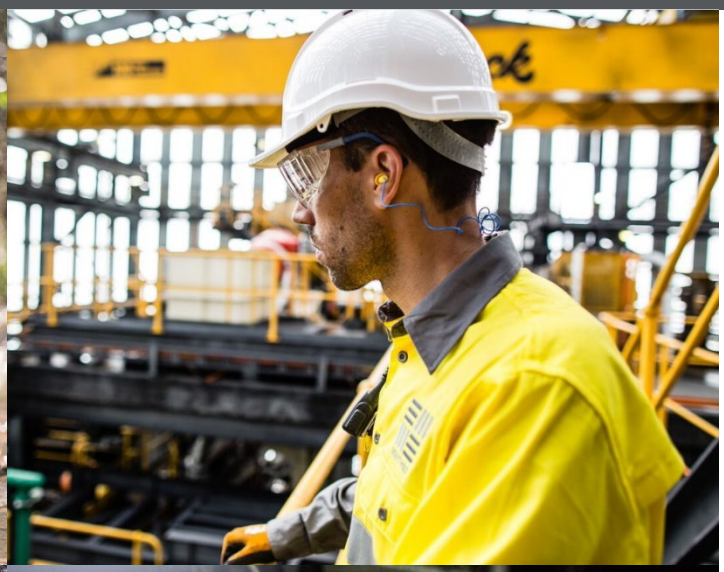
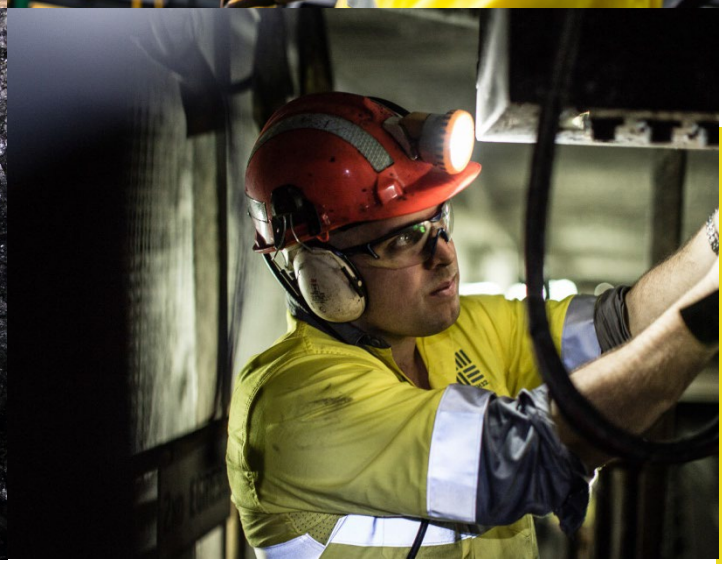
SOUTH32

DENDROBIUM
AREA 3A

OCTOBER 2022





SANDY CREEK WATERFALL MANGEMENT PLAN

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Appendix 1 – Trigger Action Response Plan

Review History

Revision	Description of Changes	Date	Approved
0	Initial document submitted to DoP and I&I	23/06/2010	RW
1	Revised document based on I&I letter date 29 June 2012 (Ref 08/3685)	9/09/2010	RW
2	Reviewed after Longwall 6 and revised to manage Longwall 7	11/09/2011	RW
3	Reviewed after Longwall 7 and revised to manage Longwall 8	14.09.2012	RW
4	Document updated to South32 format and revised to manage Longwall 19	January 2021	GB
5	Document revised to manage Longwall 19A	October 2022	GB

1 INTRODUCTION

1.1 Background

Sandy Creek Waterfall is located within the Metropolitan Special Catchment Area, at the point where Sandy Creek flows into Cordeaux Reservoir. The waterfall is a 25 m high concave cliff face with a maximum overhang of 20 m. Figure 1 shows the location of the waterfall in relation to the reservoir. Figure 2 and Figure 3 are images which capture the nature of the waterfall and the overhang.

The waterfall is located between Dendrobium Area 2 and 3A mining domains. Longwall 5, the last longwall in Area 2, is located 923 m to the east of the waterfall. Longwall 6, 7 and 8 in Area 3A mined within 388 m, 427 m and 739 m respectively, at their closest point of Sandy Creek Waterfall. Figure 4 shows the existing and proposed mining in relation to the Waterfall.

Illawarra Metallurgical Coal (IMC) recognised the significance of the waterfall during the preparation of the 2007 Environmental Assessment and committed to the formation of a Technical Committee and a Management Plan. The Dendrobium Development Consent conditions specify that in respect of mining:

(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

IMC formed the Sandy Creek Waterfall Technical Committee to assist IMC develop and implement the Management Plan.

1.2 Scope

The Sandy Creek Waterfall Management Plan has been revised to monitor and manage the proposed extraction of Longwalls 19 and 19A at Dendrobium Mine.

The Sandy Creek Waterfall Management Plan does not propose mitigation actions. In the event that mitigation is required the Area 3A Watercourse Impact Monitoring, Management and Contingency Plan will be used.

1.3 Purpose

The purpose of the Sandy Creek Waterfall Management Plan is to outline the investigations undertaken to understand the waterfall structure, geology, geomechanics, predicted mining impacts and identify the monitoring and management process to ensure management outcomes consistent with the Development Consent and Longwall 19 SMP Approval.

