

# Gas Modelling for Coal Mine Methane

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## Introduction

This presentation is concerned with methods and issues associated with forecasting coal mine methane quantities. It covers:

- Coal seam gas reservoirs
- Options for gas drainage and gas capture
- Forecasting gas quality and quantity
- Variability and risk management

Most examples shown are for the purposes of demonstration only and do not apply to any particular mine.

## Coal Seam Gas Reservoirs

Coal seams in the Sydney and Bowen Basins are characterised by highly varying gas content (Figure 1) and permeability (Figure 2).

**Figure 1 Gas Content Gradients**

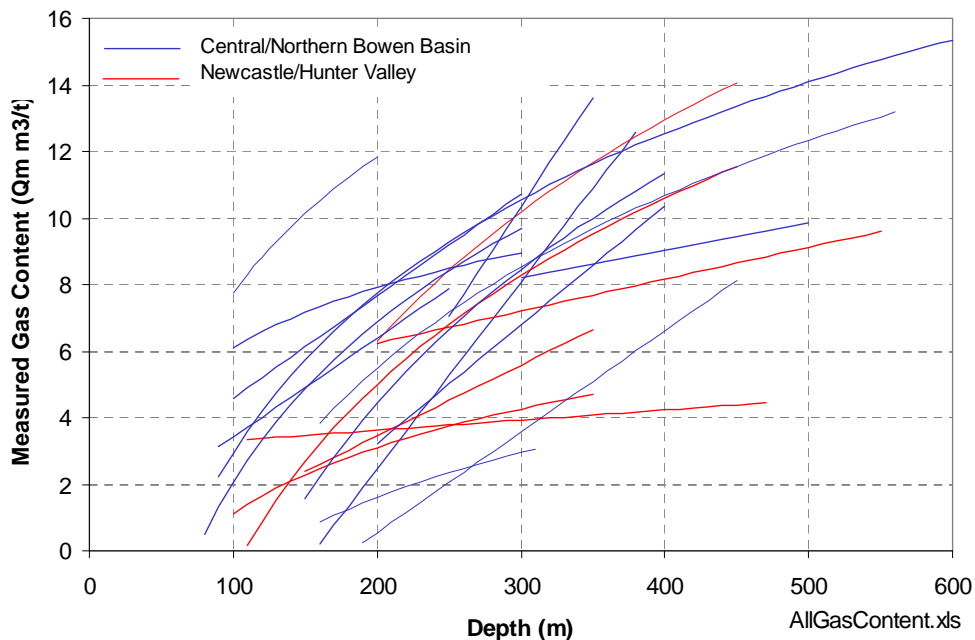
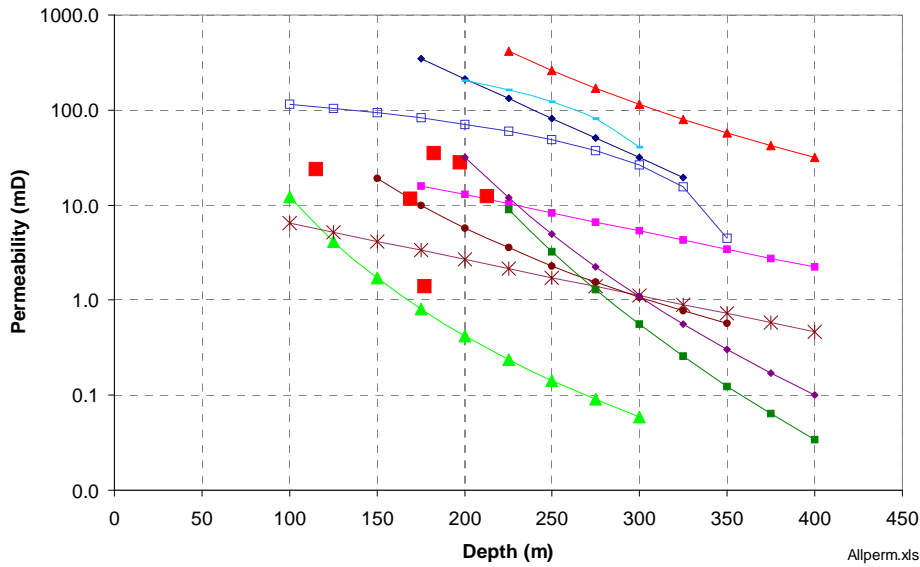


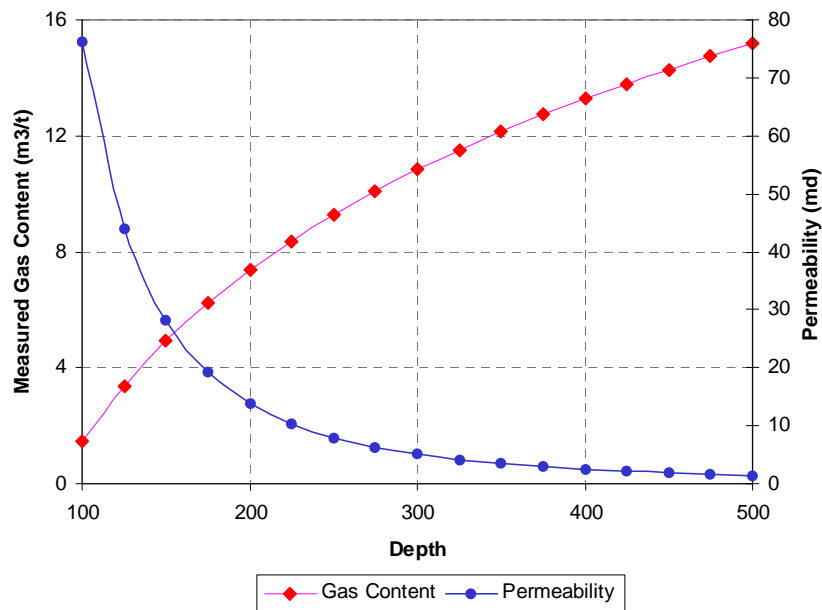
Figure 2 Permeability Gradients



Permeability measurements by Multiphase Technology Pty. Ltd.

Most mines in the Bowen Basin and Hunter Valley, mine from near outcrop to depth and experience contrasting and continuously varying gas content and permeability conditions (example Figure 3).

Figure 3 Contrasting Changes in Permeability and Gas Content With Depth



Variations in seam thickness, gas quality (CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>) and stratigraphic changes combine with permeability and gas content variations to produce unique sets of gas reservoir parameters for each mine.

