Successful Management Strategy for Mining Adjacent to a Sensitive Natural Feature

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Summary

BHP Billiton Illawarra Coal operates Dendrobium Mine in an area 10-20 km west-northwest of Wollongong in NSW, Australia. The mine recently completed mining in Area 3A adjacent to an overhanging natural rock feature known as Sandy Creek Waterfall. Illawarra Coal undertook measures to protect the waterfall and the section of Sandy Creek immediately upstream of the waterfall from the effects of longwall mining using an innovative management process and an array of high resolution monitoring systems. This paper describes the management options that were considered and the processes that were adopted to successfully protect the waterfall from the valley closure effects of mining four adjacent longwall panels in close proximity to the waterfall while continuing to maximise recovery of the coal resource in the area.

The management structure adopted involved a Technical Committee, a Steering Committee, and an external independent reviewer. The Technical Committee comprised senior representatives from Illawarra Coal, three external specialists in rock mechanics and subsidence, and a government observer. The Technical Committee was responsible for design of the monitoring systems, interpretation of the monitoring results, and the provision of recommendations to the Steering Committee suitable to guide decisions on when to cease mining each adjacent panel. The Steering Committee comprised Illawarra Coal management and technical personnel. Although the Steering Committee took advice from the Technical Committee, all decisions relating to mining were made by the Steering Committee. An external reviewer was engaged by the Steering Committee at the end of each longwall panel to review the results, interpretation and management decisions. This management structure was effective in successfully protecting the very sensitive structure of Sandy Creek Waterfall from potential impacts of nearby mining in the midst of active ongoing natural erosion processes.

1. Setting

Sandy Creek Waterfall lies within the Sydney Metropolitan Special Catchment Area at the point where Sandy Creek flows into Cordeaux Reservoir (refer Figure 1). The waterfall is approximately 20 m high and has an overhang which is 75 m long, up to 21 m deep and has a minimum thickness of less than 1 m.The overhang consists of the basal 6 m of the Hawkesbury Sandstone. The overhang has formed by preferential erosion of the softer Bald Hill Claystone which lies under the Hawkesbury Sandstone (refer Figure 2).

Figure 1 **Sandy Creek Waterfall viewed from the Cordeaux Reservoir**

Figure 2 **Sandy Creek Waterfall overhang (viewed from behind the waterfall)**

BHP Billiton Illawarra Coal's Dendrobium Mine extracts coal from the Wongawilli Seam below the catchment. Illawarra Coal recognised the significance of the waterfall during the preparation of the 2007 Environmental Assessment for Dendrobium Area 3. The company offset Longwalls 6 to 8 away from the Waterfall to ensure that conventional subsidence movements did not adversely impact the Waterfall and committed to:

(i) the formation of a technical committee;

(ii) the development of a management plan; and

(iii) provide flexible longwall finish lines.

Longwalls 6 to 8 were mined towards the waterfall. The actual finish line for each longwall was determined by the management plan based on the regular review of the monitoring results during mining. The management plan was required to manage the non-conventional subsidence movements associated with valley closure (refer Figure 3).

The Development Consent approved the maximum footprint for mining and set specific performance criteria for the waterfall. The Dendrobium Development Consent (2008) conditions specify that:

a) no rock fall occurs at Sandy Creek Waterfall or from its overhang;

b) the structural integrity of the waterfall, its overhang and its pool are not impacted;

c) cracking in Sandy Creek within 30 m of the waterfall is of negligible environmental and hydrological consequence; and

d) negligible diversion of water occurs from the lip of the waterfall.

