

# APPLIED MODELLING OF VENTILATION AND GAS EMISSIONS TO INCREASE PRODUCTION IN A SINGLE ENTRY LONGWALL PANEL

Dennis J. Black<sup>1</sup>

## ABSTRACT

Mine design and operating practices in European countries may differ significantly from those accepted in Australian mines. This paper describes work carried out to review longwall productivity and gas management at one European mine extracting multiple seams 900-1000 metres below the surface. The longwall panel that is the subject of this paper is extracting a 215 metre wide face in the 1.5 metre thick B seam, which is extracted prior to the main 3.0 metre thick A seam to assist with degassing. Gateroads developed to access the B seam longwall are single entry, developed using road headers and supported with steel arches. Additional timber cog support is installed in an attempt to reduce roadway closure due to abutment loading. Due in part to statutory limits on gas concentration and air velocity, longwall production at this mine is presently restricted to an average rate of approximately 700 tonnes per day.

Mine management were reluctant to consider significant mine design changes, such as two heading gateroads, therefore the investigation focused on determining the extent to which ventilation and gas emission impacted on longwall production performance and recommending actions to improve ventilation and gas management to support increased longwall production.

Ventilation and gas emission modelling was used to evaluate the impact of changes to the longwall ventilation arrangement and partial pre-drainage of the B seam. Modelling demonstrated that an increase in longwall production rate to 2200 tonnes per day is easily achievable. A range of additional actions that support further increases in longwall productivity are listed.

## INTRODUCTION

In 2014/15, PacificMGM completed a review of longwall productivity and gas management at a European longwall mine extracting multiple coal seams at depths in the order of 900-1000 metres below the surface. Three coal seams are present in the mining zone and the *in situ* gas content of these coal seams is reported to be greater than 20 m<sup>3</sup>/t. Mine management advised that the permeability of the B seam is very low and previous attempts to pre-drain the working seam had been unsuccessful.

The mine utilises the longwall method to extract the 3.0 metre thick A seam and 1.5 metre thick B seam. The A seam is separated from the B seam by approximately 20-25 metres of interburden. Extraction of the B seam is sequenced in advance of the A seam, with goaf formation and fracturing above the B seam used to stimulate gas emission and reduce the gas content of the A seam prior to mining. Details of the stone and strata layers above and below the B seam are listed in Table 1.

**Table 1: Stone and coal layers above and below the LW1 working seam – B seam**

Coal Mine Strata and Gas Sources		Depth to Roof (m)	Depth to Floor (m)	Thickness (m)	Rel. Density (τ/m <sup>3</sup> )	Measured Gas Content (m <sup>3</sup> /τ)
Layers Above Roof	7. Siltstone	910.3	912.0	1.7	2.5	1-2
	6. Coal seam – Working Seam (A)	912.0	915.0	3.0	1.3	20-25
	5. Argillite	915.0	916.6	1.6	2.5	1-2
	4. Siltstone	916.6	919.6	3.0	2.6	1-2
	3. Sandstone	919.6	934.0	14.4	2.6	0.05-0.3
	2. Siltstone	934.0	935.6	1.6	2.6	1.0
	1. Argillite	935.6	935.9	0.3	2.5	3-7
Coal seam – Working Seam (B)		935.9	937.4	1.5	1.3	20-25
Layers Below Floor	1. Argillite	937.4	942.3	4.9	2.6	1-2
	2. Sandstone	942.3	949.7	7.4	2.6	0.05-0.3
	3. Siltstone	949.7	951.6	1.9	2.5	1-2
	4. Coal seam (C)	951.6	951.9	0.3	1.3	20-25

<sup>1</sup> Pacific Mining and Gas Management Consultants, Australia. [www.pacificmgm.com.au](http://www.pacificmgm.com.au)

The B seam longwall panel, LW1, was the focus of this study to evaluate ventilation and gas management practices and identify opportunities to increase longwall productivity. Figure 1 shows the location of LW1 relative to older B seam workings.

