.01	< 5	< 5
88.496 km	< 20	< 0.5	< 0.01	< 0.01	< 5	< 5
88.698 km	< 20	< 0.5	< 0.01	< 0.01	< 5	< 5
89.216 km	< 20	< 0.5	< 0.01	< 0.01	< 5	< 5
89.785 km	75	0.5	< 0.01	< 0.01	100	175
90.252 km	750	0.5	0.02	0.02	125	200
90.676 km	925	3.5	0.08	0.01	100	150
91.265 km	1000	2.0	0.03	0.02	325	500
91.935 km	1075	1.5	0.03	0.02	225	325
92.060 km	1175	1.5	0.03	0.04	200	325
92+1200 km	1075	2.5	0.03	0.02	75	100

The values provided in Table 6.11 are the maximum predicted parameters within a 20 metre radius of each culvert, including the predicted movements resulting from the extraction of the approved Longwalls 22 to 30. There are, for example, four culverts within the SMP Area that are located directly above approved Longwalls 28 and 29 and very little additional subsidence, upsidence and closure are predicted to occur due to the mining of the proposed Longwalls 31 to 37.

It can also be seen that very little subsidence, tilt, curvature and valley closure is predicted to occur at the culverts located around the end or side of Longwall 33 due to the large offset distances. The predicted valley closure at the culvert at 87.331 km is relatively high on account of the deeply incised valley at this location.

The predicted tilts are the maximum values at the completion of any or all longwalls, whichever are the greatest. The predicted curvatures are the maximum values which occur at any time during or after the extraction of each of the proposed longwalls.

It is expected that mining-induced conventional tilts will not significantly impact the drainage flows in the culverts as the changes in grade are expected to be less than 1 %. It is, however, recommended that the culverts be cleared of ballast prior to mining.

The main risk identified with all the brick arch culverts is the potential for physical impacts to occur. It is possible that these culverts will experience some cracking and spalling of the masonry as a result of mining the proposed longwalls. Cracking may occur in the masonry arch or in the headwalls. The predicted movements are not considered likely to result in collapse of the culvert.

Tahmoor Colliery and ATRC have successfully developed and implemented measures to manage potential impacts on culverts during the mining of Longwalls 25 to 27. Management measures include:

- Assess pre-mining condition of the culvert;
- Consider and implement mitigation measures, such as sleeving the culvert barrel with new structural steel pipes, placing a steel baulk above the culvert, or reinforcing the culvert structure with structural steelwork, as was installed at Myrtle Creek above Longwall 25;

- Install a monitoring system, which includes, among other things, the monitoring of ground movements on and around the culvert, and track geometry above the culvert;
- Regularly review and assess the monitoring data;
- Conduct regular visual inspections of the culvert; and
- Repair the culvert if required.

Tahmoor Colliery and ARTC will continue to develop plans to manage potential impacts on culverts that are located within the SMP Area. It is recommended that mitigation measures be considered for culverts located from 89.785 km to 90.676 km. Mitigation measures are unlikely to be required for the eight culverts located around the end and side of Longwall 33 on account of the large offset distance from this longwall, though measures should be considered for the culvert at 87.331 km.

Redbank Creek Culvert 91.265 km is one of the larger culverts along the rail corridor between Picton and Tahmoor. Substantial mitigation measures have been installed in the Redbank Creek Culvert, including:

- Segmentation of the culvert into five segments by cutting movement joints through the brick walls and floor, plus segmentation of the wingwalls and cutting a movement joint between the secondary culvert and the main culvert to allow the structure to articulate.
- Installation of stainless steel bar reinforcement into the internal surface of the sidewalls and culvert obvert to improve structure ductility of each segment.
- Cross-stitching and reinforcement of existing cracks located along the culvert obvert.
- Installation of a headwall support structure at both upstream and downstream ends.

A detailed monitoring and response plan has been developed for Redbank Creek Culvert, and this will be reviewed following the mining of each longwall, including Longwalls 31 and 32.

With an appropriate management plan in place, it is considered that potential impacts on railway culverts can be managed during the mining of the proposed longwalls, even if actual subsidence movements are greater than the predictions or substantial non-conventional movements occur.

6.2.10. Railway Embankments

There are ten embankments within the SMP Area, and a summary is provided in Table 6.12.

Table 6.12 Railway Embankments within SMP Area

Kilometrage (km)	Length (mm)	Height (mm)	Description	Location relative to Proposed Longwalls
87.200 km to 87.500 km	300	12	Earth embankment	Approx. 350 m to side of LW33
88.020 km to 88.280 km	260	8	Earth embankment on either side of Subway	Outside SMP Area, approx. 450 m from LW33
88.420 km to 88.780 km	360	15	Earth embankment on side of ridge, widened on the UP side for vehicle access track	Approx. 410 m to side of LW33
89.070 km to 89.310 km	240	11	Earth embankment on either side of Thirlmere Way Rail Underbridge	Outside SMP Area approx. 460 m to end of LW33
89.670 km to 89.960 km	290	12	Earth embankment	Southern end is adjacent to LW32
90.200 km to 90.350 km	150	5	Earth embankment, widened on the UP side for vehicle access track	Above LW32
90.630 km to 90.750 km	120	9	Earth embankment, widened on the UP side for vehicle access track	Above LW30
91.230 km to 91.360 km	130	20	Earth embankment at Redbank Creek Culvert	Above LW29
91.860 km to 92.100 km	240	4	New engineering designed embankment, filling over a small watercourse	Above LW29
92+1000 km to 93.100 km	360	20	New reinforced soil embankment designed to tolerate mine subsidence movements	Above LW28

Photographs of railway embankments within the SMP Area are shown in Fig. 6.13 to Fig. 6.16.

It can be seen from Table 6.12 that only one embankment is located directly above the proposed longwalls. The embankment between 90.200 km to 90.350 km is located directly above Longwall 32 with a maximum height of approximately 5 metres, which is relatively small. This embankment will experience the full range of subsidence movements during the extraction of the proposed longwalls.

The embankments located above approved Longwalls 28 to 30 will experience the full range of the predicted subsidence movements during the extraction of the Longwalls 28 to 30. The embankments will experience a small amount of additional subsidence, tilt and curvature due to the extraction of the proposed longwalls.

The four embankments between 87.200 km and 89.310 km are located more than 350 metres to the side or end of Longwall 33. These embankments are expected to experience less than 50 mm of vertical subsidence with negligible tilts, curvatures and strains. .

The embankments are typically constructed with local fill material and contain relatively steep batters. The likelihood of impacts on the embankments is considered to be relatively low provided that the culverts remain serviceable and do not become blocked.

The embankments may experience tensile surface cracking during mining, however, these can be readily treated before they develop into a safety hazard. Compressive impacts are less likely as the voids within the embankment can accommodate some compressive movement.

The Rail Management Group will consider mitigation measures before each embankment experiences subsidence movements. Mitigation works could include, for example, cleaning out of the culverts and drainage lines beneath the embankments, or the stabilisation of the batters.

Tahmoor Colliery and ATRC have successfully developed and implemented measures to manage potential impacts on embankments during the mining of Longwalls 25 to 27. Management measures include:

- Management of potential impacts on the culvert within the embankment, which is the key element of the management strategy. This is discussed in the previous Section 6.2.9;
- Assess pre-mining condition of the embankment;
- Consider and implement mitigation measures, such as cleaning out of the culverts and drainage lines beneath the embankments;
- Install a monitoring system, which includes, among other things, the monitoring of ground movements on and around the embankment;
- Regularly review and assess the monitoring data;
- Conduct regular visual inspections of the embankment; and
- Seal cracks that develop on the embankment if required.

Tahmoor Colliery and ARTC will continue to develop plans to manage potential impacts on embankments that are located within the SMP Area. It is recommended that mitigation measures be considered for six embankments located from 89.670 km to 93.100 km. Mitigation measures are unlikely to be required for the four embankments located around the end and side of Longwall 33 on account of the large offset distances from this longwall.

With an appropriate management plan in place, it is considered that potential impacts on railway embankments can be managed during the mining of the proposed longwalls, even if actual subsidence movements are greater than the predictions or substantial non-conventional movements occur.

Fig. 6.13 Embankment on Up side (downstream side) of embankment at 87.331 km

Fig. 6.14 Embankment on Up side (upstream side) of embankment at 88.496 km

Fig. 6.15 Embankment on Up side (upstream side) of embankment at 89.785 km

Fig. 6.16 Embankment on Up side (upstream side) of Redbank Creek embankment at 91.265 km

6.2.11. Railway Cuttings

There are ten cuttings within the SMP Area, and a summary is provided in Table 6.13.