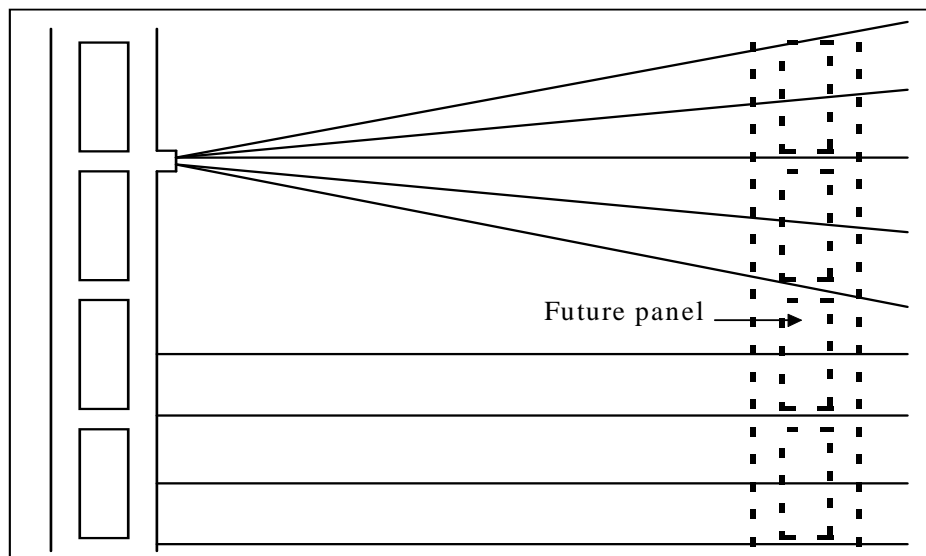
## Gas Drainage and Capture

Designs for gas predrainage and gas capture take into account the local reservoir conditions, the mining schedule and the approach to gas management.

There are two basic options for predrainage:

- Underground based, cross panel (Figure 4)
- Surface to in-seam, medium radius drilling (MRD, Figure 5).

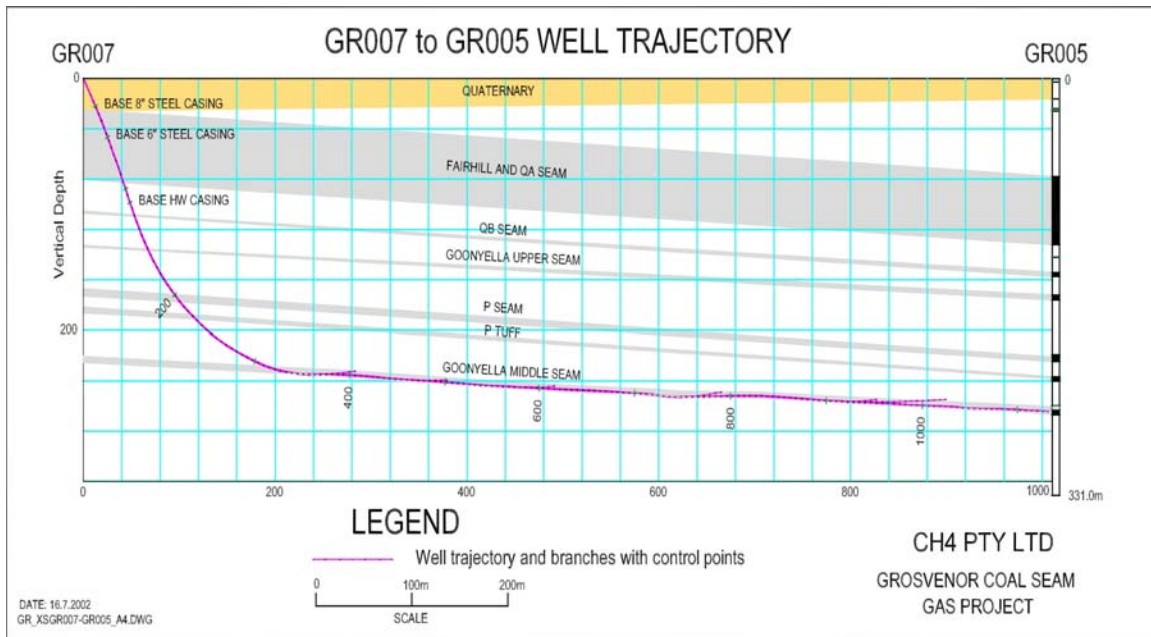
**Figure 4 Underground Cross Panel Drilling**



Both methods employ directional drilling which is required to achieve the required borehole spacing. The underground-based approach is giving way to the surface based MRD approach. It's current application in coal seams was pioneered by CH<sub>4</sub> Pty. Ltd. and Mitchell Drilling at Moranbah in 2001.

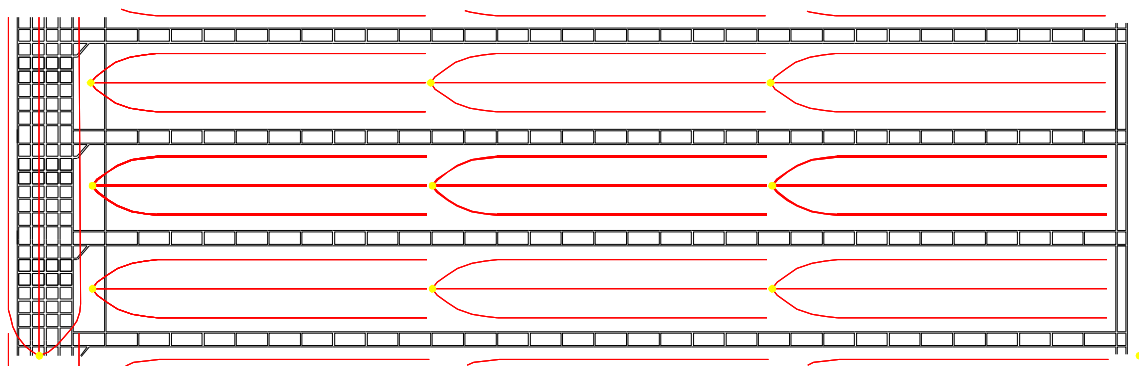
Gas predrainage is designed around providing a suitable borehole spacing to reach a target gas content in the available time. Underground-based predrainage is limited by mine access. Drainage times are usually short (eg 100 days) and hole spacings tight (eg 20 m to 50 m). With MRD, drilling is not tied to the mine schedule. Drainage times can be quite long (2 years plus) and hole spacings wide (100 m to 300 m and more). Lower permeabilities and/or shorter lead times require closer spacings (eg Figure 6). With long lead times and reasonable permeability, well spacings can be as far apart as one line of boreholes per longwall pillar (Figure 7).