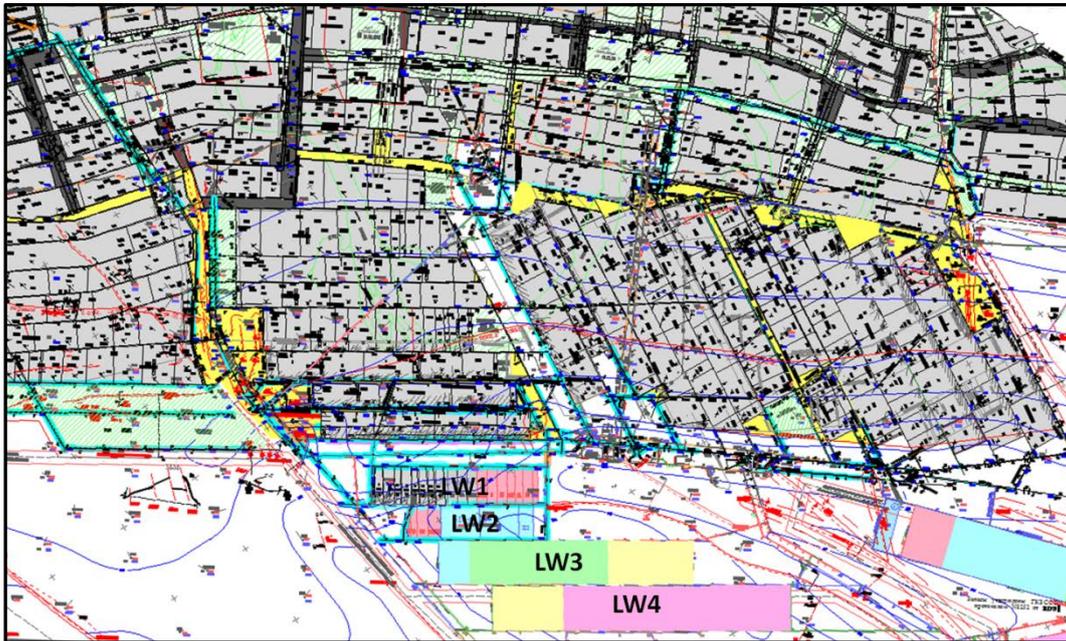


Figure 1: Location of LW1 relative to older B seam mine workings

### CURRENT MINING PRACTICE

The length of the LW1 panel is 1000 metres and the width of the longwall face is 215 metres. The layout of the LW1 and LW2 panels are shown in Figure 2. Single entry gateroads are developed using roadheaders and ground support is in the form of steel arches. Active ground support systems, such as roof bolts and cable tendons, are not routinely used in B seam operations. Timber cogs are installed in the maingate roadway, inbye the longwall face, in an attempt to reduce closure due to abutment loading. This roadway typically experiences at least 30% reduction in cross-sectional area. The installation of timber cogs also increases both the resistance and air velocity in this section the longwall ventilation circuit.

The layout of the longwall panel ventilation comprises intake air in both the single entry maingate and tailgate roadways, homotropical flow across the longwall face, and the return air exits the panel via the maingate companion road, inbye the longwall face. A small flow also exits the panel from the inbye tailgate corner of the goaf, adjacent to the installation face. The layout of the LW1 panel ventilation circuit is shown in Figure 2.

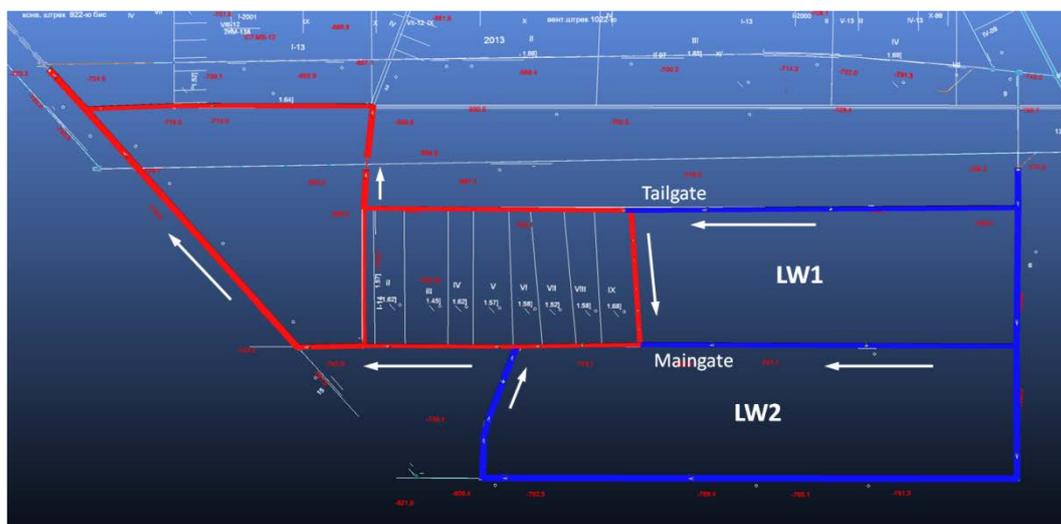


Figure 2: Layout of LW1 and LW2 panel and ventilation circuit in the new B seam mining area

Gas emission from the longwall face and goaf contaminates the ventilation air as it passes through the longwall circuit. A roadway connection exists between MG2 and MG1 which directs additional air to the longwall return that assists in diluting gas emissions to maintain CH<sub>4</sub> concentration below the statutory limit.

Statutory limits on CH<sub>4</sub> concentration are similar to Australia with a maximum permissible CH<sub>4</sub> concentration of 1.0% CH<sub>4</sub> on the longwall face and 2.0% CH<sub>4</sub> in the panel return. Local mining regulations also limit air velocity in working places to a maximum 4.0 m/s.

There is presently minimal CH<sub>4</sub> contamination of intake air entering the LW1 panel via the tailgate. This is due to LW1 being the first longwall block in the new mining area and the tailgate intake roadway passing through solid coal and is not connected to an adjacent goaf. Due to the nature of the single entry design there is a high risk of CH<sub>4</sub> contamination of the tailgate intake air in future longwall panels.

To identify and assess the significance of source of gas emission in the longwall panel, a number of measurement locations were identified where ventilation and gas concentration measurements were taken. The measurement locations are shown in Figure 3 and the results are listed in Table 2.