Table 6.13 Railway Cuttings within SMP Area

Kilometrage (km)	Length (mm)	Height (mm)	Description	Location relative to Proposed Longwalls
87.550 km to 87.665 km	115	17	Picton Railway Tunnel north portal – battered, weathered shale	Approx. 350 m to side of LW33
87.850 km to 87.890 km	50	3	Picton Railway Tunnel south portal – battered, weathered shale	Approx. 470 m to side of LW33
88.290 km to 88.430 km	140	10	Battered, weathered shale, tree vegetation on both sides. Old disused concrete platform on UP side	Approx. 410 m to side of LW33
88.740 km to 89.040 km	300	14	Connellan Crescent Overbridge cutting – battered, weathered shale with tree vegetation on UP side	Approx. 380 m to end of LW33
89.470 km – 89.650 km	180	13	Battered, weathered shale, tree vegetation on UP side	Approx. 380 m to side of LW32
90.000 km to 90.200 km	200	6	Battered, weathered shale	Above LW32
90.370 km to 90.550 km	280	4	Battered, weathered shale	Above LW31
90.900 km to 91.100 km	200	2-3	Bridge St Overbridge - Near-vertical sandstone, high strength, slightly weathered	Above LW29
91.450 km to 91.700 km	250	2	Battered, weathered sandstone and shale	Above LW28
92.100 km to 92+1030 km	800	25	Deviation Cutting - battered and benched with erosion protection and drainage structures. Geological fault visible on UP side at 92.850 km	Above LW29

Photographs of railway cuttings within the SMP Area are shown in Fig. 6.19 to Fig. 6.23.

It can be seen from Table 6.13 that the cuttings located directly above the proposed Longwalls 31 and 32 are relatively minor in size. These cuttings will experience the full range of subsidence movements during the extraction of the proposed longwalls.

The cuttings located above approved Longwalls 28 and 29 will experience the full range of the predicted subsidence movements during the extraction of the Longwalls 28 to 30. The cuttings will experience a small amount of additional subsidence, tilt and curvature due to the extraction of the proposed longwalls.

The five cuttings between 87.550 km and 89.650 km are located more than 350 metres to the side or end of Longwall 33. These cuttings are expected to experience less than 50 mm of vertical subsidence with negligible tilts, curvatures and strains.

It is extremely unlikely that the cuttings will experience impacts during the mining of the proposed longwalls, particularly the low height cuttings in weathered shale. Potential impacts on the low height cuttings will be managed primarily by visual inspections and maintaining clear access for inspections in the cess. Ground surveys along the main railway corridor monitoring line (ARTC line) will also be undertaken.

While the cutting between 90.900 km to 91.100 km consists of near vertical sandstone faces, the potential for impacts is low due to its low height. Survey marks have been installed every 20 metres along the tops of the cutting to monitor differential movements along and across it.

The potential for mine subsidence impacts on the Deviation Cutting has been reduced through design by GHD Geotechnics. Geotechnical investigations by GHD Geotechnics advise that the cutting is within (progressively upwards) Ashfield Shale, Minchinbury Sandstone and Bringelly Shale units of the Wianamatta Group.

The cutting faces have been designed with broad batter slopes of 1:1 or less, with benches spaced at elevations no greater than 10 metres in height. The benches will allow access on the cutting faces for inspections and monitoring during future mining and to undertake mitigation and/or remediation works if required. Vehicular access tracks are located on both sides of the track within the floor of the cutting.

Flexible erosion protection measures have been installed on the cutting faces such as vegetative cover and wire mesh incorporating vegetative matting, in preference to stiff inclusions such as rock anchors and shotcrete, in recognition that the cutting will experience future mine subsidence movements.

A geological fault was identified on the Up side at 92.850 km and a photograph is shown in Fig. 6.23. With increasing exposure to the elements on the Up side, material below the fault plane became detached from the cutting batters. Surveys confirmed that the rate of movement of the rock mass was of a slip-stick nature and primarily linked to rain events. Material was removed from the cutting face with excavators on two occasions. Concrete jersey barriers were located at the base of the cutting to further minimise the potential for fallen material to reach the track until reprofiling work is completed in early 2015. This section of the cutting is being re-profiled as a permanent solution to prevent ongoing instability.

The Deviation Cutting will be monitored by ground surveys and visual inspections during the mining of Longwall 28. Survey prisms located on the rail track (sleepers) and cutting face in the vicinity of the fault will also be monitored by automated total station. A weather station has also been installed.

With an appropriate management plan in place, it is considered that potential impacts on railway cuttings can be managed during the mining of the proposed longwalls, even if actual subsidence movements are greater than the predictions or substantial non-conventional movements occur.

Fig. 6.17 Railway Cutting 88.290 km to 88.430 km looking north to disused concrete platform

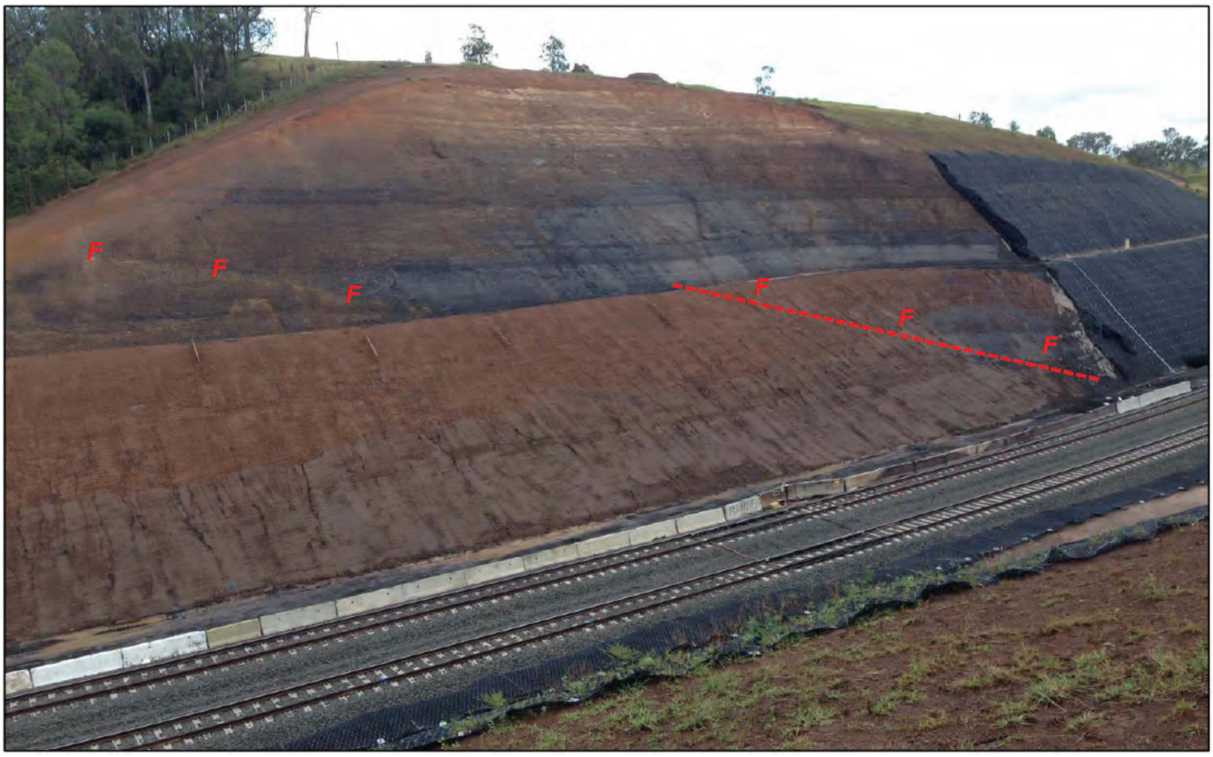
Fig. 6.18 Connellan Crescent Overbridge Railway Cutting 89.740 km to 89.040 km looking south

Fig. 6.19 Railway Cutting 89.470 km to 89.650 km above Longwall 32 looking north

Fig. 6.20 Railway Cutting 90.370 km to 90.500 km above Longwall 31 looking north

Fig. 6.21 Railway Cutting beneath Bridge St Overbridge at 91.000 km looking south

Fig. 6.22 Deviation cutting looking north, prior to the installation of flexible erosion protection measures



Marked up photograph courtesy GHD Geotechnics

Fig. 6.23 Deviation cutting looking south with fault at 92.850 km, prior to the completion of final drainage and revegetation works

6.2.12. Communications and Signalling Infrastructure

The track between Picton Station and Tahmoor Railway Station is controlled by the new Microlok signalling system, which sends coded digital signals through the rails to locate trains within this section of track. The mining of the proposed longwalls does not affect the Microlok system.