**Figure 5 Medium Radius Well, CH<sub>4</sub> Pty. Ltd. Moranbah Gas Project**



From CH<sub>4</sub> Pty. Ltd. public domain information

**Figure 6 Example MRD Pattern, Low Permeability and/or Short Lead Time**



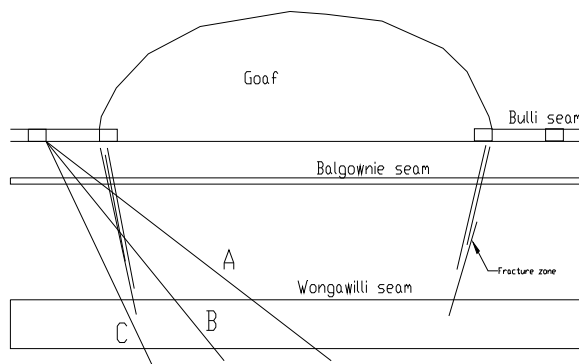
Essentially two types of post drainage is practiced:

- Cross measure drainage (“down-holes”) in the NSW South Coast mines (Figure 8)
- Goaf well drainage in the Hunter Valley and Bowen Basin mines (Figure 9).

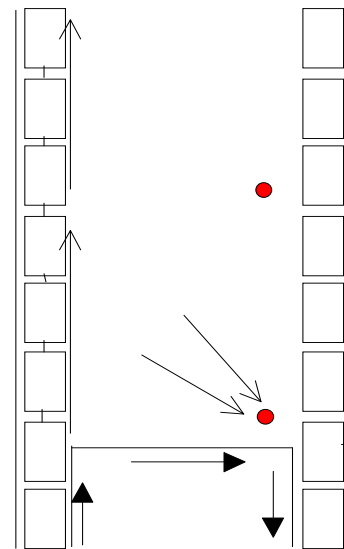
**Figure 7 Example MRD Pattern, High Permeability and/or Long Lead Time**



**Figure 8 Example Cross Measure Post Drainage**



**Figure 9 Goaf Well Gas Capture**



## Gas Forecasting

The methodology is basically one of:

- Assembling reservoir data and mining schedules
- Construct models
- Validate against past mining
- Apply to future layouts

The process being modelled is highly complex and validation against past mining is absolutely essential. On occasions, modeling has to proceed without this validation and

often without adequate gas reservoir data. This necessarily results in considerable uncertainty. Probability modeling methods are valuable in quantifying uncertainty, but rarely can a project afford the time to carry this out.

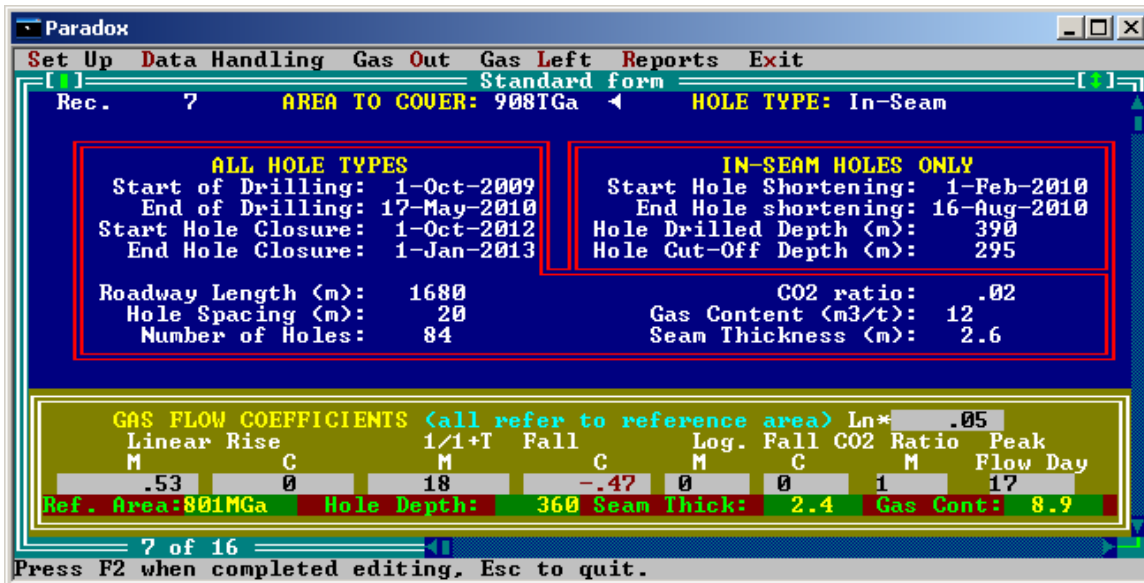
Models currently being used by GeoGAS are:

- SIMED for in-seam predrainage
- TOTGAS for in-seam predrainage and cross measure post drainage
- “Pore Pressure” LW emission model for longwall emission and goaf gas capture.

SIMED II is a two phase (gas and water), three-dimensional, multi gas component (eg CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub> simultaneous modelling capabilities), single or dual porosity reservoir simulator. The dual porosity capability is used for coal seams, simulating the slow, concentration gradient driven, desorption from the coal matrix, and the pressure gradient flow of gas through the fracture network. It was developed by the University of NSW and the CSIRO. For Coal Mine Methane (CMM) applications it is used to define borehole flow decline curves and remaining gas contents. The output requires considerable manipulation to generate life of mine gas production forecasts. This is facilitated by TOTGAS.

TOTGAS is a model developed by GeoGAS in 1993, in response to the need to provide forecasts for design of gas extraction systems for the life of the mine. It fits well into a CMM role, albeit still DOS based. The model assigns a schedule, borehole life, gas reservoir properties and gas production profile (Figure 10), for every borehole to be drilled over the life of the mine. It checks for sensibility with respect to material balance, checks the remaining gas content after drainage (Figure 11) and sums the gas production for each well (Figure 12).

Figure 10 TOTGAS Panel Data Input



Iterations of borehole spacings are run to arrive at the required remaining gas contents.

