Subsidence Analysis for Underground Coal Mining Operations: The Use of Airborne Laser Scanning Data

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Key words: LIDAR, Airborne Laser Scanning (ALS), mine subsidence, data analysis

SUMMARY

This project applied airborne laser scanning technology for the detection of mine subsidence over a broad area, a commercial application not widely used in the Australian underground coal mining industry.

The objective of the project was to prove the latest generation airborne laser technologies as a reliable and objective source of vital subsidence monitoring data for an underground coal mine and to demonstrate its potential as a complementary or alternate method to conventional geodetic subsidence detection and monitoring.

Pre-mining airborne laser scanning (ALS) data together with ALS data acquired post-mining was processed together to measure the level of vertical subsidence that had occurred across the mining area. Rigorous quantitative comparison of ALS and geodetic survey data was carried out over a range in topography and vegetation densities allowing the technology to be assessed with a variety of environmental variables.

Integrated spatial analysis and field checking of the elevation differences of the datasets showed well defined subsidence zones around the areas of longwall mining. The analysis also indicated that there was good correlation between ALS and geodetic data, although some areas of observed differences between the datasets occurred, particularly in areas with extremely steep gradients.

This paper outlines how ALS surveys can produce highly representative terrain data which can be considered to provide a relatively accurate description of the subsidence that has occurred over the entire mining area.

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1. INTRODUCTION

Mandalong Mine is wholly owned by Centennial Coal Company Limited and is located close to Morisset in the City of Lake Macquarie, New South Wales, Australia. The underground mine lies within the catchment of Lake Macquarie with the topography ranging from the broad flat floodplain of Stockton and Morans Creeks up to the foothills of the Watagan Mountain Range. The surface above the mine consists of a floodplain with an elevation of approximately 10 metres above Australian Height Datum (AHD) together with ridge and valley topography with a maximum elevation of 170 metres AHD as shown in Figure 1. The surface land is used for low-intensity agriculture and rural residential retreats.

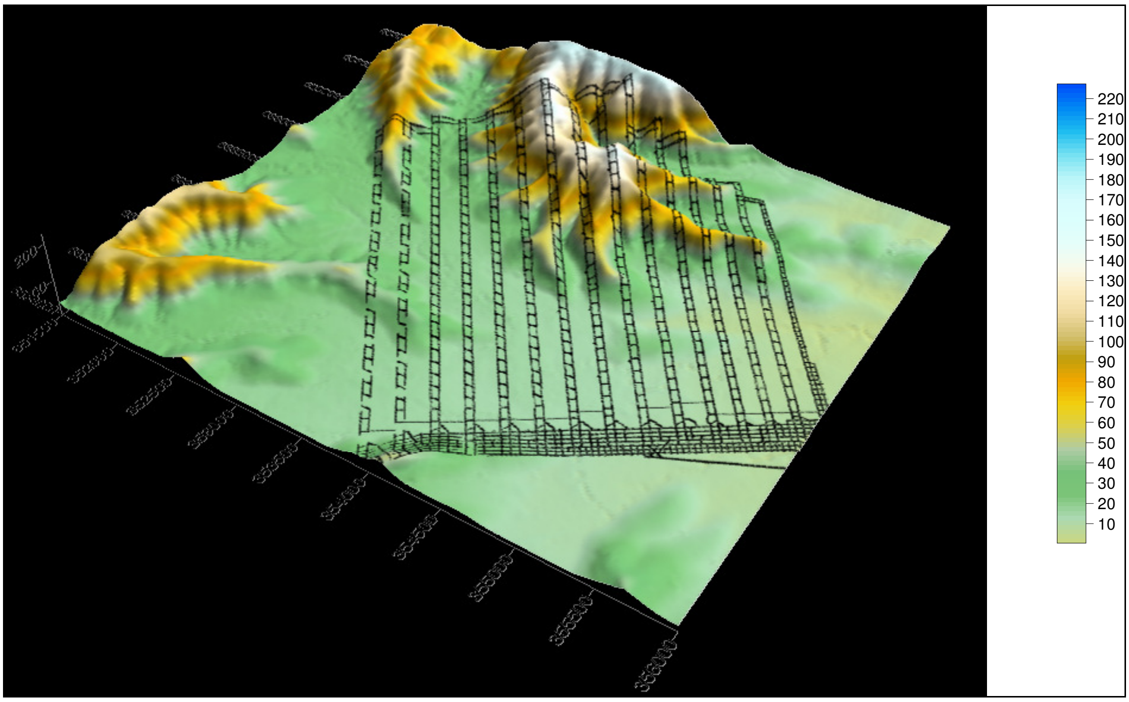

Figure 1 - Mandalong Surface Topography (Seedsman 2007)

The Mine commenced longwall extraction in January 2005 in the West Wallarah Seam, which ranges in depth between -150 metres and -240 metres AHD. The Mine uses an innovative mine design and subsidence prediction method which utilises relatively narrow width longwall panels (160m) and a massive conglomerate rock beam that is present in the overburden to minimise subsidence. This design provides reduced levels of subsidence, minimising the impact on property, the floodplain and the environment, as well as complying with stringent State Government development consent conditions.