There is also an optical fibre cable that is used for CCTV surveillance. The cable is buried in conduit and it is considered that the potential for impacts on the optical fibre cable is very low. No impacts have been observed during the mining of Longwalls 25 to 28 directly beneath the cable.

There are two fully redundant single pole radio towers within the SMP Area. One is located on the top of the former Redbank Railway Tunnel and the other is located on top of the Picton Railway Tunnel.

6.2.13. Services Crossing the Rail Corridor

Public utility services infrastructure cross the rail corridor at a number of locations within the SMP Area. The following crossings have been identified:

- Two potable water pipes cross beneath the Main Southern Railway at 89.080 km (Connellan Crescent) and 89.326 km (Thirlmere Way);
- One sewer pipe crosses beneath the Main Southern Railway at 91.21 km (Bridge Street);
- Two aerial powerlines cross over the Main Southern Railway at 89.080 km (Connellan Crescent) and 92.560 km (Deviation Cutting); and
- Two telecommunications cables beneath the Main Southern Railway at 89.326 km (Thirlmere Way) and 92.200 km (conduit beneath the northern end of the new Deviation track).

Subsidence predictions and impact assessments for public utility infrastructure are provided later in this Chapter. As part of the management measures for each infrastructure item, monitoring will be undertaken at each of the rail crossings by ground survey along the rail corridor and visual inspections.

6.3. Picton to Mittagong Loop Line

6.3.1. Description of the Picton Mittagong Loop Line

The proposed Longwalls 33 to 37 will extract directly beneath the Picton to Mittagong Loop Line, as shown in Drawing No. MSEC647-13.

The Picton to Mittagong Loop Line is part of the former alignment of the Main South Line. It was built in 1867. The Loop Line was bypassed in 1919 following the construction of a new double track deviation, which is the current alignment of the Main Southern Railway.

The original alignment of the Loop Line passed through the Mushroom Tunnel and along an old disused embankment, which can still be found near 87.500 km on the Main Southern Railway, forming a triangular wedge of land that is bounded by three embankments. An old brick culvert is located in the old embankment.

Transport Heritage NSW, operating the Trainworks Railway Museum at Thirlmere, holds a licence to use the track, and runs tourist trains between Thirlmere and Picton on most Sundays and public holidays.

The Loop Line junction to the Main Southern Railway is located at approximately 85.5 km, just north of the Picton Viaduct. The Loop Line runs as a “triple track” adjacent to the dual tracks of the Main Southern Railway until it swings away towards Thirlmere near the Up Branch Landmark at 87.152 km, which is located just outside the SMP Area.

The Loop Line is a single line jointed track, which is defined by ARTC as rails that can move through the rail/sleeper fastenings and which have standard joints with a 6 mm gap installed at neutral temperature. The rails are generally fixed to steel or timber sleepers (but not concrete).

The 83 lb rails on the Loop Line are jointed at approximately 12 metre (40 foot) lengths, staggered between the Up and Down rail. Some rails are 9 metres (30 foot) long. The rails are generally supported by steel sleepers within the SMP Area, except at the joints, which are supported by timber sleepers. The rails are fixed to the sleepers using a wedge fastening system.

A photograph of a section of Loop Line above the proposed longwalls is provided in Fig. 6.24.

Fig. 6.24 Picton to Mittagong Loop Line at 88.980 km looking north

6.3.2. Predictions for the Picton to Mittagong Loop Line

The predicted profiles of incremental and total conventional subsidence and change in grade along the alignment of the Picton to Mittagong Loop Line, resulting from the extraction of the proposed longwalls, are shown in Fig. E.12 in Appendix E. The predicted profiles of the grade along the alignment of the railway after the extraction of the proposed longwalls, are also shown in this figure.

The predicted profiles of incremental and total conventional horizontal movement across the alignment of the Picton to Mittagong Loop Line, change in track cant and long twist, resulting from the extraction of the proposed longwalls, are provided in Fig. E.13 in Appendix E.

A summary of the maximum predicted values of incremental conventional subsidence, change in grade and curvature along the alignment of the Picton to Mittagong Loop Line, due to the extraction of each of the proposed longwalls, is provided in Table 6.14. A summary of the maximum predicted values of total conventional subsidence, change in grade and curvature along the alignment of the railway, after the extraction of each of the proposed longwalls, is provided in Table 6.15.

Table 6.14 Maximum Predicted Incremental Conventional Subsidence, Change in Grade and Curvature along the Picton to Mittagong Loop Line Resulting from the Extraction of LWs 31 to 37

Longwall	Maximum Predicted Incremental Subsidence (mm)	Maximum Predicted Incremental Change in Grade (%)	Maximum Predicted Incremental Hogging Curvature (1/km)	Maximum Predicted Incremental Sagging Curvature (1/km)
Due to LW31	< 20	< 0.10	< 0.01	< 0.01
Due to LW32	< 20	< 0.10	< 0.01	< 0.01
Due to LW33	425	0.25	0.02	0.05
Due to LW34	675	0.50	0.05	0.11
Due to LW35	675	0.50	0.05	0.11
Due to LW36	675	0.40	0.03	0.06
Due to LW37	700	0.40	0.03	0.06

Table 6.15 Maximum Predicted Total Conventional Subsidence, Change in Grade and Curvature along the Picton to Mittagong Loop Line Resulting from the Extraction of Longwalls 22 to 37

Longwall	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Change in Grade (%)	Maximum Predicted Total Hogging Curvature (1/km)	Maximum Predicted Total Sagging Curvature (1/km)
After LW32	< 20	< 0.10	< 0.01	< 0.01
After LW33	425	0.25	0.02	0.05
After LW34	725	0.50	0.05	0.11
After LW35	950	0.55	0.06	0.11
After LW36	1,025	0.40	0.07	0.11
After LW37	1,050	0.45	0.07	0.11

The values provided in the above table are the maximum predicted total conventional subsidence parameters which occur within the SMP Area.

The predicted strains for the railway have been based on the statistical analysis of strains provided in Section 4.5. The railway is a linear feature and, therefore, the most relevant distributions of strain are the maximum strains measured anywhere along whole monitoring lines above the previously extracted longwalls, which are discussed in Section 4.5.2.

The railway will also experience transient subsidence movements as each of the longwalls are extracted directly beneath it. The railway is essentially perpendicular to the proposed Longwalls 33 and 34 and is oblique to the proposed Longwalls 35 to 37. The predicted transient tilts, curvatures and strains along the alignment of the railway, therefore, are less than the predicted final values. This is illustrated in Fig. E.14, which shows the development of subsidence, changes in grade and long bay lengths due to the extraction of each of the proposed longwalls, for every 50 metres of travel, which represents approximately one week of mining. It can be seen from this figure, that subsidence will firstly develop at the city (northern) end of the track during the mining of each longwall. The active subsidence zone will then migrate along the track towards the south as the longwalls progress.

The transient tilts, curvatures and strains across the alignment of the Picton to Mittagong Loop Line, however, are greater than the predicted final values.

The predictions for the infrastructure and services associated with the Picton to Mittagong Loop Line are provided in the impact assessments for each of these features in the following sections.

6.3.3. Changes in Track Geometry

Mine subsidence will result in changes to track geometry. Changes to track geometry are described using a number of parameters:-

- Vertical misalignment (top) – vertical deviation of the track from design;
- Horizontal misalignment (line) – horizontal deviation of the track from design;
- Changes in Track Cant – changes in superelevation across the rails of each track from design; and
- Track Twist – changes in superelevation over a defined travel distance, such as 13.2 metres for long twist.

Predictions of conventional subsidence, tilt and horizontal movement have been made at 5 metre intervals along the railway to calculate each track geometry parameter at any stage of mining. The predicted changes in cant and long twist for the railway are shown in Fig. E.13.

A summary of the maximum predicted values of incremental conventional horizontal movement across the alignment of the Picton to Mittagong Loop Line, change in cant and long twist, due to the extraction of each of the proposed longwalls, is provided in Table 6.16. A summary of the maximum predicted values of total conventional horizontal movement across the alignment of the railway, change in cant and long twist, after the extraction of each of the proposed longwalls, is provided in Table 6.17.