Figure 11 Check on Remaining Gas Content TOTGAS Modelling

Hole No.	Days on Line	CO2 Left m3/t	CH4 Left m3/t	Excess CO2+ CH4	Comments
908TGA-001	123	0.00	4.97	-2.53	Gas content is BELOW outburst threshold
908TGA-002	123	0.00	4.97	-2.53	Gas content is BELOW outburst threshold
908TGA-003	122	0.00	5.00	-2.50	Gas content is BELOW outburst threshold
908TGA-004	122	0.00	5.00	-2.50	Gas content is BELOW outburst threshold
908TGA-005	122	0.00	5.00	-2.50	Gas content is BELOW outburst threshold
908TGA-006	121	0.00	5.02	-2.48	Gas content is BELOW outburst threshold
908TGA-007	121	0.00	5.02	-2.48	Gas content is BELOW outburst threshold

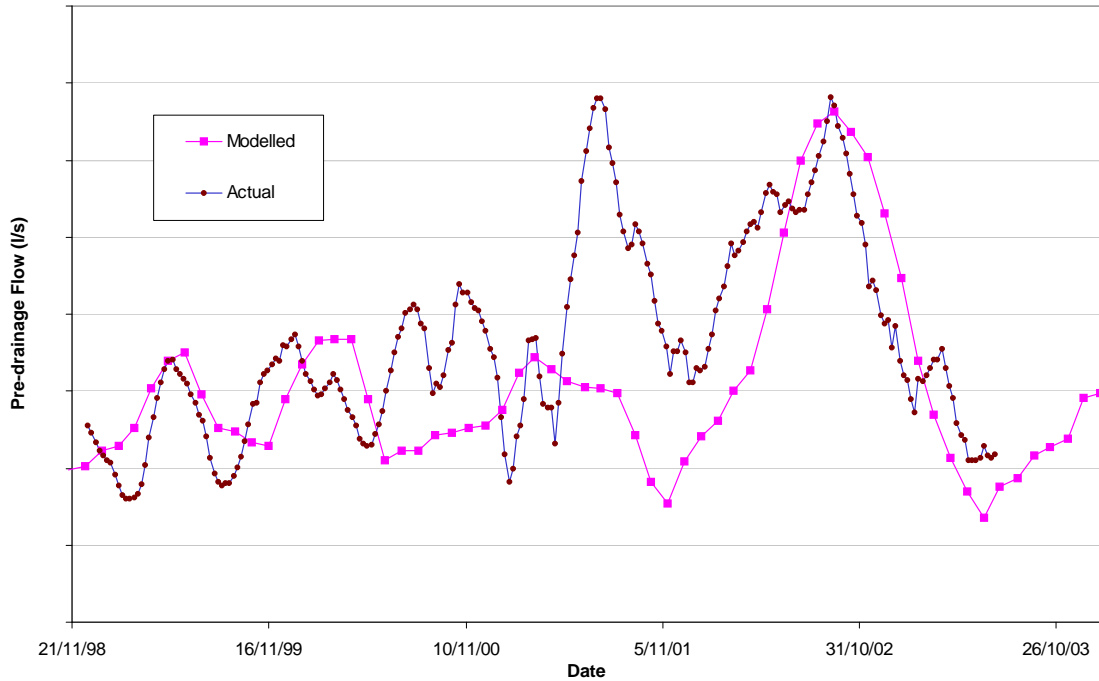
Figure 12 Gas Totals on a Monthly Basis TOTGAS Modelling

Date	Down-Hole CO2 l/s	Down-Hole CH4 l/s	Down-Hole CO2 Ratio	In-Seam CO2 l/s	In-Seam CH4 l/s	In-Seam CO2 Ratio
15-Sep-04	0.0	0.0	0.00	0.0	80.8	0.00
15-Oct-04	0.0	0.0	0.00	0.0	194.4	0.00
15-Nov-04	0.0	0.0	0.00	0.0	122.1	0.00
15-Dec-04	0.0	0.0	0.00	0.0	87.5	0.00
15-Jan-05	0.0	0.0	0.00	0.0	66.2	0.00
15-Feb-05	0.0	0.0	0.00	0.0	52.0	0.00
15-Mar-05	0.0	0.0	0.00	0.0	42.8	0.00
15-Apr-05	0.0	0.0	0.00	0.0	35.1	0.00
15-May-05	0.0	0.0	0.00	0.0	29.3	0.00
15-Jun-05	0.0	0.0	0.00	0.0	24.5	0.00
15-Jul-05	0.0	0.0	0.00	0.0	95.7	0.00
15-Aug-05	0.0	0.0	0.00	0.0	206.7	0.00
15-Sep-05	0.0	0.0	0.00	0.0	130.2	0.00
15-Oct-05	0.0	0.0	0.00	0.0	93.6	0.00
15-Nov-05	0.0	0.0	0.00	0.0	70.8	0.00
15-Dec-05	0.0	0.0	0.00	0.0	56.1	0.00
15-Jan-06	0.0	0.0	0.00	0.0	45.3	0.00
15-Feb-06	0.0	0.0	0.00	0.0	106.0	0.00

Libraries of flow decline curves are input to TOTGAS, either on the basis of empirical data or using SIMED II.

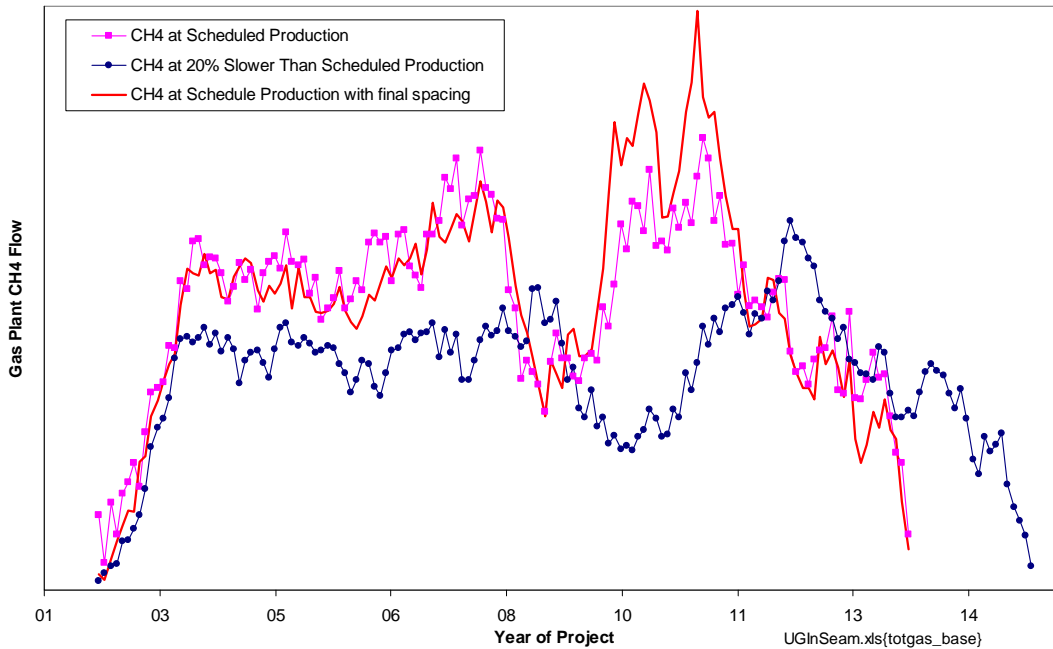
Every opportunity is taken to validate the model against past gas production results (Figure 13).