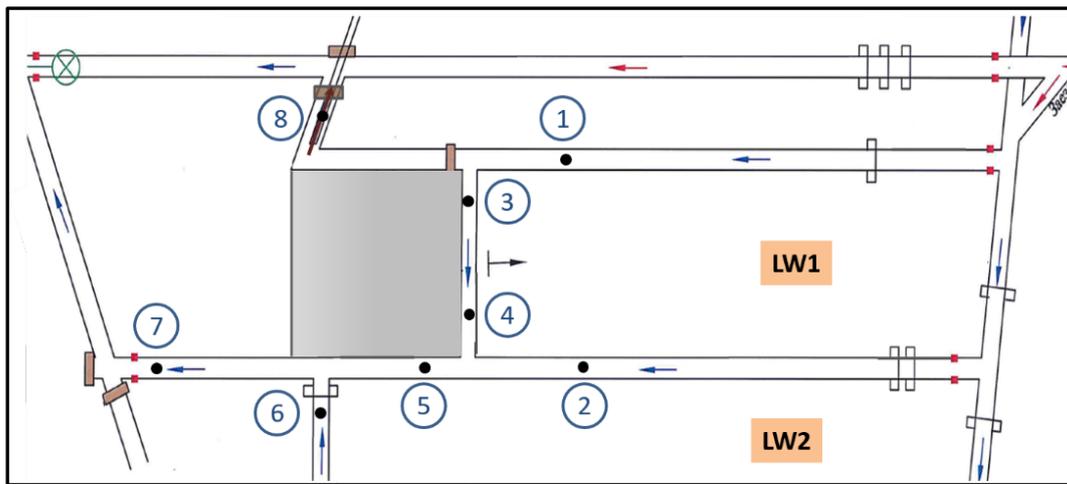


Figure 3: Ventilation and gas concentration measurement locations in LW1 panel

Table 2: Ventilation and gas concentration measurements recorded in LW1 panel

LOCATION	1	2	3	4	5	6	7	8
S = Area (m <sup>2</sup> )	12.4	11.5	5.7	5.3	10.2	16.5	12.7	0.8
V = Velocity (m/s)	1.6	0.5	2.5	2.4	1.7	0.6	2.2	1.5
Q = Quantity (m <sup>3</sup> /s)	19.6	5.4	14.1	12.9	17.2	10.2	28.3	1.2
Q = Quantity (m <sup>3</sup> /min)	1174	323	844	772	1031	614	1697	71
C = CH <sub>4</sub> %	0.0	0.0	0.0	0.9	0.7	0.1	1.3	2.0
Gas Make (L/s)	0	0	0	116	120	10	368	24
Gas Make (m <sup>3</sup> /min)	0.0	0.0	0.0	6.9	7.2	0.6	22.1	1.4

The average production rate in LW1 was approximately 700 t/d, which was largely due to gas concentrations and ventilation air velocity reaching permissible limits. The results of the ventilation survey, presented in Table 2, confirm the CH<sub>4</sub> concentration of 0.9% recorded on the longwall face (Location 5) is presently constraining production in the current ventilation circuit design. With air velocity of 2.5 m/s recorded at Location 5, there is capacity to increase air flow across the longwall face to dilute face gas emission and reduce CH<sub>4</sub> concentration, however to increase ventilation quantity to the longwall district, action must be taken outbye to increase mine ventilation efficiency, which was determined to be approximately 40%.

Longwall production is also inherently constrained by process tasks specific to the single entry mine design. One significant task in the mining process requires (a) removing the block-side legs of each steel arch support to allow the longwall face to pass, and (b) reattaching the legs to the maingate arches, inbye the longwall face. Timber cogs are also installed inbye the longwall in an attempt to resist closure of the maingate airway due to abutment loading, as this roadway must remain open and serviceable as the main return for the current longwall (LW1) and tailgate intake in the next longwall (LW2).

Details of ventilation air quantity, air velocity and CH<sub>4</sub> emission recorded at the various survey points in LW1 are presented in Figure 4.

Analysis of CH<sub>4</sub> concentrations in ventilation air and the gas drainage system determined the specific gas emission rate in LW1 was 77.5 m<sup>3</sup>/t. Of this total emission rate, 29.5 m<sup>3</sup>/t (38%) was released into the mine ventilation system and 48.0 m<sup>3</sup>/t (62%) was extracted through the goaf drainage system.

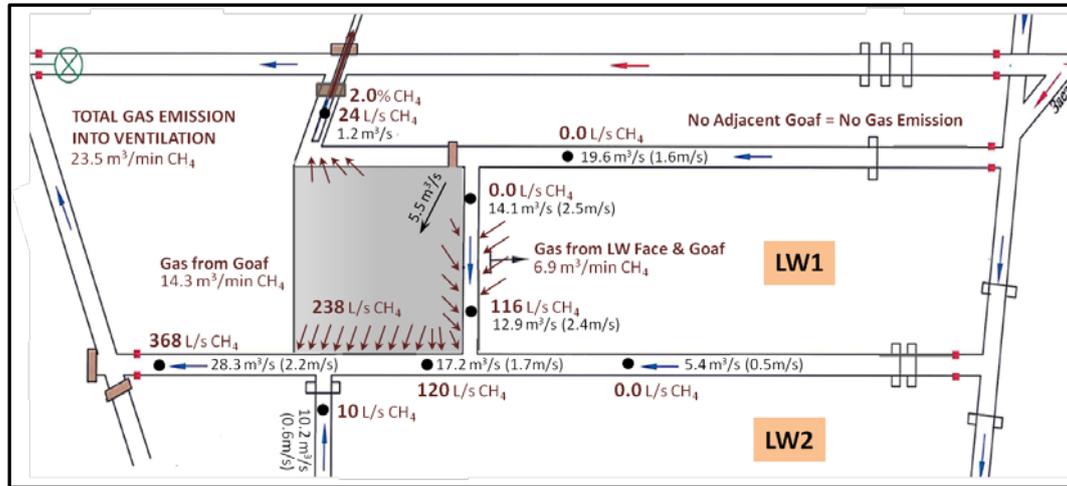


Figure 4: Summary of ventilation and CH<sub>4</sub> gas emissions recorded in the LW1 ventilation network

### VENTILATION AND GAS EMISSION MODELLING

A ventilation model was developed to simulate current 'base case' ventilation air flow and gas emission rates, similar to those measured during the ventilation survey. Including the base case, five (5) models were developed to assess the impact of (a) increasing total air quantity (m<sup>3</sup>/s) in the longwall panel, (b) modifying the panel design and ventilation circuit to increase ventilation and gas emission management capacity through the addition of a MG Bleeder Road, and (c) partial pre-drainage of the B seam to decrease gas emission during longwall extraction. Values of ventilation air quantity (m<sup>3</sup>/s), air velocity (m/s) and gas concentration (%CH<sub>4</sub>) were recorded at the eight (8) locations in the longwall ventilation circuit of each model. Modelling an increase in longwall production rate is represented by increasing the rate of gas emission from the longwall face (LW Production Gas Emission).

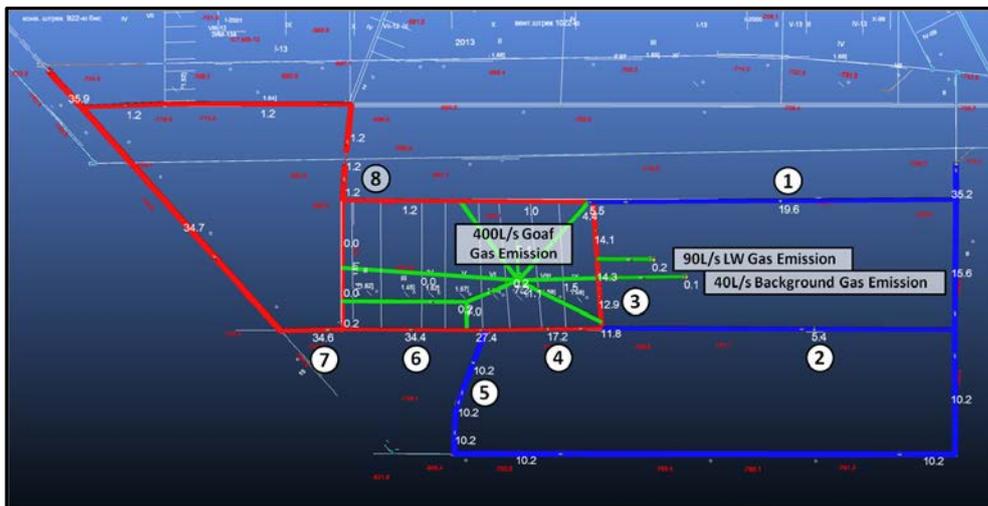
A summary of key assumptions and details of air quantity, air velocity and CH<sub>4</sub> concentration recorded at the eight (8) measurement locations in each model are listed in Table 3. Details of the longwall panel design assumptions in each of the five (5) modelled scenarios are summarised below:

- Model 1: (Base Case) Combined MG and TG ventilation = 25 m<sup>3</sup>/s, B seam gas content = 11.0 m<sup>3</sup>/t, average longwall production rate = 700 t/d, Background CH<sub>4</sub> emission rate = 45 L/s, LW production CH<sub>4</sub> emission rate = 90 L/s, Goaf gas CH<sub>4</sub> emission rate = 400 L/s. Airflow (m<sup>3</sup>/s) and gas emission (L/s) results from Model 1 are presented in Figure 5. This model shows that air velocity is 60% of capacity and the CH<sub>4</sub> concentration is approaching the 1.0% maximum permissible limit.
- Model 2: Current ventilation arrangement, assessing the impact of increasing LW production rate. Combined MG and TG ventilation = 25 m<sup>3</sup>/s, B seam gas content = 11.0 m<sup>3</sup>/t, average longwall production rate = 1050 t/d, Background CH<sub>4</sub> emission rate = 45 L/s, LW production CH<sub>4</sub> emission rate = 135 L/s, Goaf gas CH<sub>4</sub> emission rate = 400 L/s. The CH<sub>4</sub> concentration on the longwall face in this model exceeds the permissible limit.
- Model 3: Assessing the impact of (a) increasing LW panel ventilation air quantity, and (b) increasing LW production rate. Combined MG and TG ventilation = 39.7 m<sup>3</sup>/s, B seam gas content = 11.0 m<sup>3</sup>/t, average longwall production rate = 1400 t/d, Background CH<sub>4</sub> emission rate = 45 L/s, LW production CH<sub>4</sub> emission rate = 180 L/s, Goaf gas CH<sub>4</sub> emission rate = 400 L/s. Whilst the air velocity and gas concentration on the longwall face are within permissible limits, the air velocity in the maingate return exceeds the permissible limit.
- Model 4: Assessing the impact of (a) modifying the ventilation circuit to include a dedicated goaf bleed (MG Bleeder Road), (b) increasing LW panel ventilation air quantity, and (c) increasing LW production rate. Combined MG and TG ventilation = 38.9 m<sup>3</sup>/s, B seam gas content = 11.0 m<sup>3</sup>/t, average longwall production rate = 1400 t/d, Background CH<sub>4</sub> emission rate = 45 L/s, LW production CH<sub>4</sub> emission rate = 180 L/s, Goaf gas CH<sub>4</sub> emission rate = 400 L/s. This scenario is limited by air velocity and CH<sub>4</sub> concentration on the longwall face which are both at the maximum permissible limit.

- Model 5: Assessing the impact of (a) modifying the ventilation circuit to include a dedicated goaf bleed (MG Bleeder Road), (b) increasing LW panel ventilation air quantity, (c) pre-drainage to reduce B seam gas content, and (d) increasing LW production rate. Combined MG and TG ventilation = 38.9 m<sup>3</sup>/s, B seam gas content = 7.0 m<sup>3</sup>/t, average longwall production rate = 2200 t/d, Background CH<sub>4</sub> emission rate = 30 L/s, LW production CH<sub>4</sub> emission rate = 178 L/s, Goaf gas CH<sub>4</sub> emission rate = 400 L/s. Airflow (m<sup>3</sup>/s) and gas emission (L/s) results from Model 5 are presented in Figure 6. This model highlights the significant increase in longwall production capacity that may be achieved through partial pre-drainage of the B seam prior to longwall extraction.

**Table 3: Results of ventilation and gas emission modelling to evaluate ventilation design and LW production improvements**

Modelled Scenario	Scenario 1			Scenario 2			Scenario 3			Scenario 4			Scenario 5		
	Current Ventilation Arrangement LW prod. = 700 tpd (current average) No pre-drainage QM = 11.0 m <sup>3</sup> /t			Current Ventilation Arrangement LW prod. = 1050 tpd No pre-drainage QM = 11.0 m <sup>3</sup> /t			Current Ventilation Arrangement LW prod. = 1400 tpd Increased Air Quantity No pre-drainage QM = 11.0 m <sup>3</sup> /t			Modified Ventilation Arrangement LW prod. = 1400 tpd Increased Air Quantity No pre-drainage QM = 11.0 m <sup>3</sup> /t			Modified Ventilation Arrangement LW prod. = 2200 tpd Increased Air Quantity Pre-drainage QM = 7.0 m <sup>3</sup> /t		
Measurement Location	Vent Air Quantity (m <sup>3</sup> /s)	Vent Air Velocity (m/s)	General Body CH <sub>4</sub> Conc. (%)	Vent Air Quantity (m <sup>3</sup> /s)	Vent Air Velocity (m/s)	General Body CH <sub>4</sub> Conc. (%)	Vent Air Quantity (m <sup>3</sup> /s)	Vent Air Velocity (m/s)	General Body CH <sub>4</sub> Conc. (%)	Vent Air Quantity (m <sup>3</sup> /s)	Vent Air Velocity (m/s)	General Body CH <sub>4</sub> Conc. (%)	Vent Air Quantity (m <sup>3</sup> /s)	Vent Air Velocity (m/s)	General Body CH <sub>4</sub> Conc. (%)
1	19.6	1.6	0	19.6	1.6	0	28.5	2.3	0	29	2.3	0	29	2.3	0
2	5.4	0.5	0	5.4	0.5	0	11.2	1	0	9.9	0.9	0	9.9	0.9	0
3	12.9	2.4	0.94	12.9	2.4	1.24	19.9	3.7	1.03	20.9	3.9	1.02	21.1	4	0.95
4	17.2	1.7	0.64	17.2	1.7	0.85	27.9	2.7	0.62	30.7	3	0.69	30.8	3	0.64
5	10.2	0.6	0	10.2	0.6	0	10.1	0.6	0	10.4	0.6	0	10.4	0.6	0
6	34.4	3.4	1.48	34.5	3.4	1.61	48.7	4.8	1.23	35.6	3.5	0.52	35.8	3.5	0.48
7	34.6	2.7	1.53	34.7	2.7	1.65	49.1	3.8	1.27	23.2	1.8	0.52	23.3	1.8	0.48
8	1.2	0.1	2.37	1.2	0.1	2.38	1.7	0.1	2.13	9.2	0.6	2.17	9.2	0.6	2.16
Background CH <sub>4</sub> Emission Rate (L/s)	45			45			45			45			30		
LW Production CH <sub>4</sub> Emission Rate (L/s)	90			135			180			180			178		
Goaf Gas Emission Rate (L/s)	400			400			400			400			400		
Average Daily LW Production (tonnes)	<b>700</b>			<b>1050</b>			<b>1400</b>			<b>1400</b>			<b>2200</b>		
Average B seam gas content (m <sup>3</sup> /t CH <sub>4</sub> )	11.0			11.0			11.0			11.0			7.0		



**Figure 5: Layout of ventilation and gas emission Model 1 – Base Case**

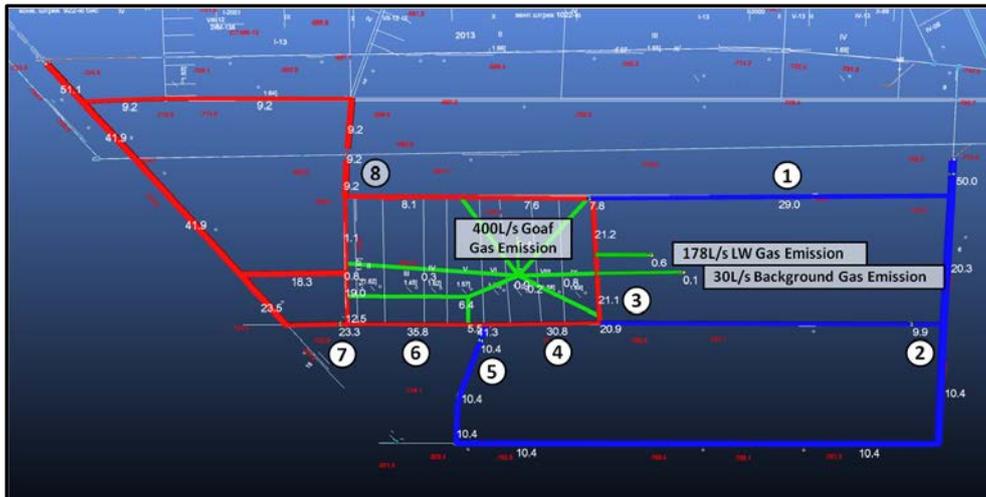


Figure 6: Layout of ventilation and gas emission Model 5 – modified ventilation circuit and increased LW production

### VENTILATION IMPROVEMENTS TO SUPPORT INCREASED LONGWALL PRODUCTION

The aim of the recommended changes to the longwall ventilation circuit is to draw goaf gas emissions away from the longwall face and maingate return, and confine the gas, as far as practicable, in the goaf and maingate bleeder roadway. The design partially segregates the maingate return roadway from the goaf and directs ventilation air to the bleeder and main return to dilute methane concentration below the legal limit.

Modelling has shown that developing an additional roadway connection between the main return airway and the longwall install face (MG Bleeder Road) and changing the ventilation arrangements in the longwall panel to direct return air to the MG Bleeder Road, as indicated in Figure 7, allows total ventilation air quantity to the longwall district to be increased, while remaining compliant with prescribed maximum air velocity limits. The improved ventilation arrangement also has a positive effect on reducing CH<sub>4</sub> concentration in the maingate return airway as the low pressure point in the ventilation circuit is located at the MG Bleeder Road which draws CH<sub>4</sub> emission from the goaf away from the maingate. Through implementing the recommended changes to the design of the longwall ventilation circuit, modelling indicates a potential 100% increase in longwall production rate.

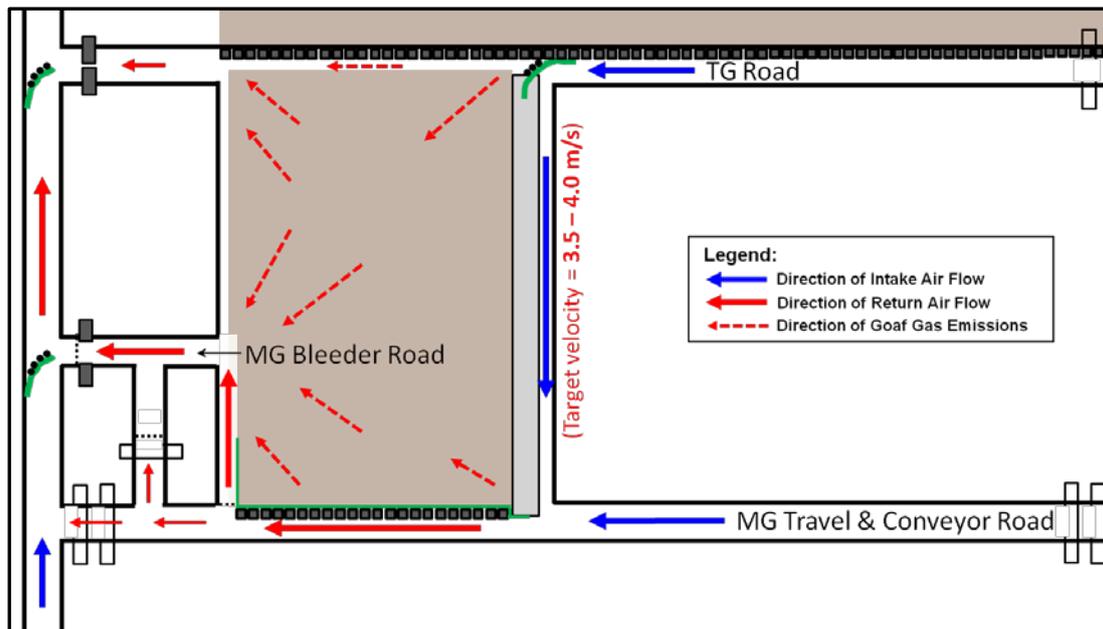
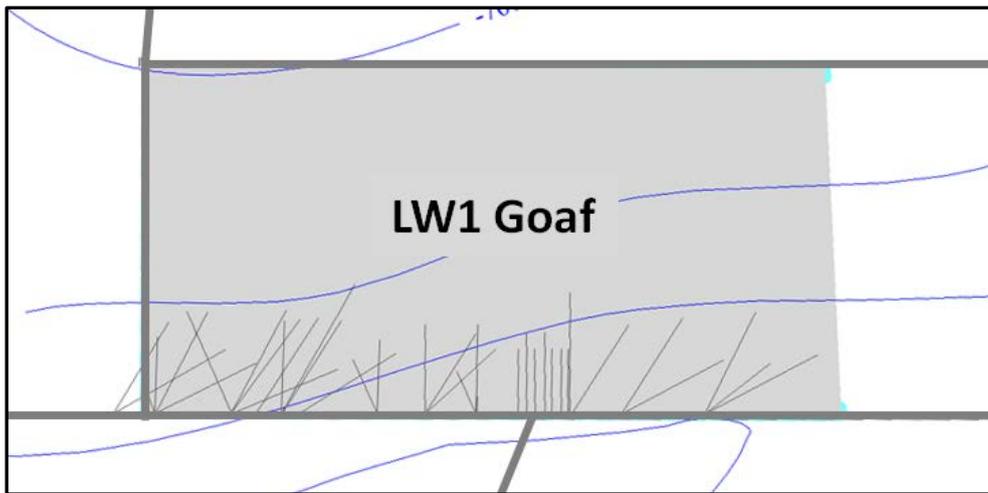