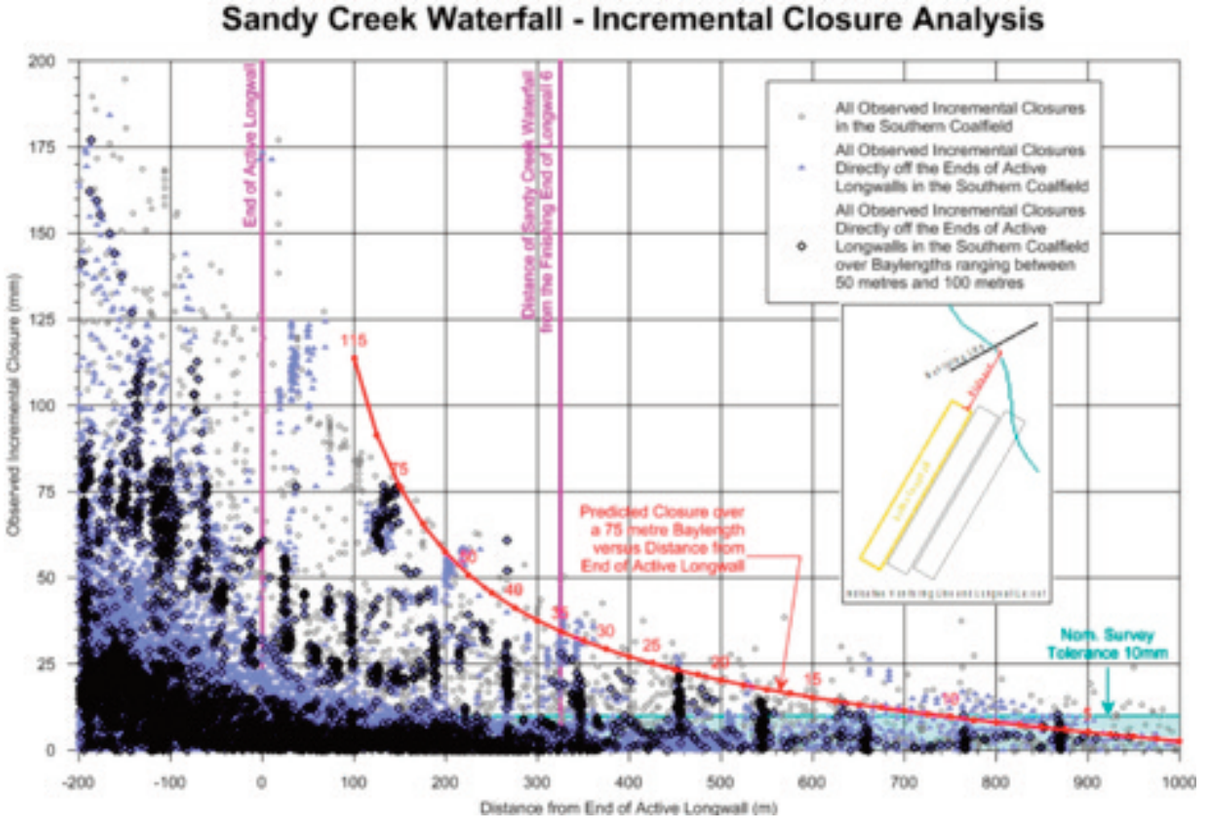

Figure 3 **Closure data in relation to offset from the end of a longwall (source: MSEC)**

2. Governance

The governance structure for the implementation and operation of the Sandy Creek Waterfall Management Plan consisted of a Steering Committee and a Technical Committee.

2.1 Steering Committee

The Steering Committee consisted of members of the Illawarra Coal Management Team including the Asset President, Dendrobium General Manager, Head of External Affairs and Head of Planning & Logistics. The Steering Committee was in a position to assess the implications of decisions on the business, regulators and our customers. The role of the Steering Committee included:

(i) providing the resources to implement the management plan;
(ii) endorsing the management plan;
(iii) reviewing and assessing information provided by the Technical Committee;
(iv) assessing the acceptability of the ongoing level of risk to the waterfall;
(v) implementing management actions to protect the waterfall; and
(vi) initiating peer reviews.

Critically the Steering Committee could provide direction for the planning of the Dendrobium Mine to ensure longwall continuity and minimise the operational & reputational risk to the business.

2.2 Technical Committee

The Technical Committee formed by Illawarra Coal consisted of consultants and employees with a strong geotechnical, subsidence and mining experience. These were:

(i) Professor Bruce Hebblewhite – acting as an independent geotechnical/subsidence consultant (Head of School of Mining Engineering, University of NSW)
(ii) Dr Ken Mills – Senior Geotechnical Engineer, Strata Control Technology
(iii) James Barbato – Subsidence Engineer, Mine Subsidence Engineering Consultants
(iv) Richard Walsh – Manager Subsidence Engineering, Illawarra Coal
(v) Michael Nicholson – Manager Survey, Illawarra Coal
(vi) Peter Brannon – Planning Manager, Dendrobium Mine, (including his precursors Sean Wood & David Thomason.)