Figure 13 Validation of Modelled Predrainage



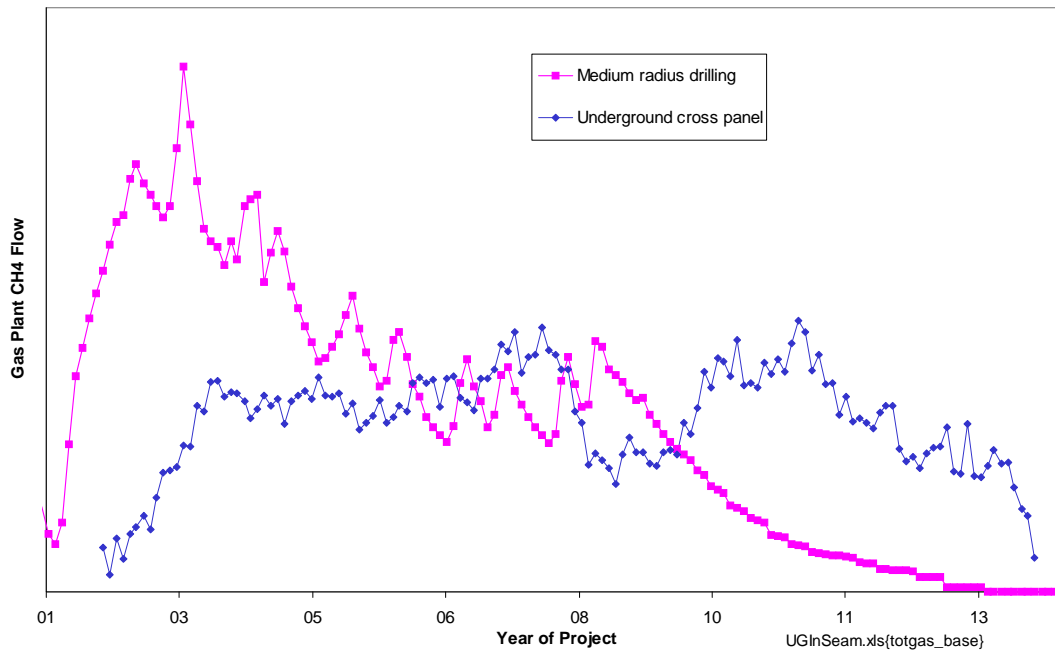
Underground in-seam predrainage quantities can be totaled according to variations in the mines scheduled rate of production and tuned for borehole spacing (Figure 14).

Figure 14 Predrainage Gas Production



Modeling a similar scenario using MRD predrainage results in the gas production being strongly skewed toward the early life of the mine (Figure 15).

**Figure 15 MRD and Underground Predrainage**



Unless considerable forethought has been given, MRD predrainage usually requires relatively closer spacings and more rapid gas content reduction in the early life of the mine, in response to shorter lead times, resulting in a lot of early gas production.

Two important points with MRD are:

- It is not tied so closely to mining operations. Gas production is largely independent of events in the mine.
- Gas production is less uniform and asymmetric.

Longwall post drainage assessments use the “Pore Pressure” model. As for predrainage modeling, the model is refined and validated by mimicking existing longwall emission and then applied to future areas. It then remains to settle on what proportion of the longwall emission will be captured by goaf gas or cross measure drainage.

As the longwall retreats, a zone of relaxation is created in the strata behind the face (Figure 16). This region of de-pressuring extends a long way into the roof and floor strata (eg 100 m below, to the surface above). When the depressuring of the strata falls to below the desorption pressure of the gas in the coal seams, the gas is allowed to desorb in the model (Figure 17). The gas flow is dependent upon the gas desorption rate of the coal. Once the rear abutment re-imposes pressure, gas release is essentially halted.

It is assumed that in the active gas zone, gas flow is only limited by rate of gas desorption, not permeability. In the example in Figure 17 the gas content shown as being released would only occur if the gas desorption rate was high enough and the time long enough to allow it. In reality, such equilibrium is never reached and this is reflected in the model.