Figure 1 Sandy Creek Waterfall Location

Figure 2 Photograph of Sandy Creek Waterfall

Figure 3 Photograph of overhang at Sandy Creek Waterfall

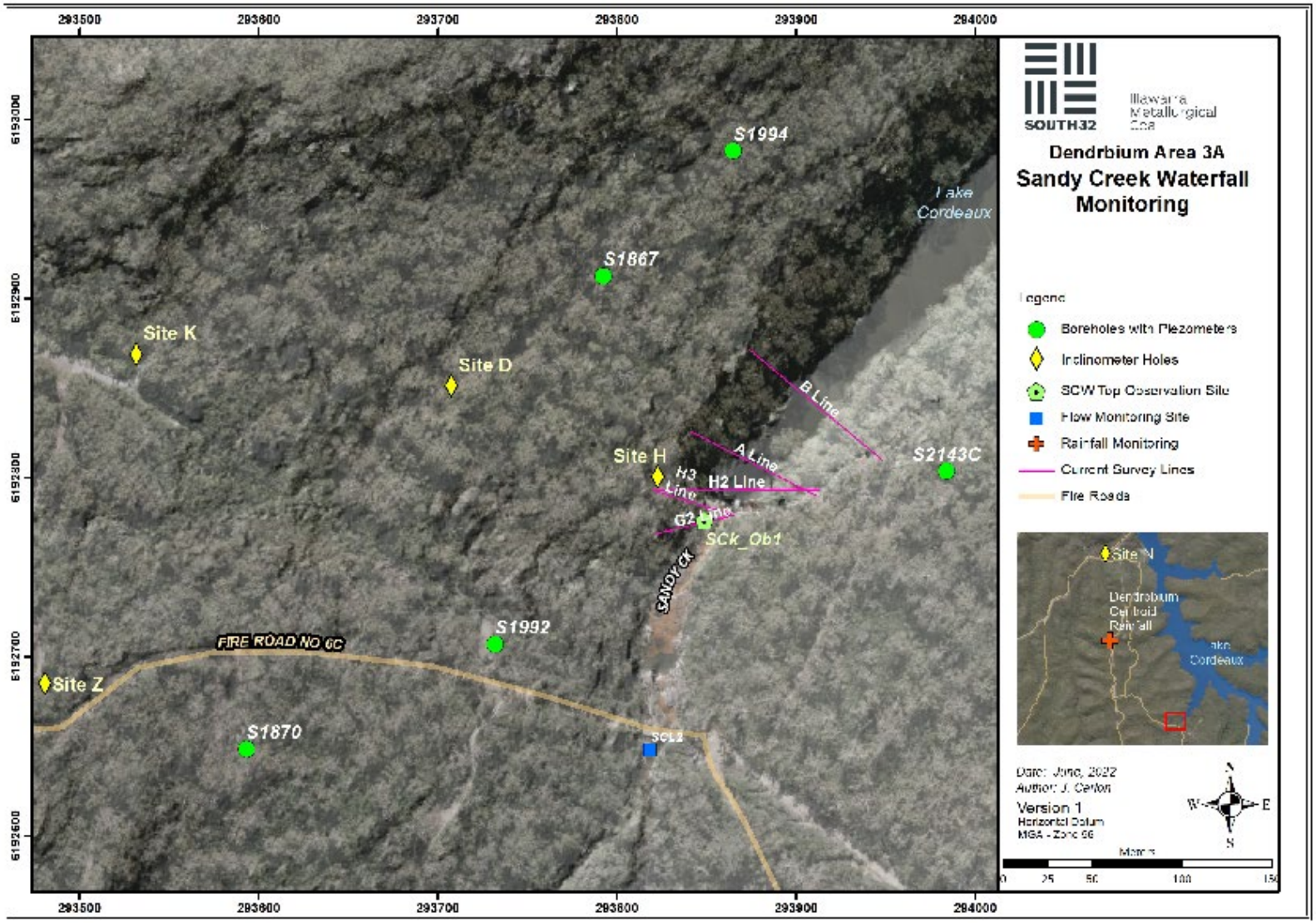

Figure 4 Relationship of Sandy Creek Waterfall to existing and proposed mining

2 REGULATORY REGIME

2.1 Dendrobium Development Consent DA60-03-2001

Condition 1 of Schedule 3 of the modified Development Consent states:

1. *The Applicant shall ensure that, as a result of the development:*

(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*

to the satisfaction of the Director-General.

2.2 Dendrobium Area 3A Subsidence Management Plan

The SMP for Longwall 6 – 8 was approved by the then Department of Planning on 28 June 2010 and the then Industry and Investment NSW on 9 July 2010.

The Longwall 19 Subsidence Management Plan application (SMP) was approved by the then Department of Planning, Industry and Environment on 11 March 2021.

This document has been updated for the Longwall 19A SMP, which will be submitted to the Department of Planning and Environment for approval.

2.3 Governance Structure

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

2.3.1 Membership and Roles of the Steering Committee

The Sandy Creek Waterfall Steering Committee will be composed of the following IMC members:

- Vice President Operations;
- General Manger of Dendrobium Mine; and
- General Manager of Mining Services.

The roles of the Steering Committee are as follows:

1. Endorse the Sandy Creek Waterfall Management Plan.
2. Provide the resources to implement the Sandy Creek Waterfall Management Plan.
3. Review and assess information provided by the Technical Committee.
4. Assess the acceptability of the ongoing level of risk to the Waterfall.
5. Implement management actions to protect the Waterfall.

2.3.2 Membership and Roles of Technical Committee

The Sandy Creek Waterfall Technical Committee will be composed of the following IMC and consultant members:

- Professor Bruce Hebblewhite – acting as an independent geotechnical/subsidence consultant.
- Dr Ken Mills – Principal Geotechnical Engineer, SCT.
- Dr James Barbato – Subsidence Engineer, Mine Subsidence Engineering Consultants.
- Superintendent Infrastructure Protection.
- Coordinator Survey and Subsidence.
- Manager Technical Services.
- Principal Approvals.

The roles of the Technical Committee are as follows:

1. Recommend the monitoring and resources to implement the Sandy Creek Waterfall Management Plan.
2. Review and interpret the results of the monitoring required in the Sandy Creek Waterfall Management Plan.
3. Assess the status of the Waterfall as per the Trigger Action Response Plan (TARP) available in Appendix 1.
4. Advise the Steering Committee of the interpretation of monitoring results with respect to the status of the Waterfall.

The committee developed the preliminary investigations, monitored and reviewed the extraction of the later part of Longwall 5 and has successfully overseen the extraction of Longwall 6, 7, 8 and 19 within the requirements of the Approvals.

3 SANDY CREEK WATERFALL

3.1 Geomorphology

The waterfall is located at the point where the Sandy Creek valley changes from a broad, gentle valley with less than 70 m relief, to an incised valley with up to 110 m relief. Figure 4 shows the topography of the Sandy Creek valley as defined by surface contours based on an Airborne Laser Scan (ALS) of the area. The ALS data is supplemented by information from a hydrographic survey within the reservoir downstream of the waterfall.

In addition to the regional topography IMC has undertaken Terrestrial Laser Scans (TLS) within the overhang and the top of the overhang to define the extent of the overhang as an input to geomechanical modelling. Figure 5 shows a section along the centreline of the creek, through Sandy Creek Waterfall.

3.2 Geology

The terrain upstream of the waterfall is dominated by the Hawkesbury Sandstone. The valley downstream of the waterfall has been incised through the Hawkesbury Sandstone, Newport Formation and the Bald Hill Claystone into the Bulgo Sandstone. The lip of the waterfall is formed from the basal section of the Hawkesbury Sandstone. The Sandy Creek Waterfall is developed due to undercutting of the softer formations under the resistant basal 5 m of Hawkesbury Sandstone. Figure 6 shows a section along the centreline of the creek, through the Waterfall and highlights the geological control for the location of the waterfall.

IMC has prepared a detailed geological model based on the regional and local surface boreholes and mapping of lithological boundaries. The geological model has provided constraints for the strain monitoring and information from the installation of the monitoring has been incorporated into the model. The geological model is an additional input to numerical modelling.

3.3 Geomechanical Testing

Rock properties were determined in laboratory tests conducted on selected core recovered from eight boreholes (EDEN139-146) drilled to investigate the lithology and install monitoring for Longwall 5. Holes EDEN 139-145 were vertical, hole EDEN146 was drilled at an angle specifically to intersect bedding planes and stratigraphic boundaries between the Hawkesbury Sandstone and the Bulgo Sandstone for laboratory testing. The results of the Laboratory testing are summarised in Table 1.

Table 1 Rock Property Laboratory Test Results

Borehole	Depth (m)	Geological Unit	UCS (MPa)	E (GPa)	k	v
EDEN139	9.6	HBSS	17	7.9		
EDEN140	9.5	HBSS	50	12	4.5	
	10	NPFM	53	8		
	13.8	NPFM	85	14	4	
EDEN141	11	HBSS	15	9		
	19	BHCS	20	7	3	

EDEN142	10.6	HBSS	29	10		
	13.4	HBSS	32	9	4.5	
EDEN143	30	HBSS	57	21		
	44	BACS	54	13		
	45	BACS	49	11		
	50	BACS	72	17		
EDEN144	10.6	HBSS	28	14		
	47	NPFM	30	7		
	57	BACS	91	21		
	63	BGSS	60	11	5	
EDEN145	34.8	HBSS	78	30	0.15	
	35	HBSS	71	30	0.16	
EDEN146	37.3	HBSS	66	30	0.2	
	17.6	HBSS	43	19		0.3
	23.7	HBSS	46	21	5	
	9.0	HBSS	40	11		
	16.5	HBSS	40	11		
	16.8	NPFM	70	12		
	18.7	NPFM	28	7.5		
	19.0	BACS	35	7.5		
	22.9	BACS	20	8		
	27.4	BACS	16	7		
	28.4	BGSS		7.5		
	32	BGSS		9		
	32.5	BGSS	20	7.5		
	35.1	BGSS	60	11		