Figure 7: Recommended longwall ventilation arrangement to support increased longwall production

### GAS DRAINAGE IMPROVEMENTS TO SUPPORT INCREASED LONGWALL PRODUCTION

The mine utilises goaf drainage to extract gas from the goaf which reduces the volume of gas that would otherwise contaminate the mine ventilation system. Boreholes are drilled into the goaf from drill sites located behind the retreating longwall face. The layout of the goaf drainage boreholes in the LW1 goaf are shown in Figure 8.



**Figure 8: Layout of goaf drainage boreholes drilled into the LW1 goaf**

The maximum length of the 48 boreholes drilled into the goaf was 120 metres and the average length was 80 metres. Drilling goaf drainage boreholes in the single entry longwall return, behind the retreating longwall face, results in the full length of the borehole, including casing, being drilled in fractured ground. In such conditions it is difficult to effectively seal the borehole to minimise leakage. The average concentration of gas present in the goaf drainage system was 28% CH<sub>4</sub> / 72% Air which highlights significant leakage.

The current goaf drainage program does have a positive impact on reducing gas emissions into the ventilation system however changes are required to increase the efficiency and effectiveness of the gas drainage program (Black and Aziz, 2011). Modelling has demonstrated that reducing the gas content of the B seam by 4.0 m<sup>3</sup>/t, in addition to modifying the longwall ventilation circuit, will support increasing longwall production to 2200 t/d. Expanding the gas drainage program to increase the volume of gas extracted by pre-drainage and goaf drainage will support further increases in longwall production.

Given the layout of the longwall panel allows air to be drawn into the goaf and the recommended change to the ventilation circuit includes ventilating the perimeter of the goaf, it is important that relatively low suction pressure is applied to goaf drainage boreholes to reduce air contamination. Therefore to increase total goaf gas extraction it will be necessary to increase the total number of boreholes available. Six (6) areas, indicated in Figure 9, have been identified where gas drainage boreholes should be drilled to increase total gas extraction. A summary of the five (5) goaf drainage targets (A – E) and one (1) pre-drainage target (F) is provided below:

- A. Continue drilling boreholes into the goaf from drill sites along the main gate return. Increased total gas extraction and reduced air contamination will be achieved by (a) improved sealing around longer standpipes, (b) reducing the suction pressure applied to each borehole, and (c) increasing the total number of active boreholes.
- B. Maintain active gas extraction from the goaf above the installation face position of the previous longwall panel.
- C. Maintain gas extraction from the goaf of the previous longwall block. Gas drainage range to be maintained in the tailgate and connected to goaf drainage boreholes. Regulate flow from each borehole to maintain high CH<sub>4</sub> concentration.
- D. Drill additional boreholes into the roof above the longwall installation face and connect to the main gas drainage range using a pipeline that extends through the tailgate seal. Regulate flow from this group of boreholes to maintain high CH<sub>4</sub> concentration.
- E. Drill extended length boreholes into the A Seam from the B seam tailgate road. The A seam, located 20-25 metres above the B seam, is approximately 3.0 metres thick and is a significant source of gas emission into the B seam longwall goaf. The purpose of these boreholes is to extract gas released from the A seam as it is fractured, thereby reducing the volume of gas liberated into the B seam goaf.
- F. Drill a regular pattern of pre-drainage boreholes across the adjacent longwall block and gateroad. The purpose of these boreholes is to pre-drain the B seam and reduce the gas content prior to mining.

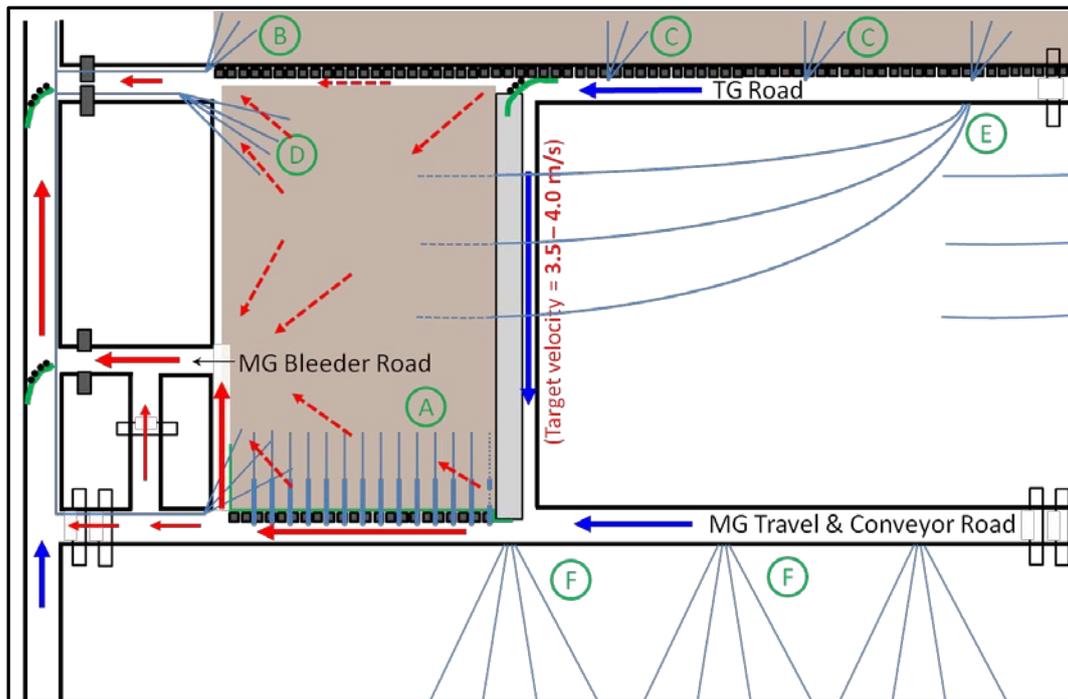


Figure 9: Recommended gas drainage to reduce gas emissions to support increased LW production

In addition to the improvement actions listed above, a second round of investigation and onsite testing is recommended to identify and evaluate additional actions that may further improve the effectiveness of the mine ventilation and gas management systems and support increased productivity and reduced operating cost. Methods to stimulate increased gas production from low permeability and undersaturated coal seams, such as Cyclic Inert Gas Injection (Black, 2011 and Black, 2013), should be considered for site testing and evaluation.

## CONCLUSIONS

This project aimed to identify and evaluate practical improvements to reduce the impact of CH<sub>4</sub> on longwall productivity. Ventilation and gas emission modeling confirmed that modifying the ventilation circuit to include an additional heading between the installation face and main return (MG Bleeder Road) and directing the bulk of longwall return air flow through this bleeder road has the potential to support a 100% increase in longwall production. Modeling also confirmed that pre-draining gas from the B seam and increasing goaf gas extraction offers a minimum 100% increase in longwall production.

To support further increases in longwall production it will be necessary to (a) reduce losses and inefficiency in the mine ventilation system to increase the quantity of ventilation air available to the longwall panel, (b) implement pre-drainage of the working seam and adjacent coal seams, (c) expand the goaf drainage program to include an increased number of boreholes, and (d) expand the drainage reticulation system to efficiently extract increased gas volumes.

Longer term actions that offer a step change improvement in development and longwall productivity include:

- Introduce an alternate roof support system, such as roof bolts and cable tendons, to replace steel arches;
- Increase the cross-sectional area of the airways in the longwall ventilation circuit to reduce air velocity which presently prevents ventilation air quantity being increased to dilute CH<sub>4</sub> emissions; and
- Develop two (2) heading gateroads to replace single entry.

## REFERENCES

- Black, D J, 2011. Factors affecting the drainage of gas from coal and methods to improve drainage effectiveness, PhD thesis, University of Wollongong, Australia.
- Black, D J, 2013. Cyclic inert gas injection – an alternative approach to stimulate gas drainage from tight coal zones, in *Proceedings of the 13th Underground Coal Operator's Conference COAL2013*. University of Wollongong, (eds: N I Aziz and R J Kininmonth), Wollongong, 14-15 February, pp. 292-299.

Black, D J, 2016. Applied modelling of ventilation and gas management to increase production in a single-entry longwall panel, in *Proceedings of the 2016 Coal Operator's Conference*, University of Wollongong, (eds: N I Aziz and R J Kininmonth), Wollongong, 10-12 February, pp. 298-306.

---

Black, D J and Aziz, N I, 2011. Actions to improve coal seam gas drainage performance, in *Proceedings of the 11th Underground Coal Operator's Conference COAL2011*. University of Wollongong, (eds: N I Aziz, R J Kininmonth, J A Nemcik and T X Ren), Wollongong, 10-11 February, pp. 309-316