Mandalong's unique method of mining meant that there was no available subsidence information from other mines that could be used to validate the subsidence prediction model. As such regulators took a cautious approach when negotiating subsidence monitoring agreements to ensure that any subsidence greater than the predicted level would be detected. Monitoring methods consisted of conventional surveys on longwall centreline marks and perpendicular crosslines at specific points. Centreline and crossline monitoring as shown in Figure 2, provides an accurate sectional view of the subsidence occurring in that vicinity, but does not provide data across the whole of the undermined area. Therefore another method of proving/detecting subsidence across the whole mine in comparison to predictions was necessary.

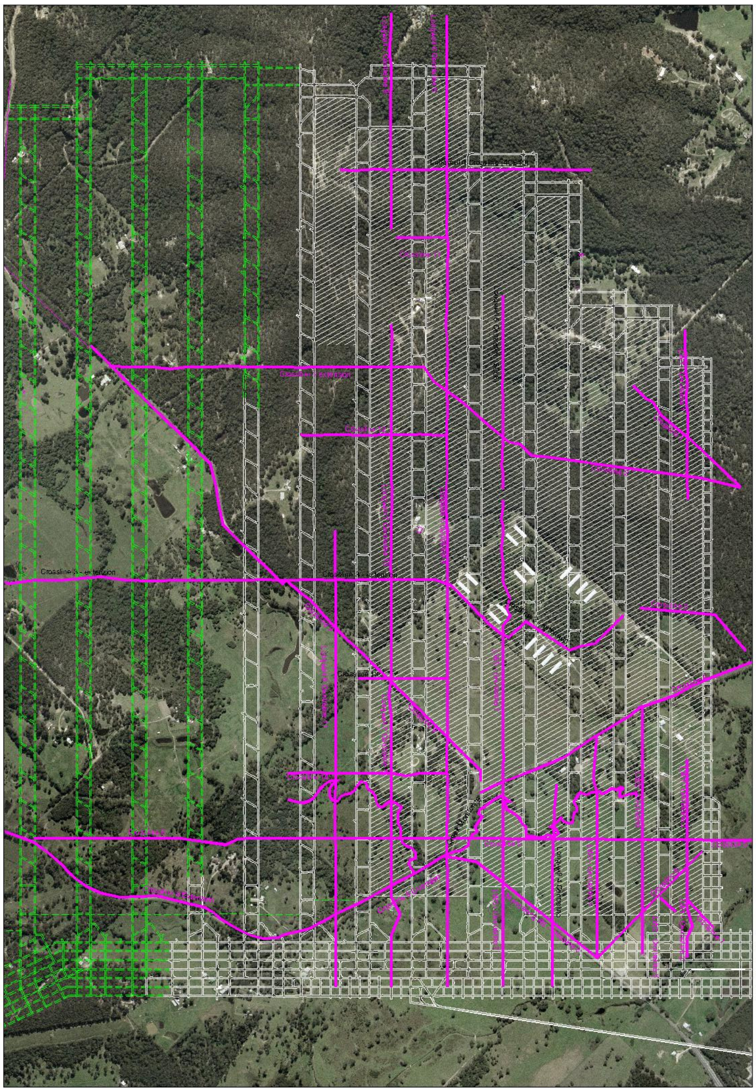

Figure 2 - Surface Area Effected by Mining Overlayed

with Conventional Subsidence Monitoring Lines shown.

Airborne Laser Scanning data was originally acquired over the mining area in 2003 by AAM Geoscan for the purposes of producing topographic contours for the Mine. This method was chosen over photogrammetric methods because of Airborne Laser Scanning technology's ability to penetrate the gaps in the vegetation canopy and capture separate returns from vegetation and from the ground. This feature ensured that an accurate and reliable terrain model was derived and initially used to model flooding levels.