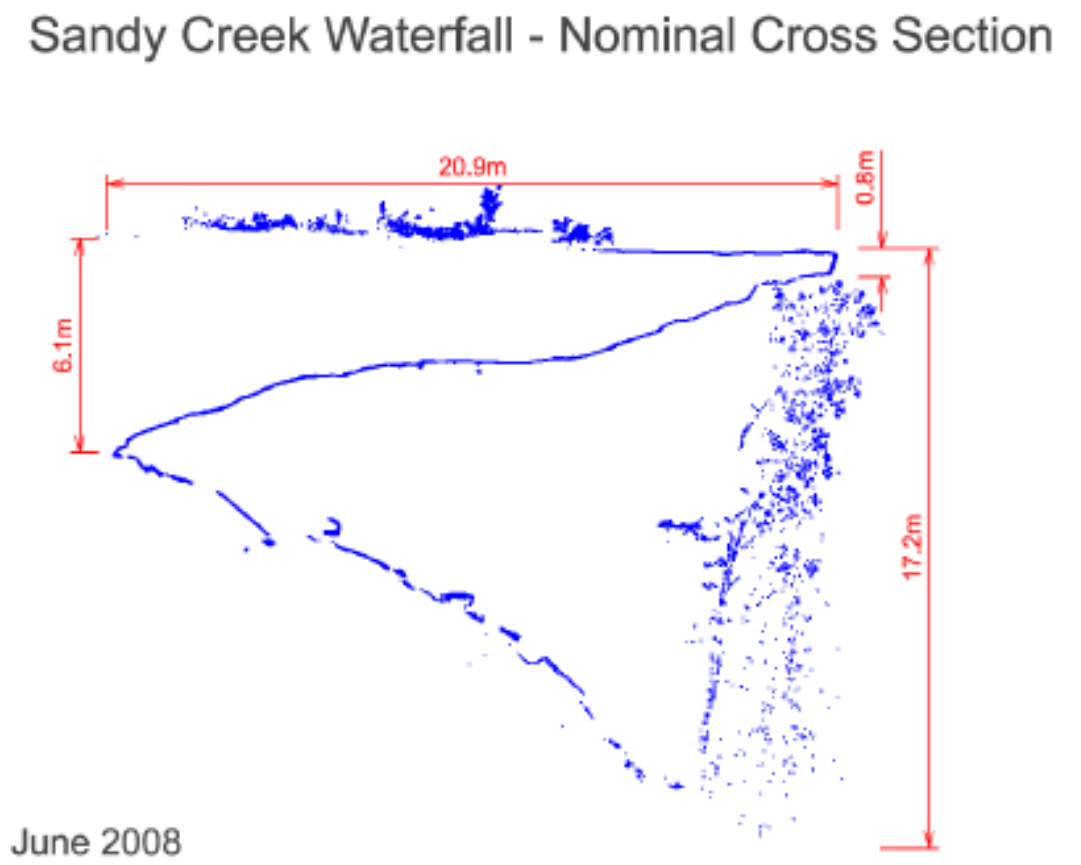

Figure 5 Sandy Creek Waterfall Nominal Cross Section based on Terrestrial Laser Scan

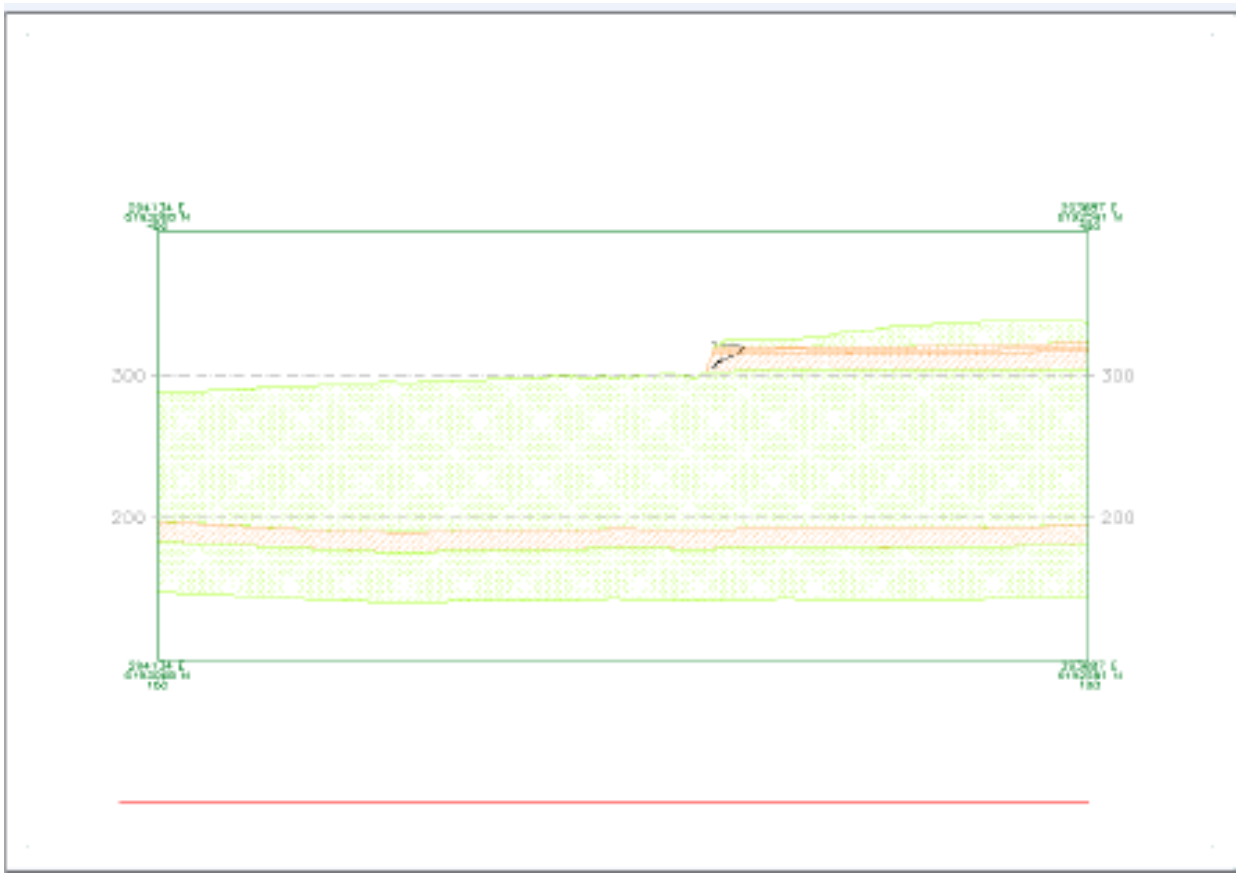

Figure 6 Geological Cross Section along Sandy Creek

3.4 Existing Stress Field

Four initial measurements of in situ stress were conducted using the overcoring technique, at two sites near the waterfall, prior to the commencement of Longwall 6. Overcore tests DEN3 and DEN4 are located in borehole EDEN142A approximately 160 m upstream of Sandy Creek Waterfall, some 16 m below the surface and 4 m above the base of the Hawkesbury Sandstone. Both instruments indicate a similar stress field. The vertical stress is the major principal stress with a magnitude of 1.1-1.6 MPa. The major horizontal stress is oriented at 40-50ºGN with a magnitude of 0.6-0.8 MPa in rock with a modulus of 11-12 GPa. The minor horizontal stress is approximately half the major horizontal stress. Overcore tests DEN8 and DEN9 are located in borehole EDEN144A approximately 200 m northwest of the waterfall, approximately 35 m deep and 12 m above the base of the Hawkesbury Sandstone. Both instruments provide measurements of the in situ stress with very high correlation coefficients and indicate essentially the same stress field. The vertical stress indicated ranges between 2.0-3.2 MPa. The major horizontal stress ranges 3.0-4.9 MPa at 127ºGN.

The results of the stress tests are used to assess the existing state of the stress field and as input to numerical modelling.

Assessment of the data indicated that there is likely to be a stress concentration in the strata at the waterfall area due to the shape of the valley. The magnitude of the stress concentration was expected to be confirmed by the numerical model and the testing in the additional monitoring sites adjacent to the waterfall for Longwall 6.