Table 6.16 Maximum Predicted Incremental Horizontal Movement Across the Picton to Mittagong Loop Line, Change in Cant and Long Twist Resulting from the Extraction of Longwalls 31 to 37

Longwall	Maximum Predicted Incremental Horizontal Movement Across the Alignment (mm)	Maximum Predicted Incremental Change in Cant (mm)	Maximum Predicted Incremental Long Twist over 13.2 m Bay lengths (mm)
Due to LW31	< 5	< 1	< 1
Due to LW32	< 5	< 1	< 1
Due to LW33	20	2	< 1
Due to LW34	25	2	1
Due to LW35	10	1	< 1
Due to LW36	50	5	1
Due to LW37	55	5	1

Table 6.17 Maximum Predicted Total Horizontal Movement Across the Picton to Mittagong Loop Line, Change in Cant and Long Twist Resulting from the Extraction of Longwalls 22 to 37

Longwall	Maximum Predicted Total Horizontal Movement Across the Alignment (mm)	Maximum Predicted Total Change in Cant (mm)	Maximum Predicted Total Long Twist over 13.2 m Bay lengths (mm)
After LW32	< 5	< 1	< 1
After LW33	20	2	< 1
After LW34	25	2	1
After LW35	20	2	1
After LW36	55	5	1
After LW37	60	6	1

The values provided in the above table are the maximum predicted total conventional subsidence parameters which occur within the SMP Area, including the predicted movements resulting from the extraction of the approved Longwalls 22 to 30.

The predicted values are substantially less than the maximum allowable deviations for the Loop Line. When compared to the maximum allowable deviations for the full speed track on the Main Southern Railway in Table 6.3, it can be seen from that the maximum allowable deviations specified in the ARTC National Code of Practice are an order of magnitude greater than the predicted conventional subsidence movements for the Loop Line. For example, the maximum allowable change in cant is 40 to 75 mm over a length of 1505 mm before the trains are stopped. In mining terminology, this represents a tilt of approximately 27 to 50 mm/m, which is substantially greater than the maximum predicted conventional tilt of 6 mm/m due to mine subsidence.

As the trains operate at a slow speed along the Loop Line, the maximum allowable deviations will be less than those specified along the Main Southern Railway. It is therefore expected that in general, mining-induced changes in track geometry will impose minor changes to the existing track geometry.

It is, however, possible that mine subsidence could result in changes in track geometry that exceed operating standards for the Loop Line in the following ways:-

- Track loses support as the result of failure or collapse of culverts or embankment slopes, which is discussed in Sections 6.3.6 and 6.3.7; or
- Development of substantial non-conventional ground movements.

Non-conventional movements can occur and have occurred in the Southern Coalfield as a result of, among other things, valley upsidence and closure movements and anomalous movements. The impact assessments for the valley related movements at the stream crossings are provided in Section 6.2.9. Discussion on the likelihood and nature of anomalous movements is provided in Sections 3.4 and 4.7.

An example of substantial non-conventional movement in the Southern Coalfield occurred above Appin Longwall 408. In this case, a low angle thrust fault was re-activated in response to mine subsidence movements, resulting in differential vertical and horizontal movements across the fault. Observations at the site showed that the non-conventional movements developed gradually and over a long period of time. Regular ground monitoring across the fault indicated that the rate of differential movement was less than 0.5 mm/day at the time non-conventional movements could first be detected. Subsequently as mining progressed, the rate of differential movement increased to a maximum of 28 mm/week. In comparison with the National Code of Practice, the maximum allowable deviations in track geometry are much larger than the measured daily rates of change due to mining.

Two localised non-conventional subsidence events have adversely impacted on track geometry. Differential subsidence movements developed gradually at each site, such that visual inspections could detect small changes at an early stage. This allows time to resurface the track in between the passing of trains and return track geometry parameters to within safety limits. In the case of the Loop Line, there is ample time between trains, which generally run only on weekends.

It is therefore considered that while non-conventional movements may potentially result in adverse changes to track geometry, the potential risk to track safety can be managed through early detection via monitoring and early response through the implementation of triggered response plans. A number of management measures are proposed to manage changes in track geometry:-

- Assess pre-mining track condition and adjust track (if necessary) so that pre-mining track geometry is within normal operating standards for the Loop Line prior to the development of subsidence;
- Identify potential sites of non-conventional movement, such as creeks and geological structures;
- Install a monitoring system, which includes, among other things, the monitoring of ground movements along the Loop Line;
- Regularly review and assess the monitoring data;
- Conduct regular visual inspections of the track prior to the operation of the Loop Line; and
- Adjust the track in response to monitoring results during mining if required to keep the track well within safety limits.

With an appropriate management plan in place, it is considered that potential impacts on track geometry can be managed during the mining of the proposed longwalls, even if actual subsidence movements are greater than the predictions or substantial non-conventional movements occur.

6.3.4. Changes in Track Grades

The Loop Line climbs steadily in a southbound direction through the SMP Area from Picton to Thirlmere.

The maximum gradient along the Loop Line within the SMP Area is 1 in 37 near 88.5 km above the proposed Longwall 35.

The predicted changes in track gradient along the Loop Line and the predicted gradients along the track after the completion of mining are shown in Fig. E.12.

It should be noted, however, that the locations of steeper grades exist over relatively short lengths (a couple of hundred metres), which is of less concern to trains than steep grades over longer lengths (kilometres).

6.3.5. Changes in Rail Stress

Mine subsidence will results in changes in distances between the sleepers, transferring rail stress into the rails. The amount of transfer, however, will be limited by the short 9 to 12 metres lengths of rail, which are separated by 6 mm wide joints, and the types of fastenings used to secure rails to the sleepers.

It is possible that mining-induced tensile ground strains could result in opening of joints. Mining-induced compressive ground strains could result in closing of joints. The gaps between rails at the joints can, however, be reset prior to the passage of trains. In the case of the Loop Line, there is ample time between trains, which generally run only on weekends.

It is therefore considered that while the proposed extraction of Longwalls 33 to 37 may potentially result in adverse changes to the rail joints, the potential risk to track safety can be managed through early detection via monitoring and early response through the implementation of triggered response plans. A number of management measures are proposed to manage potential impacts on rail joints :-

- Assess pre-mining track condition and adjust track (if necessary) so that pre-mining rail joints are within normal operating standards for the Loop Line prior to the development of subsidence;
- Identify potential sites of non-conventional movement, such as creeks and geological structures;
- Install a monitoring system, which includes, among other things, the monitoring of ground movements along the Loop Line;

- Regularly review and assess the monitoring data;
- Conduct regular visual inspections of the track, including rail joints and fittings, prior to the operation of the Loop Line; and
- Adjust the track in response to monitoring results during mining if required to keep the track, including rail joints and fittings, well within safety limits.

With an appropriate management plan in place, it is considered that potential impacts on the track can be managed during the mining of the proposed longwalls, even if actual subsidence movements are greater than the predictions or substantial non-conventional movements occur.

6.3.6. Predictions and Impact Assessment for the Line Culverts

There are five drainage culverts associated with the Picton to Mittagong Loop Line within the SMP Area and their locations are shown in Drawing No. MSEC647-13. A summary is provided in Table 6.10.

Table 6.18 Loop Line Culverts within SMP Area

Kilometrage (km)	Width (mm)	Height (mm)	Description	Location relative to Proposed Longwalls
87.330 km	1200 dia		Brick arch culvert (circa 1919, part of section built to join onto Main Southern Railway)	Approx. 380 m from LW33
87.850 km	1500 dia		Brick arch culvert (circa 1919, part of section built to join onto Main Southern Railway)	Above LW33
88.400 km	2500 dia		Stone arch culvert (circa 1867)	Chain pillar between LWs 34 and 35
88.980 km	2500 dia		Stone arch culvert (circa 1867, restored as part of Stonequarry Estate development)	Above LW36
89.629 km	3200	3000	Stone arch culvert (circa 1867) with brick wingwalls (circa 1919) on the upstream side to support vehicular track	Approx. 60 m from side of LW37

Photographs of the five culverts are shown in Fig. 6.25 to Fig. 6.29.

A summary of the maximum predicted conventional subsidence and valley related movements for the Loop Line culverts located within the SMP Area is provided in Table 6.19.