ALS surveys have been successfully used by open cut coal operations for a number of years to calculate stockpile and void volumes from scans of locations before and after an event. It was subsequently theorised that the pre-mining ALS data, together with ALS data acquired post-mining could be processed together to measure the level of vertical subsidence that had occurred across the mining area in a similar way, albeit with the added difficulty of thick vegetation and steep terrain.

2. PROJECT OVERVIEW

The objective of the project was to use Airborne Laser Scanning to bring transparency to the subsidence monitoring process along with the ability to quantitatively demonstrate the magnitude of subsidence and other environmental changes across the whole of the mining area.

Pre-mining ALS data was sourced for the Mine by AAM GeoScan (now AAM Pty Ltd) in June 2003 and February 2004, with subsequent post-mining ALS data acquired in August 2006 and June 2008. AAM used various models of Optech Airborne Laser Scanners on each occasion, including use of the Optech ALTM GEMINI 167kHz in 2008.

Umwelt (Australia) Pty Limited (Umwelt) where engaged to undertake a comparison of Airborne Laser Scanning data of a 6km^2 area of the Mandalong Valley for pre-mining and two post-mining datasets provided by AAM. This comparison was undertaken to determine whether ALS is a suitable method of measuring subsidence as a result of longwall mining in the Mandalong Valley by comparison to data collected by conventional survey methods, and the actual subsidence over the mined longwalls.

2.1 Datasets

Pre-mining ALS data was sourced for Longwalls 1 to 4 of the mining area on 18 June 2003. ALS data for the remainder of the Mandalong Valley was sourced on 8 February 2004. Ground support (i.e. a GPS base station) was provided by local surveyors, C.R. Hutchison & Co. Pty. Ltd. The ground check points acquired by the surveyors allowed an assessment of the accuracy of the ALS data. One hundred and eleven ground check points were used, which concluded a vertical standard error of 0.04 metres for points on open clear ground (AAMHatch, 2003). The supplied point cloud of the 2003 ALS data (ground strikes only) has a 2.06 metre estimated average point density (i.e. points per m^2) (AAM GeoScan, 2003).

Since the commencement of underground mining two additional ALS datasets have been sourced. The first post-mining ALS data was acquired on 12 August 2006. This data corresponds to the completion of mining of Longwalls 1 and 2 and part of Longwall 3. Ground check points were again used by AAM to assess the accuracy of the ALS data. The supplied ground check points were in the same area as the check points for the previous 2003 ALS survey. One hundred and sixty three check points were used for validation, resulting in a vertical standard error of 0.024 metres for points on open clear ground. The supplied point cloud of 2006 ALS data (ground strikes only) has a 7.81 metre estimated point density (AAMHatch, 2006).

Post-mining ALS data was again sourced on 10 June 2008. This data corresponds to the completion of Longwalls 1 to 5 and part of Longwall 6. Ground check points were again used to assess the accuracy of the ALS data. The supplied ground check points were in the same area as the check points for the previous 2006 ALS survey. Two hundred and fifteen points were used for validation, resulting in a vertical standard error of 0.051 metres for points on open clear ground. The supplied point cloud of 2008 ALS data (ground strikes only) has a 4.6 metre estimated point density (AAMHatch, 2008).

2.2 Expected Accuracy & Data Limitations

Information provided by AAM indicated that the horizontal accuracy of ALS data points on open clear ground is: 0.55 metres in 2003, 0.55 metres in 2006 and 0.2 metres in 2008, with a stated vertical accuracy of all datasets is 0.15 metres to 1 sigma (ie 68% of the ALS point data utilised by Umwelt in their analysis was plus or minus 0.15 metres of its true elevation).

AAM has also indicated that accuracy estimates for terrain modelling refer to the terrain definition on clear ground. In addition, ground definition in vegetated terrain may contain localised areas with systematic errors or outliers that fall outside this accuracy estimate.

Laser strikes were classified into ‘ground’ and ‘non-ground’ by AAM, based upon algorithms tailored for the major terrain/vegetation combinations existing in the project area. AAM has indicated that the classification algorithm may be less accurate in isolated pockets of dissimilar terrain/vegetation combinations and under trees.

AAM has also confirmed that the algorithm used to classify points as ‘ground’ or ‘non ground’ may have differed between the 2003 dataset and the 2006 and 2008 datasets, resulting in significant differences in some areas. This effect was particularly noticeable in areas of high relief (eg creek banks and steep terrain) and low thick vegetation (e.g. noxious weed *Lantana camara*), for the comparison between the 2003 and 2006 datasets.