Four additional in situ stress measurements were conducted using the overcore technique at two sites within 10m of the waterfall overhang, The tests were undertaken in the basal few metres of the Hawkesbury Sandstone, stratigraphically equivalent to the overhang. The tests were undertaken as the monitoring for Longwall 6 was installed. Overcore Tests DEN16 and DEN17 are located just to the west of the Waterfall overhang. Both tests indicate the same stress field. The major horizontal stress magnitude is 1.53 MPa oriented at 333-355ºGN, which 'parallels' the back of the overhang. The minor horizontal stress is approximately half the major horizontal stress and oriented towards the valley opening. Overcore Tests DEN19 and DEN20 are located just to the south of the Waterfall overhang. Both tests indicate a similar stress field. The major horizontal stress magnitude is 0.94-1.53 MPa oriented at 280-307ºGN, which 'parallels' the back of the overhang. The minor horizontal stress is approximately half the major horizontal stress and oriented towards the valley opening.

The in situ stress measurements undertaken adjacent to the waterfall provided a consistent, logical stress field aligned with the back of the overhang. The in situ stress was not elevated due to the termination of the incised valley and this lack of a stress concentration was also apparent from the modelling work.

At the review of Longwall 6 stress data it was identified that the stress change monitored during the extraction of Longwall 6 could be confirmed by re-testing adjacent to DEN16 and 17 and DEN19 and 20.

The post Longwall 6 stress field was confirmed as additional monitoring was installed for Longwall 7. Overcore tests DEN22 and 23 are located adjacent to overcore tests DEN16 and 17. Overcore tests DEN25 and 26 are located adjacent to overcore tests DEN19 and 20. The results of these overcores have been reviewed by the Technical Committee.

The review of the Longwall 6 monitoring in particular the 3D regional movements and stress field, indicated that a key driver for the movements observed at Sandy Creek is the stress concentration around the Longwall 6 goaf.

3.5 Subsidence Predictions

Mine Subsidence Engineering Consultants (MSEC) have prepared subsidence predictions for the Sandy Creek Waterfall. MSEC Report 1081 (MSEC 2020) considers the Longwall 19 layout; MSEC Report 1234 (MSEC 2022) consider the proposed Longwall 19A. The thalweg of the creek is located 750 m from the commencing end of Longwall 19, at its closest point. Sandy Creek is therefore located outside the Study Area based on the 600 m boundary.

The maximum measured total closure across Sandy Creek Waterfall due to the mining of Longwalls 6 to 8 was approximately 17 mm. The greatest closure was measured across the SCW HRS H1-Line located downstream of the waterfall and across the valley of Lake Cordeaux.

A summary of the measured incremental closure movements for the SCW HRS H1-Line, due to the mining of each of Longwalls 6 to 8, is provided in Table 2. The distances of the longwalls from the centreline of the waterfall are also provided in the Table 2.

Table 2 Measured incremental closure for the SCW HRS H1-Line due to Longwalls 6 to 8

Monitoring Line	Longwall	Distance from the centreline of Sandy Creek Waterfall (m)	Measured incremental closure (mm)
SCW HRS H1-Line	6	390	4
	7	430	5
	8	500	5

The maximum predicted incremental vertical subsidence, upsidence and closure for Sandy Creek, due to the mining of Longwall 19, are all less than 20 mm. While the creek could experience very low levels of these subsidence effects, it is not expected to experience measurable tilts, curvatures or strains as a result of vertical subsidence. It is unlikely, therefore, that adverse impacts would occur along Sandy Creek due to the mining of Longwall 19.

The maximum predicted incremental vertical subsidence, upsidence and closure for Sandy Creek, due to the mining of Longwall 19A, are all less than 5 mm. While the creek could experience very low levels of these subsidence effects, it is not expected to experience measurable tilts, curvatures or strains. It is unlikely, therefore, that adverse impacts would occur along Sandy Creek due to the mining of Longwall 19A.

The predicted incremental closure for Sandy Creek Waterfall due to the mining of Longwalls 19 and 19A are less than 2 mm each. These movements are similar to the order of survey tolerance and environmental effects. It is considered unlikely, therefore, that Sandy Creek Waterfall would experience adverse impacts due to the mining of Longwalls 19 and 19A. (MSEC 2022).

The valley closure effects across Sandy Creek Waterfall due to the mining of Longwall 19 were measured using the SCW High Resolution Survey (HRS) A, B, H2, H3 and G2 Lines. The locations of these monitoring lines are shown in Figure 7. Three survey lines which were monitored during extraction of Longwall 6 to 8 were not able to be re-established due to significant vegetation growth blocking the line of sight.

Figure 7 SCW High Resolution Survey A, B, H2, H3 and G2 Lines

The measured total closures for SCW HRS lines are illustrated in Figure 8. The survey accuracy for these high-resolution monitoring lines is in the order of ±0.5 mm to ±1 mm. The measured movements also include a component due to environmental effects (i.e. changes in temperature and rainfall) in the order of ±1 mm to ±2 mm.

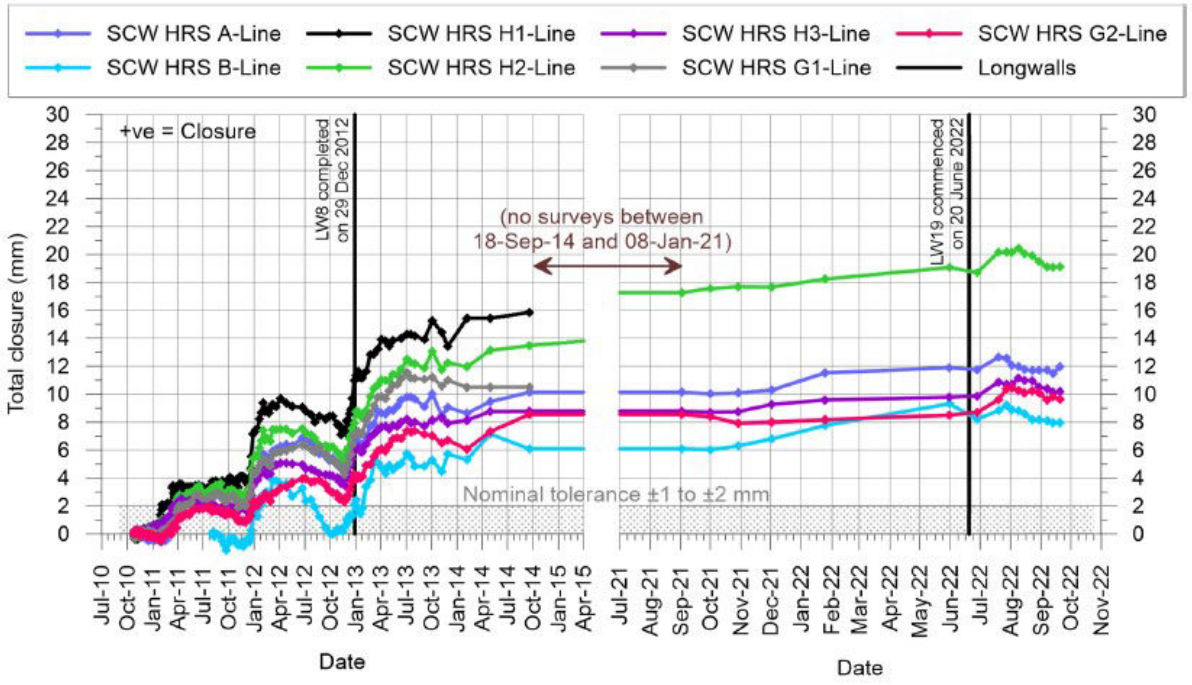

Figure 8 Measured total closure for the Sandy Creek Waterfall high resolution survey monitoring lines for Longwalls 6 to 8 and Longwall 19

Longwall 19 and the proposed Longwall 19A are located 900 m and 1200 m, respectively, from the centreline of Sandy Creek Waterfall. These longwalls are between 1.8 to 3.1 times the distances of Longwalls 6 to 8 from the centreline of the waterfall. Also, the eastern end of Longwall 8 extends beyond the eastern ends of both Longwalls 19 and 19A and, therefore, it provides shadowing effects. On this basis, the predicted incremental closure for Sandy Creek Waterfall due to the mining of Longwalls 19 and 19A are less than 2 mm each. The predicted incremental movements therefore are in the order of the survey tolerance and environmental effects. It is unlikely that Sandy Creek Waterfall would experience adverse impacts due to the mining of Longwalls 19 and 19A.