Figure 16 Zone of Relaxation Behind the Longwall Face

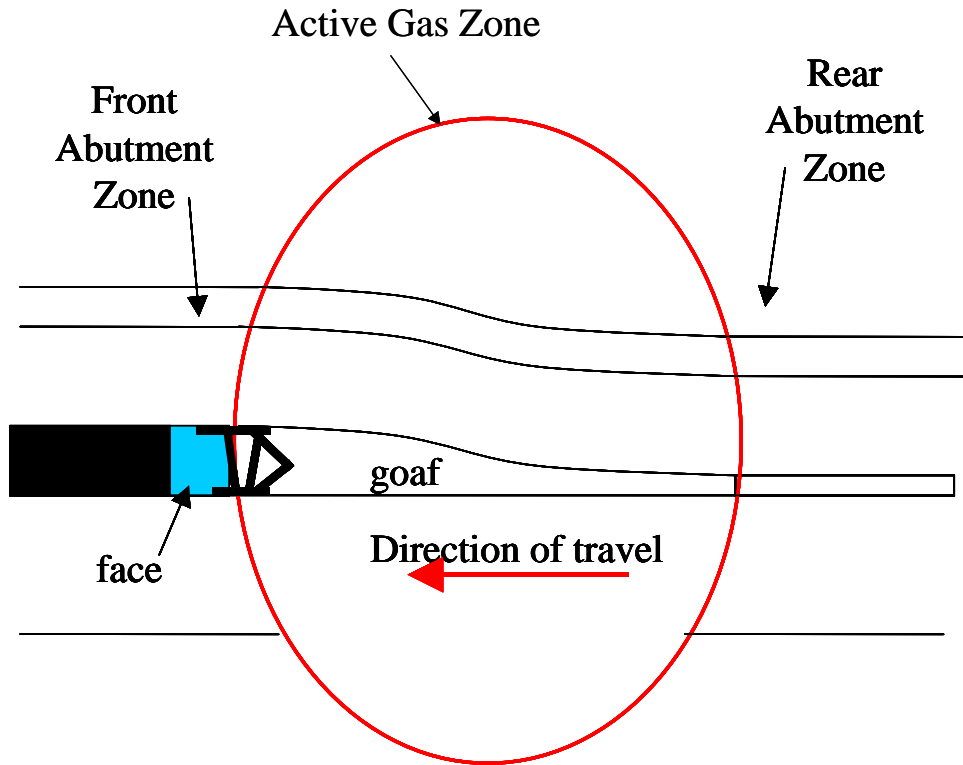
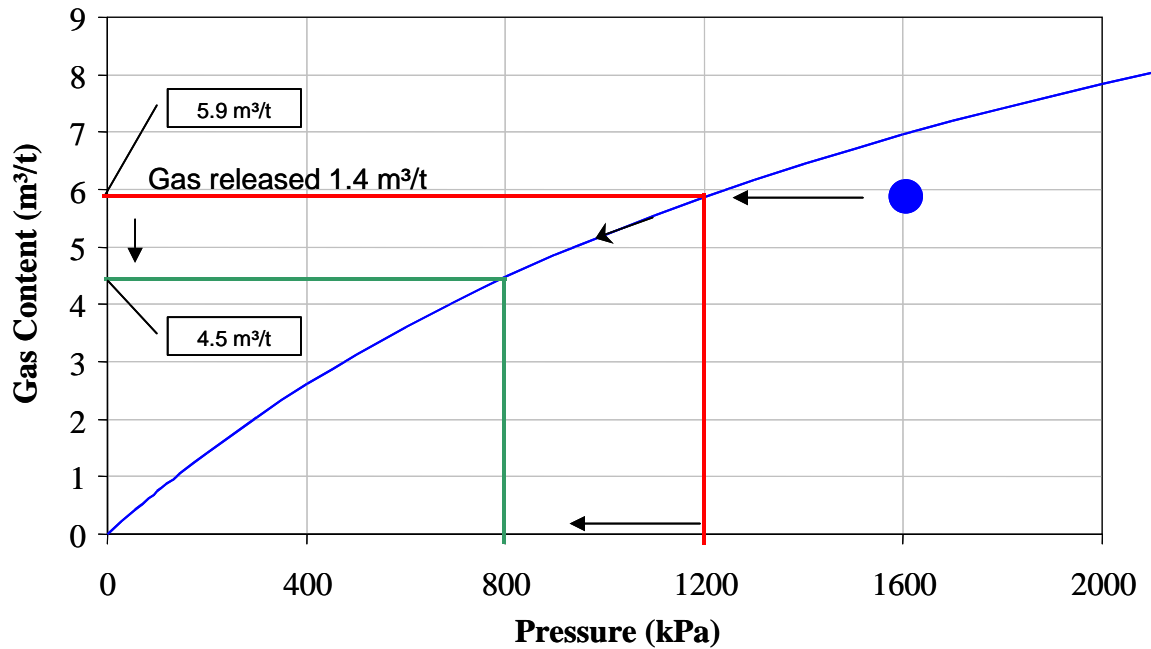
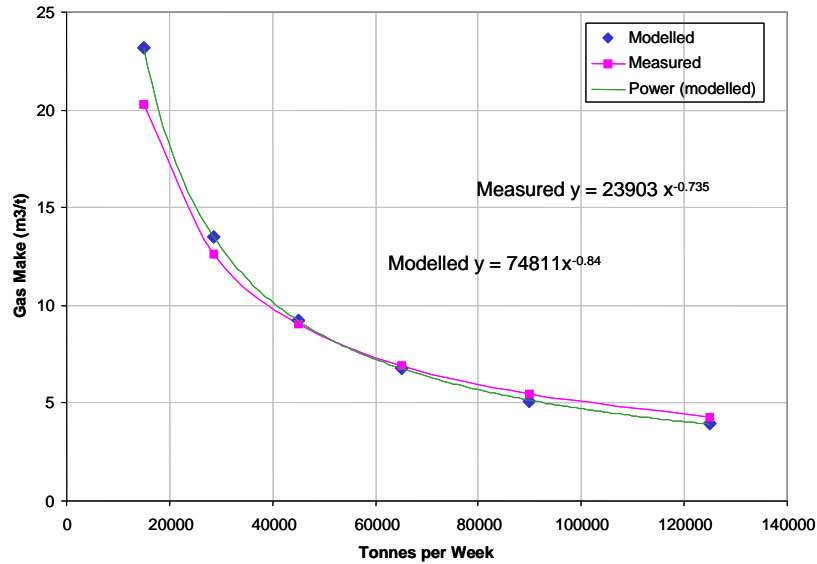


Figure 17 Gas Content Reduction According to Change in Pore Pressure

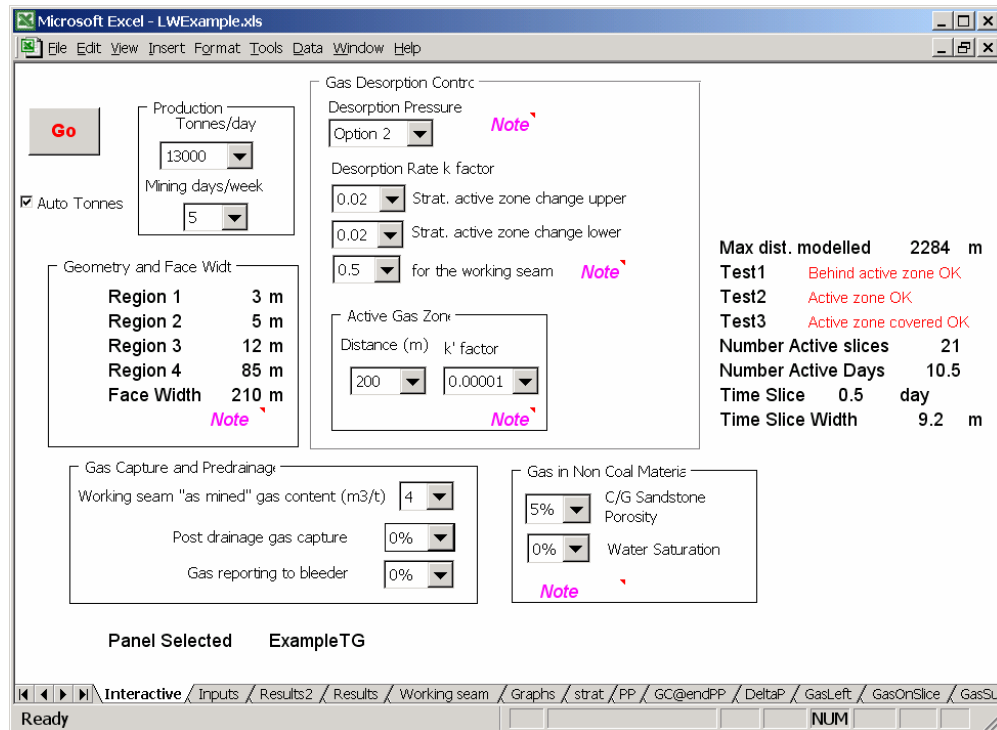


In longwall gas emission assessment, defining the gas make curve<sup>1</sup> is critical. Every effort is made to match the modelled curve to measured data (Figure 18) by adjustment of parameters such as desorption rate and the width of the active gas zone (Figure 19).

**Figure 18 Matching Model and Measured Gas Makes**



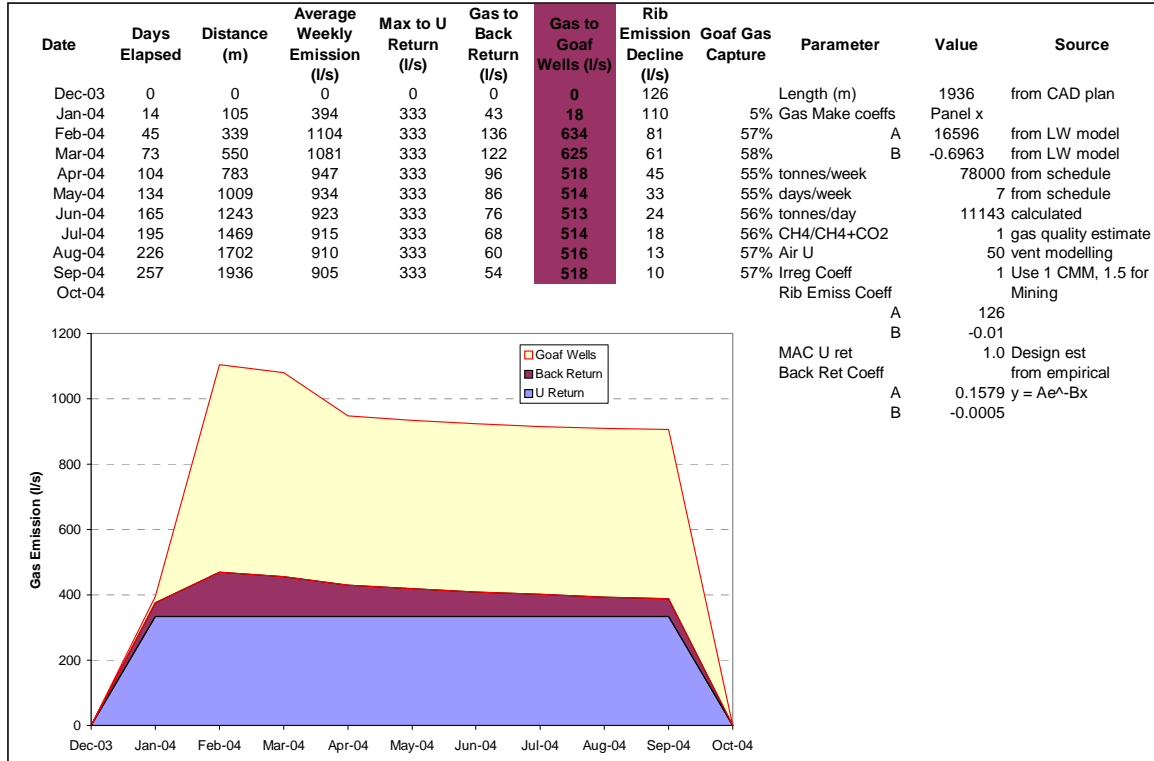
**Figure 19 Main Input Options, Pore Pressure Model**



<sup>1</sup> Relates gas make in m<sup>3</sup>/t to production rate

For the scheduled level of production, gas emission is calculated from the gas make curve. Gas reporting to the goaf wells is essentially that left over after accounting for the other gas streams, ie to the U return, to the back return and rib bleed.

**Figure 20 Calculating Goaf Gas Capture**

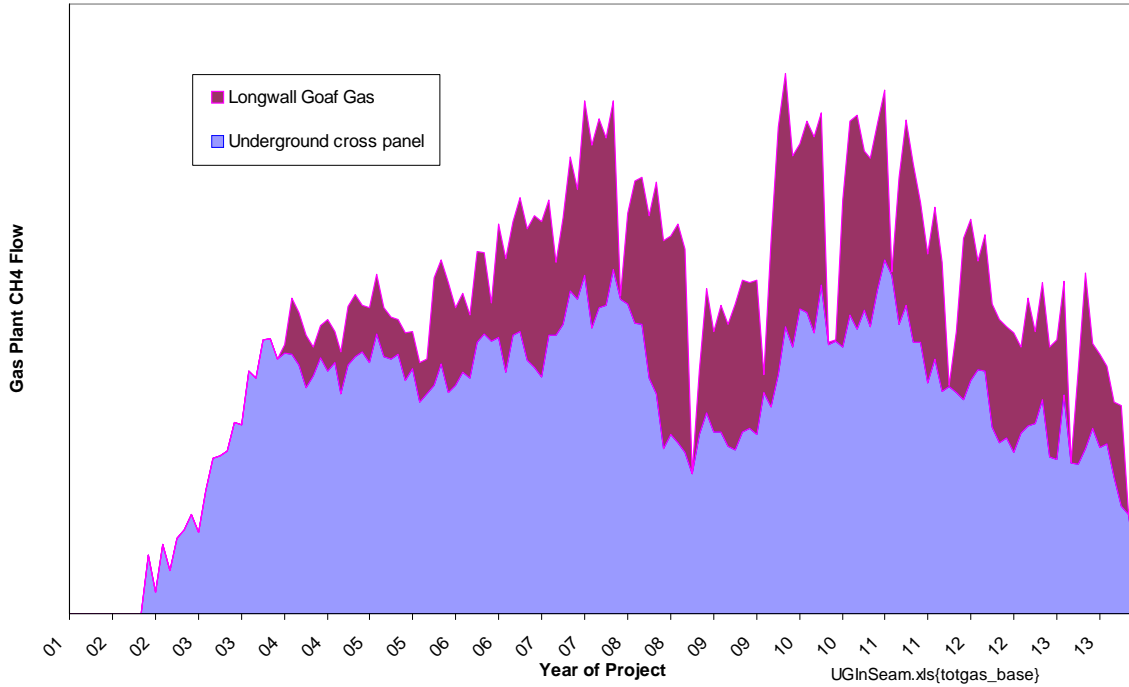


The capacity of the U return to carry gas is determined by the mines ventilation modeling and whether the roadway will be required for diesel vehicle access. For the example in Figure 20, the U return maximum allowable concentration is set at 1% CH<sub>4</sub> and a ventilation quantity of 50 m<sup>3</sup>/s giving a gas emission rate of 500 l/s. The return will need to operate at well below this value to allow for peak emissions. From experience, peak emissions are usually 1.5 times higher than weekly average emissions, resulting in a design capacity of 500/1.5 = 333 l/s.