Future scope of work will specify the application of the data sets so that identical sensor settings and algorithm for processing are utilised. This will increase the suitability of the ALS datasets for this important temporal work.

2.3 Analysis Approach

The ALS data points sourced by AAM in 2003, 2006 and 2008 were interpolated to obtain grid based digital terrain models (DTM) with grid spacing of 2.0 metres.

Subsidence values were calculated by comparing the elevation differences between the corresponding points of the DTMs.

The analysis of the elevation differences of the datasets (i.e. 2003 to 2006 and 2003 to 2008) shows well defined subsidence zones around the areas of longwall mining (refer to Figure 3 and Figure 4). The analysis also indicated some areas of significant observed differences between the datasets. These differences are discussed further in Section 2.4.

The calculated subsidence using the ALS data was also compared against subsidence monitoring line data surveyed by Centennial Mandalong (refer to Section 2.5).

Umwelt utilised customised in-house database applications, MySQL, Bentley Microstation and ArcView^{TM} GIS software in the analysis of the ALS data.

2.4 Comparison of ALS Datasets

2.4.1 2003 to 2006

An analysis of the elevation differences of the 2003 and 2006 datasets shows a wide range of difference in elevation, from approximately minus 6 metres to approximately plus 6 metres. The analysis also indicates that 99.7% of the elevation differences are within the range of minus 1.5 metres to plus 0.5 metres.

Some of these differences between the two ALS datasets can be explained by processes other than subsidence, including limitations of horizontal and vertical ALS data accuracy, differences in the classification of ‘ground’ and ‘non-ground’ data of two ALS surveys, changes in elevation of water surfaces (i.e. dams and creeks) at localised landform features within the study area and changes/improvements made to the processing algorithms used when processing the ALS in 2003 and 2006 (refer to Section 2.2).

Additional calculations revealed that in areas where subsidence has not occurred, the average elevation of 2006 survey was 0.05 metres higher than the average elevation of pre-mining survey. Even with these discrepancies, it is considered that the difference between the 2003 and 2006 ALS datasets provides an accurate description of subsidence associated with Longwalls 1 and 2.

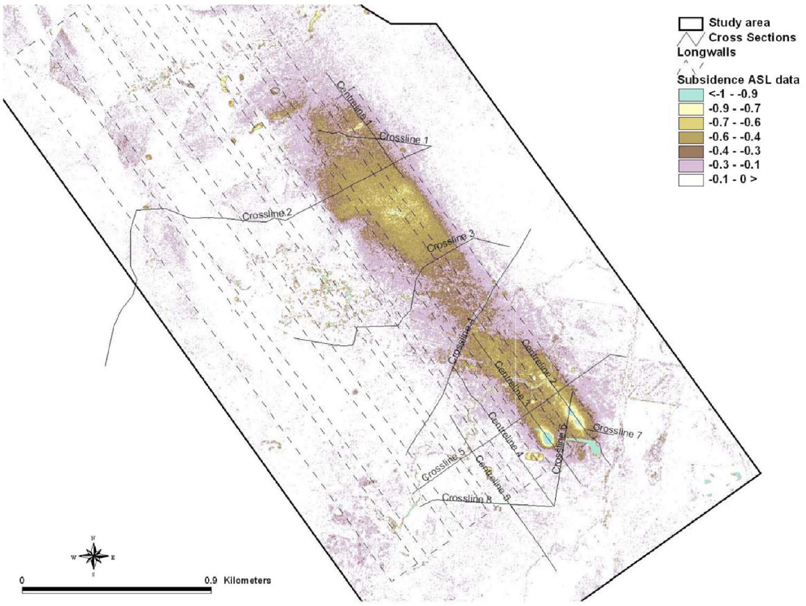

Figure 3 - 2006 Airborne Laser Scanning - Observed Subsidence (Umwelt)

2.4.2 2003 to 2008

An analysis of the elevation differences of the 2003 and 2008 datasets shows a wide range of difference in elevation, from approximately minus 86 metres to approximately plus 10 metres. The analysis also indicates that 99.6% of the elevation differences are within the range minus 1.75 metres to plus 0.21 metres.

Some of these differences between the two ALS datasets can be explained by processes other than subsidence. Again many of these differences are likely the result of changes/improvements made to the processing algorithms used when processing the ALS in 2003 and 2008.

Additional calculations revealed that in areas where subsidence has not occurred, the average elevation of 2008 survey was 0.082 metres higher than the average elevation of pre-mining survey. Again, even with the discrepancies, it is considered that the difference between the 2003 and 2008 ALS datasets provides an accurate description of subsidence of Longwall 1 to Longwall 5.

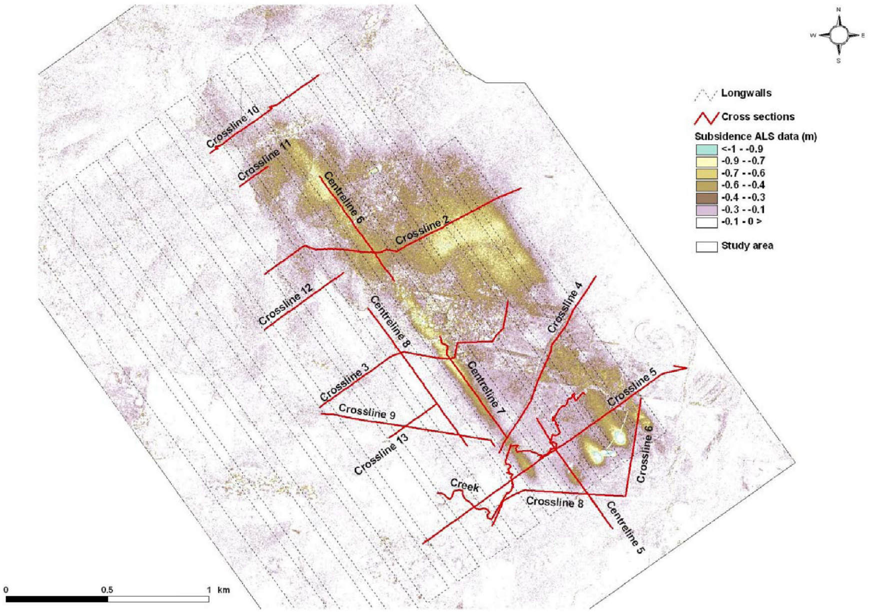

Figure 4 - 2008 Airborne Laser Scanning – Observed Subsidence (Umwelt)

2.5 Analysis of ALS Results versus Geodetic Survey

Geodetic surveys using conventional leveling and traversing techniques are conducted on a regular basis along subsidence monitoring lines in the longwall mining area. The geodetic subsidence monitoring line data was compared with the ALS survey data for the both datasets. For each dataset the geodetic survey closest in time to the ALS survey capture date was used in the analysis. Rigorous comparison of ALS and survey data over a range in topography and vegetation densities was possible due to the extensive subsidence monitoring network installed by the mine, allowing the technology to be proven with a variety of environmental variables.

2.5.1 2003 to 2006

The subsidence monitoring line data with the closest date to ALS survey date (i.e. 12 August 2006) was compared to the ALS analysis of subsidence up to 2006. Survey data was available at 478 points along nine survey lines (refer to Figure 3).

Each supplied survey point was compared against the ALS dataset. The difference is calculated as surveyor's elevations minus ALS elevations. Table 1 shows the average, maximum and minimum differences calculated from the geodetic subsidence survey minus ALS subsidence.

The analysis indicates that there is a good correlation between the geodetic survey measured subsidence and the ALS analysis subsidence for all subsidence monitoring lines, except Centreline 3. The average elevation difference between the ALS data and the geodetic survey data (excluding the data for Centreline 3) is 0.031 metres. The area where Centreline 3 varies between the two methods is immediately to the south of Deaves Road. An inspection of this area from Deaves Road during February 2007, did not indicate any aspect of the area that might significantly influence the ALS data acquisition or accuracy. As such, the differences in this area are yet to be determined. Figure 5 shows Crossline 5 comparison between Geodetic survey and ALS.

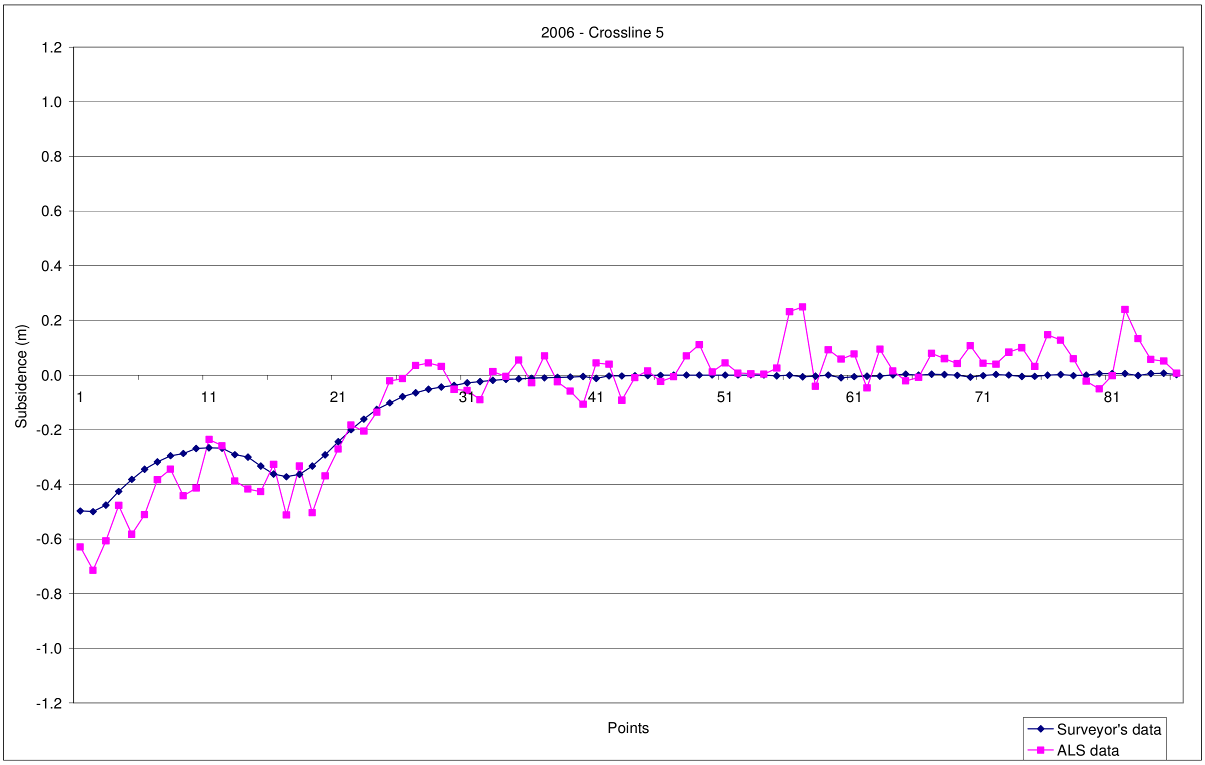

Figure 5 - 2006 Crossline 5 Subsidence Monitoring Line Comparison – (Umwelt)

Cross Section Name	Date of Geodetic Survey	Number of Points	Average Elevations Difference to ALS Data (m)	Minimum Elevations Difference to ALS Data (m)	Maximum Elevations Difference to ALS Data (m)
Crossline 1	09 Sep 2006	58	0.031	-0.169	0.173
Crossline 2	28 Jul 2006	65	0.042	-0.204	0.182
Crossline 3	04 Aug 2006	36	0.006	-0.143	0.149
Crossline 4	14 Aug 2006	86	0.021	-0.129	0.270
Crossline 5	09 Aug 2006	86	-0.008	-0.255	0.215
Crossline 6	26 Oct 2006	27	0.013	-0.191	0.130
Crossline 7	26 Oct 2006	18	0.046	-0.087	0.170
Centreline 2	26 Oct 2006	23	0.093	-0.011	0.213
Centreline 3	26 Oct 2006	43	0.145	-0.319	0.474

Table 1 – Summary of 2006 Subsidence Differences along Survey Lines (Umwelt)

2.5.2 2003 to 2008

The subsidence monitoring line data with the closest date to ALS survey date (i.e. 10 June 2008) was compared to the ALS analysis of subsidence up to 2008. Survey data was available at 1250 points along 16 survey lines (refer to Figure 4). Due to the expansion of the mining area additional cross sections were included for the 2008 analysis. In addition, some of the survey lines included in the 2006 analysis were not included as these lines have not been recently surveyed. Survey dates for the subsidence monitoring lines are typically within one month from the ALS survey date.

Each supplied survey point was compared against the ALS dataset. Table 2 shows the average, maximum and minimum differences calculated for the geodetic survey subsidence minus ALS subsidence. A representative sample of the comparison graph for Crossline 3 can be seen in Figure 6.

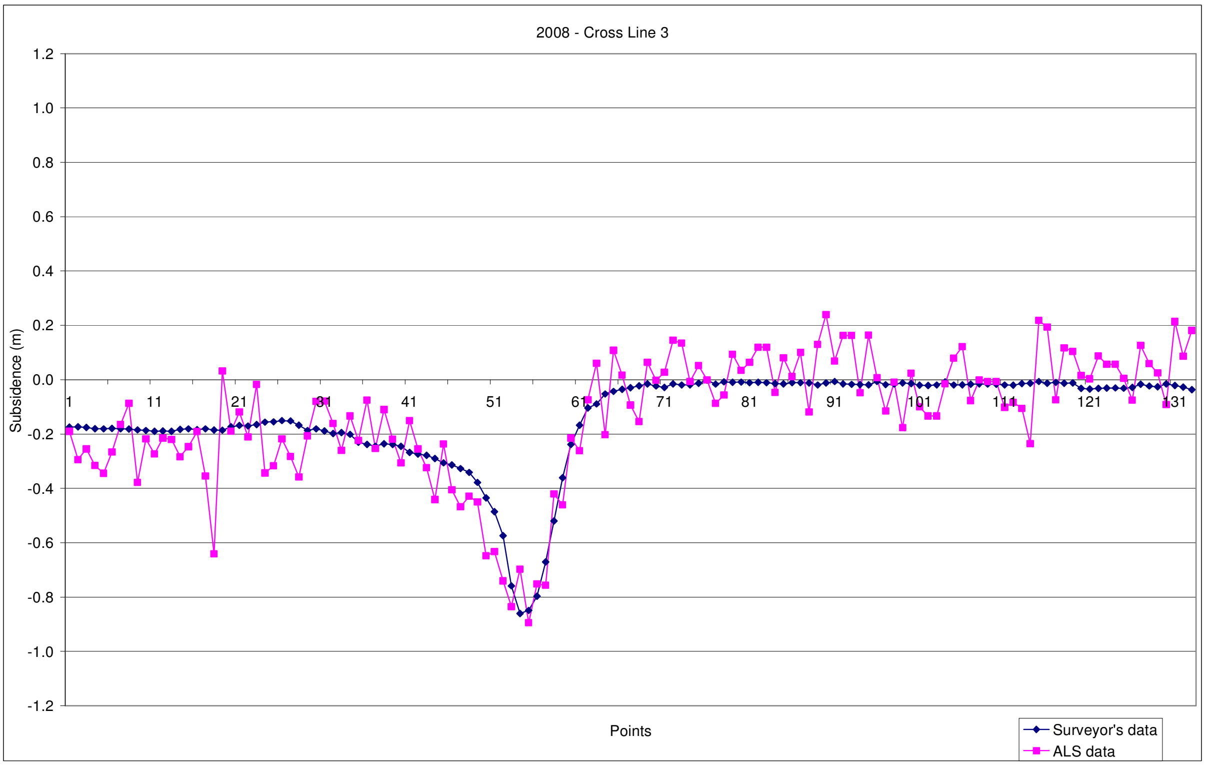

Figure 6 - 2008 Crossline 3 Subsidence Monitoring Line Comparison – (Umwelt)

Cross Section Name	Date of Geodetic Survey	Number of Points	Average Elevations Difference to ALS Data (m)	Minimum Elevations Difference to ALS Data (m)	Maximum Elevations Difference to ALS Data (m)
Crossline 2	02 Jul 2008	163	0.018	-0.427	0.412
Crossline 3	08 May 2008	133	-0.003	-0.252	0.456
Crossline 4 (Deaves Rd)	04 Jul 2008	41	-0.023	-0.243	0.235
Crossline 5	07 Jul 2008	85	0.008	-0.412	0.272
Crossline 6	07 Jul 2008	24	-0.077	-0.273	0.149
Crossline 8	07 Jul 2008	79	-0.063	-0.367	0.187
Crossline 9	12 May 2008	106	-0.077	-0.423	0.106
Crossline 10	27 Jun 2008	84	-0.118	-1.118	0.213
Crossline 11	16 Jun 2008	20	0.094	-0.156	0.280
Crossline 12	16 Jul 2008	54	-0.091	-0.427	0.279
Crossline 13	30 Jun 2008	34	-0.008	-0.118	0.091
Centreline 5	15 Jul 2008	67	-0.101	-0.371	0.110
Centreline 6	02 Jul 2008	74	-0.157	-1.041	0.143
Centreline 7	29 Jul 2008	69	-0.129	-0.517	0.283
Centreline 8	22 Jul 2008	96	-0.285	-0.701	0.192
Creek	08 Jul 2008	94	0.025	-0.583	0.972

Table 2 – Summary of 2008 Subsidence Differences along Survey Lines (Umwelt)

The analysis indicates that there is a good correlation between the geodetic survey measured subsidence and the ALS analysis subsidence for all subsidence monitoring lines, except Centreline 8. It is likely that as the geodetic survey data available for these lines is six weeks after the ALS survey, additional subsidence from the mining of Longwall 6 may have contributed to these differences. The differences in the geodetic survey measured subsidence and the ALS analysis on Centreline 5 is a result of water ponding on the surface in the subsidence trough and providing a false ground reading on the ALS survey. The false ground reading is estimated to be in the order of 0.3 metres. The average elevation difference between the ALS data and the geodetic survey data (excluding the data for Centreline 8) is minus 0.013 metres.

The analysis also indicates that there is a wider variability of minimums and maximums of elevation differences of the same cross sections for the 2008 survey to the 2006 survey. This variability can likely be explained by the increase in the number of points along the cross sections suitable for a comparison in the 2008 survey and a longer time gap between the monitoring lines and ALS survey dates for the 2008 survey.

3. CONCLUSIONS

A solid technical appreciation has been attained for the data collection and analysis specifications to ensure accurate subsidence monitoring. This data can supplement the other monitoring undertaken by the mine. The data from the ALS technology provided a detailed dataset enabling temporal comparisons of terrain surface across a broad area that can be utilised to supplement the extensive conventional subsidence monitoring program. ALS also provided the ability to obtain data in areas with access difficulties and on private land that would otherwise have been without monitoring.

Specifications for the stringent Scope of Works in data collection and analysis have been developed for land subsidence while showcasing the reliability, safety and accuracy achievable from the latest generation of aerial laser technology.

The comparison of the Airborne Laser Scanning (ALS) data for the Mandalong Valley for the pre-mining and two post-mining datasets indicates that even with consideration of the outliers in the analysis, the ALS survey produces highly representative terrain data that can be considered to provide a relatively accurate description of the subsidence that has occurred over the entire mining area with a variety of surface topography and vegetation. It should be noted that the accuracy of this analysis is governed by the vertical accuracy of the ALS data (i.e. 0.15 metres vertically) – though higher accuracy can be obtained.

It is envisaged that ALS monitoring will continue to be used in combination with conventional monitoring, such that the extent and frequency of conventional monitoring may be reduced. Future data capture using ALS technology should ensure that as far as possible the parameters are consistent between surveys, including ground point density and processing algorithms. Major subsidence line comparisons must be surveyed as close to the date of data capture as possible to reduce any issues surrounding movement occurring between the dates of the two surveys.

To improve the accuracy of the capture and processing of future data, ALS flight paths should be planned such that they are perpendicular to the slope of terrain to reduce the effect that horizontal position error has on height. The ability to improve the accuracy of the ALS subsidence calculation, particularly in area of steep terrain by generating higher resolution digital terrain model grids from existing and especially new data should also be investigated.

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BIOGRAPHICAL NOTES

Mark Harrower is a New South Wales Registered Mining Surveyor with over 25 years of underground mining and subsidence monitoring experience. Mark is currently employed as the Subsidence and Projects Surveyor for Centennial Coal's Mandalong Mine overseeing the survey of over 37km of subsidence monitoring lines across an area of 12km^2. Mark has previously held the position of Mine Surveyor at Mandalong Mine and before that Mine Surveyor at the adjacent Cooranbong Colliery. Mark is a Member of the Australian Institute of Mine Surveyors and has also received a number of industry awards for his involvement in mine surveying projects.

Peter Sergeant is a Graduate from the University of Newcastle, Australia and is a Registered Mining Surveyor in New South Wales. Peter's background is in underground coal mining and he is currently employed by Centennial Coal as Mine Surveyor for Mandalong Mine located on the New South Wales Central Coast. Peter is a Member and Director of the Australian Institute of Mine Surveyors and in 2007 was recognised for his commitment to the industry, receiving the title of New South Wales Young Surveyor of the year. Peter was also the recipient of the 2008 NSW Surveyor General International Fellowship in Surveying and Spatial Information, which saw him further his knowledge of mine surveying by undertaking study tours to South Africa and the United Kingdom.

Susan Shield is a Civil/Environmental Engineer with experience in the mining, consultancy and water industries. Susan is the Technical Engineering Manager and an Associate at Umwelt, where part of her role includes spatial data manipulation and creation of digital terrain models for analysis and terrain visualisation. In this work Susan combines digital terrain models and spatial data for use in flood modelling, stormwater drainage, subsidence assessments, noise and air modelling, archaeological investigations, terrain visualisations and civil design and planning assessments for various urban, coal mining and quarrying developments.

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