3.6 Recent High Resolution Survey

The latest surveys and visual observations were carried out on 20 September 2022, during the extraction of Longwall 19. The Technical Committee reviewed the latest monitoring data in the meeting held on 23 September 2022. There were only small changes in the closures measured at the Sandy Creek Waterfall HRS monitoring lines. The trend over the last month indicates slight reductions in closures. The movements were in the order of survey tolerance and likely comprise both seasonal and mining-related effects.

3.7 Numerical Model

Prior to Longwall 6 approaching the Waterfall, Dr Michael Coulthard of M.A. Coulthard and Associates prepared a three dimensional numerical model using FLAC3D software under the direction of Dr K Mills in consultation with the Technical Committee. The model is based on input from the topography defined by the ALS and TLS, geological model, geomechanical testing of rock properties and in situ stress. The model is 1,500 m x 1,500 m area to the base of the Bulgo Sandstone, centred on the waterfall. The model has graduated cell sizes 2 m adjacent to the waterfall, increasing to 10 m at the margins of the model. Figure 9 shows the central part of the model grid showing the valley geometry and stratigraphy.

The model is intended to allow investigation of the nature of ground movements that would be expected in the vicinity of Sand Creek Waterfall as a result of longwall mining in Area 3A. The model was set up to investigate the natural stress concentrations expected around Sand Creek Waterfall and the potential for down slope movement associated with Longwall 6 to impact on Sand Creek Waterfall. An artificial boundary consistent with the geometry of the approaching face of Longwall 6 was used to simulate the down slope movement expected to be generated ahead of Longwall 6. Although the model runs conducted ahead of mining Longwall 6 provided a useful framework for investigating the potential for down slope movement, the stress concentrations measured at several locations around Sand Creek Waterfall did not correlate in magnitude or alignment with the stress concentrations indicated

by the model. Furthermore the stress changes observed during the retreat of Longwall 6 did not closely follow the path indicated by the model. This disparity reduced confidence in the model outcomes during the period of mining Longwall 6.

Ground movements observed at the completion of Longwall 6 by surveying along the power line survey line perpendicular to the middle of Longwall 6 indicated that perceptible ground movements in a NE direction were observed (and extrapolated) to extend to a distance of approximately 1.6 km from the southern goaf edge of Longwall 6. This movement is entirely consistent with the regional stress field and more consistent with the general alignment of stress changes observed around Sand Creek Waterfall by stress change monitoring instruments and high resolution surveying. Similar behaviour has been observed at other sites. It appears as though the focus of the model on a down slope movement mechanism did not represent the actual mechanism that was loading Sandy Creek Waterfall during the retreat of Longwall 6. The poor correlation between the stress changes and displacements observed and those indicated by the model for the down slope mechanism that was simulated is consistent with the model having been focussed on the wrong mechanism.

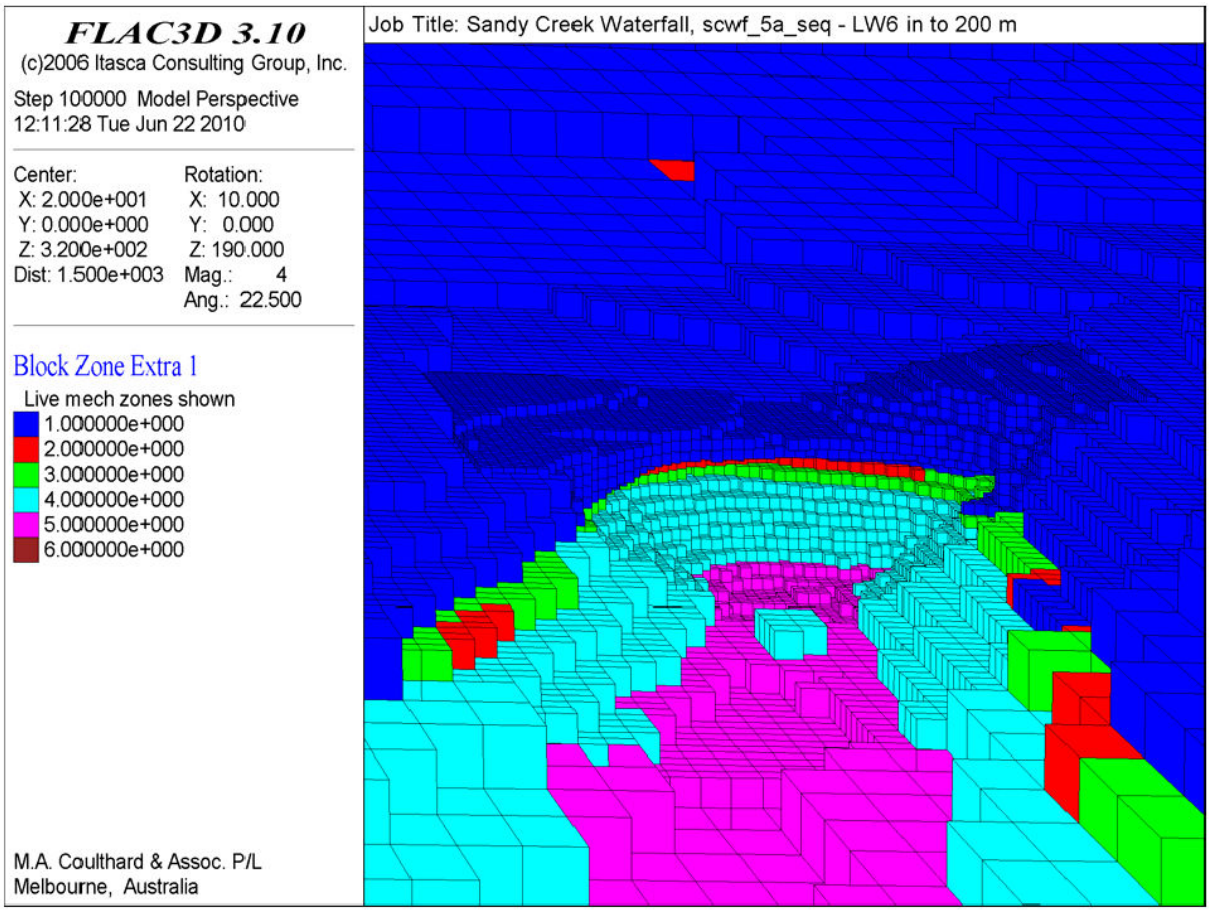

Figure 9 Detail of Sandy Creek Waterfall in Numerical Model

3.8 Longwall 5 Monitoring

The Technical Committee developed a monitoring programme to understand the effects of Longwall 5 extraction and as a basis for the development of Area 3A monitoring. The Longwall 5 Monitoring Programme included:

- Sandy Creek 3D Ground Survey, in addition to existing Area 2 3D Ground Survey;
- Strain;
- Rock / Joint Strain Monitoring;
- Borehole Shear;
- Micro-seismic; and
- Photographic record.

An ALS was also undertaken at the completion of Longwall 5 which allowed the comparison of observed and predicted subsidence above the extracted longwall panel.

Summary Reports were prepared and distributed during the period of active subsidence. The summary reports reviewed key data including the longwall face location, incremental and cumulative 3D ground movement, ground movement in relation to distance from the goaf edge and the development of strain at 2 key sites. The result and interpretation of the monitoring programme are documented and reviewed in three reports:

- MSEC report End of Panel Subsidence Monitoring Report for Dendrobium Longwall 5.
- SCT report Sandy Creek Waterfall Monitoring Initial Measurements and Monitoring to end of Longwall 5.
- CSIRO Report A trial of micro-seismic monitoring of ground stability at Sandy Creek Waterfall, adjacent to longwall panels of Dendrobium Coal Mine.