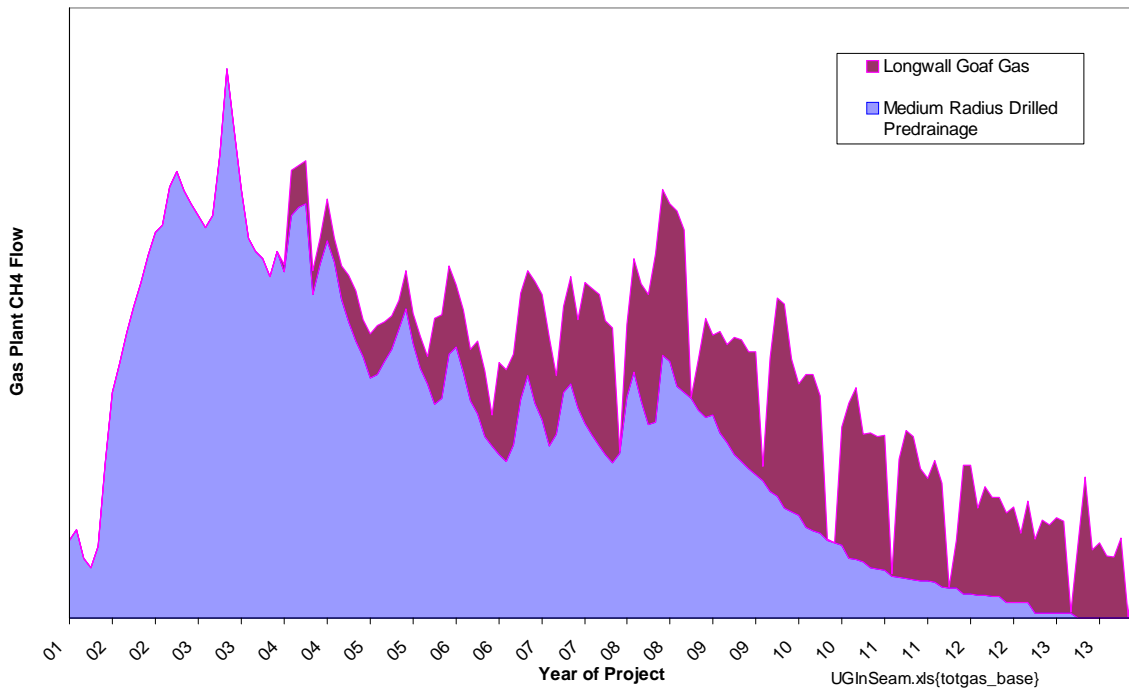
Allowance also needs to be made for gas reporting to a back return if present. The ability of the back return to pull gas to it reduces as the face retreats. Relationships describing this are derived empirically.

Post drainage gas for each longwall is summed and charted alongside the predrainage gas (Figure 21 underground predrainage, Figure 22 MRD predrainage).

**Figure 21 Combined Underground Predrainage and Post Drainage Gas**



**Figure 22 Combined MRD Predrainage and Post Drainage Gas**



Gas quality is a significant additional consideration. Australian coals frequently have high proportions of CO<sub>2</sub> in the seam gas. The models are able to account for changes in the proportions of CO<sub>2</sub> and CH<sub>4</sub>.

Air dilution is estimated from the various sources and included in final gas totals to the point of delivery. Longwall goaf gas has the highest air dilution. MRD gas should have no air dilution unless negative pressure is used to aid gas migration and recovery.

## Risks

The main factors impacting on risk are:

- Gas forecast reliability
  - Inadequate gas reservoir data  
*Occurs in some situations. Many mines have good gas content data, but lack adequate knowledge of permeability*
  - Inadequate forward mine planning  
*This is often a problem, with schedules in various states of review.*
  - Lack of appreciation of what is involved in the modelling process to arrive at a bankable result  
*A common problem with requests sought against unreasonable deadlines.*
  - Lack of coordination between the players  
*A significant problem, in that the whole process should be overseen by miners but rarely is in the author's experience. Projects pushed due to time and resource constraints run the risk of not having sufficient mine site input.*
  - Modelling limitations  
*Regardless of the state of gas reservoir and mining data, the complexity of modeling is such that models rely strongly on validation against empirical data. Without such validation, the model would have low confidence. Increasing sophistication of models would probably be reflected in costs that would need to be accepted in the industry.*
- Uniformity in gas supply
  - Mines are rapidly heading towards MRD with its much greater asymmetry in gas production.  
*MRD wells introduce far more design, scheduling and operational options than underground drilling. The asymmetry is only likely to be an issue while mines apply the technology in a "catch up" mode.*
- Uncertainty in gas supply
  - Scheduled production rates not realized  
*Apart from MRD methods, mine gas production is highly dependent upon the progress of mining.*
  - Change in mine planning  
*Such changes frequently occur in spite of advances in forward assessment methods.*
  - Stoppages  
*Significant production delays have occurred in most mines. They are certain to continue.*
  - Premature mine closure  
*Economics, major incidents*

## **Conclusions**

The modelling process is complex with non unique results. Better communication is required to arrive at the right mix of resources to adequately scope a project.

To improve modelling reliability, increased focus needs to be placed on back analysis and history matching. There is a rapidly expanding data base and experience base that needs to be adequately reviewed if model development is to be targeted and effective.

Issues of uniformity in gas supply require an alternate source that can be accessed as required. Augmenting CMM with non-mine related Coal Seam Gas (CSG) should be considered. The most likely development in this regard is MRD for CSG, which also serves to limit exposure to dependence on mine production.