Table 6.19 Predicted Conventional Subsidence and Valley Related Movements for the Picton to Mittagong Loop Line Drainage Culverts within the SMP Area

Label	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Tilt (mm/m)	Maximum Predicted Total Hogging Curvature (1/km)	Maximum Predicted Total Sagging Curvature (1/km)	Maximum Predicted Total Upsidence (mm)	Maximum Predicted Total Closure (mm)
87.330 km	25	0.5	< 0.01	< 0.01	50	100
87.850 km	775	3.0	0.02	0.05	425	650
88.400 km	875	2.0	0.02	0.02	125	175
88.980 km	1,000	4.5	0.05	0.06	100	150
89.629 km	125	0.5	0.01	< 0.01	75	125

The values provided in the above table are the maximum predicted parameters within a 20 metre radius of each culvert, including the predicted movements resulting from the extraction of the approved Longwalls 22 to 30. The predicted tilts are the maximum values at the completion of any or all longwalls, whichever are the greatest. The predicted curvatures are the maximum values which occur at any time during or after the extraction of each of the proposed longwalls.

It is expected that mining-induced conventional tilts will not significantly impact the drainage flows in the culverts as the changes in grade are expected to be less than 1 %. It is, however, recommended that the culverts be cleared of vegetation and debris prior to mining.

The main risk identified with all the brick arch and stone culverts is the potential for physical impacts to occur. It is possible that these culverts will experience some cracking and spalling of the masonry as a result of mining the proposed longwalls. Cracking may occur in the masonry arch or in the headwalls. These can be reinforced prior to mining or subsequently repaired as required. In the case of the Loop Line, there is ample time between trains, which generally run only on weekends.

It is therefore considered that while the proposed extraction of Longwalls 33 to 37 may potentially result in impacts on the culverts, the potential risk to track safety can be managed through early detection via monitoring and early response through the implementation of triggered response plans. A number of management measures are proposed to manage potential impacts on rail joints :-

- Assess pre-mining culvert condition prior to the development of subsidence;
- Consider and implement mitigation measures, if required, which may include measures such as:
    - Installation of steel reinforcement structures within the culvert opening;
    - Installation of steel reinforcement within the masonry itself (as undertaken at Redbank Creek culvert); or
    - Installation of a steel sleave within the culvert opening (as undertaken at the skew culvert);
- Install a monitoring system, which includes, among other things, the monitoring of ground movements on and around the culvert, and track geometry above the culvert;
- Regularly review and assess the monitoring data;
- Conduct regular visual inspections of the culvert; and
- Repair the culvert if required.

With an appropriate management plan in place, it is considered that potential impacts on the culverts can be managed during the mining of the proposed longwalls, even if actual subsidence movements are greater than the predictions or substantial non-conventional movements occur.

Fig. 6.25 Loop Line Culvert at 87.330 km

Fig. 6.26 Loop Line Culvert at 87.850 km

Fig. 6.27 Loop Line Culvert at 88.400 km

Fig. 6.28 Loop Line Culvert at 88.980 km

Fig. 6.29 Loop Line Culvert with wingwalls at 89.629km

6.3.7. Loop Line Embankments

There are five Loop Line embankments within the SMP Area, and a summary is provided in Table 6.20.

Table 6.20 Loop Line Embankments within SMP Area

Kilometrage (km)	Length (mm)	Height (mm)	Description	Location relative to Proposed Longwalls
Embankment at 87.331km	360	14	Earth embankment	Approx. 250 m to side of LW33
Embankment at 87.850km	260	11	Earth embankment	Above LW33
Embankment at 88.400km	200	8	Earth embankment	Above LWs 34 and 35
Embankment at 88.980km	80	8	Earth embankment	Above LW36
Embankment at 89.629km	280	12	Earth embankment	Approx. 60 m from side of LW37

The embankments are typically constructed with local fill material and contain relatively steep batters. The likelihood of impacts on the embankments is considered to be relatively low provided that the culverts remain serviceable and do not become blocked.

The embankments may experience tensile surface cracking during mining, however, these can be readily treated before they develop into a safety hazard. Compressive impacts are less likely as the voids within the embankment can accommodate some compressive movement.

Tahmoor Colliery will consider mitigation measures before each embankment experiences subsidence movements. Mitigation works could include, for example, cleaning out of the culverts and drainage lines beneath the embankments, or the stabilisation of the batters.

Potential impacts on embankments on the Loop Line can be managed using measures include:

- Management of potential impacts on the culvert within the embankment, which is the key element of the management strategy. This is discussed in the previous Section 6.3.6;
- Assess pre-mining condition of the embankment;
- Consider and implement mitigation measures, such as cleaning out of the culverts and drainage lines beneath the embankments;
- Install a monitoring system, which includes, among other things, the monitoring of ground movements on and around the embankment;
- Regularly review and assess the monitoring data;
- Conduct regular visual inspections of the embankment; and
- Seal cracks that develop on the embankment if required.

With an appropriate management plan in place, it is considered that potential impacts on Loop Line embankments can be managed during the mining of the proposed longwalls, even if actual subsidence movements are greater than the predictions or substantial non-conventional movements occur.

6.3.8. Loop Line Cuttings

There are three cuttings within the SMP Area, and a summary is provided in Table 6.21.

Table 6.21 Loop Line Cuttings within SMP Area

Kilometrage (km)	Length (mm)	Height (mm)	Description	Location relative to Proposed Longwalls
Cutting at 88.1 km	150	15	Battered, weathered shale	Above LW32
Cutting at 88.7 km	220	8	Battered, weathered shale	Above LW35 & LW36
Cutting at 89.3 km	300	4	Battered, weathered shale	Above LW37

A photograph of the low height cutting at 88.7 km was shown previously in Fig. 6.24.

It can be seen from Table 6.21 that the cuttings within the SMP Area are relatively minor in size. The cuttings will experience the full range of subsidence movements during the extraction of the proposed longwalls.

It is extremely unlikely that the cuttings will experience impacts during the mining of the proposed longwalls. Potential impacts on the low height cuttings will be managed primarily by visual inspections and maintaining clear access for inspections in the cess. Ground surveys along the Loop Line corridor monitoring line will also be undertaken.

With an appropriate management plan in place, it is considered that potential impacts on Loop Line cuttings can be managed during the mining of the proposed longwalls, even if actual subsidence movements are greater than the predictions or substantial non-conventional movements occur.

6.3.9. Recommendations for the Picton Mittagong Loop Line

Tahmoor Colliery and Transport Heritage NSW (THNSW), operating the Trainworks Railway Museum at Thirlmere, have previously managed potential mine subsidence impacts on the Picton to Mittagong Loop Line due to the extraction of Longwall 21, when a corner of the panel extracted directly beneath the Loop Line. A subsidence management plan was also developed in consultation and agreement with the then New South Wales Rail Transport Museum to manage the low likelihood risks associated with the mining of Longwalls 24 to 26 at a remote distance from the Loop Line.

It is recommended that Tahmoor Colliery and THNSW develop a new plan to manage potential impacts during the mining of the proposed Longwalls 33 to 37.

In the case of the Loop Line, there is ample time between trains, which generally run only on weekends. It is therefore possible to undertake monitoring and contingent response measures during weekdays prior to trains running.

With an appropriate management plan in place, it is considered that potential impacts on Loop Line can be managed during the mining of the proposed longwalls, even if actual subsidence movements are greater than the predictions or substantial non-conventional movements occur.

6.4. Local Roads

The locations of local roads within the SMP Area are shown in Drawing No. MSEC647-14. The descriptions, predictions and impact assessments for the local roads are provided in the following sections.

6.4.1. Descriptions of the Local Roads

Approximately 14.6 kilometres of road are located within the SMP Area, of which 4.7 kilometres will be directly mined beneath by the proposed longwalls. Their locations are shown in Drawing No. MSEC647-14.

The main road is Remembrance Drive (formerly the Hume Highway), which connects Tahmoor with Picton to the north, and Bargo to the south. Some main services infrastructure is located along Remembrance Drive, including gas mains and water mains. Remembrance Drive crosses over Longwall 32 and passes beyond the southern ends of Longwalls 33 and 34. Several retail and commercial buildings are also located along Remembrance Drive within the SMP Area.

There are two main roads that connect Thirlmere and Picton. Bridge Street is located directly above Longwalls 31 and 32. Thirlmere Way is located directly above Longwalls 32 and 37. A number of smaller local roads also run directly above Longwalls, an example being Stonequarry Creek Road, which runs above Longwalls 35 to 37.

6.4.2. Predictions for the Local Roads

The local roads are located across the SMP Area and, therefore, are expected to experience the full range of the predicted mine subsidence movements. The maximum predicted subsidence parameters resulting from the extraction of the proposed longwalls are provided in Chapter 4. Specific subsidence predictions for Remembrance Drive, Thirlmere Way, Bridge Street and Stonequarry Creek Road have been provided below, which illustrate the variations in the predicted subsidence parameters across the mining area.