The Technical Committee identified key learning's from the Longwall 5 monitoring:

- The extent of vertical subsidence as measured by the ALS and confirmed by 3D control is almost entirely localised to immediately above the workings. The effective angle of draw is nominally <20^{o}.
- Within the limitations of survey tolerance the extent of measurable horizontal movement (3D survey) is localised to within 400 m of the edges of the longwall panel.
- The development of ground movement away from Longwall 5 (vertical and horizontal) appears more localised than the ground movements associated with the deeper Bulli Seam Operations, which occur over wider areas. The Longwall 5 movements are consistent with the Dendrobium Longwall 1 – 4 experience.
- The subsidence, upsidence and closure movements due to Longwall 5 at the Sandy Creek Waterfall were less than survey tolerance (923m away from the closest point of Longwall 5).
- The analysis of the strain monitoring determined that a tension effect with good correlation was measured at DEN1, 600 m away from Longwall 5.
- The remaining six strain cells located closer to the Waterfall did not detect significant change in stress.
- Identified the need to monitor the development of strain adjacent to the waterfall, in the same stratigraphic unit.
- The rock/joint strain monitoring was overwhelmed by the diurnal temperature variations and processing was not able to render the data useful.
- The micro-seismic monitoring detected >100 events, including 26 during the longwall changeover.
- The micro-seismic events occurred at depths greater than 150m associated with the goaf. There were additional weak events (low signal to noise ratio) which were not processed and could not be related to depth.
- A more extensive array of geophones, including deeper installation is required to obtain event location.
- No visual change was observed at Sandy Creek Waterfall.

3.9 Longwall 6 Monitoring

The Technical Committee reviewed the Longwall 5 monitoring results and developed a monitoring programme to understand the effects of Longwall 6 extraction. The monitoring programme is documented in Revision 0 and 1 of the Management Plan. The Longwall 6 Monitoring Programme included additional monitoring in close proximity to the overhang, indicative of conditions in the overhang but which did not compromise the integrity of the overhang. An early warning site close to the longwall which was expected to undergo a range of conditions as the longwall passed the site and finally a Reference Site was developed at Cordeaux Colliery.

Summary Reports were prepared and distributed during the period of active subsidence. The summary reports reviewed key data including the longwall face location, incremental and cumulative 3D ground movement, ground movement in relation to distance from the goaf edge and the development of strain at 2 key sites. The result and interpretation of the monitoring programme are documented and reviewed in three reports:

- MSEC Report 488, End of Panel Subsidence Monitoring Report for Dendrobium Longwall 6.
- CSIRO Report Microseismic monitoring of ground stability at Sandy Creek Waterfall.
- Technical Committee Longwall 6 Monitoring Summary.

The Technical Committee identified several key learning's from the Longwall 6 monitoring. The key learning's are:

- There has been no impact observed at the waterfall, in compliance with the Development Consent criteria.

- The monitoring indicates that the effects of Longwall 6 have ceased prior to any incremental effect from the commencement of mining Longwall 7.
- The cessation of mining effects was nominally 2 months after Longwall 6 stopped cutting.
- Subsidence of up to 1.2m was measured nominally 85% of predicted.
- The extent of vertical subsidence as measured by the ALS and confirmed by 3D control and the North and South Lines is almost entirely localised to immediately above the workings. The effective angle of draw is nominally <20^{o}.
- The regional 3D ground surveying identified that there was little to no measurable movement observed in front (East) of the longwall. Movements were measured after the longwall had passed monitoring sites.
- The regional 3D ground surveying confirms that horizontal movements beyond the longwall are consistent with the regional stress direction.
- High resolution closure lines installed during Longwall 6 extraction near the waterfall measured movements of 2.0 to 3.6 mm near the Waterfall.
- Stress monitoring at the early warning site behaved as expected (magnitude and direction).
- Stress change measured next to the Waterfall was nominally in the secondary horizontal stress direction, towards the overhang.
- The accumulation of stress near the waterfall did not respond to the precautionary delays (1 week and 3 weeks duration).
- Greater than 95% of the micro-seismic events observed were associated with the strata failure near the Longwall face with estimated magnitude from -1 to 1 (MMI).
- Shallow micro-seismic events observed (less than 100 m depth) were mostly located behind the longwall face, associated with subsidence.
- Very weak events were sparsely distributed ahead of the longwall face and generally only triggered on one nearby geophone.
- No micro-seismic events were identified within 160 m of the waterfall.

3.10 Longwall 7 Monitoring

The Technical Committee reviewed the Longwall 6 monitoring results and developed a monitoring programme to understand the effects of Longwall 7 extraction. The monitoring programme is documented in Revision 2 of the Management Plan. The Longwall 7 Monitoring Programme included:

- shear monitoring using real time and manual inclinometers as well as real time continuity loops;
- additional closure lines;
- additional stress monitoring to support the existing array and provide redundancy;
- a centralised data logger for the seismic monitoring; and
- the inclusion of a reference site adjacent to the Cordeaux River.

Summary Reports were prepared and distributed during the period of active subsidence. The summary reports reviewed key data including the longwall face location, incremental and cumulative 3D ground movement, ground movement in relation to distance from the goaf edge and the development of strain at 2 key sites.

The result and interpretation of the monitoring programme are documented and reviewed in six reports:

- Implementation of the Sandy Creek Waterfall Management Plan – Longwall 7 by R Walsh dated 5 April 2012.
- Stress Change Monitoring at Sandy Creek Waterfall to End of Longwall 7 SCT Report DEN3531G by K Mills and J Puller dated 20 March 2012.
- Summary Report – Dendrobium Area 3A Longwall 7 Survey Monitoring by M Nicholson 24 March. 2012.
- Microseismic monitoring of ground stability at Sandy Creek Waterfall Dendrobium Coal Mine Longwall 7 CSIRO Report by X Luo and J Duan 20 February 2012.

- Sandy Creek Waterfall Shear Monitoring – Longwall 7 Summary by R Walsh, J Doyle and A Gurba dated 5 April 2012.
- Brief comments-changes in the Hawkesbury Sandstone Piezometric Levels during the extraction of LW7 by J Doyle dated 22 March 2012.

The Technical Committee identified several key learning's from the Longwall 7 monitoring. The key learning's are:

- There has been no impact observed at the waterfall, in compliance with the Development Consent criteria.
- The monitoring indicates that the effects of Longwall 7 have ceased prior to any incremental effect from the commencement of mining Longwall 8.
- The high resolution closure lines in the vicinity of the Waterfall have again proven to be the critical, high confidence data set that has allowed the Technical Committee to confidently assess the onset of closure and hence deformation at the Waterfall.
- The onset of closure in the vicinity of the Waterfall in both Longwall 6 and 7 has been rapid and the technique is reliant on suitable survey frequency. The Technical Committee has reviewed the survey frequency and has made appropriate changes to ensure sufficient data was captured to make timely decisions.
- The installation of inclinometers for the monitoring of Longwall 7 has provided another high resolution, high confidence data set that has proven very useful to the Technical Committee. The inclinometers have provided data which clearly identifies the onset of shear and hence deformation in the vicinity of the Waterfall. In addition the technique provides data that supports the mechanism for the development of deformation at the Waterfall.
- The ANZI stress change monitoring instruments have again proven to be very sensitive and were able to detect the approach of mining from about 1.5 km ahead of the longwall face at very low levels. These initial changes were not regarded by the Technical Committee as either being definitive enough to act on or significant enough to cause perceptible changes at the waterfall above those caused naturally by seasonal variations in temperature.
- The stress change instruments are able to detect seasonal thermal variations within the rock mass of the waterfall (nominally 10µS/°C for sandstone). For much of the period of mining Longwalls 6 and 7, the magnitude of these thermal changes was of the same order as the magnitude of far field stress changes.
- The shallow microseismic events monitored during Longwall 7 were almost exclusively associated with subsidence over Longwall 7 or the proceeding longwall. It was observed that during Longwall 6 (the first longwall in the Area 3A domain) there were significantly more shallow events in advance of the longwall face. The difference in behaviour is postulated to be due to the initiation of shear planes due to Longwall 6 and simple reactivation of existing planes in Longwall 7.
- The changes to the monitoring requirements for Longwall 8 were documented in the Sandy Creek Waterfall Longwall 8 Additional Monitoring Requirements by R Walsh dated 25 March 2012.