Dr Gang Li, Principal Subsidence Engineer, Department of Trade & Investment, Regional Infrastructure & Services (T&I) attended meetings as an 'observer'.

The role of the Technical Committee was to:

(i) recommend and implement the site investigations;
(ii) recommend and implement the monitoring;
(iii) develop the management plan including the Decision Matrix;
(iv) review and interpret the results of the monitoring required in the plan;
(v) assess the status of the waterfall monitoring as per the Decision Matrix;
(vi) advise the Steering Committee of the interpretation of monitoring results with respect to the status of the waterfall.

The Technical Committee was formed in 2009 during the extraction of Longwall 5, the last longwall in Dendrobium Area 2, which was over 900m from the waterfall.

The Technical Committee received additional technical support as required, including from Dr Xun Luo (CSIRO), Dr Peter Tune (SIGRA), John Doyle (Geosensing), Mike Coulthard (Coulthard & Associates) and Illawarra Coal Resource & Exploration Department, on aspects of microseismic monitoring, geology, drilling & installation of monitoring equipment, numerical modelling and communications systems.

3. Site investigation & monitoring program

Illawarra Coal had extensive mining focussed exploration and already had a geological model for the area, airborne laser scans of the surface topography and specific site scans. The Technical Committee developed a program of coring, geomechanical testing and stress testing specific to the waterfall vicinity. The site investigations enabled a geomechanical model to be developed for the waterfall. The site investigation activities are described in detail in Walsh et al (2014).

A monitoring program was developed by the Technical Committee for each longwall. Monitoring results were rigorously reviewed by the Technical Committee during the extraction of each longwall. The merits and limitations of each technique were discussed. The need for additional

monitoring, to resolve uncertainty, was critical. The monitoring was supplemented during the extraction of Longwall 6 and as a result of the review at the end of Longwall 6.

There were only minor changes associated with subsequent reviews, primarily related to the variations in the locations of the Longwalls. The monitoring included numerous ground survey techniques, borehole stress, borehole strain and deformation using inclinometers, micro-seismic and visual as well as environmental factors (e.g. temperature, groundwater, rainfall). The monitoring program and the results are described in detail in Walsh et al (2014).

Real time monitoring systems are reliant on good communications systems. The Sandy Creek Waterfall Site was located in a communications black hole. One of the many challenges included the implementation of a communication network to recover real-time data.

The critical lessons were:

(i) Monitor the ground between the longwall and the feature, not just at the feature. Monitoring sites located between the longwall and the waterfall enabled deformation to be progressively tracked towards the waterfall.

(ii) Generic monitoring of subsidence over the longwall was useful to confirm that subsidence was developing normally and as predicted.

(iii) The differentiation of environmental and mining effects is best determined using baseline data or use of a reference site.

(iv) Not all data is equal: the importance of a data set may change and, hence, the reliance on a specific monitoring technique can change.

(v) It is important to have some level of redundancy in the monitoring system. For example, in establishing the monitoring for Longwall 6, seven of the eight VW stress cells failed on installation. Existing ANZI strain cells provided coverage.

(vi) Continuously review and question the results and cross check different techniques. For example, the highest confidence monitoring in Longwall 8 was not even used when the Longwall 6 monitoring was implemented.

4. Management plan

Management plans are a common tool for managing subsidence for protection of built features including major infrastructure, e.g. Hume Highway (Kay et al 2011) and Main Southern Railway (Pidgeon et al 2011). The benefit of management plans for built features is the ability to define the 'strength' (i.e. allowable capacity) of the structure and assess the likelihood of impact due to subsidence movements. The ability to define the strength of the structure is fundamental to designing and implementing mitigation, monitoring and determining the acceptable levels of all subsidence effects. Understanding the 'strength' and the appropriate factor of safety enables Triggered Action Response Plans to be developed. These are a fundamental tool in built feature subsidence management plans.