The predicted profiles of incremental and total conventional subsidence, tilt and curvature along the alignments of Remembrance Drive, Bridge Street, Stonequarry Creek Road and Thirlmere Way, resulting from the extraction of the proposed longwalls, are shown in Figs. E.15, E.16, E.17 and E.18, respectively, in Appendix E.

A summary of the maximum predicted values of incremental conventional subsidence, tilt and curvature for Remembrance Drive, Thirlmere Way, Bridge Street and Stonequarry Creek Road, due to the extraction of each of the proposed longwalls, is provided in Table 6.22. A summary of the maximum predicted values of total conventional subsidence, tilt and curvature for these roads, after the extraction of each of the proposed longwalls, is provided in Table 6.23.

Table 6.22 Maximum Predicted Incremental Conventional Subsidence, Tilt and Curvature for Remembrance Drive, Bridge Street, Stonequarry Drive and Thirlmere Way

Location	Longwall	Maximum Predicted Incremental Subsidence (mm)	Maximum Predicted Incremental Tilt (mm/m)	Maximum Predicted Incremental Hogging Curvature (1/km)	Maximum Predicted Incremental Sagging Curvature (1/km)
Remembrance Drive	Due to LW31	40	< 0.5	< 0.01	< 0.01
	Due to LW32	250	1.0	0.05	0.01
	Due to LW33 to LW37	< 20	< 0.5	< 0.01	< 0.01
Thirlmere Way	Due to LW31 to LW32	70	0.6	< 0.01	< 0.01
	Due to LW33 to LW37	250	1.5	0.01	< 0.01
Bridge Street	Due to LW31	700	5.0	0.05	0.10
	Due to LW32	700	3.5	0.03	0.07
	Due to LW33 to LW37	< 20	< 0.5	< 0.01	< 0.01
Stonequarry Creek Road	Due to LW31 to LW33	< 20	< 0.5	< 0.01	< 0.01
	Due to LW34	30	< 0.5	< 0.01	< 0.01
	Due to LW35	150	1.0	0.02	< 0.01
	Due to LW36	650	5.0	0.05	0.11
	Due to LW37	675	4.0	0.06	0.11

Table 6.23 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature for Remembrance Drive, Bridge Street, Stonequarry Drive and Thirlmere Way

Location	Longwall	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Tilt (mm/m)	Maximum Predicted Total Hogging Curvature (1/km)	Maximum Predicted Total Sagging Curvature (1/km)
Remembrance Drive	After LW30	< 20	< 0.5	< 0.01	< 0.01
	After LW31	50	< 0.5	0.05	< 0.01
	After LW32	300	1.0	0.06	0.01
	After LW37	300	1.0	0.06	0.01
Thirlmere Way	Due to LW31 to LW32	80	0.5	< 0.01	0.02
	Due to LW33 to LW37	310	1.7	< 0.01	< 0.01
Bridge Street	After LW30	1,200	5.5	0.09	0.13
	After LW31	1,225	5.5	0.09	0.13
	After LW32	1,225	4.5	0.09	0.13
	After LW37	1,225	4.5	0.09	0.13
Stonequarry Creek Road	After LW35	175	1.5	0.02	< 0.01
	After LW36	750	5.0	0.06	0.10
	After LW37	1,075	4.5	0.08	0.11

The values provided in the above table are the maximum predicted total conventional subsidence parameters which occur along the roads within the SMP Area, including the predicted movements resulting from the extraction of the approved Longwalls 22 to 30.

The predicted strains for the local roads have been based on the statistical analysis of strains provided in Section 4.5. The roads are linear features and, therefore, the most relevant distributions of strain are the maximum strains measured anywhere along whole monitoring lines above the previously extracted longwalls, which are discussed in Section 4.5.2.

6.4.3. Impact Assessments for the Local Roads

Approximately 24.5 kilometres of asphaltic pavement lie directly above the previously extracted Longwalls 22 to 27 and a total of 46 impact sites have been observed. The observed rate of impact equates to an average of one impact for every 533 metres of pavement. The impacts were minor and did not present a public safety risk. A selection of photographs is provided in Fig. 6.30.

Lintina Street (most severe to date)

Small bump on Remembrance Drive

Brundah Road (typical impact to pavement)

Patterson Street (typical impact to kerb)

Photographs courtesy of Tahmoor Colliery and Colin Dove

Fig. 6.30 Photographs of impacts to road pavements and kerbs during the mining of Longwalls 22 to 27

Impacts have also been observed to concrete kerbs and gutters. The impacts are most commonly focussed around driveway laybacks and involve cracking, spalling or buckling. A typical buckling impact is shown in Fig. 6.30.

Some drainage pits have been damaged during the mining of Longwalls 24A and 25 in Janice Drive and Abelia Street.

Approximately 14.6 kilometres of road are located within the SMP Area. The majority of these roads are located above Longwalls 31 to 32 and 36 to 37. Approximately 4.7 kilometres of road will be directly mined beneath by the proposed Longwalls 31 to 37. It is expected that minor impacts will occur to the local roads during mining, similar in frequency and severity to those experienced during the mining of Longwalls 22 to 27.

The maximum predicted tilt of 5.5 mm/m, or a change in gradient of 0.55% is very small considering that sealed roads are usually constructed with gradients of approximately 3.0%. The resulting change in road superelevation or gradient is unlikely to affect the serviceability of the roads.

Tahmoor Colliery and Wollondilly Shire Council have developed and acted in accordance with an agreed risk management plan to manage potential impacts to local roads during the mining of Longwalls 22 to 30. The management plan provides for ground and visual monitoring of road pavements. If impacts occur to the road network, Wollondilly Shire Council is able to quickly repair the pavement, if required.

The management plan is reviewed periodically by Tahmoor Colliery and Wollondilly Shire Council.

It is recommended that Tahmoor Colliery and Wollondilly Shire Council continue to develop management plans to manage potential impacts to roads during the mining of the proposed longwalls.

Thirlmere Way runs along the top of ridge within the SMP Area. As shown in Drawing No. MSEC647-12, steep slopes are located on either side of the road directly above the end of proposed Longwall 32 and between Longwalls 31/32 and Longwalls 36/37. The road narrows in this section, with no shoulders on either side of the pavement. Small but deeply incised valleys are located adjacent to the road on the southern side. It is possible that surface cracks or slippage may develop near the top of the ridge as a result of the extraction of the proposed longwalls, and that these may intersect with the Thirlmere Way pavement. Whilst repairs can be readily undertaken, traffic would need to be managed carefully during these works.

If the predicted movements were to be exceeded by 25% to 100%, the impacts on the roads would increase slightly, but the remedial measures would be similar.

6.4.4. Impact Assessments for the Local Roads Based on Increased Predictions

If the actual tilts exceeded those predicted by a factor of 2 times, the maximum tilt at the local roads would be 11 mm/m (i.e. 1.1 %), or a change in grade of 1 in 90. The potential impacts on the serviceability and surface water drainage of the roads would not be expected to significantly increase, as the maximum change in grade would still be small, in the order of 1 %. If any additional ponding or adverse changes in surface water drainage were to occur as the result of mining, the local roads could be repaired using normal road maintenance techniques.

If the actual curvatures exceeded those predicted by a factor of 2 times, the maximum curvature at the local roads would be 0.26 km^{-1}, which represents a minimum radius of curvature of 3.8 kilometres. In this case, the incidence of cracking, stepping and heaving of the local road surfaces would increase directly above the proposed longwalls. It would still be expected that any impacts could be repaired using normal road maintenance techniques.

While the predicted ground movements are important parameters when assessing the potential impacts on the local roads, it is noted that the impact assessments were primarily based on historical observations from previous longwall mining in Tahmoor and the Southern Coalfield. The overall levels of impact on the local roads, resulting from the extraction of the proposed longwalls, are expected to be similar to those observed where longwalls have previously mined directly beneath roads in Tahmoor and in the Southern Coalfield.

6.4.5. Recommendations for the Local Roads

Tahmoor Colliery and Wollondilly Shire Council have developed and acted in accordance with an agreed risk management plan to manage potential impacts to local roads during the mining of Longwalls 22 to 30. It is recommended that this management plan is reviewed and updated to incorporate the proposed longwalls.

6.5. Road Drainage Culverts

6.5.1. Descriptions of the Road Drainage Culverts

There were 16 road drainage culverts identified along the local roads within the SMP Area. The locations of these culverts are shown in Drawing No. MSEC647-15 and details are provided in Table 6.24. There are also likely to be other drainage culverts beneath private driveways across the SMP Area.

The majority of the road drainage culverts are reinforced concrete pipes (RCP), with diameters ranging between 300 mm and 900 mm. There are two concrete box culverts on Bridge Street (BR-C1) and Stilton Lane (SL-C1) and a wrought iron culvert on Remembrance Drive (RE-C4).

6.5.2. Predictions for the Road Drainage Culverts

A summary of the maximum predicted values of conventional subsidence, tilt and curvature for the road drainage culverts, resulting from the extraction of the proposed longwalls, is provided in Table 6.24. The remaining drainage culverts beneath private driveways are located across the SMP Area and, therefore, could experience the full range of predicted subsidence parameters, which are summarised in Chapter 4.

Table 6.24 Predicted Conventional Subsidence, Tilt and Curvature at the Road Drainage Culverts within the SMP Area Resulting from the Extraction of Longwalls 22 to 37

Location	Culvert ID	Culvert Size And Type	Maximum Predicted Subsidence (mm)	Maximum Predicted Tilt (mm/m)	Maximum Predicted Hogging Curvature (1/km)	Maximum Predicted Sagging Curvature (1/km)
Bridge Street	BR-C4	Single RCP 600 mm dia	1,000	2	0.03	0.02
Bridge Street	BR-C5	Single RCP 600 mm dia	900	2.5	0.08	0.01
Bridge Street	BR-C6	N/A	775	0.5	0.03	0.02
Bridge Street	BR-C7	Box Culvert *	50	< 0.5	< 0.01	< 0.01
Connellan Crescent	CR-C1	Triple RCP 600 mm dia	20	< 0.5	< 0.01	< 0.01
Remembrance Drive	RE-C2	Single RCP 600 mm dia	350	4	0.06	< 0.01
Remembrance Drive	RE-C3	Single RCP 300 mm dia	200	1.5	0.02	< 0.01
Remembrance Drive	RE-C4	Single wrought iron culvert 450 mm dia	100	0.5	< 0.01	< 0.01
Stonequarry Creek Road	SC-C1	Single RCP 600 mm dia	125	0.5	< 0.01	< 0.01
Stonequarry Creek Road	SC-C2	Single RCP 600 mm dia	1,050	1.5	0.03	0.02
Stonequarry Creek Road	SC-C3	Single RCP 900 mm dia	1,000	1.5	0.02	0.02
Stilton Lane	SL-C1	RCP Box Culvert 1500 mm Square	175	1.5	0.02	< 0.01
Stilton Lane	SL-C2	N/A	950	4.5	0.06	0.05
Stilton Lane	SL-C3	Single RCP 600 mm dia	850	4	0.07	0.01
Thirlmere Way	TH-C1	Twin RCP 600 mm dia	30	< 0.5	< 0.01	< 0.01
Thirlmere Way	TH-C2	Single RCP 800 mm dia	100	0.5	< 0.01	< 0.01

Note: * denotes that the Bridge Street culvert overgrown and could not be measured.

The values provided in the above table are the maximum predicted parameters within a 20 metre radius of each culvert, including the predicted movements resulting from the extraction of the existing and approved Longwalls 22 to 30. The predicted tilts are the maximum values at the completion of any or all longwalls, whichever are the greatest. The predicted curvatures are the maximum values which occur at any time during or after the extraction of each of the proposed longwalls.

The culverts are located within drainage lines and could experience valley related movements in these locations. The maximum predicted upsidence, closure and compressive strains along the larger streams are discussed in Section 5.4. The maximum predicted valley movements at the smaller tributary crossing directly above the proposed longwalls are 300 mm upsidence and 400 mm closure.

6.5.3. Impact Assessments for the Road Drainage Culverts

The maximum predicted tilt for the culverts is 4.5 mm/m (i.e. 0.5 %, or 1 in 220). It is unlikely that the mining induced tilts would result in adverse impacts on the serviceability of the culverts, as the changes in grade are less than 1 %.

The mining induced curvatures and strains could be of sufficient magnitudes to result in cracking in the concrete culvert or the headwalls. It is unlikely, however, that these movements would adversely impact on the stability or structural integrity of the culvert. The potential impacts on the drainage culvert could be managed by visual inspection and, if required, any affected sections of the culvert repaired or replaced.

There have been no reports of impacts to road drainage culverts during the mining of Longwalls 22 to 27. This is understandable as the culverts are typically constructed of jointed circular concrete pipes, which are able to tolerate substantial differential ground movements. While it is possible that the culverts could experience physical impacts such as cracking, the probability is considered low.

Tahmoor Colliery and Wollondilly Shire Council have developed and acted in accordance with an agreed risk management plan to manage potential impacts to culverts during the mining of Longwalls 22 to 30. The management plan provides for visual monitoring of culverts. If impacts occur to the culverts, Wollondilly Shire Council is able to quickly repair the culverts, if required.

The management plan is reviewed periodically by Tahmoor Colliery and Wollondilly Shire Council.

6.5.4. Impact Assessments for the Road Drainage Culverts Based on Increased Predictions

If the actual tilts exceeded those predicted by a factor of 2 times, the maximum tilt at the local road drainage culverts would be 9 mm/m (i.e. 0.9 %, or 1 in 110). The potential impacts on the serviceability and surface water drainage through the culverts would not be expected to significantly increase, as the maximum change in grade would still be small, in the order of 1 %.

If the actual curvatures exceeded those predicted by a factor of 2 times, the maximum curvature at the road drainage culverts would be 0.08 km^{-1}, which represents a minimum radius of curvature of 13 kilometres. In this case, the incidence of cracking in the culverts would increase, however, it would not be expected to affect the structural capacity or stability of the culverts. If any adverse impacts were to occur as the result of mining, the affected culverts could be replaced.

6.6. Road Bridges

6.6.1. Description of Road and Pedestrian Bridges

The location of the road bridges in the vicinity of the proposed longwalls are shown in Drawing No. MSEC647-15. The bridges associated with the Main Southern Railway, which include road overpass bridges, are also shown in this drawing and these are discussed separately in Section 6.2.

There is only one road bridge located within the SMP Area, where Remembrance Drive crosses Redbank Creek (RE-B1), which is located 350 metres north-east of the proposed Longwall 32. This bridge is a two lane, reinforced concrete arch structure, with a single span of approximately 8 metres. The bridge surface is sealed with asphalt, and there is a steel guardrail crash barrier on each side.

The adjacent footbridge over Redbank Creek is a separate structure, with has a single span of approximately 10 metres. The bridge is formed from reinforced precast concrete, supported on reinforced concrete plinths on rock. The balustrades are built from proprietary steel fence sections. Photographs of these road and pedestrian bridges are provided in Fig. 6.31 and Fig. 6.32, respectively.

Fig. 6.31 Remembrance Drive Road Bridge over Redbank Creek (RE-B1)

Fig. 6.32 Remembrance Footbridge over Redbank Creek

There are also two road bridges that are located just outside the SMP Area which are described below:

- The Remembrance Drive Bridge over Myrtle Creek (RE-B2) is a two-lane bridge, which is located 500 metres south of the proposed Longwall 31. Roads and Maritime Services provided a copy of the structural design drawings, which show that the dual-span bridge is constructed with a concrete deck on concrete abutments and a central pier. The span of the deck is approximately 18 metres and the heights of the abutments are approximately 7 metres.

  The deck comprises pre-tensioned bridge units that span between the abutments and the central pier. The bridge units have been integrated with a reinforced concrete slab. The reinforced concrete abutments appear to rest on pad and strip footing foundations. The pre-tensioned bridge deck units are connected to the central pier with dowels. The drawings do not include the abutment connections, but it appears that the bridge units rest on a corbel at each end. It is likely that a concrete upstand has been constructed at the ends of the deck.

- The Victoria Bridge over Stonequarry Creek is a single lane timber truss bridge constructed in 1897. It is listed as an item of environmental heritage in Wollondilly Shire Council's Local Environmental Plan. The bridge is located approximately 520 metres east of the commencing end of Longwall 33. Photographs of this bridge are provided in Fig. 6.33.

Fig. 6.33 Victoria Bridge over Stonequarry Creek

The descriptions of the bridges associated with the Main Southern Railway, which include road overpass bridges, are provided in Section 6.2.

6.6.2. Predictions for the Bridges

A summary of the maximum predicted values of total conventional subsidence, tilt and curvature for the Remembrance Drive Bridge over Redbank Creek (RE-B1) and adjacent pedestrian bridge, after the extraction of each of the proposed longwalls, is provided in Table 6.25. The values provided in this table are the maximum predicted parameters within a 20 metre radius of the bridges.