3.11 Longwall 19 Monitoring

The monitoring programme for Longwall 19 is discussed in Section 5.1.

4 MANAGEMENT STRATEGIES

Mining is required to retreat east to west during the extraction of Longwalls 19 and 19A, in the opposite direction to that of Longwalls 6 to 8. It will therefore commence at the closest point to Sandy Creek Waterfall. Previous panels in Area 3A were developed from South Mains with Longwalls 6, 7 and 8 being extracted towards the east. Maingate 19 will be developed from Wongawilli Mains development panel to the east between 20 and 23 cut troughs.

The Dendrobium Nepheline Syenite sill largely determines the lengths of the Longwalls 19 and 19A blocks and is the primary reason this block was not extracted after Longwall 8. Figure 10 shows the geological structures constraining the South Mains, Longwall 19 and Longwall 19A extents.

The entire South Mains conveyor system has been recovered and removed after completion of Longwall 8. A longwall retreating west to east would require a complete new South Mains conveyor installation as well as new Longwalls 19 and 19A conveyor installation on the eastern side of the maingate roadways. The cost and timing associated with procuring and installing this equipment would result in longwall discontinuity. The amount of work and time required to develop and operationally configure South Mains as an intake and conveyor set of mains is equivalent to setting up an entire new mining area. As well as the safety and operational risks associated with mining through the hard Nepheline Syenite sill there are many operational factors that result in Longwalls 19 and 19A retreating west to east becoming a non-feasible option.

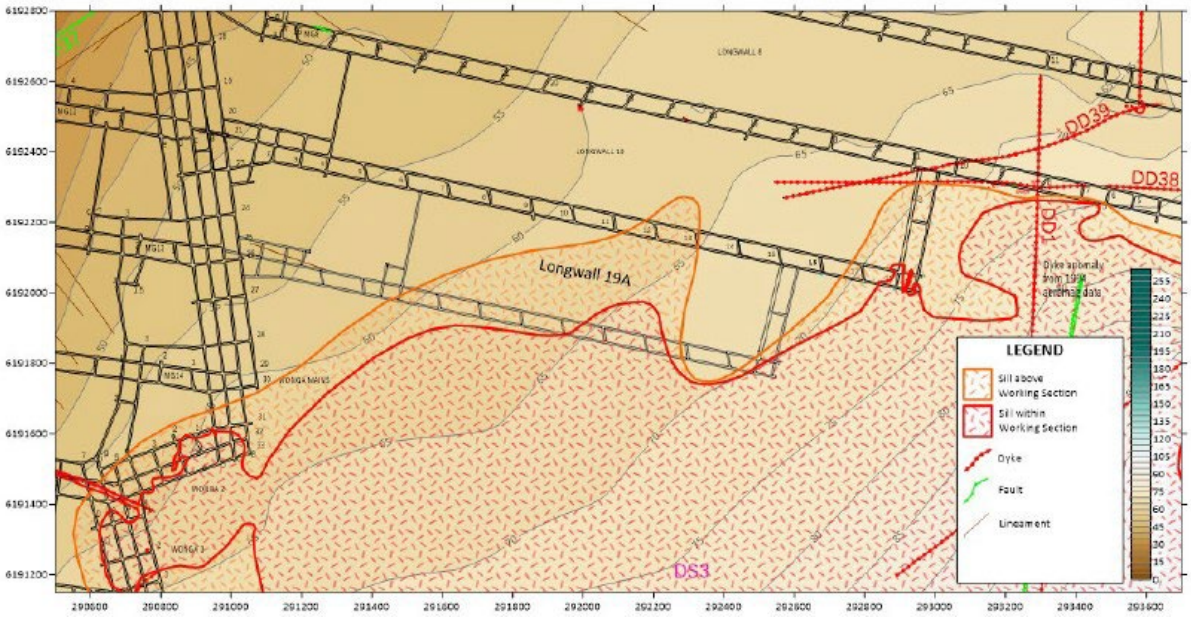

Figure 10 Geological structure and seam floor contours

4.1 Longwall 19 Risk Assessment

Following receiving advice from the Independent Advisory Panel for Underground Mining, the Department requested further information from IMC via a letter dated 22 December 2020.

In response, IMC conducted a risk assessment (AXYS 2021) on the potential impacts to Sandy Creek Waterfall from the extraction from the Longwall 19. The following controls were identified for valley closure movements which may result in impacts in excess of Development Consent Condition 1 for Sandy Creek Waterfall:

- Longwall 19 is setback from Sandy Creek Waterfall in excess of 900 m.
- Longwall 8 goaf lies between Longwall 19 and the Sandy Creek Waterfall. Longwall 19 is set back a minimum of 272 m from the eastern end of Longwall 8, buffering the effects on Sandy Creek Waterfall.
- The ridgeline over Longwall 19 is separated from Sandy Creek Waterfall by an additional drainage line SC10C, so that the slope towards Sandy Creek Waterfall is not mined under.
- Longwall 19 is mining away from Sandy Creek Waterfall and in an upslope direction, so that horizontal topographic effects and conventional horizontal effects counteract (subtract from) each other.

- Surface water monitoring data is analysed in independent studies, results inform surface data analysis and TARPs. Data is used to demonstrate compliance with the Development Consent and approval conditions.
- Visual inspections at Sandy Creek Waterfall during previous mining have not identified:
    - rock falls from its overhang;
    - impacts to the structural integrity of the waterfall, its overhang or pool;
    - cracking in Sandy Creek within 30 m of the waterfall; and/or
    - diversion of water from the lip of the waterfall

  related to the mining of Longwalls 6 to 8 in Area 3A, in compliance with Dendrobium Development Consent – Schedule 3 Condition 1.
- Subsidence Management Plan - including End of Panel reporting and auditing against performance measures, including the 2020 Independent Environmental Audit for Dendrobium Mine (ERM 2020).
- Ground monitoring including high resolution closure lines data is reviewed and assessed against the TARP and Development Consent and approval conditions.
- In the absence of massive strata, experience with mining at depth in NSW shows surface subsidence occurs gradually (not step like) at the commencement of the longwall panel. There is no massive strata above the start of Longwall 19 with a minimum depth of cover of 290 m.

4.2 Longwall 19A Risk Assessment

In accordance with the recommendation from the Independent Advisory Panel, IMC conducted a risk assessment on the potential impacts, including Sandy Creek Waterfall, to support the Longwall 19A SMP (AXYS 2022). The Longwall 19A SMP Risk Assessment is presented as an attachment to the Longwall 19A SMP.

4.3 Monitor and Trigger Action Response Plan

Investigations by the Technical Committee and experience from successfully mining Longwalls 6 to 8 have developed an effective, robust monitoring plan. The review of the monitoring data by the Technical Committee will provide the basis to inform the Steering Committee.

The TARP relate to identifying, reporting, assessing and responding to potential impacts to Sandy Creek Waterfall (including impacts greater than predicted) from subsidence in Dendrobium Area 3A. These TARPs have been prepared using knowledge gained from previous mining in Longwalls 6 to 8 and other areas of Dendrobium Mine.

The TARPs represent actions (including reporting) to be taken upon reaching each defined trigger level. If required, a Corrective Management Action (CMA) is developed in consultation with stakeholders to manage an observed impact in accordance with relevant approvals.

For Longwall 6 the criteria used to protect Sandy Creek Waterfall was, the absence of “Real Compressive Stress” measured in the sandstone unit that forms the overhang. Real compressive stress was considered to be the main mechanism for damaging the waterfall/overhang. Based on the results of Longwall 6 monitoring the simplest and most reliable and accurate monitoring is the High Resolution Closure Lines at the Waterfall which were initiated during Longwall 6 to complement and provide independent confirmation of initial changes indicated by the stress change monitoring.