The conundrum for Sandy Creek Waterfall, as with many natural features, was that despite the abundance of geological and geotechnical data, the 'strength' of the overhang that defines the waterfall could not be determined. The existing stress on the waterfall and the additional strain that the overhang could tolerate could not be determined.

It was apparent from the lack of recent rock falls that the Waterfall was currently withstanding the normal cyclical environmental loading due to thermal variation and the volume of water flowing in the creek. However, as a result of this conundrum, it was cautiously assumed that no additional mining-induced subsidence effects could be accommodated.

The traditional TARP approach was not applicable, as there were no appropriate trigger levels. The fundamental tool for the Waterfall Management Plan was a Decision Matrix which focussed on the identification of the onset and increase in rate of mining-induced effects identified by each monitoring technique. Figure 4 is the Longwall 8 Decision Matrix developed by the Technical Committee.

The monitoring techniques were prioritised within the Decision Matrix. The most reliable and useful techniques used to recognise mining induced change were located at the top of the list. The preferred techniques invariably had a quick turn-around time between measurement and the

availability of results. The frequency of Technical Committee meetings increased from monthly to bi-weekly teleconferences during the critical periods of extraction for each Longwall. Monitoring data needed to be able to be updated and reproduced for review meetings. At critical times the preferred techniques were the only data sets available as the lower priority techniques took too long to process. The results of each Technical Committee meeting were reported to the Steering Committee.

The Dendrobium Longwall 8 extracted an average of 50m per week over the last kilometre of the panel. During the latter stages of each longwall the Technical & Steering Committee meetings were programmed prior to the longwall passing each maingate cut-through. The meetings enabled the

LONGWALL 8 SANDY CREEK WATERFALL DECISION MATRIX

Monitoring Dimension	Measurement	Level 1 Condition after Longwall 7	Level 2 Measurable change in observations beyond Level 1 condition (ie: above measurement tolerances)	Level 3 Definitive change in the rate of observations beyond Level 2 condition
Closure	Primary High Resolution Closure Lines G1, H2 & H3	No measurable movement beyond end LW7 steady state	Repeatable Measurable Movement consistent with low level mining influence	Increasing rate of movement
Shear Movement	Inclinometers I1, I2, I4 , I5 & I6	No measurable movement beyond end LW7 steady state	Repeatable Movement on Bedding Planes	Repeatable shear movements observed at I2, I4 & I5 [ie within 150m of SCW]
Ground Survey	Secondary High Resolution Closure Lines A, B, H1, G2 & Strain Line J	No measurable movement beyond end LW7 steady state	Repeatable Measurable Movement	Increased rate associated with mining or Abnormal Movements
Stress	ANZI cells VW cells	No measurable change in indicated stress beyond end LW7 steady state (excluding thermal effects)	Change in indicated stress consistent with low level mining influence (excluding thermal effects)	Change in indicated stress consistent with significant mining influence (excluding thermal effects)
Shallow Micro-Seismic events	CSIRO Event Location [Accuracy +/- 50m]	No events within 150 metres of SCW	Isolated events within 150m of SCW	Three or more events within 150 metres of SCW [based on stated accuracy event is >50m from SCW]
Visual Observation		No visible fracturing, ecological impact or water diversion in advance of Longwall face position	Visible fracturing, ecological impact or water diversion in advance of Longwall face position & beyond 150 metres of SCW	Visible fracturing, ecological impact or water diversion within 150 metres of SCW
Event Frequency	Scope	Level 1	Level 2	Level 3
Measurement	Non real time information	Monthly till 1000m ex SCW then weekly	Twice weekly	Daily
Review	Technical Committee	Monthly	Weekly/Mid Pillar	Twice weekly
TC Reporting to SC	Technical Committee	Monthly	Weekly/Mid Pillar	Twice weekly Notification of any Level 3 Status within 24 hours of review, including summary status report

Figure 4 **Longwall 8 Decision Matrix**

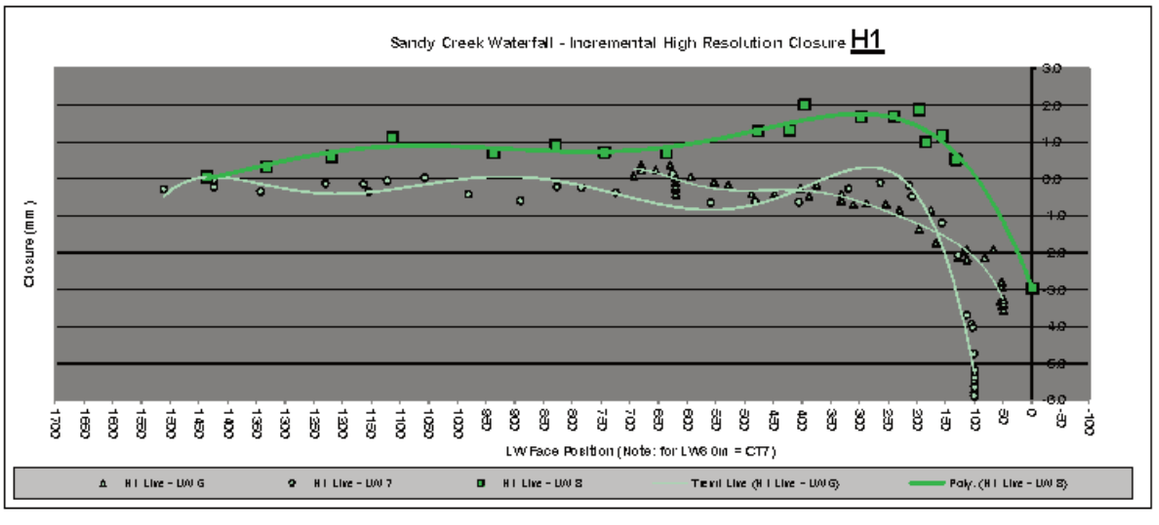

Figure 5 **Forecast closure and comparison of the development of closure from successive longwalls**

Technical Committee to determine if there was any mining-induced change at the Waterfall and hence advise on the current risk. If mining induced change was not identified the longwall was authorised by the Steering Committee to extract another pillar of coal. The rate of change of preferred monitoring techniques was a very useful guide for the Steering Committee as was the relationship with the trends from the previous longwalls, refer Figure 5. Forecasts were developed for deformation, if mining was authorised for an additional pillar.

5. Review

The Technical Committee reviewed the monitoring and the Decision Matrix after the completion of each longwall. Illawarra Coal also sought additional advice from Emeritus Professor ET Brown, AC in a peer review role. Technical reviews were undertaken in November 2010 during Longwall 6 extraction and subsequently in May 2011, 2012 and 2013 after the completion of each longwall. The reviews focused on the management plan, its implementation and the monitoring results. The reviews have informed the process for revising the management plan.

6. Conclusions

Longwalls 6, 7 & 8 have successfully been mined in Area 3A. Longwall 8 was completed in December 2012 and, 14 months after completion, there has been no visible change to Sandy Creek Waterfall.

The approved finish lines for Longwalls 6, 7 & 8 were considered to be a maximum footprint with the actual finish line determined by the management plan (refer Figure 6). Dendrobium adopted a conservative approach for business planning to ensure continuity between Longwalls 7 & 8, and also to Longwall 9 in the next domain. As can be seen in the Figure 6 the actual Longwall finish lines were significantly better than the business plan in Longwalls 7 & 8 and this helped Dendrobium ensure longwall continuity.

Figure 6 Approved, planned and actual finish lines for Longwalls 6, 7 & 8

With the successful implementation of the management plan, the Sandy Creek Waterfall was protected whilst maximising the coal resource recovered.

The Management Plan was approved by T&I and progress reports were provided to the regulators and stakeholders. The regulator approved a maximum footprint and Illawarra Coal managed the mining to meet our Statement of Commitments and the performance criteria. The required expertise was drawn together in the Technical Committee, the process was controlled and managed by Illawarra Coal. The management of mining Longwalls 6 to 8 near Sandy Creek Waterfall could be described as 'self management'.

7. References

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Pidgeon AR, Barber RE, Christie D, Kay DJ, Robinson GK, Sheppard IC, Sweeting RD 2011 'Management of the Main Southern Railway for-subsidence impacts from longwall mining' in Proceedings of the 8th Triennial Conference of the Mine Subsidence Technological Society, Pokolbin NSW, 15-17 May 2011, pp231-245

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