Table 6.25 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature at the Remembrance Drive Road and Pedestrian Bridges over Redbank Creek

Location	Longwall	Maximum Predicted Subsidence (mm)	Maximum Predicted Tilt (mm/m)	Maximum Predicted Hogging Curvature (1/km)	Maximum Predicted Sagging Curvature (1/km)
Remembrance Drive Road (RE-B1) and Pedestrian Bridges over Redbank Creek	After LW31	< 20	< 0.5	< 0.01	< 0.01
	After LW32	35	< 0.5	< 0.01	< 0.01
	After LW35	35	< 0.5	< 0.01	< 0.01

The Remembrance Drive road and pedestrian bridges over Redbank Creek could also experience valley related movements. The predicted profiles of upsidence and closure along Redbank Creek are shown in Fig. E.03, in Appendix E. The maximum predicted valley related movements at the bridges, after the completion of the proposed longwalls, are 20 mm upsidence and 20 mm closure.

The Remembrance Drive Bridge over Myrtle Creek (RE-B2), the Victoria Bridge over Stonequarry Creek and other road bridges located outside the SMP Area are predicted to experience less than 20 mm of vertical subsidence. It is unlikely, therefore, that these bridges would experience any measurable conventional tilts, curvatures or strains.

The bridges located outside the SMP Area could experience small far-field horizontal movements resulting from the extraction of the proposed longwalls. It can be seen from Fig. 4.13, that incremental far-field horizontal movements around 175 mm, 100 mm and 50 mm have been measured at distances of 200 metres, 600 metres and 1,200 metres, respectively, from previously extracted longwalls in the NSW Coalfields.

The potential for impacts on the bridges located outside the SMP Area do not result from absolute far-field horizontal movements, but rather from differential horizontal movements over the lengths of the structures. The potential for differential horizontal movements at the bridge has been assessed by statistically analysing the available 3D monitoring data from the Southern Coalfield.

The Remembrance Drive Bridge over Myrtle Creek (RE-B2) has a total length of around 20 metres. The observed incremental differential longitudinal movements and mid-ordinate deviation for survey marks spaced at 20 metres ±10 metres, relative to the distance from the active longwall, are shown in Fig. 4.14 and Fig. 4.16. The maximum predicted differential horizontal movements for the bridge, based on a minimum distance of 500 metres from the proposed longwalls, are 7 mm opening, 8 mm closure and 9 mm mid-ordinate deviation, based on the 95 % confidence levels.

The Victoria Bridge has a total length of around 100 metres. The histograms of the maximum observed incremental opening and closing movements for survey marks spaced at 100 metres ±10 metres, at distances between 400 metres and 600 metres from active longwalls, are shown in Fig. 6.34. The *Generalised Pareto Distributions (GPDs)* which have been fitted to this data have also been shown in these figures.

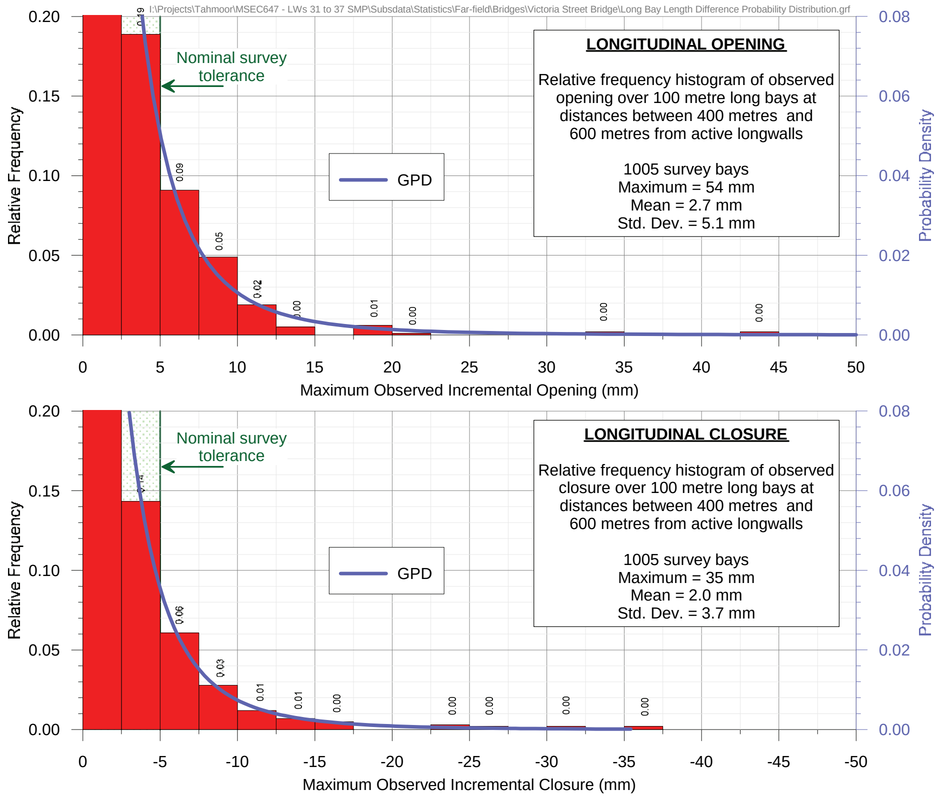


Fig. 6.34 Distributions of the Maximum Observed Incremental Opening and Closure for Survey Marks Spaced at 100 metres ±10 metres at Distances between 400 metres and 600 metres from Active Longwalls

The maximum incremental longitudinal movements over the total length of the Victoria Bridge, based on the fitted GPDs to the available ground monitoring data, are 10 mm opening and 8 mm closure, based on the 95 % confidence levels.

6.6.3. Impact Assessments for the Remembrance Drive Road Bridge over Redbank Creek (RE-B1)

The Remembrance Drive Bridge across Redbank Creek (RE-B1) and associated pedestrian bridge are located 350 metres north-east of the proposed Longwall 32. At this distance, the bridges are predicted to experience around 35 mm vertical subsidence, 20 mm upsidence and 20 mm closure. Whilst the bridges could experience low level subsidence movements, they are not expected to experience any measurable tilts, curvatures or strains, even if the predictions were exceeded by a factor of 2 times.

Tahmoor Colliery and Wollondilly Shire Council have previously developed and acted in accordance with agreed risk management plans to manage potential impacts to other bridges during the mining of Longwalls 22 to 30, with mitigation measures installed, as required. These management plans provide for visual monitoring and responses if differential mining-related movements exceed pre-determined trigger levels.

The management plan is reviewed periodically by Tahmoor Colliery and Wollondilly Shire Council. It is expected that a similar management plan will be developed and remain in operation for the Remembrance Drive Bridge across Redbank Creek during the mining of Longwalls 31 to 37. Development of this management plan will require a detailed inspection of the bridge by a structural engineer, including bearings and supports.

6.6.4. Impact Assessments for the Remembrance Drive Bridge over Myrtle Creek (RE-B2) and the Victoria Bridge

The Remembrance Drive Bridge across Myrtle Creek (RE-B2) and the Victoria Bridge are predicted to experience less than 20 mm vertical subsidence resulting from the extraction of the proposed longwalls. Whilst the bridges could experience very low levels of vertical subsidence, they are not expected to experience any measurable tilts, curvatures or strains, even if the predictions were exceeded by a factor of 2 times.

The predicted differential horizontal movements over the lengths of these bridges are small and comprise a large proportion of survey tolerance, which is in the order of ±3 mm. The mining induced differential movements are expected to be a similar order of magnitude as those resulting from changes in ambient temperature. It is unlikely, therefore, that these bridges would experience adverse impacts resulting from the mining induced far-field movements, even if the predictions were exceeded by a factor of 2 times.

Stonequarry Creek runs along the alignment of the Nepean Fault where it crosses beneath the Victoria Bridge. While the proposed longwalls are approximately 520 metres from the bridge, there is a remote chance that differential movements could occur at the structure.

6.6.5. Recommendations for the Road Bridges

Tahmoor Colliery and Wollondilly Shire Council have previously developed and acted in accordance with agreed risk management plans to manage potential impacts to other road bridges during the mining of Longwalls 22 to 30. It is recommended that this management plan is reviewed and updated to incorporate the roads bridges within and immediately adjacent to the SMP Area.

6.7. Tunnels

The brick arch Picton Rail Tunnel and the stone arch Mushroom Tunnel are located at minimum distances of 380 metres and 470 metres from proposed Longwall 33. The tunnels have overall lengths of around 200 metres. Photographs of these tunnels are provided in Fig. 6.35 and Fig. 6.36. The tunnels are shown in Drawing No. MSEC674-13.

Fig. 6.35 Picton Rail Tunnel