The monitoring of the Waterfall during the extraction has confirmed that there are changes associated with Longwalls 6 and 7. Measurable deformation has been detected in the High Resolution Closure Lines and the Inclinometers. The Stress Change Monitoring has also detected measurable changes as Longwall 8 approached the Waterfall. The monitoring indicates that there has been a measurable change in the high resolution survey monitoring data from the Waterfall following the completion of Longwall 6, 7 and 8 with an additional 3.8 mm of valley closure movement measured. This is discussed in detail in Section 3.6. The recent measurable changes have been incorporated into the revised subsidence predictions for Sandy Creek Waterfall (MSEC 2021).

Weekly high resolution surveys and visual inspections will be carried out for the first 600 m of Longwall 19 extraction. Monthly monitoring of high resolution survey lines is recommended for the first 1000 m of Longwall 19A. Monitoring frequency for the remainder of the extraction will be reviewed by the Technical Committee based on the monitoring data and rate of longwall advance.

A one year of suitable baseline data prior to Longwall 19A will be collected for the high resolution survey monitoring lines.

5 REVIEW AND REPORTING

5.1 Monitoring and Data Review

The monitoring data review processes are outlined in Table 3, monitoring and data review frequency is determined by the TARP level. Most of the data is manually downloaded, analysed and reported, normally within 24 hours.

Table 3 Monitoring and Data Review

Review	Responsibility	Frequency
Survey Data	IMC	Monthly / Weekly / Biweekly
Manual Inclinometer	IMC	Monthly / Weekly / Biweekly
Visual Observation	IMC	Monthly / Weekly / Biweekly
SCW Technical Committee	SCW Technical Committee	Monthly / Weekly / Biweekly

5.2 Management Plan Review

The TARP will be reviewed during the extraction of Longwall 19 based on new, unexpected or unusual monitoring results. Results during the extraction of Longwall 19 will be reviewed to inform the TARP for the extraction of Longwall 19A.

5.3 Reporting

DPE and WaterNSW will be notified within 24 hours of conformation of any of the following:

- failure of the monitoring system; and
- exceedance of the Development Consent or SMP Approval conditions.

6 REFERENCES AND SUPPORTING DOCUMENTATION

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Appendix 1 – Trigger Action Response Plan

OBSERVATIONAL MONITORING		
Relevant Performance Measure(s): • no rock fall occurs at Sandy Creek Waterfall or from its overhang; • the structural integrity of the waterfall, its overhang and its pool are not impacted; • cracking in Sandy Creek within 30 m of the waterfall is of negligible environmental and hydrological consequence; and • negligible diversion of water occurs from the lip of the waterfall	***Level 1*** • Visible fracturing, ecological impact or water diversion on Sandy Creek due to mining Longwalls 19 or 19A	• Continue weekly monitoring until 600 m of Longwall 19 or Longwall 19A extraction is complete • Technical Committee to advise on monitoring frequency • Submit an Impact Report to BCS, DPE, MEG and Water NSW • Report in the End of Panel Report • Summarise actions and monitoring in AR
	Level 2 • Visible fracturing, ecological impact or water diversion within 300 m - 150 m of Sandy Creek Waterfall on Sandy Creek	• *Actions as stated for Level 1* • Continue weekly monitoring until 1,000 m of Longwall 19 of Longwall 19A extraction is complete • Technical Committee to advise on monitoring frequency
	Level 3 • Visible fracturing, ecological impact or water diversion within 150 m of Sandy Creek Waterfall on Sandy Creek	• *Actions as stated for Level 2* • Increase monitoring frequency to twice weekly • Offer site visit with BCS, DPE, MEG and Water NSW • Develop site CMA (subject to agency feedback). This may include: grouting of rockbar where it is appropriate to do so in consultation with BCS, DPE, MEG and Water NSW • Completion of works following approvals and at a time agreed between S32, DPE, MEG and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success • Review relevant TARP and Management Plan in consultation with key agencies
	Exceeding Prediction • Mining results in rock fall at Sandy Creek Waterfall or from its overhang • Mining results in impacts on the structural integrity of Sandy Creek Waterfall, its overhang or its pool • Mining results in cracking in Sandy Creek within 30 m of Sandy Creek Waterfall and is of greater than negligible environmental and hydrological consequence • Mining results in greater than negligible diversion of water from the lip of Sandy Creek Waterfall	• *Actions as stated for Level 3* • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation • Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent

VALLEY CLOSURE		
Relevant Performance Measure(s): • no rock fall occurs at Sandy Creek Waterfall or from its overhang; • the structural integrity of the waterfall, its overhang and its pool are not impacted; • cracking in Sandy Creek within 30 m of the waterfall is of negligible environmental and hydrological consequence; and High resolution closure lines: • A Line • B Line • H2 Line • H3 Line • G2 Line	***Level 1*** • No measurable movement beyond Longwalls 19 or 19A baseline steady state	• Continue weekly monitoring until 600 m of Longwall 19 or Longwall 19A extraction is complete • Technical Committee to advise on monitoring frequency • Submit an Impact Report to BCS, DPE, MEG and Water NSW • Report in the End of Panel Report • Summarise actions and monitoring in AR
	Level 2 • Repeatable measurable movement consistent with low level mining influence	• *Actions as stated for Level 1* • Continue weekly monitoring until 1,000 m of Longwall 19 or Longwall 19A extraction is complete • Technical Committee to advise on monitoring frequency
	Level 3 • Increased rate of movement associated with mining or abnormal movements	• *Actions as stated for Level 2* • Increase monitoring frequency to twice weekly • Offer site visit with BCS, DPE, MEG and Water NSW • Develop site CMA (subject to agency feedback). This may include: grouting of rockbar where it is appropriate to do so in consultation with BCS, DPE, MEG and Water NSW • Completion of works following approvals and at a time agreed between S32, DPE, MEG and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success • Review relevant TARP and Management Plan in consultation with key agencies
	Exceeding Prediction • Mining results in rock fall at Sandy Creek Waterfall or from its overhang • Mining results in impacts on the structural integrity of Sandy Creek Waterfall, its overhang or its pool • Mining results in cracking in Sandy Creek within 30 m of Sandy Creek Waterfall and is of greater than negligible environmental and hydrological consequence • Mining results in greater than negligible diversion of water from the lip of Sandy Creek Waterfall	• *Actions as stated for Level 3* • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation • Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent
SHEAR		

Relevant Performance Measure(s): • the structural integrity of the waterfall, its overhang and its pool are not impacted; Inclinometers • Site D, H and Z	***Level 1*** • No measurable movement beyond Longwalls 19 or 19A baseline steady state	• Continue weekly monitoring until 600 m of Longwall 19 or Longwall 19A extraction is complete • Technical Committee to advise on monitoring frequency • Submit an Impact Report to BCS, DPE, MEG and Water NSW • Report in the End of Panel Report • Summarise actions and monitoring in AR
	Level 2 • Multiple measurable movement consistent with low level mining influence	• *Actions as stated for Level 1* • Continue weekly monitoring until 1,000 m of Longwall 19 or Longwall 19A extraction is complete • Technical Committee to advise on monitoring frequency
	Level 3 • Shear movements result in shearing of the inclinometer	• *Actions as stated for Level 2* • Increase monitoring frequency to twice weekly • Offer site visit with BCS, DPE, MEG and Water NSW • Develop site CMA (subject to agency feedback). This may include: grouting of rockbar where it is appropriate to do so in consultation with BCS, DPE, MEG and Water NSW • Completion of works following approvals and at a time agreed between S32, DPE, MEG and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success • Review relevant TARP and Management Plan in consultation with key agencies
	Exceeding Prediction • Mining results in impacts on the structural integrity of Sandy Creek Waterfall, its overhang or its pool	• *Actions as stated for Level 3* • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation • Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent